1.1 Frozen in Time: Ice Cores and Earth's Recent Climate Changes

AGE RANGE

9th—12th grade

TIME REQUIRED

100 minutes

ACTIVITY OVERVIEW

Engage: Connect-it!
Explore: Ice core graphing
Explain: Discussion
Elaborate: Carbon dioxide concentrations
Evaluate: Discussion

MATERIALS

"Vostok, Antarctica, Ice Core Data" worksheet for each student
"Carbon Dioxide Concentration and Temperature Rate of Change" for each student
Graph paper
Colored pencils
Connect-It Cards

BASED ON:

"Getting to the Core" EPA

LESSON TOPIC: Climate change

ACTIVITY SUMMARY: Students will graph data from Antarctic ice core samples.

OBJECTIVES:

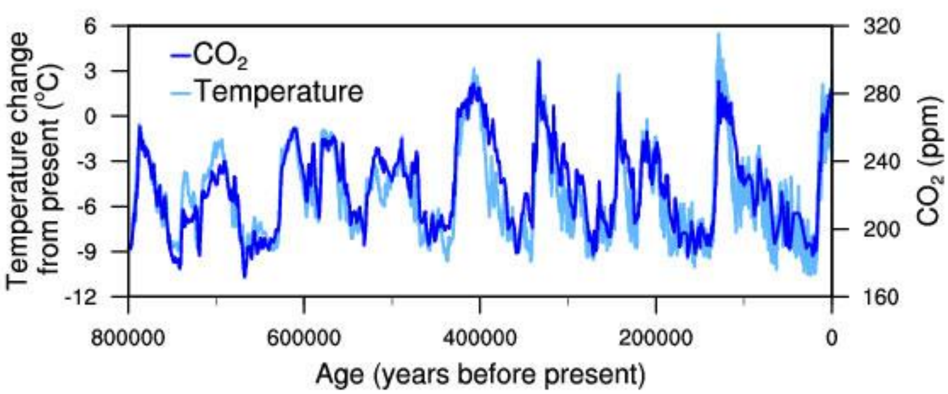
Students will be able to explain that:

- Ice core data shows Earth's record for hundreds of thousands of years.
- As carbon dioxide increases, so does temperature.
- Past patterns can help understand future scenarios.
- Changes and rates of change to systems can be quantified over short or long time periods.

LESSON BACKGROUND: Since the start of the Industrial Revolution around 1750, people have burned large amounts of coal, oil, and natural gas to power their homes, factories, and vehicles. Today, most of the world relies on these fossil fuels for their energy needs. Burning fossil fuels releases excess carbon dioxide (CO_2); this builds up in the atmosphere like a blanket and traps heat, warming the Earth. We rely on our atmosphere to trap heat to maintain the temperature on Earth, but our rate of burning fossil fuels is adding too much CO_2, termed a greenhouse gas, and warming the Earth too much.

The Earth's climate has changed many times before. There have been times when most of the planet was covered in ice, and there have also been much warmer periods than we are experiencing today. Over at least the last 650,000 years, CO_2 levels in the atmosphere have increased and decreased in a cyclical pattern. The Earth's temperature has also experienced a similar cyclical pattern characterized by glacial and interglacial periods. During glacial periods (more commonly called ice ages), the Earth has experienced a widespread expansion of ice sheets on land. Intervals between ice ages, called interglacial periods, are marked by higher temperatures. The Earth has been in an interglacial period for more than 11,000 years. Historically, temperature and CO_2 have followed similar patterns and for hundreds of thousands of years, the concentration of CO_2 in the atmosphere cycled between 200 and 300 parts per million (ppm). Today, it's up to nearly 400 ppm, and the amount is still rising.

Before temperatures were recorded with modern instruments, the Earth itself recorded clues about temperature, precipitation, atmospheric gases, and other aspects of the environment in the thick layers of ice that have accumulated in places like Greenland and Antarctica. To reveal these clues to the past, researchers drill into glaciers and ice sheets and remove cylinder-shaped samples of ice called ice cores. Back in the laboratory, scientists can use chemical sampling techniques to determine the age of each layer of ice and the concentrations of different gases trapped in tiny air bubbles within the ice, revealing the composition of the atmosphere in the past. They can also examine the water molecules in the ice to get information about historical temperatures. Trapped pollen and dust provide additional clues about the climate. Ice core records can go back hundreds of thousands of years, and they help scientists find out whether the rapid increase in CO_2 levels and temperature we are currently observing fits a natural pattern or not. The first and deepest ice core drilling occurred at Vostok, a research station located in Antarctica. From the Vostok ice core samples and other ice core drillings, researchers can determine temperature and the amount of trace gases in Earth's atmosphere dating back over 400,000 years ago. Investigating the Earth's air temperature and the amount of CO_2 in the atmosphere over a long time period helps us to better understand the Earth's carbon cycle, its relationship to the greenhouse effect, and its role in regulating the Earth's climate.



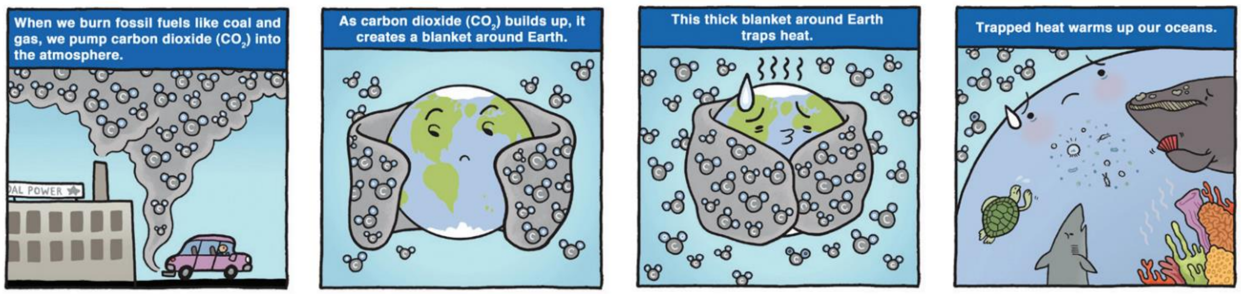
Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).

VOCABULARY:

Carbon Emissions	Release of carbon (i.e., carbon dioxide) gas into the atmosphere through direct (e.g., driving cars, shipping industry, airplanes, etc.) or indirect (e.g., food, textiles, etc.) means.
Carbon Storage	Capture and storage of carbon dioxide before release to the atmosphere (also known as 'carbon sequestration') through natural and/or anthropogenic (i.e., human) processes. Carbon storage can mitigate climate change.
Changes in Air Quality	Increases and decreases in pollutants (e.g., particulate matter, sulfates, volatile organic compounds, etc.) and/or changes in the health and safety of the atmosphere. These can be caused by a changing climate (i.e., increasing temperatures result in lower air quality).
Climate	Weather conditions prevailing in general or over a long period.
Climate Change	Long-term change in the average weather patterns that have come to define Earth's local, regional, and global climates.
Climate Scenarios	Projected characteristics of potential future climate(s) (e.g., hotter, wetter).
Emissions Scenarios	Modeled future changes in releases of greenhouse gases into the atmosphere.
Fossil Fuels	A fuel (e.g. coal, oil, or natural gas) formed in the earth from plant or animal remains.
Temperature Anomaly	A difference in temperature, compared with a particular baseline or reference point.
Weather	Day-to-day changes in atmospheric conditions.

ENGAGE:

Demonstrate how the greenhouse effect works by having students explore the Connect-it! Cards: https://climateinterpreter.org/resource/climate-training-activities-connect-it. Discuss the greenhouse effect and the link between temperature and CO_2.



EXPLORE:

1. A student reading *Introduction to Climate and Climate Change* is provided for students to read before the lesson, during the lesson, or after the lesson.
2. Let students see first-hand how scientists are working in the field to collect ice cores. (See https://tinyurl.com/r4erwjj.)
3. **Ask students:** Why are scientists examining ice cores? What information does it provide?
4. Hand out copies of the "Vostok, Antarctica, Ice Core Data" worksheets, two sheets of graph paper per student, and colored pencils. **Discuss what is meant by a temperature anomaly**. [Answer: Temperature anomaly means a departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value. For this data set, the reference value is -56 °C.]
5. Students complete the Vostok, Antarctica, Ice Core Data worksheet following the below instructions:
   a. In the space provided in column three, round the carbon dioxide (CO_2) concentration to the nearest whole number. If your students are adept at rounding, you can direct them to skip this step and proceed to graphing.
   b. In the space provided in column five, round the temperature anomaly to the nearest tenth of a degree.
6. Students graph the results following the below instructions:
   a. You will create two graphs: one for CO_2 concentration and one for temperature anomaly.
   b. On both graphs, your x-axis will represent years. Start with 400,000 BC on the left and number as far as the year 0 on the right, counting by intervals of 10,000 years. Label the axis.
   c. On the first graph, the y-axis on the left side of the paper will represent the CO_2concentration using units of parts per million (ppm). Begin with 100 ppm at the

lower end, and number up to 400 ppm, counting by intervals of 10 ppm. Label the axis.

d. On the second graph, the y-axis on the left side of the paper will represent the temperature anomaly in degrees Celsius (°C). Begin with -10.0 °C at the lower end and number up to 2.0 °C, counting by intervals of 0.5 °C. Label the axis.
e. Using different colored pencils, plot the points for CO_2 concentration and temperature anomaly.
f. Write a title on each graph.

EXPLAIN:

When students have finished their graphs **discuss** the following questions as a class:

- What pattern(s) do you notice on the graphs?
  - [Answer: A repeating cycle. When the carbon dioxide concentration goes up, temperature goes up. When the carbon dioxide concentration goes down, temperature goes down.]
- How many peaks (top) can you identify? How many troughs (bottom)? Count the high points as peaks and the low points as troughs.
  - [Answer: Five peaks and four troughs.]
- What is the approximate number of years in one complete cycle? (Hint: A cycle is the time between two peaks or between two troughs.)
  - *[Answer: 100,000 years.]*
- Do peaks represent glacial (cold) periods, or do troughs? How do you know?
  - *[Answer: Troughs, because the temperature is at its lowest.]*

ELABORATE:

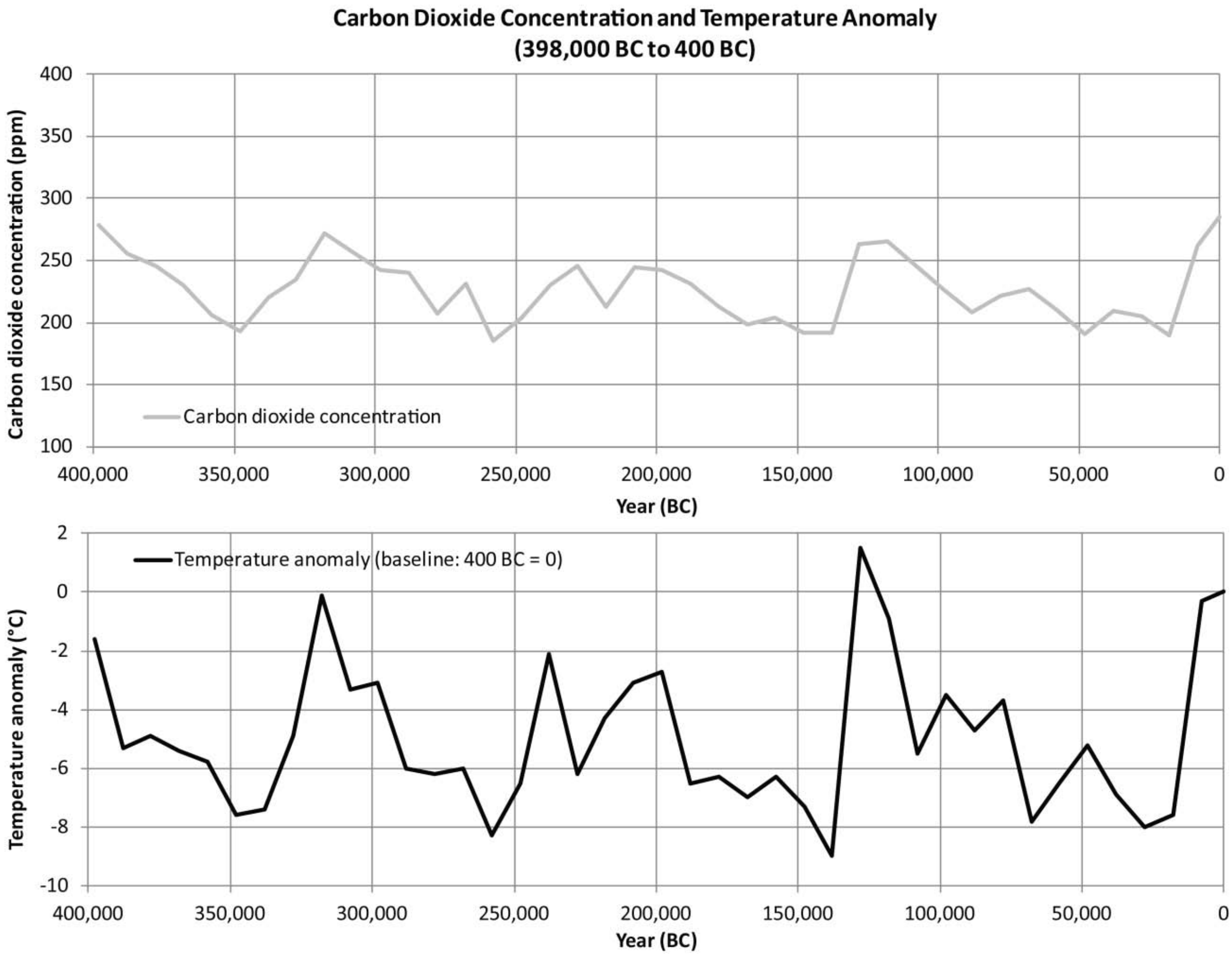
Students will further explore using the "Carbon Dioxide Concentration and Temperature Rate of Change" worksheet. Explain that temperature anomaly values in the first table (398,000 BC to 400 BC) use a different reference value from the temperature anomaly values in the second table (1901 to 2018).

Ask students if choosing a different reference value would change the shape of the trend. Why or why not? *[Answer: No, even if a new reference point is used, the shape and direction of the trend or repeating pattern would stay the same. The overall pattern would just shift up or down.]*

Direct students to use the "Vostok, Antarctica, Ice Core Data" worksheet and their graphs to fill in the blank boxes in the first table ("48,000 BC to 400 BC") on the "Carbon Dioxide Concentration and Temperature Rate of Change" worksheet. Then ask them to finish filling in the second table ("1901 to 2018"), which has been partially populated with more recent data from another source.

Answer Key:

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
398,000	278	278	-1.64	-1.6
388,000	255.2	255	-5.34	-5.3
378,000	245.9	246	-4.88	-4.9
368,000	229.7	230	-5.42	-5.4
358,000	206.4	206	-5.8	-5.8
348,000	193	193	-7.64	-7.6
338,000	220.4	220	-7.44	-7.4
328,000	234.2	234	-4.9	-4.9
318,000	271.8	272	-0.12	-0.1
308,000	256.3	256	-3.32	-3.3
298,000	241.9	242	-3.08	-3.1
288,000	240.2	240	-6	-6
278,000	207.7	208	-6.17	-6.2
268,000	231.4	231	-5.95	-6
258,000	184.7	185	-8.3	-8.3
248,000	203.9	204	-6.52	-6.5
238,000	230.4	230	-2.12	-2.1
228,000	245.2	245	-6.15	-6.2
218,000	212.2	216	-4.31	-4.3
208,000	244.6	245	-3.07	-3.1
198,000	242.6	243	-2.68	-2.7
188,000	231.4	231	-6.49	-6.5
178,000	213.2	213	-6.34	-6.3
168,000	197.9	198	-7.01	-7
158,000	204.4	204	-6.25	-6.3
148,000	191.9	192	-7.34	-7.3
138,000	192.3	192	-8.99	-9
128,000	263.4	263	1.47	1.5
118,000	265.2	265	-0.86	-0.9
108,000	245.7	246	-5.53	-5.5
98,000	225.9	226	-3.45	-3.5
88,000	208	208	-4.69	-4.7
78,000	221.8	222	-3.66	-3.7
68,000	227.4	227	-7.84	-7.8
58,000	210.4	210	-6.53	-6.5
48,000	190.4	190	-5.18	-5.2
38,000	209.1	209	-6.91	-6.9
28,000	205.4	205	-7.95	-8
18,000	189.2	189	-7.62	-7.6
8,000	261.6	262	-0.28	-0.3
400	284.7	285	0	0



Data source: National Oceanic and Atmospheric Administration (NOAA):
www.esrl.noaa.gov/gsd/outreach/education/poet/Global-Warming.pdf

CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE

Answer Key:

48,000 BC to 400 BC

Length of time: 47,600 years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)	190.4 ppm	284.7 ppm	+94.3 ppm	94.3 ppm / 47,600 years = 0.0020 ppm per year
Temperature anomaly (°C)	-5.18 °C	0 °C	+5.18 °C	0.00011 5.18 °C / 47,600 = °C per year

1901 to 2018

Length of time: 117 years

Variable	Value in 1901	Value in 2018	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	410.8 ppm	114.7 ppm	114.7 ppm / 117 years = 0.980 ppm per year
Temperature anomaly (°C)	-0.16 °C	0.83 °C	+0.99°C	0.99°C / 117 years = 0.0085°C per year

EVALUATE:

Review the graphs and table with students.

Ask students the following questions regarding the parts of the table that they filled in:

- How many years of data are shown in the “48,000 BC to 400 BC” table?
  - [Answer: About 47,600 years.]
- How many years of data are shown in the “1901 to 2018” table?
  - [Answer: 117 years.]
- Did either table, both tables, or neither table show a warming trend? Explain.
  - [Answer: Both. CO_2 concentrations increase and temperature anomaly increases. Both increase at a greater rate more recently.]
- What trend, upward or downward, are we currently experiencing?
  - [Answer: Upward for both CO_2 concentration and temperature anomaly.]
- What is the change in the temperature anomaly between 1901 and 2018?
  - [Answer: +0.99°C]
- In 1971, the globally averaged CO2 concentration was approximately 330 ppm. If the CO2 concentration in 2000 was about 384 ppm, calculate the average rate of increase per year.
  - [Answer: Approximately 1.5 ppm per year.]
- What is happening to the rate of change for CO2 concentrations and temperature anomalies over time?
  - [Answer: The rate of change increases. This is another way of saying that if you graphed the results, the slope of the line would become steeper over time.]
- Why is the temperature data presented as a temperature anomaly? What does this mean?
  - [Answer: A temperature anomaly is the difference from an average, or baseline, temperature. The baseline temperature is typically computed by averaging 30 or more years of temperature data. A positive anomaly indicates the observed temperature was warmer than the baseline, while a negative anomaly indicates the observed temperature was cooler than the baseline.]
- Why was it important to calculate the rate of change for CO_2 concentration and temperature anomaly and not just the absolute change in either parameter?
  - [Answer: The rate of change shows how fast or slow the changes are occurring, so that we can track the changes over time.]
- In your own words, define the relationship over time between CO_2 and temperature.

VOSTOK, ANTARCTICA, ICE CORE DATA

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178,000	213.2		-6.34	
168,000	197.9		-7.01	
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28,000	205.4		-7.95	
18,000	189.2		-7.62	
8,000	261.6		-0.28	
400	284.7		0	

Data source: National Oceanic and Atmospheric Administration (NOAA): https://www.esrl.noaa.gov/gsd/education/poet/Act-9_POET_GlobalWarmingFinal_Feb2016.pdf

CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE

Remember that the rate of change is equal to the change divided by length of time.

48,000 BC to 400 BC

Length of time: ______ years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)				
Temperature anomaly (°C)				

1901 to 2018

Length of time: ______ years

Variable	Value in 1901	Value in 2018	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	410.8 ppm		
Temperature anomaly (°C)	-0.16 °C	0.83 °C		

Data source: U.S. EPA, Climate Change Indicators in the United States:
https://www.epa.gov/climate-indicators
CO_2 concentrations are from Antarctica (1901) and Hawaii (2019).

STUDENT PAGE | Reading - Introduction to Climate and Climate Change

Weather and climate are distinct. Weather refers to short-term variability of environmental parameters while climate refers to long-term stability of these patterns. Weather is the local and temporary conditions happening at a particular time and place. When describing a region's climate, you are describing conditions over the long term and over an entire region.

Climate is a system of multiple components that include the interactions between the atmosphere, the ocean, and land. These function as an integrated system. Because they are interdependent, changes in one component of the climate system lead to changes throughout the system. The ocean plays a critical role in regulating the climate system.

Climate change refers to changes that exceed the expected levels of variability over decades or more and occur on a global scale. The change in climate is observable and measurable. Climate change is both a natural and a human-caused phenomenon. There are naturally occurring changes in global temperature, however human activities are causing changes that are not attributed to natural variability, also referred to as "anthropogenic climate change".

The primary cause of human-caused, or anthropogenic, climate change is the release of greenhouse gases like carbon dioxide through the burning of fossil fuels. Carbon normally cycles between the land, the oceans, and the atmosphere — but the increased burning of fossil fuels has disrupted this balance by moving enormous amounts of carbon into the atmosphere much faster than the normal cycle. Excess carbon dioxide in the atmosphere acts like a blanket, trapping heat near the planet that would normally be released into space. For over a century, researchers have been studying global processes, the Earth's climate, and the effects of natural processes being altered. They have concluded that carbon emissions from increased fossil fuel use are causing Earth's climate to change.

Carbon dioxide emissions are changing the oceans. Experts noted that carbon dioxide emissions are impacting both the temperature and the acidity of the Earth's oceans. Oceans absorb heat from the atmosphere; as the temperature of the atmosphere warms because of the increased concentration of carbon dioxide, so too does the ocean warm. Due to the critical role the ocean plays in regulating the climate system, changes in the ocean affect the entire planet.

The impacts of climate change are widespread, resulting in a cascade of changes related to increasing atmospheric temperatures. These include sea-level rise and coastal flooding, more extreme weather events, severe drought, species loss, and amplifications of existing weather patterns. These changes will vary by location and while they are long-term, the specifics will be difficult to predict.

Reducing global carbon emissions is key to addressing climate change. Practical short-term ways to mitigate some of the effects of climate change include slowing the rate of carbon dioxide emissions and reducing other human activities that alter the environment. For example, marine systems might be better able to adapt to warming temperatures if pollution and over-fishing were not also stressing these systems. Effective solutions require more than just individual behavior changes. Policy change where governments implement policies that both reduce future carbon dioxide emissions and address the existing impacts of climate change by making investments in new technologies and infrastructure are needed.

Adapted from Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). "Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. Washington, DC: FrameWorks Institute.

DO NOW:

How do we measure historic Earth conditions?

EXIT TICKET:

What is “The Heat Trapping Blanket” metaphor?