RESOURCE LIBRARY
LESSON

What Is the Future of Earth's Climate?

Through a series of guided questions, students will explore the question, what will Earth's climate be in the future? Students will not be able to answer the question at the end of the lesson, but they will be able to explain how scientists can be certain that Earth is warming while not being entirely certain about how much Earth will warm.

GRADES

7 - 12+

SUBJECTS

Earth Science

CONTENTS

6 Activities

Content Created by

The Concord Consortium

ACTIVITY 1: CONSTRUCTING AN ARGUMENT: CLIMATE | 10 MINS

DIRECTIONS

Tell students that Activity 1 (Constructing an Argument) of the lesson What is the Future of Earth's Climate? introduces the structure of the scientific argumentation they will be asked to do in the rest of the lesson. Tell students that Activity 1 will give them practice with analyzing a data set and making a good scientific argument from the evidence. Encourage students to review the questions and example best answers provided in Activity 1 before starting on the current activity.

OBJECTIVES

Subjects & Disciplines

Earth Science

Teaching Approach

- Inquiry-based learning

Teaching Methods

- Self-directed learning
- Self-paced learning
- Writing

Skills Summary

This activity targets the following skills:

- Critical Thinking Skills
  - Creating

National Standards, Principles, and Practices

Preparation

BACKGROUND & VOCABULARY

Background Information

Prior Knowledge

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Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition
claim	*verb*	to state as the truth.
evidence	*noun*	data that can be measured, observed, examined, and analyzed to support a conclusion.
solar	*adjective*	having to do with the sun.
solar flare	*noun*	explosion in the sun's atmosphere, which releases a burst of energy and charged particles into the solar system.
sunspot	*noun*	dark, cooler area on the surface of the sun that can move, change, and disappear over time.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.

FUNDER

This material is based upon work supported by the National Science Foundation under Grant No. DRL-1220756. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

PARTNER

The Concord Consortium

ACTIVITY 2: EARTH'S CHANGING CLIMATES I 45 MINS

DIRECTIONS

1. Activate students' prior knowledge about Earth's climates.

Tell students that climate is the average weather of a region over a long period of time and that there are many different climates on Earth today. Ask:

- *What are some examples of climates?* (Some commonly known climates are desert, rain forest, tropical monsoon, tropical savanna, humid subtropical, humid continental, oceanic, subarctic, and tundra.)
- *What factors determine a region's climate?* (Climate determining factors are location—next to an ocean or near the equator, for example—precipitation, and temperature.)

Tell students that climate scientists use the average temperature of the Earth as a measure of climate change. Ask: *Has Earth always had the same climates as it has today?* (No. Earth has gone through many climatic shifts in its history, including ice ages and warm periods.) Tell students that they will be looking at global temperature data to investigate how different Earth's climates might be in the future.

2. Discuss the role of uncertainty in the scientific process.

Tell students that science is a process of learning how the world works and that scientists do not know the “right” answers when they start to investigate a question. Tell students they can see examples of scientists' uncertainty in climate forecasting.

Show the **Global Temperature Change Graph** from the 1995 IPCC (Intergovernmental Panel on Climate Change) report. Tell students that this graph shows several different models of forecast temperature changes. Ask: *Why is there more variation (a wider spread) between the models at later dates than at closer dates?* (There is more variation between the models at later dates than at closer dates because there is more variability in predicting the far future than in predicting the near future.)

Tell students that the ability to better predict near-term events occurs in hurricane and tropical storm forecasting as well. Project **The Definition of the National Hurricane Center Track Forecast Cone** and show students the "cone of uncertainty" around the track of the storm. Tell students that the cone shows the scientists' uncertainty in the track of the storm, just as the climate models show the scientists' uncertainty in how much Earth's temperature will change in the future. Ask: *When are scientists most confident in their predictions?* (Scientists are most confident in their predictions when they have a lot of data. This is why the forecast for near-term events is better than forecasts of longer-term events, both in storm forecasting and in climate forecasting.)

Tell students they will be asked questions about the certainty of their predictions and that they should think about what scientific and model-based data are available as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

3. Have students launch the Earth's Changing Climates interactive.

Provide students with the link to the Earth's Changing Climates interactive. Divide students into groups of two or three, with two being the ideal grouping to allow students to share computer work stations. Tell students they will be working through a series of pages of data with questions related to the data. Ask students to work through the activity in their groups, discussing and responding to questions as they go.

NOTE: Teachers can access the Answer Key for students' questions—and save students' data for online grading—through a free registration on the High-Adventure Science portal page.

Tell students that this is Activity 2 in the **What Is the Future of Earth's Climate?** lesson.

4. Have students discuss what they learned in the activity.

After students have completed the activity, bring the groups back together and lead a discussion focusing on the questions below. Show the graphs on page 7 of the activity. Point out the different time scales represented on the two graphs. Ask:

- *Why don't you see the temperature trend from the first graph (1880-2010) represented on the second graph (Vostok ice core)?* (The first graph shows a shorter time period (130 years) than the Vostok ice core graph [400,000 years]. The longer-term graph smooths out the short-term fluctuations while showing the longer-term temperature trend.)

- *How are ice ages represented on the Vostok ice core graph?* (Ice ages [glacial periods] are shown when the temperature is low.)

- *What is the average temperature difference between glacial and interglacial periods?* (The average temperature difference is 10 degrees Celsius [50 degress Fahrenheit].)

- *How long (in thousands of years) did it take to go from glacial periods to interglacial periods?* (The warming happens very quickly, within about five thousand years.)

- *How do these changes compare to the time scale for the most recent (current) warming trend?* (The current warming appears to be happening much faster.)

- *Why do you think scientists think the warming of the 20th century cannot be explained by the natural variability seen over geologic time?* (The warming is happening quickly, and it is occurring in synchrony with increased levels of carbon dioxide.)

TipTeacher Tip

This activity is part of a sequence of activities in the What Is the Future of Earth's Climate? lesson. The activities work best if used **in sequence**.

TipTeacher Tip

To save your students' data for grading online, register your class for free at the High-Adventure Science portal page.

Modification

This activity may be used individually or in groups of two or three students. It may also be modified for a whole-class format. If using as a whole-class activity, use an LCD projector or interactive whiteboard to project the activity. Turn embedded questions into class discussions. Uncertainty items allow for classroom debates over the evidence.

Informal Assessment

1. Check students' comprehension by asking them the following questions:

- How has Earth's average temperature changed over the past 400,000 years?
- How do scientists determine what the temperature was 400,000 years ago?
- What makes scientists more confident in their predictions of future climates?

2. Use the answer key to check students' answers on embedded assessments.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- explore and critically analyze real-world data
- make claims about data and determine their own level of certainty with regard to their claims

Teaching Approach

- Learning-for-use

Teaching Methods

- Discussions
- Multimedia instruction
- Self-paced learning

- Visual instruction
- Writing

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information Literacy
  - Learning and Innovation Skills
    - Critical Thinking and Problem Solving
- 21st Century Themes
  - Global Awareness
- Critical Thinking Skills
  - Analyzing
  - Evaluating
  - Understanding

National Standards, Principles, and Practices

NATIONAL SCIENCE EDUCATION STANDARDS

• **(5-8) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(5-8) Standard A-2:**
Understandings about scientific inquiry
• **(9-12) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(9-12) Standard A-2:**
Understandings about scientific inquiry
• **(9-12) Standard D-1:**
Energy in the earth system

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.11-12.4
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.9-10.1
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.9-10.4
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
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• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.11-12.3
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.6-8.4
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.9-10.3
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.6-8.3

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 3:**
Research and Information Fluency
• **Standard 4:**
Critical Thinking, Problem Solving, and Decision Making

NEXT GENERATION SCIENCE STANDARDS

• **Crosscutting Concept 1:**
Patterns
• **Crosscutting Concept 2:**
Cause and effect: Mechanism and prediction
• **Crosscutting Concept 3:**
Scale, proportion, and quantity
• **Crosscutting Concept 7:**
Stability and change
• **HS. Earth and Human Activity:**

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

• **HS. Earth and Human Activity:**
HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

• **HS. Earth's Systems:**
HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

• **HS. Earth's Systems:**
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.

• **HS. Earth's Systems:**
HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

• **MS. Earth and Human Activity:**
MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

• **Science and Engineering Practice 1:**
Asking questions and defining problems

• **Science and Engineering Practice 2:**
Developing and using models

• **Science and Engineering Practice 4:**
Analyzing and interpreting data

• **Science and Engineering Practice 6:**
Constructing explanations and designing solutions

• **Science and Engineering Practice 7:**
Engaging in argument from evidence

• **Science and Engineering Practice 8:**
Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

Earth's climate is continually changing. Earth has been covered in ice (snowball Earth) at some points during its existence, while at others, Earth has been ice-free. Earth is now in a warming period, due in part to enhanced human emissions of greenhouse gases. (Greenhouse gases, such as carbon dioxide, methane, and water vapor, trap heat in the atmosphere by absorbing heat energy emitted from the surface.)

Scientists use past and current temperature data to develop climate models to predict how warm the planet might get. Scientists use ancient sediments and ice cores to measure past temperatures. They put these data into sophisticated computational models to make predictions about the future.

Prior Knowledge

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Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition
annual	*adjective*	yearly.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
carbon dioxide	*noun*	greenhouse gas produced by animals during respiration and used by plants during photosynthesis. Carbon dioxide is also the byproduct of burning fossil fuels.
climate	*noun*	all weather conditions for a given location over a period of time.
error bar	*noun*	visual representation used in graphs to indicate the uncertainty in a measurement.
glacier	*noun*	mass of ice that moves slowly over land.
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.

Term	Part of Speech	Definition
ice age	*noun*	long period of cold climate where glaciers cover large parts of the Earth. The last ice age peaked about 20,000 years ago. Also called glacial age.
ice core	*noun*	sample of ice taken to demonstrate changes in climate over many years.
model, computational	*noun*	a mathematical model that requires extensive computational resources to study the behavior of a complex system by computer simulation.
running mean	*noun*	calculation that analyzes data by creating a series of averages of different groups of a whole data set. Also called a moving mean, rolling mean, or moving average.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.
variable	*noun*	piece of data that can change.

FUNDER

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PARTNER

The Concord Consortium

ACTIVITY 3: INTERACTIONS WITHIN EARTH'S ATMOSPHERES | 45 MINS

DIRECTIONS

1. Activate students' prior knowledge about greenhouse gases.

Tell students that greenhouse gases cause a warming of Earth's atmosphere. Have students brainstorm a list of greenhouse gases and hypothesize how they warm Earth's atmosphere. Student responses should include greenhouse gases such as carbon dioxide, water vapor, and methane. Responses about how these gases warm Earth's atmosphere should include that the gases prevent the escape of heat energy (infrared radiation) from the atmosphere.

2. Discuss the role of uncertainty in the scientific process.

Tell students that science is a process of learning how the world works and that scientists do not know the “right” answers when they start to investigate a question. Let students know they can see examples of scientists' uncertainty in climate forecasting.

Show the **Global Temperature Change Graph** from the 1995 IPCC (Intergovernmental Panel on Climate Change) report. Tell students that this graph shows several different models of forecast temperature changes. Ask: *Why is there more variation (a wider spread) between the models at later dates than at closer dates?* (There is more variation between the models at later dates than at closer dates because there is more variability in predicting the far future than in predicting the near future.)

The ability to better predict near-term events occurs in hurricane and tropical storm forecasting as well. Project **The Definition of the National Hurricane Center Track Forecast Cone** and show students the “cone of uncertainty” around the track of the storm. Tell students that the cone shows the scientists' uncertainty in the track of the storm, just as the climate models show the scientists' uncertainty in how much Earth's temperature will change in the future. Ask: *When are scientists most confident in their predictions?* (Scientists are most confident in their predictions when they have a lot of data. This is why the forecast for near-term events is better than forecasts of longer-term events, both in storm forecasting and in climate forecasting.)

Tell students they will be asked questions about the certainty of their predictions and that they should think about what scientific data are available as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

3. Discuss the role of systems in climate science.

Tell students that forecasting what will happen in Earth's climate system is a complicated process because there are many different interacting parts. Scientists think about how one part of the system can affect other parts of the system. Give students a simple example of a system, as described in the scenario below.

On an island, there is a population of foxes and a population of rabbits. The foxes prey on the rabbits. Ask:

- *When there are a lot of rabbits, what will happen to the fox population?* (It will increase because there is an ample food supply.)
- *What happens to the fox population when they've eaten most of the rabbits?* (The foxes will die of starvation as their food supply decreases.)
- *What happens to the amount of grass when the fox population is high?* (The amount of grass will increase because there are fewer rabbits to eat the grass.)
- *If there is a drought and the grass doesn't grow well, what will happen to the populations of foxes and rabbits?* (The rabbit population will decrease because they have a lesser food supply. The fox population should also decrease as their food supply decreases.)

Humans introduce dogs to the island. The dogs compete with the foxes over the rabbit food supply. Ask: *What will happen to the populations of foxes, rabbits, and grass after the dogs are introduced?* (The foxes will decrease because they are sharing their food supply, the rabbits will decrease because they have more predators, and the grass will do well because of the lowered impact of the smaller rabbit population.)

Tell students that these simple cause-effect relationships can expand into more complex system relationships. Let students know that they will be exploring cause-effect and system feedback relationships between carbon dioxide and water vapor in this activity. Ask students to think about how each piece of the system affects other pieces of the system.

4. Introduce and discuss the use of computational models.

Introduce the concept of computational models, and give students an example of a computational model that they may have seen, such as forecasting the weather. Project the NOAA **Weather Forecast Model**, which provides a good example of a computational model. Tell students that:

- scientists use information about the past to build their climate models.
- scientists test their climate models by using them to forecast past climates.
- when scientists can accurately forecast past climates, they can be more confident about using their models to predict future climates.

5. Have students launch the Interactions Within the Atmosphere interactive.

Provide students with the link to the Interactions Within the Atmosphere interactive. Divide students into groups of two or three, with two being the ideal grouping to allow groups to share a computer workstation. Tell students they will be working through a series of pages of models with questions related to the models. Ask students to work through the activity in their groups, discussing and responding to questions as they go.

NOTE: You can access the Answer Key for students' questions—and save students' data for online grading—through a free registration on the High-Adventure Science portal page.

Let students know that this is Activity 3 of the **What Is the Future of Earth's Climate?** lesson.

6. Have students discuss what they learned in the activity.

After students have completed the activity, bring the groups back together and lead a discussion focusing on these questions:

- *What do models help you visualize?* (Models are used to show systems that are too small to see or too big to see. They can also show events that happen really fast or really slow, allowing you to see what's happening.)

- *What are the similarities and differences between the* ***Earth System Model (Model 1)*** *and the* ***Molecular Model (Model 2)****?* (Both models show the interactions of radiation [solar and infrared] with particles on Earth. The molecular model shows how the greenhouse gases absorb and reflect only the infrared radiation in a way that is more difficult to see in the larger-scale model [Earth system model]. The larger-scale model shows how the temperature changes as a result of the greenhouse gases.)

- *What are the limitations of the models in this activity?* (The models don't show all of the types of radiation emitted by the sun. They also don't show all of the interactions that happen in Earth's climate system.)

- *Based on these models, what is the relationship between atmospheric carbon dioxide and temperature?* (When there is more carbon dioxide, there is a higher temperature. This is because carbon dioxide is a greenhouse gas.)

- Show the **Keeling curve**. *Why do you think the carbon dioxide level fluctuates so regularly?* (The carbon dioxide level fluctuates because of the seasons. In the spring and summer, plants are actively growing and taking up carbon dioxide. In the winter, plants are not growing, and as organisms decay, carbon dioxide is released into the atmosphere.)

- *Based on the Keeling curve, what do you expect the temperature of Earth to do?* (Based on the Keeling curve, the temperature should increase. This is because carbon dioxide is a greenhouse gas, which absorbs and re-emits infrared radiation in the atmosphere, keeping heat energy in the atmosphere for longer than would happen without greenhouse gases.)

TipTeacher Tip

This activity is part of a sequence of activities in the What Is the Future of Earth's Climate? lesson. The activities work best if used **in sequence**.

TipTeacher Tip

To save your students' data for grading online, register your class for free at the High-Adventure Science portal page.

Modification

This activity may be used individually or in groups of two or three students. It may also be modified for a whole-class format. If using as a whole-class activity, use an LCD projector or interactive whiteboard to project the activity. Turn embedded questions into class discussions. Uncertainty items allow for classroom debates over the evidence.

Informal Assessment

1. Check students' comprehension by asking them the following questions:

- What two things can happen to solar radiation as it enters Earth's atmosphere?
- Which type of solar radiation is absorbed by greenhouse gases?
- What is the long-term trend of carbon dioxide concentration in the atmosphere and global temperature?

2. Use the answer key to check students' answers on embedded assessments.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- explore and critically analyze real-world data about changes in atmospheric carbon dioxide levels over Earth's history
- describe what happens when solar radiation interacts with Earth's surface and atmosphere
- explain how greenhouse gases cause Earth's temperature to warm

Teaching Approach

- Learning-for-use

Teaching Methods

- Discussions
- Multimedia instruction
- Self-paced learning
- Visual instruction
- Writing

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information Literacy
  - Learning and Innovation Skills
    - Critical Thinking and Problem Solving
- 21st Century Themes
  - Global Awareness
- Critical Thinking Skills
  - Analyzing
  - Evaluating
  - Understanding

National Standards, Principles, and Practices

NATIONAL SCIENCE EDUCATION STANDARDS

• **(5-8) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(5-8) Standard A-2:**
Understandings about scientific inquiry
• **(9-12) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(9-12) Standard A-2:**

Understandings about scientific inquiry

• **(9-12) Standard D-1**:

Energy in the earth system

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.11-12.4

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.9-10.1

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.9-10.4

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.6-8.1

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.11-12.1

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.11-12.3

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.6-8.4

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.9-10.3

• **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.6-8.3

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 3**:

Research and Information Fluency

• **Standard 4**:

Critical Thinking, Problem Solving, and Decision Making

NEXT GENERATION SCIENCE STANDARDS

• **Crosscutting Concept 2**:

Cause and effect: Mechanism and prediction

• **Crosscutting Concept 3**:

Scale, proportion, and quantity

- **Crosscutting Concept 4**:

Systems and system models

- **Crosscutting Concept 5**:

Energy and matter: Flows, cycles, and conservation

- **Crosscutting Concept 7**:

Stability and change

- **HS. Earth and Human Activity**:

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

- **HS. Earth and Human Activity**:

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

- **HS. Earth's Systems**:

HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

- **HS. Earth's Systems**:

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

- **HS. Earth's Systems**:

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.

- **MS. Earth and Human Activity**:

MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

- **Science and Engineering Practice 1**:

Asking questions and defining problems

- **Science and Engineering Practice 2**:

Developing and using models

- **Science and Engineering Practice 4**:

Analyzing and interpreting data

- **Science and Engineering Practice 6**:

Constructing explanations and designing solutions

- **Science and Engineering Practice 7**:

Engaging in argument from evidence

- **Science and Engineering Practice 8**:

Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

In this activity, students use computational models to explore how Earth's surface and greenhouse gases interact with radiation. Computational models are used to explore phenomena that are too large, too small, too quick, or too slow to observe otherwise. The computational models with which you may be familiar are used for forecasting weather events such as hurricanes. Scientists are more confident in the output of their models when they can input a lot of data. Other scientists check their models against what happens in reality; when the model accurately reflects what happens in reality, scientists can be more confident in their models.

Greenhouse gases warm the atmosphere by trapping outgoing infrared (heat) radiation. Sunlight brings visible (and ultraviolet and infrared) light to Earth. The radiation can be absorbed by Earth's surface, or it can be reflected back into space. The radiation that is absorbed heats molecules in Earth's surface. This heat energy, or infrared radiation, is radiated back out towards space. The infrared energy can be absorbed and re-emitted by greenhouse gases in the atmosphere. This absorption and re-emission keeps heat trapped in the atmosphere for longer periods of time, leading to an increased atmospheric temperature.

Prior Knowledge

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Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition

Term	Part of Speech	Definition
absorb	*verb*	to soak up.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
carbon dioxide	*noun*	greenhouse gas produced by animals during respiration and used by plants during photosynthesis. Carbon dioxide is also the byproduct of burning fossil fuels.
climate	*noun*	all weather conditions for a given location over a period of time.
emit	*verb*	to give off or send out.
greenhouse effect	*noun*	phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.
ice core	*noun*	sample of ice taken to demonstrate changes in climate over many years.
infrared radiation	*noun*	part of the electromagnetic spectrum with wavelengths longer than visible light but shorter than microwaves.
model, computational	*noun*	a mathematical model that requires extensive computational resources to study the behavior of a complex system by computer simulation.
parts per million (ppm)	*plural noun*	A unit of measure of the amount of dissolved solids in a solution in terms of a ratio between the number of parts of solids to a million parts of total volume.
radiation	*noun*	energy, emitted as waves or particles, radiating outward from a source.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.

FUNDER

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PARTNER

ACTIVITY 4: SOURCES, SINKS, AND FEEDBACKS | 45 MINS

DIRECTIONS

1. Activate students' prior knowledge about carbon dioxide in the Earth system.

Tell students that matter cycles throughout Earth's system and that matter is not destroyed as it moves throughout the system. Ask:

- *What are some sources of carbon dioxide?* (Carbon dioxide is emitted when organisms respire and decay, as well as when materials are burned.)
- *Where is carbon stored when it is not carbon dioxide?* (The elements in carbon dioxide came from foods and fuels.)
- *Where does carbon dioxide go after it's released into the atmosphere?* (Carbon dioxide in the atmosphere can be taken up by plants during photosynthesis, or it can be absorbed by the ocean.)

2. Discuss the role of uncertainty in the scientific process.

Let students know that in this activity they will be asked questions about the certainty of their predictions. Tell them to think about what scientific data are available and the evidence they get from the model as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

Explain that science is a process of learning how the world works and that scientists do not know the “right” answers when they start to investigate a question. Tell students they can see examples of scientists' uncertainty in climate forecasting.

Show the **Global Temperature Change Graph** from the 1995 IPCC (Intergovernmental Panel on Climate Change) report. Tell students that this graph shows several different models of forecast temperature changes. Ask: *Why is there more variation (a wider spread) between the models at later dates than at closer dates?* (There is more variation between the models at later dates than at closer dates because there is more variability in predicting the far future than in predicting the near future.)

Tell students that the ability to better predict near-term events occurs in hurricane and tropical storm forecasting as well. Project **The Definition of the National Hurricane Center Track Forecast Cone** and show students the "cone of uncertainty" around the track of the storm. Tell students that the cone shows the scientists' uncertainty in the track of the storm, just as the climate models show the scientists' uncertainty in how much Earth's temperature will change in the future. Ask: *When are scientists most confident in their predictions?* (Scientists are most confident in their predictions when they have a lot of data. This is why the forecast for near-term events is better than forecasts of longer-term events, both in storm forecasting and in climate forecasting.)

Tell students they will be asked questions about the certainty of their predictions and that they should think about what scientific and model-based data are available as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

3. Discuss the role of systems in climate science.

Tell students that forecasting what will happen in Earth's climate system is a complicated process because there are many different interacting parts. Scientists think about how one part of the system can affect other parts of the system. Give students a simple example of a system, as described in the scenario below.

On an island, there is a population of foxes and a population of rabbits. The foxes prey on the rabbits. Ask:

- *When there are a lot of rabbits, what will happen to the fox population?* (It will increase because there is an ample food supply.)

- *What happens to the fox population when they've eaten most of the rabbits?* (The foxes will die of starvation as their food supply decreases.)

- *What happens to the amount of grass when the fox population is high?* (The amount of grass will increase because there are fewer rabbits to eat the grass.)

- *If there is a drought and the grass doesn't grow well, what will happen to the populations of foxes and rabbits?* (The rabbit population will decrease because they have a lesser food supply. The fox population should also decrease as their food supply decreases.)

Humans introduce dogs to the island. The dogs compete with the foxes over the rabbit food supply. Ask: *What will happen to the populations of foxes, rabbits, and grass after the dogs are introduced?* (The foxes will decrease because they are sharing their food supply, the rabbits will decrease because they have more predators, and the grass will do well because of the lowered impact of the smaller rabbit population.)

Tell students that these simple cause-effect relationships can expand into more complex system relationships. Let students know that they will be exploring cause-effect and system feedback relationships between carbon dioxide and water vapor in this activity. Ask students to think about how each piece of the system affects other pieces of the system.

4. Introduce and discuss the use of computational models.

Introduce the concept of computational models, and give students an example of a computational model they may have seen, such as forecasting the weather. Project the NOAA **Weather Forecast Model**, which provides a good example of a computational model. Tell students that:

- scientists use information about the past to build their climate models.
- scientists test their climate models by using them to forecast past climates.

- when scientists can accurately forecast past climates, they can be more confident about using their models to predict future climates.

5. Have students launch the Sources, Sinks, and Feedbacks interactive.

Provide students with the link to the Sources, Sinks, and Feedbacks interactive. Divide students into groups of two or three, with two being the ideal grouping to allow groups to share a computer workstation. Tell students that they will be working through a series of pages of models with questions related to the models. Ask students to work through the activity in their groups, discussing and responding to questions as they go.

NOTE: You can access the Answer Key for students' questions—and save students' data for online grading—through a free registration on the High-Adventure Science portal page.

Tell students this is Activity 4 of the **What Is the Future of Earth's Climate?** lesson.

6. Have students discuss what they learned in the activity.

After students have completed the activity, bring the groups back together and lead a discussion focusing on these questions:

- Show the **biogeochemical cycle of carbon** (file in media carousel). Ask: *Is there a source that does not act as a sink?* (No. All of the sources of carbon in the Earth system are also sinks for another source.)

- *In the **Earth system model with ocean and water vapor (Model 5)**, how did the level of carbon dioxide affect the amount of water vapor in the atmosphere?* (When the carbon dioxide level is high, the temperature is high, because carbon dioxide is a greenhouse gas. The higher temperature causes water to evaporate from the surface, leading to more water vapor in the atmosphere.)

- *What is the effect of water vapor on temperature?* (Water vapor increases temperature because water vapor is also a greenhouse gas.)

- *What is the feedback relationship between carbon dioxide level and water vapor level?* (It is a positive feedback relationship. When carbon dioxide is high, the temperature is higher, leading to more evaporation of water and lower solubility of carbon dioxide, leading to higher temperatures, leading to more water vapor and still lower solubility of carbon dioxide, leading to higher temperatures, and so on.)

- *Is the **Earth system model with ocean and water vapor (Model 5)** a good model of the Earth system?* (No. This model is not a good model of the Earth system. The temperature keeps going higher and higher, which is not realistic. There is something missing from this model.)

TipTeacher Tip

This activity is part of a sequence of activities in the What Is the Future of Earth's Climate? lesson. The activities work best if used **in sequence**.

TipTeacher Tip

To save your students' data for grading online, register your class for free at the High-Adventure Science portal page.

Modification

This activity may be used individually or in groups of two or three students. It may also be modified for a whole-class format. If using as a whole-class activity, use an LCD projector or interactive whiteboard to project the activity. Turn embedded questions into class discussions. Uncertainty items allow for classroom debates over the evidence.

Informal Assessment

1. Check students' comprehension by asking them the following questions:

- How is the solubility of carbon dioxide affected by temperature?
- How do atmospheric carbon dioxide levels affect ocean temperature?
- What is the effect of water vapor on temperature?
- Why is the relationship between carbon dioxide and water vapor considered a positive feedback relationship?

2. Use the answer key to check students' answers on embedded assessments.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- describe how carbon dioxide travels through Earth's system and identify sources and sinks for carbon dioxide
- explain how temperature affects the ocean's ability to absorb carbon dioxide
- explain the role of water, a greenhouse gas, on Earth's temperature
- explain the effects of temperature on carbon dioxide uptake by the oceans and water vapor in the atmosphere
- describe an example of a positive feedback loop in the Earth's climate system
- explain why it is necessary to consider multiple factors when modeling the climate

Teaching Approach

- Learning-for-use

Teaching Methods

- Discussions
- Multimedia instruction
- Self-paced learning
- Visual instruction
- Writing

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information, Communications, and Technology Literacy
  - Learning and Innovation Skills
    - Critical Thinking and Problem Solving
- 21st Century Themes
  - Global Awareness
- Critical Thinking Skills
  - Analyzing
  - Evaluating
  - Understanding

National Standards, Principles, and Practices

NATIONAL SCIENCE EDUCATION STANDARDS

• **(5-8) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(5-8) Standard A-2:**
Understandings about scientific inquiry
• **(5-8) Standard D-1:**
Structure of the earth system
• **(9-12) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(9-12) Standard A-2:**
Understandings about scientific inquiry
• **(9-12) Standard D-1:**
Energy in the earth system

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.11-12.4
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.6-8.3
• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**

Key Ideas and Details, RST.9-10.3

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.11-12.3

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.6-8.4

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.9-10.1

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.9-10.4

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.6-8.1

• **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.11-12.1

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

• **Standard 3:**
Research and Information Fluency

• **Standard 4:**
Critical Thinking, Problem Solving, and Decision Making

NEXT GENERATION SCIENCE STANDARDS

• **Crosscutting Concept 2:**
Cause and effect: Mechanism and prediction

• **Crosscutting Concept 3:**
Scale, proportion, and quantity

• **Crosscutting Concept 4:**
Systems and system models

• **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation

• **Crosscutting Concept 7:**
Stability and change

• **HS. Earth and Human Activity:**
HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

• **HS. Earth and Human Activity:**

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

• **HS. Earth's Systems:**
HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

• **HS. Earth's Systems:**
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.

• **HS. Earth's Systems:**
HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

• **MS. Earth and Human Activity:**
MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

• **Science and Engineering Practice 1:**
Asking questions and defining problems

• **Science and Engineering Practice 2:**
Developing and using models

• **Science and Engineering Practice 4:**
Analyzing and interpreting data

• **Science and Engineering Practice 6:**
Constructing explanations and designing solutions

• **Science and Engineering Practice 7:**
Engaging in argument from evidence

• **Science and Engineering Practice 8:**
Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

Like all matter, carbon cycles throughout the Earth system. Carbon dioxide is released into the atmosphere from rocks as they weather. It is taken up by plants and incorporated into proteins, carbohydrates, and fats. It is released when organisms respire, and it is released when fossil fuels are burned. Carbon dioxide is removed from the atmosphere when it dissolves into the ocean.

The oceanic uptake of carbon dioxide is temperature-dependent. Carbon dioxide, like all gases, is less soluble in water as the water temperature warms. So as Earth warms, the oceans are less able to remove carbon dioxide from the atmosphere.

At the same time, the increased temperature resulting from increased levels of atmospheric carbon dioxide causes water to evaporate from the ocean surface. Water vapor is a powerful greenhouse gas. With increased water vapor in the atmosphere, the temperature increases even more. The relationship between atmospheric carbon dioxide and water vapor is a type of positive feedback—an increase in one leads to an increase in the other, leading to a continual increase in temperature.

Prior Knowledge

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Recommended Prior Activities

- None

Vocabulary

Term	Part of Speech	Definition
absorb	*verb*	to soak up.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
carbon dioxide	*noun*	greenhouse gas produced by animals during respiration and used by plants during photosynthesis. Carbon dioxide is also the byproduct of burning fossil fuels.
climate	*noun*	all weather conditions for a given location over a period of time.
greenhouse effect	*noun*	phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.

Term	Part of Speech	Definition
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.
model, computational	*noun*	a mathematical model that requires extensive computational resources to study the behavior of a complex system by computer simulation.
parts per million (ppm)	*plural noun*	A unit of measure of the amount of dissolved solids in a solution in terms of a ratio between the number of parts of solids to a million parts of total volume.
sink	*noun*	part of a physical system that absorbs some form of matter or energy.
solubility	*noun*	ability of a substance to be dissolved or liquified.
source	*noun*	any thing or place from which something comes, arises, or is obtained.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.
water vapor	*noun*	molecules of liquid water suspended in the air.

FUNDER

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PARTNER

The Concord Consortium

ACTIVITY 5: FEEDBACKS OF ICE AND CLOUDS | 45 MINS

DIRECTIONS

1. Activate students' prior knowledge about reflection and absorption.

Show the **photos of the Bear Glacier in Alaska (1909 and 2005)**. Tell students that some surfaces reflect light more than others and that more reflective surfaces have a higher albedo. Ask:

- *Which photo shows surfaces with higher albedo?* (The 1909 photo shows surfaces with a higher albedo. There is more snow and ice in that photo than in the 2005 photo.)
- *Which photo shows surfaces that would absorb the most solar radiation?* (The 2005 photo shows surfaces that would absorb the most solar radiation. The ice and snow in the 1909 photo would reflect most of the solar radiation.)
- *Why does a dark-colored surface feel much hotter than a light-colored surface in the sunshine?* (The dark-colored surface absorbs more radiation than the light-colored surface. The absorbed radiation becomes heat energy in the surface.)

2. Discuss the role of uncertainty in the scientific process.

Tell students that science is a process of learning how the world works and that scientists do not know the “right” answers when they start to investigate a question. Let students know they can see examples of scientists' uncertainty in climate forecasting.

Show the **Global Temperature Change Graph** from the 1995 IPCC (Intergovernmental Panel on Climate Change) report and tell them that this graph shows several different models of forecast temperature changes. Ask: *Why is there more variation (a wider spread) between the models at later dates than at closer dates?* (There is more variation between the models at later dates than at closer dates because there is more variability in predicting the far future than in predicting the near future.)

Tell students that the ability to better predict near-term events occurs in hurricane and tropical storm forecasting as well. Project **The Definition of the National Hurricane Center Track Forecast Cone** and show students the “cone of uncertainty” around the track of the storm. The cone shows the scientists' uncertainty in the track of the storm, just as the climate models show the scientists' uncertainty in how much Earth's temperature will change in the future.

Ask: *When are scientists most confident in their predictions?* (Scientists are most confident in their predictions when they have a lot of data. This is why the forecast for near-term events is better than forecasts of longer-term events, both in storm forecasting and in climate forecasting.)

Tell students that they will be asked questions about the certainty of their predictions and that they will need to think about what scientific data are available as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

3. Discuss the role of systems in climate science.

Tell students that forecasting what will happen in Earth's climate system is a complicated process because there are many different interacting parts. Scientists think about how one part of the system can affect other parts of the system. Give students a simple example of a system, as described in the scenario below.

On an island, there is a population of foxes and a population of rabbits. The foxes prey on the rabbits. Ask:

- *When there are a lot of rabbits, what will happen to the fox population?* (It will increase because there is an ample food supply.)
- *What happens to the fox population when they've eaten most of the rabbits?* (The foxes will die of starvation as their food supply decreases.)
- *What happens to the amount of grass when the fox population is high?* (The amount of grass will increase because there are fewer rabbits to eat the grass.)
- *If there is a drought and the grass doesn't grow well, what will happen to the populations of foxes and rabbits?* (The rabbit population will decrease because they have a lesser food supply. The fox population should also decrease as their food supply decreases.)

Humans introduce dogs to the island. The dogs compete with the foxes over the rabbit food supply. Ask: *What will happen to the populations of foxes, rabbits, and grass after the dogs are introduced?* (The foxes will decrease because they are sharing their food supply, the rabbits will decrease because they have more predators, and the grass will do well because of the lowered impact of the smaller rabbit population.)

Tell students that they will be exploring cause-effect and system feedback relationships between carbon dioxide and water vapor in this activity. Ask students to think about how each piece of the system affects other pieces of the system.

4. Introduce and discuss the use of computational models.

Introduce the concept of computational models, and give students an example of a computational model that they may have seen, such as forecasting the weather. Project the NOAA **Weather Forecast Model**, which provides a good example of a computational model. Tell students that:

- scientists use information about the past to build their climate models.
- scientists test their climate models by using them to forecast past climates.
- when scientists can accurately forecast past climates, they can be more confident about using their models to predict future climates.

5. Have students launch the Feedbacks of Ice and Clouds interactive.

Provide students with the link to the Feedbacks of Ice and Clouds interactive. Divide students into groups of two or three, with two being the ideal grouping to enable sharing computer workstations. Tell students they will be working through a series of pages of models with questions related to the models. Ask students to work through the activity in their groups, discussing and responding to questions as they go.

NOTE: You can access the Answer Key for students' questions—and save students' data for online grading—through a free registration on the High-Adventure Science portal page.

Tell students this is Activity 5 of the lesson **What is the Future of Earth's Climate?**

6. Have students discuss what they learned in the activity.

After students have completed the activity, bring the groups back together and lead a discussion focusing on these questions:

- *What is the relationship between ice cover and temperature?* (When there is a lot of ice cover, the temperature is low. This is because the solar radiation is reflected into space rather than absorbed.)
- *In the* ***model of the Earth system with clouds (Model 7)****, how did clouds affect the temperature?* (In the model, clouds have a cooling effect.)
- *Is this model (Model 7) realistic?* (The model is realistic, but it is not complete. Clouds can have cooling effects or warming effects depending on the location and makeup of the clouds. This model only shows high clouds that reflect sunlight back into space.)
- *What would happen to ice cover if greenhouse gas concentrations increase?* (Ice cover would decrease. This is because greenhouse gases trap heat energy in the atmosphere, causing the ice to melt because of the increased temperature. As the ice melts, more radiation is absorbed because there are fewer light-colored surfaces to reflect the radiation, leading to further warming.)
- *What type of feedback is the relationship between clouds and temperature?* (This is a negative feedback relationship. The cloud cover increases with increasing water vapor, but the cloud cover serves to reduce incoming solar radiation which leads to cooling. The stimulus is counteracted by the response.)
- *What type of feedback is the relationship between ice and temperature?* (This is a positive feedback relationship. The melting ice leaves a darker surface that absorbs more solar radiation, leading to more heating, leading to more melting. The stimulus is reinforced and accelerated by the response. Similarly, when the temperature is cold, more ice forms, which reflects more solar radiation, which leads to less heat absorption, which leads to further ice formation.)

TipTeacher Tip

This activity is part of a sequence of activities in the What Is the Future of Earth's Climate? lesson. The activities work best if used **in sequence**.

TipTeacher Tip

To save your students' data for grading online, register your class for free at the High-Adventure Science portal page.

Modification

This activity may be used individually or in groups of two or three students, or as a whole class activity. If using as a whole class activity, use an LCD projector or interactive whiteboard to project the activity.

Informal Assessment

1. Check students' comprehension by asking them the following questions:

- How do ice, snow, and clouds affect temperature?
- Why is it colder on clear nights than on cloudy nights?
- If the sea ice melts, how might that affect global temperature and the atmospheric concentrations of carbon dioxide and water vapor?

2. Use the answer key to check students' answers on embedded assessments.

OBJECTIVES

Subjects & Disciplines

Earth Science

Learning Objectives

Students will:

- explain why light-colored surfaces have a cooling effect on Earths' temperature

- describe the positive feedback loop between temperature and ice cover
- describe the negative feedback loop between cloud cover and temperature
- describe the uncertainty about the feedbacks of temperature, water vapor, and cloud cover that complicate scientists' ability to predict future climate conditions

Teaching Approach

- Learning-for-use

Teaching Methods

- Discussions
- Multimedia instruction
- Visual instruction
- Writing

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Learning and Innovation Skills
    - Critical Thinking and Problem Solving
- 21st Century Themes
  - Global Awareness
- Critical Thinking Skills
  - Analyzing
  - Evaluating
  - Understanding

National Standards, Principles, and Practices

NATIONAL SCIENCE EDUCATION STANDARDS

- **(5-8) Standard A-1:**

Abilities necessary to do scientific inquiry

- **(5-8) Standard A-2**:

Understandings about scientific inquiry

- **(5-8) Standard B-1**:

Properties and changes of properties in matter

- **(5-8) Standard B-3**:

Transfer of energy

- **(5-8) Standard D-1**:

Structure of the earth system

- **(5-8) Standard E-1**:

Abilities of technological design

- **(5-8) Standard E-2**:

Understandings about science and technology

- **(5-8) Standard F-5**:

Science and technology in society

- **(5-8) Standard G-1**:

Science as a human endeavor

- **(9-12) Standard A-1**:

Abilities necessary to do scientific inquiry

- **(9-12) Standard A-2**:

Understandings about scientific inquiry

- **(9-12) Standard B-5**:

Conservation of energy and increase in disorder

- **(9-12) Standard D-1**:

Energy in the earth system

- **(9-12) Standard E-1**:

Abilities of technological design

- **(9-12) Standard E-2**:

Understandings about science and technology

- **(9-12) Standard G-1**:

Science as a human endeavor

- **(9-12) Standard G-2**:

Nature of scientific knowledge

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.6-8.4
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.6-8.3
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.9-10.3
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.9-10.4
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.6-8.1
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.11-12.1
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.11-12.3
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Craft and Structure, RST.11-12.4
- **Reading Standards for Literacy in Science and Technical Subjects 6-12:**
Key Ideas and Details, RST.9-10.1

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

- **Standard 3:**
Research and Information Fluency
- **Standard 4:**
Critical Thinking, Problem Solving, and Decision Making

NEXT GENERATION SCIENCE STANDARDS

- **Crosscutting Concept 2:**
Cause and effect: Mechanism and prediction
- **Crosscutting Concept 3:**
Scale, proportion, and quantity
- **Crosscutting Concept 4:**
Systems and system models
- **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation
- **Crosscutting Concept 7:**
Stability and change

- **HS. Earth and Human Activity**:
HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- **HS. Earth and Human Activity**:
HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- **HS. Earth's Systems**:
HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- **HS. Earth's Systems**:
HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- **HS. Earth's Systems**:
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.
- **MS. Earth and Human Activity**:
MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.
- **Science and Engineering Practice 1**:
Asking questions and defining problems
- **Science and Engineering Practice 2**:
Developing and using models
- **Science and Engineering Practice 4**:
Analyzing and interpreting data
- **Science and Engineering Practice 6**:
Constructing explanations and designing solutions
- **Science and Engineering Practice 7**:
Engaging in argument from evidence
- **Science and Engineering Practice 8**:
Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

Solar radiation consists of visible light, infrared radiation (heat), and ultraviolet radiation. When solar radiation encounters Earth's atmosphere and surface, it can be reflected (sent back into space) or absorbed. Energy that is absorbed becomes heat in Earth's surface. This heat can be re-radiated into space. Light-colored surfaces reflect more solar energy than dark-colored surfaces.

Infrared radiation is emitted by Earth's surface. Instead of the infrared radiation being allowed to exit Earth's atmosphere into space, greenhouse gases absorb it and re-emit it, keeping more heat in the atmosphere. Greenhouse gases include carbon dioxide, methane, and water.

Clouds can have a cooling effect or a warming effect, depending on their makeup and position in the atmosphere. High-level clouds have a net cooling effect as they reflect incoming solar radiation. Low-level clouds have a net warming effect as they prevent infrared radiation from escaping into space.

Prior Knowledge

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Recommended Prior Activities

- Sources, Sinks, and Feedbacks

Vocabulary

Term	Part of Speech	Definition
absorb	*verb*	to soak up.
albedo	*noun*	scientific measurement of the amount of sunlight that is reflected by a surface.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.
carbon dioxide	*noun*	greenhouse gas produced by animals during respiration and used by plants during photosynthesis. Carbon dioxide is also the byproduct of burning fossil fuels.
climate	*noun*	all weather conditions for a given location over a period of time.

Term	Part of Speech	Definition
emit	*verb*	to give off or send out.
greenhouse effect	*noun*	phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.
ice core	*noun*	sample of ice taken to demonstrate changes in climate over many years.
infrared radiation	*noun*	part of the electromagnetic spectrum with wavelengths longer than visible light but shorter than microwaves.
model, computational	*noun*	a mathematical model that requires extensive computational resources to study the behavior of a complex system by computer simulation.
parts per million (ppm)	*plural noun*	A unit of measure of the amount of dissolved solids in a solution in terms of a ratio between the number of parts of solids to a million parts of total volume.
radiation	*noun*	energy, emitted as waves or particles, radiating outward from a source.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.

FUNDER

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PARTNER

The Concord Consortium

ACTIVITY 6: USING MODELS TO MAKE PREDICTIONS | 45 MINS

DIRECTIONS

1. Activate students' prior knowledge about greenhouse gases and global warming.

Tell students they will be investigating how much greenhouse gas concentrations need to be reduced to prevent major warming of Earth's atmosphere. Review with students the interactions of greenhouse gases with radiation and temperature and Earth's surfaces and temperature. Ask:

- *How do greenhouse gases cause atmospheric warming?* (Greenhouse gases absorb outgoing infrared radiation and re-emit it, trapping the heat energy in the atmosphere.)
- *How does the level of carbon dioxide in the atmosphere affect the level of water vapor in the atmosphere?* (When there is more carbon dioxide in the atmosphere, there will be more water vapor in the atmosphere. Carbon dioxide increases temperatures, which leads to increased evaporation of water. This leads to more warming, and more carbon dioxide in the atmosphere as it is released from the oceans and more water vapor as more water evaporates. This is a positive feedback relationship.)
- *How does the color of Earth's surfaces affect temperature?* (When the surface is light-colored, solar radiation is reflected, leading to less heating. When the surface is dark-colored, solar radiation is absorbed, leading to more heating.)
- *What is the relationship between water vapor and clouds?* (When there is more water vapor, there are more clouds. The clouds can reflect solar radiation, leading to cooling, which can decrease the amount of water vapor in the air. This is a negative feedback relationship.)

2. Discuss the role of uncertainty in the scientific process.

Science is a process of learning how the world works and that scientists do not know the “right” answers when they start to investigate a question. Tell students they can see examples of scientists' uncertainty in climate forecasting.

Show the **Global Temperature Change Graph** from the 1995 IPCC (Intergovernmental Panel on Climate Change) report. Tell students that this graph shows several different models of forecast temperature changes. Ask: *Why is there more variation (a wider spread) between the models at later dates than at closer dates?* (There is more variation between the models at later dates than at closer dates because there is more variability in predicting the far future than in predicting the near future.)

Tell students that the ability to better predict near-term events occurs in hurricane and tropical storm forecasting as well. Project **The Definition of the National Hurricane Center Track Forecast Cone** and show students the “cone of uncertainty” around the track of the storm. Tell students that the cone shows the scientists' uncertainty in the track of the storm, just as the climate models show the scientists' uncertainty in how much Earth's temperature will change in the future.

Ask: *When are scientists most confident in their predictions?* (Scientists are most confident in their predictions when they have a lot of data. This is why the forecast for near-term events is better than forecasts of longer-term events, both in storm forecasting and in climate forecasting.)

Tell students they will be asked questions about the certainty of their predictions and that they will need to think about what scientific data are available as they assess their certainty with their answers. Encourage students to discuss the scientific evidence with each other to better assess their level of certainty with their predictions.

3. Discuss the role of systems in climate science.

Tell students that forecasting what will happen in Earth's climate system is a complicated process because there are many different interacting parts. Scientists think about how one part of the system can affect other parts of the system. Give students a simple example of a system, as described in the scenario below.

On an island, there is a population of foxes and a population of rabbits. The foxes prey on the rabbits. Ask:

- *When there are a lot of rabbits, what will happen to the fox population?* (It will increase because there is an ample food supply.)
- *What happens to the fox population when they've eaten most of the rabbits?* (The foxes will die of starvation as their food supply decreases.)
- *What happens to the amount of grass when the fox population is high?* (The amount of grass will increase because there are fewer rabbits to eat the grass.)
- *If there is a drought and the grass doesn't grow well, what will happen to the populations of foxes and rabbits?* (The rabbit population will decrease because they have a lesser food supply. The fox population should also decrease as their food supply decreases.)

Humans introduce dogs to the island. The dogs compete with the foxes over the rabbit food supply. Ask: What will happen to the populations of foxes, rabbits, and grass after the dogs are introduced? (The foxes will decrease because they are sharing their food supply, the rabbits will decrease because they have more predators, and the grass will do well because of the lowered impact of the smaller rabbit population.)

Tell students that these simple cause-effect relationships can expand into more complex system relationships. Let students know they will be exploring cause-effect and system feedback relationships between carbon dioxide and water vapor in this activity. Ask students to think about how each piece of the system affects other pieces of the system.

4. Introduce and discuss the use of computational models.

Introduce the concept of computational models, and give students an example of a computational model that they may have seen, such as forecasting the weather. Project the NOAA **Weather Forecast Model**, which provides a good example of a computational model. Tell students that:

- scientists use information about the past to build their climate models.
- scientists test their climate models by using them to forecast past climates.
- when scientists can accurately forecast past climates, they can be more confident about using their models to predict future climates.

5. Have students launch the Using Models to Make Predictions interactive.

Provide students with the link to the Using Models to Make Predictions interactive. Divide students into groups of two or three, with two being the ideal grouping to allow students to share a computer workstation. Tell students they will be working through a series of pages of models with questions related to the models. Ask students to work through the activity in their groups, discussing and responding to questions as they go.

NOTE: You can access the Answer Key for students' questions—and save students' data for online grading—through a free registration on the High-Adventure Science portal page.

Tell students this is Activity 6 of the lesson **What Is The Future of Earth's Climate?**

6. Have students discuss what they learned in the activity.

After students have completed the activity, bring the groups back together and lead a discussion focusing on these questions:

- *Are models necessary to understand climate change?* (No. The basic cause of Earth's warming is understood without models, but the interactions are complex enough that models help in trying to fully understand all of the relationships between the components in Earth's climate system.)

- *How can you tell that the results from a climate model are valid?* (When a climate model can accurately predict past climates, you can have more confidence in its ability to predict future climates. If the inputs to the model are good enough to predict the past, they should be enough to give a good indication of the future.)

- *In the* ***Earth system model with human emissions slider (Model 8)****, how much of a decrease in greenhouse gas emissions was needed to keep the temperature from rising too much?* (The model shows that a 50-75% decrease is necessary. There are many factors missing from this model though. It doesn't show the warming effect of clouds or ocean currents, which can affect global temperatures.)

TipTeacher Tip

This activity is part of a sequence of activities in the What Is the Future of Earth's Climate? lesson. The activities work best if used **in sequence**.

TipTeacher Tip

To save your students' data for grading online, register your class for free at the High-Adventure Science portal page.

Modification

This activity may be used individually or in groups of two or three students. It may also be modified for a whole-class format. If using as a whole-class activity, use an LCD projector or interactive whiteboard to project the activity. Turn embedded questions into class discussions. Uncertainty items allow for classroom debates over the evidence.

Informal Assessment

1. Check students' comprehension by asking them the following questions:

- What is the relationship between greenhouse gas emissions and Earth's temperature?
- Why does the temperature not decrease immediately after greenhouse gas emissions decline?
- Why do scientists think the warming of the 20^{th} century cannot be explained by natural variability?

2. Use the answer key to check students' answers on embedded assessments.

OBJECTIVES

Subjects & Disciplines

- **Earth Science**

Learning Objectives

Students will:

- explore the complex interrelationships between Earth's surface and oceans, greenhouse gases, and temperature
- analyze the validity of climate models for predicting future climate conditions

Teaching Approach

- Learning-for-use

Teaching Methods

- Discussions
- Multimedia instruction
- Visual instruction
- Writing

Skills Summary

This activity targets the following skills:

- 21st Century Student Outcomes
  - Information, Media, and Technology Skills
    - Information, Communications, and Technology Literacy
  - Learning and Innovation Skills
    - Critical Thinking and Problem Solving
- 21st Century Themes
  - Global Awareness
- Critical Thinking Skills

- Analyzing
- Evaluating
- Understanding

National Standards, Principles, and Practices

NATIONAL SCIENCE EDUCATION STANDARDS

• **(5-8) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(5-8) Standard A-2:**
Understandings about scientific inquiry
• **(5-8) Standard B-1:**
Properties and changes of properties in matter
• **(5-8) Standard B-3:**
Transfer of energy
• **(5-8) Standard E-1:**
Abilities of technological design
• **(5-8) Standard E-2:**
Understandings about science and technology
• **(5-8) Standard F-5:**
Science and technology in society
• **(5-8) Standard G-1:**
Science as a human endeavor
• **(5-8) Standard G-2:**
Nature of science
• **(9-12) Standard A-1:**
Abilities necessary to do scientific inquiry
• **(9-12) Standard A-2:**
Understandings about scientific inquiry
• **(9-12) Standard B-2:**
Structure and properties of matter
• **(9-12) Standard B-5:**
Conservation of energy and increase in disorder
• **(9-12) Standard D-1:**
Energy in the earth system
• **(9-12) Standard E-1:**

Abilities of technological design

- **(9-12) Standard E-2**:

Understandings about science and technology

- **(9-12) Standard G-1**:

Science as a human endeavor

- **(9-12) Standard G-2**:

Nature of scientific knowledge

COMMON CORE STATE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.11-12.3

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.6-8.3

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.9-10.3

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.11-12.1

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.11-12.4

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.6-8.4

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.9-10.1

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Craft and Structure, RST.9-10.4

- **Reading Standards for Literacy in Science and Technical Subjects 6-12**:

Key Ideas and Details, RST.6-8.1

ISTE STANDARDS FOR STUDENTS (ISTE STANDARDS*S)

- **Standard 3**:

Research and Information Fluency

- **Standard 4**:

Critical Thinking, Problem Solving, and Decision Making

NEXT GENERATION SCIENCE STANDARDS

- **Crosscutting Concept 2:**
Cause and effect: Mechanism and prediction
- **Crosscutting Concept 3:**
Scale, proportion, and quantity
- **Crosscutting Concept 4:**
Systems and system models
- **Crosscutting Concept 5:**
Energy and matter: Flows, cycles, and conservation
- **Crosscutting Concept 7:**
Stability and change
- **HS. Earth and Human Activity:**
HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- **HS. Earth and Human Activity:**
HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
- **HS. Earth's Systems:**
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.
- **HS. Earth's Systems:**
HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- **HS. Earth's Systems:**
HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- **MS. Earth and Human Activity:**
MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.
- **Science and Engineering Practice 1:**
Asking questions and defining problems
- **Science and Engineering Practice 2:**
Developing and using models
- **Science and Engineering Practice 3:**
Planning and carrying out investigations
- **Science and Engineering Practice 4:**
Analyzing and interpreting data

• **Science and Engineering Practice 6**:
Constructing explanations and designing solutions
• **Science and Engineering Practice 7**:
Engaging in argument from evidence
• **Science and Engineering Practice 8**:
Obtaining, evaluating, and communicating information.

Preparation

BACKGROUND & VOCABULARY

Background Information

Climate scientists use models to test their predictions about climate change. They test different scenarios by changing their inputs to the model and algorithms for how various factors interact with each other.

When scientists can accurately predict past climates with their inputs and algorithms, they can be more sure that their models will be able to correctly predict future climates. There are many different factors that can affect Earth's atmosphere and temperature, and scientists continually update their models to reflect as many of these interactions as they can.

Prior Knowledge

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Recommended Prior Activities

- Sources, Sinks, and Feedbacks

Vocabulary

Term	Part of Speech	Definition
absorb	*verb*	to soak up.
atmosphere	*noun*	layers of gases surrounding a planet or other celestial body.

Term	Part of Speech	Definition
carbon dioxide	*noun*	greenhouse gas produced by animals during respiration and used by plants during photosynthesis. Carbon dioxide is also the byproduct of burning fossil fuels.
climate	*noun*	all weather conditions for a given location over a period of time.
emit	*verb*	to give off or send out.
greenhouse effect	*noun*	phenomenon where gases allow sunlight to enter Earth's atmosphere but make it difficult for heat to escape.
greenhouse gas	*noun*	gas in the atmosphere, such as carbon dioxide, methane, water vapor, and ozone, that absorbs solar heat reflected by the surface of the Earth, warming the atmosphere.
ice core	*noun*	sample of ice taken to demonstrate changes in climate over many years.
infrared radiation	*noun*	part of the electromagnetic spectrum with wavelengths longer than visible light but shorter than microwaves.
model, computational	*noun*	a mathematical model that requires extensive computational resources to study the behavior of a complex system by computer simulation.
parts per million (ppm)	*plural noun*	A unit of measure of the amount of dissolved solids in a solution in terms of a ratio between the number of parts of solids to a million parts of total volume.
radiation	*noun*	energy, emitted as waves or particles, radiating outward from a source.
system	*noun*	collection of items or organisms that are linked and related, functioning as a whole.
temperature	*noun*	degree of hotness or coldness measured by a thermometer with a numerical scale.

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