AMERICAN METEOROLOGICAL SOCIETY



Project Ocean

Sea Level Change

TEACHER'S GUIDE

Project Ocean

This guide is one of a series produced by Project Ocean, a U.S. Office of Naval Research-sponsored initiative of the American Meteorological Society (AMS), in recent partnerships with St. Mary's College of Maryland, Washington College, and the United States Naval Academy. Project Ocean is a continuation of past projects focused on creating and training a network of master teachers to provide peer training sessions in pre-college (K-12) physical oceanographic education. To support these teachers in their teacher training, Project Ocean develops and produces course modules and other educational materials.

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Figure i. Atlantic Ocean coastline at Hampton, NH. [NOAA]

“Coastal sea level rise is among the most severe societal consequences of anthropogenic climate change. Contemporary global mean sea level rise will continue over many centuries as a consequence of anthropogenic climate warming, with the detailed pace and final amount of rise depending substantially on future greenhouse gas emissions.”

- World Climate Research Program
  Grand Challenge on Regional Sea-Level Change and Coastal Impacts

“There’s no scenario that stops sea level rise this century. We’ve got to deal with this indefinitely.”

- Michael Oppenheimer
  Climate Scientist at Princeton University and co-author, IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019)

Module: Sea Level Change
Audience/Grade Level: K-12 Educators

Learning Objectives

After completion of this module participants will be able to:

3. Open Ocean Water Column Structure

- Describe the relationship between temperature, salinity, pressure, and seawater density.
- Explain how pressure acts on a parcel of seawater, describe the concept of hydrostatic balance in the ocean, and analyze how pressure influences seawater density and temperature with increasing depth.
- Explain how temperature, pressure, and salinity interact to influence the in situ and potential temperature of seawater parcels, and analyze how changes in temperature affect seawater density through molecular kinetic energy and spacing.
- Analyze how stratification contributes to ocean stability and inhibits mixing.

12. Changes in the Ocean

- Describe the trends in global temperature increases since 1880, including the acceleration of warming in recent years and the predominance of record-high temperatures in the 21st century.
- Identify short- and long-term contributors to sea level changes, distinguishing between natural and human-driven factors.
- Explore the major contributors to both global and regional sea level changes, such as thermal expansion, land ice melt, and regional geological factors.
- Discuss historical sea level changes, comparing rates of change before and after the satellite era.
- Analyze scenarios for future sea level rise, taking into account current trends and potential climate interventions.
- Understand NASA resources concerning sea-level rise

STANDARDS:

Project Ocean Fundamental Understandings:

Open Ocean Water Column Structure (3.4, 3.6, 3.10. 3.14)

Changes in the Ocean (12.1-12.6)

Applicable Ocean Literacy Principles:

1.A, 1.C, 1.D, 3.A, 3.F, 3.G, 6.D, 7.D, 7.E, 7.F

Next Generation Science Standards

Performance Expectations

2-ESS1-1. Use information from several sources to provide evidence that Earth events can occur quickly or slowly.

2-ESS2-3. Obtain information to identify where water is found on Earth and that it can be solid or liquid.

5-ESS2-1. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.

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

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Disciplinary Core Ideas

ESS1.C: The History of Planet Earth

ESS2.A: Earth Materials and Systems

ESS2.B: Plate Tectonics and Large-Scale System Interactions

ESS2.C: The Roles of Water in Earth's Surface Processes

Crosscutting Concepts

2. Cause and effect: Mechanism and explanation.

5. Energy and matter: Flows, cycles, and conservation.

7. Stability and change.

Science and Engineering Practices

2. Developing and Using Models

4. Analyzing and Interpreting Data

5. Using Mathematics and Computational Thinking

Engage | Scenarios for 21st Century Global Sea Level Rise:

The Earth's **hydrosphere** includes all of the planet's water—whether found on, beneath, or above the surface. Within the hydrosphere, the cryosphere is the portion that contains water in its solid, or ice, form. According to USGS, approximately 96.5% of Earth's water is saltwater in the oceans, while only 2.5% is freshwater. Of that small freshwater portion, the majority (about 68.7%) is stored in *land ice*, glaciers and ice sheets. The largest ice sheet in terms of area and volume is in Antarctica, followed by the ice sheet in Greenland. *Sea ice*, by comparison, makes up a very small fraction of this volume of frozen water, though it covers a larger area than glacial ice. **Figure 1** shows the Antarctic Ice Sheet (brighter white areas) surrounded by sea ice (grayish-white).

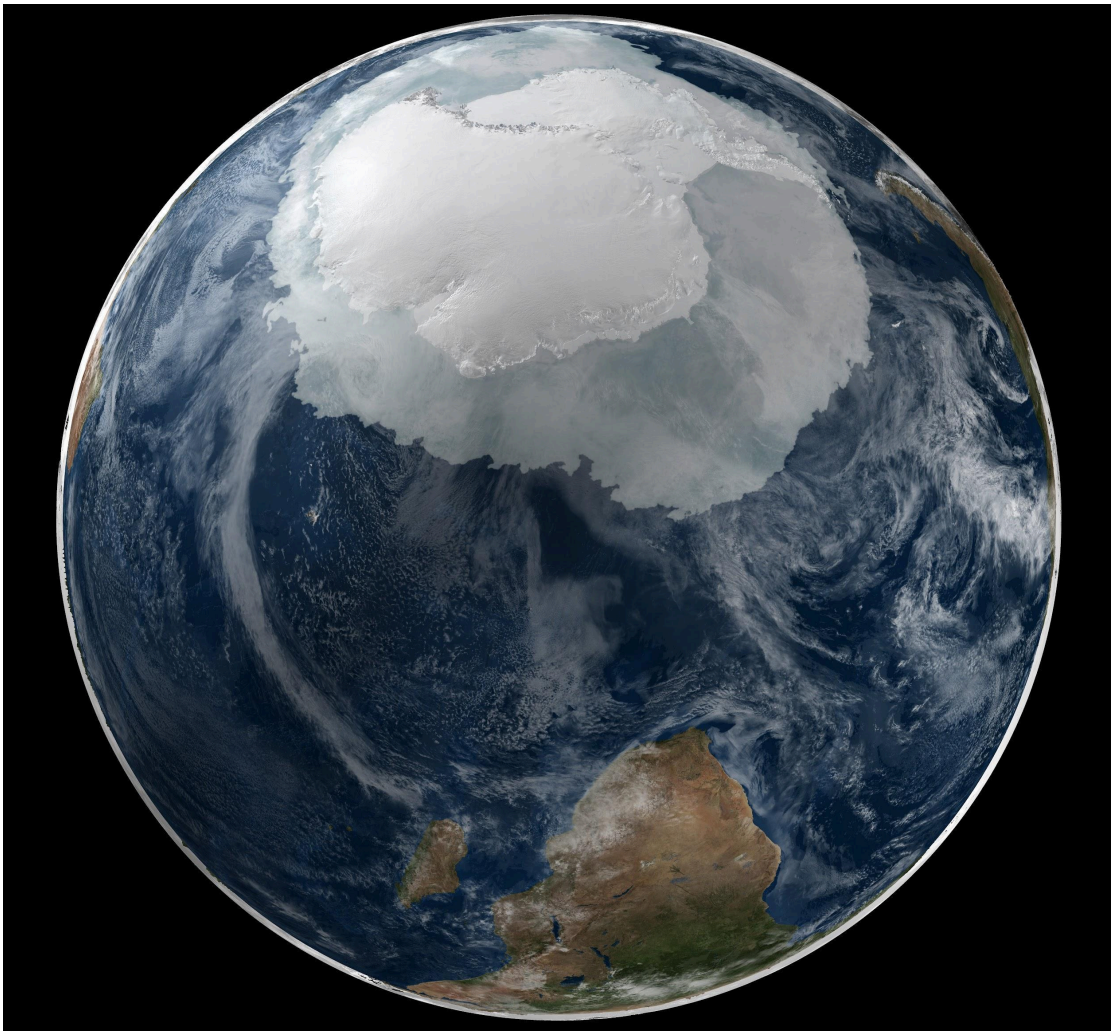


Figure 1. Satellite image compilation of Antarctica from multiple data sources. [NASA SVS]

Despite being a relatively small part of the hydrosphere, ice plays a critical role in Earth's climate. Both land ice and sea ice influence climate, but land ice contributes to

sea level rise when it melts, while sea ice impacts ocean salinity, temperature, and circulation patterns. Melting of sea ice has a significant impact on Earth's absorption of solar radiation and warming at higher latitudes.

Melting land ice, including alpine glaciers and polar ice sheets, was the major contributor to sea level rise in the early 21st century and is expected to remain the primary factor for decades to come. Even though the Greenland Ice Sheet is smaller than the Antarctic Ice Sheet, it is in a more temperate climate and currently contributes more meltwater per year to sea level rise. Additionally, ocean thermal expansion—caused by the warming of seawater—significantly contributes to rising sea levels.

To explore the idea of sea level rise, watch either or both of the following videos.

Watching Rising Seas from Space

NASA's Earth Minute: Sea Level Rise

The steep rise in greenhouse gases since the dawn of the industrial age is causing our atmosphere and ocean to warm and glaciers and ice sheets to melt. Consequently, sea level is rising globally, and the rate of sea level rise is increasing. Between 2006 and 2023, global mean sea level rose at a rate of 3.2 mm per yr, which is more than twice as fast as the rate for most of the 20th century, 1.4 mm per yr (AMS State of the Climate 2023; Lindsey, 2021).

In many coastal regions, sea level is rising at a rate higher than the global average due to local factors such as ground subsidence, changing ocean currents, and the uneven distribution of glacial meltwater. For example, in Annapolis, MD, ground subsidence and the slowing and movement of the Gulf Stream are exacerbating sea level rise. The linear trend in relative sea level rise for the period 1928 to 2021 is 3.7 mm/yr (+/- 0.2 mm/yr), and Ezer et al. (2013) report a rate of 8.3 mm/yr for the period of 2002–2011. As a result of these increases in sea level, high tide flooding and the recurrence of extreme water levels due to storm surge have become more frequent, affecting infrastructure, property values, transportation, and freshwater supplies.

Figure 2 shows the Kunta Kinte-Alex Haley Memorial and storefronts at the Annapolis City Dock during flooding from Hurricane Isabel in 2003. Under the Intermediate Scenario for 21st-century sea level rise presented in Sweet et al. (2022), which involves an increase of Mean Sea Level in Annapolis by approximately 4.5 ft. relative to the current tidal datum, flooding of this magnitude could become an annual event by 2100.



Figure 2. This extreme water level occurred on 19 September 2003, when Hurricane Isabel flooded downtown Annapolis with a 6 ft. storm surge. [Kunta Kinte-Alex Haley Foundation]

In this module, we will review short- and long-term contributions to sea level change, explore the major contributors to global and regional sea level changes, and then discuss historical sea level change and scenarios for future sea level rise.

Group Review and Discussion:

1.) *Where is most of the land ice in the world? Explain your answer.*
2.) *What are the major factors in sea-level rise? Do land ice and/or sea ice contribute?*
3.) *Speculate on how coastal areas of the United States, particularly heavily populated areas of the Atlantic and Gulf Coasts, might be impacted by rising sea levels.*

Explore | Melting Land and Sea Ice (demo)

Science Buddies provides a demonstration that illustrates the different effects of melting land ice and melting sea ice, appropriate for grades 5-8, and the National Park Service provides a video demonstration.

Another demonstration that depicts the effects of melting land and sea ice on sea level can be accomplished with two glasses or beakers of water, ice cubes, and a funnel.

1. Fill both glasses to the same level (about 1/2 full), and have students mark these levels either on the glasses or on separate rulers.

2. In “glass A”, place a few ice cubes in the water. These represent floating sea ice or icebergs
3. Place a funnel on top of “glass B,” and add an equal number of ice cubes to the funnel. These represent land ice, such as glaciers or ice sheets, melting and flowing into the ocean.
4. Have students speculate about what will happen to the water level in each glass as the ice melts.
5. Once the ice melts, record the water level change. This represents any change in sea level that occurs when sea ice melts versus when an iceberg calves from a glacier and falls into the ocean.

Through this experiment it should be apparent that the water level in “glass A” will remain the same as it was initially. This is because floating ice displaces a volume of water equal to its weight, so melting does not contribute additional mass or volume to the ocean. The water level in “glass B” will rise slightly. When land ice melts, it adds new water to the ocean, increasing its volume and contributing to sea level rise.

Group Review and Discussion:

1.) Will one or both sources of ice (land ice and sea ice) cause sea level to rise when they melt?
2.) What are the implications for land and sea ice on and above Antarctica and Greenland?

Explain | Sea Level Rise in Perspective

The Geoid and Mean Sea Level

Sea level serves as the basis for measuring depth and elevation on Earth, but measuring sea level is not a simple task. A calm ocean appears smooth, but it is not, in fact, a flat surface. In the absence of wind, ocean currents, and other disturbing forces, the average shape of the sea surface (mean sea level) would feature broad hills and valleys that mirror the shape of Earth’s **geoid** – a surface on which Earth’s gravity field is uniform. Large undulations of the geoid are due to the nonhomogeneous nature of Earth’s interior; the density of magma and rocks in Earth’s mantle and crust is unevenly distributed. Smaller-scale variations in gravity caused by differences in the thickness of Earth’s lithosphere (the crust and upper mantle), the distribution of mass in Earth’s mantle, and bathymetry, including ocean ridges, seamounts, and ocean trenches, create smaller-scale variations in the ocean’s surface. Variations in the geoid have magnitudes of +/-10 m over hundreds of kilometers. The “reference ellipsoid” is a

smooth, idealized, hypothetical shape of Earth's gravity field, and the geoid varies above and below the reference ellipsoid by tens of meters over distances of thousands of kilometers. **Figure 3** shows a model of Earth with the actual land surface as a green line, the geoid as a blue line, and the ellipsoid as an orange dashed line.

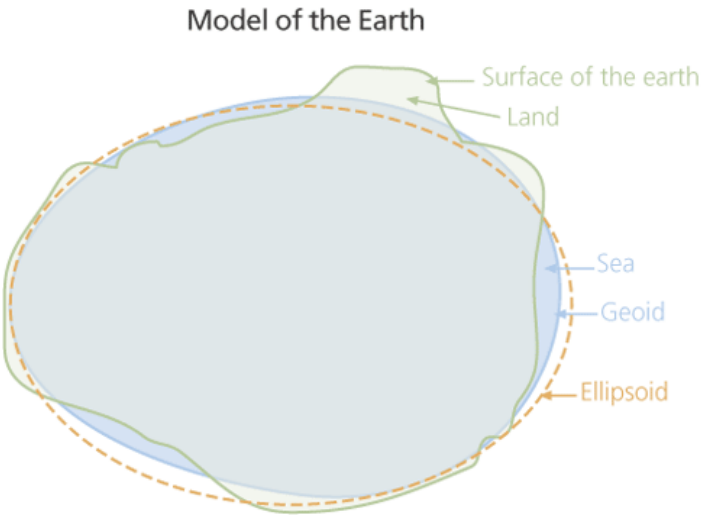


Figure 3. A model of Earth with the actual surface of Earth, the geoid, and the ellipsoid. [Fraczek, 2003]

While Figure 3 shows a simplistic model of Earth, **Figure 4** is a more detailed model of Earth's gravitational field based on gravity field measurement. Areas where the geoid is above the ellipsoid are shown in warm colors like pink and red, while areas below the ellipsoid are in cool colors like blue and green.

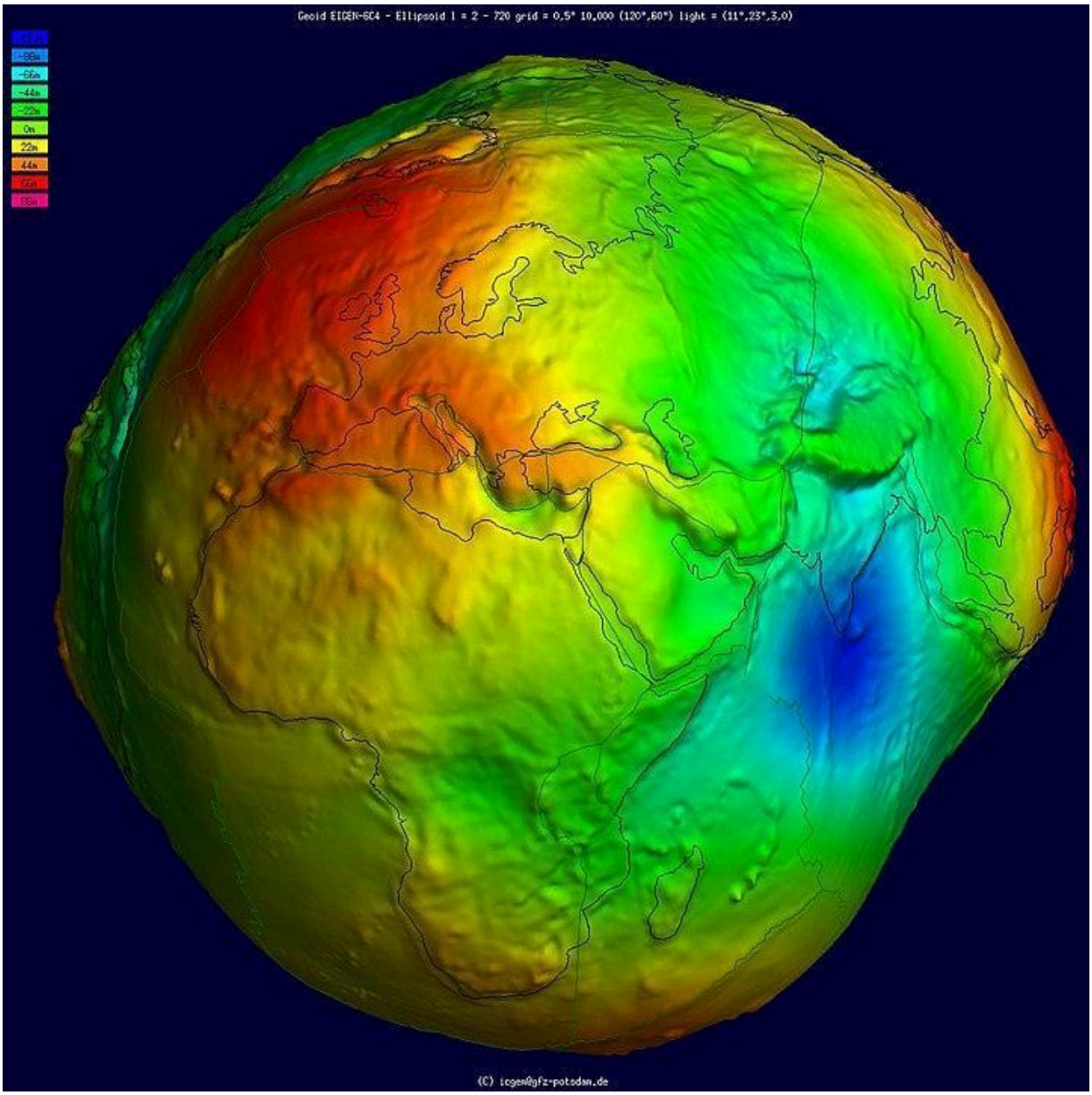


Figure 4. Geoid undulations, with 10,000 times vertical exaggeration, centered over the Middle East. [Ince et al., 2019]

Though not shown in Figure 4, the highest peaks in the geoid occur over Iceland and New Guinea, north of Australia, and are approximately 85 m above the reference ellipsoid. The lowest point in southern India is approximately 106 m below.

Sea Level Changes Associated with Dynamic Topography

There are still smaller-scale, more transient anomalies in the gravity field and the ocean surface due to variations in the density of ocean water. Warm water expands and is therefore less dense than a similar mass of cold water (recall that pure water reaches its

maximum density at about 4°C or 39°F). Warm water masses, such as those near the equator, have a larger vertical extent than cold water masses. These more transient variations in the ocean surface, referred to as dynamic topography, are most noticeable near the boundaries of major ocean currents, such as the Gulf Stream, and in the movement of water masses associated with El Niño and other decadal oscillations that we cover in the Wind Driven Ocean Circulation Module. The ocean's dynamic topography fluctuates approximately 1 meter above or below Earth's geoid over horizontal distances of just a few kilometers. These variations occur on much shorter time scales—ranging from days to seasons—compared to the larger and more stable geoid anomalies, which develop over much longer periods and cover much larger areas. **Figure 5** is a snapshot of ocean dynamic topography from a 10-day period in October 1992.

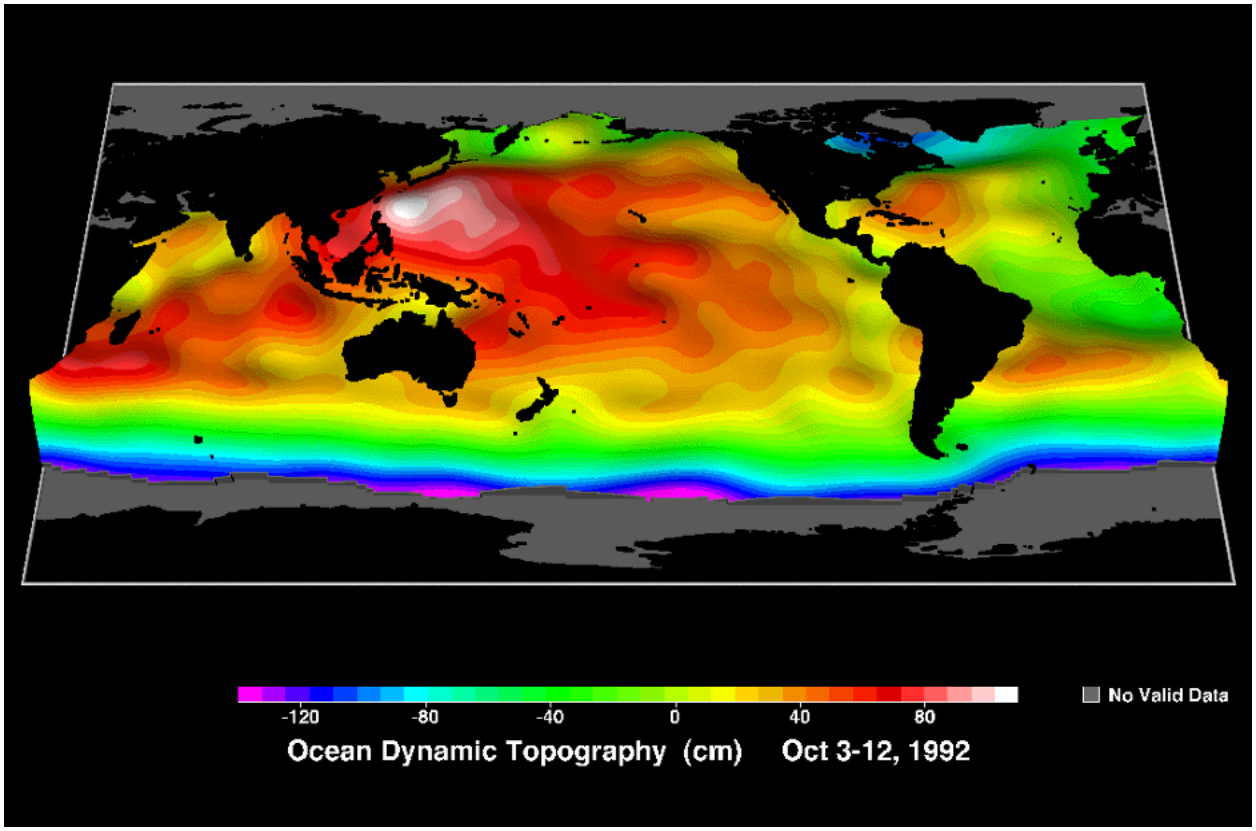


Figure 5. Ocean dynamic topography in cm from 3–12 OCT 1992 by the NASA/CNES Topex/Poseidon satellite mission. [NASA/JPL-Caltech]

The variations in the height of the ocean surface, like those shown in Figure 5, are influenced by water temperature and salinity, atmospheric pressure, and the location and strength of ocean currents. Accordingly, maps of dynamic topography can be used to estimate the speed and direction of ocean currents, just as maps of atmospheric pressure can be used to estimate the speed and direction of winds.

More rapid, local changes in sea level are caused by the tides, wind set up, tsunamis, and storm surge. As described in the Ocean Tides and Ocean Waves Modules, sea level can be forced to change by tens of meters by the periodic changes in the gravitational pull of the Sun and Moon and by the episodic generation of waves and storm surge by surface winds. Tsunamis can briefly raise local sea level by tens to hundreds of meters.

Climatological Changes in Sea Level

Slow changes in sea level, with time scales ranging from decades to millions of years, are caused by changes in the volume of water in the ocean. **Figure 6** shows the volume of ocean water varies with climatological warming and cooling, the transfer of mass between land ice and ocean waters, changes in the water cycle on land, geological processes, and plate tectonics. To study climatological changes in sea level, records of sea level spanning several decades are necessary to filter out the contributions of shorter time scale variations.

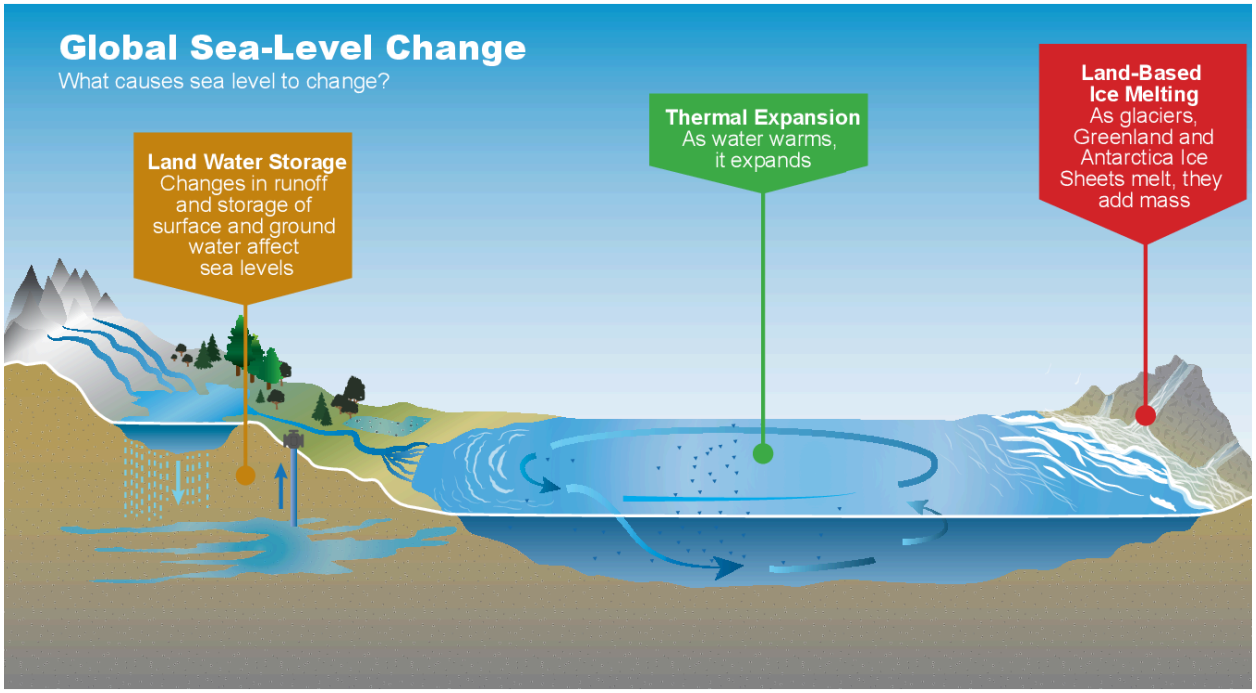


Figure 6. Major contributing factors to global sea level change. [Hall, 2016]

Sea level can be accurately measured within a few centimeters by tide gauges, pressure sensors positioned on the seafloor, and radar and laser altimeters carried on aircraft and satellites. Global measurements from radar altimeters on satellites have been publicly available since the start of the NASA/CNES TOPEX/Poseidon mission in 1992. These satellites determine their distance above the ocean surface by transmitting

microwave pulses and timing the arrival of the reflected pulses. The position of the satellite is determined with GPS receivers on the satellites, lasers ranging from various ground stations, and other technology, and then the ocean surface heights can be referenced to the center of the Earth. A clear explanation of how radar altimeters are used to measure sea level is provided by the NASA Jet Propulsion Laboratory at the California Institute of Technology.

Since 2005, about 2/3 of global mean sea level rise has been caused by melting land ice, and 1/3 has been caused by thermal expansion (Thompson et al., 2020). Contributions from land ice melt are expected to increase later this century and are the largest source of uncertainty in estimating the amount of future sea level rise.

As shown in **Figure 7**, sea level rise varies regionally due to local vertical land movement, regional ocean circulation, and the uneven distribution of water from land ice melt due to gravity and Earth's rotation. Vertical land movement results from glacial isostatic adjustment, plate tectonics, and the withdrawal of groundwater and fossil fuels. The effects of gravity and Earth's rotation cause water to redistribute unevenly, with melting ice reducing local gravitational pull and shifting water to distant regions, further influenced by the Earth's rotational dynamics.

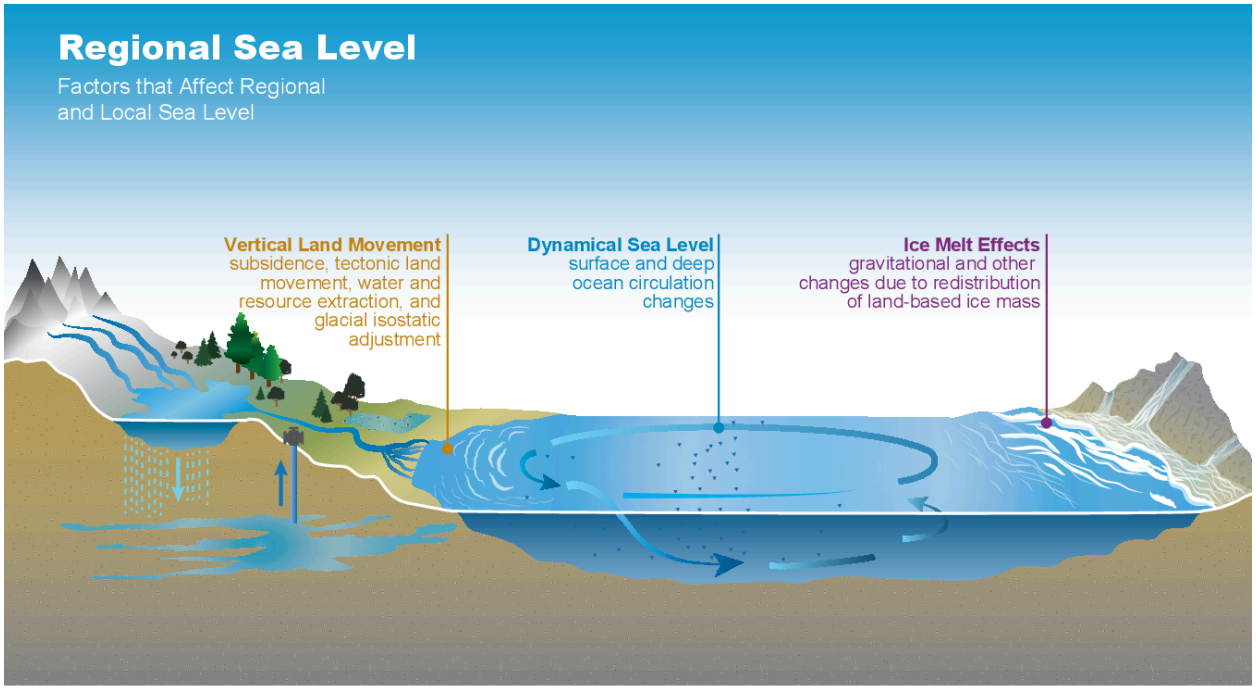


Figure 7. Major factors that cause deviation of regional and local sea level from the global average. [Hall, 2016]

One of the major factors affecting regional sea level rise along the Mississippi Delta, Mid-Atlantic states, and Gulf of Alaska is vertical land movement. Near the Mississippi Delta, compaction of sediment deposited at the mouth of the Mississippi is causing the highest rate of relative sea level rise in the U.S.—a linear trend of 9.16 mm/yr (3 ft./ century) at Grand Isle, LA, from 1947 to 2020. Along the Mid-Atlantic coast, subsidence is occurring for a different reason. During the most recent glaciation, an ice sheet created a forebulge, an uplifted area of Earth's crust, from the Ohio Valley to the Mid-Atlantic states. Since the retreat of the ice sheet, the forebulge has been sinking, and it is expected to continue sinking at the same rate for centuries to come. The rate of subsidence associated with this glacial isostatic adjustment in Annapolis is estimated to be approximately 1.88 mm/yr or 0.074 in./yr (Boon et al., 2010). Thus, ground subsidence has contributed nearly half of the 14 inches of relative sea level rise experienced in Annapolis between 1930 and 2020. Along the Gulf of Alaska, the ground that was formerly weighed down by the ice sheet is rebounding at a rate faster than the rise of absolute sea level, causing relative sea level in this area to be negative (falling). In Skagway, AK, the linear trend in monthly mean sea level between 1944 and 2020 was –18 mm/yr, producing a fall in mean sea level of nearly 6 ft. in 76 years.

Historical Changes in Sea Level

Paleo sea level changes dating back hundreds of millions of years are inferred from proxies for actual measurements, including depths of fossil coral reefs and the populations of different salinity-sensitive microfossils within salt marsh sediments.

During Earth's 4.5-billion-year existence, the climate alternates between warm and cool conditions, as shown in **Figure 8**. During warm, ice-free Greenhouse conditions, which have dominated 85% of Earth's history and last occurred 34–260 million years ago, sea level was hundreds of feet higher than today. During cool *Icehouse conditions*, an ice sheet is present on at least one of the poles, and sea level is typically hundreds of feet lower.

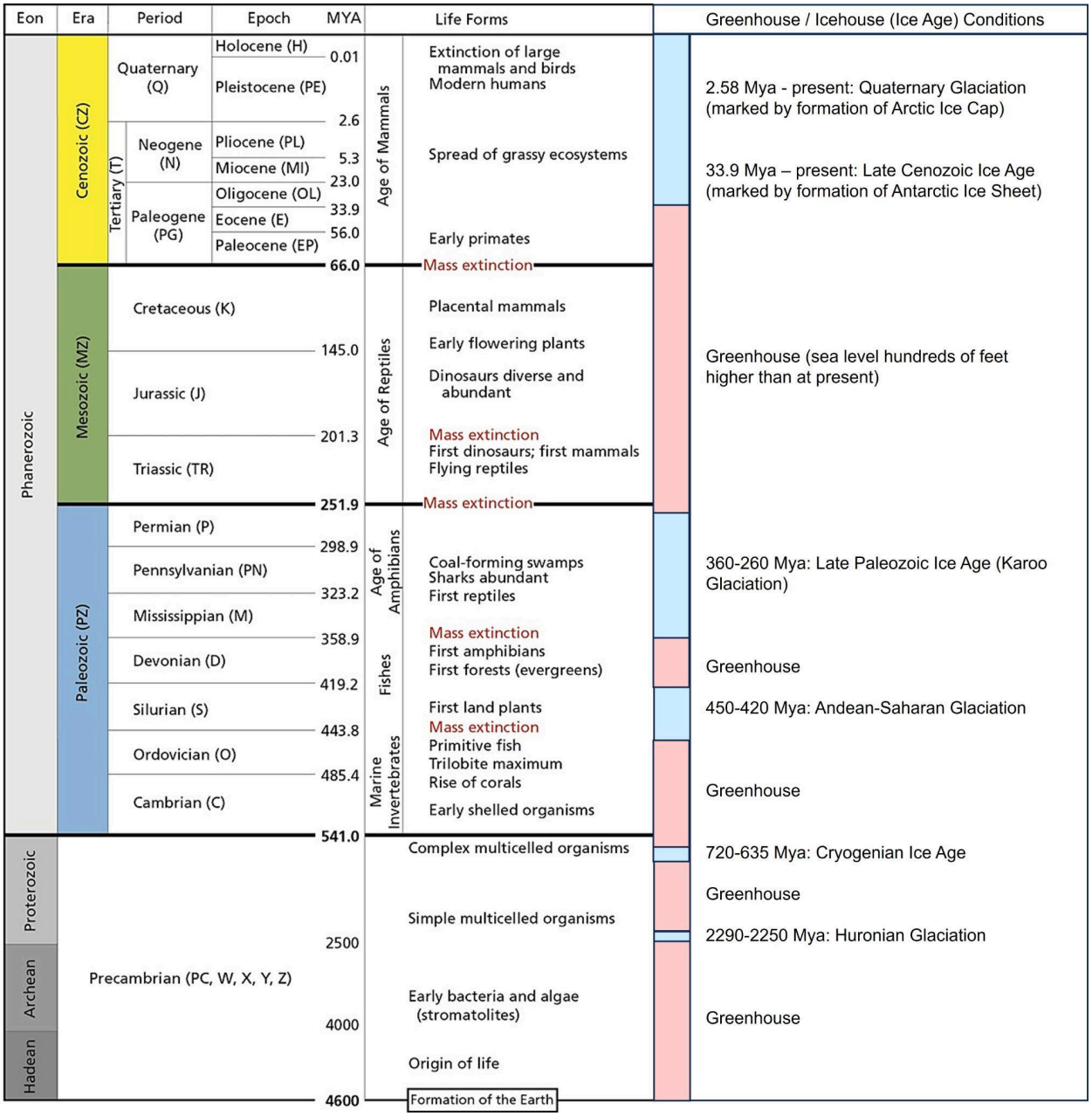


Figure 8. Geological time scale and duration of Greenhouse / Icehouse conditions. [Adapted from the National Park Service. Greenhouse / Icehouse conditions added by Emil Petruncio].

We are currently in the midst of the Late Cenozoic Ice Age, which began with the formation of the Antarctic ice sheet approximately 34 million years ago. The shift from Icehouse to Greenhouse conditions may be brought on by significant increases in atmospheric greenhouse gasses from volcanic activity. Conversely, the transition from Greenhouse to Icehouse conditions may be caused by plate tectonics and associated changes in ocean circulation. The current Ice Age, for example, was likely initiated by

the opening of the Drake Passage and the Tasmanian Seaway, which allowed the Antarctic Circumpolar Current to isolate Antarctica from warmer waters to the north.

The glaciation of North America that peaked about 20,000 years ago is one of many that occurred over a 2.6-million-year period referred to as the Quaternary Glaciation of the Late Cenozoic Ice Age. The Quaternary Glaciation was likely initiated by the appearance of the Panama Isthmus, which closed off circulation between the Gulf of Mexico and the Pacific Ocean, and the partial closure of the Indonesian Seaway. These two major changes in ocean circulation allowed more heat and moisture to be transported northward, resulting in more snowfall in the Arctic. Over the past million years, the Quaternary Glaciation alternated between glacial and interglacial periods with a periodicity of about 100,000 years. These temperature changes were driven by Milankovitch Cycles, changes in the tilt and orientation of Earth's axis, and the ellipticity of Earth's orbit around the Sun. The temperature changes initiated by the Milankovitch Cycles are amplified by changes in concentrations of atmospheric greenhouse gasses, including carbon dioxide and methane.

Of each 100,000-year cycle, 80% is glacial, and 20% is interglacial. Currently, Earth is in an interglacial period in the Holocene Epoch during the Late Cenozoic Ice Age. During these glacial-interglacial cycles, global sea level varies by about 100 m as mass is transferred between the ocean and the ice sheets.

The peak extent of the ice sheet that covered North America 20,000 years ago is referred to as the Last Glacial Maximum (LGM), and at that time, global sea level was approximately 120 m (400 ft.) lower. Since the LGM, sea level has risen in alternating periods of rapid rise, meltwater pulses, (MWPs), which last several centuries, and periods of little to no rise, which typically last several millennia. **Figure 9** is a graph of the sea level rise since the LGM with MWPs labeled. The most significant period of rapid rise, Meltwater Pulse 1A, began approximately 15,000 years ago and lasted 500 years. Over those five centuries, sea level rose at a rate of approximately 12 ft. per century (Lin et al., 2021).

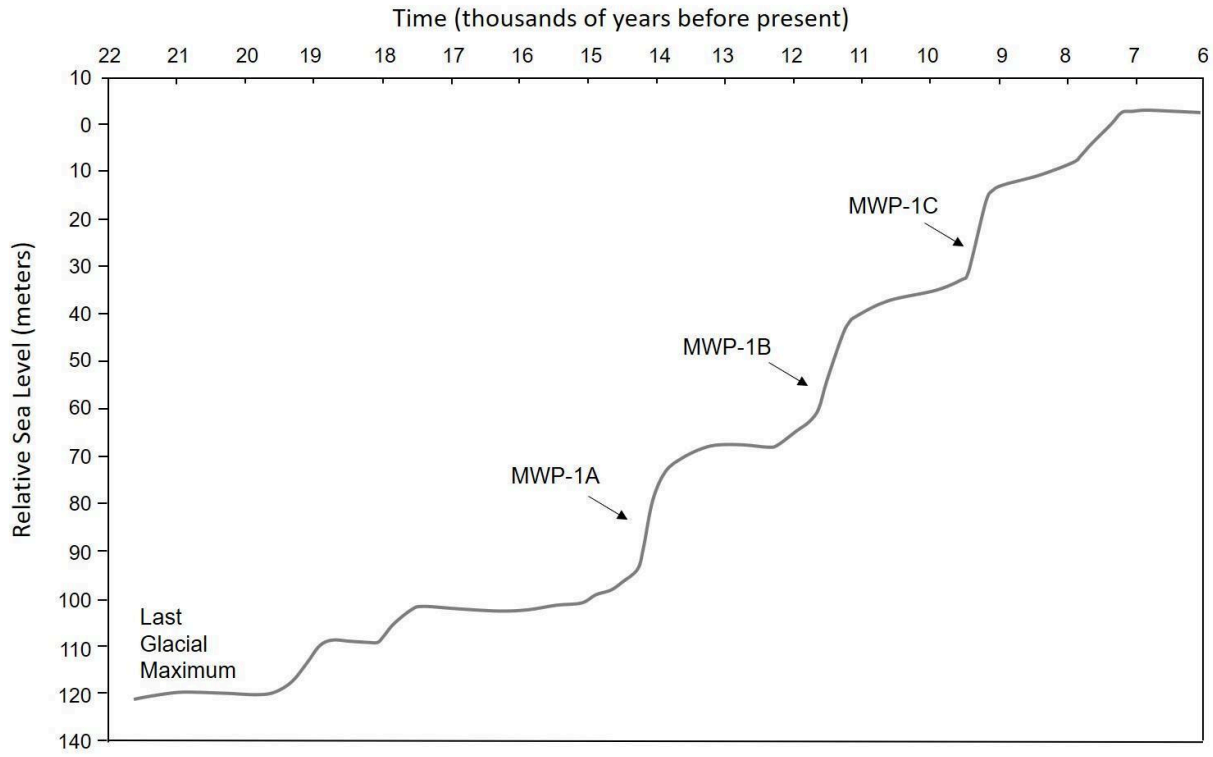


Figure 9. Sea level rise in the western Pacific (Yellow Sea, East China Sea, and South China Sea) since the LGM reflecting periods of rapid rise (meltwater pulses (MWP)) and intervals of little to no rise. [Figure by Emil Petruncio, adapted from Liu et al. (2004)]

Approximately 8-in. global mean sea level rise since 1900 is very likely the largest rise in the past 2,800 years (Kopp, 2016). The worst-case scenario for 21st-century global mean sea level rise published by NOAA (Sweet et al., 2022) – 2 m (6.6 ft.), relative to 2000 – is less than any of the major meltwater pulses that have occurred since the LGM. This highest plausible scenario would require high greenhouse gas emissions throughout the 21st century and the corresponding maximum amount of melting from the Antarctic and Greenland ice sheets.

Anthropogenic greenhouse gas emissions have disturbed the natural equilibrium of atmospheric temperature and CO_2 concentrations that have been characteristic of the Quaternary Glaciation. Global average temperatures today are approximately 1°C warmer than the preindustrial era. To estimate how high sea level may rise with continued warming, we can look at previous warm periods like those presented in **Figure 10**.

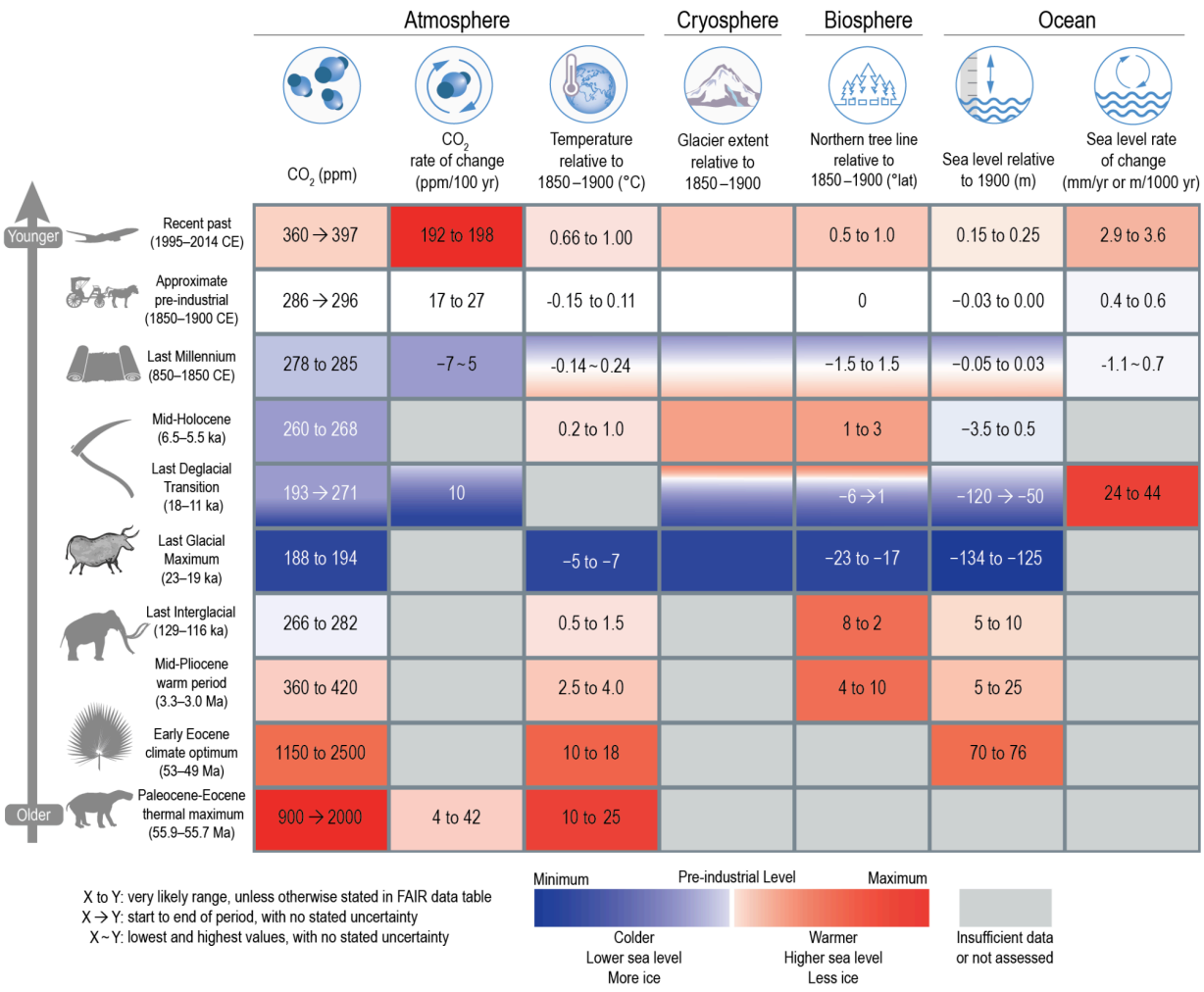


Figure 10. Selected large-scale climate indicators during paleoclimate and recent reference periods of the Cenozoic Era (Figure 2.34 in IPCC (2021). "Values are based upon assessments carried out in this chapter, with *confidence* levels ranging from *low* to *very high*. Refer to Cross-Chapter Box 2.1 for description of paleoclimate reference periods and Section 1.4.1 for recent reference periods. Values are reported as either the *very likely* range (x to y), or best estimates from beginning to end of the reference period with no stated uncertainty (x→y), or lowest and highest values with no stated uncertainty (x ~ y). Temperature is global mean surface temperature. Glacier extent is relative and color scale is inverted so that more extensive glacier extent is intuitively blue." [IPCC, 2021]

During the interglacial period from 129,000 to 116,000 years ago, global average temperatures were approximately 0.5° to 1.5°C warmer than the preindustrial era, CO_2 levels were considerably lower than present (266-282 ppm), significant portions of the Greenland and Antarctic ice sheets were likely melted, and sea level was likely 5-10 m (16-33 ft.) higher than at present. Another period with conditions resembling those of today was the Pliocene, three million years ago (during the current Ice Age but before

the Quaternary Glaciation). During this time, atmospheric CO_2 levels were comparable to today's level, global temperatures were 2.5° to 4.0°C warmer than the preindustrial era, Greenland was likely ice-free, and sea level is estimated to have been 5-25 m (16-82 ft.) higher than at present.

Assuming that the relationships between atmospheric CO_2, global temperatures, and global mean sea level remain consistent with historical periods, current CO_2 levels will likely cause at least 5 meters of future sea level rise.

Elaborate | NASA data exercise

We now know that sea level rise during the 20th century was probably the greatest in the past 2,800 years, and that sea level rise is accelerating. The acceleration in sea level rise correlates to trends of global temperature increase. We will use this exercise to examine temperature and sea level changes over portions of the 20th and 21st centuries. (Note: the first part of this section is adapted from a lesson from NASA JPL.)

Examine the line graph for average global temperature shown in **Figure 11**.

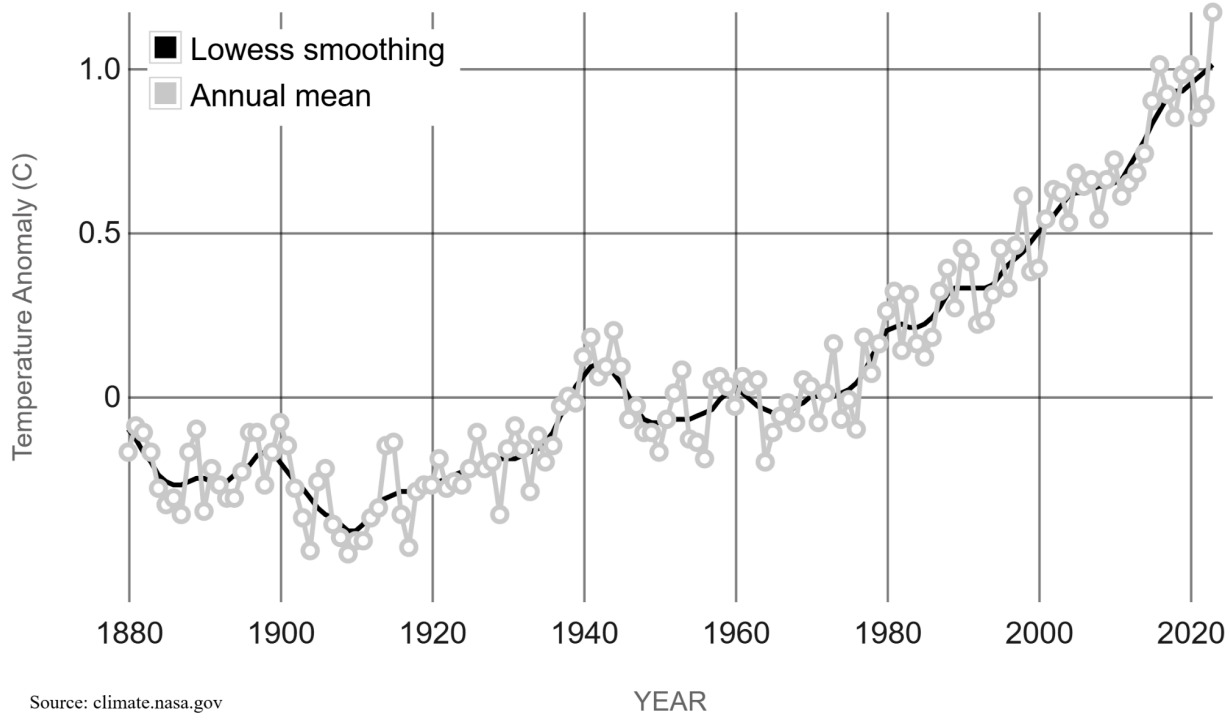


Figure 11. Global land and ocean temperature anomalies from 1880–2023. [Emil Petruncio with data from NASA/GISS data]

This graph illustrates the change in global surface temperature relative to 1951–1980 average temperatures. 19 of the warmest years have occurred since 2000, with the exception of 1998. The year 2024 is the warmest year since record-keeping began in 1880, and the past 10 years have been the hottest on record.

1. According to Figure 11, using values from the smoothed curve, how much has the average land and ocean global temperature increased since 1880?
   a. 0.5°C
   b. 0.9°C
   c. 1.1°C
   d. 2.5°C

2. The average global temperature increase from -0.1°C in 1880 to 0.33°C in 1990 was about _____°C/yr.
   a. 0.002
   b. 0.003
   c. 0.004
   d. 0.005

3. The average global temperature increase from 0.33°C in 1990 to 0.95°C in 2020 was considerably greater at about _____°C/yr.
   a. 0.02
   b. 0.03
   c. 0.04
   d. 0.05

Figure 12 shows sea level change for 1900–2018 relative to 1900 levels. The black line is data from tide gauges, and the orange line is from satellite altimeters.

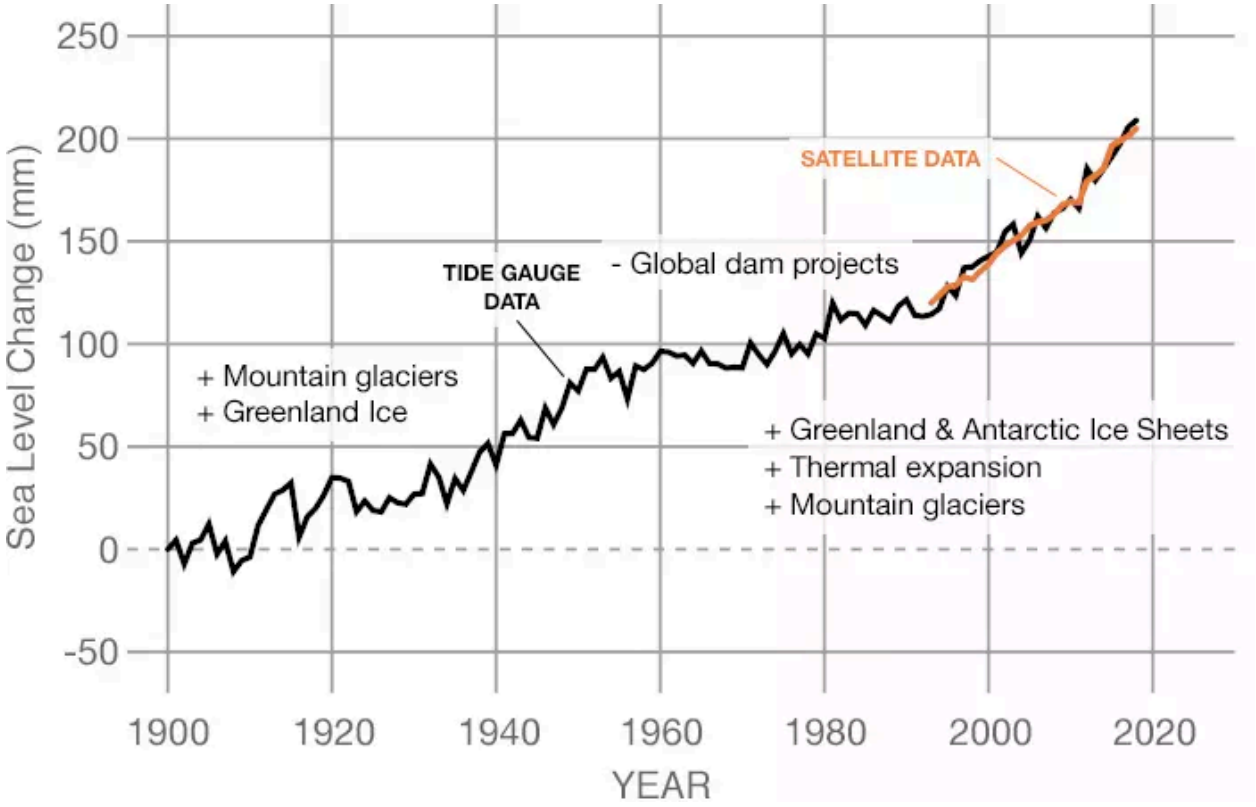


Figure 12. Sea level changes from 1900–2018 based on tide gauge data and, more recently, satellite altimetry data. [NASA GSFC]

4. _____ saw the highest rate of sea-level rise, as shown by the slope of the line.
   a. 1920–1940
   b. 1940–1960
   c. 1980–2000
   d. 2000–2018

5. The average rate of increase was _____ mm/yr between 1900 and 2000.
   a. 1.5
   b. 2.2
   c. 3.8
   d. 6.0

6. According to Figure 12, which of these causes a decrease in sea level?
   a. Building of major dams globally
   b. Melting of the Greenland and Antarctic Ice Sheets
   c. Ocean thermal expansion

Figure 13 shows the change in global sea level (mm) since 1993 when satellites began measuring it. Blue shading around the thick black line shows measurement uncertainty. The exact values on the graph and the data can be obtained at the NASA Goddard Space Flight Center website.



Figure 13. Satellite altimetry sea level observations from 1993 to JUL 2024. [NASA GSFC]

7. According to Figure 13, sea level has risen about _____ during the satellite era.
   a. 65 mm
   b. 80 mm
   c. 95 mm
   d. 105 mm

8. The rate of increase over the 31-yr period was approximately _____ mm/yr.
   a. 2.2
   b. 3.4
   c. 4.6
   d. 5.5

9. The rate of sea-level rise thus far in the 21st century is more than _____ times the rate during the 20th century.
   a. 1
   b. 2

c. 3
d. 4

Figure 14 illustrates projected sea level rise trends and scenarios for the contiguous U.S. coasts. The left panel shows tide gauge observations as a solid black line, with extrapolated trends represented by a dashed black line. Projections through 2150 are color-coded to reflect different scenarios based on future greenhouse gas emissions and their impacts on ocean and atmospheric warming: low (blue), intermediate-low (green), intermediate (yellow), intermediate-high (dark orange), and high (purple). The right panel includes a color-coded, stacked bar chart that overlaps with the projections in the left panel. It presents a detailed breakdown of projected sea level rise scenarios corresponding to the IPCC Sixth Assessment Report's surface temperature warming levels. Each bar illustrates the likely range of sea level rise for a given warming scenario, with black lines indicating median values. Regardless of whether greenhouse gas emissions stabilize this century, sea level rise is expected to persist into the next century and beyond.

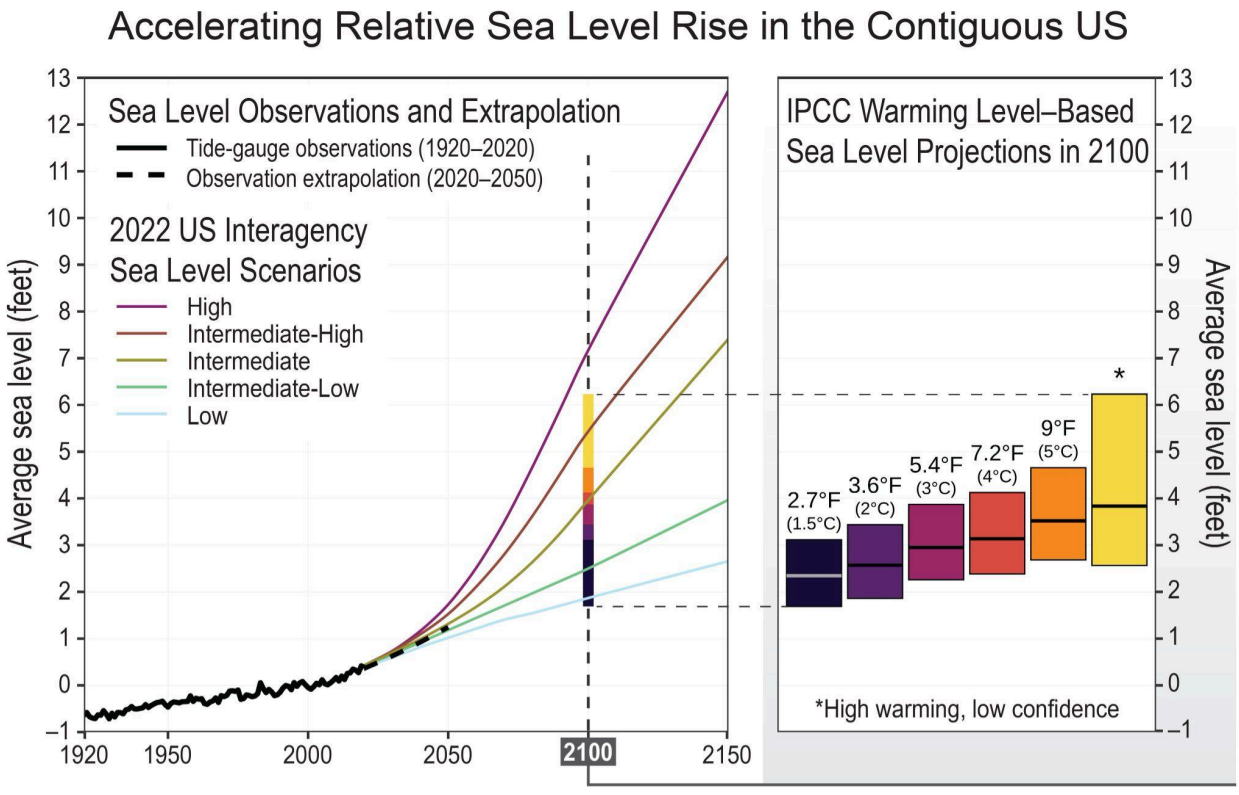


Figure 14. Observed global mean sea level from 2000–2020, with projections of sea level rise in the 21st century and beyond. [NCA5 Figure 9.1]

10. Under the Intermediate Scenario in yellow, mid-range sea-level rise by 2100 will be about _____ ft.
    a. 1.8
    b. 2.5
    c. 3.9
    d. 5.3

11. According to the IPCC Warming-Level Based Sea Level Projections in the right panel, sea-level rise ranging from about 2.7 ft. to 4.6 ft. is associated with a warming of _____°C.
    a. 2
    b. 3
    c. 4
    d. 5

Evaluate | Sea Level Change

12. What instrument is used to make global measurements of mean sea level in the open ocean, complementing measurements made by coastal tide gauges?
    a. Bottom pressure sensors
    b. Radar altimeters on satellites
    c. Drifting buoys

13. What are the two main contributors to the rise in global mean sea level since 2005?
    a. Thermal expansion and land ice melt
    b. Ground subsidence and land ice melt
    c. Sea ice and land ice melt

14. Which of the following is *not* a direct factor in the regional variability of sea level?
    a. Differences in solar radiation across latitudes
    b. Dynamic ocean topography
    c. Ground subsidence
    d. Regional distribution of meltwater from glaciers and ice sheets

15. Global mean sea level during the Last Glacial Maximum was _____ the present day?
    a. much lower than
    b. about the same as
    c. much higher than

16. During the last interglacial period, 125,000 years ago, atmospheric carbon dioxide levels were approximately 266-282 ppm, and global surface temperatures were 0.5° to 1.5°C warmer than the preindustrial era. How much higher was global mean sea level during that period, relative to today? (Note: the current level of atmospheric carbon dioxide is approximately 420 ppm, and global surface temperatures are approximately 1.0°C warmer than the preindustrial era).
    a. 1–3 m (3.3–9.8 ft.)
    b. 5–10 m (16–33 ft)
    c. 10–30 m (32.8–98.4 ft.)

Extend **| Personal Reflection**

Did you have any misconceptions before beginning the module? What were they, and how might you explain the scientific reasoning to your students?

How could you use the information and data in this module to cover your school's learning objectives or standards?

How would you scaffold the content in this module for your grade level?

Additional Resources:

General Information - Overviews of Past and Present Sea Level Rise:
NASA (2020) – Sea Level 101: What Determines the Level of the Sea?
https://climate.nasa.gov/blog/2990/sea-level-101-what-determines-the-level-of-the-sea/

NASA (2020) – Sea Level 101, Part Two: All Sea Level is 'Local'.
https://climate.nasa.gov/blog/3002/sea-level-101-part-two-all-sea-level-is-local/

NOAA (2021) – Climate Change: Global Sea Level.
https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

SeaLevelRise.org (2021) - https://sealevelrise.org/ (Forecasts, Causes, Risk, Solutions, Analyses by State)

Sea Level Rise Viewers:
NOAA:
https://coast.noaa.gov/slr/#/layer/slr

Climate Central:
https://riskfinder.climatecentral.org

NASA:
https://climate.nasa.gov/interactives/climate-time-machine

Lesson Plans:

Science Buddies - Lesson Plan Resources (Grades 5-8):
https://www.sciencebuddies.org/teacher-resources/lesson-plans/climate-change-and-sea-level-rise

National Park Service videos to accompany the Science Buddies Lesson Plan:

Why Melting Glaciers Matter to the Coasts:
https://www.nps.gov/media/video/view.htm?id=36B7DE5E-0259-E02A-7AC6E2838AF5DB31

How Warming Leads to Sea Level Rise:
https://www.nps.gov/subjects/climatechange/explainingccvideos.htm

NASA Jet Propulsion Laboratory – Lesson in Sea-Level Rise (Grades 5-12):
https://www.jpl.nasa.gov/edu/teach/activity/the-science-of-earths-rising-seas/

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