Climate Change - Student Materials

Unit 4	Earth and Space Science

Student Materials Table of Contents

Performance Task Organizer

Unit 4 Climate Change	Earth and Space Science
Student Name:	

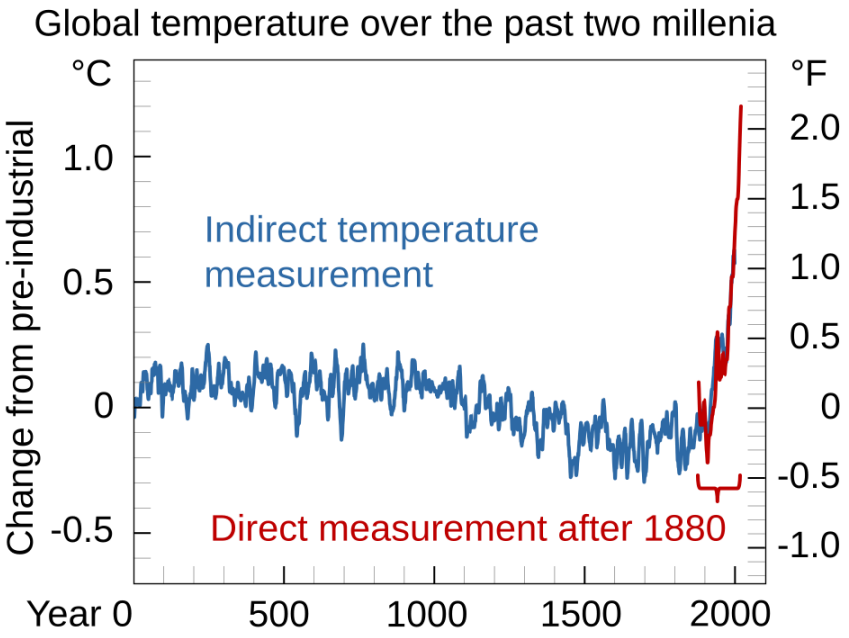
Tell the Story

The Effects of Climate Change and its Perceptions

Directions:

1. Silently read or watch the "text" provided to you.
2. Record or annotate three details that are most important to the phenomenon being described for each text.
3. Share with your group. Each person should identify the details that they circled.
4. Discuss as a group, and determine the overall story. What is the phenomenon?

Text #1: Arctic (above 65° north) Summer Temperature Over Last 2000 Years



- The y-axis is difference **compared** to the average Arctic Temperature over the last 2000 years
- The blue line shows estimates of Arctic temperatures over the last 2,000 years, based on records from lake sediments, ice cores and tree rings
- The red line shows the recent warming based on actual observations

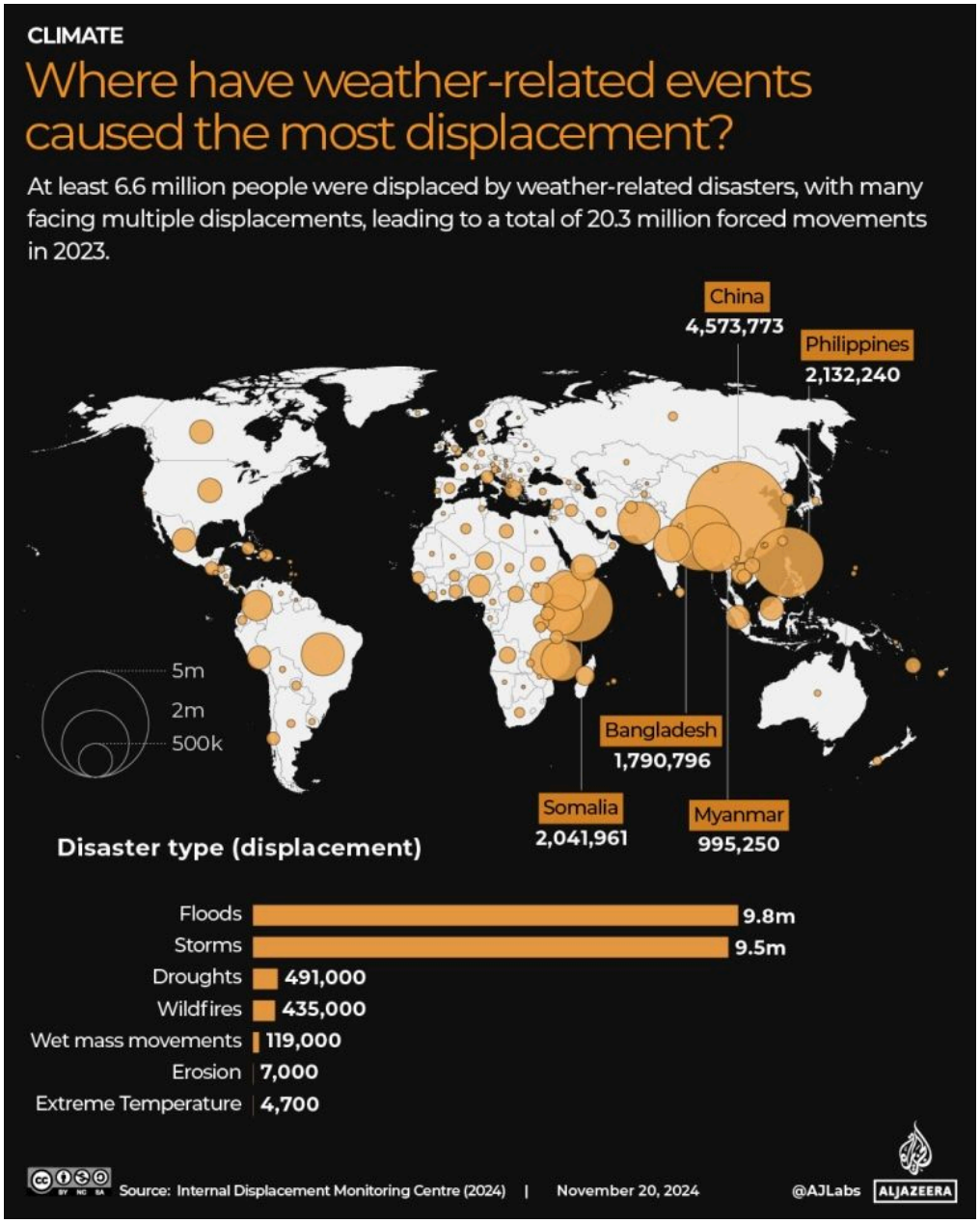
Important Details

1. _____

2. _____

3. _____

Text #2: Climate-Related Human Displacement in 2023



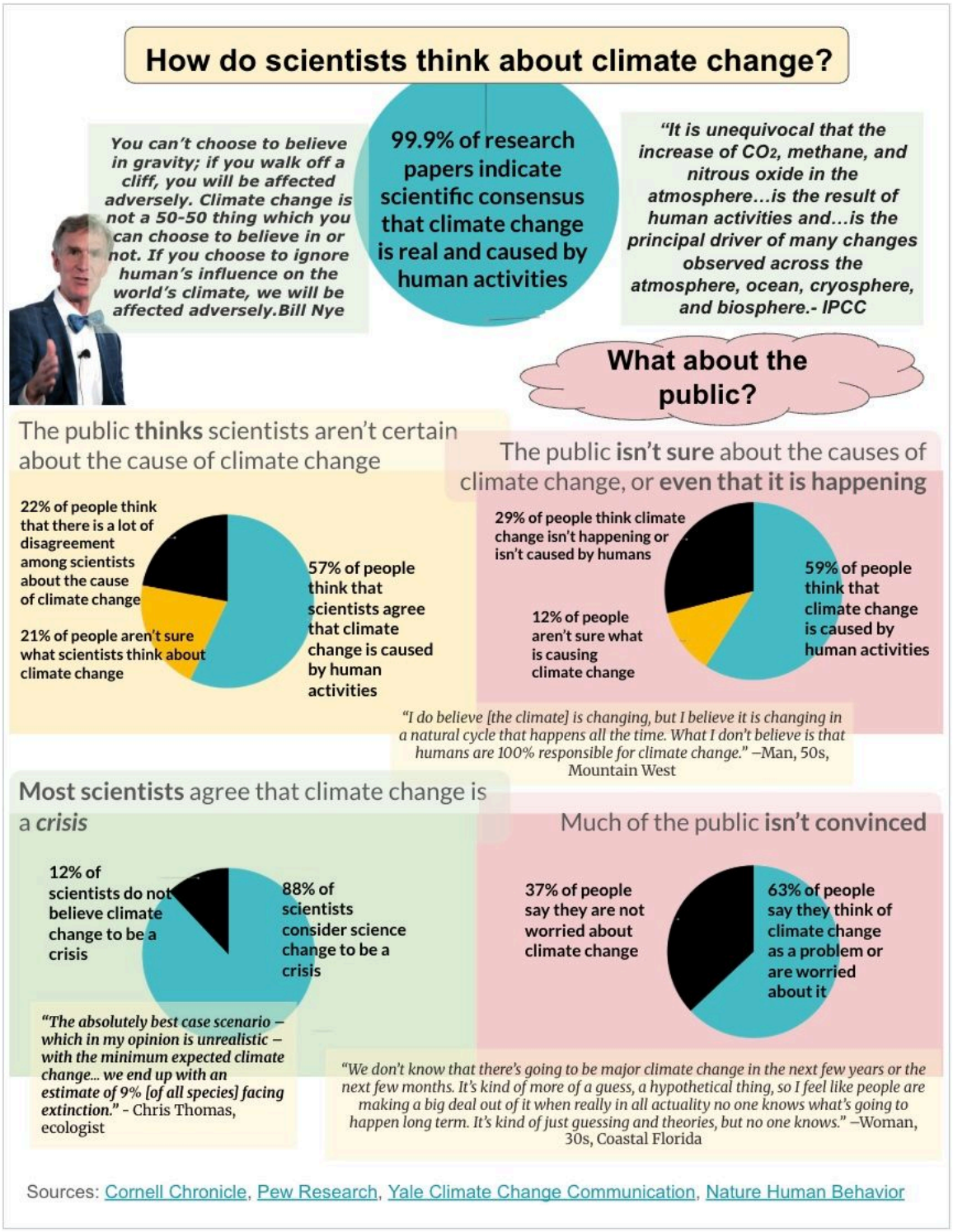
Important Details

1. _____

2. _____

3. _____

Text #3: Scientist vs. Public Opinions of Climate Change



Important Details

1. _____

2. _____

3. _____

Important details our group surfaced (provide at least 5):

1. _____
2. _____
3. _____
4. _____
5. _____

Overall Story of the Phenomenon (based on group discussion):

Use details from above to tell the story of the phenomenon.

Performance Task Introduction

Educating your Community about the Predicted Impacts of Climate Change on Human Populations

Climate change, a scientifically proven phenomenon with dire consequences, faces significant public skepticism despite overwhelming consensus among experts. Research reveals that 99.9% of climate scientists attribute global warming to human activities. However, in the United States, skepticism persists, with over 40% of citizens doubting human involvement and one-third unconcerned about its repercussions.

While global efforts intensify, political leaders are not taking enough action to adequately address the challenge. Urgent public demand is crucial to motivating leaders into meaningful climate policies. This will require educating individuals to grasp why experts overwhelmingly blame human actions, specifically greenhouse gas emissions, for climate shifts, and what negative effects will likely result from these shifts.

Your task in this unit is to communicate the validity of the scientific consensus around the cause and importance of climate change. To do so, you will:

1. Analyze and interpret data to confirm scientists' understanding of human activities as the cause of climate change in this moment in time
2. Analyze and interpret data to determine future impacts of climate change
3. Explain how these impacts are expected to affect human populations

Initial Model

What factors are contributing to climate change, and how is that resulting in human displacement?

Your first step in this investigation is to work with classmates to develop an initial model that illustrates how different climate factors and how those factors impact average global temperatures.

Initial Climate Change Models

Directions

1. Review all the climate factor ideas the class surfaced during the Rumors routine.
2. In your group, identify the most likely causes of present climate change on Earth.
3. Consider how those factors and resulting climate change could result in the climate displacements we observed
4. Represent all your ideas in the form of a model.

Revisiting the Performance Task: Earth-Sun Dynamics 5E

Disproving climate skeptics

Using the data about historical temperature changes over time, the changes in orbital factors over the past 9,000 years, the solar cycles, and the effect of solar factors on energy entering Earth's systems, make and support a valid claim about the role of orbital factors and solar cycles on the melting of ice caps today.

Revisiting the Performance Task: Climate Feedbacks 5E

Disproving Climate Skeptics

Using the data about carbon dioxide levels and temperature changes, the roles of carbon dioxide and ice caps in climate change, and the feedback mechanisms between parts of Earth's systems, make and support a valid claim about the role of carbon dioxide and human activities on the warming of the planet today.

Disproving Climate Skeptics

Using the data about projected temperature changes, other projected climate changes, and information about their role in shaping human lives, make and support a claim about how human populations will likely be impacted by climate related hazards in the near future.

Final Performance Task

Share with the community

For this final task, communicate to someone in your community who is skeptical about climate change. In a letter, public service announcement, pamphlet, or other format:

1. Explain how the data demonstrates human causes of climate change
2. Describe the ongoing and future impacts on the planet of climate change
3. Explain how these changes are likely to affect people in your community

Use the space below to craft your communication. If you are using a written format, you can write it below. If you are using something with video/audio elements, write the script below.

Seasons Optional 3E

Unit 4 Climate Change	Earth and Space Science
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Why do we have seasons?

At lunch you overhear some of the kids at school talking about why it's so much warmer in New York City during the Summer than it is during the Winter. Read their ideas below and decide which one you agree with most.

Devon: "It's because the winter clouds block heat from the Sun."

Lisa: "It's because the Sun gives off more heat in the summer than in winter."

Omar: "It's because Earth's tilt changes the angle of sunlight hitting Earth."

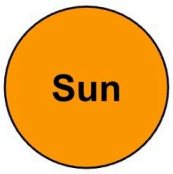
Derek: "It's because the Earth orbits closer to the Sun in the summer than in the Winter."

Simone: "It's because one side of Earth faces the Sun and the other side faces away."

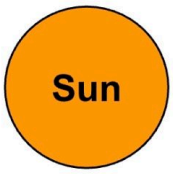
Susan: "It's because the Northern Hemisphere is closer to the Sun in summer than in the winter."

Which idea do you agree with most? Draw a diagram and write a few sentences below to explain your thinking.

New York City in the Summer



New York City in the Winter



What causes seasons? Part 1: Using Physical Models

Instructions for Setup:

1. Mark three inches to the right and left from the central axis of the North Pole (90° N) with masking tape. This will represent the natural 23.5° tilt of the Earth.
2. Next, mark three locations along the same longitude across the various latitudes in the tables below with masking tape.
3. Carefully place the heat lamp in a secure spot six inches away from the center of the globe (as seen in Figure 1).
4. Record temperature by pointing the temperature reader at all designated spots after the 5-minute mark.
   To ensure accurate readings, take a 1 minute pause and allow globe to cool before recording data in subsequent tables.

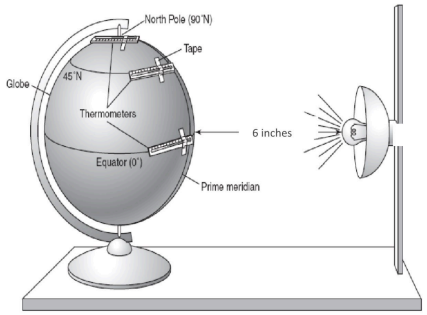


FIGURE 1

Safety:

Exercise **extreme caution** when using heat lamps. They get very hot!!!
Do not touch them without an oven mitt.
Have your teacher check your set-up before you turn on the lamp.

Part A:
In this part of the investigation you will be collecting data on how the temperature at different latitudes is affected by the changing position of the Earth with respect to the Sun.

North Pole Tilted Towards the Sun

Initial Room Temp: _____

Latitude	Final Temp at 5 Min
45˚N	
equator (0˚)	
45˚S	

North Pole Tilted Way From the Sun

Initial Room Temp: _____

Latitude	Final Temp at 5 Min
45˚N	
equator (0˚)	
45˚S	

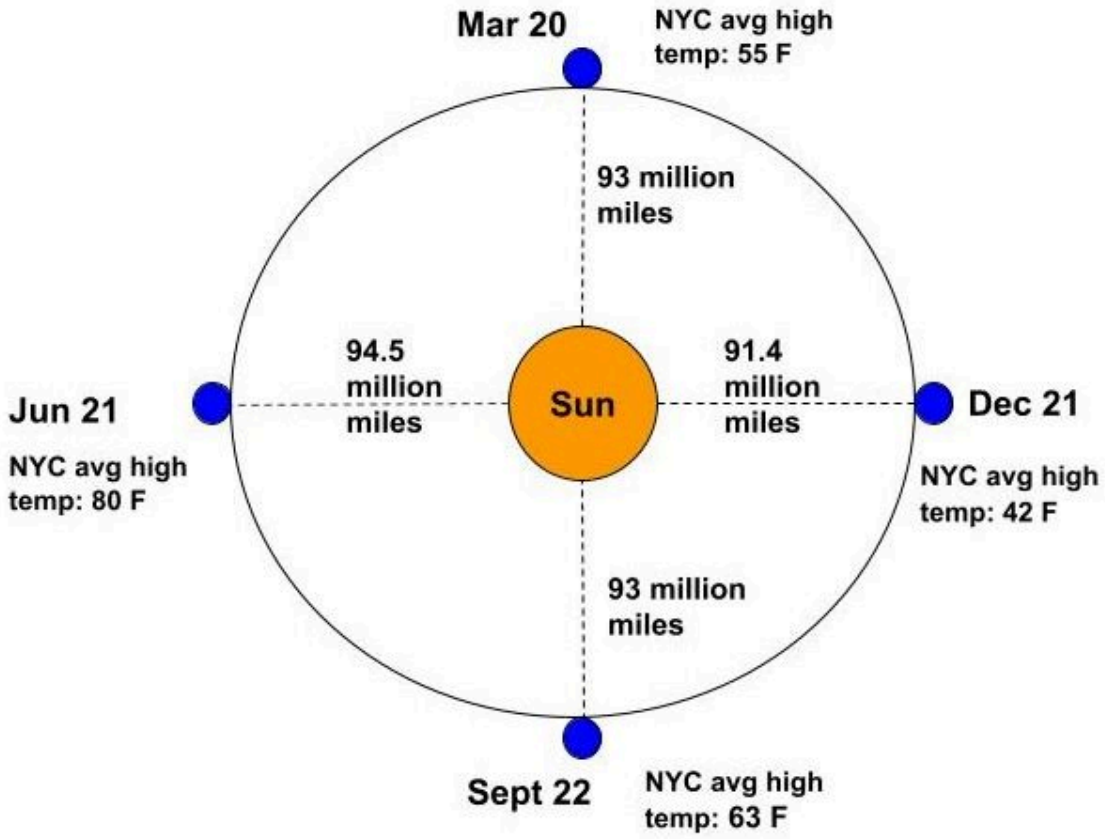
No Tilt Towards or Away From the Sun
Initial Room Temp: _____

Latitude	Final Temp at 5 Min
45˚N	
equator (0˚)	
45˚S	

1. What do you notice about the way the temperature changes at different latitudes?

2. What do you think is causing those temperature changes?

Part B.
The diagram below shows the Earth at four different dates of the year and the average temperature in NYC. Examine the diagram and use the information it provides to fill in the data table below.



Time of Year	Season	NYC Average Temp	Distance Between Earth and the Sun
Dec 21			
March 20			
June 21			
Sept 22			

1. What do you notice in the data?

2. Can you reach any conclusions about the factors that cause seasons based on the data?

Part C:
In this section, we will recreate the Sun's rays as they interact with our Earth. Observe and note the spread of light at different latitudes across the globe.

Instructions:
Hold a flashlight parallel to the floor, 3-6 inches away from the globe, and point the light at all latitude points listed in the table below. Notice the concentration and intensity of the light and record your observations below. The lights in the room can be dimmed to notice the effects further.

Latitude	Observations of the Spread of Light
90^{o}N	
45^{o}N	
0^{o}	
45^{o}S	
90^{o}S	

1. Do you think the amount of light coming out of the flashlight changed?

2. Where on the globe was the light most concentrated (least spread out)? Why do you think that is?

3. Where on the globe was the light least concentrated (most spread out)? Why do you think that is?

4. Compare your observations from **Part C** with your temperature data from **Part A**. What is the relationship between the spread of light and temperature? Cite evidence from the investigation to support your thinking.

As the spread of light increases the temperature _____

As the spread of light decreases the temperature _____

Making Sense of the What causes seasons? Part 1: Using Physical Models Investigation

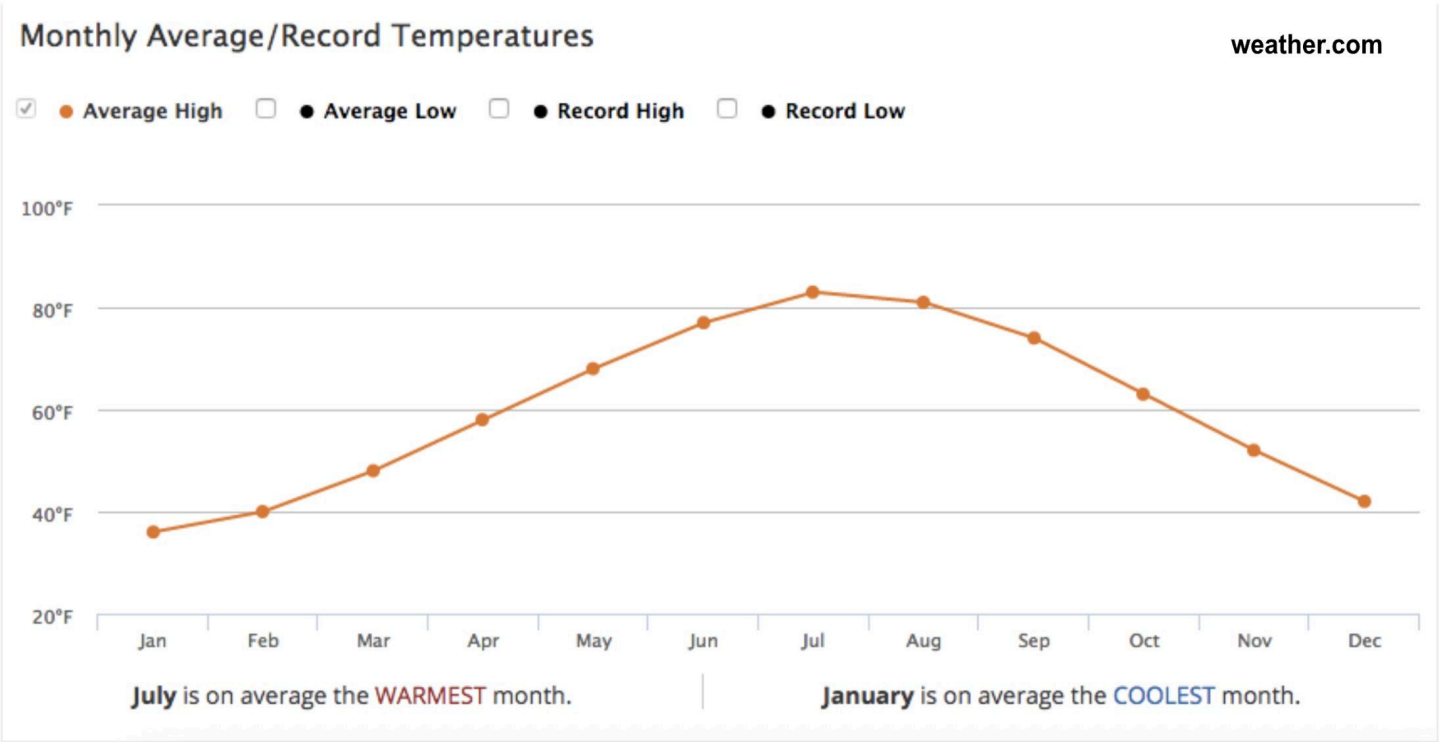
See-Think-Wonder

See What did you observe?	Think What does each observation make you think?	Wonder What questions do you have about each observation?
What latitude(s) were the warmest? What latitude(s) were the coldest?	What do you think explains these observations?	
How far is New York from the Sun when New York is experiencing Summer? How far is New York from the Sun when New York is experiencing Winter?		
Where on the Earth was light least spread out? Where on the Earth was light most spread out?	What does this make you think about the relationship between spread of light and heat absorbed?	

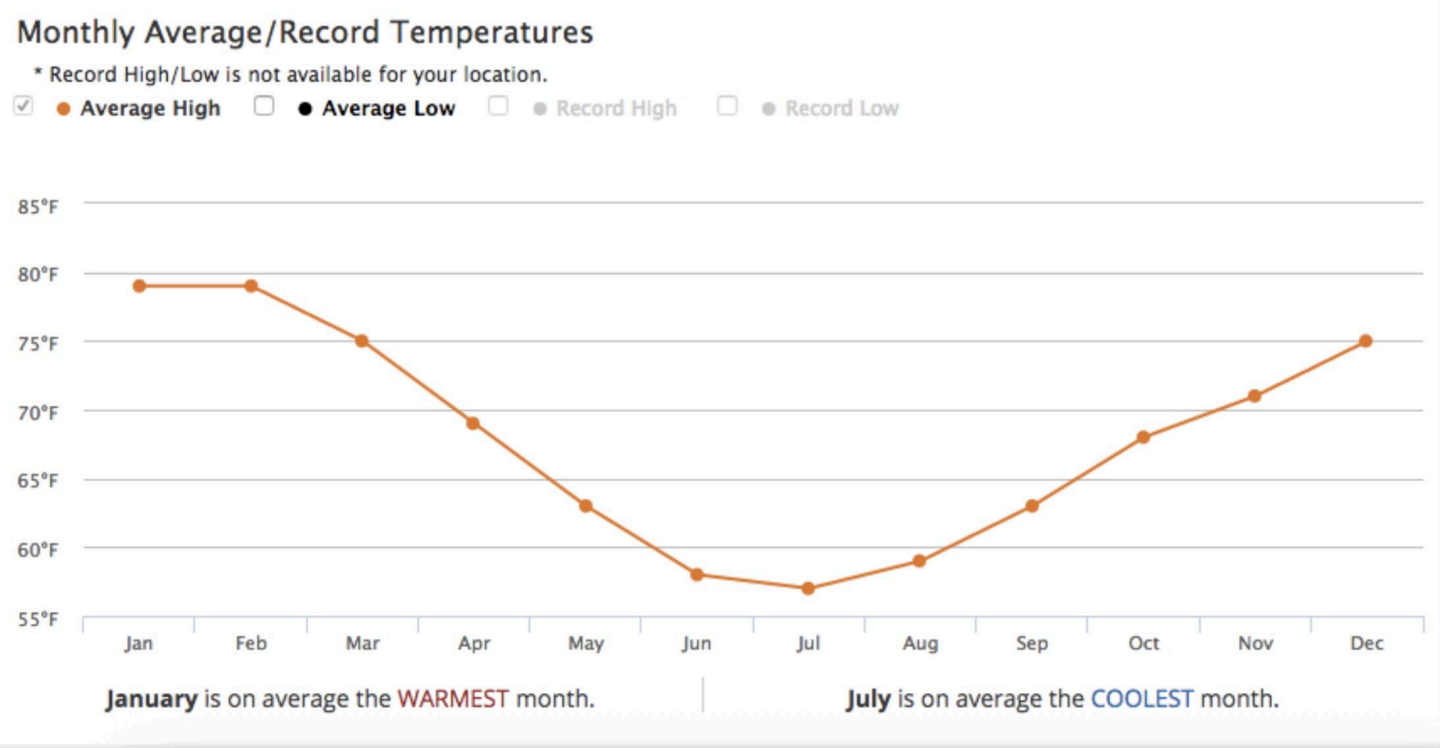
What causes seasons? Part 2. Using Computational and Visual Models

Part D: Below is a world map with markers on New York, USA and Melbourne, Australia. Examine the average monthly temperature graphs for New York, USA and Melbourne, Australia. Then, use the information on the graphs to fill in the data table below the graphs.

City: New York City, USA; **Lat:** 40°N



City: Melbourne, Australia; **Lat:** 38°S



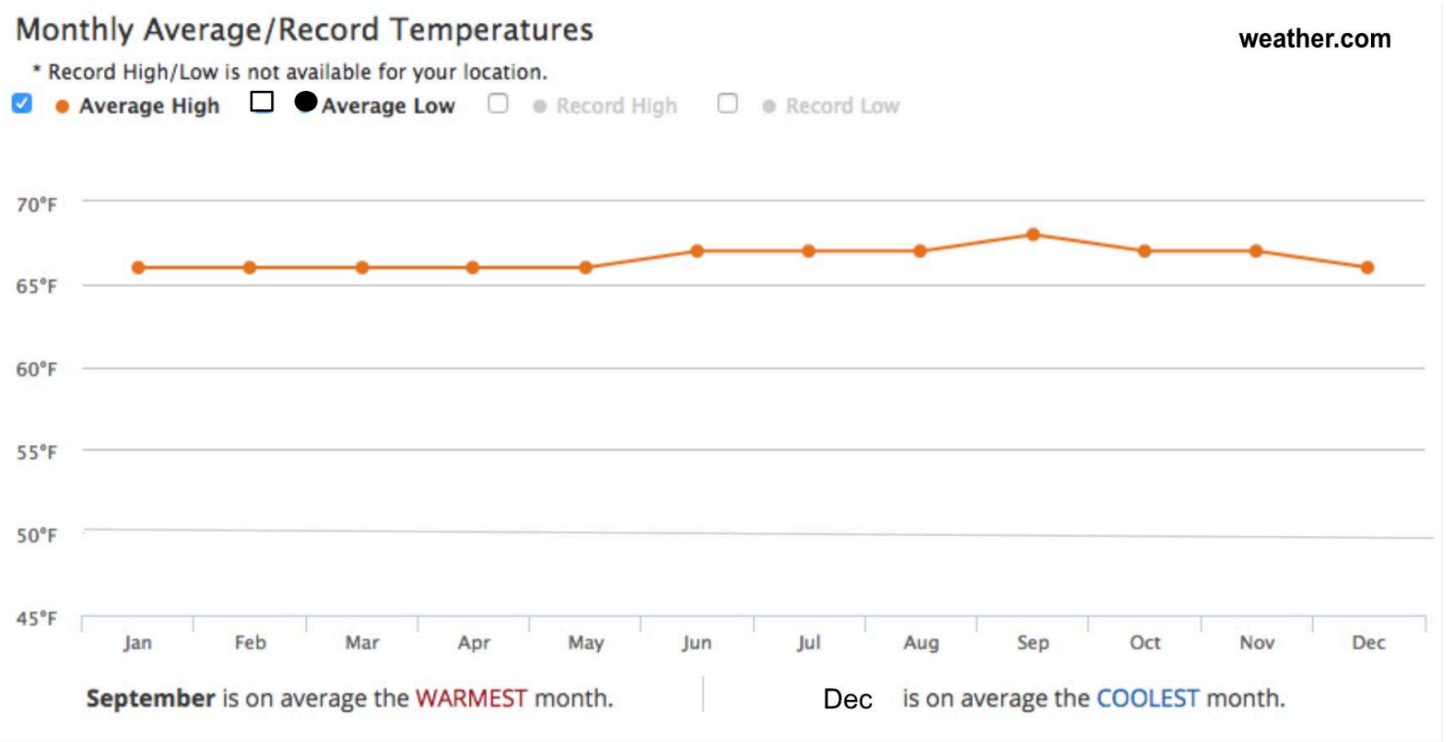
Historical Average Monthly Temperature Data

City	Warmest Month	Coldest Month
New York		
Melbourne		

1. What surprises you most about the data?

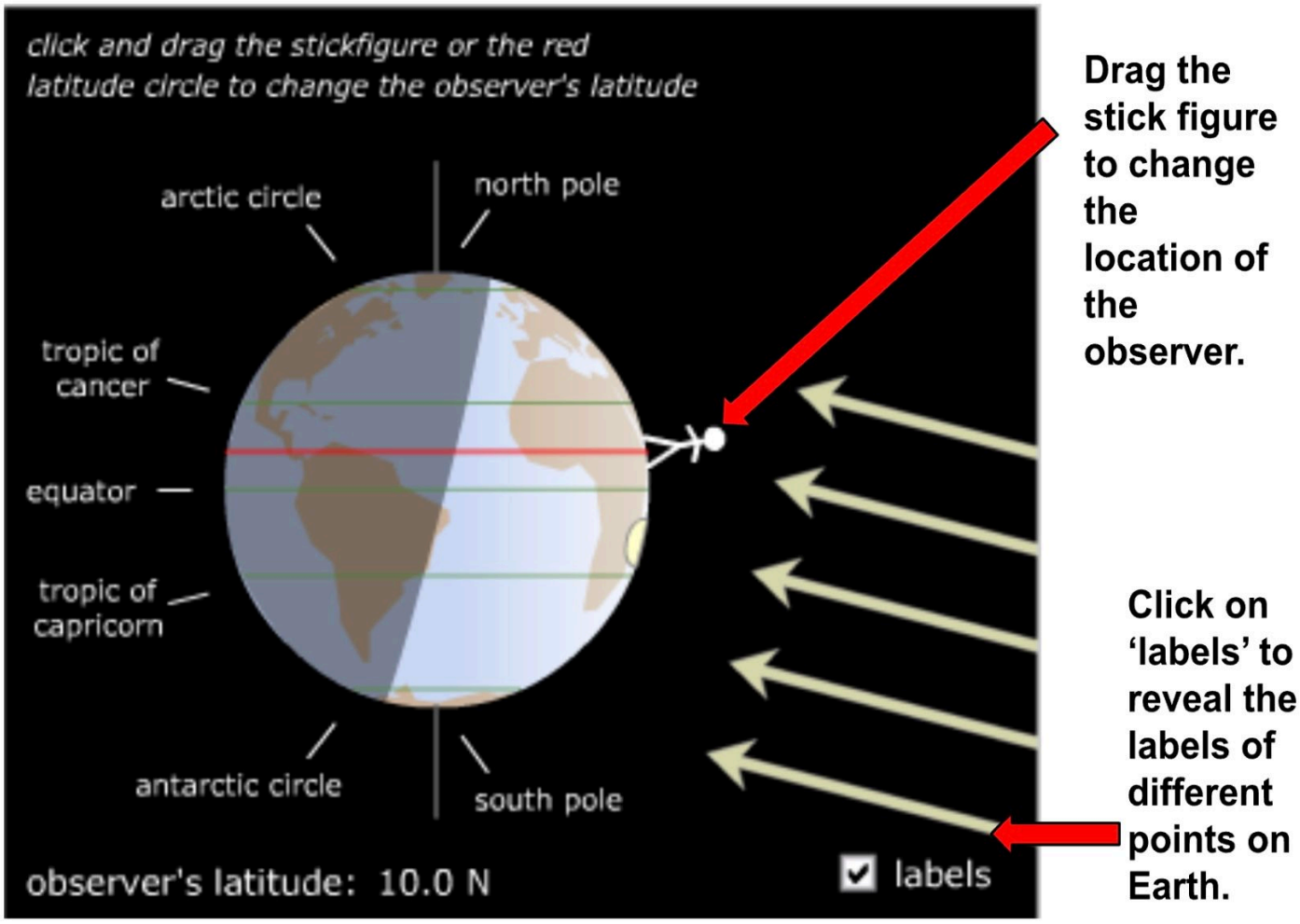
2. The world map below has an additional marker for Quito, Ecuador. Examine the average monthly temperature graph below for Quito, Ecuador and compare it to the graphs for New York City and Melbourne.

City: Quito, Ecuador**; Lat:** 0° (Equator)



3. What surprises you about the data?

In order to better understand the way the Sun's rays hit the Earth's surface at different locations throughout the year, you will make observations from an interactive simulator. Carefully examine the diagrams with annotations below so that you have some familiarity with the simulator before using it.

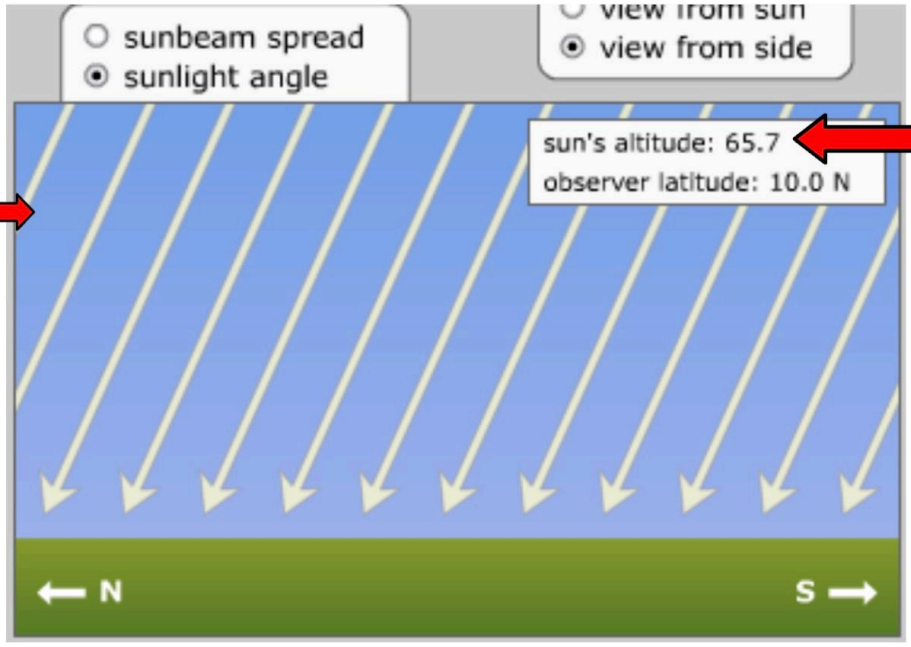


This tells you the exact day of the year shown in the simulator.

You can control the animation by dragging this arrow to a specific date.

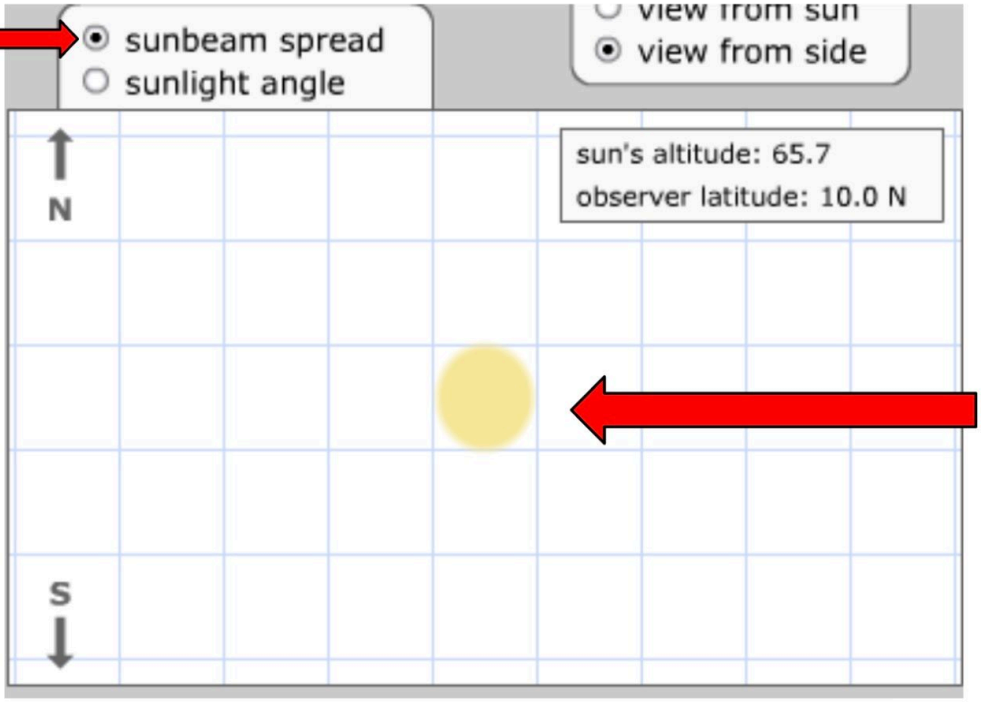
You can start and stop the simulation by clicking here.

These arrows give you a visual of the angle at which sunbeams are hitting the Earth's surface at different locations.



'sun's altitude' tells you the angle of the Sun's rays at the observer's latitude.

Click ‘sunbeam spread’ to see this window that shows the spread of the Sun’s beams.

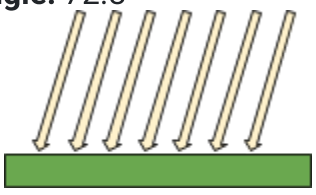


This yellow circle shows how spread out the Sun’s beams are at any given angle.

1. Click on the Seasons and Ecliptic simulator. Play with the simulator for 3 minutes and note any observations, thoughts, and wonderings you have below.

2. Use the simulator to collect data for New York, Melbourne, and Quito and fill in the three tables below. Before collecting data for each city, be sure that you move the stick figure so that the ‘observer’s latitude’ matches the latitude for that city.

City: New York City, USA; Latitude: 41°N

Date	**Earth’s Tilt** Look at the left side of the sim screen. Is the north pole tilted toward or away from the Sun?	**Angle of Sun’s Rays** What is the angle at which the Sun’s rays are hitting the Earth’s surface? Draw them!	**Spread of Sun’s Rays**
June 21	toward	**Angle:** 72.8° 	

Sept 22	neither	**Angle:**	
Dec 21		**Angle:**	
March 20	neither	**Angle: of**	

City: Melbourne, Australia; Latitude: 38°S

Date	**Earth's Tilt** Look at the left side of the sim screen. Is the north pole tilted toward or away from the Sun?	**Angle of Sun's Rays** What is the angle at which the Sun's rays are hitting the Earth's surface? Draw them!	**Spread of Sun's Rays**

June 21		**Angle:**	
Sept 22		**Angle:**	
Dec 21		**Angle:**	

March 20		**Angle:**	

City: Quito, Ecuador; Latitude: 0° (equator)

Date	**Earth's Tilt** Look at the left side of the sim screen. Is the north pole tilted toward or away from the Sun?	**Angle of Sun's Rays** What is the angle at which the Sun's rays are hitting the Earth's surface? Draw them!	**Spread of Sun's Rays**
June 21		**Angle:**	
Sept 22		**Angle:**	

Dec 21		**Angle:**	
March 20		**Angle:**	

Making Sense of the What causes seasons? Part 2. Using Computational and Visual Models Investigation

See-Think-Wonder

See What did you observe?	Think What does each observation make you think?	Wonder What questions do you have about each observation?
How did the angle of the Sun's rays change throughout the year?	How do you think this relates to seasons?	
How did the Earth's revolution around the Sun affect its position in relation to the Sun?		

What Causes Seasons on Earth?

Question 1: Why does NYC experience the peak of Summer in late June, while Melbourne experiences its coldest temperatures at that same time?

a. Use your observations from the explore phase to fill in the June 21st data for each city in the table below.

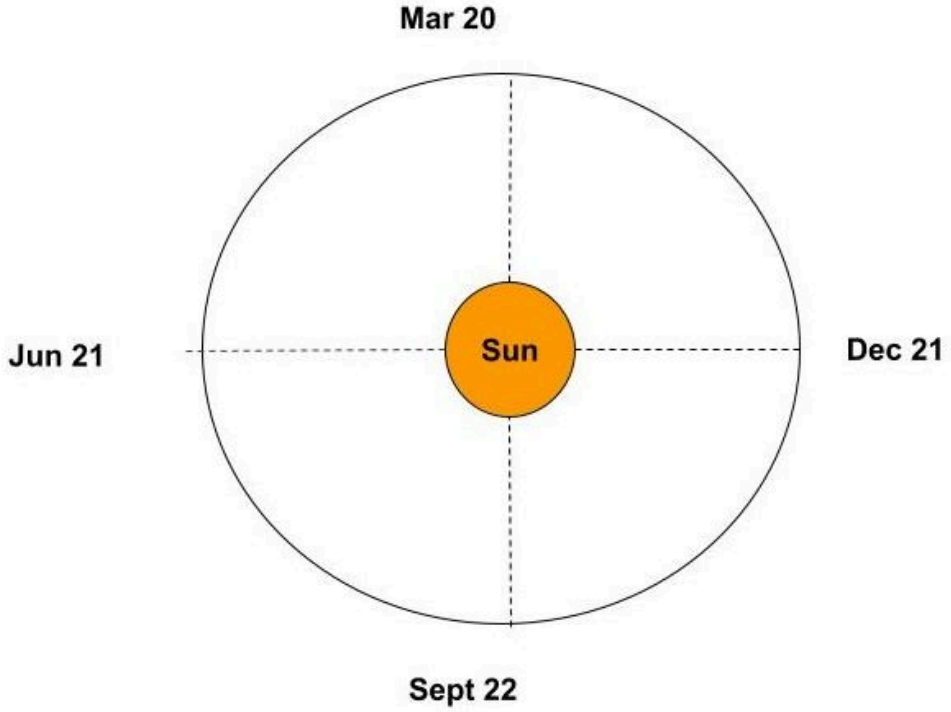
June 21 - New York City

Angle of Sun's rays	Compared to the rest of the year, are the Sun's rays more spread or focused?	How does this affect the temperature?

June 21 - Melbourne

Angle of Sun's rays	Compared to the rest of the year, are the Sun's rays more spread or focused?	How does this affect the temperature?

b. Complete the diagram below to show your thinking about 'Question 1'. Be sure to include a drawing of Earth on June 21st and label the North Pole, New York City, and Melbourne. Add any other information you think is relevant to the 'Question 1'.



c. Write a response to ‘Question 1’ that refers to your diagram and data.

Question 2: Why are late December and early January the coldest part of winter in New York City and one of the warmest parts of Summer in Melbourne?

a. Use your observations from the explore phase to fill in the Dec 21st data for each city in the table below.

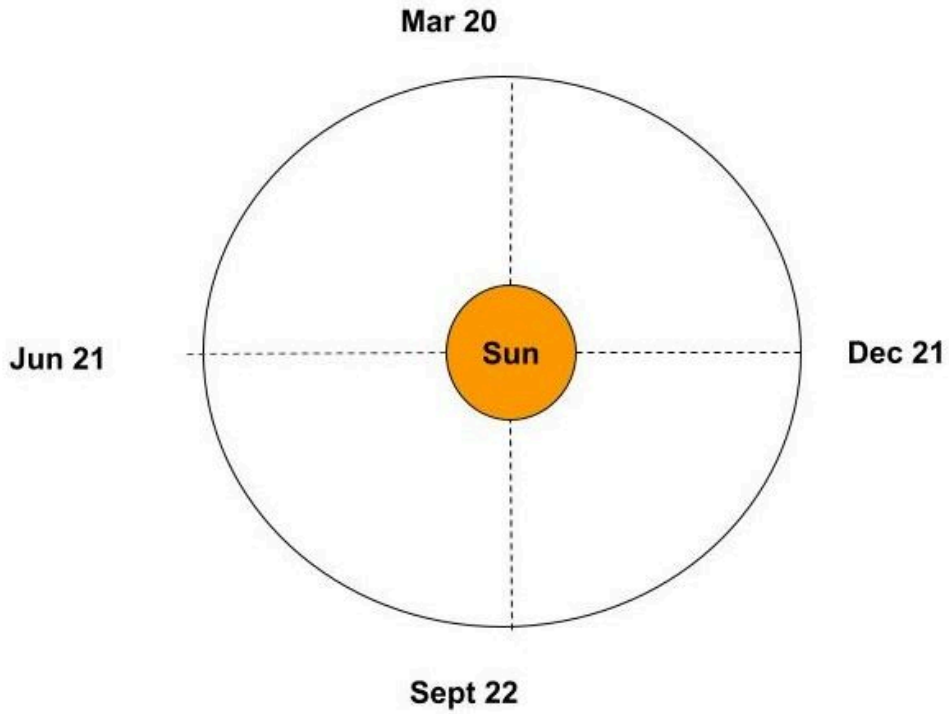
Dec 21 - New York City

Angle of Sun’s rays	Compared to the rest of the year, are the Sun’s rays more spread or focused?	How does this affect the temperature?

Dec 21 - Melbourne

Angle of Sun’s rays	Compared to the rest of the year, are the Sun’s rays more spread or focused?	How does this affect the temperature?

b. Complete the diagram below to show your thinking about the ‘Question 2’. Be sure to include a drawing of Earth on Dec 21st and label the North Pole, New York City, and Melbourne. Add any other information you think is relevant to the ‘Question 2’.



c. Write a response to 'Question 2' that refers to your diagram and data.

Read this The Seasons and/or watch this Insolation Part 2a- Reasons for the Seasons that explains why different places on Earth experience different seasons at the same time. Jot ideas from the text or video that either confirm your thinking, are in contradiction with your thinking, or that you have questions about.

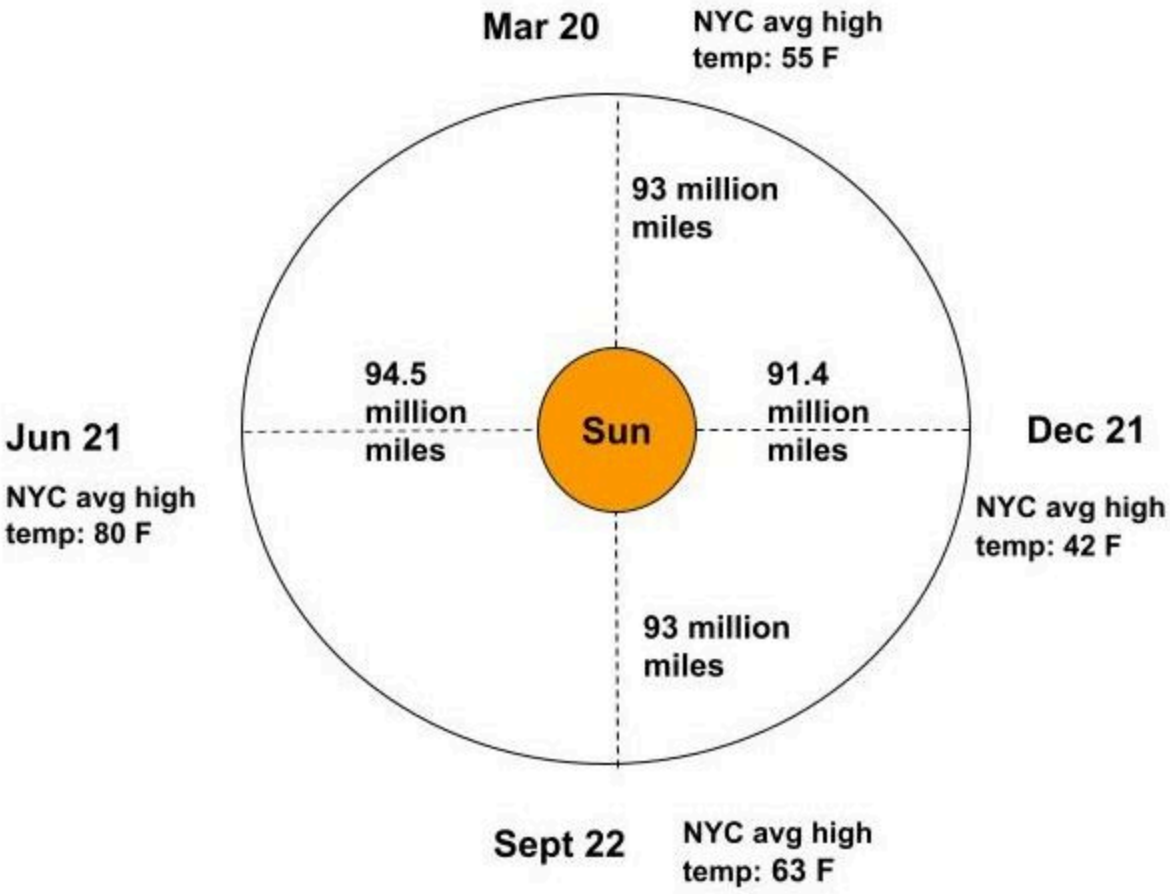
Ideas from the text or video that confirm your thinking about the reason there are seasons.	Ideas from the text or video that contradict your thinking about the reason there are seasons.	Ideas from the text or video that you have questions about the reason there are seasons.

Question 3: In your own words, explain why different locations on Earth experience different seasons on any given date. Create a diagram to support your written explanation.

Be sure your explanation includes the following concepts:

- revolution of Earth around the Sun
- tilt of the Earth
- angle insolation
- focus/spread of Sun's rays
- temperature

You must also explain how you know that seasons are not caused by the Earth's slight changes in distance from the Sun throughout the year.


Mar 20
NYC avg high temp: 55 F
93 million miles
94.5 million miles
Sun
91.4 million miles
Jun 21
NYC avg high temp: 80 F
Dec 21
NYC avg high temp: 42 F
93 million miles
Sept 22
NYC avg high temp: 63 F

What Causes Seasons on Earth?

Today we completed a Class Consensus Discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following question, based on what we discussed today:

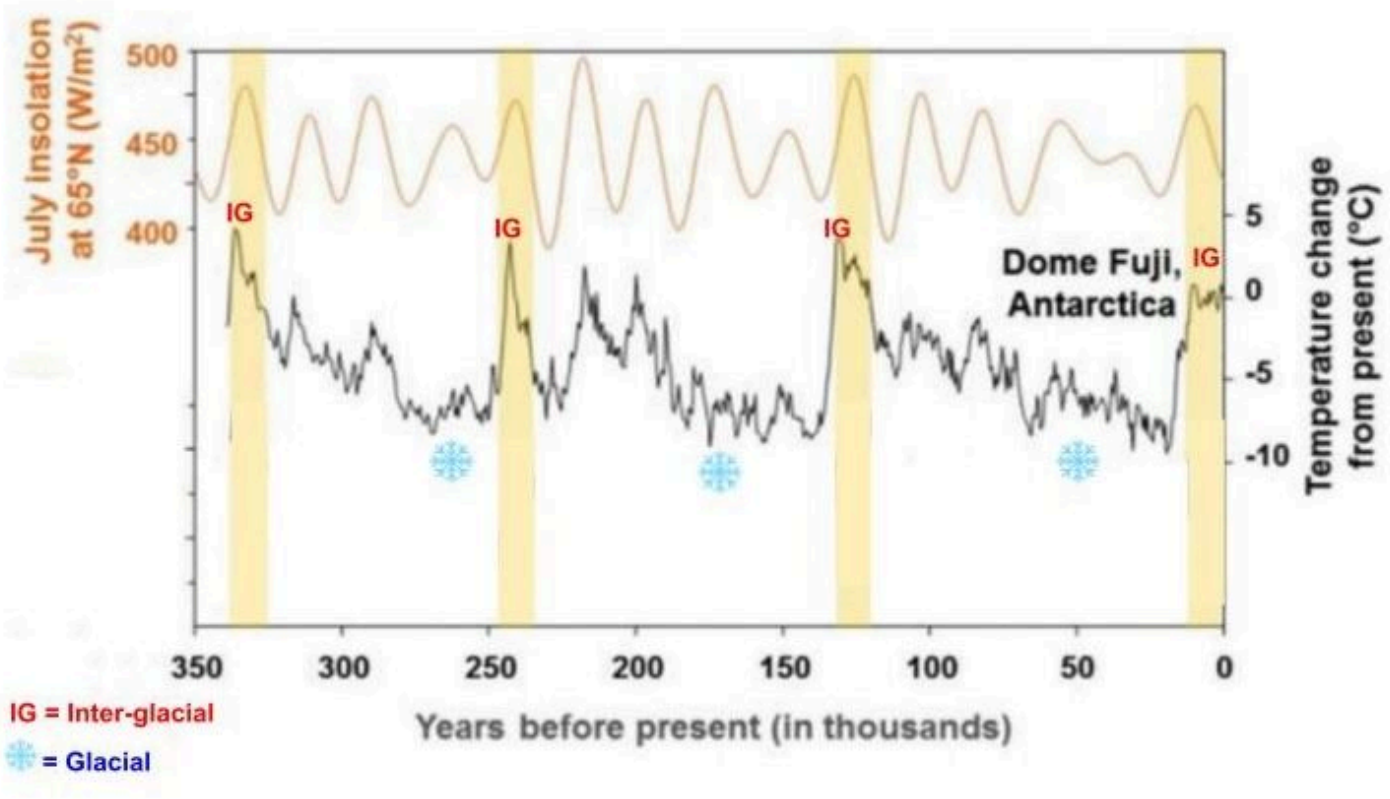
5. Explain how using patterns of temperature and sunlight helped you determine how how the relative motion of the Earth compared to the sun and the perspective of people living in different locations on the earth contribute to the experience of seasons.

Earth-Sun Dynamics 5E

Unit 4 Climate Change	Earth and Space Science
Student Name:	

Radiation and Temperature During Earth's Past

The graph below shows the total amount of radiation from the Sun reaching Earth at 65° N latitude and the temperature of the Earth compared to today over the past 350,000 years.



To help you with your analysis, complete the See-Think-Wonder table that follows.

See What did you observe?	**Think** What do these observations make you think?	**Wonder** What questions do you have about these observations?
What pattern do you observe in the frequency of interglacial and glacial periods?	What do you think might be causing these interglacial and glacial periods?	

What pattern do you observe in the July insolation graph?	What factors do you think influence the amount of insolation reaching Earth at 65°N in July?	

Orbital Factors Investigation

As Earth orbits the Sun, the shape of the orbit, the tilt of Earth's axis, and the direction in which Earth's axis points change over the course of 10s and 100s of thousands of years.

Your task is to draw and describe how each orbital factor changes the Earth's position with respect to the Sun over time. Then, develop a model and collect evidence to help you determine whether Earth's changing position with respect to the Sun can cause the patterns in the amount of radiation that reaches Earth's surface at 65° N latitude.

Orbital Factor: The direction of Earth's tilt with respect to the Sun

Draw a representation of how this factor changes over time.		

1. How much time does it take to complete a full cycle?

Use the materials provided by your teacher to model how the total amount of radiation reaching Earth is impacted by the direction of Earth's tilt toward the Sun. **Model materials:** small flashlight; sphere; markers / pen / pencil	
Observation when Earth's northern hemisphere is tilted toward the Sun	**Observation when Earth's northern hemisphere is tilted away from the Sun**

1. Does the total amount of radiation that reaches Earth change? Provide evidence to support your claim.

2. Does the total amount of radiation that reaches Earth at 65° N change? Provide evidence to support your claim.

Orbital Factor: The degree of Earth's tilt toward the Sun

Draw a representation of how this factor changes over time.		

1. How much time does it take to complete a full cycle?

Use the materials provided by your teacher to model how the total amount of radiation reaching Earth is impacted by the degree of Earth's tilt toward the Sun. **Model materials:** small flashlight; sphere; markers / pen / pencil	
Observation when Earth is less tilted toward the Sun	**Observation when Earth is more tilted toward the Sun**

1. Does the total amount of radiation that reaches Earth change? Provide evidence to support your claim.

2. Does the total amount of radiation that reaches Earth at 65° N change? Provide evidence to support your claim.

Orbital Factor: The shape of Earth's orbit (eccentricity)

Draw a representation of how this factor changes over time.		

1. How much time does it take to complete a full cycle?

Use the materials provided by your teacher to model how the total amount of radiation reaching Earth is impacted by the distance of the Earth from the Sun. **Model materials:** small flashlight; sphere; markers / pen / pencil	
Observation at shorter distance between Earth and the Sun	**Observation at longer distance between Earth and the Sun**

1. Does the total amount of radiation that reaches Earth change? Provide evidence to support your claim.

2. Does the total amount of radiation that reaches Earth at 65° N change? Provide evidence to support your claim.

Making Sense of the Orbital Factors Investigation

See What did you observe?	**Think** What do these observations make you think?	**Wonder** What questions do you have about these observations?
How did the direction of Earth's tilt affect the amount of radiation reaching Earth's surface?		
How did the degree of Earth's tilt affect the amount of radiation reaching Earth's surface?		
How did the eccentricity of Earth's orbit affect the amount of radiation reaching Earth's surface?		

Analysis Question

1. Based on what you observed in the models, do you think Earth's changing orbit and tilt could be the cause of the patterns in total amount of radiation reaching Earth's at 65 ° N latitude? Provide evidence to support your claim.

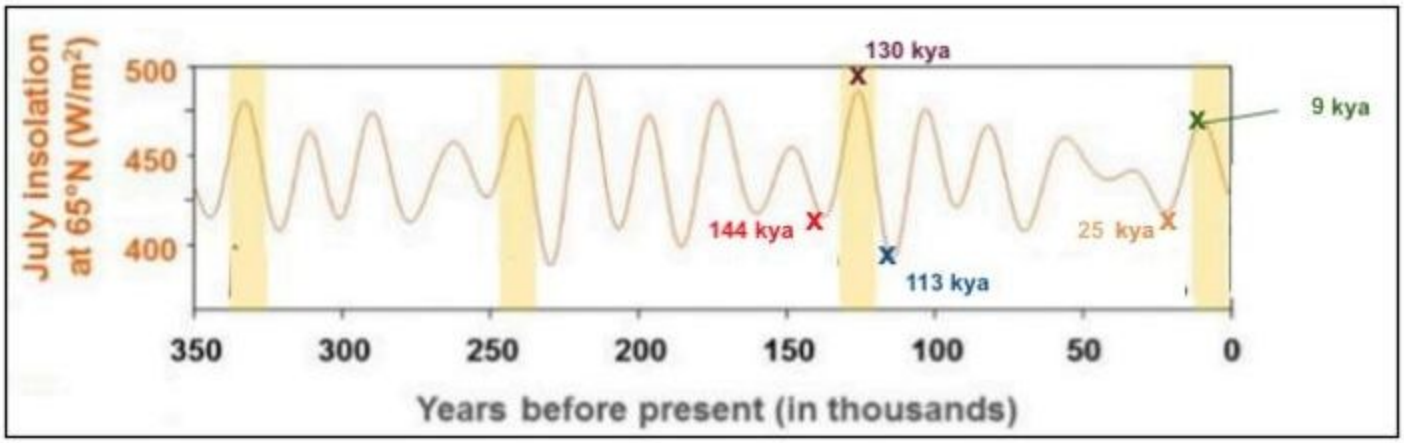
Orbital Factors and Glacial Cycles Part 1

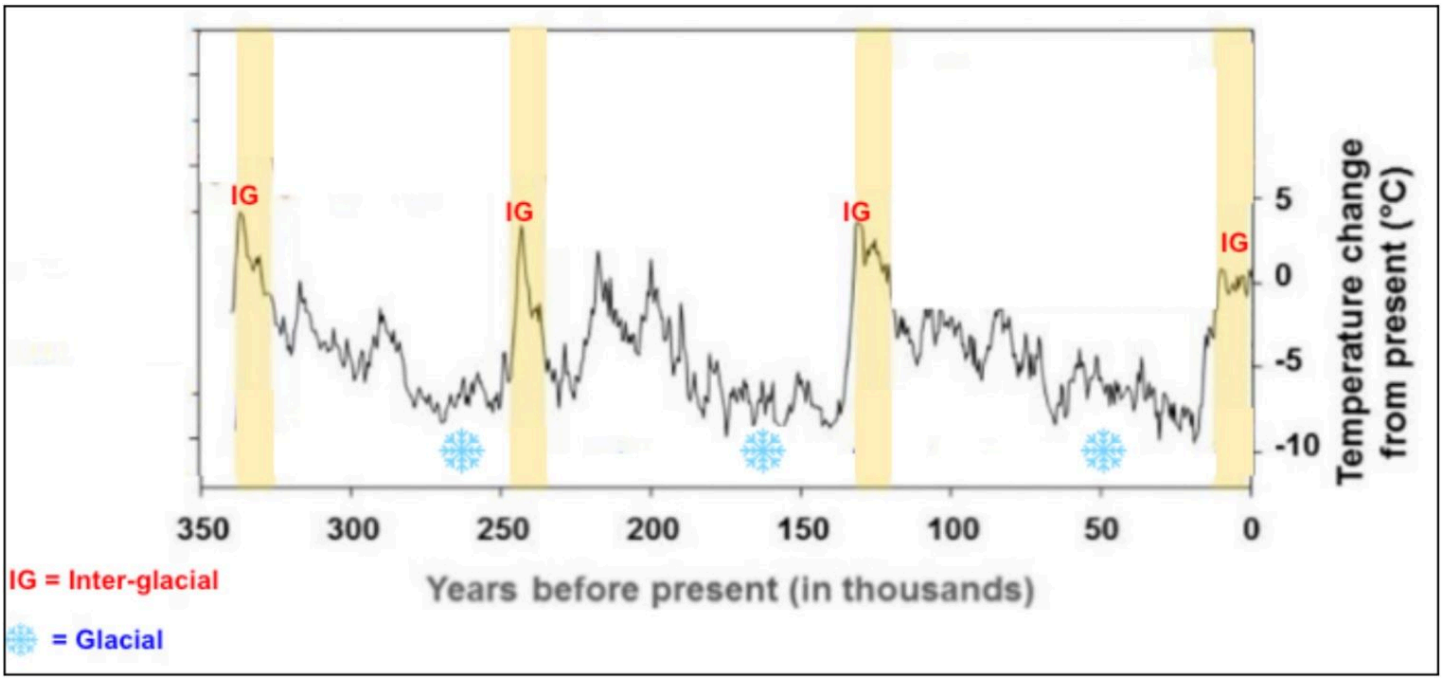
Part 1: Revisit the investigative phenomenon!

Below is the glacial-interglacial graph you examined during the Engage phase of this 5E. You will now have an opportunity to apply what you have learned so far as you determine whether changes in the position of the Earth with respect to the Sun can explain shifts between glacial and interglacial periods.

You will focus specifically on the following shifts:

- 144 kya → 130 kya
- 130 kya → 113 kya
- 25 kya → 9 kya

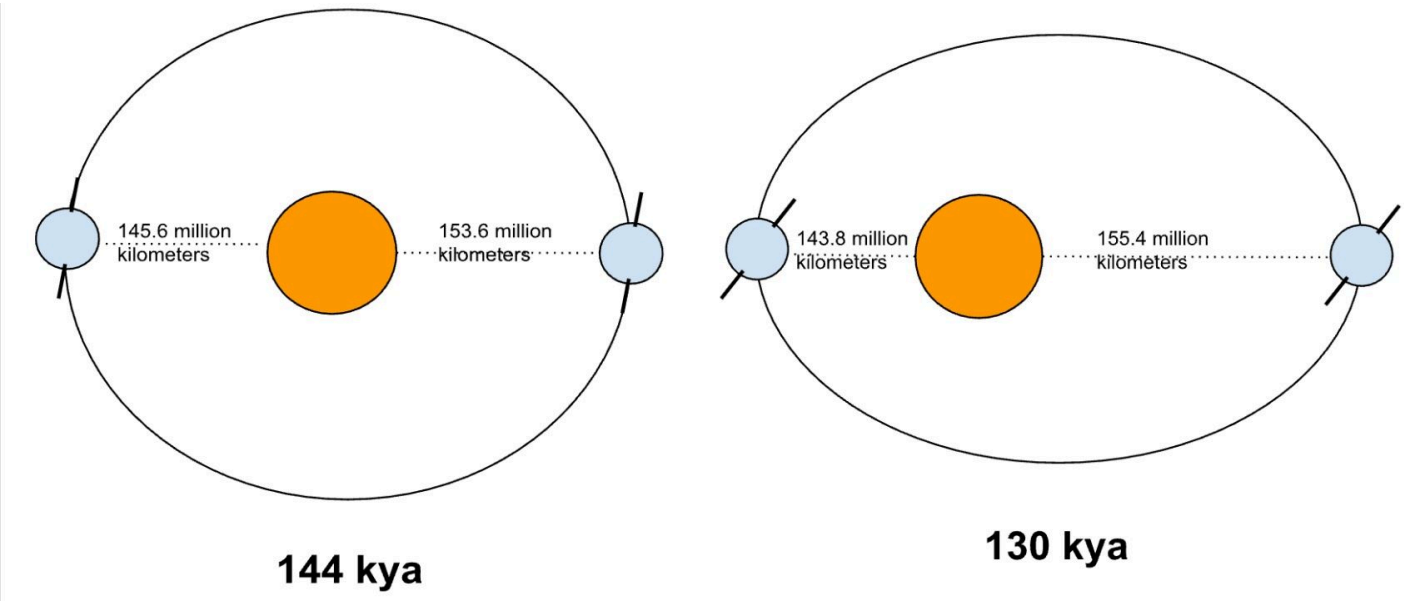




Data about Earth's position with respect to the Sun for each of shifts between glacial and interglacial periods is represented in the diagrams on the following page. You can use your models from the Explore phase to help you analyze and interpret the data.

144 kya → 130 kya

Orbital Factor	144ka		130ka	
Eccentricity	**Minimum Distance**	**Maximum Distance**	**Minimum Distance**	**Maximum Distance**
	145.6 million km	153.6 million km	143.8 million km	155.4 million km
Tilt	22.6 degrees		24.25 degrees	
Precession	• (Northern hemisphere towards sun when closer)		• (Northern hemisphere towards sun when closer)	



1. On the model, identify Earth's position during the northern hemisphere summer.
2. Complete this table below to figure out what the relative impacts of each orbital factor are in the changes demonstrated in the model

Factor	Did it Change?	What will the effect be on summer at 65 N ?	Explain why (think about amount and angle of sun)
Precession			

Eccentricity			
Tilt			

1. How will summer in the northern hemisphere be impacted by the change between 150 kya and 130 kya depicted in diagrams above?

Provide evidence to support your claim and be sure to explain your thinking through words and/or a drawing.

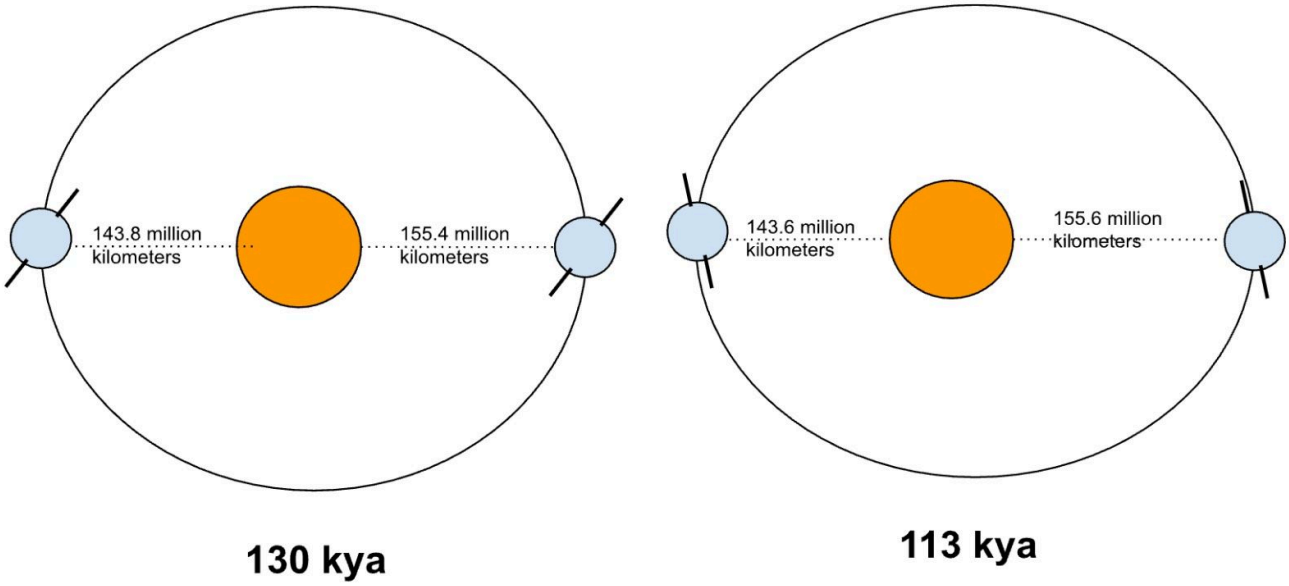
2. How will the ice sheets in the northern hemisphere be impacted by these changes?

Provide evidence to support your claim and be sure to explain your thinking through words and/or a drawing.

3. Does what you predicted by analyzing the data through a model match the July insolation at 65° N and the glacial-interglacial graph?

130 kya → 113 kya

Orbital Factor	130ka		113ka	
Eccentricity	**Minimum Distance**	**Maximum Distance**	**Minimum Distance**	**Maximum Distance**
	143.8 million km	155.4 million km	143.6 million km	155.6 million km
Tilt	24.25 degrees		22.25 degrees	
Precession	• (Northern hemisphere towards sun when closer)		• (Northern hemisphere away from sun when closer)	



1. On the model, identify Earth's position during the northern hemisphere summer.
2. Complete this table below to figure out what the relative impacts of each orbital factor are in the changes demonstrated in the model.

Factor	Did it Change?	What will the effect be on the amount of radiation reaching 65N in summer?	Explain why (think about amount and angle of sun)
Precession			
Eccentricity			

Tilt			

3. How will summer in the northern hemisphere be impacted by the change between 130 kya and 113 kya depicted in diagrams above?

Provide evidence to support your claim and be sure to explain your thinking through words and / or a drawing.

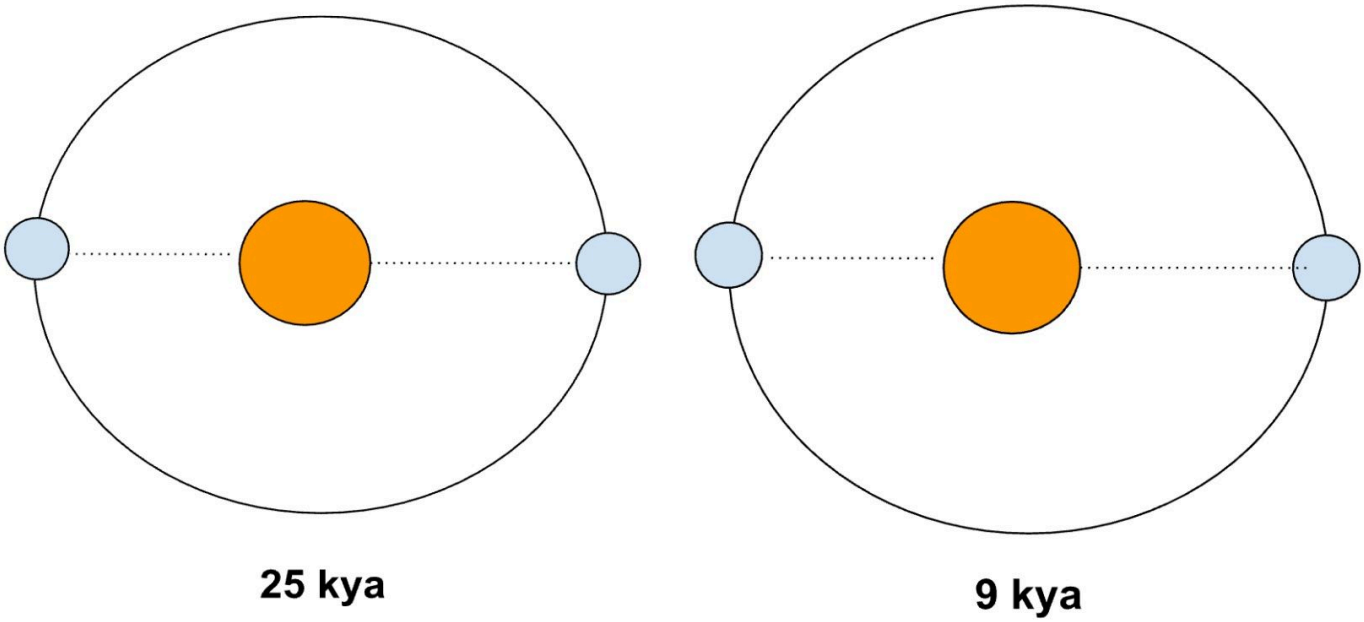
4. How will the ice sheets in the northern hemisphere be impacted by these changes?

Provide evidence to support your claim and be sure to explain your thinking through words and/or a drawing.

5. Does what you predicted by analyzing the data through a model match the July insolation at 65° N and the glacial-interglacial graph?

25 kya → 9 kya

Orbital Factor	25ka		9ka	
Eccentricity	**Minimum Distance**	**Maximum Distance**	**Minimum Distance**	**Maximum Distance**
	147.36	151.84	146.61	152.59
Tilt	22.3 degrees		24.25 degrees	
Precession	• (Northern hemisphere away from sun when closer)		• (Northern hemisphere away from sun when closer)	



25 kya **9 kya**

1. Complete the model by drawing the angle and direction of the tilt in each scenario and labeling the orbital distances.
2. On the model, identify Earth's position during the northern hemisphere summer.
3. Complete this table below to figure out what the relative impacts of each orbital factor are in the changes demonstrated in the model.

Factor	Did it Change?	What will the effect be on the amount of radiation reaching 65N in summer?	Explain why (think about amount and angle of sun)
Precession			

Eccentricity			
Tilt			

4. How will summer in the northern hemisphere be impacted by the change between 25 kya and 9 kya depicted in diagrams above?

Provide evidence to support your claim and be sure to explain your thinking through words and / or a drawing.

5. How will the ice sheets in the northern hemisphere be impacted by these changes?

Provide evidence to support your claim and be sure to explain your thinking through words and/or a drawing.

6. Does what you predicted by analyzing the data through a model match the July insolation at 65° N and the glacial-interglacial graph?

Summarize: Overall, how do these factors affect the total amount of energy that Earth receives from the sun, the distribution of the sunlight reaching Earth, and over what time scale? And how do they impact glacial-interglacial cycles?

Orbital Factors and Glacial Cycles Part 2

Part 2: Using a Computational Model for Additional Analysis of the Data
You will now have an opportunity to use another model that will allow you to further analyze how well each of the orbital factors explain the glacial-interglacial cycles we have observed.
In other words this is an opportunity to test your explanation for glacial-interglacial cycle events from the past! You'll first have the chance to familiarize yourself with the model by observing and responding to a few questions below. Go to The Vostok Core and Milankovitch Cycles to view the Earth orbiting the sun and a graph of data from an ice core documenting earth's temperature over 400,000 years.

1. Click on the button "Top View". You should now be able to view the orbit of the earth from above. Circle the correct answer in the parenthesis of each question.

    a. The summer solstice is at the **aphelion** of the earth's orbit. Aphelion means the earth is **(closer to, farther from)** the sun.

    b. The winter solstice is at the perihelion of the earth's orbit. Perihelion means the earth is **(closer to, farther from)** the sun.

2. Click on the button "Oblique View". You should now be able to view the tilt of the earth on its axis as it rotates around the sun. Circle the correct answer in the parenthesis of each question.

    c. The tilt of the earth's axis is **(toward the sun, away from the sun)** during the aphelion. (*Hint: Using the 'Season Lock' button may be useful.)

    d. The tilt of the earth's axis is **(toward the sun, away from the sun)** during the perihelion.

3. In your own words, explain how the tilt of the earth and its orbit determine the amount of solar radiation we receive in New York City, New York.

The Vostok ice core was the result of a collaborative ice-drilling project between Russia and the U.S. in 1998. The core was drilled at the Russian station named Vostok in East Antarctica and produced the deepest ice core ever recovered. It reached a depth of 3,623 meters and the trapped air in the ice reveals changes in atmospheric composition of trace gases.

Serbian geophysicist and astronomer, Milutin Milanković, found that over time there are seasonal and latitudinal variations in the amount of solar radiation the earth receives. This can also be seen in the temperatures associated with the Vostok ice core on the graph to the right of the earth's orbit. Click the 'Vostok Ice Core' button on the bottom right to observe the graph, then use your observations to circle the correct answer in the parenthesis of each question below.

Below are some practice questions to become familiar with the graph. For each question circle one of the responses in bold.

1. Look at the temperature key below the graph. In what direction does temperature increase? (**left to right, right to left**)

2. In the 400,000 years shown on the graph there are **(2, 3, 4)** distinct temperature cycles.

3. **(True, False)** Present day temperatures are the warmest we have ever experienced in the last 400,000 years.

Data Analysis Questions

1. Click on the 'Eccentricity' box on the bottom of the screen. This will produce a **purple line** on the Vostok ice core graph.

(True, False) The graph (purple line) indicating the eccentricity correlates to (closely matches) the temperature of the earth. Support your response with evidence from the graphs.

2. Unclick the 'Eccentricity' box on the bottom of the screen. Click on the 'Precession' box on the bottom of the screen. This will produce a purple line on the Vostok ice core graph. Precession means the direction of Earth's tilt.

(True, False) The graph (purple line) indicating the precession correlates to (closely matches) the temperature of the earth. Support your response with evidence from the graphs.

3. Unclick the 'Precession' box on the bottom of the screen. Click on the 'Tilt' box on the bottom of the screen. This will produce a purple line on the Vostok ice core graph.

(True, False) The graph (purple line) indicating the tilt correlates to (closely matches) the temperature of the earth. Support your response with evidence from the graphs.

4. Which of the factors correlates most with the temperature on Earth? (**eccentricity, precession, or tilt**). Support your response with evidence from the graphs.

5. **Do not** unclick the 'Tilt' box on the bottom of the screen. Now also click on the 'Eccentricity' and 'Precession' boxes so that all 3 factors contribute to the purple line on the Vostok ice core graph.

Of all of the purple lines that have been produced, this line that results from all 3 factors of eccentricity, precession and tilt is **(most closely, less closely)** related to temperatures in the last 400,000 years. Support your response with evidence from the graphs.

6. Looking at the ice core temperature line and the purple line showing the orbital factors, locate an area where the impact of orbital factors correlate closely with temperatures shown in the Vostok data. State the time period you are observing and describe what you see happening at that time, supporting your answer with details from the model.

7. Looking at the ice core temperature line and the purple line showing the orbital factors, locate an area where the impact of orbital factors do not correlate closely with temperatures shown in the Vostok data. State the time period you are observing and describe what you see happening at that time, supporting your answer with details from the model.

Summarize:

1. Describe any evidence you see of a correlation between orbital factors and global temperatures.

2. Based on what we've learned throughout this unit, has your group established a causal link that could explain the relationship between orbital factors and global temperatures? If so, how?

3. What further questions do you have about orbital factors and their relationship with global temperature?

Summary Task

Today we completed a Class Consensus Discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. Explain how the Earth's orbital shape, degree of tilt, and direction of tilt impact the amount and distribution of energy reaching Earth, and therefore affect global ice sheets.

2. How did using models give you evidence to determine correlational and/or causational relationships between orbital factors and glacial-interglacial cycles?

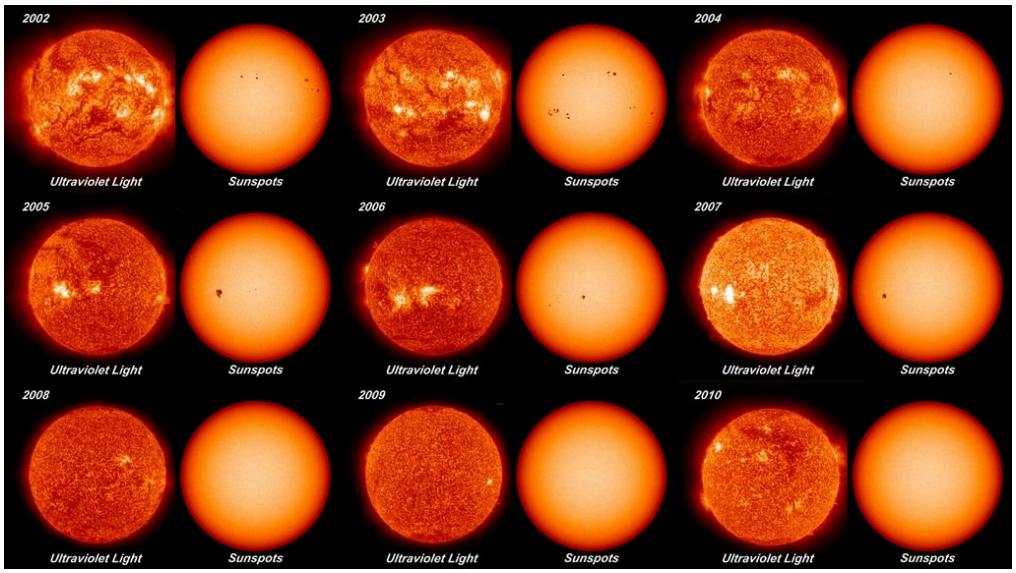
3. How did the timescale of each orbital factor compare to the timescale of glacial and interglacial cycles? What about the timescale of changes brought on by all three factors combined?

Solar Cycles

Guiding question: Did changes in the amount of radiation the Sun was emitting contribute to climate change events in the past?

Work independently or in pairs to analyze and interpret the images and graphs of the Sun's total irradiance vs average global temperatures over time, and use what you observe to answer the questions.

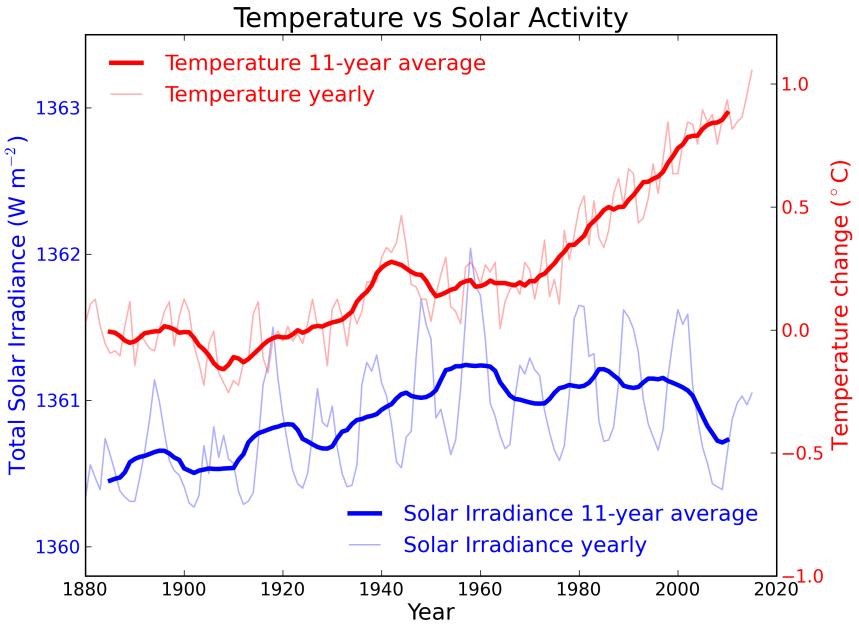
Sunspots are dark spots that appear on the sun and correlate to how much ultraviolet radiation it is emitting. The image below shows sunspots changing over time and the corresponding changes in ultraviolet radiation. There were more sunspots in 2002 and fewer in 2010, and special telescopes show the amount of radiation decreasing over that time. Note: brighter pictures of ultraviolet light mean more solar radiation.



1. How would increasing radiation impact energy input on Earth?

2. Do you think that increasing radiation from the sun impacts temperature on Earth?

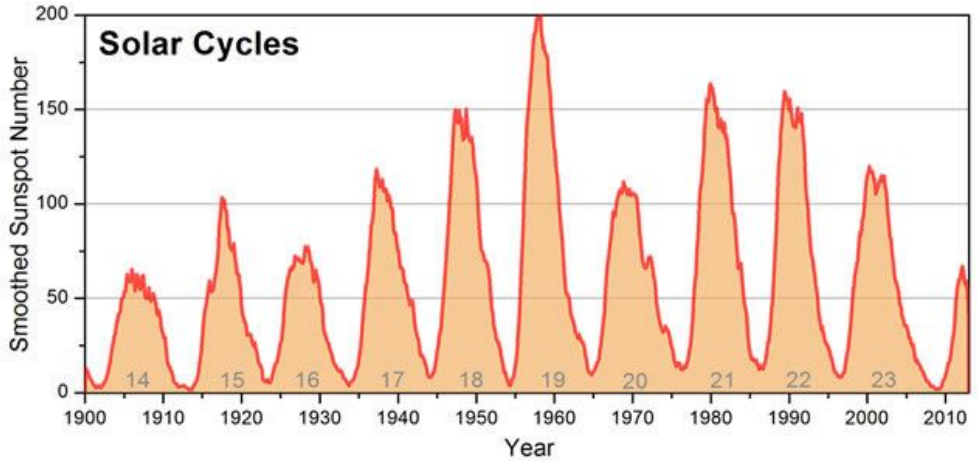
The graph below shows how sunspot activity and temperature have varied over the past 10,000 years.



3. Are sunspot activity and temperature always correlated? Support your answer using information from the graph.

4. Why do you think there are times on the graph when sun activity is increasing but global temperatures are decreasing? Can you think of other contributing factors that might explain that difference?

The Solar Cycle describes the regular changes in the number of sunspots visible on the surface of the sun and the corresponding change in solar radiation. A Solar Minimum refers to the time when the number of sunspots and radiation is lowest; a Solar Maximum means the years when there are the most sunspots and radiation. **Analyze the graph below to determine the likely impact of solar cycles on global temperatures.**



1. Approximately how long are solar cycles?

2. Look back at the glacial-interglacial cycles graph. Approximately how long are those cycles?

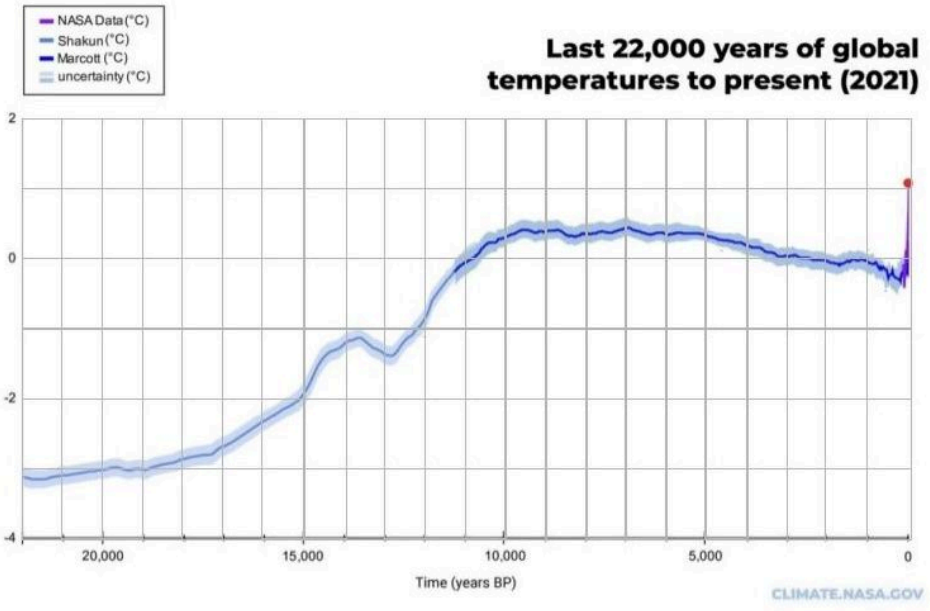
3. Do the timescales shown in the solar cycles correlate with the timescales in the glacial-interglacial graphs?

4. Based on the lengths of these cycles, do you think that there is a strong causal link between changes in radiation from the sun and the glacial-interglacial cycling?

The Sun and Current Climate Change - Performance Task Data

Review the data below and respond to the prompts to help you complete the performance task

Historical Global Temperature



1. How long did it take for temperatures to rise 1.25 degrees during this climate change event

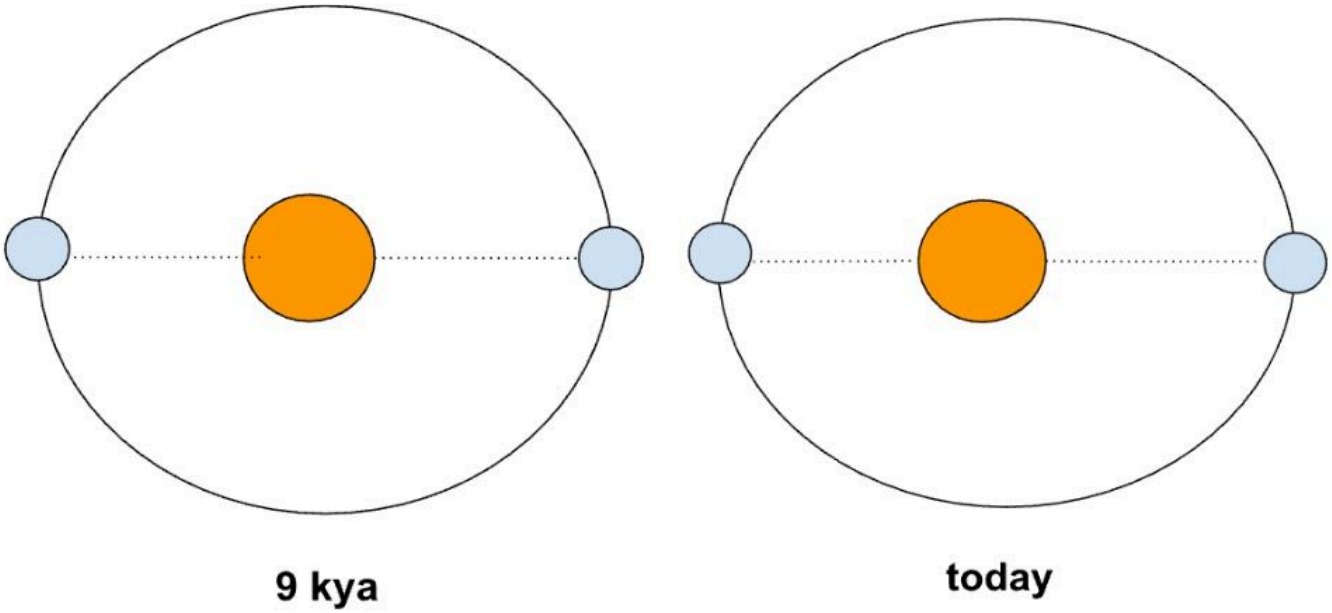
2. Identify the next fastest warming event. How long did it take temperatures to rise 1.25 degrees at that time?

3. When temperatures rose from 20,000 years ago, how long did it take temperatures to rise 1.25 degrees?

Historical Position of the Earth with Respect to the Sun

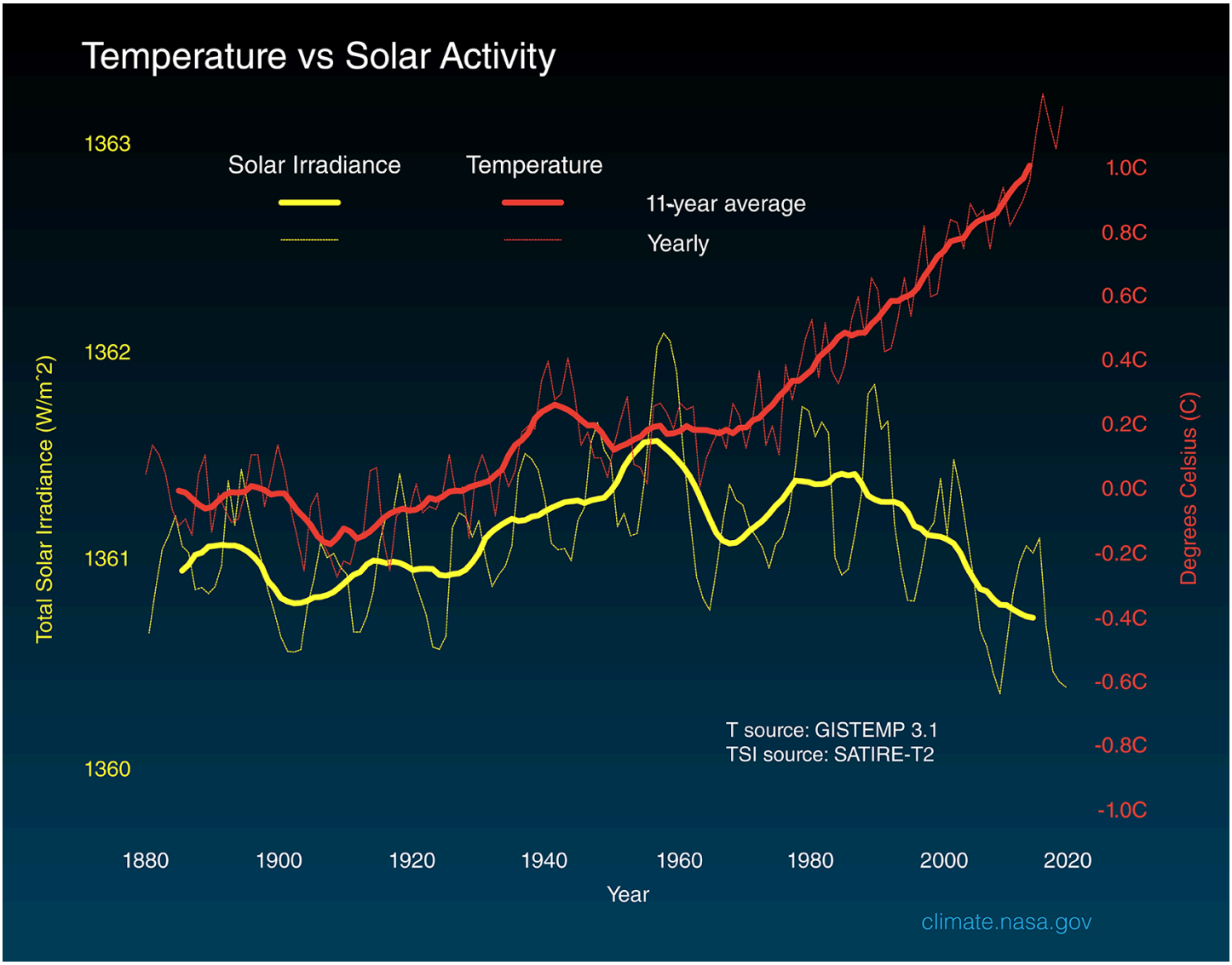
9 kya → today

Orbital Factor	9ka		0ka	
Eccentricity	**Minimum Distance**	**Maximum Distance**	**Minimum Distance**	**Maximum Distance**
	146.61	152.59	147.06	152.14
Tilt	24.25 degrees		23.4 degrees	
Precession	- (Northern hemisphere towards sun when closer)		+ (Northern hemisphere away from sun when closer)	



1. Complete the model by drawing the angle and direction of the tilt in each scenario and labeling the orbital distances.
2. On the model, identify Earth's position during the northern hemisphere summer.
3. How should summer in the northern hemisphere be impacted by the change between 9 kya and today depicted in diagrams above?
4. Based on these changes, should the Earth be moving toward a glacial or interglacial period?

Total Solar Radiation Output vs Global Average Temperatures



Earth-Sun Dynamics Rubric

Earth-Sun Dynamics	Proficient	Developing
Explanation	The explanation effectively and accurately uses multiple lines of valid and reliable evidence to explain why scientists are sure that natural cycles are not causing climate change today, **including all** of the components below: • what has been happening with each of these factors in recent history up until now, and what will happen in the near future • the overall impact these factors are having on the total amount and distribution of energy on Earth • how these factors relate to current temperature changes on Earth Evidence is linked to the explanation using scientific logic and reasoning	The explanation is incomplete in effectively and accurately using multiple lines of valid and reliable evidence to explain why scientists are sure that natural cycles are not causing climate change today, , **missing one or more** of the components below: • what has been happening with each of these factors in recent history up until now, and what will happen in the near future • the overall impact these factors are having on the total amount and distribution of energy on Earth • how these factors relate to current temperature changes on Earth Evidence is not well linked to the explanation using scientific logic and reasoning
Cause & Effect	Responses to questions clearly articulate and explain whether there is a correlation and/or causal link between orbital factors and glacial and interglacial periods in the present.	Responses to questions do not clearly articulate and explain whether there is a correlation and/or causal link between orbital factors and glacial and interglacial periods in the present.
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

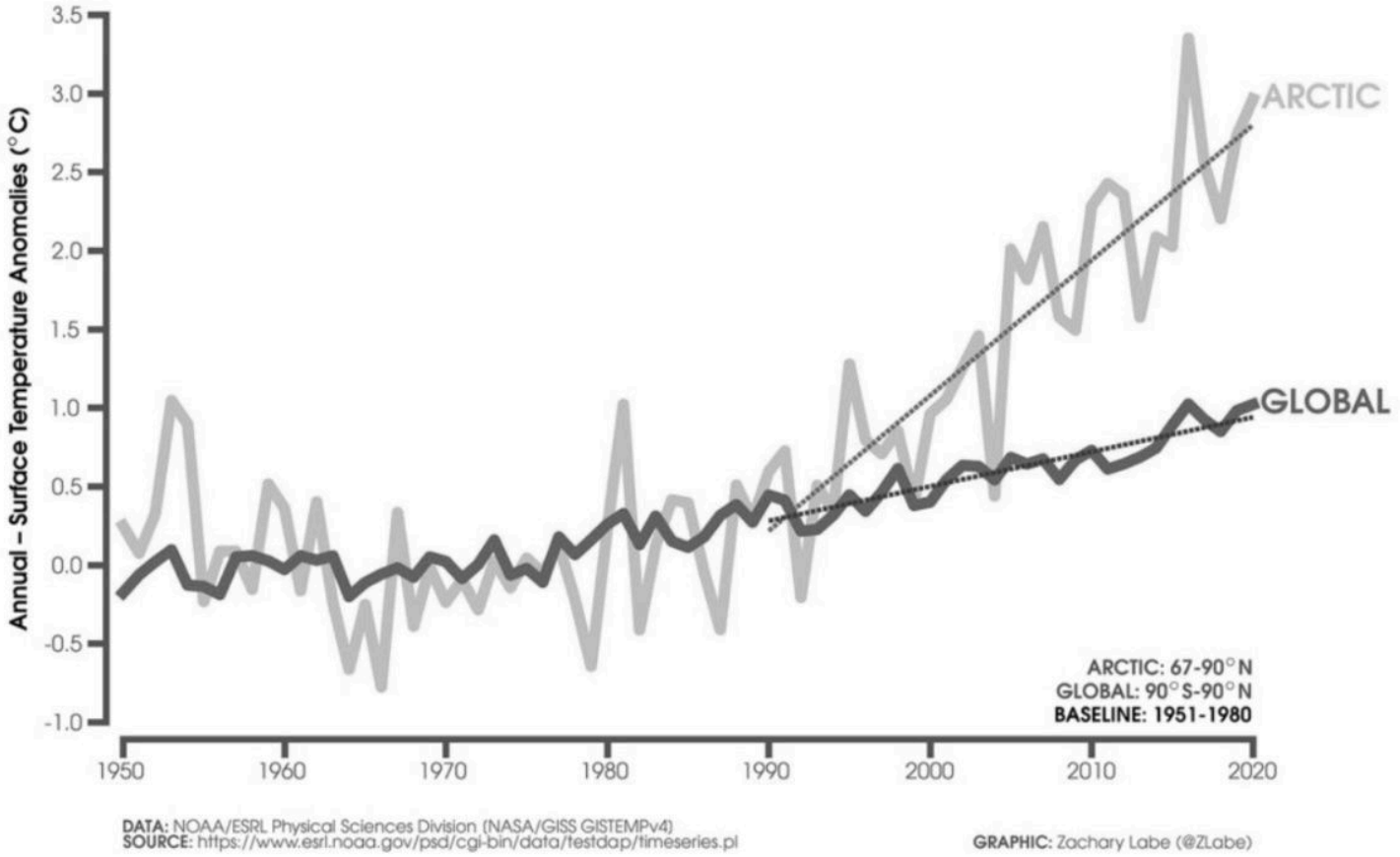
2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

Climate Feedbacks 5E

Unit 4 Climate Change	Earth and Space Science
Student Name:	

We are Warming

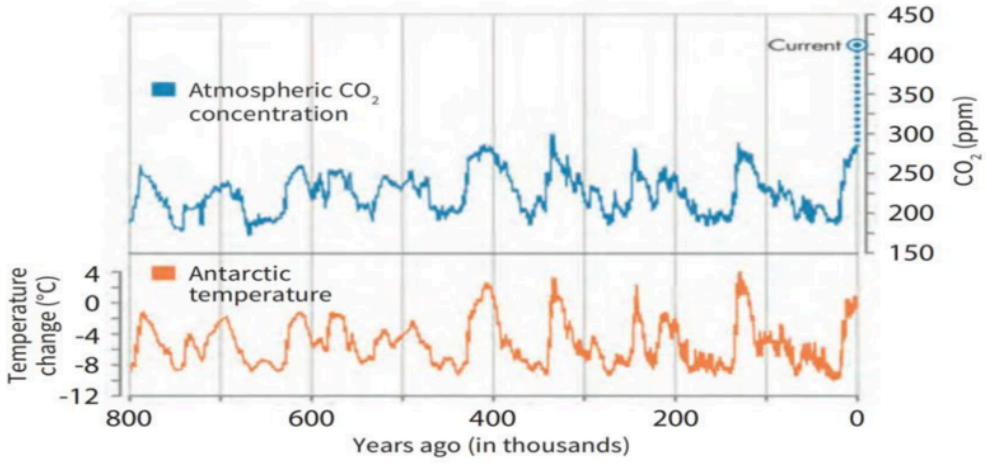
*Note: the graph shows change in temperatures, not actual temperatures

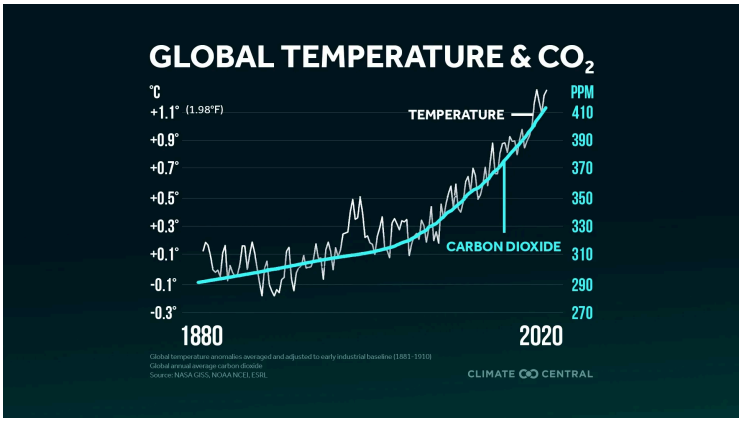


Brainstorm: Since we know this isn't due to orbital factors, what do you think is causing warming, and why is the rate of warming not consistent across the planet?

Carbon Dioxide and Air Temperature Investigation

Part 1. Analyzing Changing Carbon Levels over Time

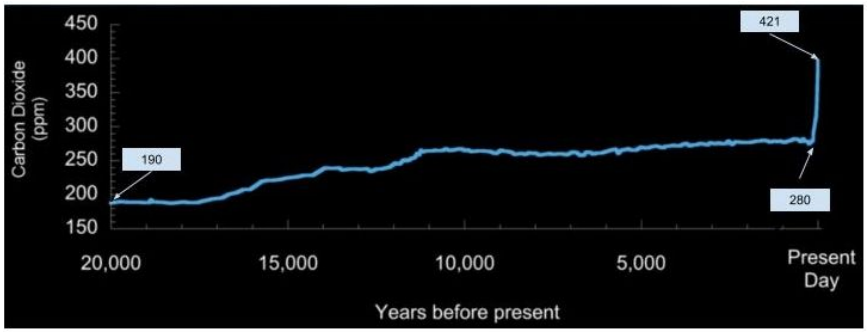




1. What do you notice about the relationship between temperature and atmospheric CO2?

2. What had the range of atmospheric carbon dioxide levels been over the past 800 thousand years prior to the industrial revolution, as indicated by the ice core data?

3. How is the rate of change in atmospheric CO2 different now than it was in the past?



1. Estimate the length of time it took CO_2 levels in the atmosphere to go from 190 ppm to about 280 ppm.

2. Calculate the rate of change of atmospheric carbon dioxide over that period of time by using this equation:

$$\text{Rate of change} = \frac{\text{Final carbon dioxide level - initial carbon dioxide level}}{\text{Number of years}}$$

3. Estimate the length of time it took CO_2 levels in the atmosphere to go from 280 ppm to about 421 ppm.

4. Calculate the rate of change of atmospheric carbon dioxide over that period of time by using this equation:

$$\text{Rate of change} = \frac{\text{Final carbon dioxide level - initial carbon dioxide level}}{\text{Number of years}}$$

Part 2. Modeling Pre- and Post-Industrial Revolution Carbon Cycles

In this activity, you will explore how much carbon is stored in each system (called reservoirs), how carbon moves between systems, and analyze the impact that burning fossil fuels since the industrial revolution has had on the storage of carbon dioxide.

In order to do this you will develop a quantitative model of the carbon cycle before and after the industrial revolution.

Developing a Model of the Carbon Cycle - Pre-Industrial Revolution

1. Review the carbon reservoirs in Table 1 on the following page. In the space below create a diagram that includes the Earth systems that act as carbon reservoirs. Then use the data in Tables 1 and 2 to add the amount of carbon stored in each reservoir and how much carbon flowed from each reservoir to another per year.

Table 1: Amount of Carbon Stored in Reservoirs Pre-Industrial Revolution

Carbon Reservoir	Amount of Carbon Held measured in Gigatons (Gt)
Atmosphere	560

Ocean (Hydrosphere)	38,000
Land Biomass (Biosphere)	2,160
Fossil Fuels (Geosphere)	10,000

Table 2: Flow of Carbon Between Reservoirs Pre-Industrial Revolution

Direction of Carbon Flow	**Gigatons of Carbon Per Year**
Ocean → Atmosphere	62
Atmosphere → Ocean	60
Land Biomass → Atmosphere	107
Atmosphere → Land Biomass	109
Fossil Fuels → Atmosphere	0

2. Use your quantitative model of the carbon cycle prior to the Industrial Revolution to calculate the net change in carbon stored in each reservoir each year.

Atmosphere	In:	Out:	Net Change:
Land Biomass	In:	Out:	Net Change:
Ocean	In:	Out:	Net Change:
Fossil Fuels	In:	Out:	Net Change:

Developing a Model of the Carbon Cycle - Post-Industrial Revolution

In the space below create a diagram that includes the Earth systems that act as carbon reservoirs. Then use the data in Tables 1 and 2 to add the amount of carbon stored in each reservoir and how much carbon flows from each reservoir to another per year.

Table 1: Amount of Carbon Stored in Reservoirs Post-Industrial Revolution

Carbon Reservoir	Amount of Carbon Held measured in Gigatons (Gt)
Atmosphere	840
Ocean (Hydrosphere)	41,000
Land Biomass (Biosphere)	2,500
Fossil Fuels (Geosphere)	9,000

Table 2: Flow of Carbon Between Reservoirs Post-Industrial Revolution

Direction of Carbon Flow	Gigatons of Carbon Per Year

Ocean → Atmosphere	77.5
Atmosphere → Ocean	80
Land Biomass → Atmosphere	120
Atmosphere → Land Biomass	122.5
Fossil Fuels → Atmosphere	10

1. Use your quantitative model of the carbon cycle after the Industrial Revolution to calculate the net change in carbon stored in each reservoir each year.

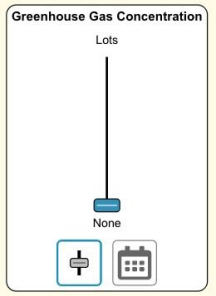
Atmosphere	In:	Out:	Net Change:
Land Biomass	In:	Out:	Net Change:
Ocean	In:	Out:	Net Change:
Fossil Fuels	In:	Out:	Net Change:

Part 3. Modeling the Effect of the Carbon Cycle on Temperature

What impact does atmospheric carbon dioxide, a greenhouse gas, have on air temperature?

Explore the components of the model

1. Open the simulation: Greenhouse Effect and click “waves”



2. Using the slider bar on the right, reduce the Greenhouse Gas Concentration to “none,” and then press “start sunlight”

3. According to the key, what do the yellow lines represent?

---

4. How does the yellow line change when it encounters a cloud? Why do you think that is happening?

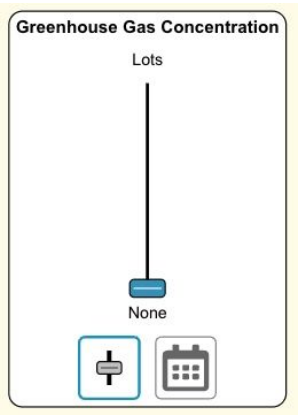
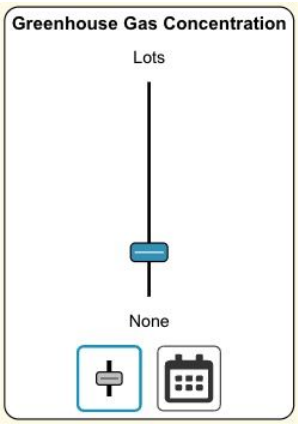
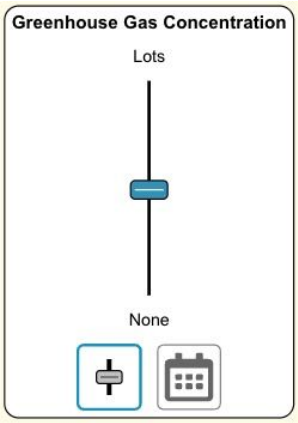
---

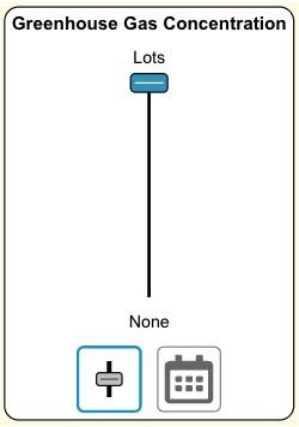
5. According to the key, what do the red lines represent?

Note: sunlight means solar irradiance, which is light energy that comes from the sun. Infrared means heat energy, which is radiated from objects as they release energy they can no longer hold.

Increasing Greenhouse Gas Levels

6. Starting with no greenhouse gases and slowly increasing the levels, describe how the yellow and red lines change and their impact on temperature by completing the table below.

Amount of Greenhouse Gases	Describe the motion of the yellow lines	Describe the motion of the red lines	Temperature
			
			
			

 Greenhouse Gas Concentration Lots None			

See-Think-Wonder

Use the graphic organizer below to record your ideas from the investigation.

See What did you observe?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
How did the rate of change in carbon levels compare after the industrial revolution to before?	What do you think can explain that difference?	
Where does carbon dioxide from the atmosphere come from and go to?	Is carbon from the atmosphere created or destroyed?	
How has the movement of carbon dioxide changed after the industrial revolution?		
How do greenhouse gas levels impact temperatures?		

How does energy move and change between components of Earth's systems?	Is energy in the atmosphere created or destroyed?	

Analysis Questions

1. Which reservoirs are holding more carbon now than they were 300 years ago?

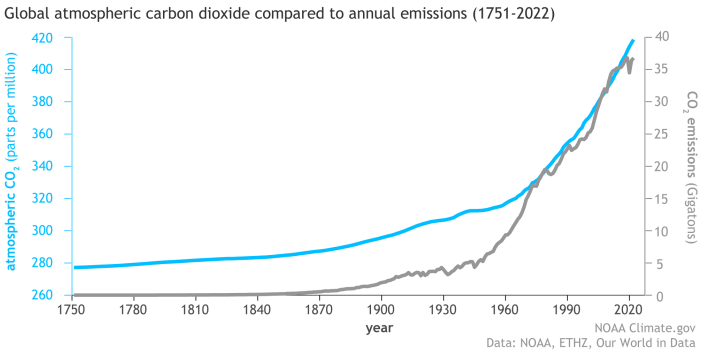
2. How did human activity change the relationships between the geosphere, atmosphere, the biosphere, and the hydrosphere?

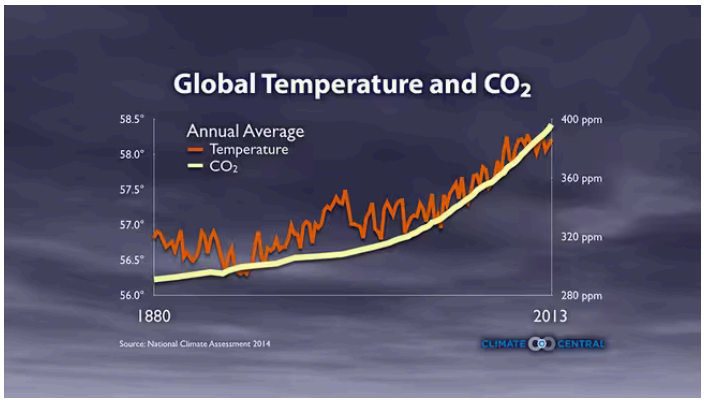
3. What is the relationship between temperature and carbon dioxide levels?

As temperature _____, atmospheric carbon dioxide levels _____ because

The Enhanced Greenhouse Effect

Part 1.
The graph below shows a strong correlation between carbon dioxide emissions by humans since the Industrial Revolution began and an increase of atmospheric carbon dioxide to levels much higher than then the Earth has seen in 800 thousand years. That increase has also been correlated with increased global temperature.





Natural and Human Emitted Carbon Dioxide in the Atmosphere Today

Current Total Atmospheric CO_2	Atmospheric CO_2 Due to Human Activity	Atmospheric CO_2 Due to Natural Factors
421.6 ppm	**134.91 ppm**	**286.68 ppm**

1. What would atmospheric CO_2 concentration be today if humans had not engaged in activities that emit CO_2 into the atmosphere?

2. Does your response above fall within the range of atmospheric CO_2 during the 800,000 years prior to the Industrial Revolution?

3. How do the human-driven changes to CO in our atmosphere change the balance of energy in the Earth system?

Part 2.
Using evidence from this investigation, the *The Greenhouse Effect* text, and the *Burning Fossil Fuels* text, you will make and support a claim in answer to the following question: What is the relationship between human activities and temperature increase since the industrial revolution?

1. Brainstorm the evidence that would support your claim in response to the prompt

2. Record any additional ideas you gained from your conversation

3. Using those ideas, outline your claim, evidence, and reasoning using the structure below

Claim based on the evidence What is the answer to your question based on your evidence?	**Evidence** Observations or data that support your claim Consider evidence that comes from: • The quantities of human generated carbon dioxide • *Burning Fossil Fuels* and *the Greenhouse Effect* text • Data from the quantitative model you developed during the Explore 2 phase • The scale of carbon dioxide and scale of time	**Scientific Reasoning** Why do you think this happened, based on background research/scientific logic? How do we know this is causation and not correlation?

4. Independently write your argument

Scientific Explanation = Claim + Evidence + Science Reasoning

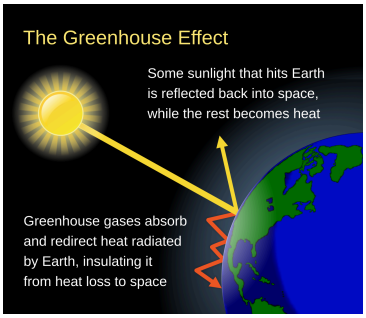
My claim is _____, because _____.

The Greenhouse Effect Text

The Greenhouse Effect

When sunlight reaches the Earth, it comes as long-wave radiation, which we see as light. Some of that radiation is reflected by Earth's surfaces or by clouds, sending it back out into space. But the rest of that light energy is absorbed by its surface, and becomes converted to infrared (short wave) radiation (heat), which is then released back into the atmosphere. That heat dissipates as it moves away from Earth. That's one of the reasons it is colder outside an airplane, even though they fly closer to the sun.

If all the heat released by Earth drifted back into space, the surface temperature would be about -18° C, or 0° F. Luckily for life on Earth, we have an atmosphere that contains greenhouse gases, like carbon dioxide, water vapor, and methane. These gases absorb heat and re-release it back towards Earth, like a puffy coat keeping body heat trapped inside. These gases are so named because that is exactly how a greenhouse or a hot car works; sunlight enters through the clear windows, is converted to heat on the surfaces inside, and then is trapped as heat by those same clear windows, warming up the area inside.



When greenhouse gases increase in the atmosphere, they trap more of the heat radiating from the Earth. The total amount of energy coming from the sun hasn't changed, but the amount of its energy that is retained and bounced back to Earth increases. When that happens, temperatures increase as well. While some warming, compared to the temperatures that would exist without the greenhouse effect, is good, too much warming creates environmental damage.

Burning Fossil Fuels Text

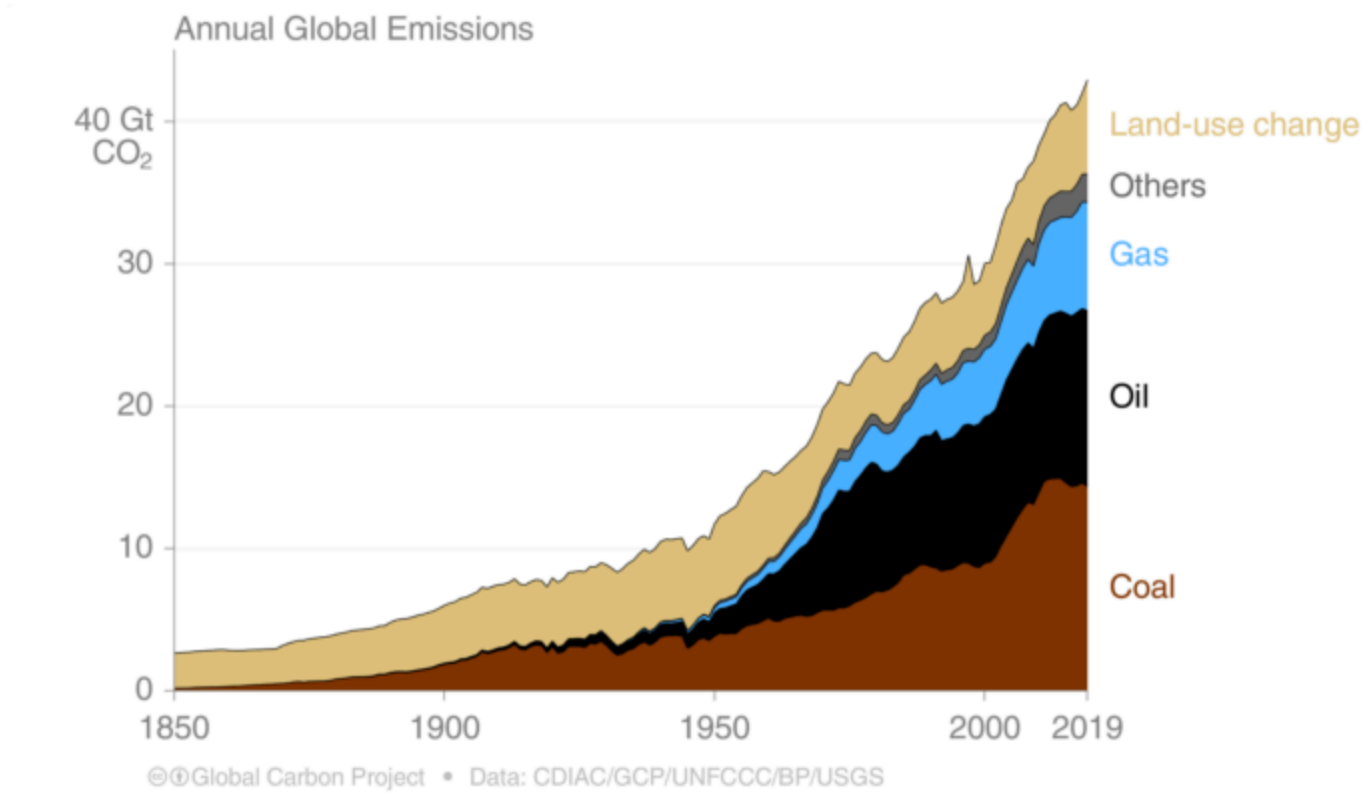
Human Emissions Of Greenhouse Gases

The Industrial Revolution was a period from 1760-1840 in which Great Britain, followed by the rest of the world, began mechanizing manufacturing and other processes. The result was much higher levels of production than before, leading to economic development and an increase in the quality of life for many working class people. This mechanization relied on many innovations, including agricultural improvements that made food easier to produce, increase in international trade, the growth of cities, and the development of the steam engine.

Though industrialization was beneficial in many ways, it has come with an unanticipated tradeoff. The steam engine ran on water heated from burning fossil fuels, like coal, gas, and oil. By 1850, global carbon dioxide emissions had risen from nearly 0 to 204 metric tons of carbon dioxide. Engines used in transportation, industry, and the production of electricity all often rely on burning fossil fuels, so as industrialization overtook the globe, these emissions increased.

The carbon cycle, as it had existed before this time, was interrupted. What had been a cycle that kept carbon levels in each reservoir stable was now destabilized: more carbon dioxide was being pumped into the atmosphere and at a faster rate than could be sunk back into the geosphere.

In 2023, the world emitted about 37.4 billion metric tons of carbon dioxide, which is approximately 82,452,886,057,144 lbs. That's more than 82 *trillion* pounds.



To help think about this, let's consider the carbon dioxide released by burning gasoline in America alone. The United States burns 369 million gallons of gasoline every day, creating 7,000,0000,000 (7 billion) pounds of carbon dioxide *every day*.

Burning 1 gallon of gasoline creates 19 pounds of carbon dioxide, an amount that would fill approximately *1100* balloons. From just one gallon! The amount of carbon dioxide created from the 369 million gallons of gasoline we burn daily would fill more than 400,000 balloons, every single day. And gasoline isn't the only source of greenhouse gases; whenever we burn coal, oil, or any other fossil fuel, we are also producing carbon dioxide. Agricultural practices and land use release yet more greenhouse gases. Multiply that across the globe, and it becomes clear how quickly we are spewing climate-change causing gases into the atmosphere.

Modified from: Dr. Don Haas, Fear is Our Best Hope/On 2x4s, graphite & gasoline

Summary Task

Today we completed a Class Consensus Discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

Systems can be made of smaller systems, called subsystems. For example, Earth as a system consists of the biosphere, hydrosphere, atmosphere, and cryosphere, among others.

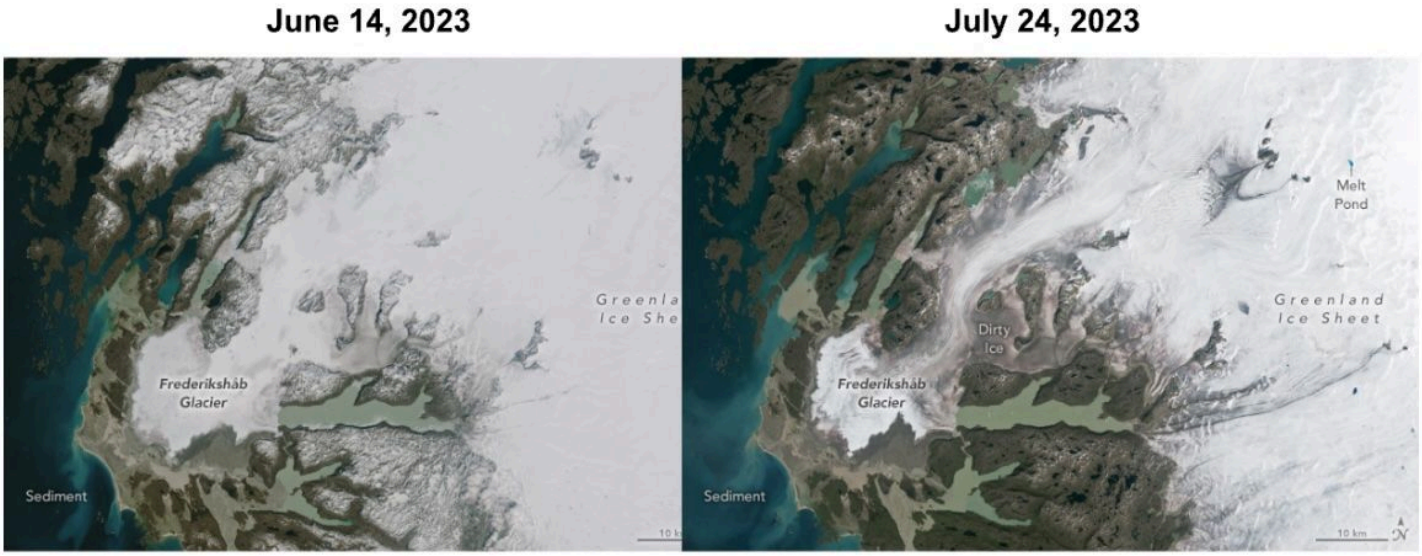
1. While we've observed that matter can increase or decrease in subsystems, explain why matter is conserved in the overall Earth system.

2. While we've observed that energy can increase or decrease in subsystems, explain why energy is conserved in the overall Earth-Sun system.

3. How did empirical evidence in this learning sequence help you establish a causal link and not just a correlation between greenhouse gas levels and the energy retained by Earth, which is measured as Earth's temperature?

4. How did empirical evidence related to rates of change in this learning sequence help you establish a causal link and not just a correlation between human activity and the increase in atmospheric carbon dioxide since the Industrial Revolution?

5. Compared to temperatures and carbon dioxide levels before the industrial revolution, how have human activities and feedback mechanisms either stabilized or destabilized Earth's systems?



Part 1. Exploring sunny surfaces

Describe your observations of the outdoor surfaces in sunlight:

Surface Type	Appearance/Color	Temperature	How does it feel to touch?

Part 2. Experimenting with Surface Color

Experimental Question: What impact does ice have on solar radiation retained by Earth?

Experimental Question with our model: What impact does surface color have on air inside a jar?

Materials:

- 4 cups or jars
- Green, blue, black, and white construction paper
- 4 thermometers
- Tape
- Scissors
- Timer
- Heat lamp

1. Hypothesis: What do you predict will happen?

2. Independent Variable (factor you will change on purpose to test if it causes a different result):

3. Dependent Variable (factor you measure to see if changing the independent variable has an effect; Suggestion: temperature over time):

Directions:

1. Cover each of your jars or cups with construction paper so that each is covered in a different color, including the top
2. Poke a hole in the top of each container to place the thermometer inside, so that you can see the temperature reading on top
3. Record the temperatures of each container
4. Place the containers under the heat lamp so they get equal amounts of light
5. Use the timer to record the temperatures of each container at 5 minute intervals for 20 minutes

Data Table

	Temperature Recorded in 5 minute Intervals

Paper Color	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes	30 minutes
White paper						
Blue paper						
Green paper						
Black paper						

Data Analysis:
Graph Your Data using the table below or another method. Be sure to fully label the X and Y axes.

Part 3. Sea Ice Extent Since 1980

Open the spreadsheet showing temperature, arctic sea ice extent, greenland ice mass, and ocean heat.

Use the data to create line graphs of each data set.

1. Which factors are trending upwards?

2. Which factors are trending downwards?

3. Describe the relationships between the graphs

Making Sense of the Ice and Radiation Investigation

See-Think-Wonder
Use the graphic organizer below to record your ideas from the investigation.

See What did you observe in the model?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
How did surface color impact temperature?	How do you think those observations relate to Earth's systems?	
What relationships did you observe between the variables?	Why do you think those relationships exist? What do you think the connection is between these variables and the colors of their surfaces?	

1. Record your response to the investigation question, *What impact does ice have on solar radiation reaching Earth?*

2. What do you think is happening to the arctic that would explain why it is warming four times faster than the rest of the planet?

Ice Caps and Global Temperatures

Cause and Effect Model:
Construct your cause-and-effect model explaining what is happening to the arctic ice by sorting the cards into the correct arrangement, connecting the events with arrows, and adding the cause or mechanism for each effect. When your group is done, individually draw, sketch, insert a picture, and/or summarize your work here:

Revisiting the Investigative Phenomenon!

Using everything you have learned in this lesson sequence to explain why the arctic has been warming and at a faster rate than the rest of the planet. In your answer, be sure to include:

- What caused a change to begin in the 1800s
- How that change impacted temperatures
- Further impacts on Earth's systems as a result of changing temperatures
- The role of feedback loops in changing temperatures
- The rates of change of temperature and other factors since 1850

Summary Task

How did the class consensus discussion go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

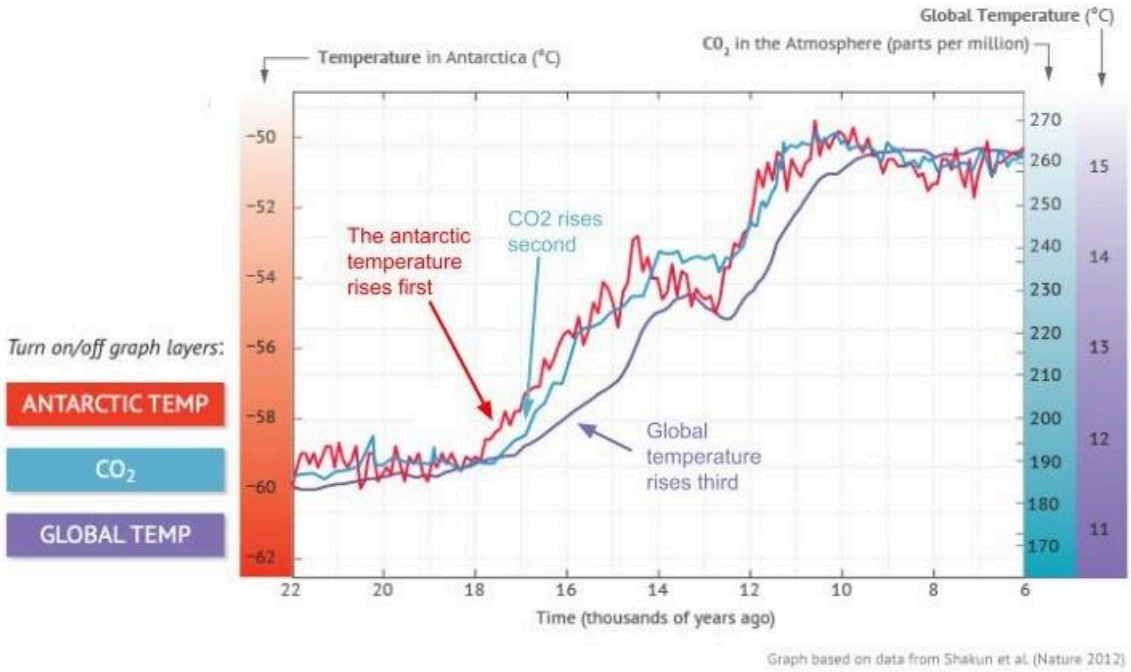
4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

1. Use your models to describe how energy from the sun affects the temperature of Earth through the absorption, storage, and redistribution of that energy.

2. Using your models and the graphs, how are feedback loops and the rates of change of temperature, ice extent, and carbon dioxide levels related?

Greenhouse Gas Feedback Mechanisms



Brainstorm: how is this series of events different from what you've seen so far?

Part 1: Modeling the Effect of Temperature on the Carbon Cycle

Read the table below and use it to complete the model that follows.

Exchange of Carbon Between Earth's Systems

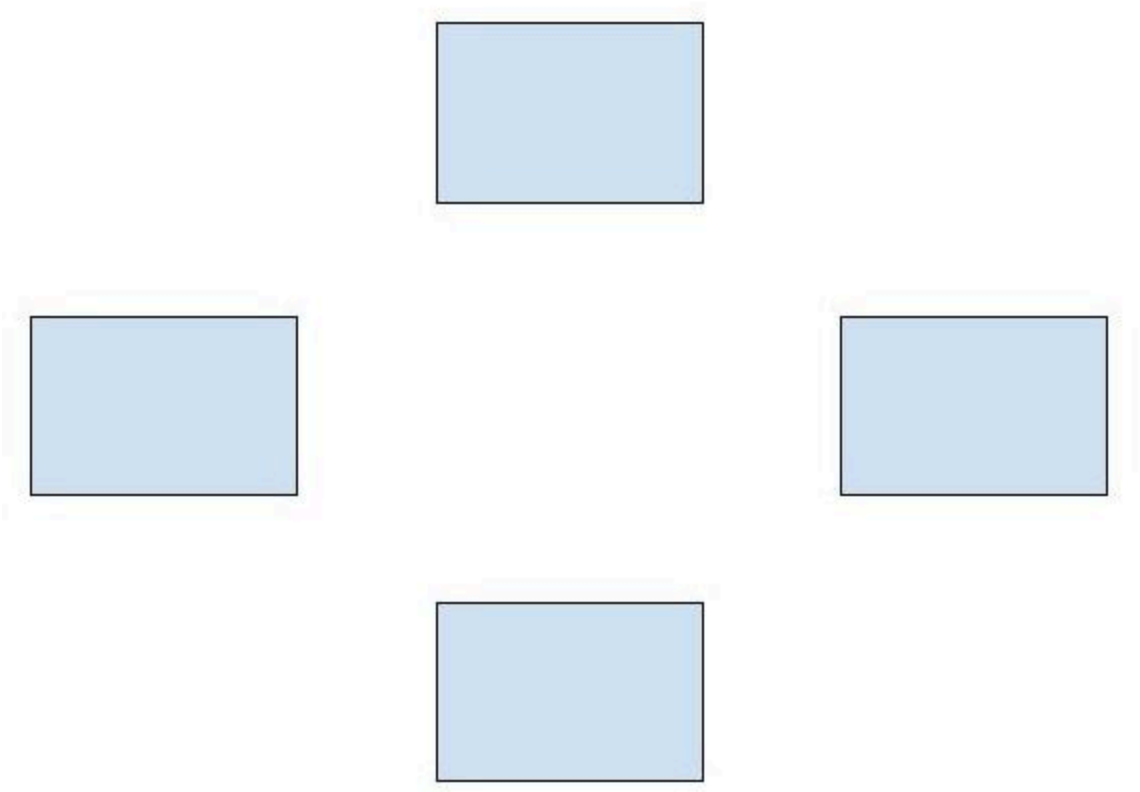
Systems Interaction: what reservoirs does carbon move between?	**How does carbon move when temperatures are stable?**	**How does carbon move as temperatures are increasing?**	**How does carbon move as temperatures are decreasing?**
Hydrosphere (Oceans and water) ← → Atmosphere	Carbon dioxide in the atmosphere can be absorbed by the ocean, and carbon dioxide in the ocean is also released into the atmosphere	The ocean is able to hold less carbon dioxide and releases more into the atmosphere than it absorbs.	The ocean is able to hold more carbon dioxide and absorbs more from the atmosphere than it releases.
Terrestrial Biosphere (all living things on land) ← → Atmosphere	Living things release carbon dioxide into the atmosphere through cellular respiration and decomposition/decay Plants absorb carbon dioxide from the atmosphere through photosynthesis	Plants have longer growing seasons and store more carbon dioxide from the atmosphere, sinking it back into the terrestrial biosphere. Warming also increases respiration in plants and soil, and decay of organic materials, which increases the release of carbon dioxide into the atmosphere.	Plants have decreased growing seasons so they remove less carbon dioxide from the atmosphere Cooling also decreases soil and plant respiration as well as decay of organic materials, decreasing the amount of carbon released into the atmosphere.
Cryosphere (frozen areas like permafrost and glaciers) ← → Atmosphere	Seasonal changes can cause the cryosphere to melt and thaw. Melting releases carbon dioxide into the atmosphere, and freezing traps carbon dioxide in ice and frozen soil. Bacteria are frozen and not actively producing gases.	Permafrost warms and thaws, allowing for bacteria to live and convert carbon in the permafrost to methane and carbon dioxide; gases trapped in the permafrost are released into the atmosphere when it thaws.	Permafrost cools and freezes, not allowing for bacteria to live and convert carbon in the permafrost to methane and carbon dioxide so it stays in the soil. Trapped gases stay trapped in the frozen permafrost.

Modeling the Movement of Carbon Dioxide

Complete the model that follows using the information in the table and following these instructions:

1. Write the name of the carbon reservoirs in each box
2. Use a black pen or pencil to add arrows to show which reservoirs carbon moves between
3. Use a red pen or colored pencil to draw arrows showing the directions of carbon movement when air temperature increases.
4. Use a blue pen or colored pencil to draw arrows showing the directions of carbon movement when air temperatures decrease.

The Movement of Carbon Dioxide Between Reservoirs



1. When temperatures increase, do carbon dioxide levels increase or decrease in the atmosphere? Support your answer with information from the table

2. When temperatures decrease, do carbon dioxide levels increase or decrease in the atmosphere? Support your answer with information from the table

3. What is the relationship between carbon dioxide levels and temperature?

As atmospheric carbon dioxide levels _____, temperature _____ because

Part 2: Why is temperature rising so rapidly?

Your task is to use what you learned from the models of the carbon cycle and greenhouse effect in the previous activities to construct a mechanistic account for how global temperatures are increasing and predict how that could impact climate in the future. You will do this by adding two more cards to your cause-and-effect model of the albedo effect.

Use what you have learned about the albedo effect, the relationship between atmospheric carbon dioxide levels and temperature, and *The Greenhouse Effect* text to put the cards in order and provide a mechanistic account for how each event in the cause and effect sequence occurred.

Think-Talk-Open Exchange

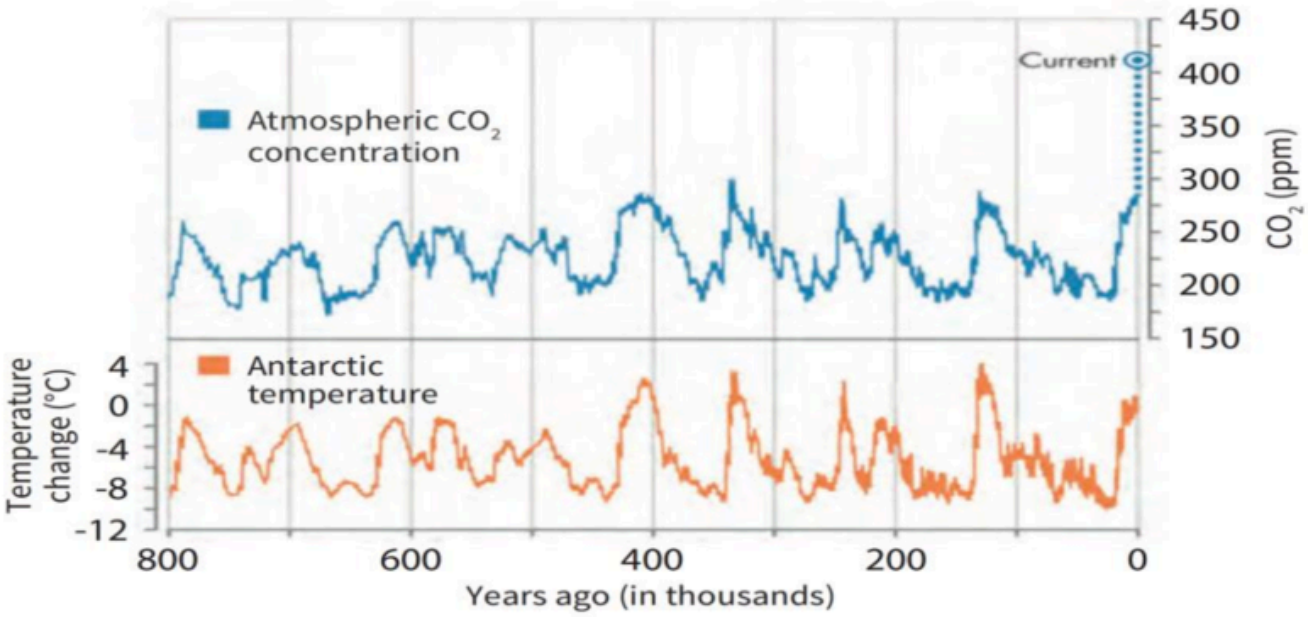
Brainstorm ideas around the prompt: how did the results of the card sort demonstrate the role of feedback mechanisms in this warming event, and how could that impact climate change in the future?

Discuss your ideas with your group using the think-talk-open exchange routine.

Based on your group conversation, independently write a summary that predicts how climate change could unfold in the future. In your explanation, be sure to reference the models from the investigation and explain the role that **feedback mechanisms** played in this event.

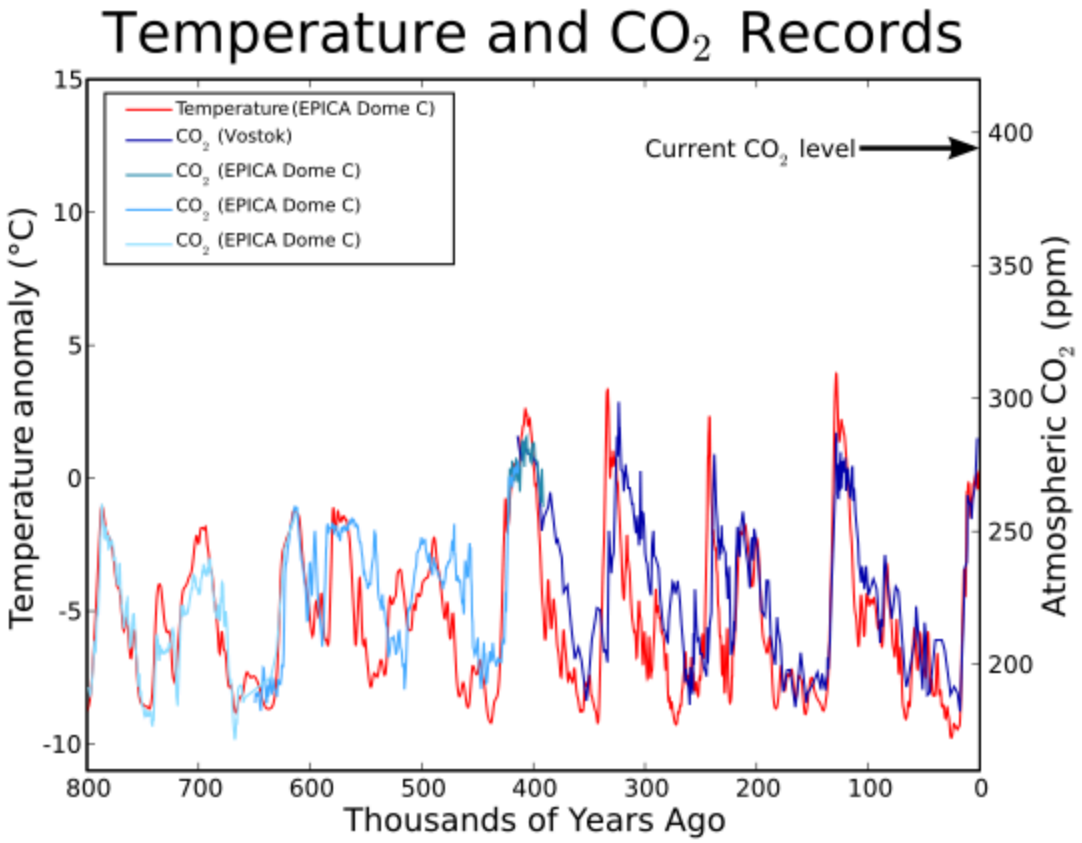
Disprove the Skeptics

Skeptics like to point out that this graph shows a correlation, not a causation.

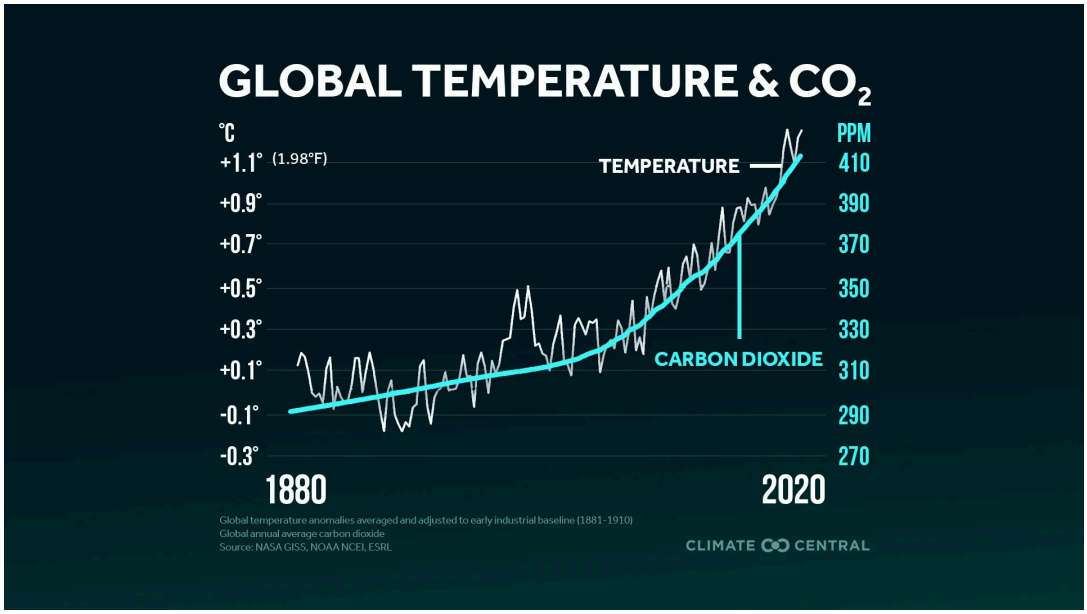


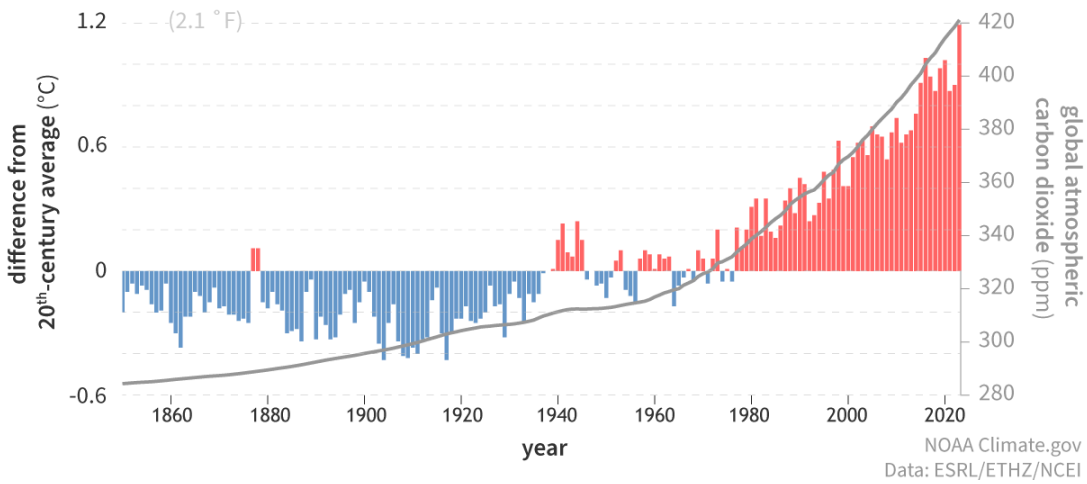
And in fact, they point to the fact that there have been times when carbon dioxide has risen as a result of increasing temperatures instead of vice versa, as seen on the graph below.
On the graph below,

1. label places where carbon dioxide levels change before the temperature
2. Label places where the temperature changes before the carbon dioxide levels



The data below shows the set of changes happening today. Analyze the data to determine which factor is rising first and indicate that time period on the graph below.




Earth's surface temperature and atmospheric carbon dioxide (1850–2023)
1.2
(2.1 °F)
0.6
0
-0.6
difference from 20th-century average (°C)
420
400
380
360
340
320
300
280
global atmospheric carbon dioxide (ppm)
1860
1880
1900
1920
1940
1960
1980
2000
2020
year
NOAA Climate.gov
Data: ESRL/ETHZ/NCEI

Climate Feedbacks Rubric

Climate Feedbacks	Proficient	Developing
Explanation	The explanation effectively and accurately uses multiple lines of valid and reliable evidence to prove why scientists are certain that humans are causing climate change, **including all** of the components below: • description of the current level of greenhouse gases and their sources • mechanistic explanation of the greenhouse effect and its role in climate • description of the current melting rate of northern ice caps • the impact the current melting rate is having on Earth temperatures • concepts of albedo and positive feedback loops regarding sea ice and greenhouse gases Evidence is linked to the explanation using scientific logic and reasoning	The explanation is incomplete in effectively and accurately using multiple lines of valid and reliable evidence to prove why scientists are certain that humans are causing climate change, **including some** of the components below: • description of the current level of greenhouse gases and their sources • mechanistic explanation of the greenhouse effect and its role in climate • description of the current melting rate of northern ice caps • the impact the current melting rate is having on Earth temperatures • concepts of albedo and positive feedback loops regarding sea ice and greenhouse gases Evidence is not well linked to the explanation using scientific logic and reasoning
Cause & Effect	Responses clearly articulate and explain whether there is a causal link between ice caps and/or ocean currents and arctic amplification.	Responses do not clearly articulate and explain whether there is a causal link between ice caps and/or ocean currents and arctic amplification.
Student Self-Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?

The Past and the Future 5E

Unit 4 Climate Change	Earth and Space Science
Student Name:	

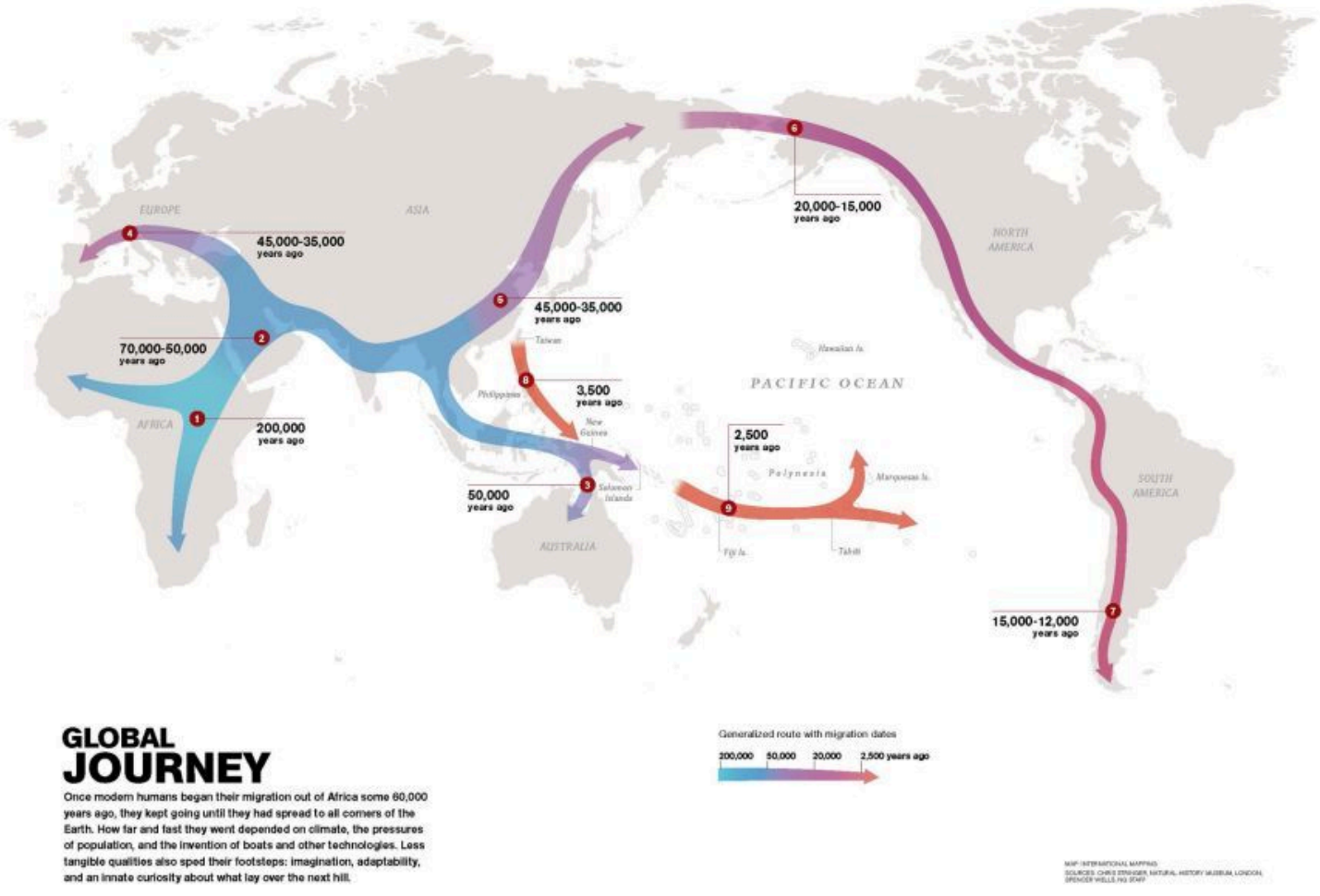
Climate and Human Populations

Humans have lived through climate change in the past. As a species, we've survived ice ages, periods of warming, floods, droughts, and huge volcanic eruptions.

However, just because our species survived does not mean that we have been unscathed by these events.

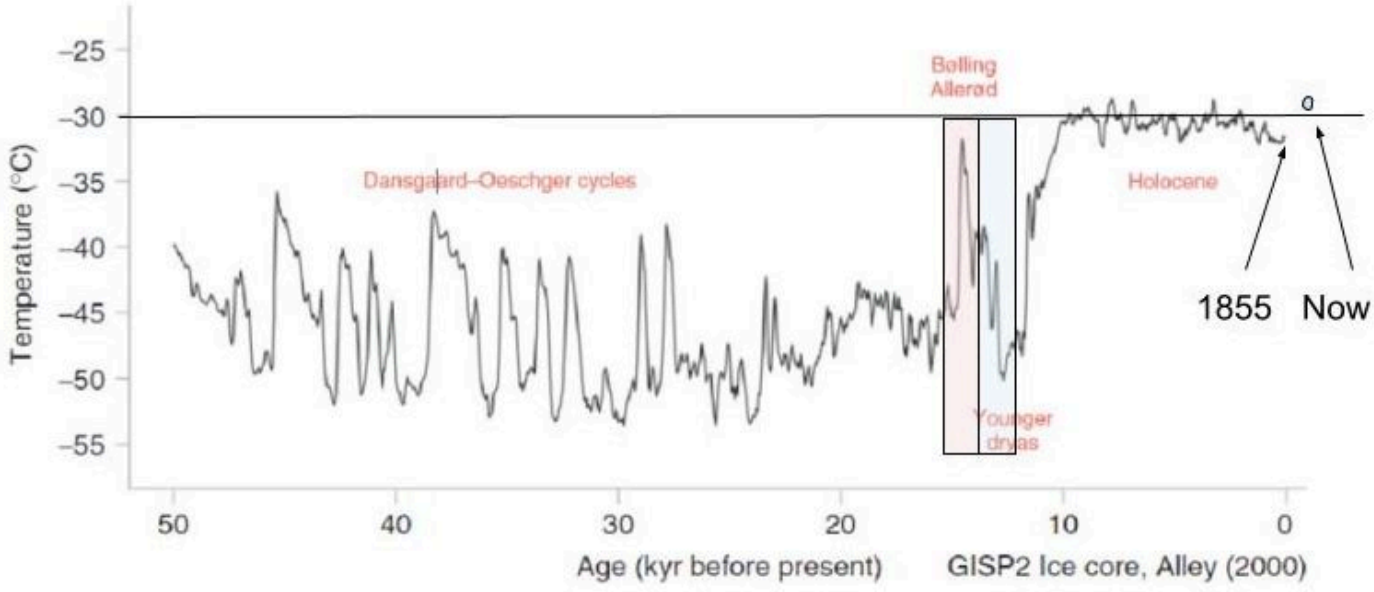
Modern humans evolved in Africa about 200,000 years ago. As deserts grew, shrank, shifted into grasslands and back to deserts, human populations migrated, increased, and decreased. Around 120,000 years ago, modern humans first ventured out of Africa into the Middle East. That first wave was unable to survive a drought brought on by global glacial conditions, and that population died off. Though populations remained in Africa at that time, huge climatic changes brought on by orbital factors and suspected volcanic activity plunged the continent into crisis, killing much of the plant life, and resulting in the human population shrinking to as few as 10,000 mating pairs.

The next wave out of Africa happened about 60,000 years ago across land bridges into the Middle East. Temperatures were milder than they were during the previous migration attempt, and this time, the population survived. As our numbers grew, humans began to spread out over the globe, expanding to new continents at times of low sea level and present land bridges.



This expansion was not without setbacks, though. One of the earliest populations in North America was called the Clovis culture, who likely crossed into North America across the Bering Land Bridge from Siberia 15-20,000 years ago. The Clovis culture left their signature stone tools and projectile points throughout the area beginning 13,500 years ago, and then disappeared from the fossil record 12,750 years ago.

Many hypotheses exist about what happened to this culture, but one thing we do know is that their disappearance happened at the same time as major changes to the climate.

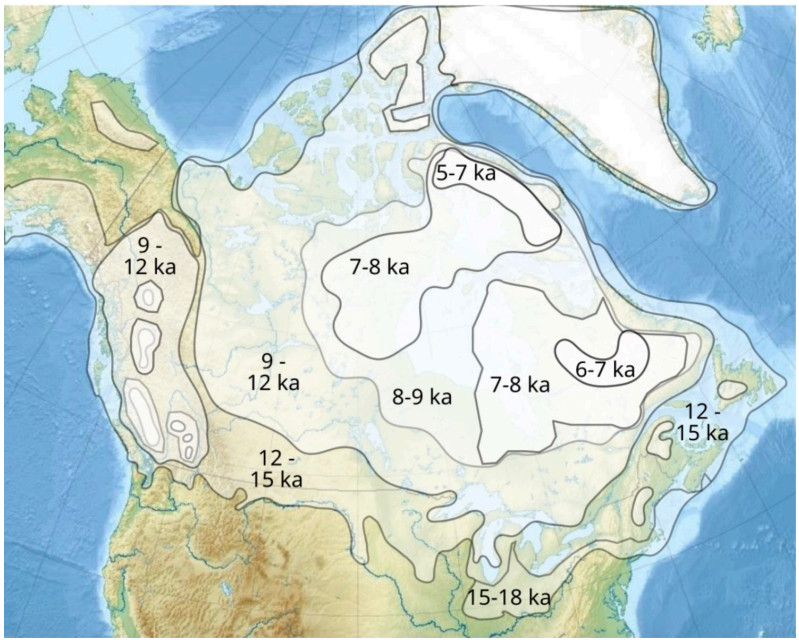


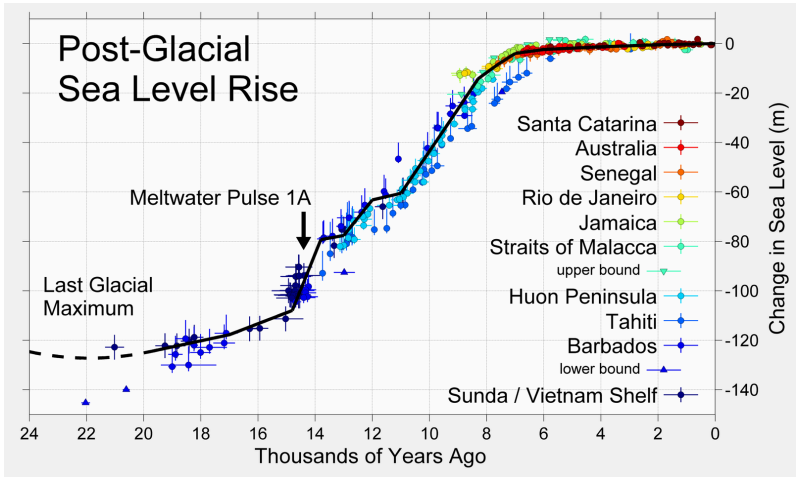
Melting Ice Investigation

Part 1. Sea Level

Watch this video The Blue Marble up to 1:36 and observe the two images below, then respond to the prompts.

This image shows the times that the ice sheet over North America melted.





1. How did glacial levels change over the past 20,000 years?

2. How did sea level change over the past 20,000 years?

Part 2. Ocean Circulation

Planning your investigation:

1. Based on your group or class discussion, and using the materials available to you, describe how you will set up the global ocean circulation model.

Plan for Setting up the Global Ocean Circulation Model (before a glacier melts)


2. **Brainstorm:** How is glacial water different from sea water? How can we change our model to show glacial melt entering the water at the north pole?

3. **Make a prediction:** Before creating the model, use your scientific knowledge to predict what will happen to the circulation of the current when you run the model of a glacier melting. Use the following prompts to guide your thinking, and then draw and describe what you predict to observe when you run the model.
    - How will glacial water interact with the cold, very salty water of the arctic ocean?
    - How will glacial water interact with warm salt water coming from the equator?

4. **Conduct your experiment by building two models:**
    - Global current circulation without glacial melt added (“before” the glacier melts)
    - Global current circulation with glacial melt added (“after” the glacier melts)

5. **Record your observations** using words and diagrams of what happened in each model

Observation of the model before a glacier melts into the seawater at the North Pole	Observation of the model after a glacier melts into the seawater at the North Pole

Making Sense of the Melting Ice Investigation

See-Think-Wonder

Use the graphic organizer below to record your ideas from the investigation.

See What did you observe in the model?	Think What do those observations make you think about?	Wonder What questions do you have?
What did you notice about the relationship between glacier size and sea level?	How do you think these changes would have impacted people living in the changing areas?	
When you reduced the salt concentration to model glaciers melting, how did the currents change?	What do you think would happen to the current if glaciers kept melting and diluting the salt concentration?	

Identify and Interpret:

1. How do changes in the cryosphere induce changes in the hydrosphere?

2. How is energy moving in this system, both before and after the glacier melts? In your response, include where the energy is coming from, both in the model and in the oceans.

3. Based on what you saw in the model, how do you predict that ocean currents slowing due to melting glaciers would affect the amount of energy being distributed from the equator to the northern hemisphere?

Melting Ice and Currents

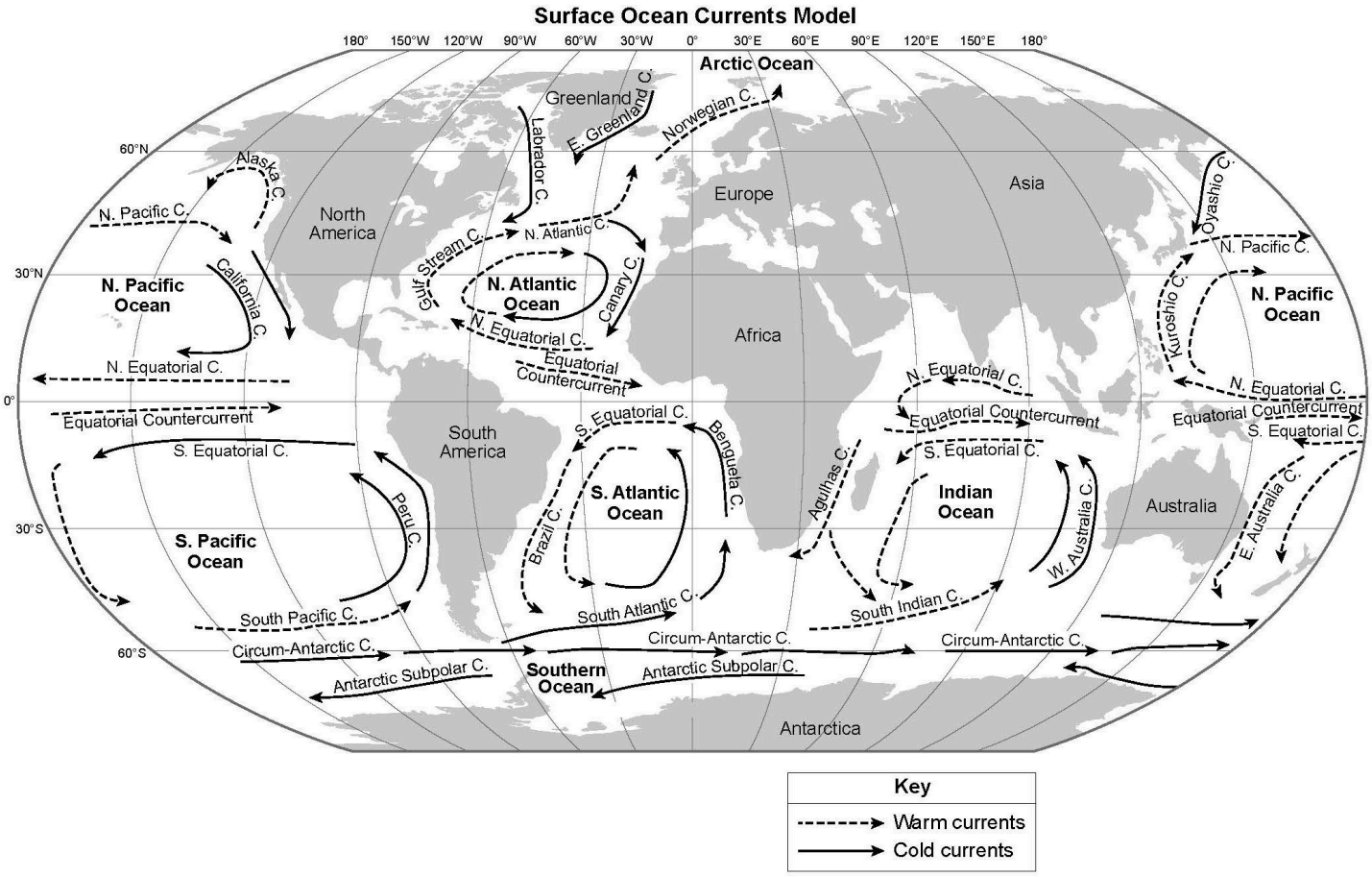
Part 1: Develop a Model for how Changes in Ocean Currents Occur

Using observations from your experiment and scientific ideas related to ocean circulation (density, sinking, rising, etc), develop a model that shows how a change in ocean currents can occur.

In your model, be sure to include how ocean currents affect the distribution of energy in Earth's system and over what timeframe.

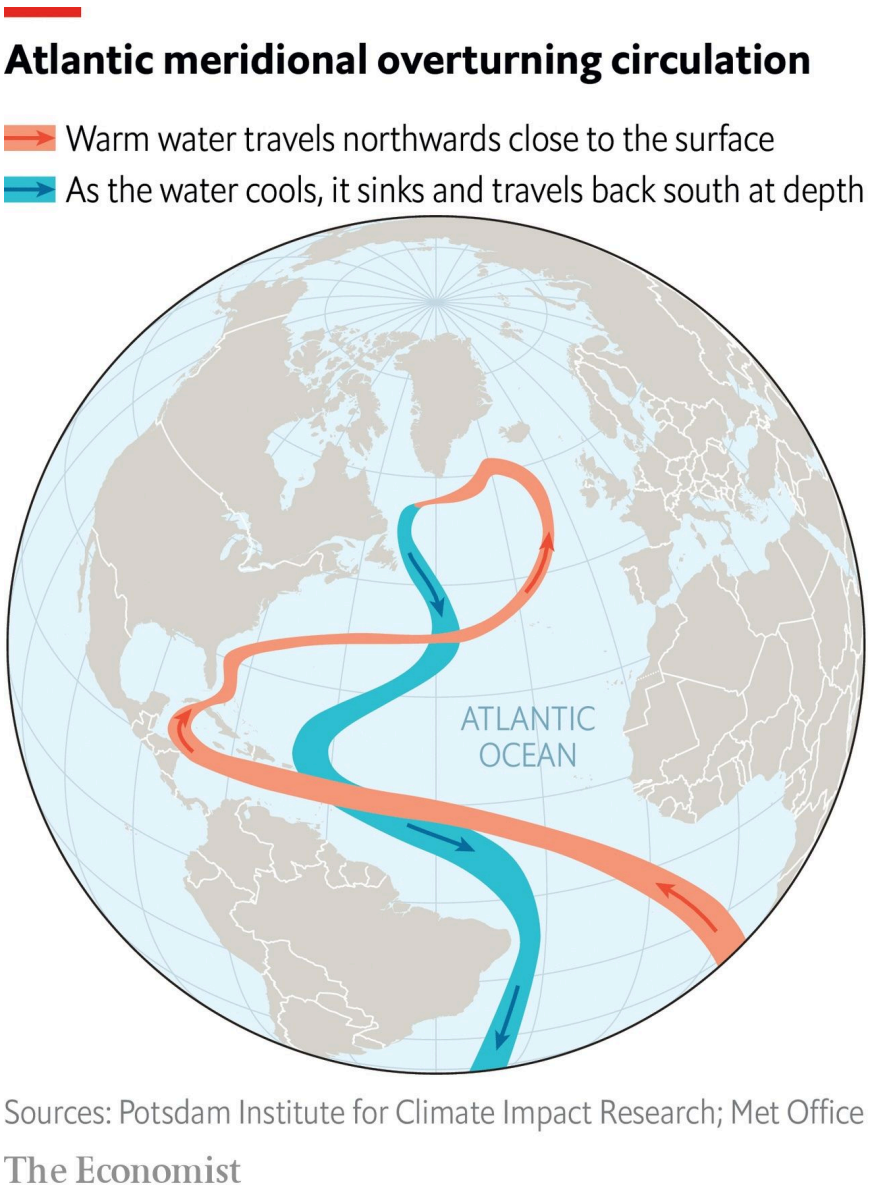
Part 2: Develop a Model for how Changes in Ocean Currents Can Affect Climate

Analyze the global ocean circulation map and read about scientific ideas related to heat storage and transfer in the text below, then use what you learn to develop a model that shows how a change in ocean currents can affect air temperature.



See What did you observe in the model?	**Think** What do those observations make you think about?	**Wonder** What questions do you have?
What patterns do you notice about the movement of warm currents?	How do you think that movement impacts the climate?	

What patterns do you notice about the movement of cold currents?	How do you think that movement impacts the climate?	



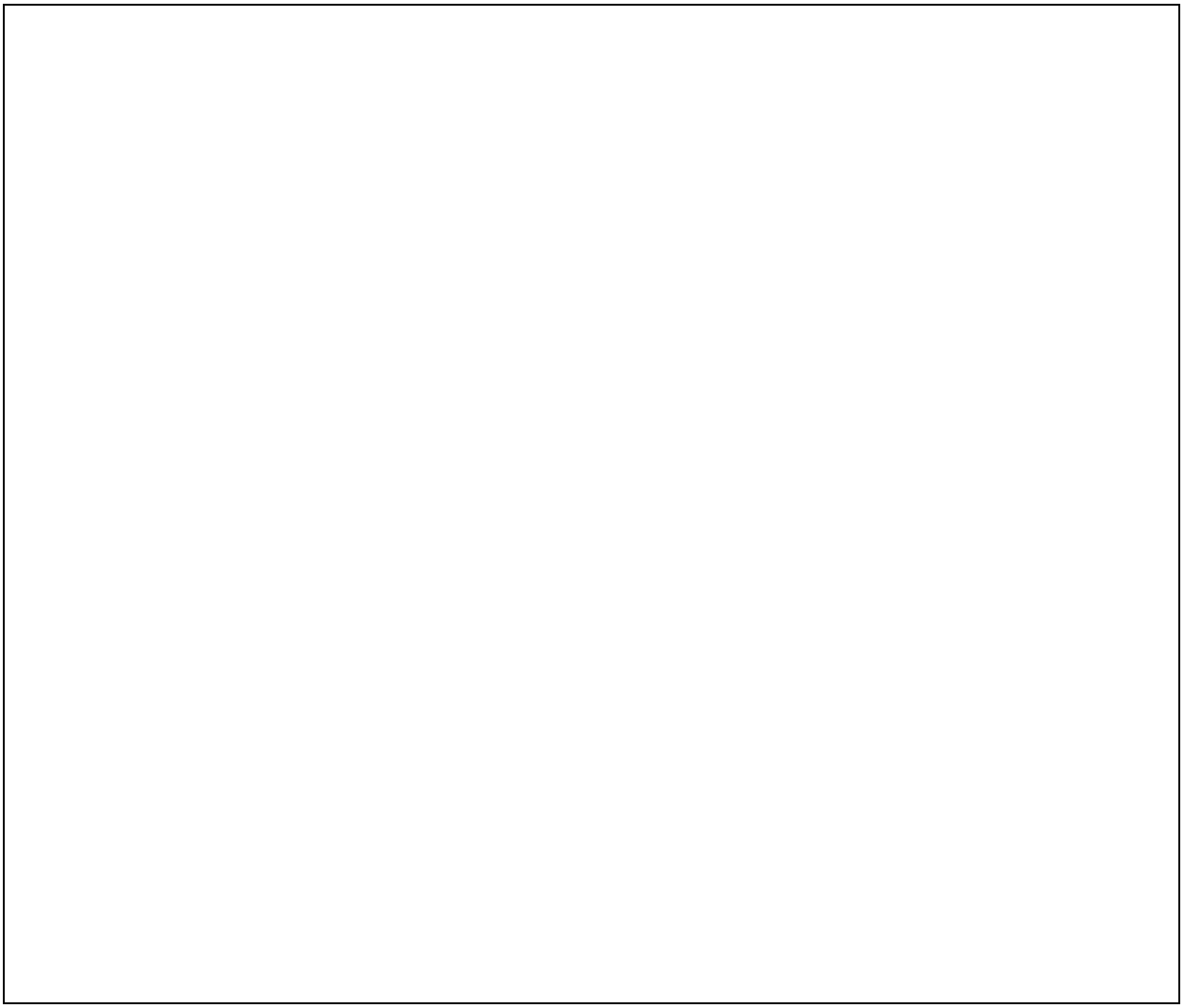
Ocean Heat Storage and Transfer

Ocean currents like the Gulf Stream have a significant influence on the temperature of the land they flow near due to the concept of heat capacity and heat transfer. Water, with its high heat capacity, can absorb and store large amounts of heat without a significant rise in temperature. As warm ocean currents like the Gulf Stream flow near coastal areas, they transfer heat to the surrounding land through convection and conduction.

The warm water from the Gulf Stream warms the air above it, creating milder climates along the coastlines it passes. This effect is particularly noticeable in regions like western Europe, where the Gulf Stream contributes to relatively warmer temperatures compared to areas at similar latitudes. Conversely, cold ocean currents can have the opposite effect, cooling the air and leading to cooler land temperatures along their paths.

Understanding how ocean currents transfer heat to land helps us predict and explain regional climate patterns and their impacts on ecosystems and human activities.

Modeling How Ocean Currents Affect Climate
Using observations from the global ocean circulation map and scientific ideas related to heat storage and transfer from the text you just read, develop a model that shows how a change in ocean currents can affect climate.



Part 3. Impact on People

1. Arrange the *The End of the Clovis Population Cards* to explain how climate factors affected that group of people
2. Use evidence from this learning sequence and the card sort to respond to the prompt: *How did changes in climate influence the Clovis population?*

Summary Task

Today we completed a Class Consensus Discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

1. How did the use of models help you determine the mechanism of rapid warming and cooling in the Northern hemisphere 16,000-12,000 years ago?

2. Explain how using empirical evidence helped you understand the cause and effect mechanisms of environmental factors and their impact on human populations.

Forecasting the Future Investigation Part 1

Predicting Climate Impacts

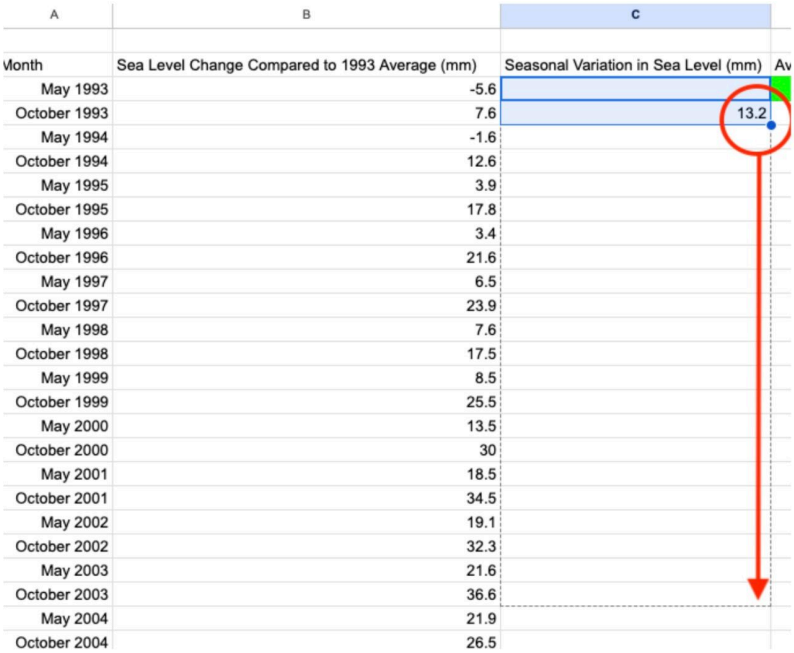
1. Open the Sea Level Change Data Spreadsheet
2. Highlight both columns and select “Insert” → “chart”
3. Insert or draw the resulting graph in the space below

4. Describe the overall trend in sea level over the 32 years of data

5. Describe the seasonal variation depicted in the data

6. Use the spreadsheet to calculate the average seasonal sea level change since 1993 by following these steps:
    a. Go to the column “Seasonal Variation in Sea Level (mm)”

b. In row 4, October 1993 (cell C:4), it shows the October Sea Level - the May Sea Level (B4-B3)
c. Drag that formula to every October cell by highlighting cells C:3 **and** C:4 and then clicking the blue dot in the bottom right corner and dragging it down the whole column



A	B	C	
Month	Sea Level Change Compared to 1993 Average (mm)	Seasonal Variation in Sea Level (mm)	Av
May 1993	-5.6		
October 1993	7.6	13.2	
May 1994	-1.6		
October 1994	12.6		
May 1995	3.9		
October 1995	17.8		
May 1996	3.4		
October 1996	21.6		
May 1997	6.5		
October 1997	23.9		
May 1998	7.6		
October 1998	17.5		
May 1999	8.5		
October 1999	25.5		
May 2000	13.5		
October 2000	30		
May 2001	18.5		
October 2001	34.5		
May 2002	19.1		
October 2002	32.3		
May 2003	21.6		
October 2003	36.6		
May 2004	21.9		
October 2004	26.5		

Note: it is very important to highlight both cells C:3 AND C:4. Highlighting only C:4 will copy this formula to every cell, which will distort the calculation. You can tell if there are errors if any negative numbers appear in column C.

d. The average seasonal change will be calculated in the green highlighted cell titled Average Seasonal Variation. Record that value here:

---

7. Calculate the average monthly rate of change of seasonal variation by using the formula below

$$\text{Average monthly rate of change} = \frac{\text{Average Seasonal Variation (mm)}}{\text{7 months}}$$

8. Calculate the annual rate of change of sea level over the 32 years of data by using the formula below:

$$\text{Annual rate of change} = \frac{\text{Sea Level Change May 2025 - Sea Level Change May 1993}}{\text{2025-1993}}$$

9. Using this calculated annual rate of change, predict how sea level will change over the next 50 and 100 years

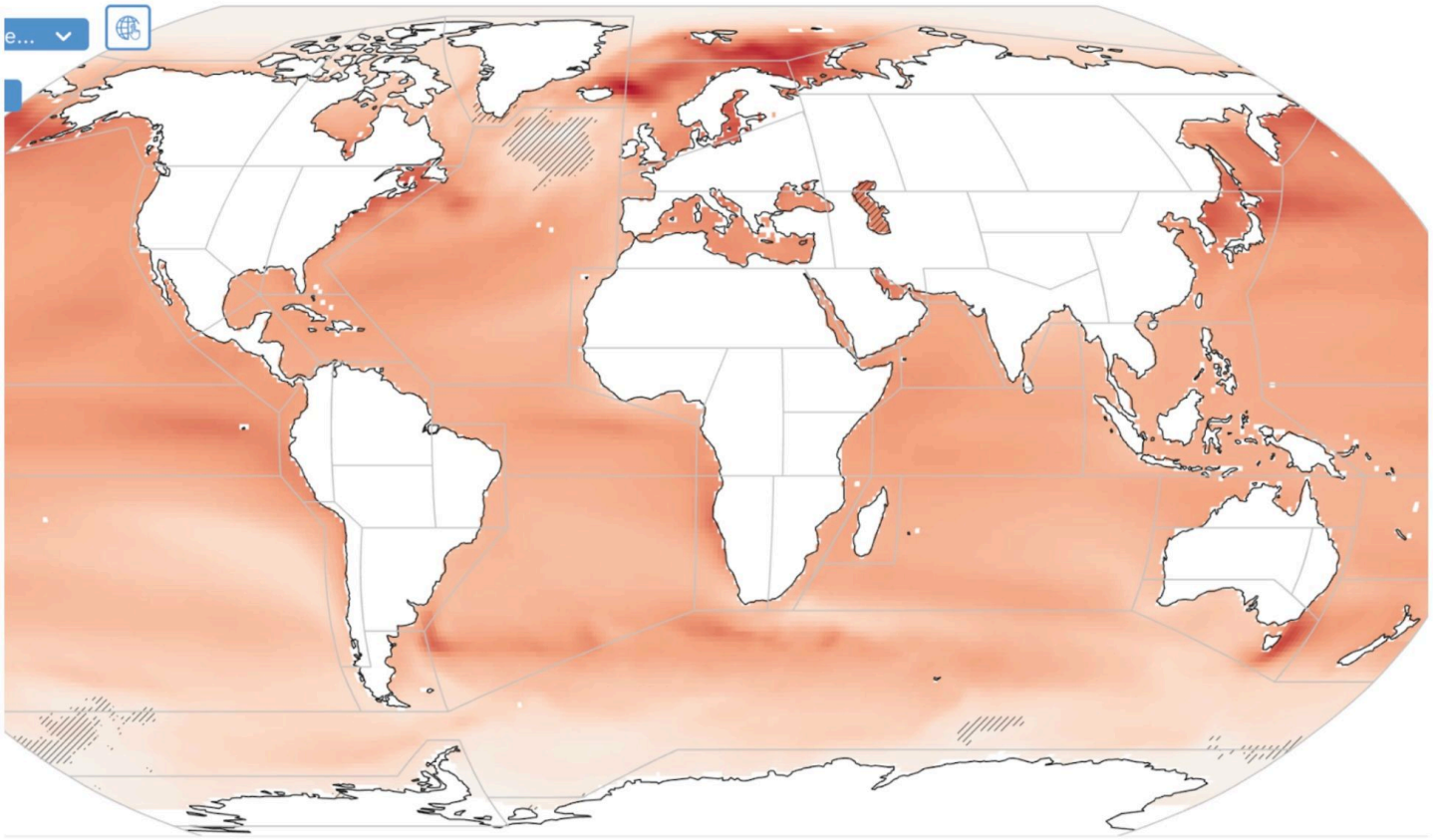
50 years:

100 years:

Forecasting the Future Investigation Part 2

Observing Climate Impacts

1. Open the IPCC WGI Interactive Atlas: Regional information (Advanced)
2. Choose a region that interests you and click on it. Mark the region you selected on the image below:



3. Use the **variable** tab to choose “sea level rise” to examine.

4. Use the **quantity and scenario** tab to choose “long term” and “Scenario SSP1-2.6”

5. In the data table, describe how sea level rise will be affected by a warming scenario SSP1-2.6 in the year 2080. In your description, note the direction of change (increase or decrease) and if the rate of change increases over time. You do not have to worry about specific numbers at this point.

6. Use the quantity and scenario tab to change the warming scenario to SSP2-4.5, SSP3-7.0, and SSP5-8.5, describing how the variable is affected in the table.

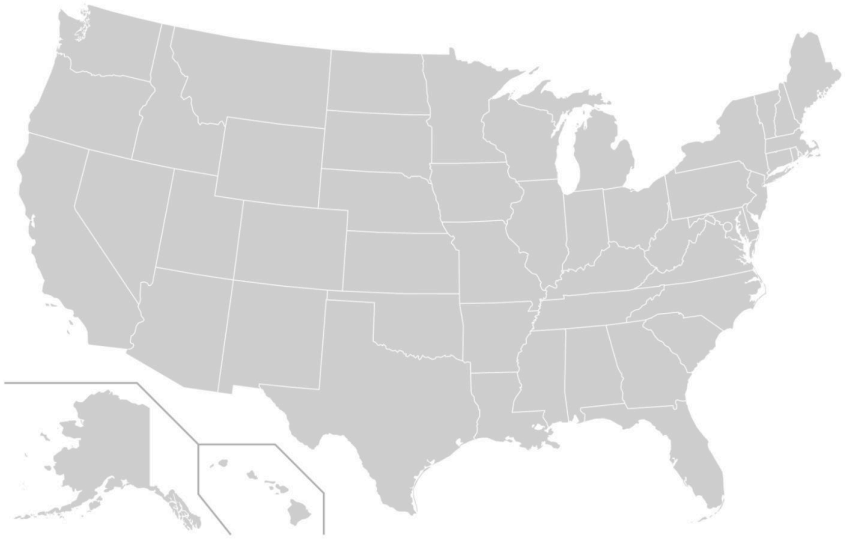
7. Repeat this process for three additional variables, recording them in the data table. Choose variables from different categories, such as temperature, precipitation, wind, or water temperature.

Data Table: Climate Outcomes under Different Warming

	Warming Scenario			
Variable of Interest	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Sea Level Rise				

Observing Sea Level Rise

1. Open the IPCC WGI Interactive Atlas: Regional information (Advanced) and change the year to 2080 to project what could happen in the next 50-60 years
2. Choose a coastal area in the United States to focus on and circle it on the map below



3. Use the simulator to observe how much sea level is expected to rise by 2080 under different warming scenarios and record the data below

Warming Scenario	**Projected Sea Level Rise in meters**	**Rate of sea level rise** *meter increase/years*
SSP1 - 2.6		
SSP2 - 4.5		
SSP3 - 7		
SSP5 - 8.5		
High End Scenario		

4. Open Sea Level Rise Scenarios visualizing sea level rise in the United States and navigate to the same area you observed for the previous simulation.

5. Using the numbers you generated from the last simulation, increase the water level and observe the changes to the landscape as the water rises. Describe what you see here

6. Find a blue flag within the area you are observing and click on it to view a picture of the street in that area. Describe how the image changes as the water level rises, using specific water levels.

Making Sense of the Forecasting the Future Investigation

See-Think-Wonder

Use the graphic organizer below to record your ideas from the investigation.

See What did you observe in the model?	Think What do those observations make you think about?	Wonder What questions do you have?
What did you notice about the relationship between temperature increase and climate factors?	How do you think that might impact people living in that area?	
Were the rates of change for each climate factor the same, or did some change more quickly than others?		
What did you notice about the projected changes in sea level?	How do you think that might impact people living in that area?	

What did you notice about the rate of sea level rise in each warming scenario?		

Analysis Questions:

1. Based on what you've observed in the data and models, do you think that the changes described could be prevented or reversed? Support your answer with evidence from the investigation.

2. What limitations do you think may exist in using data from the past and present to make predictions about the future?

3. If this pattern of glacial melt and sea level rise continues, what impacts could that have on the AMOC?

Impacts of Melting Ice

Directions for Read-Generate-Sort-Solve:

1. Read: Read your assigned text silently
2. Generate: On your group's chart paper, generate ideas from the investigation and texts about how climate change will affect populations worldwide
3. Sort: Have everyone in the group star one idea that they think is most relevant to the question.
4. Solve: As a group, discuss the ideas you deemed most important, and come up with a response to the question.

How will climate change impact populations?
Generate Ideas.

Name:	**Name:**
Name:	**Name:**

How will climate change impact populations?

Individually record your response to the prompt above. In your response, be sure to include specific data and evidence from the investigation and texts to support your claim.

Text 1 - Glacial Lakes

Excerpt From NRDC
How Melting Ice Affects People and the Planet
Across the world, thawing landscapes, seascapes, and freshwater reserves are reshaping environments and lives for the communities that rely on them.
Susan Cosier

November 5, 2024

High in the Himalayan mountains of rural Bhutan, Thorthormi Lake is hemmed in by a rock dam. Every year, the water within gradually rises, inch by inch, as the glacier feeding it melts. Snow-peaked crags rise above while far below, villages dot the landscape and rivers braid over a flat floodplain where the glacier once extended.

This remote area is one that glaciologist Rachel Carr studies as part of her work on glacial lake outburst floods (GLOFs), events that occur when a rock dam holding back meltwater fails and floods the valley below. Thorthormi Lake is one of four glacial lakes in the Lunana area, which is among the highest-risk sites of its kind in the world.

“It's a bit of a microcosm,” says Carr, who visited the site in September as part of her research at Newcastle University in the United Kingdom. “But I think it's a very good example of what we're all facing, to some extent.”

Scientists estimate that 15 million people are vulnerable to sudden flooding from glacial lakes, one of various consequences of melting ice throughout our climate-disrupted world. The floods are increasingly likely as glaciers melt—and they can prove disastrous for the communities below. When the dam failed near another Lunana-area lake in 1994, a torrent of water flowed into the valley below, killing 21 people. To prevent another disaster like this, Bhutan recently announced that it would relocate nearly 80 families from high-risk areas below Thorthormi Lake.

Extreme adaptation measures like these are typically a last resort. But many communities face complex decisions as thawing accelerates and impacts environments around the globe.

Researchers are learning to predict where certain changes will occur. For some areas, melting ice will compromise drinking water resources. For others, it will impact agriculture or aquaculture. Coastal areas will continue to be significantly inundated by rising seas. And for the millions of people who live in permafrost zones, costs to repair crumbling infrastructure will pile up.

“We are surprised by the rate at which climate change is impacting the icy parts of the world. But I'm not going to say that it doesn't make sense,” says Doug MacAyeal, a professor emeritus at the University of Chicago who studied glaciers for four decades. “Sadly, it is fully understandable.”

Text 2 - Mountains

Excerpt From NRDC
How Melting Ice Affects People and the Planet
Across the world, thawing landscapes, seascapes, and freshwater reserves are reshaping environments and lives for the communities that rely on them.
Susan Cosier

November 5, 2024

From the Himalayas to the Andes to East Africa, many alpine glaciers are melting at unprecedented rates. This effect is particularly pronounced in the high mountain ranges of the tropics. Unlike peaks at the midlatitudes—say, those in the Sierra Nevadas, where heavy winter snowfalls can cause glaciers to gain mass after a summer melting period—tropical glaciers don't experience the same extreme seasonal temperature changes. As a result, they're shrinking rapidly.

The effects trickle down to communities in many ways. In India, areas exposed to receding glaciers resulted in a devastating landslide and flood in 2021 that killed approximately 200 people. The debris took out two hydroelectric dams and led authorities to evacuate numerous villages downstream.

"It all started sometime around 10 in the morning. We heard a bang, which shook our village," Dinesh Negi, a resident of Raini village, told the Associated Press at the time. "We knew something wrong had happened….We could see the fury of the river." Researchers later determined that an ice and rock avalanche caused the disaster, demonstrating the increasing risk from warming and development.

In the Andes, where scientists have documented unprecedented glacier retreat, the impacts are being felt in Cordillera Blanca, a mountain range in Peru. There, local farmers who traditionally grew corn, wheat, and potatoes are contending with hotter, drier conditions. To adapt, they're experimenting with different crops, such as sugar snap peas, and relying on the increased meltwater collecting in glacial lakes. But this shift has created tensions with others seeking to profit from the lake surpluses, including large-scale irrigation projects and power companies.

"One of the things we've been looking at is who gets to manage that water and who has the rights," says Mark Carey, a professor of environmental studies and geography at the University of Oregon, who has studied the region's increased glacier hazards and resulting water troubles. "We see a lot of communities who are really struggling to ensure that they have a water supply as the climate changes."

Even as a severe drought grips much of South America, hydroelectric companies are capitalizing on the influx of water from melting glaciers. One company, Ardian, acquired six hydroelectric plants in Peru just last year.

NRDC's global managing director Amanda Maxwell, who has worked on water access rights and other environmental issues in Latin America for more than a decade, has observed a troubling pattern of exploitation of local waterways by corporations like Ardian. "Local communities who depend on that ecosystem for their livelihood, they're the ones who will feel the change in that ecosystem most acutely," Maxwell says. "If that's fishing or tourism or farming, any change to a nearby river can have ripple effects throughout those very immediate economies that depend on that river. These companies often come with promises of jobs and economic benefits, but we've seen enough now where those promises fall flat and aren't actually delivered."

Text 3 - The Poles

Excerpt From NRDC
How Melting Ice Affects People and the Planet
Across the world, thawing landscapes, seascapes, and freshwater reserves are reshaping environments and lives for the communities that rely on them.
Susan Cosier

November 5, 2024

The poles: From sea level rise to shellfish decline

As global average temperatures tick up, the sea ice that covers the Arctic Ocean forms later in the fall and melts earlier in the spring. That ice reflects sunlight back into the atmosphere. When it melts, the darker water surfaces below absorb more sunlight and heat—leading to further warming and more melting.

Coastal sea ice also absorbs ocean wave energy. When it melts, or doesn't solidify for as long in the winter, waves crash directly into the shore, erode the land, and carve off chunks of earth. In Alaska, for example, the shorelines of many northern and western communities are shrinking by more than 3 feet a year. Several villages along the state's rivers and coasts have engaged in costly relocation efforts as they've watched their waters deluge local infrastructure.

Less sea ice paired with warmer ocean temperatures could also contribute to milder cold snaps, a concern because of the rain-on-snow events that can ensue. The resulting crusty ground conditions can have dire consequences for Arctic wildlife, including reindeer herds—as well as for the communities that rely on them.

A recently published study in Geophysical Research Letters suggests that "Arctic warming and sea ice loss are already impacting the Arctic communities, whose lifestyles and livelihoods were adapted to cold weather through generations of lived knowledge." That's the case for the Inuit communities of Alaska's North Slope, who can no longer rely on year-round underground ice cellars to store the meat from their hunts and ensure a consistent food supply.

Arctic sea ice loss also disrupts marine ecosystems. Researchers who investigated very cold water in the Bering Sea found that less sea ice could constrict shellfish production. The snow crab is a prime example—the fishery, estimated to be worth $227 million annually, crashed in 2018–2019. It still hasn't fully recovered, nor have the fishing communities who depend on it; a recent study by NOAA Fisheries scientists suggests that the crabs may never come back.

In Antarctica, on the other hand, the effects are quite different. Ice is now melting from below, thanks to warming seas. The impacts of climate change there are "insidiously indirect," says MacAyeal. Ice is melting "around the fringe of the continental ice sheet where it's running into the ocean." That also destabilizes ice shelves and contributes to rising seas.

Scientists have been sounding the alarm bells on West Antarctica's 80-mile-wide Thwaites Glacier, which is increasingly losing structural integrity, and may very well shatter in as little as five years. The resulting chain of effects would trigger global sea level rise that impacts millions of people.

Summary Task

Today we completed a Class Consensus Discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

What did you learn from this person?

4. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today:

5. Some climate events are temporary, like a seasonal shift in precipitation, and damage may be reversible. How are the situations you observed here similar to or different from those events?

6. How does the rate of change in climate factors combined with our ability to use data to make predictions about the future contribute to the ability of communities to adapt and respond to these changes?

Managing Other Climate Change Disruptions

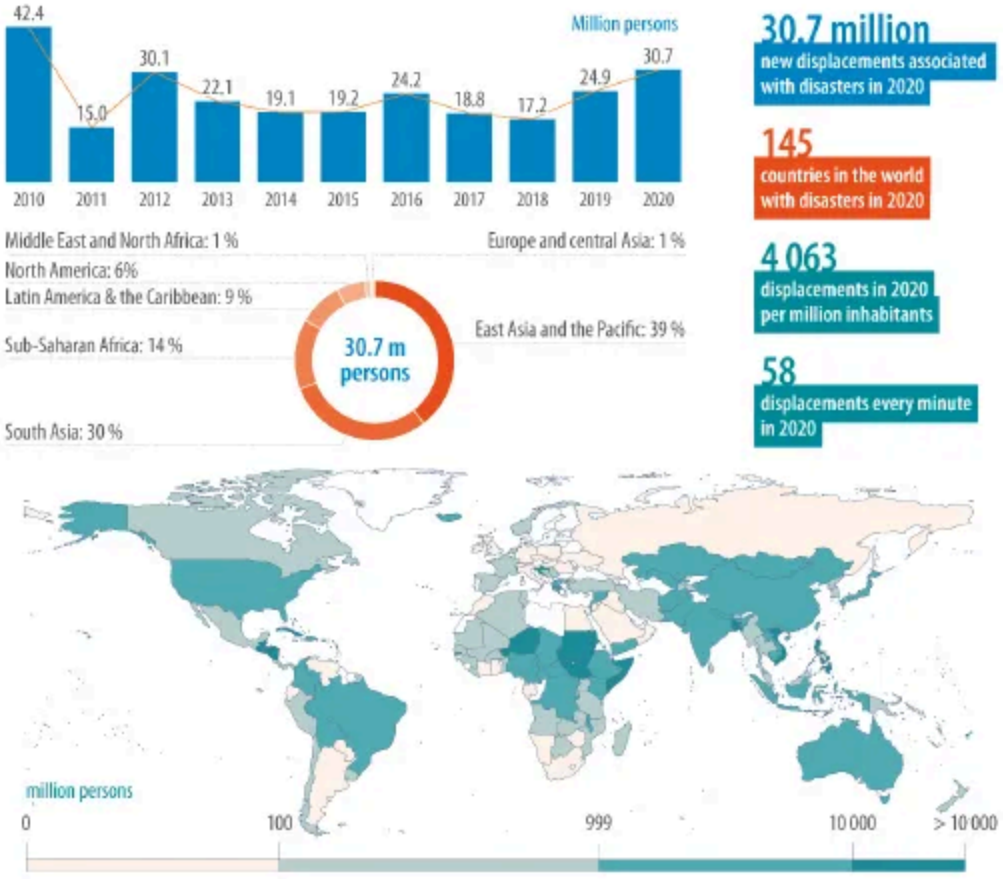
Directions for Think-Talk-Open Exchange:

1. After watching the two videos, write your own response to the prompt below.
    - These crops are suffering most from climate change | World Economic Forum
    - How Climate Extremes are Causing World Hunger

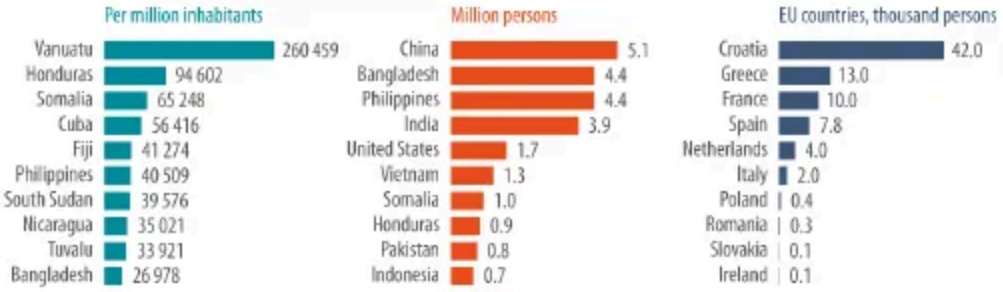
How is climate change affecting populations, and what actions could be taken to prevent increasing harm?

2. Follow the think-talk-open exchange protocol to discuss your responses
3. **Reflection:** After listening to your group-mates, how would you change your original answer?

Human Displacement and Disaster Data

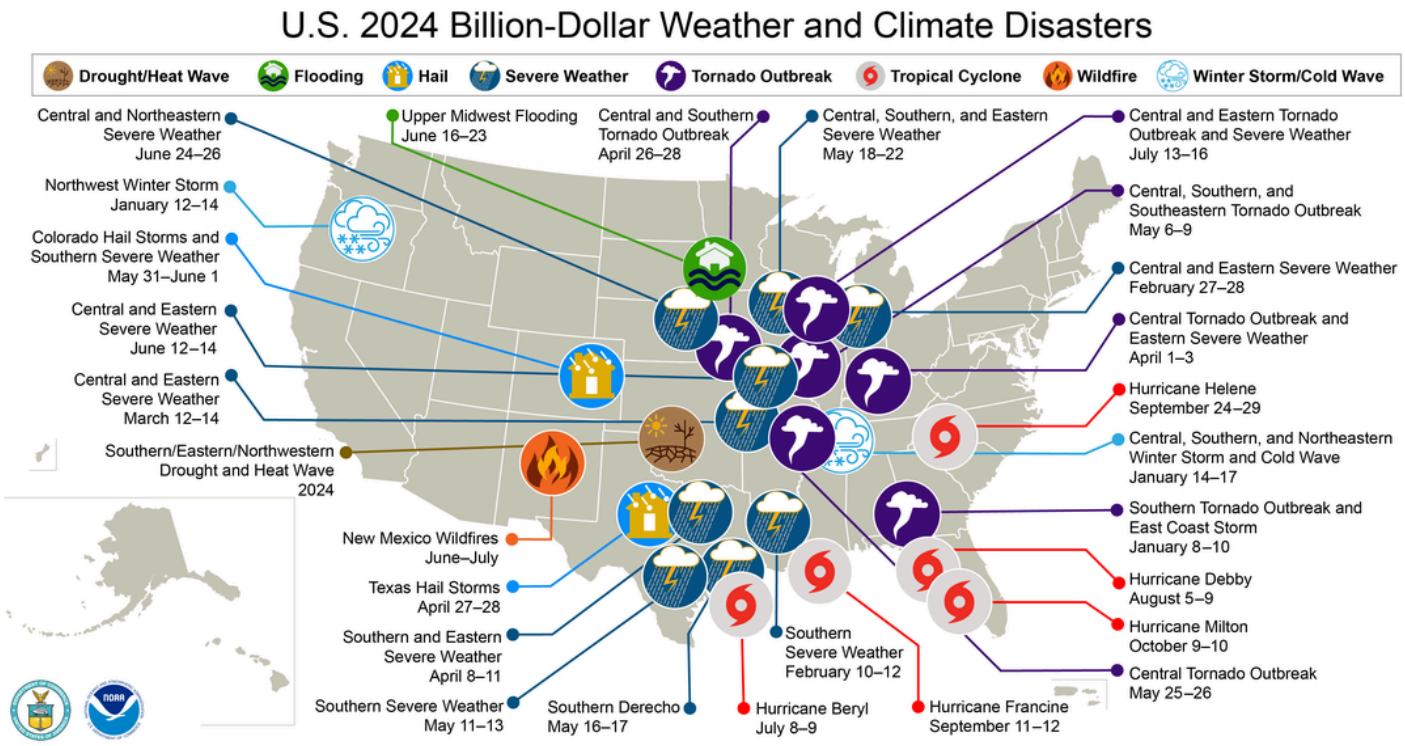


Countries with the highest number of new displacements

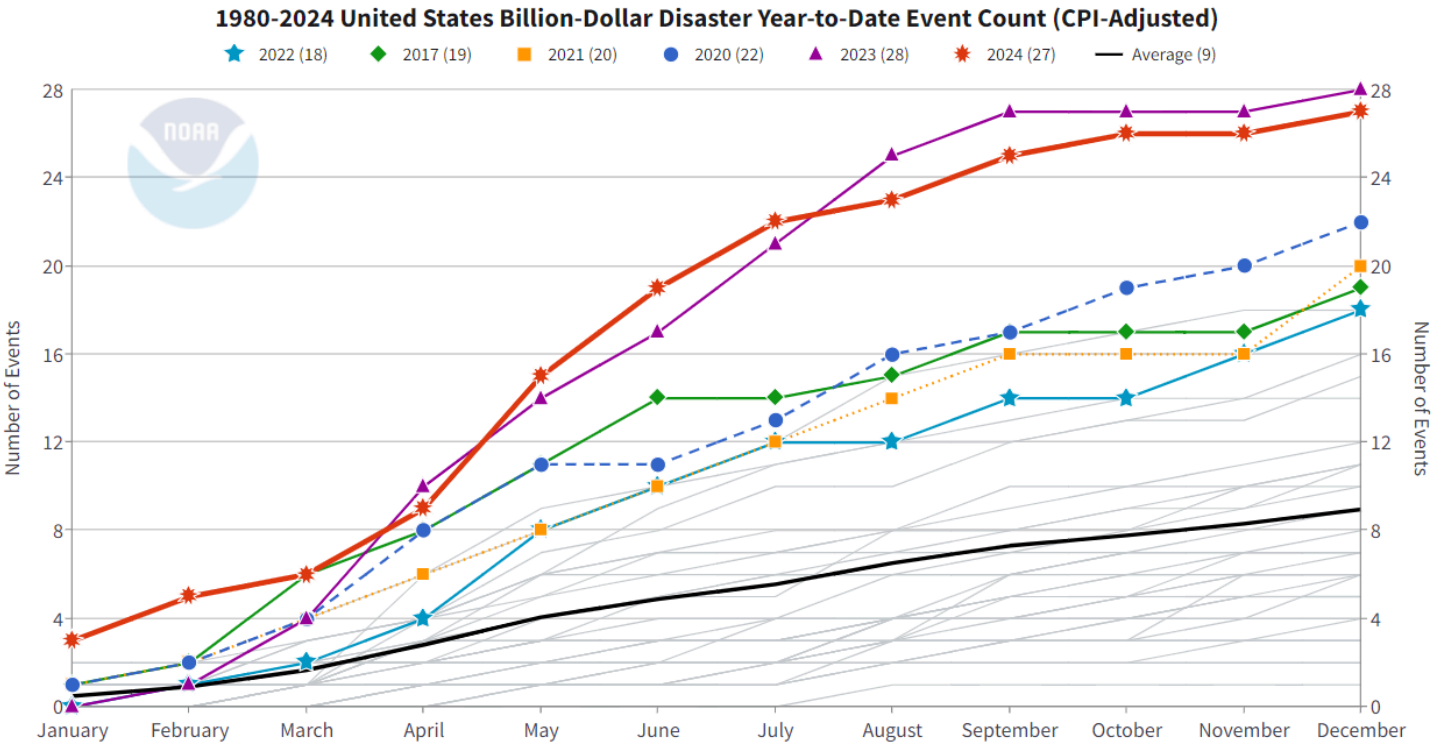


Internally displaced persons (IDPs): persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, as a result of or in order to avoid the effects of natural disasters, and who have not crossed an internationally recognised state border. Natural disasters refers, for instance to earthquakes, hurricanes, typhoons, floods, volcanic eruptions, tsunamis, tornadoes, landslides, extreme temperatures, etc.

Data sources: Global Report on Internal Displacement, IDMC, 2021 and World Bank, World Development Indicators, 2021. Graphic update by Samy Chahri and Gyorgyi Macsai, based on an original infographic by Giulio Sabbati, EPRS.



*This map denotes the approximate location for each of the **27 separate billion-dollar weather and climate disasters that impacted the United States in 2024.***



Month-by-month accumulation of billion-dollar disasters for each year on record. The colored lines represent the top 6 years for most billion-dollar disasters. The dark gray line shows the average. All other years are colored light gray. NOAA NCEI Billion-dollar Disasters webpage.

The Past and the Future Rubric

The Past and the Future	Proficient	Developing
Explanation	The explanation effectively and accurately describes how climate change has been and will continue to impact human populations, **including all** of the components below: • How rapid climate change has impacted populations in the past • The potential impacts on the AMOC of ongoing climate change • How climate change has already impacted people through melting ice • How climate change has already affected food supplies • How climate change could continue to affect displacements and human migration Evidence is linked to explanation using scientific reasoning and logic	The model is incomplete in showing the current levels of carbon dioxide in the atmosphere and the impact carbon dioxide gases are impacting the total amount and distribution of energy on Earth, **missing one or more** of the components below: • How rapid climate change has impacted populations in the past • The potential impacts on the AMOC of ongoing climate change • How climate change has already impacted people through melting ice • How climate change has already affected food supplies • How climate change could continue to affect displacements and human migration Evidence is not well linked to explanation using scientific reasoning and logic
Cause & Effect	Responses to questions clearly articulate and explain whether there is a causal link between human activities, climate change, and impacts on human populations	Responses to questions do not clearly articulate and explain whether there is a causal link between human activities, climate change, and impacts on human populations
Student Self- Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:
Teacher Score	**Circle One** **Proficient** **Developing**	**Glow**: **Grow**:

Relevance to your life: Think about everything that you have learned throughout this unit so far.

1. What is one idea and/or skill you learned that you think is important to teach someone in your family or community?

2. To whom do you intend to teach this idea and/or skill? Why do you think it is important for this person to learn this idea and/or skill?