AMERICAN METEOROLOGICAL SOCIETY:

A COLDEX Center for Oldest Ice Exploration PARTNER

Project Ice

Understanding the Polar Regions

—

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:

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Figure i. This aerial photograph, taken as part of the NASA Operation IceBridge campaign, shows a multi-layered lenticular cloud hovering near Mount Discovery in Antarctica, a volcano about 70 km (44 mi.) southwest of McMurdo Station on the Antarctic Peninsula. IceBridge was an airplane-based mission that flew over Antarctica and the Arctic, monitoring conditions there until a year after NASA's new ice-observing satellite, ICESat-2, launched in 2018. [Photo by Michael Studinger, NASA Earth Observatory]

"I believe it is in our nature to explore, to reach out into the unknown."

- Ernest Shackleton, Antarctic Explorer (1874-1922)

"Life is either a daring adventure or nothing."

- Helen Keller, American Author, Educator, and Activist

Module: Understanding the Polar Regions
Instructor: Project Ice Instructor or Project Ice Graduate
Audience/Grade Level: K-12 Educators

STANDARDS:

Project Ice Objectives

Understanding Climate Change and Paleoclimate -

3. Analyze feedback mechanisms in the climate system, such as ice-albedo feedback, and their influence on Earth's climate system.

Studying Ice Dynamics and Glacial History -

1. Compare the behavior of land and sea ice in the Arctic, including Greenland, and Antarctic regions

2. Differentiate between the West Antarctic and East Antarctic Ice Sheets and their different responses to climate change

Climate Literacy Principles from: https://cleanet.org/clean/literacy/climate/index.html

2. Climate is regulated by complex interactions among components of the Earth system. (b, f)

4. Climate varies over space and time through both natural and man-made processes (e)

5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling. (b)

7. Climate change has consequences for the Earth system and human lives. (a)

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.

Performance Expectations

- 2-ESS2-2. Develop a model to represent the shapes and kinds of land and bodies of water in an area.
- 2-ESS2-3. Obtain information to identify where water is found on Earth and that it can be solid or liquid.
- 3-ESS2-2. Obtain and combine information to describe climates in different regions of the world.
- 4-ESS2-2. Analyze and interpret data from maps to describe patterns of Earth's features.
- MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.
- 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.

Science and Engineering Practices

1. Asking Questions and Defining Problems
4. Analyzing and Interpreting Data
8. Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas

- ESS2.C: The Roles of Water in Earth's Surface Processes
- ESS2.D: Weather and climate

Crosscutting Concepts

1. Patterns
2. Cause and Effect
3. Scale, Proportion, and Quantity
7. Stability and Change

Engage | Where in the world are we?

If presented with the **Figure 1** satellite image compilation of the Earth without any map guides or other labeling, what knowledge would you use to discern what area of the world you are viewing? Your eyes are likely drawn to the expansive area of white in the top part of the image. Within this expansive area of white, notice the solid, brighter white regions encircled by areas of grayish-white. There are other areas of white on the satellite image, but the swirls indicate patterns of clouds. Therefore, this expansive white area must be cold, moderately to highly reflective ice. This huge area of ice is surrounded by an extensive region of blue, signifying ocean water. Three main continental land areas around the circumference of the image appear brown.

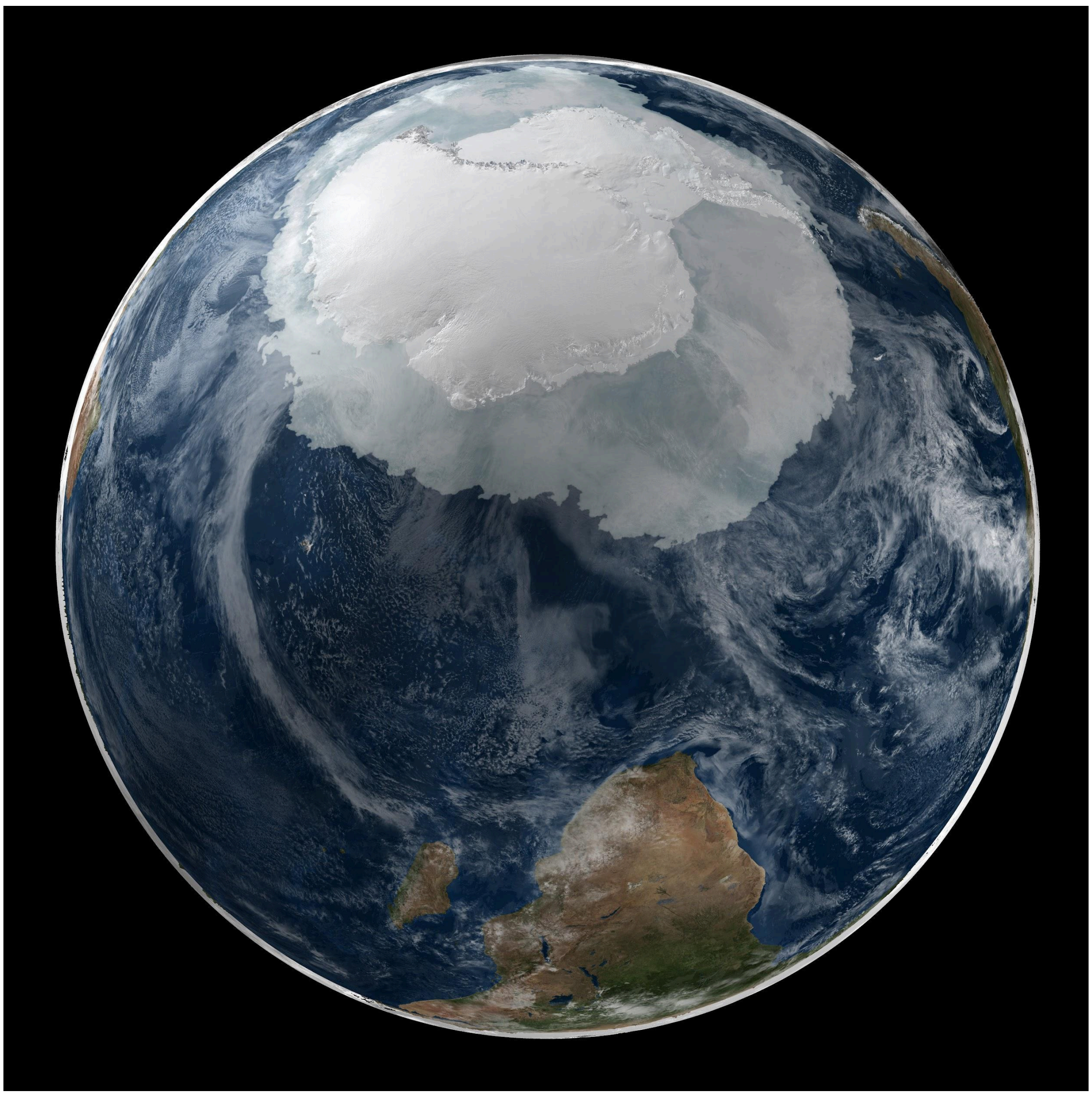

Figure 1. Satellite image compilation of a polar region from multiple data sources. [NASA SVS]

Group Review and Discussion:

Consider these geographical characteristics of Figure 1:

- an expansive area of ice surrounded by ocean water
- different shading of white within this expansive area, signifying a variation in the type of ice
- the area of ice is surrounded on all sides by ocean
- a continental land mass extends into the bottom of the image

1.) Is the focus of the image a tropical, midlatitude, or polar region?

2.) If this is a polar region, which pole is shown? If tropical or midlatitude, what continent are we viewing?

3.) What continent is shown in the lower part of the image? What about on the upper right side of the image?

4.) Why are there different shadings of white/grayish white shown within the ice area?

Explore | The Polar Regions

The **polar regions** are the regions surrounding the geographic **North and South Poles,** as shown in **Figure 2**. Both areas experience extreme cold, with the Antarctic being colder overall. The only ice sheets on Earth (Greenland and Antarctica) are found in the polar regions. Both regions have significant formation of sea ice, but its seasonal behavior, significance for climate, and response to climate change vary. Because the polar regions are so cold and remote, it is easy to think they are virtually the same, but while there are some similarities, there are also some large-scale differences, including geography, geology, and biology.

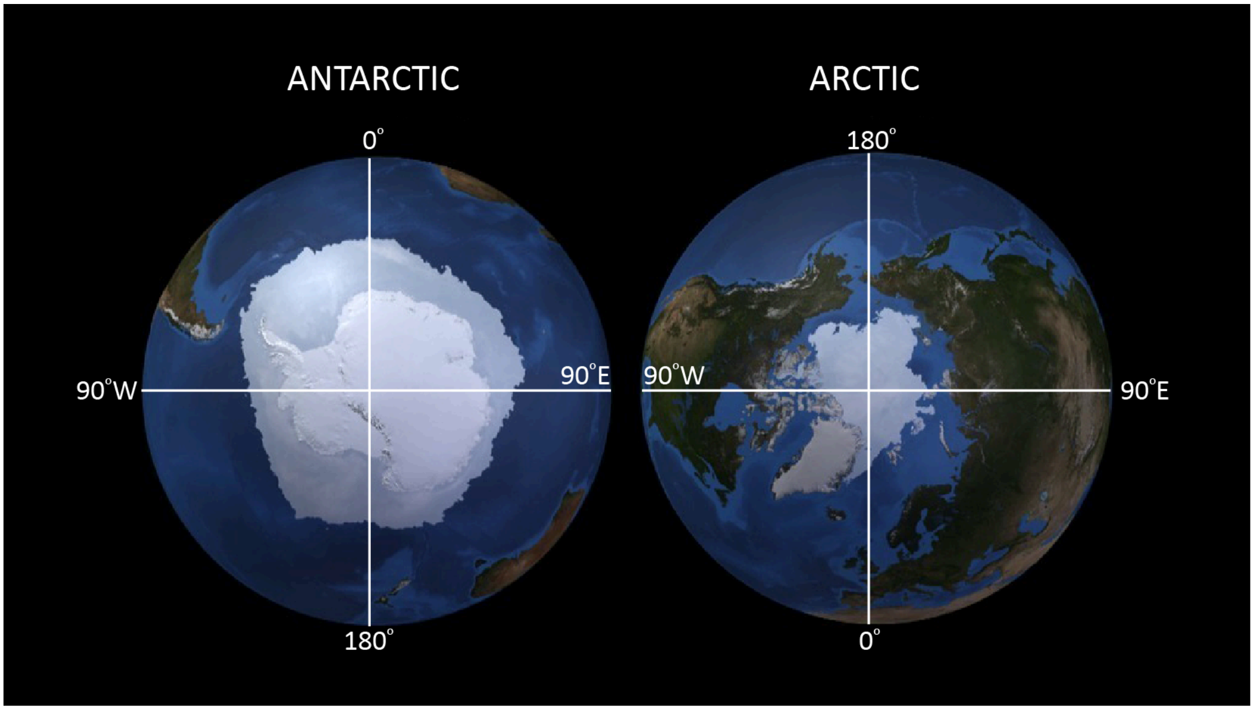

Figure 2. Views of the Antarctic and Arctic showing the Southern Hemisphere winter and Northern Hemisphere summer. Note that this particular view of the Antarctic differs from Figure 1. [Modified from NASA Goddard Space Flight Center]

The area in the south is called the **Antarctic** (left side of Figure 2) and includes the area south of the Antarctic Circle (66°34' S latitude). From the Antarctic Circle to the South Pole, there are approximately (accounting for refraction) 6 months of darkness during the winter and 6 months of light during the summer. At the South Pole, the Sun only rises and sets once each year! The Antarctic region encompasses the vast Antarctic continent, which is surrounded by a surrounding expanse of ocean. Other than scientists and the staff that support the research, no one lives on the continent of Antarctica. However, 30 countries operate scientific bases, including 35 field research stations. Antarctica is not owned by any country but is governed by the Antarctic Treaty, which was signed by 48 nations and protects the continent for science. Antarctica has no land mammals, and the largest purely terrestrial animal is a wingless fly. There are penguins that generally live on extensive areas of sea ice "fastened" to the Antarctic continent (known as fast ice) but also hunt for food in the ocean. The ocean also contains whales, seals, sea birds, and other marine animals that either directly or indirectly depend on the abundance of Antarctic krill as a food source.

The northern polar area is called the **Arctic** (right side of Figure 2) and includes most of the Arctic Ocean as well as the northern parts of North America, Europe, and Asia. Unlike the Antarctic, the Arctic region is an ocean surrounded by land. The most common definition of “Arctic” is the area within the imaginary circle at 66°34’ N latitude above which the Sun does not set during the summer and does not rise during the winter. Like the South Pole, the North Pole experiences 6 months of light and 6 months of darkness. Some define the Arctic as the region above the “treeline” where only shrubs and lichens grow, while other researchers define it as the region where the average daily summer temperature does not rise above 10°C (50°F) (**Figure 3**). Millions of people have lived in the Arctic for thousands of years and have adapted well to the frigid temperatures and the long, dark winter nights. There is also a large diversity of plant and animal species that live on land and in the ocean in the Arctic Region, including land mammals, polar bears, whales, and seals.

Figure 3. Map of the Arctic Region. The dashed blue line shows the Arctic Circle. The solid red line encompasses the region where the average daily summer temperature does not rise above 10°C (50°F). [CIA World Fact Book]

Group Review and Discussion:

1.) The Antarctic is a continent surrounded by ocean, whereas the Arctic is an ocean surrounded by land. How might this varied geography affect polar climate and the response of these regions to climate change?

2.) The world's ice sheets are found on Greenland and Antarctica. Why do you think this is?

3.) The website https://nsf.gov/news/overviews/arcticantarctic/index.jsp states "The Antarctic, uniquely in the world, is a continent set aside by treaty purely for science." Discuss the implications of this statement.

4.) Why do you think scientists are so interested in studying the structure and behavior of ice sheets and sea ice?

Explain | Characteristics of the Polar Regions

The Hydrosphere and Cryosphere

The Earth's **hydrosphere**, a vital component of its climate system, encompasses all water in various states—whether it be on, under, or above the Earth's surface. The **cryosphere** is the portion of the hydrosphere that contains water in solid (ice) form. **Figure 4** shows the distribution of Earth's water, the vast majority of which is found in the ocean. The amount of water located in the atmosphere is critical for life on the planet as we know it, but is a tiny percentage of all of Earth's water.

Saltwater in the ocean represents about 96.5% of Earth's water and is an essential part of Earth's climate system. According to NASA, the ocean "has absorbed 90% of the warming that has occurred in recent decades due to increasing greenhouse gases, and the top few meters of the ocean store as much heat as Earth's entire atmosphere." Other forms of water, including ice and water vapor, are also integral players affecting climate. **Freshwater** encompasses 2.5% of Earth's water. Of this 2.5%, the majority (68.7%) is contained within glaciers and ice sheets. Of the 2.5%, a small percentage (1.2%) is surface and other freshwater, of which ground ice and permafrost are the major components. Ice has a significant influence on climate despite its rather small segment of the hydrosphere as a whole.

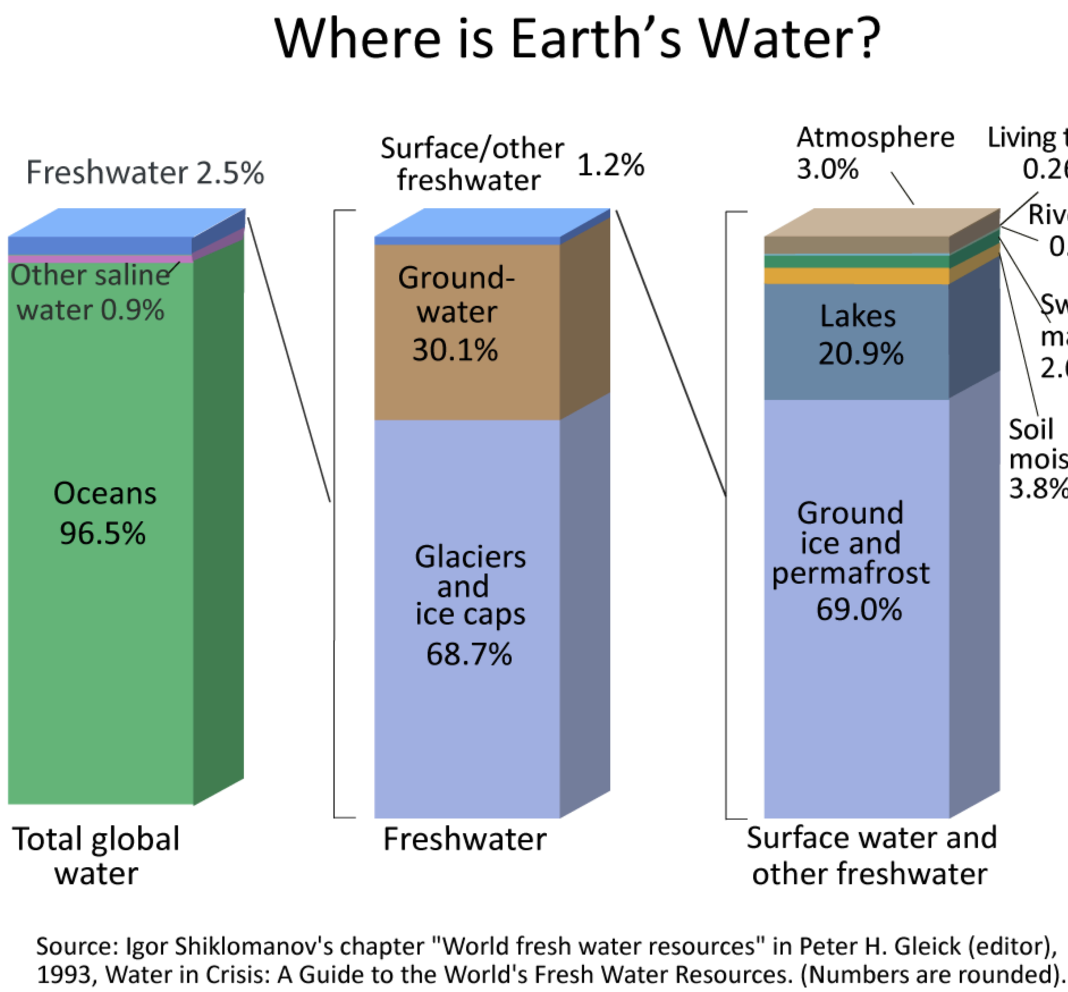

Figure 4. Distribution of Earth's water. [USGS]

The cryosphere is the portion of the hydrosphere in solid form. This frozen freshwater is found in massive glacial ice sheets, glaciers, floating sea ice, and permafrost (permanently frozen ground). A **glacier** is a mass of ice on land that forms where annual snowfall exceeds annual snowmelt. As snow accumulates, the pressure of the new snow transforms the underlying snow into ice. Glaciers are dynamic and able to move under their own weight. Most (99%) of Earth's freshwater ice is contained within the massive **ice sheets** found on Greenland and Antarctica. An ice sheet is glacier land ice extending 50,000 km^2 (20,000 $mi.^2$) or more. These ice sheets formed when, over thousands of years or more, layers of winter snow did not fully melt in summer and were eventually compressed into thick, dense masses of ice. Glacier land ice (including the Greenland and Antarctic ice sheets) currently covers about 10% of the planet's surface area, but, at times during the past 1.8 million years, it has expanded to cover as much as 30% of Earth's surface, primarily in the Northern Hemisphere. At the peak of the last major glacial advance (during the Ice Ages), about 20,000 to 18,000 years ago, ice covered much of what is now Canada, the northern tier states of the United States, the British Isles, and parts of northwest Europe.

Under the perpetual pull of gravity, glacier land ice flows slowly from sources at higher elevations to lower elevations, where the ice melts and flows into the ocean. Areas of relatively “fast” moving land ice are called **ice streams**. Around Antarctica, glacier land ice flows to the ocean and, since ice is less dense than seawater, it floats and forms **ice shelves** (typically about 500 m or 1600 ft. thick) that extend out from the coastline. As ice breaks off the shelf edge, flat-topped icebergs are formed and float in surface ocean currents around Antarctica. Irregularly shaped icebergs break off the ice streams of Greenland and flow out into the Atlantic Ocean. Whereas 75% of the coastline of Antarctica is fringed by ice shelves in the ocean, Greenland has outlet glaciers and ice streams that end in **ice tongues** (located in fjords) rather than ice shelves.

Sea ice forms when ocean water freezes during the colder months of the year. When ocean water freezes, the ice contains relatively little salt because most of the impurities are excluded as ice crystals form. The salt that is trapped between crystals gradually migrates downward to the water below, leaving “freshened” sea ice. In the summer, most of the sea ice around Antarctica melts. In the Arctic Ocean, however, most sea ice melts annually, though some multi-year sea ice persists for several years before flowing out through Fram Strait into the Greenland Sea and eventually melting.

The Antarctic and Greenland Ice Sheets

Most of the world’s ice volume is found at polar locations. Since there is a large continent positioned at the South Pole versus the ocean surface of the North Pole, a greater proportion of the world’s ice is deposited in Antarctica. About 90% of the planet’s land ice blankets Antarctica, which is roughly the size of the United States (including Alaska), Mexico, and the Central American countries combined. Of Antarctica's 14 million km^2 (5.4 million $mi.^2$) of land area, 97.6% (13.7 million km^2) is ice-covered. Separated by the Transantarctic Mountains, two major ice sheets cover Antarctica (**Figure 5**). The **East Antarctic Ice Sheet (EAIS),** which averages 2.6 km (1.6 mi.) in thickness and is situated well above sea level, accounts for about two-thirds of the ice. The thickest portions of the EAIS (generally about 3.2 km or 2 mi. thick) are found over the polar plateau, whereas thinner portions are nearer the ice edge. The **West Antarctic Ice Sheet (WAIS)** sits on a series of islands and the floor of the Southern Ocean, with parts of the base of the ice sheet more than 1.7 km (1 mi.) below mean sea level (MSL). This is due to the unique geology and climate of the region. The ice sheet is grounded to the bedrock in that region, much of which happens to be well below sea level. The mean thickness of the WAIS is less than the EAIS. The portion of the WAIS over the Antarctic Peninsula is often referred to as the *Antarctic Peninsula ice sheet*.

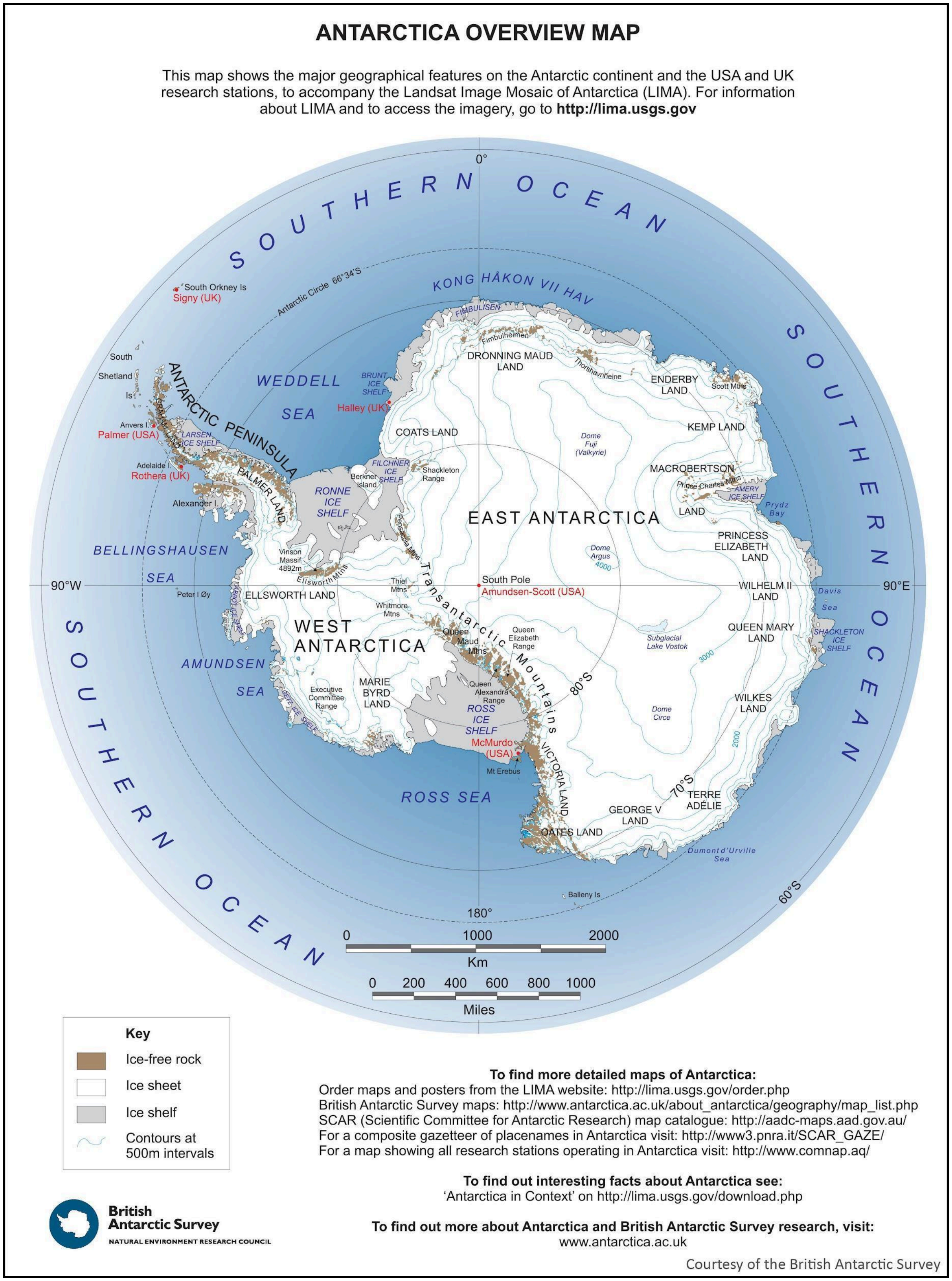

Figure 5. Major geographical features of Antarctica, including the EAIS and WAIS, which can be further segmented into the Antarctic Peninsula and WAIS regions. [British Antarctic Survey]

The ice sheets covering the continent are made up of many glaciers that flow together like frozen rivers, constantly moving under their own weight, pulled by the force of gravity down elevation toward the ocean. **Figure 6** is a diagram of an Antarctic glacier, in this case, the Thwaites Glacier in the WAIS. When the terminus, or end of the glacier or ice sheet, meets the Southern Ocean, it stays attached to the land-based ice as it floats, creating an ice shelf. Some large ice shelves are beginning to break up, and scientists are studying the mechanisms that may be causing this, including the warming of air temperatures, the changing of albedo (the reflectivity of the ice surface changes when it develops meltwater), and the increased temperature of the ocean water under the ice shelves. Ice shelves act as a "buttress" to the land-based ice, slowing its flow to the ocean. Because floating ice is already displacing its own volume, sea level will not be affected by ice shelf breakup, but when land-based ice flows into the ocean, there will be sea level rise, which can be abrupt.

Consider the analogy of an ice cube placed in a glass of water. As the ice cube melts, the water level will not rise; in fact, it will go down very slightly due to liquid water being less dense than ice.

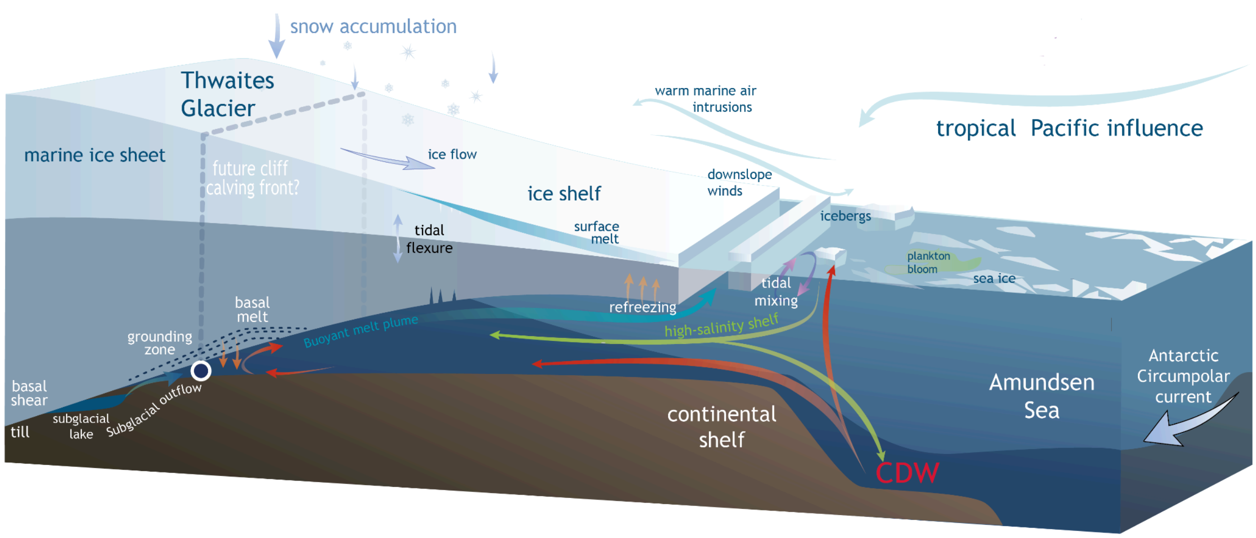

Figure 6. Diagram of Thwaites Glacier in the WAIS, and the key processes impacting its stability. [Modified from Scambos et al., 2017]

In the Northern Hemisphere, the **Greenland Ice Sheet**, with a surface area of about 1.7 million km^2 (600 million $mi.^2$) and an average thickness of about 1.4 km (0.9 mi.), covers 80% of the island of Greenland's land area. This ice sheet is what remains of the massive **Laurentide ice sheet** that blanketed most of Canada and the Northern U.S. about 20,000 years ago (**Figure 7**).

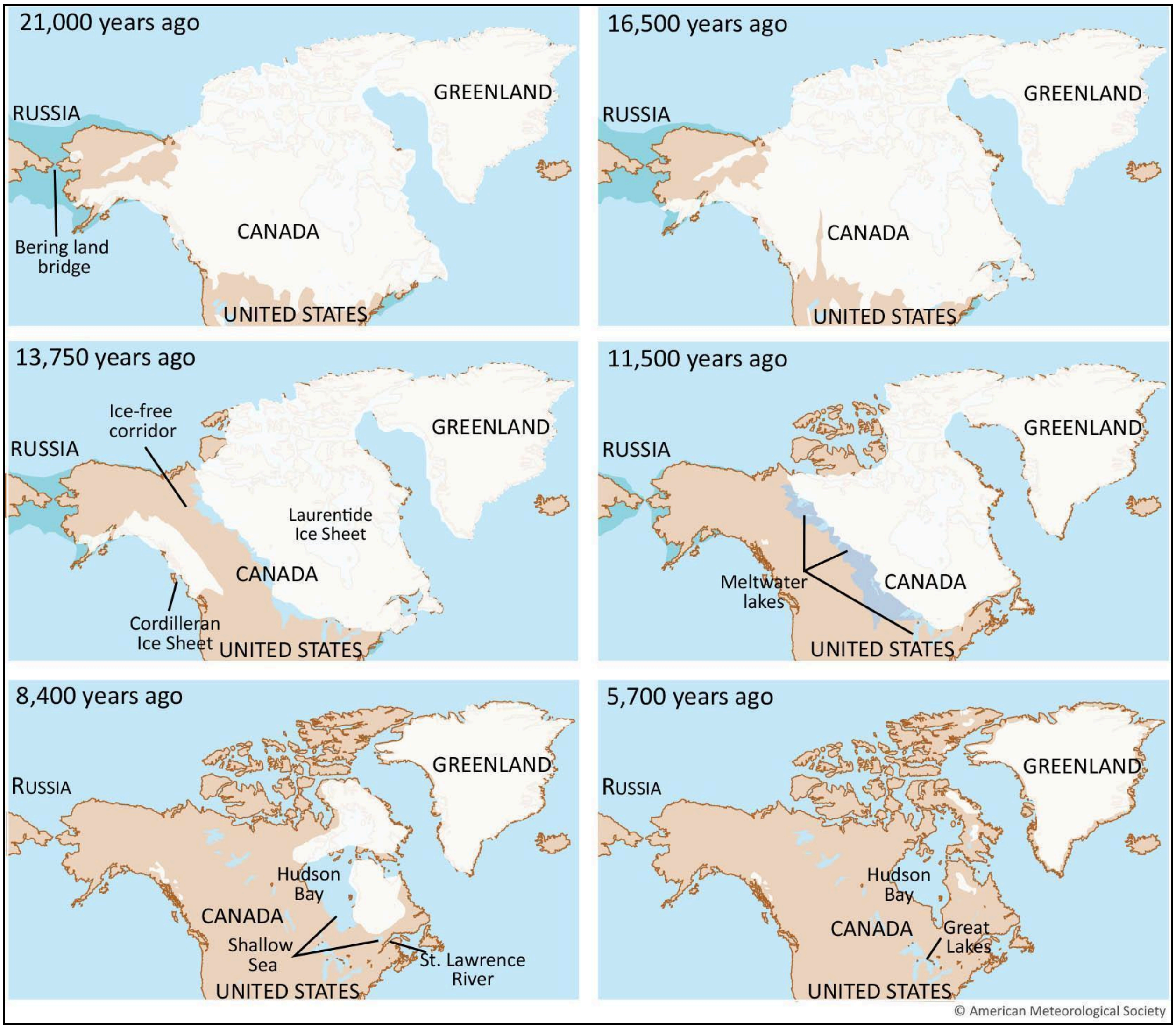

Figure 7. At its maximum, the Laurentide Ice Sheet extended across about half of North America. It contributed to the formation of the present-day Great Lakes and Hudson Bay, as well as other aesthetic physical features like those in Acadia National Park in Maine. [Modified from Figure 8.4, *Our Changing Climate* textbook]

Greenland (**Figure 8**) is slightly larger than three times the size of Texas, located between the Atlantic and Arctic Oceans, and geologically part of North America. The total land area is more than 2.16 million km^2 (836,000 mi.^{2}). The ice sheet covers about 79% of Greenland, and is 1.71 million km^2 (660,000 mi.^{2}) Politically, the island is a territory of Denmark, with a population of about 56,000, primarily Inuit peoples. Being in a more temperate climate, the Greenland ice sheet differs from the polar Antarctic ice sheets. Much of the Greenland ice sheet is at a temperature near the pressure-melting point, while the Antarctic ice sheets have temperatures well below the pressure-melting point. The melting point is the temperature at which ice will begin to melt. This temperature decreases with increasing pressure, or at increased depths within the ice sheet. Meltwater is more readily generated in temperate ice sheets and tends to move faster than in polar ice sheets.

Most ice sheets experience some degree of melt during the summer months, which is actively monitored via satellite imagery analysis. The margin of the Greenland ice sheet has thinned substantially, particularly on the western and northern sides. The second highest (in the 45-year satellite record) cumulative melt area in Greenland occurred in 2023.

Figure 8. Map of Greenland (with major towns, glaciers, and surrounding oceans marked) and the approximate extent (in white) of the ice sheet. [NSIDC]

Interestingly, the highest elevations of Greenland's bedrock are found near the coasts, particularly on the east and south sides (**Figure 9**). The bedrock at the center of Greenland is actually below sea level due to the weight of the ice sheet in that region over time.

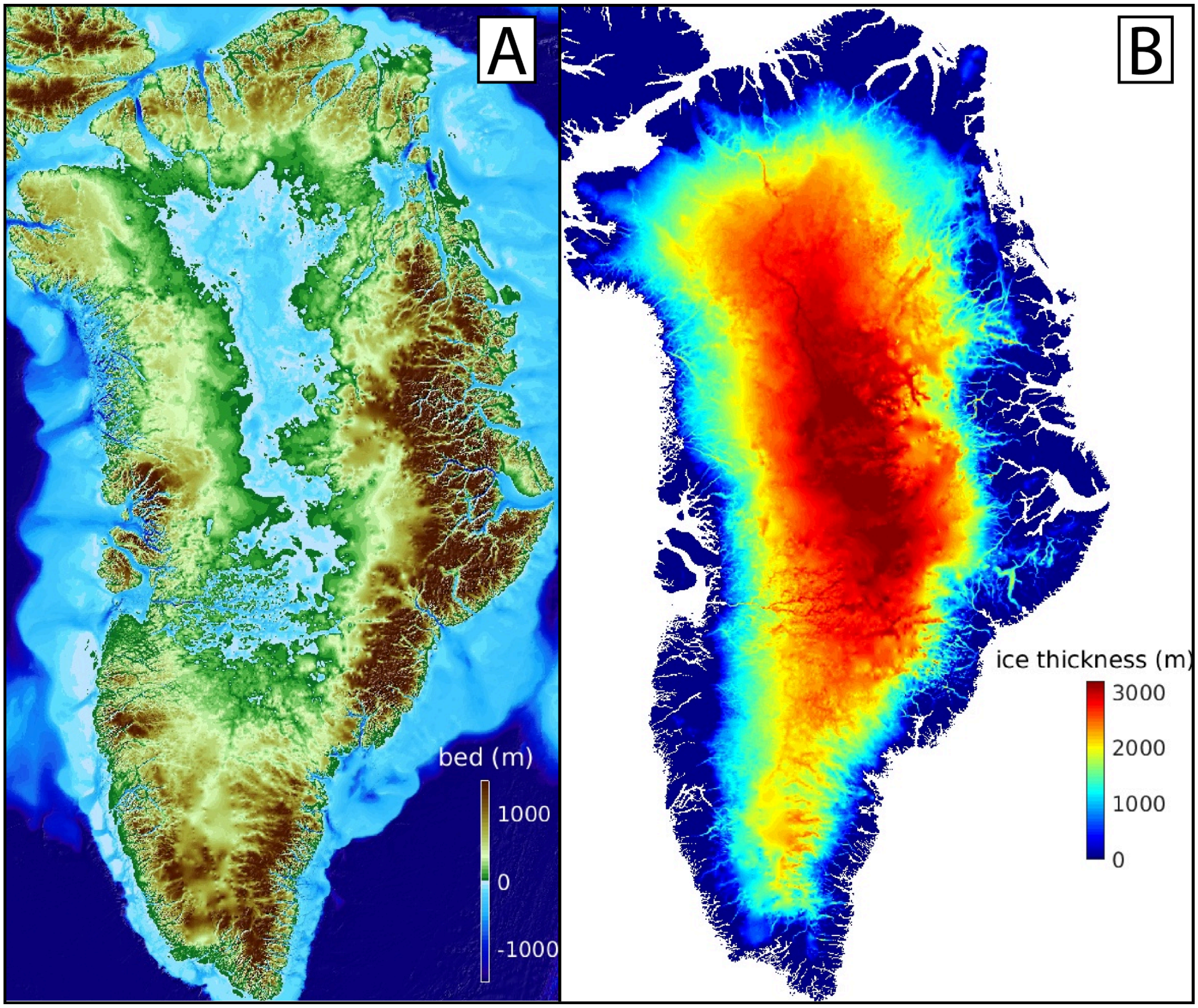

Figure 9: (a) Greenland bedrock topography and (b) thickness of the Greenland ice sheet. [Morlighem M. et al., 2017]

Even though Antarctica's ice sheet is considerably larger, being at a more temperate climate, Greenland has lost more ice by melting since 2002. NASA states that "Antarctica is losing ice mass (melting) at an average rate of about 150 billion tons per year, and Greenland is losing about 270 billion tons per year, adding to sea level rise." Mass loss from the Greenland Ice Sheet contributes about 0.74 mm/yr to global sea level rise, whereas mass loss from the Antarctic Ice Sheet contributed about 0.6 mm/year from 2012–2017, a threefold increase from 2002–2007 (Shepherd et al., 2018).

Arctic and Antarctic Sea Ice Cover

Since satellite monitoring began in 1979, sea ice cover in the Arctic has been steadily shrinking both in winter and summer coverage; the average thickness has decreased such that near the middle of the 21st century, and perhaps as early in the late 2020s or 2030s, little or no multi-year ice is expected to remain and the Arctic Ocean could become ice-free (having less than 1 million km^2 or 368,102 $mi.^2$ of sea ice) in summer. In contrast, Antarctic sea ice coverage remained fairly steady, with considerable annual variation. In recent decades there has been a slight increase in coverage, although there has been a noted decrease since 2015, primarily around the Antarctic Peninsula.

Due to geographical differences, sea ice in the Antarctic region behaves differently than in the Arctic. In the Antarctic, sea ice can expand further equatorward in winter, but this ice melts more readily in the summer due to its expansion into warmer latitudes. In the Arctic, sea ice formation is closer to the pole and bound by land masses on its southern flanks. Given the greater surface area of ocean vs. land, the Arctic is also more sensitive to the ice-albedo feedback mechanism described below.

Albedo of Ice

Albedo is the fraction of incident (incoming) solar radiation that is backscattered by airborne particles or reflected by a surface (or interface), that is, albedo = (reflected radiation)/(incident radiation) expressed either as a percentage or a fraction. Surfaces that are light in color with a high albedo, such as snow or ice, reflect a relatively large fraction of incident solar radiation while absorbing a small amount. Surfaces with a low albedo appear dark in color, such as ocean water and land, and reflect a relatively small fraction of incident solar radiation and absorb a larger amount. Darker, low-albedo surfaces absorb more solar radiation, so they typically are warmer than those that are lighter, higher albedo surfaces. The albedo of expansive glacial ice sheets can be 0.8 to about 0.9, whereas sea ice has a lower albedo that varies from 0.5 to 0.7. Note that mountain glaciers are “dirtier” and, therefore, darker in color than expansive glacial ice sheets and have lower albedos.

The albedo of ocean water, generally about 0.06, is much lower than that of sea ice. The ocean reflects about 6% of solar radiation and absorbs about 94% of incoming solar radiation.

Albedo is a fundamental concept in climate science, playing a key role in Earth’s energy balance. Decreasing the albedo of a certain region can lead to increased absorption of solar radiation and warming while increasing the albedo can lead to decreased absorption and cooling within that region and Earth’s climate system as a whole. For example, in the positive feedback loop (or amplifying an initial change) illustrated in **Figure 10**, higher temperatures in the polar regions lead to increased melting of lighter sea ice (high albedo) and exposure of darker ocean water (low albedo). This reduced sea ice cover leads to increased absorption of solar radiation and warmer temperatures, further fueling the feedback loop.

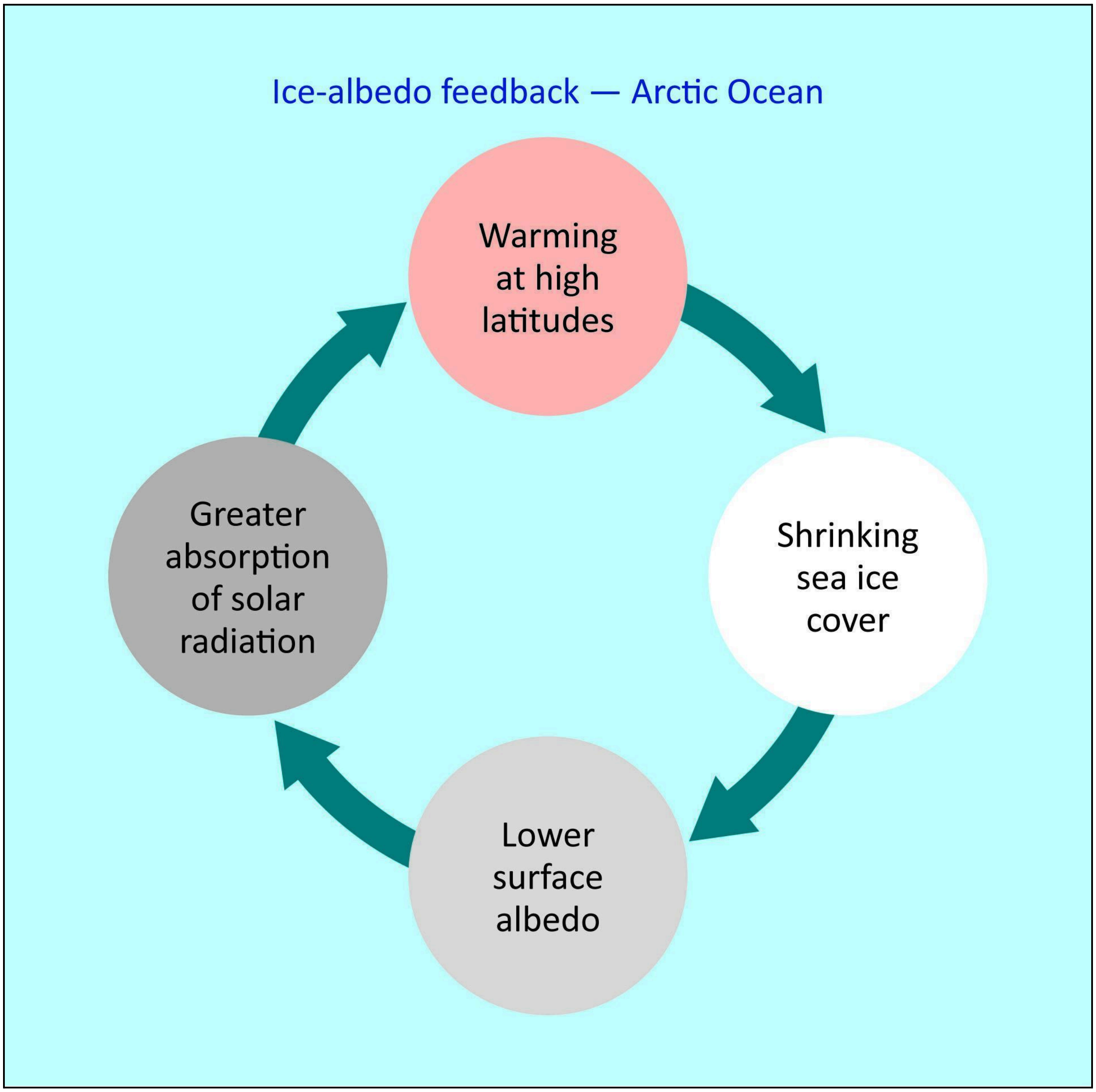

Figure 10. Positive ice-albedo feedback in the Arctic is likely to accelerate warming of surrounding surface waters and shrinkage of sea ice cover. [Figure 8.20, *Our Changing Climate* textbook]

Current and Future Changes

The Arctic environment is particularly sensitive to changes in climate. **Polar temperature amplification** means that the current global warming trend is greater at higher latitudes. Significant changes are already taking place in the Arctic, consistent with an enhanced greenhouse effect and higher temperatures. The **greenhouse effect** refers to the absorption (and emission) of outgoing infrared radiation by specific gases in the atmosphere, such as water vapor (H_2O) and carbon dioxide (CO_2), which keep the Earth at a habitable temperature for humans. An enhancement to the greenhouse effect is caused by significant increases in greenhouse gases, namely (CO_2) and methane (CH_4), due to anthropogenic and natural emissions.

Arctic sea ice cover is shrinking at an accelerating rate through the ice-albedo feedback mechanism. The Arctic Ocean could be nearly ice-free in the summer while precipitation over land and river discharge into the Arctic Ocean increase. Some researchers believe melting sea ice could interfere with ocean circulation. In the Arctic, ocean circulation is driven by the sinking of dense, salty water. An influx of fresh meltwater, primarily from the Greenland ice sheet, could interfere with ocean circulation at high latitudes, slowing down poleward flowing warmer surface currents and subsequent deep-water return flow, as well as contributing to sea level rise. Other potential impacts in the Arctic region include changes in the Arctic Oscillation, wind circulation patterns contributing to climate variability within the Northern Hemisphere, and significant food web and societal ramifications.

One particular group dramatically affected by Arctic changes is Canada's Inuit communities. Living at very high latitudes, the Inuit experience some of the most extreme examples of a changing climate, and their location and way of life make them more vulnerable to changes in climate. Decreasing Arctic sea ice affects migration of the wildlife, while the thawing permafrost hinders access to roads, both of which the Inuit depend on for food. Changes in the Arctic hydrologic cycle alter fishing opportunities and freshwater sources. These environmental changes affect their culture and heritage.

The most immediate climate change-related concern in the Antarctic is melting of the WAIS and associated sea level rise. Geological evidence suggests that the WAIS has undergone episodes of rapid disintegration and may have completely melted at least once in the past 600,000 years. Relatively unstable, the WAIS sheet could collapse in a few centuries or less because its ice streams flow from the interior to two major ice shelves (the portion of the ice sheets extending over water) on the periphery of the WAIS. Such a catastrophic event would accelerate the rate of sea level rise. Due to melting, the region of the WAIS that feeds two large glaciers is thinning, which leads to sea level rise.

The EAIS has been stable for the past 30 million years and remains fairly stable today. However, a change in this state could lead to a significant contribution to sea level rise as there is a large basin of ice (Wilkes Basin) currently “clamped” into place on the fringe of the EAIS. Wilkes Basin has outlet glaciers, but they are not as large and prone to rapid and runaway retreat as the Thwaites and Pine Island glaciers on the WAIS. Wilkes is home to vast amounts of ice, but it will more slowly contribute to sea level rise going forward as it is geometrically more stable.

Group Review and Discussion:

1.) Where is most of the freshwater on the Earth, and is it accessible for human use (i.e., drinking, bathing, etc.)? What percentage of water on Earth is fresh and available for human use?

2.) Explain why the melting of the Greenland ice sheet currently contributes slightly more to sea level rise even though that ice sheet is significantly smaller than the ice sheet areas covering Antarctica.

3.) Explain the role of polar temperature amplification in the Arctic Ocean ice-albedo feedback loop.

4.) Why is the WAIS much less stable than the EAIS?

Elaborate | Characteristics of the Polar Regions

Recall that the Transantarctic Mountains separate the WAIS from the EAIS. **Figure 11** bisects the continent (perpendicular to the Transantarctic Mountains) from point A to point B and then shows elevation data for the two ice sheets as well as the elevation of the bed topography (bedrock), which is the rock surface underlying the ice sheets.

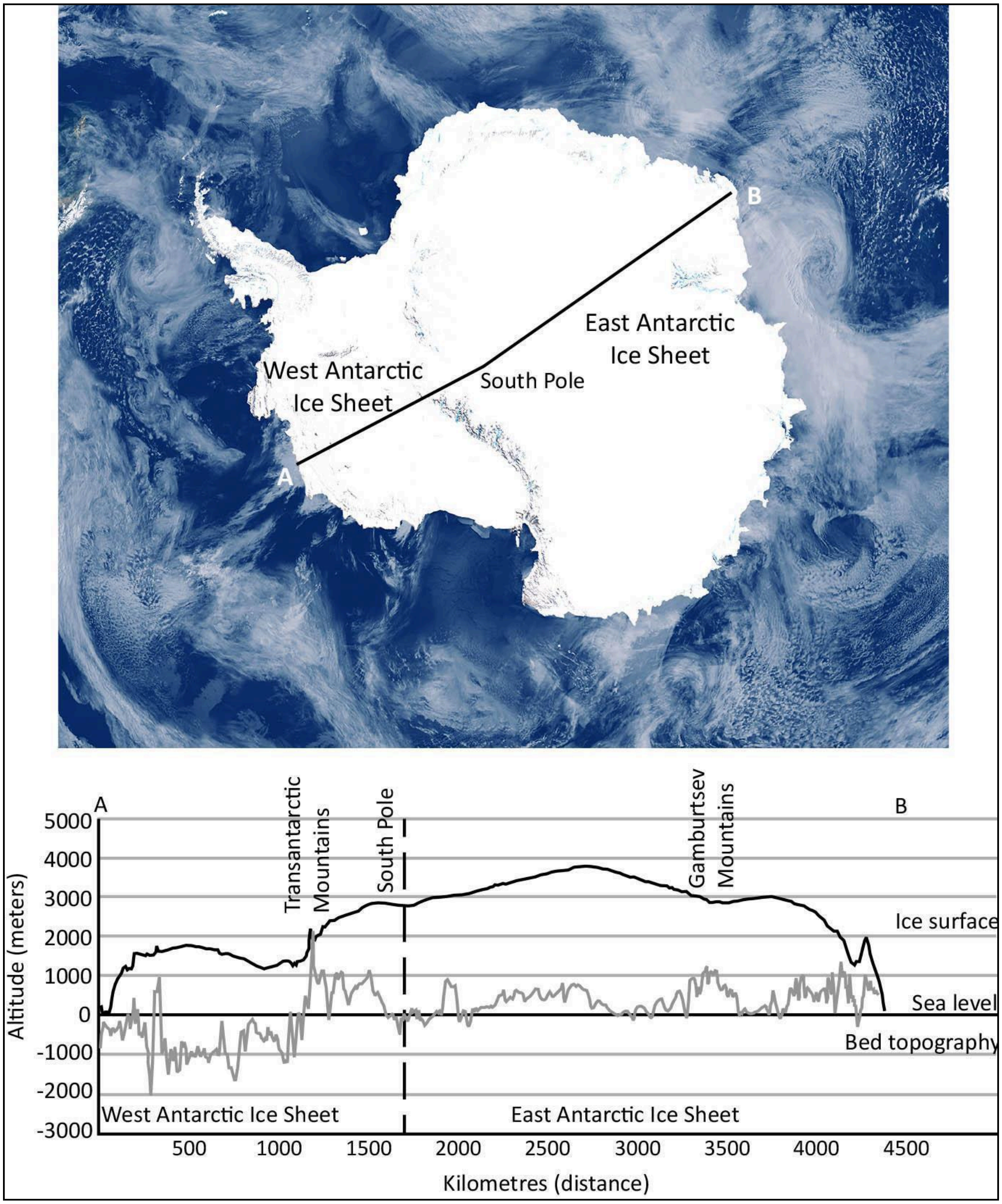

Figure 11. The location (top) and cross-section (bottom) of Antarctica's Ice Sheets. In the bottom graph, the y-axis shows height above or below sea level. The black curve is the height of the ice surface, and the gray curve is the height of the bedrock. [Modified from Bethan Davies/AntarcticGlaciers.org]

1. For the WAIS, with the exception of the Transantarctic Mountain region, most of the bedrock is:
    a. above sea level

   b. approximately at sea level
   c. below sea level

2. The cross-section from point A to point B stretches approximately 4500 km. At 0 km at the coast of the WAIS, the height of the ice surface is about ________ m, whereas at 1000 km near the Transantarctic Mountains it is about ________ m.
   a. 0 … 500
   b. 0 … 1200
   c. 500 … 0
   d. 1200 … 0

3. At 3000 m near the middle of the EAIS, the bedrock is:
   a. well above sea level
   b. approximately at sea level
   c. well below sea level

4. At this point, the height of the ice surface is about:
   a. 500 m
   b. 1500 m
   c. 3500 m
   d. 4500 m

Recall that the **albedo** of ice and snow is generally high, but varies by the type of ice present. **Figure 12** shows graphs of Antarctic ice sheet and sea ice regional albedo (where 0 = 0% reflected solar radiation and 1 = 100% reflected solar radiation), for 1981–2000, from AVHRR Polar Pathfinder satellite data.

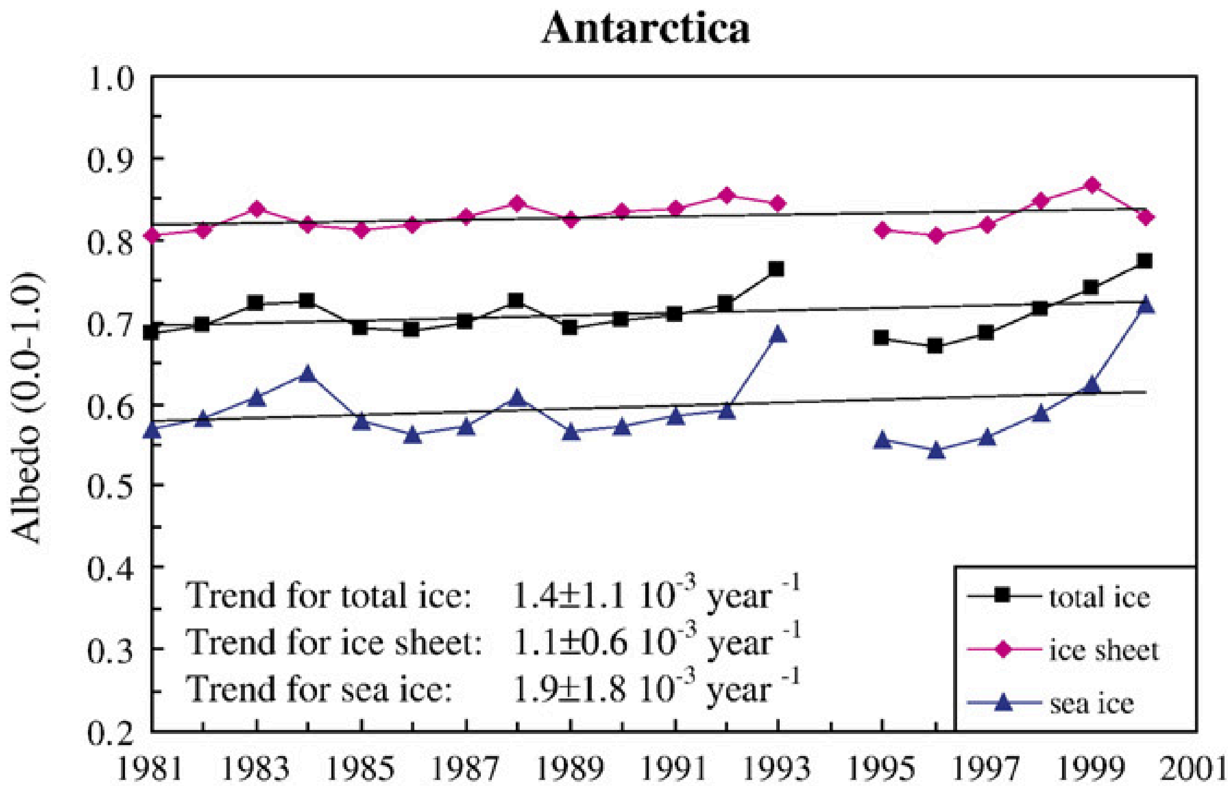

Figure 12. Antarctic ice sheet, sea ice, and total ice albedo trends. [Laine, V., 2008]

5. The albedo of the glacial ice sheet is __________ the albedo of sea ice.
   a. about the same as
   b. higher than
   c. lower than
6. The albedo of the total Antarctic ice area is about:
   a. 0.3
   b. 0.5
   c. 0.7
   d. 0.9

Go to NASA's World of Change: Antarctic Sea Ice and play (or click through) the animation of Antarctic sea ice (from 1990–91 to 2020–21) at the top of the page.

7. Antarctica has the most sea ice in the month of __________, which is at the end of the Southern Hemisphere __________.
   a. February … summer
   b. February … winter
   c. September … summer

   d. September … winter

8. By the end of the Southern Hemisphere summer (represented by the February maps), the 1981–2010 median sea ice extent line indicates that ___________ sea ice has melted.
   a. all
   b. most
   c. no

Evaluate | Characteristics of the Polar Regions

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

9. Which polar region has a continent surrounded by ocean?
   a. Antarctic
   b. Arctic
   c. Both regions

10. Which polar region is more likely to have significant areas of multi-year sea ice?
    a. Antarctic
    b. Arctic

11. The melting of which ice sheet currently contributes more to sea level rise on an annual basis?
    a. East Antarctic Ice Sheet
    b. Greenland
    c. West Antarctic Ice Sheet

12. Which polar region does not have permanent human inhabitants?
    a. Antarctic
    b. Arctic
    c. Both regions

13. Which polar region contains land area from several nations?
    a. Antarctic
    b. Arctic
    c. Both regions

14. Which has the highest albedo:
    a. ice sheets

b. mountain glaciers
c. sea ice

15. Which Antarctic ice sheet poses the most immediate concern to sea level rise?
    a. East Antarctic ice sheet
    b. West Antarctic ice sheet

16. Which Antarctic ice sheet contains the Wilkes Basin?
    a. East Antarctic ice sheet
    b. West Antarctic ice sheet

17. The Greenland ice sheet has temperatures ________ the pressure-melting point. The Antarctic ice sheet has temperatures _________ the pressure-melting point.
    a. near … near
    b. near … well below
    c. well below … near
    d. well below … well below

18. In Greenland glaciers commonly end in ________.
    a. ice shelves extending over ocean water
    b. ice tongues located in fjords

19. Greenland's bedrock is highest in ________.
    a. the central region
    b. the southern and eastern coastal regions
    c. the western coast regions

20. Ice-core drilling takes place in:
    a. Antarctica
    b. Greenland
    c. Mountain glaciers
    d. All of these regions

Workshop Extensions |
"To the Ends of the Earth - Polar Opposites"
"Antarctic Map Discovery"