# MODULE 1: SEA-LEVEL RISE AND FLOODING BASICS

MODULE & LESSON TIMING: There are four lessons in Module 1. Each lesson should be able to be completed in one or two class periods, with student readings before or during.

WHAT TO EXPECT: Module 1 introduces the causes and impacts of sea-level rise and flooding.

1.1 Frozen in Time: Ice Cores and Earth's Recent Climate Changes – climate change (page #4)

1.2 Rising Waters: The Ocean Is Getting Too Big for Its Beaches – causes of sea-level rise (page #18)

1.3 High Tide Flooding: Rainboots Required Even on Sunny Days? – types of flooding (page #30)

1.4 Climate Change Anomalies and Suffering Economies – economics and interpreting sea-level rise modeling (page #45)

## TEACHER BACKGROUND RESOURCES:

*Videos*

- Introductory video about sea-level rise in the northern Gulf of Mexico
  - "The Basics: Northern Gulf Sea-Level Rise" https://vimeo.com/322867969
- Introductory video about sea-level rise and storm surge in the northern Gulf of Mexico
  - "Amplified Storm Surge: Northern Gulf Sea-Level Rise" https://vimeo.com/323815181
- Introductory video about global and local sea-level rise by NOAA
  - NOAA Ocean Today, "Global vs Local Sea Level" https://oceantoday.noaa.gov/globalvslocalsealevel/welcome.html
- Case study videos about responding to sea-level rise exacerbated hazards sea-level rise in the northern Gulf of Mexico
  - "Responding to Hazards in Mississippi" https://vimeo.com/322242202
  - "Responding to Hazards in Alabama" https://vimeo.com/322242513

*Educational Resources*

- Lesson about sea-level rise by NOAA National Ocean Service
  - "Is sea level rising?" https://oceanservice.noaa.gov/facts/sealevel.html
- Additional digital activity by NOAA with real-time NOAA data for students to explore sea-

level rise
    - Data in the Classroom: https://dataintheclassroom.noaa.gov/content/sea-level
- Additional sea-level rise educational activities from NOAA National Ocean Service
    - "Sea Level Rise" https://oceanservice.noaa.gov/education/sea-level-rise/welcome.html
- Article with five steps for teaching climate change
    - "How to teach climate change in a non-scary way" https://www.tes.com/news/how-teach-climate-change-non-scary-way
- Online module with introduction to climate change
    - "ClimatEdu" Climate education made by students, for students: https://climatedu.org/

*Readings*

- Additional resources for talking about climate change
    - Frameworks Institute, "How to Talk about Climate Change and the Ocean": http://www.frameworksinstitute.org/assets/files/PDF_oceansclimate/climatechangeandtheocean_mm_final_2015.pdf
- Informational NOAA webpage about sea-level rise with graphs and images
    - NOAA Climate, "Climate Change: Global Sea Level": https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level
- Infographic about sea-level rise by NASA
    - https://climate.nasa.gov/climate_resources/125/infographic-sea-level-rise/
- StoryMap about the financial impact on city and state locals from the "Ellicott City Flash Flood"
    - https://www.arcgis.com/apps/Cascade/index.html?appid=0496f01f99604990b10519b5b144040f & https://apps.npr.org/ellicott-city
- Article from NASA, "NASA-led Study Reveals the Causes of Sea Level Rise Since 1900"
    - https://climate.nasa.gov/news/3012/nasa-led-study-reveals-the-causes-of-sea-level-rise-since-1900/
- Article on connection of sea-level rise and stormwater management, "In Norfolk, sea level rise reduces some stormwater system capacity by 50%, data shows"
    - https://www.pilotonline.com/news/environment/vp-nw-fz20-sensor-stormwater-flooding-norfolk-20210103-t4jofv7hbff3dgcposbf7z7p5m-story.html?fbclid=IwAR29Mph9-3Myduj1oXMIPmJeWs035z0K_9Vb9LZDlu3TSoStrO0ac6tnx-Y
- Article on the differences of sea-level rise impacts on marginalized communities, "Mexico explains decision to flood poor, Indigenous areas"
    - https://apnews.com/article/floods-mexico-898bd6f13f6a5c2e1a4dc2b0217def62

## RECOMMENDED CURRICULUM CITATION:

Vedral, Sonia, Collini, Renee C., Miller-Way, Tina, Rellinger, Alison N., Sempier, Tracie T., Smallegan, Stephanie M., Sparks, Eric. (2021). Sea-Level Rise in the Classroom. MASGP-21-056

Curriculum developed by Northern Gulf of Mexico Sentinel Site Cooperative in collaboration with Alabama School of Mathematics and Science, Dauphin Island Sea Lab, Mississippi-Alabama Sea Grant Consortium, Mississippi State University, Smart Home America, and University of South Alabama.

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## 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:

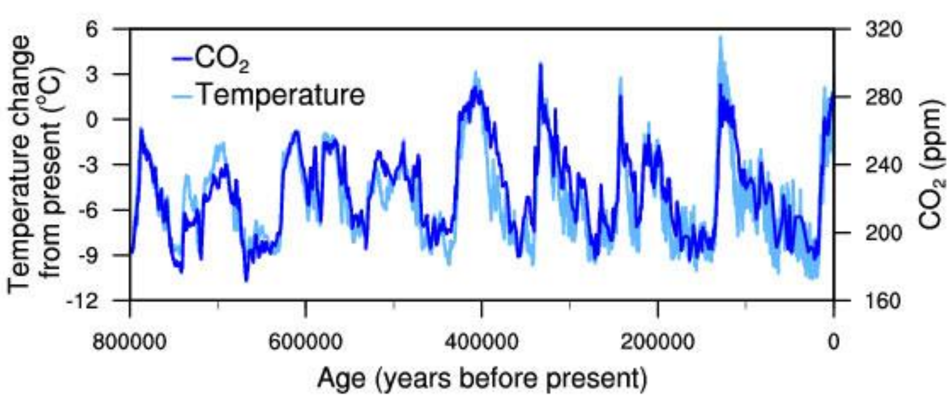
Students will be able to explain that:

- 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.



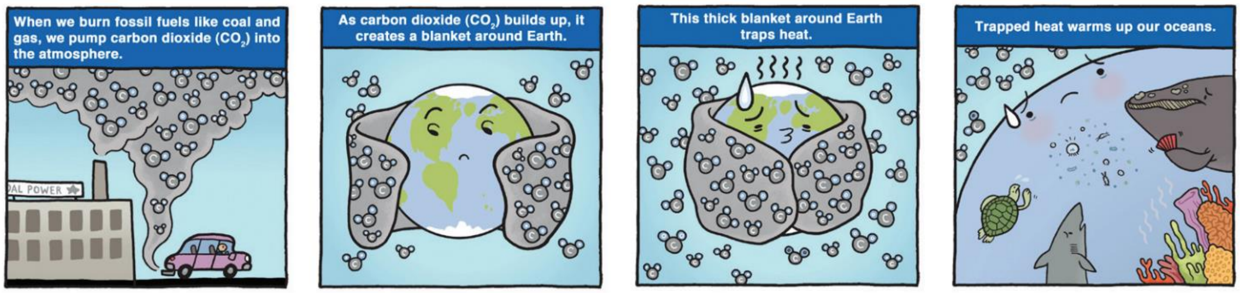

Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).

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 $CO_2$concentration 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:

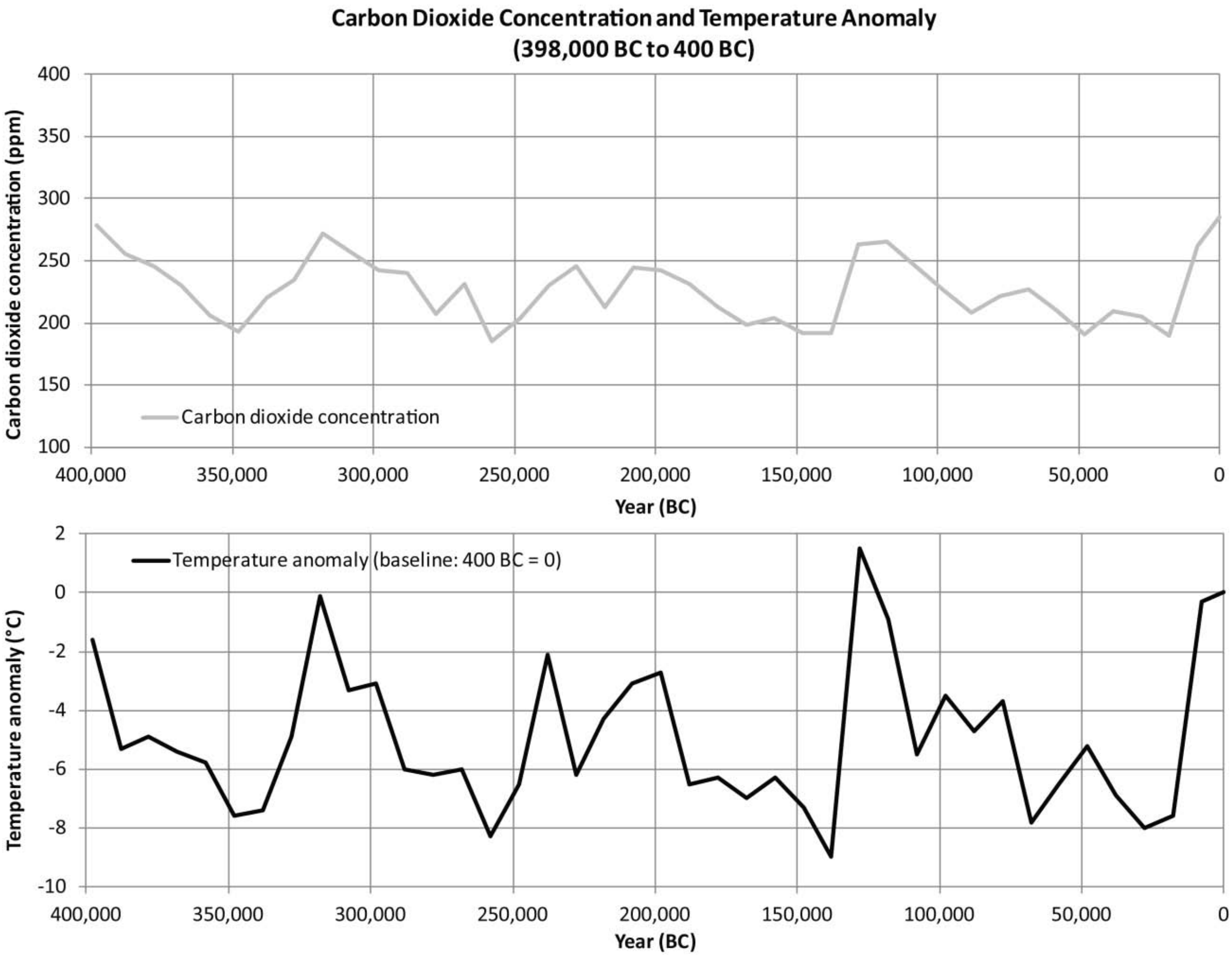
Students will further explore using the “Carbon Dioxide Concentration and Temperature Rate of Change” worksheet. Explain that temperature anomaly values in the first table (398,000 BC to 400 BC) use a different reference value from the temperature anomaly values in the second table (1901 to 2018).

**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

| 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 | | -1.64 | |
| 388,000 | 255.2 | | -5.34 | |
| 378,000 | 245.9 | | -4.88 | |
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| 308,000 | 256.3 | | -3.32 | |
| 298,000 | 241.9 | | -3.08 | |
| 288,000 | 240.2 | | -6 | |
| 278,000 | 207.7 | | -6.17 | |
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| 208,000 | 244.6 | | -3.07 | |
| 198,000 | 242.6 | | -2.68 | |
| 188,000 | 231.4 | | -6.49 | |
| 178,000 | 213.2 | | -6.34 | |
| 168,000 | 197.9 | | -7.01 | |
| 158,000 | 204.4 | | -6.25 | |
| 148,000 | 191.9 | | -7.34 | |
| 138,000 | 192.3 | | -8.99 | |
| 128,000 | 263.4 | | 1.47 | |
| 118,000 | 265.2 | | -0.86 | |
| 108,000 | 245.7 | | -5.53 | |
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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).

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.*

# STUDENT PAGE | Frozen in Time

## DO NOW:

How do we measure historic Earth conditions?

## EXIT TICKET:

What is “The Heat Trapping Blanket” metaphor?

## 1.2 Rising Waters: The Ocean Is Getting Too Big for Its Beaches

### AGE RANGE

9th—12th grade

### TIME REQUIRED

90 minutes

### ACTIVITY OVERVIEW

Engage: NASA SLR graph
Explore: Land & sea ice melt
Explain: Discussion
Elaborate: Thermal expansion
Evaluate: Discussion and graphs

### MATERIALS

Probe thermometer
Heat lamp
Water
Food Coloring
Marker
Plastic bottle
Clear plastic straw
Scissors
Modeling clay
Two clear, plastic food-storage containers, approx. 6in by 6in
Clay (enough to fill about a quarter of each tub with 1-2 inches of clay)
Ice cubes
Ruler

### BASED ON:

Lesson based on "What's Causing Sea-Level Rise? Land Ice Vs. Sea Ice" JPL, "Thermal Expansion Model" JPL, and "Thermal Expansion and Sea Level Rise" Centers for Ocean Science Education Excellence.

### LESSON TOPIC: Thermal expansion and ice melt

### ACTIVITY SUMMARY: Students will explore the two main causes of sea-level rise by recreating ocean water processes through a classroom lab.

### OBJECTIVES:

Students will be able to explain that:

- Thermal expansion is the increase in volume of water as a result of increased water temperature.
- Melting land ice contributes to sea-level rise. Not melting sea ice.
- Global sea-level rise is due to warming atmospheric temperatures leading to
    - thermal expansion of ocean water, and
    - addition of water volume from melting land ice.
- Changes in sea-level affect living organisms including humans.

LESSON BACKGROUND: Global sea level has increased by 24 cm since 1880, with 8 cm of that rise occurring since 1993. The rate of sea-level rise since 1900 has been faster than during any other time period in the last 2800 years. The rate of sea-level rise is being driven by global climate change. Sea-level rise impacts coastal areas by increasing the vulnerability of communities to severe storms, erosion of land, inundation of low elevation, salt-water intrusion into aquifers, and increased flooding. Coasts are especially densely populated with about 40% of the world's population living within 100 km of a shoreline. A rise in sea-level of 0.9 meters would permanently inundate areas that 2 million Americans call home.

There are two main factors that drive sea-level rise are a result of a warming atmosphere and ocean. The first factor is thermal expansion of water. As water warms, the molecules vibrate more and take up more space, causing the overall volume of water to expand. The ocean absorbs heat from the atmosphere, and as the ocean warms the water level rises due to thermal expansion. The second factor is melting land ice. Warming atmosphere temperatures melt ice that is stored on land in glaciers and ice sheets and it flows into the ocean, further increasing the volume of water and causing the water level to rise.

Sea level is measured by monitoring stations on the shoreline and at sea. There are over 120 sea level monitoring stations in the U.S. and 240 additional stations worldwide. Sea level has been measured at some stations for more than a century, providing sea level data going back to 1880. In addition to the individual monitoring stations, satellites such as NASA's JASON-3 satellite collect data on sea level. By looking at data from these stations and satellites over periods of 25 years or more, trends can be identified at specific locations along the coast and compared with global trends. This gives scientists useful information about local conditions. Those data can also be used to calculate the global average sea level and study it over time, giving scientists a picture of what's happening to the ocean on a planetary scale.

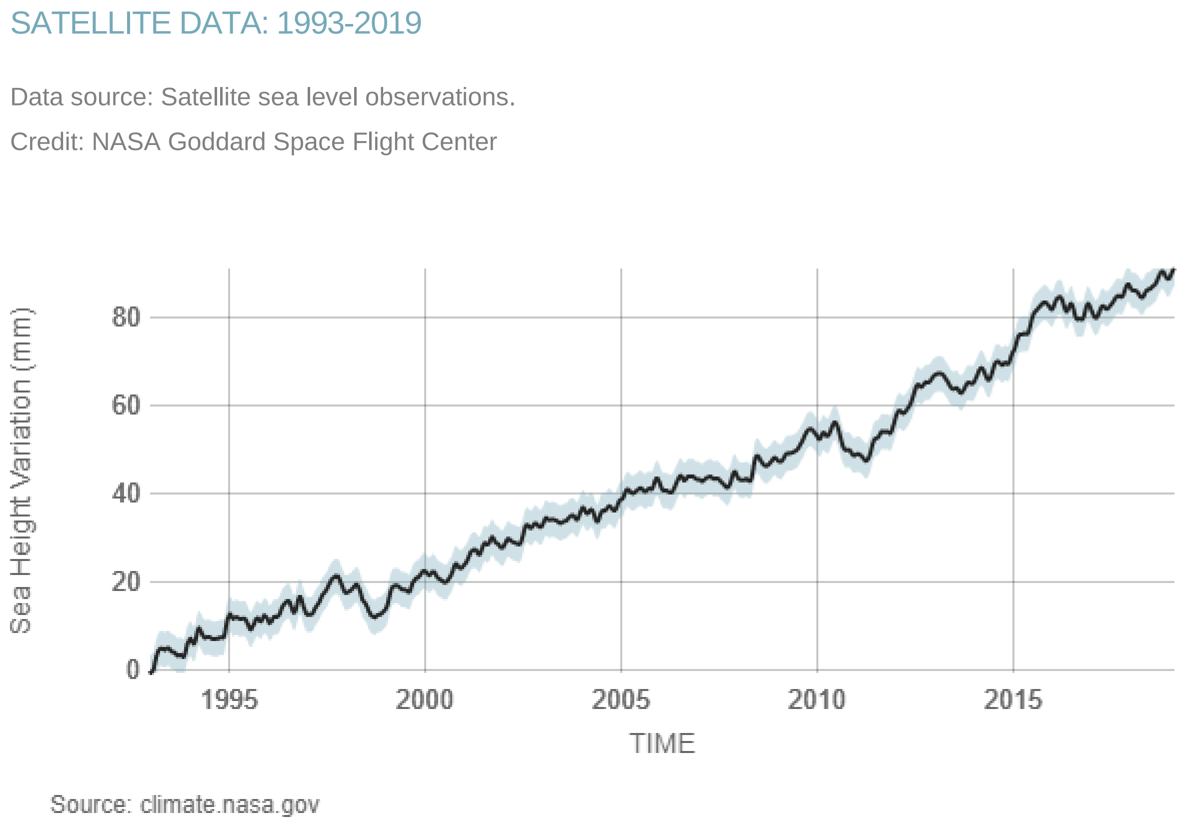
*Sea-level projections and scenarios from: Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.*

## VOCABULARY:

| | |
|---|---|
| Changes in Temperature | Fluctuations (increases or decreases) in temperature. Climate projections show increasing temperatures across the Gulf of Mexico as well as on average globally. |
| Land Ice | Land ice in the form of glaciers and ice sheets contains the majority of the world's fresh water and covers about 10 percent of the world's land area. |
| Sea Ice | Frozen ocean water (e.g., icebergs). |
| Sea Level | Base level for measuring elevation and water depth on Earth. Because the ocean is one continuous body of water, its surface tends to seek the same level throughout the world. However, winds, ocean currents, river discharges, and variations in gravity and temperature prevent "sea level" from being truly level. |
| Sea-Level Rise | Increase in sea level caused in part by melting land-based ice and expanding water. Exacerbates existing coastal hazards such as flooding, erosion, inundation, and extreme events. Often abbreviated to SLR. |
| Thermal Expansion | Increase in linear dimensions of a solid or in volume of a fluid because of a rise in temperature. |
| Global Sea-Level Rise | Average increase in sea level caused primarily by land-ice melt and water expansion across the entire world. |
| Relative Sea-Level Rise | Rate of sea-level rise at any given point on the coast. Affected by local processes that can reduce or exacerbate global sea-level rise (e.g., subsidence [ground sinking], tectonic plate movement, etc.). |

## ENGAGE:

Show graph of global sea level from NASA: https://climate.nasa.gov/vital-signs/sea-level/




**Ask students**: What is the trend of the data? What would cause sea level to rise? What impact does an increase in temperature have on sea level? What human action contributes to sea-level rise?

## EXPLORE:

**Activity Overview**: In this activity students will compare the added volume of ocean water from melting ice that is on land and melting ice that is in the sea. It can be set up in the classroom using a purchased land model or created using clay. Two trays will be set up with "land" and water. In one tray, ice cubes will be placed in the water and in the other tray the ice cubes will be placed on land. Students record and measure the water level of the tray as the ice melts. The water level will only increase in the tray with the ice on land.

**Discuss** climate change and sea-level rise with students.
**Ask students** to identify causes of sea-level rise.
**Ask students**: What impacts does temperature increase have on water? Target answer: Melting of ice.
**Ask students**: Where is ice located on Earth? A: Ice sheets on Greenland and Antarctica and glaciers are land ice. Frozen seawater ice and icebergs are sea ice.
**Direct students** to record their hypothesis for which ice will contribute more to sea-level rise.

<u>Materials</u>
Two clear, plastic food-storage containers, approx. 6 inches by 6 inches
Clay (enough to fill about a quarter of each tub with 1-2 inches of clay)
Tray of ice cubes
Ruler
Water
Permanent marker or tape

<u>Procedure</u>

1. Press clay into one side of the plastic tub, making a ledge. Repeat exactly on other container.
    a. Consider adding push pins along the edge of the clay to represent cities or landmarks.
2. In one container place as many ice cubes as can fit on the clay ledge to represent land ice.
3. In the other container place the same number of ice cubes on the bottom of the container not on the clay to represent sea ice.
4. Pour water in the sea-ice container until the ice floats. The clay ledge should remain out of the water.
5. Pour an equal amount of water into the land-ice container without touching the ice cubes.
6. Use the rule to measure the water level in millimeters in each tub. Mark the water level on the outside of the containers with the marker or tape.
7. At regular intervals measure the water and record the water level. Allow the ice in both containers to melt completely. Using a heat lamp will speed this up.
8. Allow the ice to melt while you move onto the other activity.

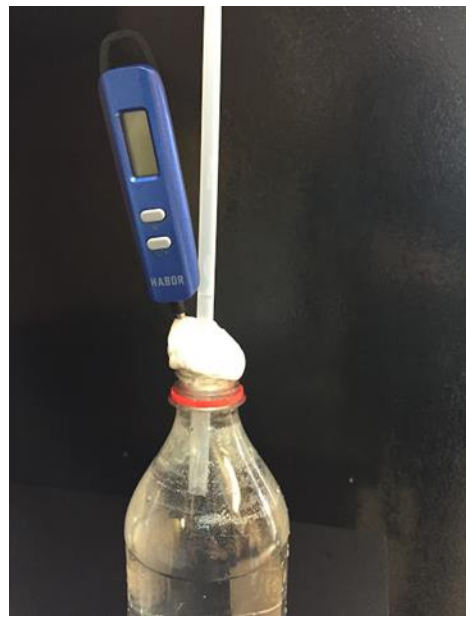
**EXTENSION:** Follow the same procedure as above but in step 1 switch out the clay for another material, like sand. This will allow for a conversation about different types of land and how the ice will still add to volume of water.

## EXPLAIN:

Again, **discuss** climate change and sea-level rise with students. If students did not mention thermal expansion before, explain that in addition to ice melt, there is another phenomenon that contributes to sea-level rise. The following activity will demonstrate that phenomenon.

## ELABORATE:

**Activity Overview**: In this activity students will observe thermal expansion of water. This activity can be set up in a classroom using either science lab equipment (flask and clear glass tube) or using everyday items (water bottle and straw). As the water is heated under a lamp the level in the straw rises, demonstrating thermal expansion.



Materials
Probe thermometer
Heat lamp
Water
Food Coloring
Marker
Plastic bottle
Clear plastic straw
Scissors
Modeling clay

Procedure

1. Completely fill the plastic bottle with water and food coloring to improve visibility.
2. Surround the thermometer and straw with modeling clay a few inches from the bottom of the straw. Do not block the straw with clay.
3. Place the clay into the bottle and press to seal to edges. The water should rise up the straw.
4. Mark the water level using the marker on the straw. Record the temperature of the water.
5. Place a heat lamp approximately 5 inches away from the bottle. Direct the light towards the middle of the water, not at the top.
6. Have students make hypothesis for how the water level will change when the lamp is turned on.
7. Turn on the lamp. Record the temperature and mark the water level after 5-10 minutes.

**Ask students**: What happened to the water level? What was the impact of the lamp?
A: The water level rose. The lamp added heat energy and increased the temperature of the water.
**Ask students**: Why did the water level rise as the temperature increased?
A: The lamp adding heat energy to the water resulted in the water molecules moving around more and taking up more space. Each molecule taking up more space increased the volume of water in the bottle and the only place to move was up the tube/straw. This is thermal expansion.

## EVALUATE:

**Record** the measurements from the ice-melt activity to create a line graph representing water level in each tub.
**Ask students**: Under which ice conditions did the water level rise more? A: The container with the land-ice.
**Ask students**: Why did this happen? A: The sea-ice was already adding its volume to the water, but the land-ice was adding new water so it increased the total volume as more melted.
**Ask students**: What does this mean on a global scale? A: Ice melting from land-ice increases global sea-level.

## MELTING LAND AND SEA ICE

**Which type of ice (land or sea) will contribute more to sea-level rise?**

**Hypothesis:**

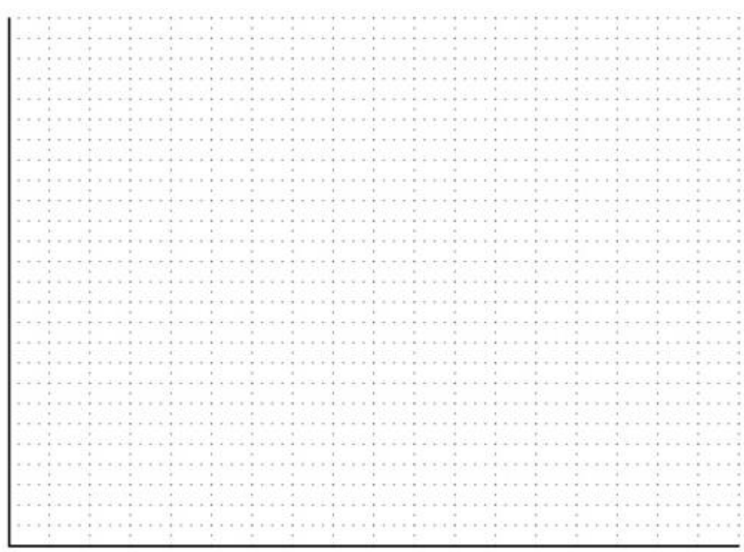
**Record the water level in millimeters at the indicated time increments in the chart below:**

| Time | Land Ice Water Level (mm) | Sea Ice Water Level (mm) |
|---|---|---|
| 0 min | | |
| 10 min | | |
| 20 min | | |
| 30 min | | |
| | | |

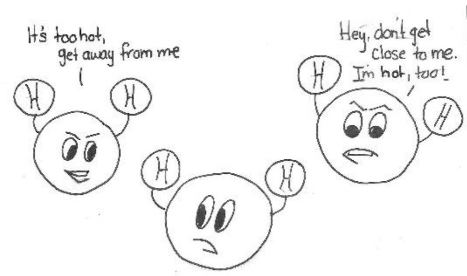
**Describe the results from the melting ice lab:**

**Explain whether or not your hypothesis was supported by the data:**

**Graph:** Create a line graph with time in minutes on the x-axis, water level in millimeters on the y-axis, and the land and sea ice containers represented by different lines.



# THERMAL EXPANSION OF WATER




Credit: Kate Tagai, Island Institute

**What impact will the heat lamp have on the water in the bottle?**

**Hypothesis:**

**Record the water temperature at the indicated time increments in the chart below:**

| Time | 0 min | 5 min | 10 min | 15 min |
|---|---|---|---|---|
| Water Temperature (°C) | | | | |

**Describe the results from the thermal expansion lab:**

**Explain whether or not your hypothesis was supported by the data:**

## STUDENT PAGE | Reading - Sea Level and Sea Level Change

Global sea level is an average level of the surface of the global ocean. Sea level varies from place to place due to shifting surface winds, the expansion of warming ocean water, and the addition of melting land ice. The sea level measurement of specific locations is called local or relative sea level. A local change can be caused by an increase in sea surface height, or by a decrease in land height. Over relatively short time spans (hours to years), the influence of tides, storms, and decadal oscillations (e.g., El Niño and La Niña) dominates sea level variations. Over longer time spans (decades to centuries), the influence of climate change is the main contributor to sea level change in most regions.

Sea level is measured using tide gauges and satellites. Tide gauges measure relative sea level, so they include changes resulting from vertical motion of both the land and the sea surface. Before computers were used to record water levels, special "tide houses" sheltered permanent tide gauges. The instrumentation—including a well and a mechanical pen-and-ink recorder—was housed inside and a tide staff was attached outside. Essentially a giant measuring stick, the tide staff allowed scientists to manually observe tidal levels and then compare them to readings taken every six minutes by the recorder. The computer age led to tide gauges that used microprocessor-based technologies to collect sea-level data. Today's recorders are more sophisticated. Some send an audio signal down a narrow "sounding tube" and measure the time it takes for the reflected signal to travel back from the water's surface. Others are on the sea floor and measure the pressure and density of the water to account for the depth of the water. Since the late 20th century, satellite measurements of the height of the ocean surface relative to the center of the Earth (known as geocentric sea level) show differing rates of geocentric sea level change around the world.

Over many coastal regions, vertical land motion is small. However, in some regions, vertical land motion has had an important influence. For example, the steady fall in sea level recorded in Stockholm is caused by uplift of this region after the melting of a large (>1 km thick) continental ice sheet at the end of the last Ice Age, between ~20,000 and ~9000 years ago. Land subsidence, the gradual settling or sinking of land, is common in many coastal regions, particularly in large river deltas like Louisiana. Subsidence can occur because of natural processes, such as the compaction of soil, or due to human processes, such as the extraction of groundwater or oil/natural gas from underground.

Melting ice from glaciers or the Greenland and Antarctic ice sheets lead to sea level rise, but it is not uniform throughout the world. Melting results in regional differences in sea level due to processes like changes in ocean currents, winds, the Earth's gravity field, and land height. Large ice sheets are so massive that they have gravitational pull on the surrounding water. When the ice sheets melt, the gravitational attraction between the ice sheets and ocean water is reduced. As the ocean water relaxes away from the ice sheets, it moves to new areas in the ocean and causes sea level to rise in greater amounts compared to the global average value.

In summary, a variety of processes drive height changes of the ocean surface and land elevation, resulting in different patterns of sea level change at local to regional scales. The combination of these processes produces a complex pattern of total sea level change, which varies through time as the relative contribution of each process changes. The global average of sea level change reflects climatic processes and represents a good estimate of sea level change across many coastal locations, but the rate and amount of sea-level rise will differ among regions.

*Adapted from: Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

*NOAA. What is a tide gauge? National Ocean Service website, https://oceanservice.noaa.gov/facts/tide-gauge.html, 06/25/18.*

## STUDENT PAGE | Rising Waters

DO NOW:

What is one impact of increased carbon dioxide in the atmosphere?

EXIT TICKET:

Why does melting sea ice not contribute to sea-level rise?

## 1.3 High Tide Flooding: Rainboots Required Even on Sunny Days?

### AGE RANGE

9th—12th grade

### TIME REQUIRED

70 minutes

### ACTIVITY OVERVIEW

Engage: NPR podcast
Explore: Days of future flooding
Explain: Discussion
Elaborate: Coastal dynamics
Evaluate: Writing assignment

### MATERIALS

Days of future flooding graphs

Computers

LESSON TOPIC: Types of flooding

ACTIVITY SUMMARY: Students explore high tide flooding projections in their local regions.

### OBJECTIVES:

Students will be able to explain that:

- High tide flooding and other hazards will be exacerbated by sea-level rise.
- Flooding will not be the same in every city.
- Natural hazards will continue to have an effect on human society.

LESSON BACKGROUND: Flooding occurs when water overflows onto land that is usually dry. Communities living along the coast are experiencing flooding events that are caused not just by hurricanes and heavy rain, but by rising sea levels. With increasing sea level, coastal flooding is occurring more often during high tides. High tide flooding can lead to road closures, waterlogged infrastructure, overwhelmed storm drains, and other public inconveniences. High tide flooding is the term used to describe flooding related to minor tidal flooding. This may be from water flooding low elevation coastal roads, overtopping a sea wall, or coming into neighborhoods through storm drains.

Annual occurrences of high tide flooding are increasing throughout communities living along the Gulf of Mexico. Along coastal Louisiana to Texas from 2000 to 2015, the annual frequency of high tide flooding increased from 1.4 days per year to 2.5 days per year. Flood frequency follows a seasonality pattern in part due to astronomical tides and changes in wind and ocean currents. Along the Gulf coast, high tide flooding occurs more often during September–November and again in June–July. With projections of future sea-level rise, it is expected that Gulf coast communities will experience many more high tide flooding events. Under the Intermediate Low projection of 0.5 m global sea-level rise by 2100, the Gulf Coast from Florida to Mississippi is projected to experience 25 days per year of high tide flooding. Under the Intermediate projection of 1 m of global sea-level rise there are 80 days per year projected of high tide flooding.

Storm surge is the rise of water caused by a tropical cyclone (e.g., hurricane or tropical storm), above the tide range. Storm surge happens when water is pushed toward the shore from strong storm winds. Storm surge can cause extreme flooding in coastal areas, bringing water farther inland due to storm winds. The width and slope of the continental shelf impacts storm surge. Here in the northern Gulf, the shallow continental shelf produces greater storm surge, that goes farther inland with potentially extreme water depths. For example, Hurricane Katrina caused severe flooding in three states and pushed over 20ft of water on land. As seas rise, storm surge will go farther inland and generate even deeper flood waters.

## VOCABULARY:

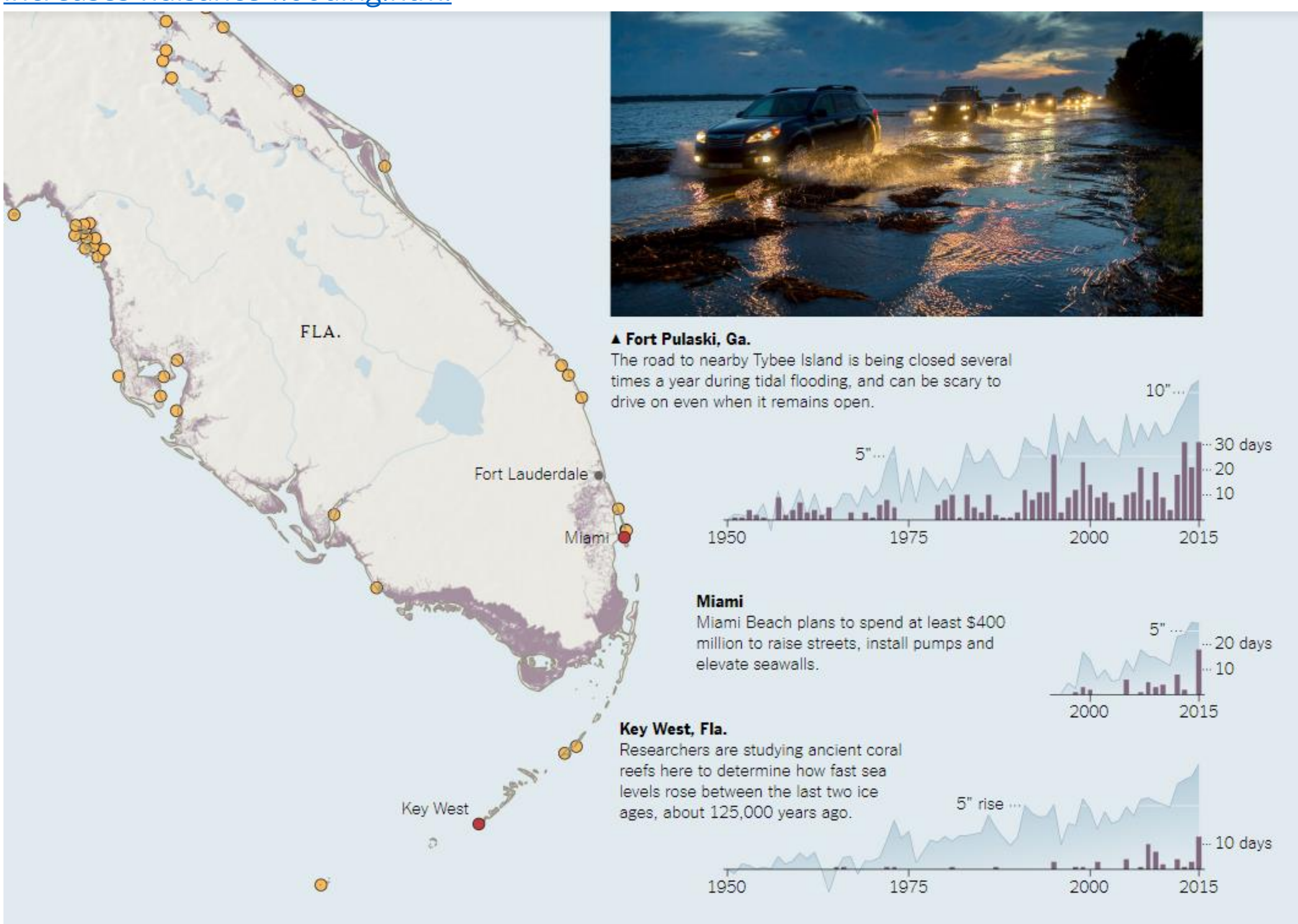
| | |
|---|---|
| Changes in Precipitation | Fluctuations (increases or decreases) in amount of precipitation. Changes due to climate change vary widely across the Gulf as well as regionally. |
| Extreme Weather Events | Weather event that is notably different from the typical weather pattern (e.g., severe, unexpected, etc.). Examples include heat waves, heavy rains, droughts and floods, and extreme storms (e.g., hurricanes). |
| Flooding | Water overflowing its confines and submerging areas that are typically dry; can result in negative impacts on natural and built environment and communities. |
| High Tide Flooding | Shallow flooding that leads to public inconveniences like frequent road closures, overwhelmed storm drains, and compromised infrastructure. Can interfere with important commerce corridors and processes. |
| Saltwater Inundation | Flooding of saltwater (i.e., ocean water) onto normally dry land or into normally freshwater (e.g., freshwater aquifers). Can be caused by high tide, sea level rise, storm surge, or other events. |
| Storm Surge | Abnormal rise of water generated by a storm, over and above the predicted astronomical tide. In coastal areas, often the greatest threat to life and property is from a hurricane or other tropical system. |

| | |
|---|---|
| Stormwater | Rainwater (or melted snow) that becomes surface water. Generally thought of as the precipitation that runs into streets or stormwater drainage systems that must be managed by communities. |
| Tide Gauge | A tide gauge measures changes in sea level relative to a datum (an established height reference) |

## ENGAGE:

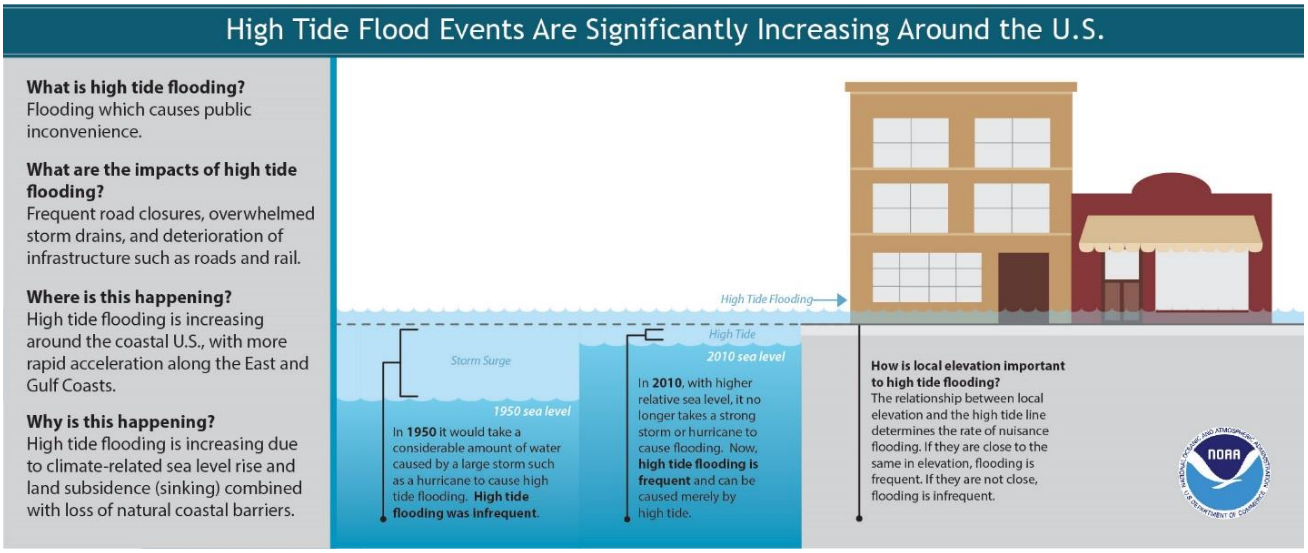
Listen with students to the NPR Science Friday segment from 2/15/2019: [What Does That Parking Lot Puddle Have To Do With Climate Change?](#) (11:19 minutes).

Show students "A Sharp Increase In 'Sunny Day' Flooding" By Jonathan Corum in The New York Times from September 3, 2016 (excerpt below) to observe differences in flooding of cities along the East coast. https://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html




**Ask students** if they have seen or experienced high tide flooding. How did it impact them? **Ask** them why it varies from town to town.

## EXPLORE:




**Distribute** graphs showing the projected days of future flooding with sea level rise to students. These graphs will be provided for coastal counties in Mississippi and Alabama with the curriculum materials. Give different groups in the classroom different locations. At the end of the lessons the groups will pair off with a group with a different location to compare their answers. They should come to the conclusion that different locations have different elevations and may have different numbers of future flooding days, but that they will all experience flooding.

> As an **EXTENSION**, teachers can generate graphs for other areas of the United States using the “Local SLR Two Pager” template: www.localSLR.org

Coastal flooding will become more frequent and occur in more places as sea levels rise. *Minor* flooding is a potential public threat and inconvenient. These graphs are projected frequencies of *minor* flooding caused by high tides under different sea level change scenarios at the NOAA Dauphin Island, AL Tide Gauge (locations matched to graphs). This a good representation of potential future flooding in the area. At Dauphin Island, AL, minor flooding starts when water level is at or above 1.7 feet. Probabilities of *moderate* and *major* flooding, which disrupt commerce, damage private and commercial property, and threaten public safety, are also increasing with sea-level rise, putting more communities and assets at risk.

The graph displays year along the x-axis and days with high tide (nuisance) flooding on the y-axis. The colored bands represent sea-level rise scenarios, low through extreme, which cover the range of scientifically plausible scenarios. The projected days of future flooding are based on the regional sea-level rise scenarios, not the global mean average, so they are location specific.

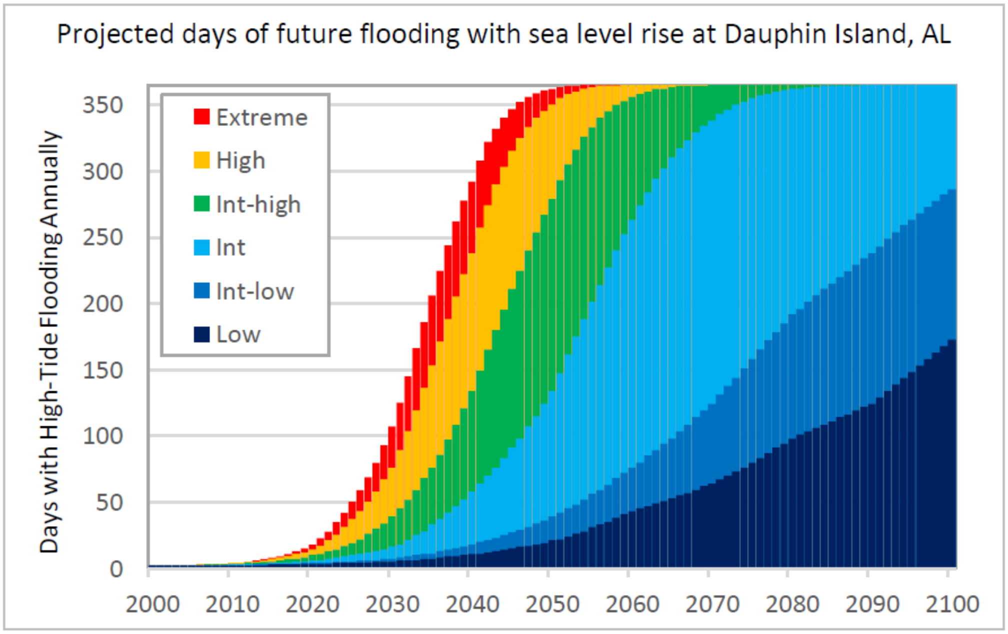
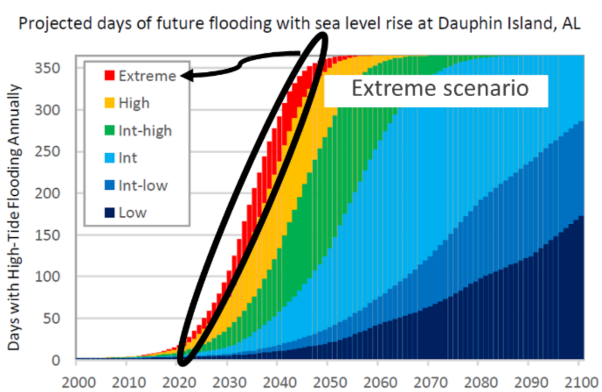
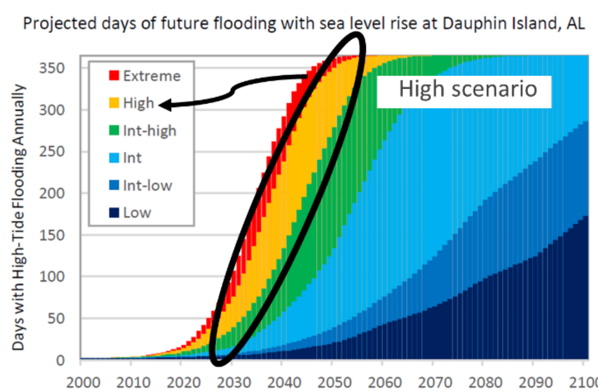


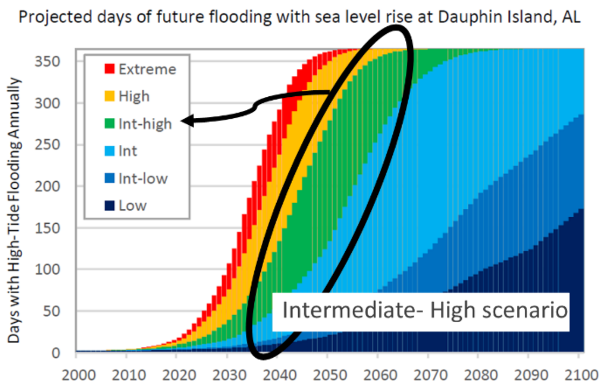

**Figure 2:** Graph displays the projected future days of minor flooding based on derived levels at Dauphin Island, AL under different sea-level rise scenarios. Data source: NOAA Technical Report NOS CO-OPS 086.

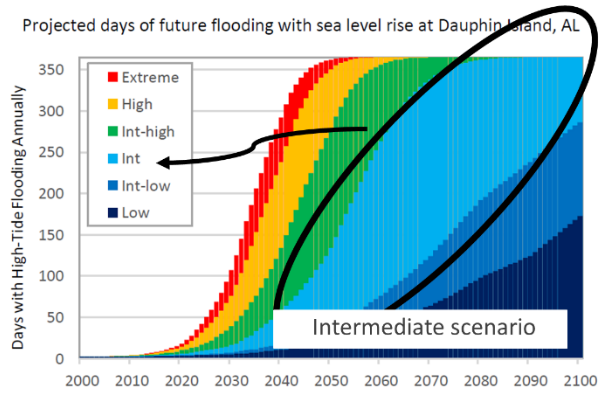
## Graph Walk-Through

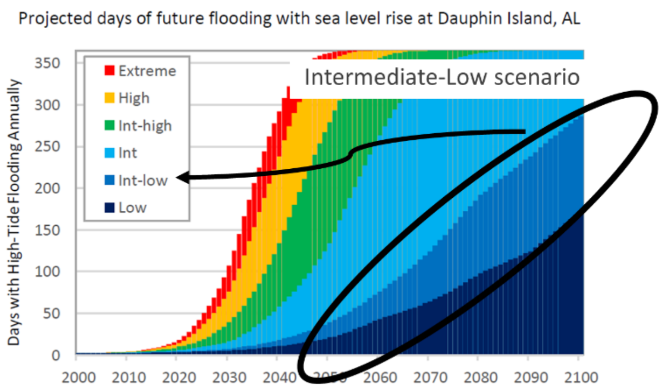
The color key shows the 6 sea-level rise scenarios depicted by a different color. Extreme as red, High as yellow, Intermediate-High as green, Intermediate as light blue, Intermediate-Low as medium blue, and Low as dark blue.

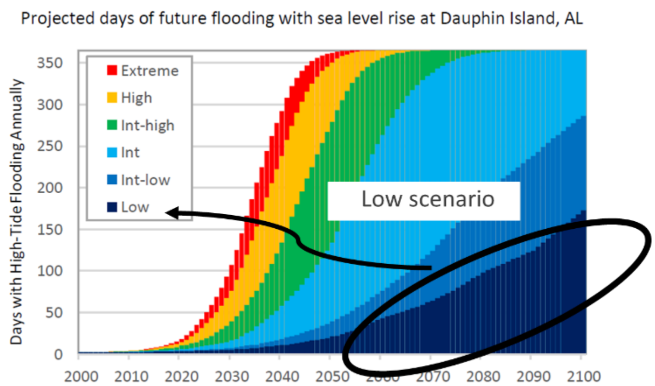




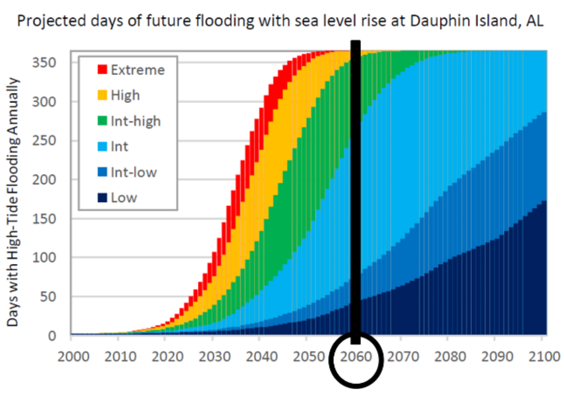



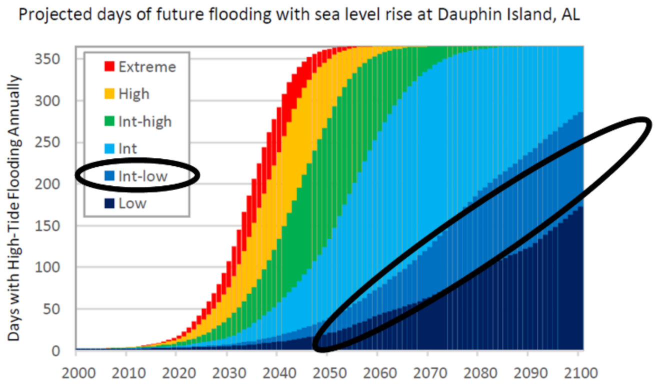




Walk through a practice question: How many days will this location experience high tide flooding with an intermediate-low scenario in the year 2060.

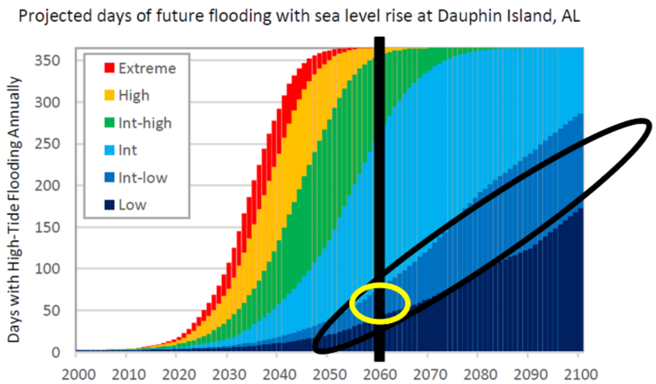
Step 1) Find the year on the x-axis. Drawing a line vertical at that point might help students visualize.



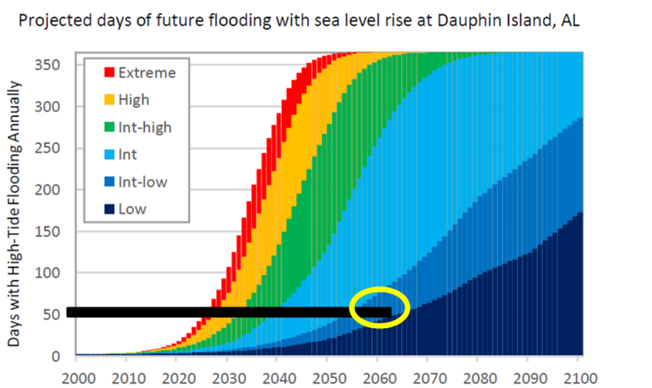
Step 2) Find the color representing the scenario in question. Intermediate-low is the medium blue.



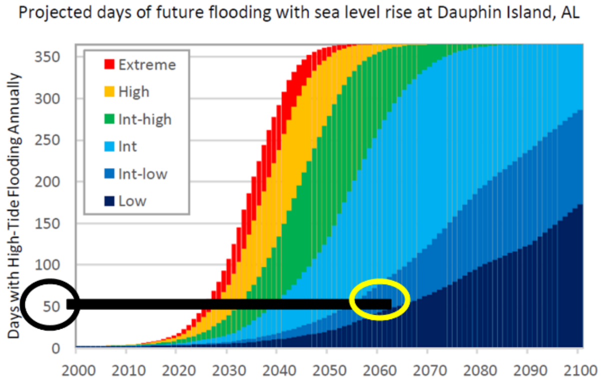

Step 3) Circle the overlap of the year and the scenario. This is the yellow circle in the image below.




Step 4) Find the number of days of flooding in this year and scenario draw a line to the y-axis.



Step 5) Record the number of days on the y-axis where the line intersects.




The answer to this question is that this location will experience 50 high tide flooding days with an intermediate-low scenario in the year 2060.

Student questions:

- Which scenario has the greatest slope? The least slope?
- Using the graph as a resource, in the year 2040, on average, how many days will your location experience high-tide flooding with an intermediate (int) scenario?
- Using the graph as a resource, in what year do all scenarios project at least 100 days of high-tide flooding?
- Using the graph as a resource, what is the earliest year in which a model predicts 100 days of high-tide flooding?

Student groups pair with another group working on a different location to discuss their answers and then talk about what it might mean for their daily lives if the main road to their school was projected to flood 50 days out of the year. What does it mean if these 50 days occur only during the school-year?

## EXPLAIN

**Discussion:** Lead full group discussion of some of the impacts that high tide flooding has on communities (e.g., needing to find alternative routes, being cut-off to certain areas, etc.) This type of flooding is an inconvenience, you might need to wear rainboots more often. There are many low-lying roads near the beach, rivers, canals, or bayous. High tide flooding means these roads might have water covering them each month.

Sea-level rise increases the distance that saltwater travels during tides, high tide flooding, and storm surge. Another impact to coastal regions is saltwater intrusion, when saltwater moves into freshwater aquifers. This can occur more frequently as sea levels rise and as coastal development withdraws freshwater from the ground. Saltwater intrusion into freshwater sources contaminates the drinking water supply for nearby communities. Saltwater causes corrosion of built civil infrastructure. When saltwater intrudes into freshwater marshes the plants that are adapted to survive in freshwater are impacted. These plants might not be able to survive with the salt and may become submerged if the water rises too high too quickly. Saltmarsh plants may move into the marsh and take the place of freshwater plants, allowing saltmarsh migration.

**Watch** "The Seeds of Ghost Forests" https://www.sciencefriday.com/videos/the-seeds-of-ghost-forests/ to see the impacts of salt-water intrusion on the coasts of North Carolina.

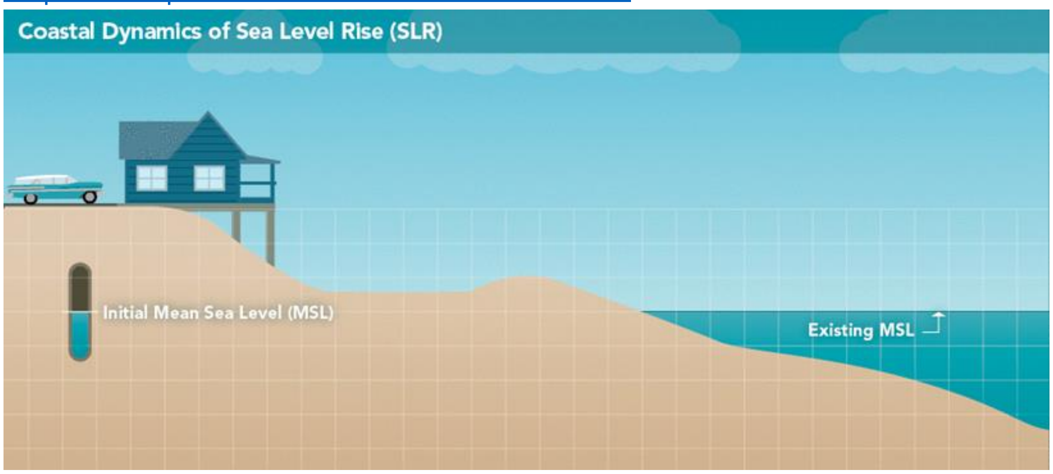
**Connect** the discussion before about how flooding and sea-level rise impacts human communities, to how it impacts coastal ecosystems. **Ask students**: how do human communities rely on coastal ecosystems?

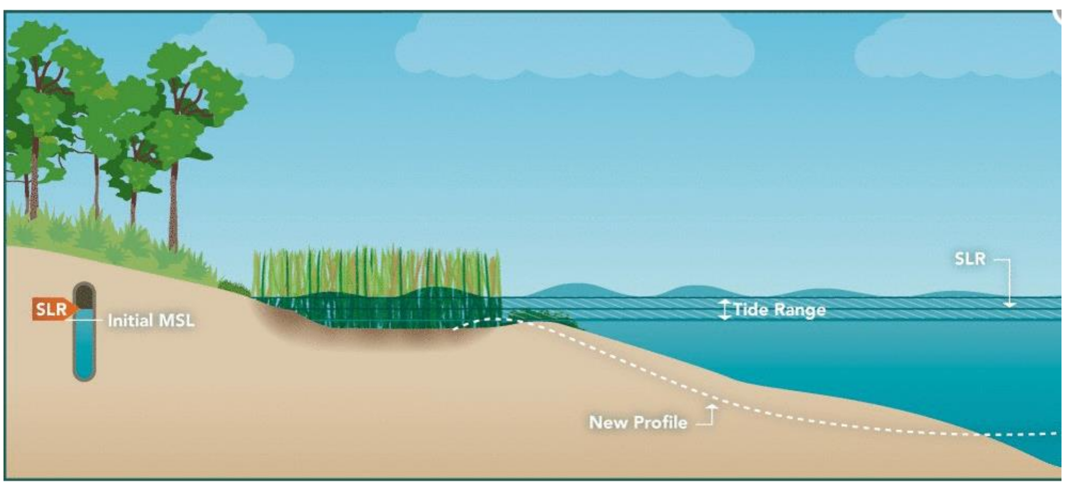
## ELABORATE

Students read the Gulf of Mexico Coastal Flooding reading.

Students use the Coastal Dynamics of Sea Level Rise graphic to see the impacts that sea-level has on changing habitat structure. Discuss that intense one time floods can be damaging, and chronic floods happening more frequently can also have more damaging impacts.

Shoreline changes sliding graphic: GOMmarsh.org and
http://champs.cecs.ucf.edu/CDSLR/index.html




## EVALUATE

To conclude the lesson, students pick one of the locations from the projected days of high tide flooding to write a paragraph on potential impacts to human communities and coastal habitats in 50 years' time.

Using the provided Projected Days of Future Flooding answer the following questions:

1. Which scenario has the greatest slope? The least slope?

2. Using the graph as a resource, in the year 2040, on average, how many days will your location experience high-tide flooding with an intermediate (int) scenario?

3. Using the graph as a resource, in what year do all scenarios project at least 100 days of high-tide flooding?

4. Using the graph as a resource, what is the earliest year in which a model predicts 100 days of high-tide flooding?

## Discussion

In a group discuss what it might mean for your daily lives if the main road to their school was projected to flood 50 days out of the year. What does it mean if these 50 days occur only during the schoolyear?


Credit: Kate Tagai, Island

## STUDENT PAGE | Reading - Gulf of Mexico Coastal Flooding

Flooding is a threat to buildings, property, and lives. Flooding is an overflowing of water onto land that is normally dry, and it can be generated by a wide variety of events such as heavy rains, when ocean waves come on shore, fast snow melt, or dam or levee breaks. Flooding may happen with only a few inches of water, or it may cover a house to the rooftop. It can occur quickly or over a long period and may last days, weeks, or longer. Floods are the most common and widespread of all weather-related disasters.

A coastal flood is the inundation of land areas along the coast and is caused by higher than average high tide and worsened by heavy rainfall and onshore winds blowing landward from the ocean. Places like Gulfport, Bay Waveland, Moss Point, Bayou la Batre, Dauphin Island, and Gulf Shores experience impacts from shallow coastal flooding because of lower elevation.

Credit: Kate Tagai, Island Institute

Storm surge is an abnormal rise in water level in coastal areas, over and above the regular astronomical tide, caused by forces generated from a severe storm's wind, waves, and low atmospheric pressure (e.g., hurricanes). Extreme flooding can occur in coastal areas particularly when storm surge coincides with normal high tide. Along the Gulf coast, storm surge is often the greatest threat to life and property from a hurricane.

High tide flooding, also referred to as nuisance flooding, is the term used to describe flooding related to minor tidal flooding. This may be from water flooding low elevation coastal roads, overtopping a sea wall, or coming back through storm drains. High tide flooding can lead to road closures, waterlogged infrastructure, overwhelmed storm drains, and other public inconveniences.

Inland flooding occurs when moderate precipitation accumulates over several days or intense precipitation falls over a short period. Water from inland flooding will partially be absorbed into the ground or vegetation, and travel along rivers to delta areas on the coast. As the rivers move the excess water to the deltas, it can cause flooding in areas downstream all the way to the coast, even though there was no precipitation in the other locations.

A flash flood is when excessive water fills normally dry creeks or riverbeds and adds water volume to flowing creeks and rivers, causing rapid rises of water in a short amount of time. The water moves very quickly, causing damages and extreme risk to life and property. Densely populated areas are at a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots typically use impervious materials, which increases runoff by reducing the amount of rain absorbed by the ground. This runoff increases the flash flood potential.

People have developed many strategies to keep water from negatively impacting their homes and businesses. Storm drains are used in cities and towns to direct rainfall down and away from roads and buildings. Levees are built along waterways and rivers to prevent high water from flooding the neighboring land. Some people elevate homes, businesses, and roads above common flood levels. Additionally, there are often laws that require building in specific ways or places to minimize flood risk.

Our developed ways of moving water away from homes do pose challenges in certain conditions. During heavy rain, storm drains can become clogged or overwhelmed and flood roads and buildings. As sea level has risen, it has also begun to block storm drain outfalls along the coast, causing inland and flash flooding. Low spots, such as underpasses, underground parking garages, and basements are especially likely to flood. The city of New Orleans experienced massive flooding days after Hurricane Katrina came onshore in 2005 due to the failure of levees along the river designed to protect the city.

Living along the Gulf coast, we experience the impacts from different floods. Proximity to the coast increases the risk of coastal flooding and impacts from storm surge and high tide flooding. But living near the coast means many large and small river systems are nearby (e.g., Mobile-

Tensaw Rivers, Mississippi River) so we also experience the impacts of inland flooding. With sea-level rise, we are already experiencing increased coastal and inland flooding and seeing the need for better prepared communities. Average global sea level has risen 24 cm (8-9 inches) since 1880 but the rate of increase is accelerating. Eight cm of the 24 cm rise has occurred since 1993. Along the low-lying Gulf of Mexico coast, we are highly vulnerable to climate change impacts. We are already experiencing increased flood frequencies from the combined effects of extreme rainfall events and sea-level rise. We need to work towards large-scale methods to improve our region's ability to prepare for more flooding as a result of sea-level rise.

*Adapted from: Sever Weather 101 – Floods. The National Severe Storms Laboratory.*

*Sea-level rise data from: Lewis, K.L.M., D.R. Reidmiller, and C.W. Avery, 2018: Information in the Fourth National Climate Assessment. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1410–1412. doi: 10.7930/NCA4.2018.AP2.*

## DO NOW:

What are the two main causes of sea-level rise?

## EXIT TICKET:

How does sea-level rise impact high tide flooding?

# 1.4 Climate Change Anomalies and Suffering Economies

## AGE RANGE

9th—12th grade

## TIME REQUIRED

90 minutes

## ACTIVITY OVERVIEW

Engage: Equal vs equitable
Explore: Reading
Explain: Discussion
Elaborate: Modeling
Evaluate: Discussion and graphs

## MATERIALS

Computers

## BASED ON:

Lesson adapted from KBS K-12 Partnership Predicting Earth's Future: Building your own climate

## LESSON TOPIC: Economics and modeling

## ACTIVITY SUMMARY: Students use carbon emission data to create a climate change model.

## OBJECTIVES:

Students will be able to:

- Explain what a model is and the basic components that go into constructing a model.
- Explain how climate and sea-level rise models work, including their limitations.
- Understand the connection of sea-level rise and economics.

## LESSON BACKGROUND:

### ECONOMICS

Rising sea levels impact communities by increasing rates of flooding, exacerbating existing hazards like erosion, and damage community infrastructure. This causes direct impacts on coastal economies through costly damage to individuals, businesses, municipalities, closed businesses, and displaced consumers. It also causes indirect impacts by reducing industry production, increasing real estate pressure, and causing long-term shifts in coastal development patterns.

### MODELING

We know that sea level is rising based on measurement data collected from tide gauges and satellites. Scientists use models to estimate how much and how fast sea level will continue rising. There are two different approaches to models: process-based and semi-empirical. Process-based models consider the different physical processes that cause sea levels to rise. Semi-empirical models extrapolate the information contained in measurements of past sea level changes.

Process-based models used for sea-level rise projections quantitatively describe the contributors of sea-level rise: thermal expansion of water and addition of water volume from melting land-ice. Three-dimensional ocean circulation models can be used to model thermal expansion. Determining the rate that heat warms the ocean surface and how deep the water is warmed below the surface are important for this model. One limitation is that as climate change alters ocean circulation, the intensity of ocean mixing changes and leads to uncertainty in the model. Another limitation is the difficulty in measuring the addition of water volume from melting land-ice because there are so many glaciers. The World Glacier Inventory contains ~123,000 glaciers (Radic and Hock 2010). Scientists cannot model the dynamics of each glacier individually. Glaciers are measured using semi-empirical scaling laws to estimate total volume from satellite measured surface area. Due to the uncertainty of glacier volume, this glacier melt could contribute as little as 5 cm (Raper and Braithwaite 2006), around 10 cm (IPCC 2007), or more than 37 cm (for moderate levels of climate change; (Bahr et al. 2009) to sea-level rise by the year 2100. The science to watch is the study of melting land-ice. Every year scientists are improving measurements of melting glaciers and in turn improving the projected range of sea-level rise models.

Semi-empirical models try to extrapolate the link between observed sea-level rise and observed global temperature changes in the past in order to predict the future. The starting point is the simple physical idea that sea level rises faster as it gets warmer. An advantage of semi-empirical projections is that they reproduce the observed past sea-level rise. A limitation is that we cannot be sure that the pattern from the past will continue to hold in the future.

Models are updated with new understanding as our research improves. As the understanding of natural processes, especially the increased understanding of glacier melt, improves, the results are used in process-based models to provide more robust projections of future sea-level rise.

Both types of models put out a range of potential sea-level rise scenarios that provides a framework of possible outcomes based on what we know. This includes accounting for our understanding of models' limitations, the range of potential future carbon emissions, and natural variability. The range of sea-level rise projections allows communities to plan for a changing coastline.

*Background information adapted from: Rahmstorf, S. (2012) Modeling sea level rise. Nature Education Knowledge 3(10):4*

## VOCABULARY:

| | |
|---|---|
| Economics | Economics is a social science concerned with the production, distribution, and consumption of goods and services. |
| Model | Systematic depiction of current and/or future conditions for different processes. Model climate tool types include theoretical, numerical, and conceptual and can range from simple to complex. |
| Semi-Empirical Models | A model involving assumptions, approximations, or generalizations designed to simplify calculation or to yield a result in accord with observations. |
| Process-Based Model | A mathematical representation of one or several processes characterizing the functioning of well-delimited biological systems of fundamental or economical interest. |
| Visualization | Climate tool type that creates simulations or graphics of current and/or potential future conditions. |
| Vulnerability | Potential for assets to be adversely affected by hazards. Encompasses exposure, sensitivity, potential impacts, and adaptive capacity. |

## ENGAGE

Show students the image “Societal Options for Resource Allocation in a Changing Climate” without the figure legend (on the next page). Ask the students what they see in the pictures and what the boxes represent for sea-level rise preparedness.

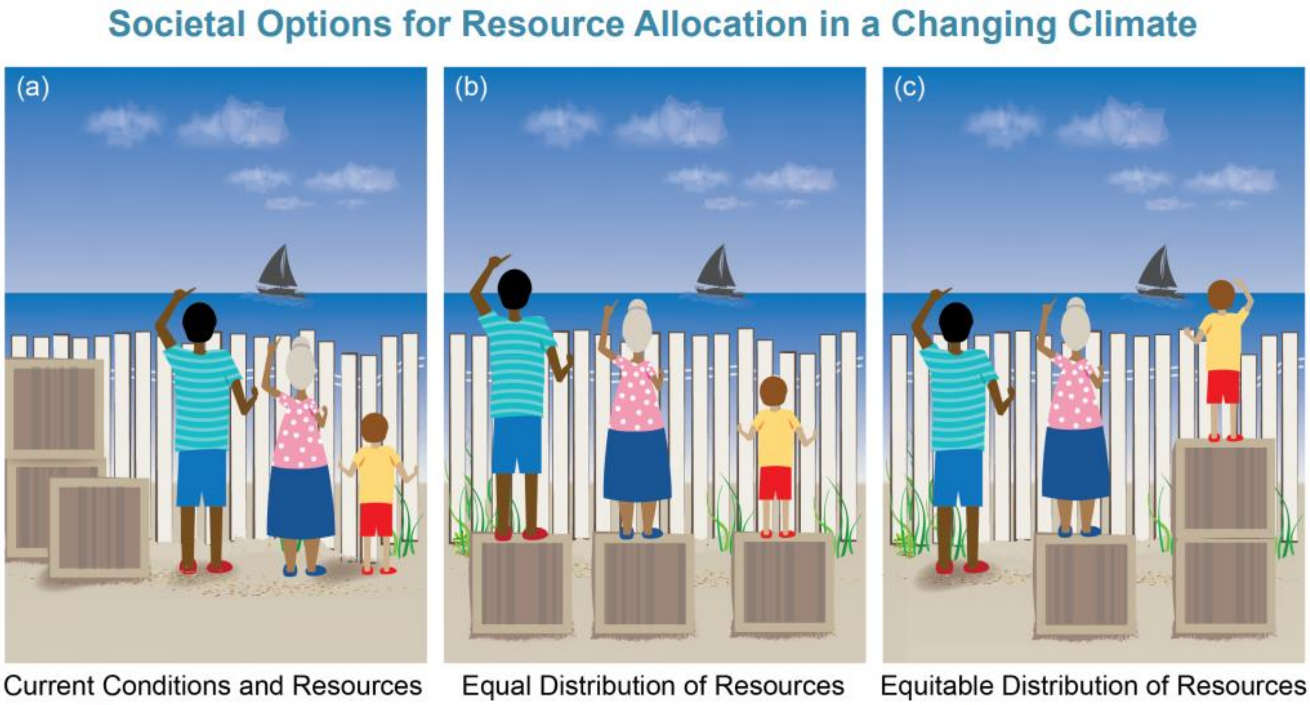



**Figure 8.5:** Society has limited resources to help individuals and communities adapt to climate change. Panel (a) illustrates that there are finite resources available and that individuals and communities are starting from different levels of readiness to adapt. Panel (b) illustrates the option for society to choose an equal allocation of resources where everyone gets the same amount of help, or as illustrated in panel (c), society can choose to distribute resources equitably to give people what they need to reach the same level of adaptation. Source: adapted with permission from Craig Froehle.

## EXPLORE

Have students read "Economic Loss Due to Frequent Flooding."
Use Think-Pair-Share with the class to answer questions about the text:
T : (Think) Students "think" about what they know or have learned about the topic.
P : (Pair) Each student should be paired with another student or a small group.
S : (Share) Students share their thinking with their partner. Can be expanded into a whole-class discussion.

Student questions:
How does flooding impact business operation?
Why are businesses important in your community?
What might a business do if high tide flooding occurs more frequently?
What might a homeowner do if high tide flooding impacts their route to school? Work? Recreation?
Why might a family not leave their community even with frequent flooding?

## EXPLAIN

We see that sea level is rising and that it will have large impacts, as well as making existing flooding worse. We can investigate the past for measurements recorded by human instruments as well as records stored in ice cores. To prepare our communities for the future of sea-level rise it is important to be able to predict how fast and how much the sea level will rise. Climate change is a result of many factors contributing to increased concentrations of greenhouse gases like carbon dioxide. Sea-level rise results from multiple factors increasing the level of the ocean, like thermal expansion of water and melting land-ice. To predict the future of sea-level rise, scientists take data about the factors contributing to sea-level rise and create models.

Some of these factors are variable while others don't really change even over the course of decades.  Scientists must decide which factors to include in their models and how much weight to give to each of them in order to construct a model that can make accurate and precise predictions.

## ELABORATE

Students use provided data and spreadsheet/graphing software (Google Sheets or Excel) to model climate impacts.

**Tell students**: Today, you are a climate scientist working for the Intergovernmental Panel on Climate Change and your job is to prepare a brief report for the United Nations showing the long-term effect of certain carbon emissions policies. You will start by developing a model to predict the average global temperature in the year 2050 and then you will use your model to estimate how much things will change if certain policies are enacted. At the end, you will turn in two things: this worksheet with questions and tables filled in and a copy of all the graphs you make using Google Sheets.

Students will complete the worksheet and create graphs using the data.

## EVALUATE

**Ask students or review their worksheet:**

In what ways do you think your model is accurate?

What other variables do you think would help your model?  What other things could influence global temperatures that could be included?

**Relate the modeling activity back to economics:**

How are economies impacted by climate change and sea-level rise?

How can communities or nations use modeling information to have more resilient economies in the future?

> **EXTENSION**: students can propose two policy changes that the United States could make that would slow the warming trend worldwide.

## STUDENT PAGE | Climate Change Anomalies and Suffering Economies

Answer the following questions after reading "Impacts from Increased Flooding."

1. How does flooding impact business operation?

2. Why are businesses important in your community?

3. What might a business do if high tide flooding occurs more frequently?

4. What might a homeowner do if high tide flooding impacts their route to school? Work? Recreation?

5. Why might a family not leave their community even with frequent flooding?

You are tasked with developing a model to predict the average global temperature in the year 2050. Complete this worksheet and create graphs using a computer.

As you build your climate model, you will have to make several decisions about what data to include in it. To do this, you will make a series of graphs that show the relationship between different climate variables and global temperature and decide which ones make sense to include in your model. Below are descriptions of the data you are using, some going back to 1750 (some data are more limited because we only started collecting the data more recently):

**You can access the data here: https://tinyurl.com/y6ozfo3b**

(full link: https://docs.google.com/spreadsheets/d/1b4O2APcy-V9gzJg9ZJ8hctDvZfvqg-U9T-Ojnevv4pI/edit?usp=sharing)

Select all the data and copy it into a new spreadsheet document.

**Global Temp**: The average land surface temperature of the Earth based on interpolations from weather stations all over the Earth (data source: Berkley Earth)

**Catastrophic Volcanos**: Number of catastrophic volcanic eruptions around the world during that year (a "catastrophic" volcanic eruption is a volcanic eruption rated at a 3 or higher on the Volcanic Eruption Index) (data source: National Centers for Environmental Information)

**Aerosol Optical Depth:** A general measure of the concentration of aerosols (small particles found in dust, smoke, and ash) in the atmosphere that can shade out sunlight (source: National Centers for Environmental Information)

**Sunspot Number**: The average number of sunspots on the sun in a given year (data source: National Centers for Environmental Information)

**$CO_2$ Concentration**: The average global atmospheric $CO_2$ concentration during in a given year (data source: Institute for Atmospheric and Climate Science)

**Cattle in USA**: The total number of cows in the USA during in a given year (data source: National Agricultural Statistics Service)

## Step 1: Variability Over Time

To model what will happen in the future you will need to determine if the variables follow a pattern. For each variable, use Google Sheets make a graph showing how it changes over time (you will make six graphs for this part). Be sure to label your axes and give each graph a title. A line graph would be a good way to represent these data.

After making your six graphs, fill in the table below, briefly describing the trend in the data (is it increasing, decreasing, or staying the same over time), variability (is the trend fairly constant over time or does it vary widely from year-to-year), and general notes on the pattern that you see.

| Variable | General Trend | Variability | Notes |
|---|---|---|---|
| Global Temperature | | | |
| Volcanic Eruptions | | | |
| Sunspot Number | | | |
| $CO_2$ Concentration | | | |
| Cattle in USA | | | |
| Aerosol Optical Depth | | | |

## Step 2: Relationship with Temperature

After determining if the variables follow a pattern, you need to examine how they affect global temperature. Now use Google Sheets to make series of graphs that show the relationship between each variable (x-axis) and the global temperature (y-axis), then fill in the table below. Be sure to label your axes and give each graph a title.

Note: Since you aren't looking at change over time, it's not appropriate to use a line graph here. You will have to visualize your data with a scatterplot.

Fill in the table below to indicate the relationship between that variable and global temperature (are they positively related, negatively related, or unrelated) and the strength of any relationship (is it a strong relationship or just a weak one with a lot of variation).

| Variable | Direction of Relationship | Strength of Relationship | Notes |
|---|---|---|---|
| $CO_2$ Concentration | | | |
| Sunspot Number | | | |
| Cattle in USA | | | |
| Aerosol Optical Depth | | | |
| Volcanic Eruptions | | | |

## Step 3: Building Your Model

Now we need to decide which variables to include in your model. Based on the relationship between global temperature and each variable, decide whether or not you think it would be important to include that variable in your model (Circle Yes or No) and briefly justify your decision.

| | | |
|---|---|---|
| $CO_2$ Concentration | YES | NO |
| Sunspot Number | YES | NO |
| Cattle in USA | YES | NO |
| Aerosol Optical Depth | YES | NO |
| Volcanic Eruptions | YES | NO |

You know two things about each variable: how it changes over time and how it is related to average global air temperature. Now it's time to put your model together. For each of the variables you chose to include in your model, look back at your graphs from Step 1 and extrapolate the trend forward to the year 2050 to see what that value is. (Remember, you only need to include the variables you decided to include in your model from above)

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Now look at your graphs from Step 2 and make a prediction for what the temperature is likely to be in 2050 based on 2050 values you determined above.

Variable: ________________________________ Predicted Temp in 2050: __________

Variable: ________________________________ Predicted Temp in 2050: __________

Variable: ________________________________ Predicted Temp in 2050: __________

Variable: ________________________________ Predicted Temp in 2050: __________

Variable: ________________________________ Predicted Temp in 2050: __________

Lastly, calculate an average of the predicted temperatures from each of the variables above to determine your final prediction.

Your prediction for average global air temperature in 2050: ___________________

In what ways do you think your model is accurate?

What other variables do you think would help your model?  What other things could influence global temperatures that could be included?

## ECONOMIC LOSS DUE TO FREQUENT FLOODING

Coastal flooding has increased across much of the United States. Sea-level rise is causing more frequent flooding outside of extreme weather conditions. Flood damage causes negative impacts to property and buildings, but it also extends to impacting business and community life. Researchers Hino, Belanger, Field, Davies, and Mach (2019) studied the impacts on business caused by high tide flood events in Annapolis, Maryland. In 2017, Annapolis had high tide flooding occur on 63 days, particularly affecting the historic downtown area. For us living along the Gulf of Mexico from Florida to Mississippi, by 2050 we will experience high tide flooding on average between 25 to 80 days each year. Understanding effects in similarly impacted communities will help us plan for impacts in our communities. The research in Annapolis, Maryland demonstrates that high tide flooding does affect their local economic activity, and the number of people visiting the historic downtown was reduced by 1.7% during flood events. Future sea-level rise will further increase the number of high tide flooding days. With just 3 inches of additional sea-level rise, the increased frequency of high tide floods would reduce visits by 3.6%, resulting in negative impacts from reduced tourism and economic exchanges. When businesses are closed, it reduces revenues that support the community through sales tax, lodging tax, and other sources. Without this revenue, the budgets of cities, towns, and counties will be reduced, minimizing the amount of services (e.g., police, fire fighters, schools, road repairs, etc.) the municipalities can provide to their residents. Understanding how frequent flooding leads to economic loss will help guide local adaptations to prepare for climate change impacts.

## SOCIETAL IMPACTS DUE TO SEA-LEVEL RISE

Climate change and sea-level rise pose risks to coastal communities around the world. Researchers Martinich and colleagues (2013) used an analytic tool to identify geographic areas in the contiguous United States that may be more likely to experience disproportionate impacts of sea-level rise and to determine if and where socially vulnerable populations would bear disproportionate costs of adaptation. They identified socially vulnerable coastal communities in four regions of the United States: North Atlantic (Maine through Virginia), South Atlantic (North Carolina through Monroe County, Florida), Gulf (Collier County, Florida through Texas), and Pacific (California through Washington). To evaluate if the communities threatened with sea-level rise would have the economic ability to adapt to the changes, they combined the vulnerable community output with a sea-level rise model. Their results show that under the mid sea-level rise scenario with around 67cm of rise by 2100, approximately 1,630,000 people are potentially affected by sea-level rise. Of the people affected, about 332,000 (~20%) are among the most socially vulnerable. Areas of higher social vulnerability are much more likely to be abandoned than protected in response to sea-level rise. In the Gulf region over 99% of the most socially vulnerable people are living in areas that are unlikely to be protected from sea-level rise inundation. In comparison, of the least socially vulnerable group in the Gulf region, only 8% of people live in areas unlikely to be protected. These results demonstrate the need to consider economic barriers of communities facing sea-level rise impacts.

*First reading adapted from: Hino, M., Belanger, S., Field, C., et al. Science Advances (2019) 8: EAAU2736 https://doi.org/10.1126/sciadv.aau2736*

*Second reading adapted from: Martinich, J., Neumann, J., Ludwig, L. et al Mitigation and Adaptation Strategies for Global Change (2013) 18: 169. [https://doi.org/10.1007/s11027-011-9356-0](https://doi.org/10.1007/s11027-011-9356-0)*

# STUDENT PAGE | Climate Change Anomalies and Suffering Economies

## DO NOW:

Draw a downtown “Main Street.” Then draw how high tide flooding might impact the area.

## EXIT TICKET:

How does sea-level rise impact the economy?