AMERICAN METEOROLOGICAL SOCIETY:

A COLDEX Center for Oldest Ice Exploration PARTNER

Project Ice

Land Ice, Sea Ice, Grounded Ice, and Impacts on Sea Level Rise

TEACHER'S GUIDE

Project Ice

This guide is one of a series produced by Project Ice, a National Science Foundation sponsored initiative of the American Meteorological Society (AMS). AMS is a subawardee of Oregon State University on its NSF Science and Technology Center institutional award (OPP-2019719), Center for Oldest Ice Exploration (COLDEX). The purpose of COLDEX is to “explore Antarctica for the oldest possible ice core records of our planet’s climate and environmental history, and to help make polar science more inclusive and diverse.” Project Ice is the annual K-12 teacher focused activity within COLDEX, and is offered via hybrid delivery that includes a one-week residency at Oregon State University. The goal of Project Ice is to create and train a diverse network of master teachers prepared to integrate paleoclimatology and polar science in their classrooms and provide peer training sessions. To support these teachers' educational experience, Project Ice develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

Project Ice
American Meteorological Society
1200 New York Avenue, NW, Suite 450
Washington, DC 20005
amsedu@ametsoc.org

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Figure i. Land Ice, sea ice, and open water over Greenland. [Photo by Linette Boisvert/NASA]

"The purpose of life is to live it, to taste experience to the utmost, to reach out eagerly and without fear for newer and richer experience."

- Eleanor Roosevelt, First Lady of the United States

"We can't save the planet without uplifting the voices of its people, especially those most often unheard"

- Leah Thomas, intersectional environmentalist and author

Module: Land Ice, Sea Ice, Grounded Ice, and Impacts on Sea Level Rise
Instructor: Project Ice Instructor or Project Ice Graduate
Audience/Grade Level: K-12 Educators

Objectives: After completion of this module participants will be able to:

1. Implement scientifically accurate and pedagogically sound instructional resource materials focused on ***types of ice and impacts on sea level rise***;
2. Integrate Climate and Ocean Science concepts related to ***types of ice and impacts on sea level rise*** into other educational settings;
3. Demonstrate knowledge of the physical foundations of ***types of ice and impacts on sea level rise*** and relate/map these to the Climate Literacy Principles and NGSS.
4. Analyze and interpret data and information related to ***types of ice and impacts on sea level rise*** acquired through direct and remote sensing data, and paleoclimate data from ice cores;
5. Conduct peer training sessions on ***types of ice and impacts on sea level rise*** on a continuing basis, with instructional resource materials, scientific guidance and opportunities to interact with scientists and professionals in the fields of climate science and polar exploration.

STANDARDS:

Ice Core Science - Basic Understandings:

<u>I. Climate Change (1,2,9,10)</u>
1. Glaciers, ice sheets and subglacial environments contain evidence of past atmospheric composition and clues to climate evolution.

2. Earth's climate system involves local, regional, hemispheric, and global phenomena. It is impossible to understand global climate without understanding both individual components of the system and the system as a whole, as evidenced by data from a large number of locations and over a range of time scales.

9. The West Antarctic Ice Sheet, and particularly Thwaites Glacier, is potentially unstable. Complete collapse is projected to contribute up to 3 meters in sea level rise.

10. Ice loss on the Greenland Ice Sheet is also happening at a dramatic rate. The ice sheet as a whole contains an additional 7.4 m of sea level equivalent.

I.a. Additional Paleoclimate Understandings (1,9)
1. Proxy climate data are obtained from indirect methods, such as historical documents, tree rings, lake and ocean sediment cores, and ice cores. Analysis of proxy data discerns trends in atmospheric and geologic variables extending millions of years into the past.

9. Glacial ice covers about 10% of Earth's land area with 99% of it found on Greenland and Antarctica.

<u>II. Ice Dynamics and Glacial History (1,2,3,4,5,6,9)</u>
1. Understanding glacier dynamics, stability of ice sheets and ice sheet response to climate change are imperative for predicting rapid sea level rise.

2. Basal conditions under glaciers have strong control on the flow of glaciers and ice sheets.

3. Ice shelves (front of a glacier pushing out over the ocean and floating) help stabilize ice sheets and limit the amount of ice that can flow into the ocean and raise sea level.

4. Ice sheets that contact the ground below sea level (which are displacing ocean water) can become unstable, particularly if the ground becomes deeper as you go inland.

5. Changes at the grounding line (where the glacier flowed off land and meets the ocean floor) are triggered by changing ocean temperatures and circulation.

6. Changes at the grounding line have the potential for rapid flow of inland ice to the ocean causing sea level rise over short timescales.

9. Scientists research the stability and rapid changes along coastal areas of the West Antarctic Ice Sheet.

Applicable Climate Literacy Principles: 2.B, 2.F, 5.C
(from https://cleanet.org/clean/literacy/climate/index.html)

Next Generation Science Standards (NGSS)

Even though this activity is more of a social studies or geography activity, it can be used to introduce and give context to any units of study that relate to the polar regions or climate change.

Science and Engineering Practices
1. Asking questions (for science) and defining problems (for engineering)
4. Analyzing and interpreting data
6. Constructing explanations (for science) and designing solutions (for engineering)

Crosscutting Concepts
1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
4. Systems and system models. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Disciplinary Core Ideas in Earth and Space Science
K-2: Water exists as solid ice-2-ESS2-3
3-5: Glacier processes—4-ESS2-1
6-8: Water movements both on land and underground (subglacial) MS-ESS2-2
Human activities and greenhouse gases—MS-ESS3-5
9-12: Current climate models-HS-ESS3-6
Human impact-HS-ESS3-5

Engage | Changes in Earth's Cryosphere

There are examples worldwide of changes within Earth's **cryosphere**, the frozen part of the hydrosphere, one of the major components of Earth's climate system. The cryosphere includes sea ice (frozen ocean water, where most salt is excluded), glaciers, ice sheets, and permafrost. The hydrosphere and cryosphere are significantly impacted by global climate change.

Figure 1 shows changes in the Muir Glacier from 1941 to 2004. This glacier is part of Glacier Bay National Park in southeast Alaska. During the Little Ice Age maximum in 1750, ice filled all of Glacier Bay. By 1879, the ice front had retreated 45 miles, and presently it is 60 miles back. Muir Glacier used to be a "tidewater glacier" that calved icebergs into the Bay, but now its terminus, like that of many other glaciers in the area, is on land. (Note that tidewater glaciers experience a natural cycle of advance and retreat, but glaciers worldwide are impacted by climate change.)

Figure 1. In 1941 (left), Muir Glacier filled this valley in Glacier National Park and Preserve in Alaska. By 2004 (right), Muir Glacier had retreated 12 kilometers (7 miles) and thinned by more than 800 meters (2,600 feet). At present, the Muir Glacier ends on land whereas it used to be a tidewater glacier. [Photographs by William Osgood Field (1941) and Bruce F. Molnia (2004). From the Glacier Photograph Collection. Boulder, Colorado USA: National Snow and Ice Data Center.]

To see a broader view of the region and see how the area has changed over the last 30 years, go to:

https://earthobservatory.nasa.gov/images/147171/inlets-iceberg-maker-is-nearly-gone

There are similar examples of before and after images that show the changeable nature of Earth's hydrosphere and cryosphere.

https://earthobservatory.nasa.gov/images/147110/grand-plateau-glacier

https://climate.nasa.gov/images-of-change/?id=778#778-melting-glaciers-enlarge-lakes-on-tibetan-plateau https://climate.nasa.gov/images-of-change/?id=792#792-ice-breakup-at-land-glacier-antarctica

https://climate.nasa.gov/images-of-change/?id=788#788-east-antarctica-ice-shelf-collapses

In groups, select one of these images to focus on. What can you share about the impact of climate change on your selected area?

Explore | Global Climate Change and Sea Level Rise

One of the major impacts of global climate change is changes in sea level. Over Earth's history, paleoclimate data shows that sea level has varied dramatically. During the last glacial maximum about 20,000 years ago (within the Pleistocene Epoch), global sea level was approximately 120 meters lower than today. During the past 7000-8000 years of the Holocene (current geological epoch), sea level has remained fairly constant. However, global sea level has shown an upward trend since 1850 due to the impacts of anthropogenic warming of the climate system. Sea level rise has significant societal consequences since 10% of the world's population lives in coastal areas 10 meters or less above sea level. In the United States, 30% of the population lives in coastal areas vulnerable to sea level rise, due to potential flooding, coastal erosion, and storm-related impacts.

Figure 2 shows satellite-based measurements of global sea level rise from 1993-2018, and independent estimates of the major contributors to this rise: added water mass and ocean thermal expansion (increased volume of the ocean due to warming of ocean water, resulting in higher sea level).

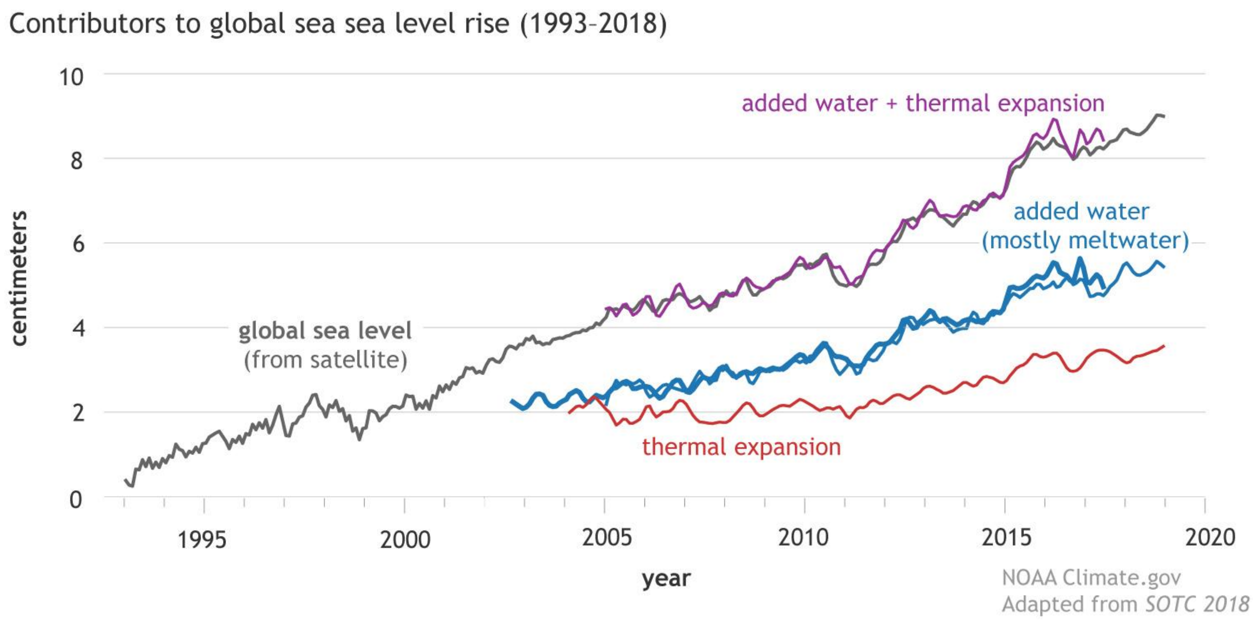

Figure 2. Observed sea level since the start of the satellite altimeter record in 1993 (black line), plus independent estimates of the different contributions to sea level rise: thermal expansion (red) and added water, mostly due to glacier melt (blue). Added together (purple line), these separate estimates match the observed sea level very well. NOAA Climate.gov graphic, adapted from Figure 3.15a in *State of the Climate in 2018*.

Group Review:

- *What has been the overall trend in global sea level since 1993?*
- *The major factors in global sea level change are ocean thermal expansion and added water. Where does most of the meltwater come from?*
- *Describe the contributions of these two major factors in 2005 vs. 2018.*

Figure 3 shows that trends in sea level change are not uniform in the United States (nor are they worldwide). In particular, note the difference between the U.S. West Coast and the Gulf and East Coasts. Also note how sea level is falling along the Alaskan coast.

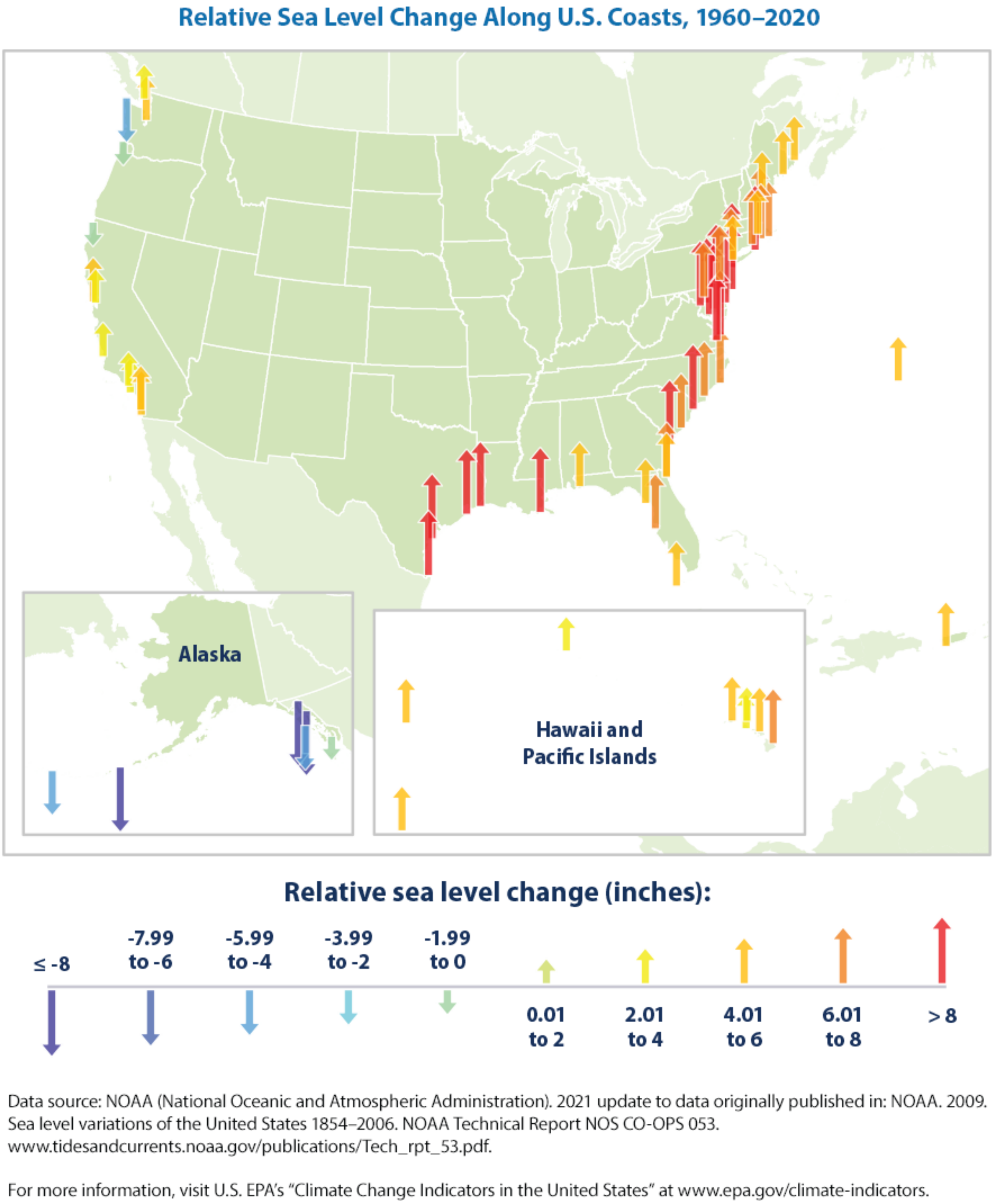

Figure 3. This map shows cumulative changes in relative sea level from 1960 to 2020 at tide gauge stations along U.S. coasts. Relative sea level reflects changes in sea level as well as land elevation. Data source: NOAA, 2021[5]

Interestingly, while glacial melt in Alaska contributes to global sea level rise, local sea levels are progressively decreasing. This has to do with a process called glacial isostatic adjustment and shifts in Earth's tectonic plates. Go to As Lands Rise, Alaska's Sea Level is Sinking to learn more.

Go to Sea Level Trends to view sea level trends in more detail and look at observations in coastal areas of the United States and in other parts of the world.

Group Review:

- *In the majority of locations in the U.S. and worldwide, what is the trend in sea level?*
- *In the U.S. which regions show the largest positive and negative relative sea level changes?*
- *Why might a region experience decreases in local sea level?*
- *Worldwide, consider if the largest increases in local sea level generally occur at tropical, mid-latitude, or polar regions.*
- *Hypothesize how sea level might continue to change over the 21st century. Is it possible that polar regions that have experienced sea level decreases might experience future increases?*

Explain | Types of Ice and Changes in Earth's Climate System

Types of Ice
Earth's cryosphere includes several different forms of ice, including glaciers, expansive glacial ice sheets covering Greenland and Antarctica, sea ice, and **permafrost** or permanently frozen ground most commonly found in polar and/or mountainous regions.

Ocean water freezes during the colder months of the year, forming **sea ice**. The ice contains relatively little salt as most of the impurities are excluded as ice crystals form. The salt trapped between crystals gradually migrates downward to the ocean below, leaving "freshened" sea ice. In the summer, most of the sea ice around Antarctica melts, but multiyear sea ice forms in the Arctic Ocean and persists for several years before flowing out through Fram Strait into the Greenland Sea and eventually melting. Seasonal sea ice is typically a meter thick, while multiyear sea ice can reach up to 10 m thick.

Glaciers are masses of ice that form on land in locations where annual snowfall exceeds annual snowmelt. The pressure of new snow falling on older snow transforms this underlying snow to ice. Glaciers are typically >50 m thick, enough that the ice begins to deform (flow) under its own weight. There are various types of glaciers worldwide; some examples are given in the initial section of this module. Glacier types are described at https://www.nps.gov/subjects/glaciers/types-of-glaciers.htm.

Massive **ice sheets**, glacier land ice extending >50,000 square kilometers (>20,000 square miles) and reaching thousands of meters thick, are found on Greenland and Antarctica. The Greenland Ice Sheet and the two major ice sheets on Antarctica formed when, over thousands of years or more, annual layers of snow were eventually compressed into thick, dense masses of ice. **Ice shelves** are the portions of ice sheets extending over ocean water. Much of Antarctica, especially the western portion, is rimmed by major ice shelves (Figure 4). Ice shelves can be held in place by features in the ocean bedrock (e.g. underwater mountains).

Figure 4. Location of Antarctic ice shelves. [Credit: Agnieszka Gautier, NSIDC]

For the purposes of examining global climate change and impacts on sea level, it is important to understand the dynamics of ice sheets, including glacier flow of the ice sheets and the floating part of the ice sheet (ice shelf) that extends out over water. It is also important to understand how the ice sheet is grounded to the bedrock. It is also essential to understand how sea ice forms and its role in the polar regions.

Consider Figure 5, of which (a) is also shown in the Project Ice module “Understanding the Polar Regions.” This is a diagram of Thwaites Glacier, which is part of the **West Antarctic Ice Sheet (WAIS)** on the Antarctic Peninsula. Figure 5b is a photograph of the “tongue” of Thwaites Glacier on the left side with sea ice seen on the right side of the image.

The WAIS is a marine ice sheet, which sits atop a series of islands and the floor of the Southern Ocean, with parts of the ice sheet more than 1.7 km (1 mi.) below mean sea level. Note that the **East Antarctic Ice Sheet (EAIS)** differs from the WAIS in that the EAIS sits on a major land mass well above sea level and is generally thicker. The EAIS is generally more stable than the WAIS. The two ice sheets are separated by the Transantarctic Mountains.

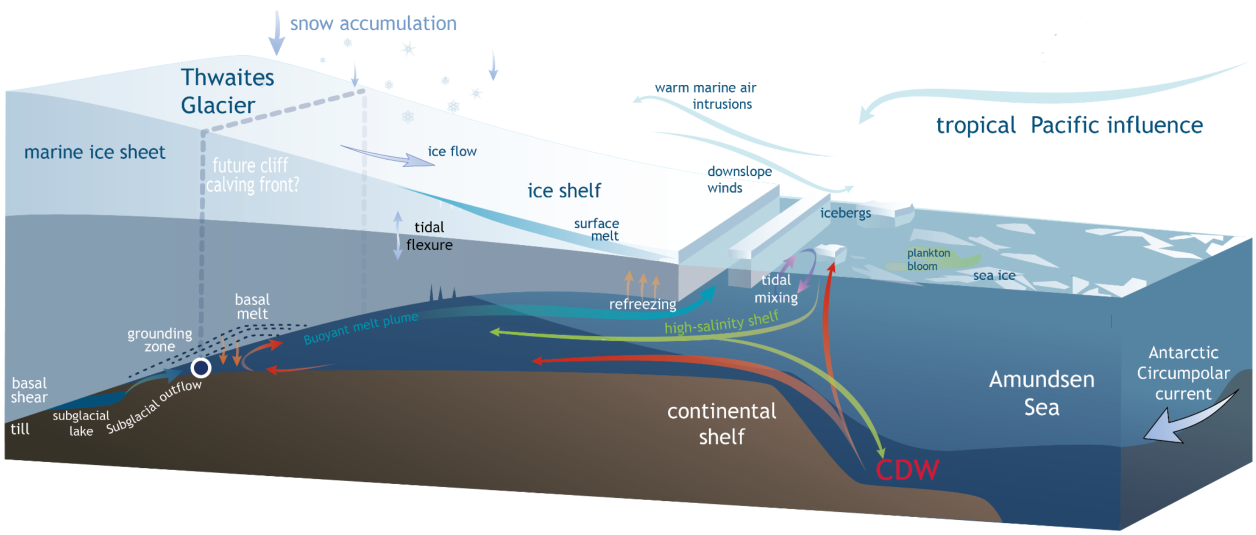

Figure 5a. Diagram of Thwaites Glacier in the West Antarctic Ice Sheet (WAIS), and the key processes impacting its stability. [Image modified from How much, how fast?: A science review and outlook for research on the instability of Antarctica's Thwaites Glacier in the 21st century. by Scambos et al. 2017 in Global and Planetary Change. Graphic derived from original version by Jennifer Matthews, Institute of Geophysics and Planetary Physics (IGPP) at Scripps Institution of Oceanography.]

Figure 5b. Photo of the “tongue” of Thwaites Glacier, with sea ice also visible on the right side of the image. [Photo by NASA/James Yungel]

Examine the following features of Figure 5a: marine ice sheet, arrow showing ice flow within Thwaites Glacier, ice shelf, formation of patches of sea ice, and the grounding zone. The grounding line is where the ice first begins to float; it extends upward from the contact of ocean water with bedrock to the surface of the ice sheet. **Grounded ice** is ice that is in contact with the underlying bedrock and is not floating. The weight of grounded ice is supported by land. The grounding line forms the boundary between the floating portion of the ice sheet (the ice shelf) and the glacier, which is land based. To learn more about grounding lines, visit Grounding Lines - AntarcticGlaciers.org.

Glacier ice flows slowly from sources at higher elevations to lower elevations, where the ice melts and flows into the ocean. The NOAA GFDL site Ice Sheet Dynamics succinctly describes the dynamic nature of ice sheet flow:

“Ice sheets flow under their own weight. The rate of ice-sheet flow is determined by the balance between the effects of gravity, basal resistance opposing the ice sheets, and internal deformation of ice. Depending on basal resistance, which is determined by the nature of underlying strata (e.g., hard rock, deformable sediments, etc), ice flow can be dominated by either basal sliding (as happens in ice streams) or vertical shear (as happens in parts of ice sheets where ice is frozen to the bed).”

Also, regarding the grounding line:
“Ice sheets that rest on bedrock below sea level are called marine ice sheets. The transition between the grounded part of marine ice sheets and their floating parts (ice shelves) is the grounding line. Dynamics of the grounding line determin[e] the horizontal extent of marine ice sheets. The ice discharge across the grounding line from the grounded part of the ice sheet to the floating part, ice shelves, determines ice-sheet contributions to the global sea level. An existing marine ice-sheet instability hypothesis suggests that the stability of marine ice sheets depends only on the local bedrock slopes. GFDL scientists have developed a theory of laterally confined marine ice sheets (Haseloff and Sergienko, 2018). This theory suggest[s] stability of the grounding line of such ice sheets is determined by the local properties of the bedrock and the integral properties of the ice shelves.”

The video at File:West Antarctic Collapse.ogv - Wikimedia Commons provides visuals of the grounding line and how it has retreated in certain areas of West Antarctica. Figure 6 shows the bedrock elevation of Antarctica and inward retreat of grounding lines.

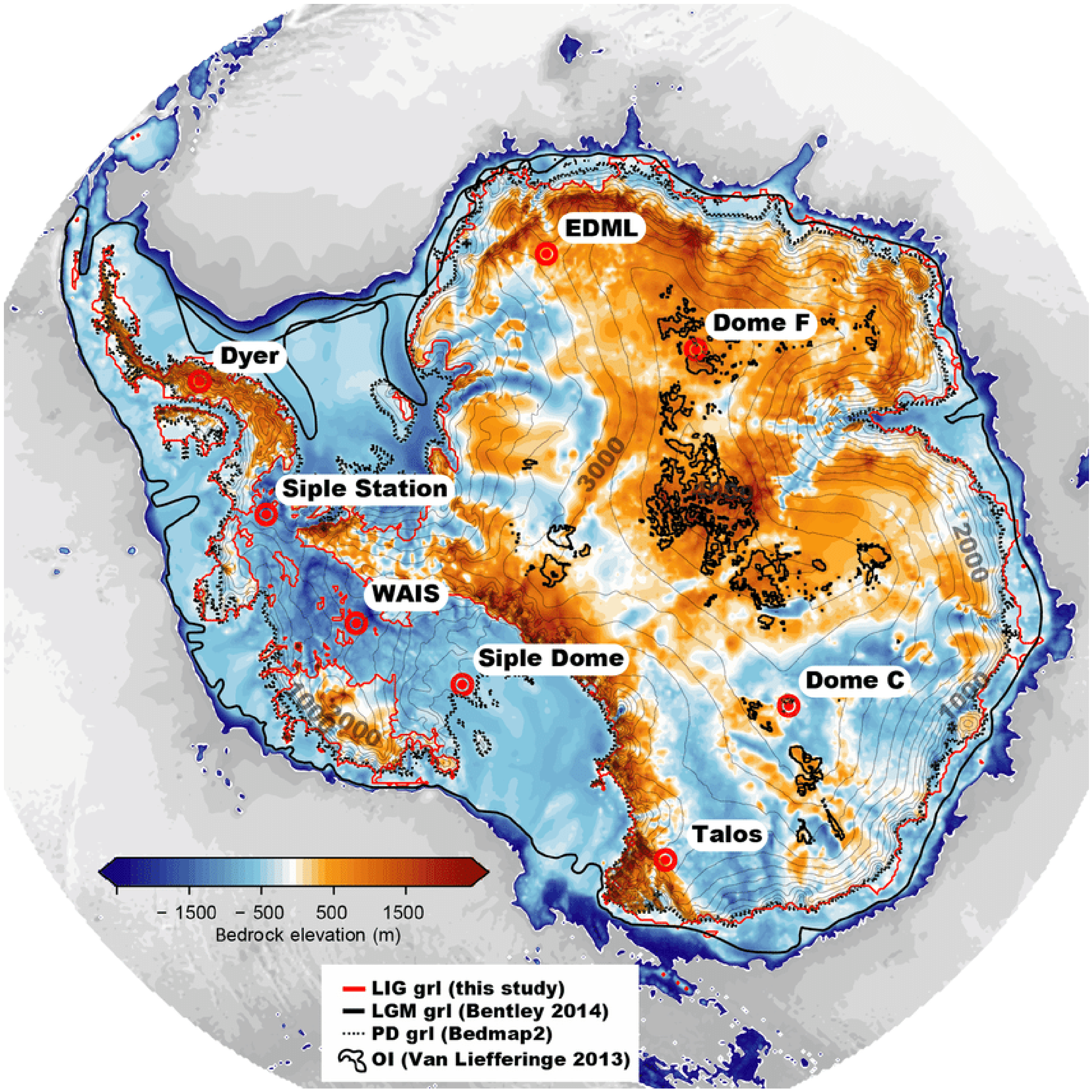

Figure 6. Antarctic bedrock topography overlain by surface contours (grey lines). The present-day (PD) grounding line (grl) from BEDMAP2 (Fretwell et al., 2013) depicted by the dashed black line. The Last Glacial Maximum (LGM) grounding line reconstruction from Bentley et al. (2014) (thick black lines) is compared to simulated grounding line retreat in one of the ensemble members for the Last Interglacial (LIG, red line). Regions previously identified as potentially viable sites for Oldest Ice (Van Liefferinge and Pattyn, 2013) are outlined by thick black lines. [From: Sutter, Johannes C. R. & Fischer, Hubertus & Grosfeld, Klaus & Karlsson, Nanna & Kleiner, Thomas & Liefferinge, Brice & Eisen, Olaf. (2019). Modelling the Antarctic Ice Sheet across the mid-Pleistocene transition – implications for Oldest Ice. The Cryosphere. 13. 2023-2041. 10.5194/tc-13-2023-2019.]

Group Discussion of Types of Ice and Glacial Ice Sheet Dynamics

Land Ice, Floating (or Sea) Ice, and Grounded Ice

To explore the impact of melting ice on global sea level rise, is is helpful to separate ice into three categories

Ice that is already floating: sea ice, ice shelves (the extensions of land-based ice sheets), icebergs

Land-based ice: glaciers, snow on mountains

Grounded ice: ice resting on Earth's bedrock

Floating ice (sea ice or ice shelves) is already displacing the ocean water surrounding it. Upon melting, the input of this fresh water has no impact on sea level. There are various ways of visualizing this, but a simple experiment is to have a clear container of water, place ice cubes in the water, mark the height of the water surface, and then let the ice completely melt and mark the final height of the water surface. While floating ice that melts has little change on sea level, global climate change has a major impact on sea ice through the ice albedo feedback loop described in the Project Ice module "Understanding the Polar Regions."

The melting of land-based ice contributes strongly to sea level rise, as seen in Figure 2 (added water). Warmer water and air temperatures, along with other circulation factors, contribute to the breakup of ice shelves. While this floating ice has minimal impact on sea level, ice shelf breakup allows glacier flow on the land-based ice sheet to accelerate, and this input of ice/water does lead to sea-level rise. Scientists are particularly concerned about acceleration and collapse in certain areas of Antarctica, such as the Thwaites glacier, which is similar to the size of Florida.

Grounded ice is the portion of the ice sheet behind the grounding line. The position of the grounding line is strongly influenced by characteristics of the ocean overlying the bedrock. If ocean temperatures warm, more ice at the grounding line melts, allowing the grounding line to retreat inland. This raises sea level.

Observed Changes in the Antarctic

The Intergovernmental Panel on Climate Climate (IPCC) Polar Regions Fact Sheet, based on the Sixth Assessment Report, succinctly describes aspects of climate change in the Antarctic (from Regional fact sheet - Polar Regions)

- "Both major ice sheets – Greenland and Antarctica – have been losing mass since at least 1990, with the highest loss rate during 2010–2019 (high confidence), and they are projected to continue to lose mass.

- Observations show a widespread, strong warming trend starting in the 1950s in the Antarctic Peninsula. Significant warming trends are observed in other West Antarctic regions and at some stations in East Antarctica (medium confidence).
- The Antarctic Peninsula, West Antarctica and some East Antarctic regions are projected to continue to warm in the 21st century at a rate greater than the global average.
- Antarctic snowfall and net snow accumulation have increased over the 20th century (medium confidence).
- Mass losses from West Antarctic outlet glaciers, mainly induced by ice-shelf basal melt, outpace mass gain from increased snow accumulation on the continent.
- At sustained warming levels between 2°C and 3°C, the West Antarctic Ice Sheet will be lost almost completely and irreversibly over multiple millennia; both the probability of complete loss and the rate of mass loss increase with higher surface temperatures.
- For Antarctic sea ice, there is no significant trend in satellite-observed sea ice area from 1979 to 2020 in both winter and summer, due to regionally opposing trends and large internal variability. "

Group Discussion of Observed Changes in the Antarctic

Elaborate | Climate Change Projections, Ice in the Antarctic, and Sea Level Change

The Polar Regions are particularly sensitive to warming of Earth's climate system. Temperature changes tend to be amplified in these regions and the cryosphere is sensitive to these changes. Scientists are concerned about how warmer ocean water and air temperatures are affecting Antarctic glaciers, particularly in the WAIS where much of the ice sheet is grounded by bedrock that is below sea level. Thwaites Glacier, which is similar in size to the land area of Florida, is of particular concern. The Cooperative Institute for Research in Environmental Sciences (CIRES) notes that mass loss at Thwaites accounts for 4% of annual global sea level rise. Glacial breakup could, over the course of centuries, lead to 2 ft. of sea level rise, and much more if its breakup destabilizes other areas of the WAIS. Thwaites is one of many glaciers in Antarctica being impacted by climate change.

Watch the video at What is happening at Thwaites Glacier? International Thwaites Glacier Collaboration to learn more about what is happening at Thwaites Glacier. Then, review the page The Threat from Thwaites: The Retreat of Antarctica's Riskiest Glacier | CIRES

1. Thwaites Glacier in the West Antarctic Ice Sheet is particularly sensitive to climate change because the grounding line is:

a. well below sea level
b. near sea level
c. well above sea level

2. The presence of an intact ice shelf _______ glacier outflow.

a. help slow down
b. does not have much impact on
c. help accelerates

3. On Thwaites Glacier, what is the main factor in ice shelf breakup?

a. Warmer air temperatures creating meltwater
b. Increased precipitation over the West Antarctic Ice Sheet
c. Warmer and salty ocean water melting the ice sheet from below
d. Stronger winds over the West Antarctic Ice Sheet

4. In areas where the bedrock gets deeper as you go inland, retreat of the grounding line _______ the height of the ice above the ocean surface.

a. increases
b. has little effect on
c. decreases

5. Will increasing the height of the ice face at the grounding line likely _______.

a. stabilize the ice front and slow ice flow
b. destabilize the ice front and lead to faster ice flow

6. If the WAIS were to break up over the course of centuries, it could lead to _______ of global sea level rise.

a. 2 in.
b. 10 in.
c. 2 ft.
d. 10 ft.

While we are focusing on the WAIS in this module, it is important to remember that there are other areas of glacier ice worldwide, such as Greenland Ice Sheet and other types of glaciers, that are at more temperate climates. While the volume of ice is not as great as in the Antarctic Ice Sheets, these areas are strongly affected by warming temperatures and are important contributors to sea-level rise.

Climate models are an essential tool for understanding and predicting natural and human-induced climate change and implications for sea-level. Projected changes are commonly described in IPCC reports, such as the Sixth Assessment Report, in relation to which Representative Concentration Pathway (RCP) emission scenario is followed. In Figure 7, RCP2.6 represents a lower level of future greenhouse gas emissions with the enactment of various climate policies and RCP8.5 represents a high level of greenhouse gas emissions, akin to a "business as usual" without climate policies scenario.

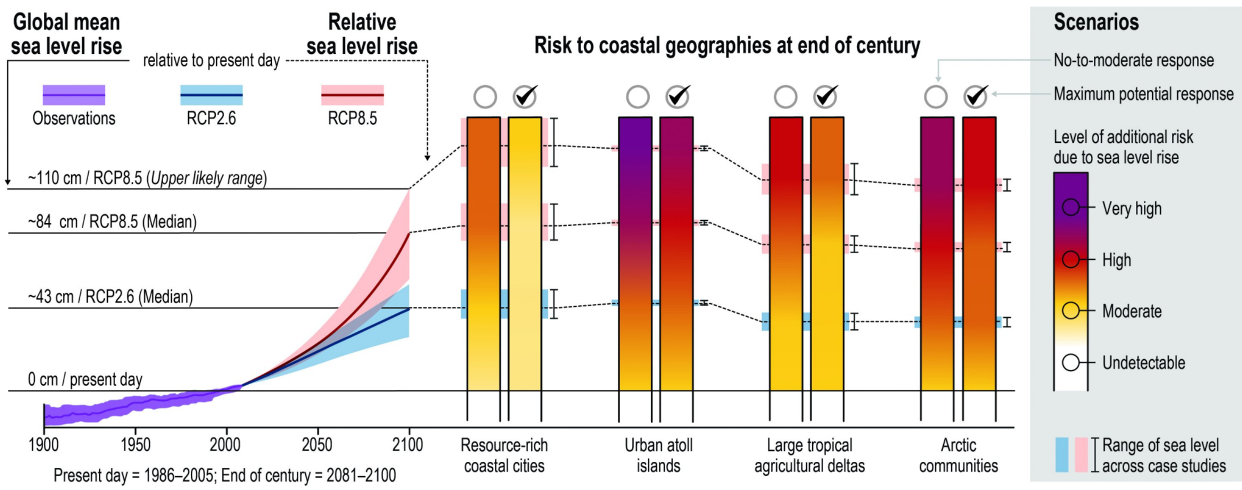

Figure 7. Additional risk related to sea level rise (SLR) for low-lying coastal areas by the end of the 21st century. [Figure 4.3 from Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321-445. https://doi.org/10.1017/9781009157964.006.]

7. According to Figure 7, under the median value of RCP2.6, how much will the global sea level rise by 2100 compared to the present-day level?

a. 15 cm (5.9 in.)
b. 43 cm (16.9 in.)
c. 84 cm (33.1 in.)
d. 110 cm (43.3 in.)

8. According to Figure 7, what is the impact on resource-rich coastal cities under RCP2.6 (Median) with no-to-moderate response?

a. undetectable
b. moderate
c. high
d. very high

9. What is the impact on urban atoll islands under RCP8.5 (Median) with a maximum potential response?

a. undetectable
b. moderate
c. high
d. very high

To visualize the impact of sea-level rise on coastal cities under 2°C and 4°C warming, go to Climate Central - Sea Level Rise and the Fate of Coastal Cities. Note that 2°C of warming would be approximately associated with the upper limit of the RCP2.6 scenario; 5°C of warming would be approximately associated with the median RCP8.5 scenario, so 4°C would be at an emissions scenario between RCP2.6 and RCP8.5.

10. It is clear that without mediating factors (e.g. significant engineering design), major coastal cities could experience _______ flooding due to sea level rise by 2100.

a. minor levels of
b. major levels of

Evaluate | Summarizing Types of Ice and Sea Level Rise

To review what has been presented and investigated during this module:

11. Describe the two major factors in global sea level rise.

12. In general, sea level has increased most in _______ latitude regions.

a. low
b. middle
c. high

13. Which Antarctic ice sheet poses the most immediate concern to sea level rise?

a. East Antarctic Ice Sheet
b. West Antarctic Ice Sheet

14. With warming ocean temperatures, the grounding line:
   a. retreats
   b. remains in the same location
   c. advances

15. Which of the following types of ice, if melted, raise sea level?
   a. grounded
   b. land
   c. sea
   d. Both a and b are correct.
   e. Both b and c are correct.

16. The water content of Thwaites Glacier translates into _______ ft. of global sea level rise.
   a. 0.5
   b. 2
   c. 10
   d. 50

17. The breakup of an ice shelf _______ glacier flow.
   a. accelerates
   b. decelerates

18. Under the climate modeling RCP2.6 scenario, global sea level would increase a little over 1 ft. by _______.
   a. 2030
   b. 2050
   c. 2100
   d. 2200

Workshop Extension | Land Ice/Sea Ice/Grounded Ice