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:

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

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Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation, the U.S. Ice Drilling Program, NASA, or NOAA.

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 courtesy of Michael Studinger, Operation IceBridge project scientist. Caption adapted from content by Adam Voiland, 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

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

1. Implement scientifically accurate and pedagogically sound instructional resource materials focused on ***polar region geography and climate***;
2. Integrate Climate and Ocean Science concepts related to ***polar region geography and climate*** into other educational settings;
3. Demonstrate knowledge of the physical foundations of ***polar region geography and climate*** and relate/map these to the Climate Literacy Principles and NGSS.
4. Analyze and interpret data and information related to ***polar region geography and climate*** acquired through direct and remote sensing data, and paleoclimate data from ice cores;
5. Conduct peer training sessions on ***polar region geography and climate*** 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:

I. Climate Change (1,2,9,10)
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, and contains an additional 7.4 meters of sea level equivalent.

I.a. Additional Paleoclimate Understandings (3,9)
3. In the climate system, feedbacks are processes in which a natural or anthropogenic driver affects the climate system by a certain amount, as measured by a specified quantity. For example, positive ice-albedo feedback in the Arctic accelerates warming of surrounding surface water and shrinks sea-ice cover.

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

II. Ice Dynamics and Glacial History (1,2,3,4)
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.

Applicable Climate Literacy Principles: 1.D, 2.B, 2.F, 4.E, 5.B, 7.A
(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)
7. Engaging in argument from evidence

Crosscutting Concepts
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.
3. Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
5. Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

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
Most of earth's fresh water is in glaciers—5-ESS2-2
Climate describes range of typical weather—3-ESS2-2
6-8: Planet's systems range in scale—MS-ESS2-2
Water movements both on land and underground (subglacial) MS-ESS2-2
Ocean influence on weather and climate—MS-ESS2-6
Human activities and greenhouse gases—MS-ESS3-5
9-12: Cyclical changes in earth's orbit—HS-ESS2-4
Geologic record (relate to ice core record)—HS-ESS2-4
Changes in the atmosphere due to human activity-HS-ESS2-4; HS-ESS2-7

Engage | Where in the world are we?

If presented with the Figure 1 enhanced visible satellite image 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 areas of brown are shown in this image, signifying different continental land areas.

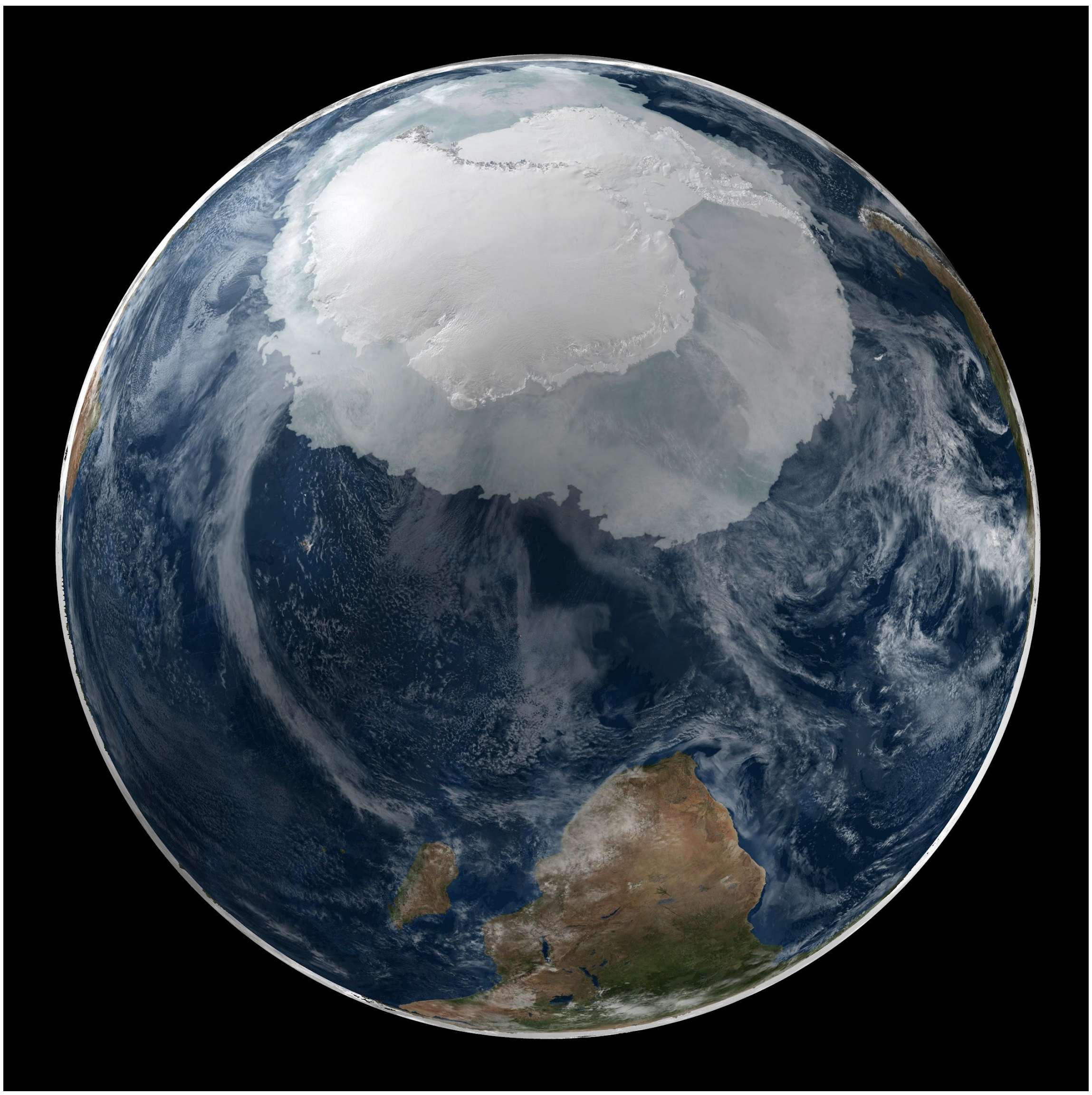

Figure 1. Satellite image of a polar region. [Courtesy of NASA]

Considering these geographical characteristics:

- expansive area of ice surrounded by ocean water
- different shading of white within this expansive areas, signifying a variation in the type of ice
- some extension of non-ice covered continental land areas into the image area

Is the focus of the image a tropical, midlatitude, or polar region?
If a polar region, which pole is shown?
What continent is shown in the lower part of the image? What about on the upper right side of the image?
Why are there different shadings of white/grayish white shown within the ice area?

Explore | The Polar Regions

Background: The **polar regions** are the regions surrounding the geographic **North and South Poles**. Both areas experience extreme cold, with the Antarctic being the coldest overall. The ice sheets (Greenland and Antarctica) are found in the polar regions. Both regions have significant formation of sea ice, but its 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. There are some similarities, but also some large-scale differences in geography, geology, and biology, among other areas.

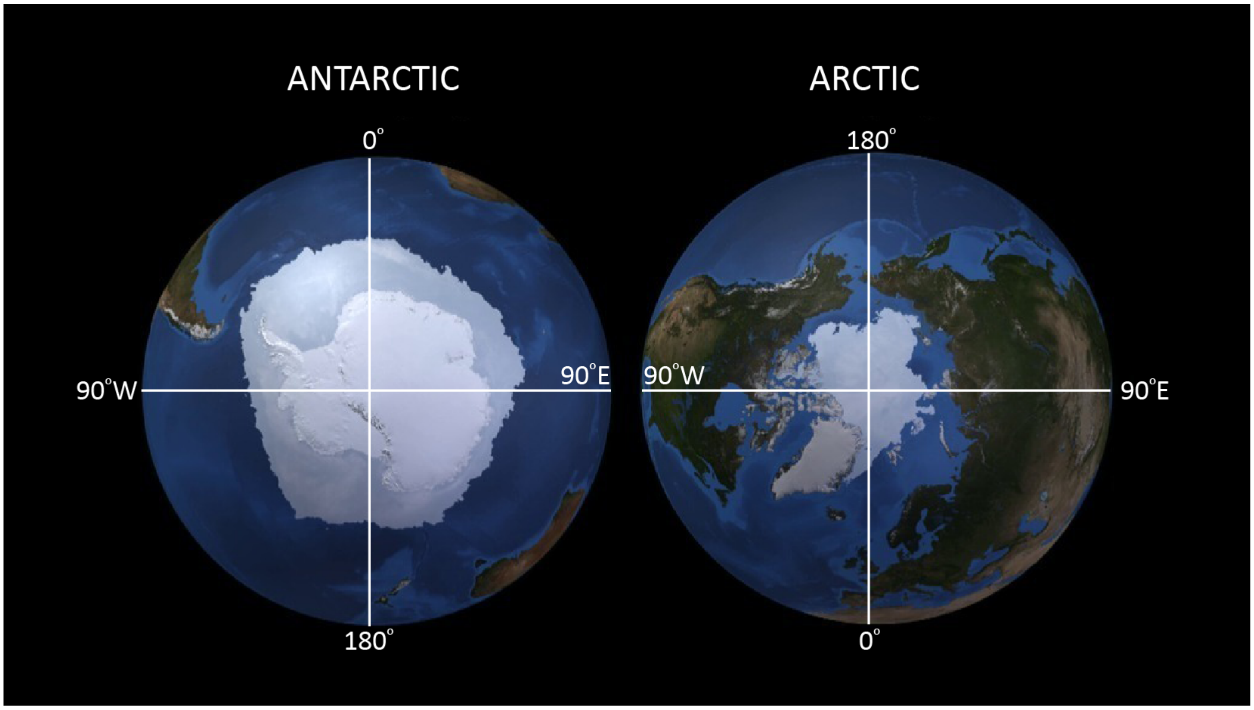

Figure 2. Views of the Antarctic and Arctic showing the Southern Hemisphere winter and Northern Hemisphere summer. Note that this particular view of the Antarctic differs from Figure 1. [Modified from NASA Goddard Space Flight Center image]

The area in the south is called the **Antarctic** (left side of Figure 2) and includes the area south of the Antarctic Circle defined as the imaginary line on the map at 66°34’ S. From the Antarctic Circle to the South Pole, the Sun does not rise on the winter solstice and does not set on the summer solstice. At the South Pole, there are 6 months of darkness and 6 months where the Sun does not set. At the South Pole, the Sun rises once each year and sets once each year! The Antarctic is a continent surrounded by ocean; the Antarctic continent encompasses much of the Antarctic region. Other than scientists and the staff that supports the research, no one lives on the continent of Antarctica, but 30 countries operate science bases including another 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 peace and science. There are no land mammals in the Antarctic, and the largest purely terrestrial animal is a type of wingless fly. There are penguins that live on land 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 area in the north 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. The Arctic is an ocean surrounded by land. The most common definition of “Arctic” is the area within the imaginary circle drawn on the map at 66°34’ N above which the Sun does not set on the summer solstice (around June 21) and does not rise on the winter solstice (around December 21). Like the South Pole, the North Pole experiences 6 months of light and 6 months of darkness. Others define the Arctic as the region above the “treeline” where only shrubs and lichens grow. Other researchers define the region as the high latitudes 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 a great 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 Arctic Circle is shown by the dashed blue circle. The solid red line encompasses the region where the average daily summer temperature does not rise above 10°C (50°F). [From CIA World Fact Book - File:Arctic.svg, https://commons.wikimedia.org/w/index.php?curid=7894803]

Group Review:

- *The Antarctic is a continent surrounded by ocean whereas the Arctic is an ocean surrounded by land. Speculate on the impacts of this varied geography on polar climate and response of the regions to climate change.*
- *The world's major ice sheets are found on Greenland and Antarctica. Why do you think this is?*
- *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…*
- *Why do you think scientists are so interested in studying the structure and behavior of polar ice sheets and sea ice?*

Explain | Characteristics of the Polar Regions

Group Discussion of Responses from the Explore Section

The Hydrosphere and Cryosphere

The **hydrosphere** in Earth's climate system includes all water, in all forms on, under and over 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.

Salt water in the ocean represents about 96.5% of Earth's water, and is of major importance in 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.

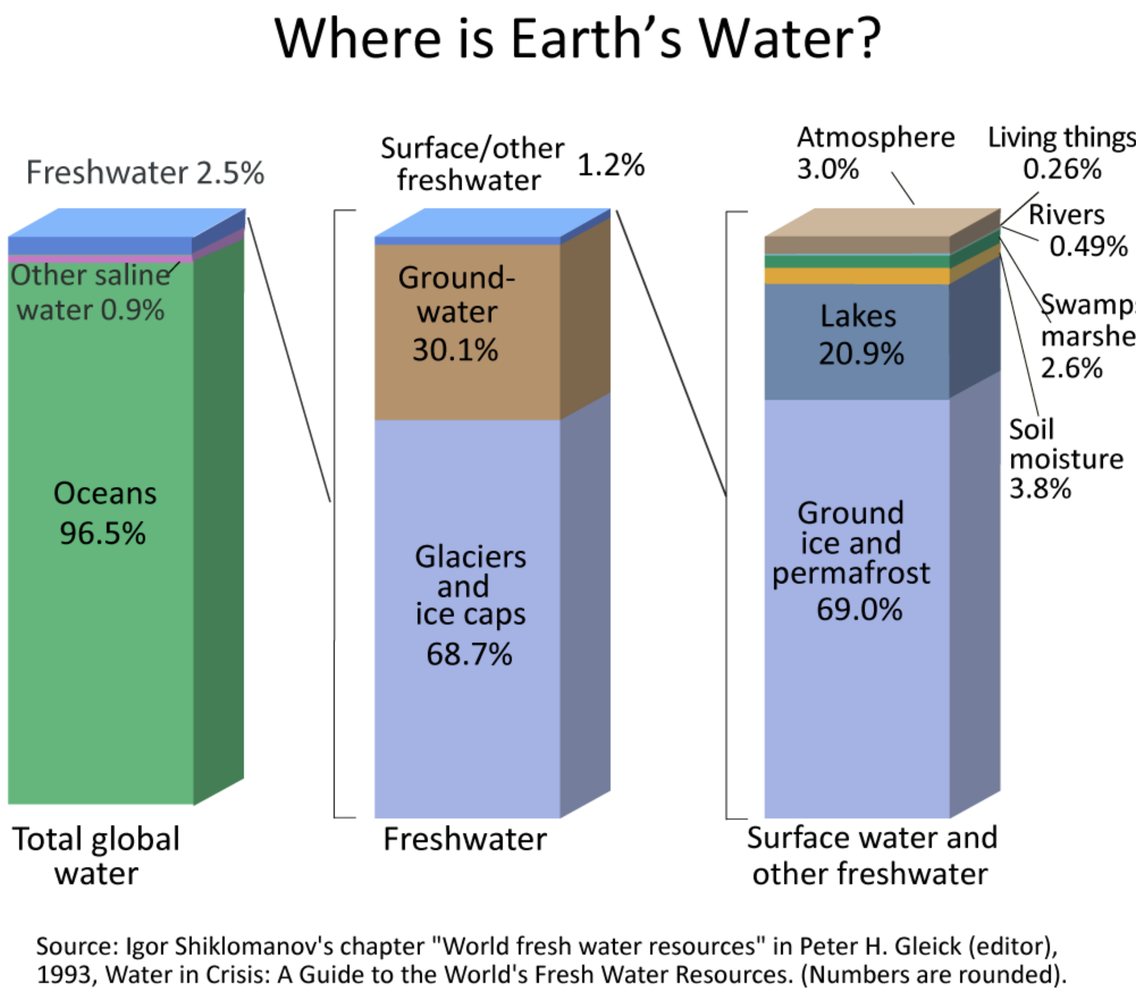

Figure 4. Distribution of Earth's water. [Courtesy of USGS]

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 underlying snow to ice. Most (99%) of Earth's freshwater ice is contained within the massive glacial **ice sheets** found on Greenland and Antarctica. An ice sheet is glacial land ice extending 50,000 square kilometers (20,000 square miles) 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. Glacial ice 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, 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, glacial ice flows slowly from sources at higher elevations to lower elevations, where the ice melts and flows into the ocean. Around Antarctica, glacial 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 float and are carried in surface ocean currents around Antarctica. Likewise, irregularly shaped icebergs break off the glacial ice streams of Greenland and flow out into the Atlantic Ocean.

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. Some salt is trapped between crystals, but that gradually migrates downward to the water below, leaving “freshened” sea ice. In the summer in polar regions, 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.

Knowledge Check and Discussion - The Hydrosphere and Cryosphere

About Albedo

Albedo is the fraction of incident radiation from the Sun that is backscattered by airborne particles or reflected by a surface (or interface), that is, albedo = (reflected radiation)/(incident radiation), where albedo is expressed either as a percentage or a fraction. Surfaces with a high albedo, such as snow or ice, reflect a relatively large fraction of incident solar radiation and appear light in color. Surfaces with a low albedo, such as ocean water and land, reflect a relatively small fraction of incident solar radiation and appear dark in color. Because low-albedo surfaces absorb more sunlight, they typically are warmer than those that are lighter in color, which have a higher albedo. The albedo of expansive glacial ice sheets can be 0.8 to about 0.9, whereas sea ice varies from 0.5 to 0.7. Note that mountain glaciers are “dirtier” 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. Therefore, the ocean reflects about 6% of solar radiation whereas sea ice reflects 50-70%. Ocean water absorbs about 94% of incoming solar radiation.

Albedo is a key concept in climate science as 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 Earth's climate system. For example, in the positive (or amplifying of an initial change) feedback loop illustrated in Figure 3, Arctic Sea Ice is strongly reflective (has a high albedo). However, higher temperatures in the polar regions lead to increased melting of sea ice and exposure of darker ocean water. This reduced sea ice cover leads to a lower albedo in the polar region, which leads to increased absorption of solar radiation and warmer temperatures.

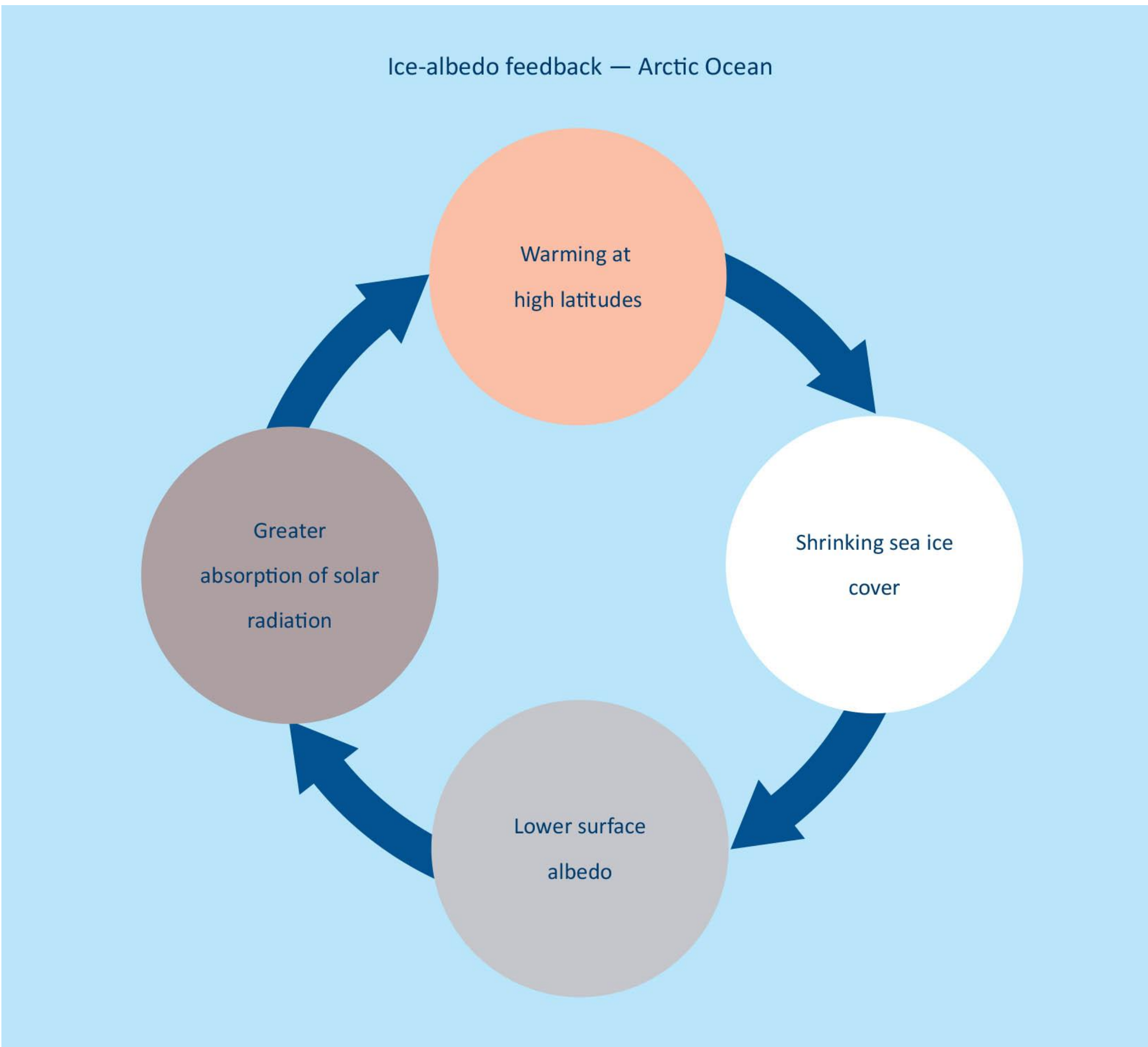

Figure 3. Positive ice-albedo feedback in the Arctic is likely to accelerate warming of surrounding surface waters and shrinkage of sea-ice cover. [AMS]

Knowledge Check and Discussion - Albedo of ice

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 glacial ice blankets Antarctica, which is roughly the size of the United States and Mexico combined. Of Antarctica's 14 million km^2 (5.4 million $mi.^2$) of land area, 97.6% is ice-covered. Separated by the Transantarctic Mountains, two major ice sheets cover Antarctica (Figure 4). 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 ice sheet more than 1.7 km (1 mi.) below mean sea level (MSL). The mean thickness of WAIS is less than the EAIS. (The portion of the WAIS over the Antarctic Peninsula can be referred to as the *Antarctic Peninsula ice sheet*.)

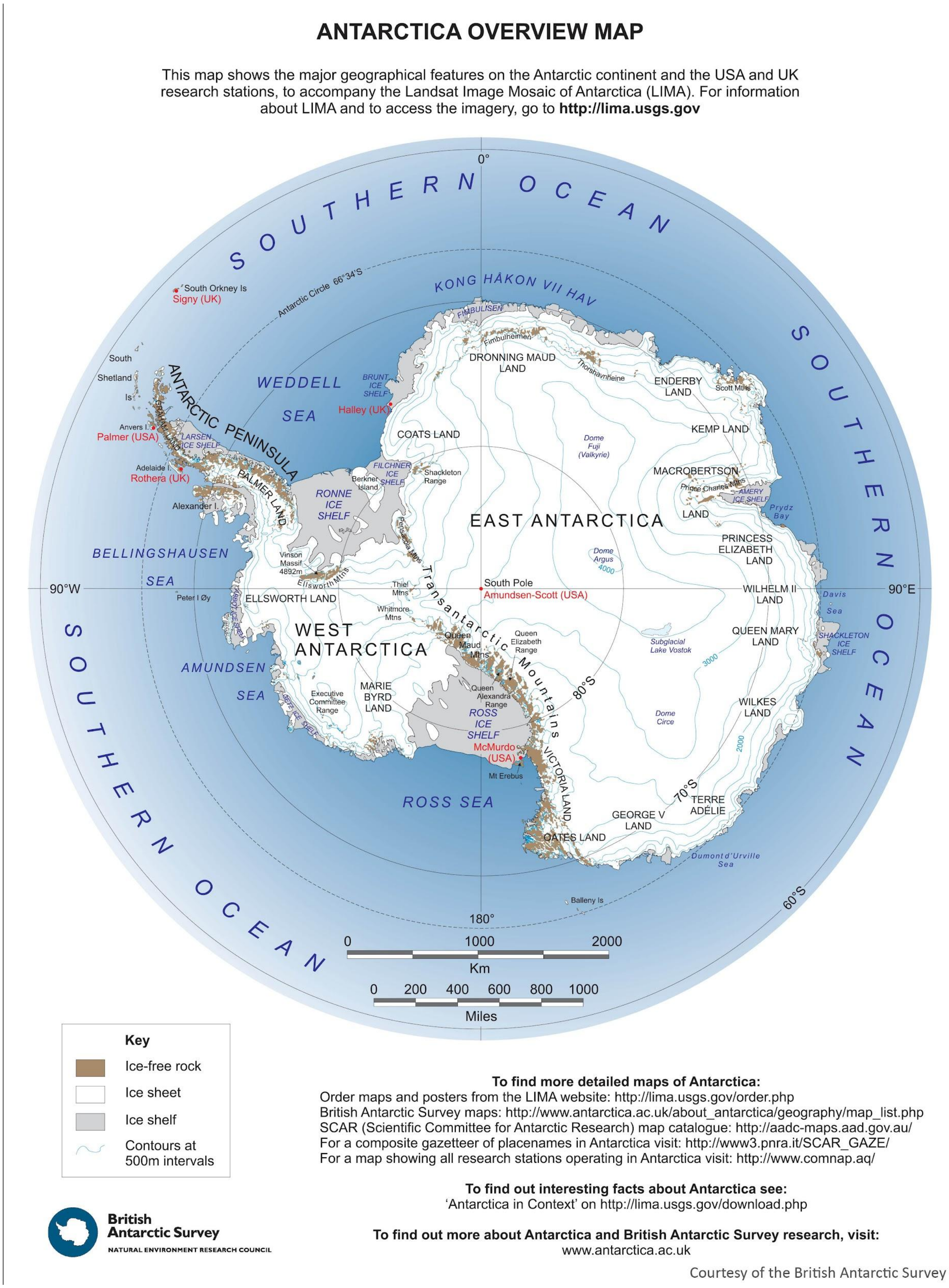

Figure 4. Major geographical features of Antarctica, including the EAIS and WAIS, which can be further segmented into the Antarctic Peninsula and West Antarctic ice sheet regions. [Courtesy of the British Antarctic Survey]

The ice sheet covering the continent is made up of many glaciers that flow together like frozen rivers, always moving under their own weight and pulled by the force of gravity down elevation toward the ocean. Figure 5 is a diagram of an Antarctic glacier, in this . case 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 that flows 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 break up, but when land based ice flows into the ocean, there can be abrupt sea level rise.

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

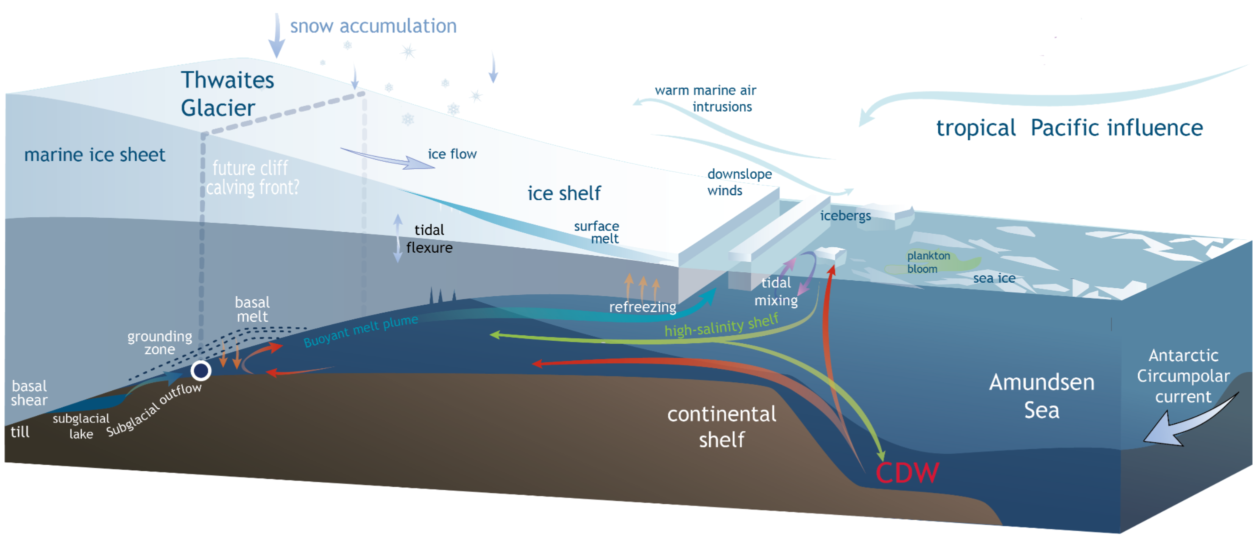

Figure 5. Diagram of Thwaites Glacier in the West Antarctic Ice Sheet (WAIS), and the key processes impacting its stability. [Image modified from How much, how fast?: A science review and outlook for research on the instability of Antarctica's Thwaites Glacier in the 21st century. by Scambos et al. 2017 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.]

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 land area of the island of Greenland. 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 6).

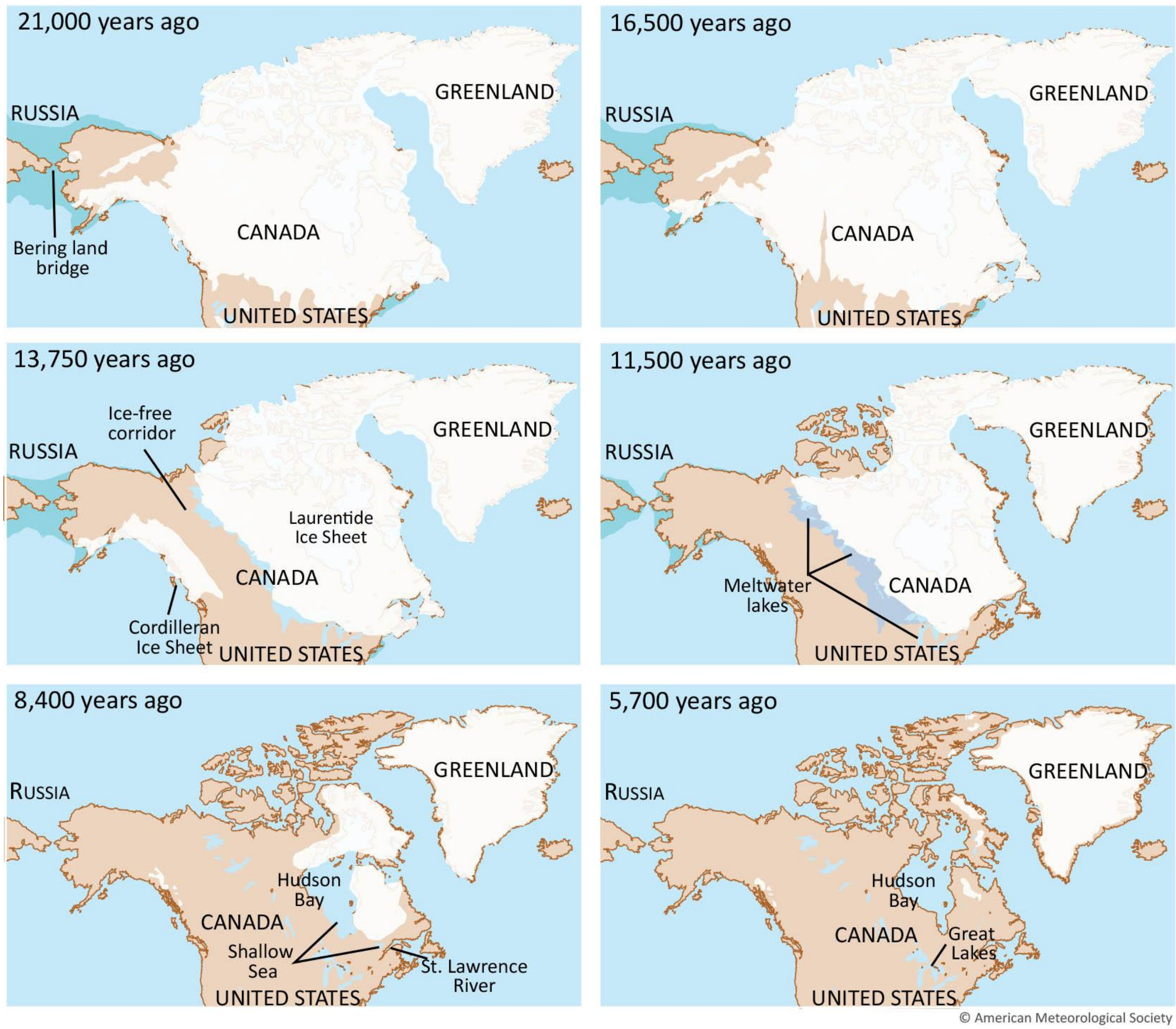

Figure 6. At its maximum, the Laurentide Ice Sheet extended across about half of North America. It contributed to the formation of the present day Great Lakes and Hudson Bay, as well as other aesthetic physical features like those in Acadia National Park in Maine. [AMS]

Greenland is approximately three times the size of Texas, located between the Atlantic and Arctic Oceans, and geologically part of North America. 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 sheet. 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 of the ice sheets experience some degree of melt during the summer months; this is actively monitored via satellite imagery analysis. The margin of the Greenland ice sheet has thinned substantially, particularly on the western and northern sides. An estimated 50 km^3 (12 $mi.^3$) of Greenland's ice melts each year, enough to raise sea level by 0.13 mm annually.

Knowledge Check and Discussion - The Antarctic and Greenland Ice Sheets

Arctic and Antarctic Sea Ice Cover

Since 1979 (when satellite monitoring began), 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 little or no multi-year ice is expected to remain and the Arctic Ocean could become ice free (having less than 1 million square km or 368,102 square mi. of sea ice) in summer. In contrast, sea ice coverage remained fairly steady, with slight decadal increase, in the Antarctic in recent decades, but some decrease has been seen since 2015, primarily around the Antarctic Peninsula. Sea ice in the Antarctic region behaves differently than that in the Arctic due to geographical differences. Sea ice is able to expand further equatorward in winter in the Antarctic, but then 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. The Arctic is also more sensitive to the ice albedo feedback mechanism described above, given the greater surface area of ocean vs. land.

Knowledge Check and Discussion - Sea Ice Cover

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 certain gases in the atmosphere such as water vapor and CO_2, which keeps the Earth at a habitable temperature. An enhancement to the greenhouse effect is caused by significant increases in greenhouse gases, namely carbon dioxide and methane, due to anthropogenic and natural emissions.

Through the ice-albedo feedback mechanism Arctic sea-ice cover is shrinking at an accelerated rate. 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 it down, as well as contributing to sea level rise. Other potential impacts in the Arctic region include changes in the Arctic Oscillation, patterns of wind circulation contributing to climate variability within the Northern Hemisphere, as well as significant food web and societal ramifications.

One particular group dramatically affected by changes in the Arctic is the Inuit communities of Canada. Living at very high latitudes, the Inuit witness some of the most extreme examples of a changing climate, and their geography and way of life leaves 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 alters fishing opportunities and freshwater sources. The environmental changes affect their culture and heritage.

In the Antarctic, the most immediate climate change-related concern is melting of the WAIS (West Antarctic Ice Sheet) 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, with ice streams flowing 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. The region of the WAIS that feeds two large glaciers is thinning, which leads to sea level rise. The EAIS (East Antarctic Ice Sheet) 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.

Knowledge Check and Discussion - Current and Future Changes

Investigating Past Climate

To better understand Earth's climate system and climate change as a basis for predicting the climate future, scientists collect and analyze **proxy climate data** from various sources, such as historical documents, tree rings, land and ocean sediment cores and ice cores. Ice cores extracted from the Antarctic (providing a continuous record back 800,000 years) and Greenland ice sheets (providing a 130,000-yr record) are important sources of information on climate change, giving the only direct measurements of gas concentrations from the ancient atmosphere spanning these long, high-resolution proxy records. Ice cores provide direct measurements of the Earth's prior atmosphere concentration through air bubbles that are trapped when snow turns into ice. Nowhere on Earth is there a larger resource for direct measurements of past atmospheric gas concentrations as in the polar ice sheets.

The Antarctic is a brutal environment for human habitation, let alone scientific inquiry. There are immense engineering challenges in transporting and executing highly precise drilling rigs to investigate large depths of snow and ice so as to reveal clues to the climatic past. Climate scientists must brave intense winds and blinding snowfall and snowdrifts in their ramshackle housing structures while setting up equipment and supplies for the extraction of ice cores. Yet the cores they work so hard to withdraw from the ice provide great detail on global climate changes from different periods of Earth's history. An example of one such extracted ice core is shown in Figure 7.

Figure 7. An ice core extracted during the 2015/16 field season at Allan Hills, Antarctica. [Photo by Yuzhen Yan]

Deep ice domes are located at various places on Antarctica, with focus on the EAIS, where the world's oldest ice cores have been found. Ice core scientists are studying cores from these locations to understand how the climate has changed over the past 800,000 years, particularly the occurrence of various glacial and interglacial periods. However, ice core records do not currently extend back far enough to periods when Earth's climate was significantly warmer and/or greenhouse gas levels (gases like carbon dioxide and methane that absorb infrared radiation and cause an increase in global temperatures) were higher than today. Such information is vital for understanding how climate will evolve as greenhouse gas levels continue to rise today due to anthropogenic activity and for developing a deeper understanding of long-term trends in Earth history. The quest for ice core data to extend the climate record to 1.5 million years back, or more (in the case of non-continuous ice found along ice margins), is the driving force behind the Center for Oldest Ice Exploration (COLDEX), for which Project Ice is the K-12 teacher educational component.

Knowledge Check and Discussion - Investigation Past Climate

Elaborate | Characteristics of the Polar Regions

Recall that the **West Antarctic Ice Sheet (WAIS)** is separated from the **East Antarctic Ice Sheet (EAIS)** by the Transantarctic Mountains. Figure 8 bisects the continent 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.

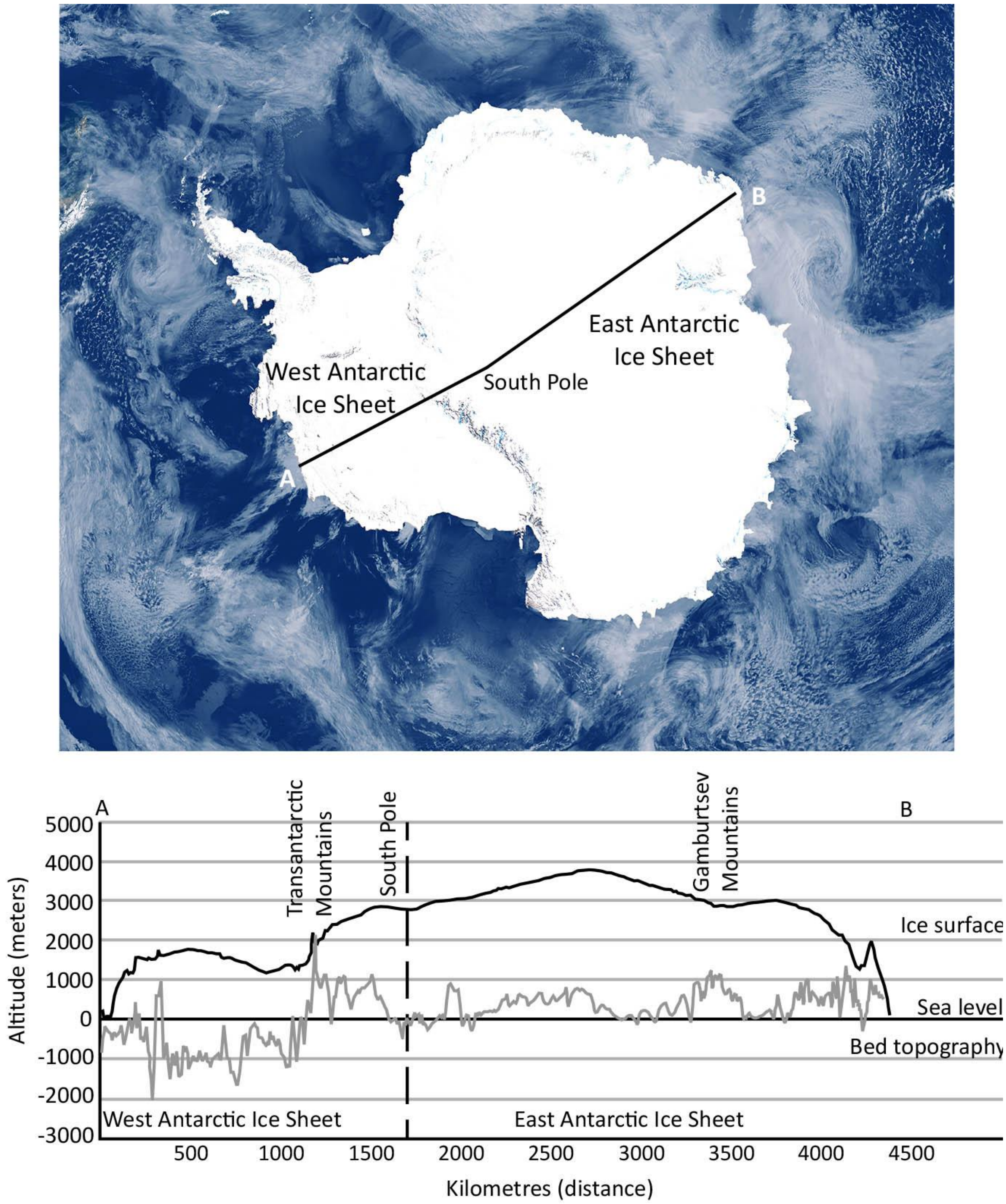

Figure 8. The location (top) and cross section (bottom) of Antarctica's Ice Sheets. In the bottom graph, the y-axis shows height above or below sea level. The black curve is the height of the ice surface and the gray curve is the height of the bedrock. [Courtesy of Bethan Davies/AntarcticGlaciers.org]

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. At 0-km distance across line segment AB, the height of the ice surface is about ________ m whereas at 1000-km distance it is about ________ m.
a. 0 … 500
b. 0 … 1200
c. 500 … 0
d. 1200 … 0

3. At 3000-m distance across line segment AB, the bedrock is:
a. well above sea level
b. approximately at sea level
c. well below sea level

4. At this point (3000-m distance), we are in the EAIS, and 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 9 shows graphs of Antarctic ice sheet and sea ice regional albedo (where 0 = 0% reflected solar radiation and 1 = 100% reflected solar radiation), 1981–2000, from AVHRR Polar Pathfinder satellite data.

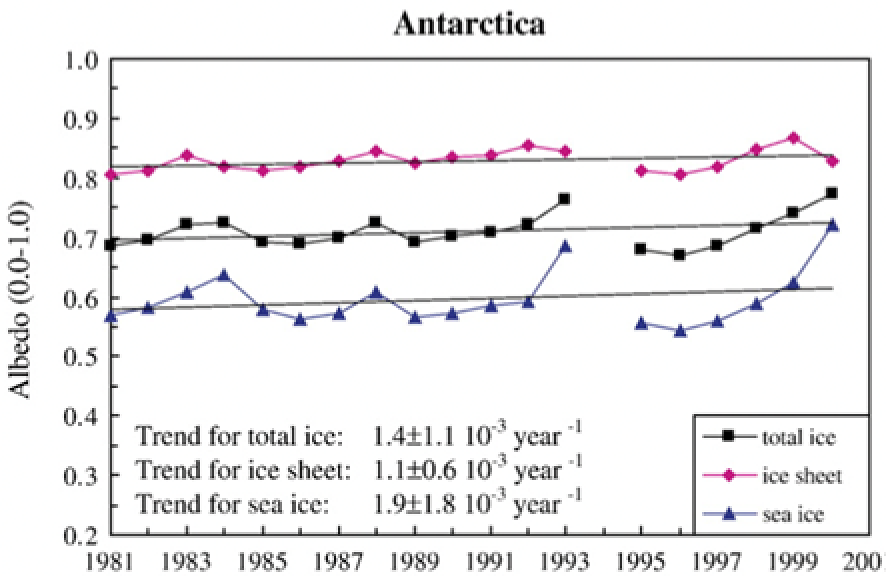

Figure 9. Antarctic ice sheet, sea ice, and total ice albedo trends. [From: Laine, V., 2008. Antarctic ice sheet and sea ice regional albedo, 1981–2000, from AVHRR Polar Pathfinder data. *Remote Sensing of Environment*, *112*(3), pp.646-667.]

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 <u>total</u> Antarctic ice area is about:
   a. 0.3
   b. 0.5
   c. 0.7
   d. 0.9

Go to https://earthobservatory.nasa.gov/world-of-change/sea-ice-antarctic 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 considerably more 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, the 1981-2010 median sea ice extent line indicates that __________ sea ice has melted.

a. all
b. most
c. none
d. either of the above answer, depending on the specific year shown

Recalling the prior discussion of **proxy climate data** and ice cores, review the site https://coldex.org/research, specifically the first image, also shown as Figure 10.

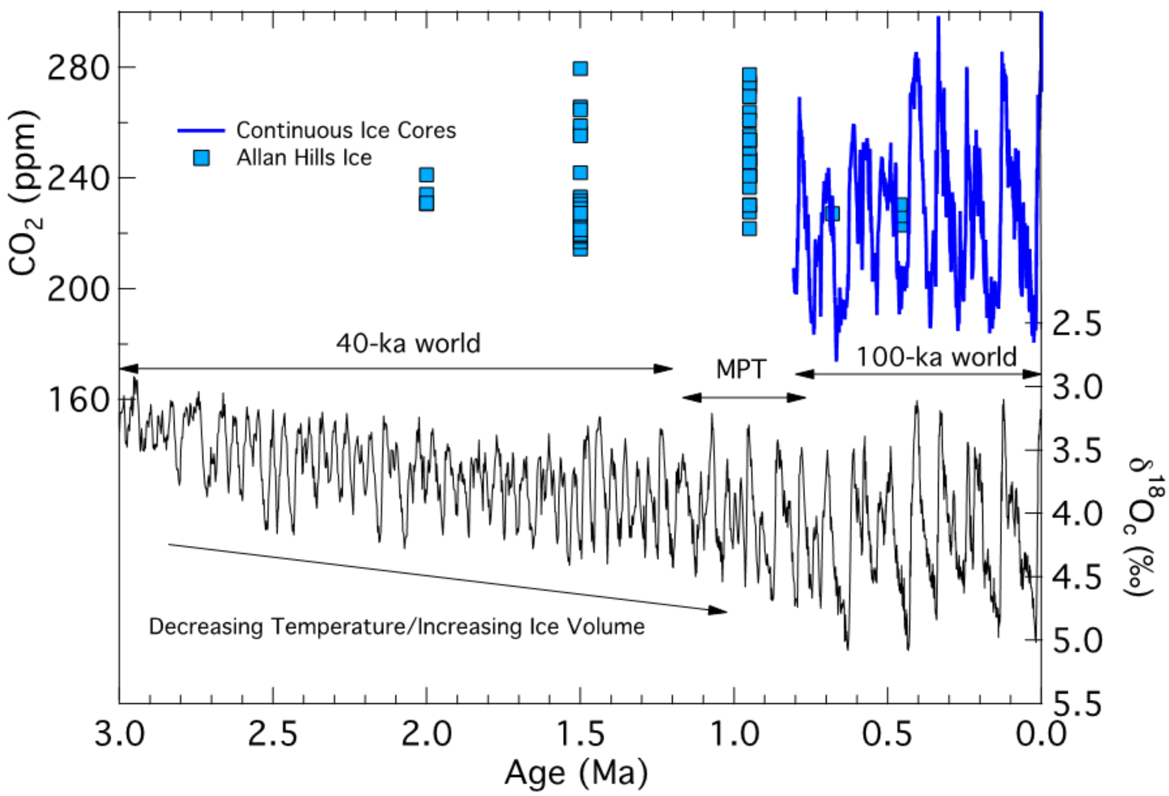

Figure 10. Atmospheric carbon dioxide (in parts per million) from ice cores along with global climate data from benthic foraminifera. [Continuous carbon dioxide data compiled by Bereiter et al (2015). Allan Hills data from Yan et al. (2019). Oxygen isotope data for benthic foraminifera in ocean sediments (Lisiecki et al., 2005) provide an index of global climate change showing gradual cooling and transition from 40,000 year glacial-interglacial cycles to 100,000 year glacial-interglacial cycles between 1.2 and 0.8 million years ago (MPT="Mid-Pleistocene Transition").]

9. The continuous atmospheric carbon dioxide (CO_2) record extends back __________ million years.

a. 0.2

b. 0.8
c. 2.0
d. 2.8

10. There are certain measurements from older ice cores shown on the graph, from the Allan Hills region of the EAIS, that are not from a continuous ice core record. COLDEX aims to extend the ice core record to 1.5 million years ago, when the Earth was in __________ climate cycles and was warmer than the vast majority of the continuous ice core record shown.

a. 40,000-yr
b. 100,000-yr

Evaluate | Characteristics of the Polar Regions

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

11. Which polar region has a continent surrounded by ocean?

a. Antarctic
b. Arctic
c. Both regions

12. Which polar region is more likely to have significant areas of multi-year sea ice?

a. Antarctic
b. Arctic

13. Which polar region does not have permanent human inhabitants?

a. Antarctic
b. Arctic
c. Both regions

14. Which polar region contains land area from several nations?

a. Antarctic
b. Arctic
c. Both regions

15. Which has the highest albedo:

a. ice sheets
b. mountain glaciers
c. sea ice

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

17. Which Antarctic ice sheet contains the Wilkes Basin?
   c. East Antarctic ice sheet
   d. West Antarctic ice sheet

18. 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

19. Ice-core drilling takes place in:
   a. Antarctic
   b. Arctic
   c. Both regions

20. Currently the continuous ice core record is __________ million year(s), and COLDEX scientists presently aim to extend it back to __________ million year(s).
   a. 0.8 … 1.5
   b. 0.8 … 4
   c. 2.0 … 3.0
   d. 2.0 … 10

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