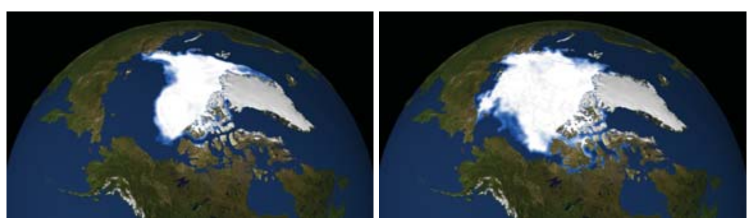
Ice

Ice has a significant impact on global climate, influencing the amount of solar radiation reflected back into space; the exchange of heat between the polar oceans and the atmosphere; the amount of freshwater entering the sea; and, indirectly, the strength of the global ocean's overturning circulation.[1] Snow and ice cover about 10 percent of the land surface of Earth, including virtually all the landmasses of Greenland and Antarctica, and seasonal sea ice spans much of the Arctic and Antarctic Circles during winter in each hemisphere.



On September 14, 2007, Arctic sea ice reached a record minimum in recorded history. The 2001 sea ice minimum is shown on the right, for comparison. *Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio*

Snow and ice factor into Earth's climate in a number of important ways. The amount of land-based ice determines global sea level—the geological record shows that higher sea levels occurred during "greenhouse Earth" periods in the past. The reflectivity, or albedo, of snow and ice introduces climate sensitivity, particularly in Earth's polar regions; as ice disappears, less solar energy is reflected away and more is absorbed, heating the surface, which causes the remaining ice to become more susceptible to melting. Ice also plays an important role in the circulation and currents of the world's ocean, because the formation and melting of sea ice affects the temperature and salinity of the surrounding seawater, which are important factors driving global ocean circulation (see *Sea* section). Snow and ice at high elevations at temperate and even tropical latitudes affect local ecosystems and regulate local climate. Throughout the world, human drinking water supplies depend on reliable and predictable patterns of glacial accumulation and thaw, which are threatened by alterations in global temperature and weather patterns. High-altitude glaciers around the world face uncertain futures. They also serve as powerful visual illustrations of a changing climate, as historical photographs reveal the dramatic extent to which many of them have receded. In some cases, they've already disappeared.

1 NSF Highlight 1992: Understanding the Structure of Sea Ice.

Top image credit: Jeffrey Kietzmann, National Science Foundation

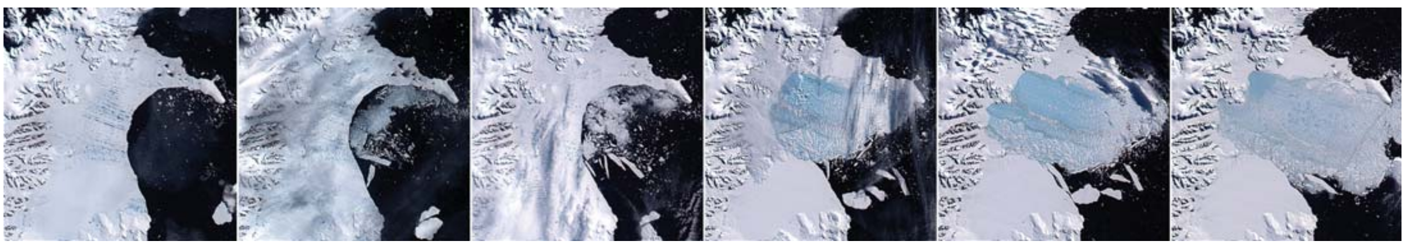
Ice is disappearing around Earth's poles as well. In 2007, satellite images confirmed what was plain enough to the researchers and indigenous people on the ground: Arctic sea ice cover shrank to a record new low.

Because of the importance of ice to Earth's climate, and because of its sensitivity to climate feedbacks, constant monitoring and observation is critical—both on the ground and from satellites. NSF's contribution to ice research, particularly in the polar regions, has led to substantial advances in what we know about Earth's changing ice and snow, and how those changes may lead to further changes.

Polar Research

Antarctica

In 2002, a sheet of ice equivalent in area to the state of Rhode Island caught scientists off guard as it broke off the Antarctic Peninsula and rapidly disintegrated into the Weddell Sea.[2] The possibility of this type of event taking place on an even larger scale at other ice shelves around the continent is currently a topic of much study, and scientists are racing to understand the stability of land- and sea-based ice masses, in the hopes of better predicting their behavior.



A series of satellite images of the Antarctic Peninsula record the catastrophic breakup of a massive portion of the Larsen B Ice Shelf—an area larger than the state of Rhode Island—in 2002. The first scene, from January 31, 2002, shows the shelf in late austral summer, with dark bluish melt ponds dotting its surface. In the next two scenes, minor retreat takes place, amounting to about 800 square kilometers (300 square miles), during which several of the melt ponds well away from the ice-front drain through new cracks in the shelf. The main collapse is seen in the last two scenes, on March 7 and 17th, with thousands of sliver icebergs and a large area of very finely divided icebergs where the shelf formerly lay. Brownish streaks within the floating chunks mark areas where rocks and morainal debris are exposed from the former underside and interior of the shelf. The last phases of the retreat totaled about 2,600 square kilometers (1,000 square miles). *Credit: MODIS images from NASA's Terra satellite supplied by Dr. Ted Scambos; National Snow and Ice Data Center, University of Colorado, Boulder*

The ecosystems of the Antarctic, particularly the marine ecosystems, provide us with compelling examples of the climatic changes already taking place.[3] Some of the best evidence comes from the Adélie penguin, a species whose bones are preserved by the cold, dry climate characteristic of high-latitude Antarctica. Researchers are exploring this detailed record of the species' response to habitat and environmental changes over the past 35,000 years to understand how the Adélies, and the ecosystem they inhabit, will respond to future climate changes.[4]

Greenland

Understanding the Greenland ice sheet is essential to predicting sea-level rise. Three main factors contribute to the amount of freshwater in the form of ice and snow that Greenland holds: precipitation, melting, and the flow of ice into the sea. In the past, Greenland's ice sheet was in an equilibrium state in which the amount of annual accumulation of snow roughly equaled the amount of snow and ice lost to melting and ice flow. Thus, Greenland's ice mass neither contributed to nor took away from the global sea level. In recent years, however, the amounts of melt water and frozen ice flowing into the sea have increased substantially. Warmer temperatures have also led to increased precipitation (as warm air holds more moisture), but the increase in precipitation does not offset the amount now lost each year to melting and ice flow. Thus, the Greenland ice sheet is no longer in equilibrium, and it contributes annually to global sea-level rise, currently at a rate of about 0.5

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2 http://nsidc.org/news/press/larsen_B/2002.html

3 See, for example, www.nsf.gov/od/opp/antarct/treaty/opp07001/organisms.jsp#Geographic.

4 Penguin Science Web site: www.penguinscience.com/clim_change.php.

millimeters per year.[5] In 2007, the melt area exceeded the previously set record by 10 percent. The edges of Greenland are experiencing the greatest amount of change, with record amounts of pooled melt water appearing in recent years.[6]

Earth's polar regions are key to our understanding of the global climate system. As evidence continues to point to the poles as both drivers and harbingers of global climate change, NSF-funded researchers are accelerating their efforts to collect data and perform research in these often inhospitable and remote areas. Polar regions offer unusual opportunities for environmental research because the polar ecosystem is sensitive to small changes in climate, rendering them important bellwethers for potential change, and because the polar regions provide information about how organisms—and the people whose livelihood and culture rely on them—adapt to environmental change.[7] In the Arctic, average temperatures have risen at almost twice the rate as the rest of the world in the past few decades. Widespread melting of sea ice, glaciers, and permafrost provide dramatic evidence of the effects of rising temperatures across this region.[8] Meanwhile, Antarctica contains some of the most poorly understood glaciers on the planet, and field research in the Antarctic is vital to improving our ability to predict how rising temperatures will affect Earth's most massive ice sheet.

NSF plays a central leadership role in coordinating U.S. Government research efforts in the areas surrounding both poles. These efforts include some the most important climate change research currently being conducted. NSF provides interagency leadership for research planning, as directed by the Arctic Research Policy Act of 1984. The NSF director chairs the Interagency Arctic Research Policy Committee. In addition, per Presidential Decision Directive, NSF manages all U.S. activities in the Antarctic as a single, integrated program, making research in Antarctica possible for scientists supported by NSF and other U.S. mission agencies, including the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey (USGS), and the Department of Energy.[9] The U.S. Antarctic Program operates two icebreaking research ships—*Laurence M. Gould* and *Nathaniel B. Palmer*— between South America and the Antarctic Peninsula, in the Antarctic Peninsula region, and in the Ross Sea near McMurdo Station.[10]

International Polar Year

The International Polar Year (IPY) 2007–2008, a worldwide scientific effort in which participating government agencies sponsor heightened activities in their polar research programs, aims to increase the public's knowledge of and benefit from research conducted at Earth's northern and southernmost extremities. The "year" (which actually runs from March 1, 2007, to March 1, 2009) models three previous international science years.[11] The first IPY was held in 1882, with a follow-up 50 years later in 1932. The International Geophysical Year of 1957–1958 was modeled on the previous IPY programs.[12] Each international year provided researchers with access to new scientific and

Desert Research Institute scientist Kendrick Taylor stands in front of the snow pit wall at the West Antarctic Ice Sheet (WAIS) Divide Ice Core Project in Antarctica. The wall is part of a study of layers of ice thousands of years old. *Credit: Desert Research Institute*

5 NSF FY 2008 Budget Request to Congress.

6 Steffen, Konrad, Briefing to Congress on Greenland ice sheet, September 2008.

7 NSF FY 2009 Budget Request to Congress.

8 ACIA, *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge University Press, 2004, p. 8.

9 NSF FY 2008 Budget Request to Congress.

10 NSF Office of Polar Programs Antarctic Infrastructure and Logistics Web site: www.nsf.gov/od/opp/ail/index.jsp.

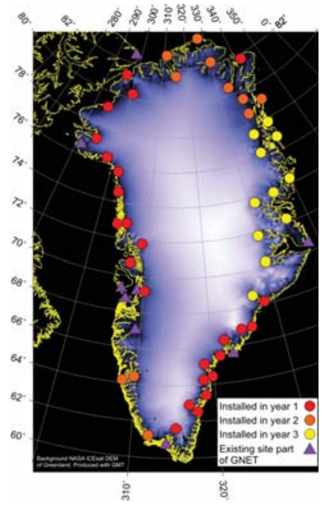
11 U.S. International Polar Year, History of International Polar Year: www.us-ipy.gov/history.shtml

12 National Academy of Sciences, The International Geophysical Year: www.nas.edu/history/igy.

physical frontiers, and added to human knowledge about the physical nature of the planet and its atmosphere. Polar year discoveries are not limited to the polar regions, but have also led to new insights into global climate, the amount of ice covering the planet, and many other physical processes. IPY projects include LARISSA (Larsen Ice Shelf System, Antarctica), an initiative to study the sudden environmental changes in the ice shelf system, and a fieldwork project to increase understanding of Pine Island Glacier, the fastest flowing glacier in Antarctica.

Polar Earth Observatory Network

When it comes to massive ice sheets, one of the most difficult questions to answer is one of the most basic: How much ice is being lost? The loss rate is critical to modeling sea-level rise in the coming century. Obtaining an accurate number is complicated because the underlying crust is rising, making even the most precise satellite altimetry and gravity measurements unreliable. To correct this problem, scientists are deploying a network of global positioning system (GPS) receivers on exposed rock outcroppings across Antarctica and Greenland. These devices will measure uplift directly and allow for corrections to the satellite results. In addition, the great sensitivity of the GPS devices will allow them to measure the tiny, springlike compressions and expansions of Earth's crust that accompany yearly snowfall and ice loss. Overall, this project will allow researchers to measure interannual variations in ice sheet mass and develop more accurate models of ice accumulation and loss.



Locations of POLENET seismic and GPS stations around the edge of Greenland.
Key:
Red Circle: Installed in year 1
Orange circle: Installed in year 2
Yellow circle: Installed in year 3
Purple triangle: Existing site part of GNET (Greenland GPS sites)
Credit: Terry Wilson and Mike Willis, The Ohio State University

NSF-supported researchers are part of the international Polar Earth Observatory Network (POLENET) project, a consortium involving researchers from 28 nations who are engaging in fieldwork to improve the collection of geophysical data around Earth's poles. The project is a core activity of IPY 2007–2008. In the south, researchers are constructing a network of GPS and seismic stations in West Antarctica to understand how the mass of the West Antarctic ice sheet changes over time. The information will be used to predict sea-level rise accompanying global warming and to interpret climate change records. In the Arctic, another NSF-funded research team is constructing a network of 38 GPS stations in Greenland (GNET) to collect better data on ice sheets.[13]

Permanent NSF Antarctic Research Facilities

Amundsen-Scott South Pole Station

In January 2008, NSF dedicated the Amundsen-Scott South Pole Station. The new elevated structure, a state-of-the-art research station, is larger and more sophisticated than any previous structure built at the bottom of the world. The station's size and capabilities are a response to the ever-growing requirement for logistical support to carry out the range and quantity of research taking place at the South Pole, which includes some of the most sophisticated astronomical observations in the world. The remote location of the station makes it an ideal, pristine setting for researchers to study the atmosphere, with virtually no local emissions to obscure atmospheric readings. Atmospheric monitoring has taken place at the South Pole since the International Geophysical Year of 1957–1958, making it one of the longest continuous atmospheric records.[14]

The exterior of the newly completed Amundsen-Scott South Pole Station. Antarctica is the coldest, highest, driest, and windiest of the continents—and the least hospitable to human life. The South Pole Station provides shelter and lab facilities to researchers, including up to 48 who overwinter during the dark austral winter, with an additional 104 berths for summer researchers. *Credit: National Science Foundation*

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13 POLENET Web site: www.polenet.org.

14 South Pole Station Special Report: www.nsf.gov/news/special_reports/livingsouthpole/sciencegoals.jsp.

McMurdo Station

Located on the Ross Sea, Antarctica's largest station serves as a gateway to Antarctica for U.S. scientific field teams, as well as the hub for most U.S. scientific activity on the continent. During the austral summer, the population of scientists and support personnel at McMurdo often exceeds 1,000.

A panoramic view of McMurdo Station, Ross Island, Antarctica. McMurdo is the largest of the three year-round stations operated by NSF's U.S. Antarctic Program. The prominent round white structures in the right foreground are fuel storage tanks. McMurdo Sound can be viewed in the left background. *Credit: Peter Somers, National Science Foundation*

McMurdo hosts a Long Term Ecological Research (LTER; see *Life* section for more details on this important program) site devoted to the study of the unique ecology of the McMurdo Dry Valleys, the largest relatively ice-free area on the Antarctic continent (approximately 4,800 square kilometers). In contrast to most other ecosystems in the world, which exist under far more moderate environmental conditions, the McMurdo Dry Valleys represent a region where life approaches its environmental limits. While the Antarctic ice sheets are slow to respond to climate change, the glaciers, streams and ice-covered lakes in the McMurdo Dry Valleys respond to change almost immediately.

Palmer Station

Located on Anvers Island in the Antarctic Peninsula region, Palmer Station is the only U.S. Antarctic station north of the Antarctic Circle. More than 40 people can occupy Palmer in the summer,[15] though Palmer's most famous residents are perhaps its Adélies penguins. Palmer serves as a research base for

Palmer Station, located midway down the Antarctic Peninsula on Anvers Island, is the smallest of the three stations operated by the U.S. Antarctic Program. *Credit: Patrick Rowe, National Science Foundation*

biologists, oceanographers, and others pursuing research on the Antarctic Peninsula.[16] Palmer Station hosts an LTER site to study a polar marine biome, with research focused on the Antarctic pelagic marine ecosystem, including sea ice habitats, regional oceanography, and nesting sites of seabird predators.[17]

Center for Remote Sensing of Ice Sheets

The Center for Remote Sensing of Ice Sheets (CReSIS), a Science and Technology Center established by NSF in 2005, develops new technologies and computer models to measure and predict the response of sea-level change to the mass balance of ice sheets in Greenland and Antarctica.[18]

Satellite-based radars have shown that parts of the ice sheets in Greenland and West Antarctic are undergoing rapid changes. However, the cause of these rapid changes is poorly understood. Constraining conditions at the bottom of the ice sheet or "bed" is essential to understanding the processes causing these changes. CReSIS has developed a radar technique to simultaneously image the ice bed, measure ice thickness, and map internal layers. Field experiments in Greenland have proven that this

15 NSF-Supported Research Infrastructure: Enabling Discovery, Innovation, and Learning, 2008.

16 Antarctic Connection Palmer Station Web site: www.antarcticconnection.com/antarctic/stations/palmer.shtml.

17 Palmer LTER Web site: http://pal.lternet.edu.

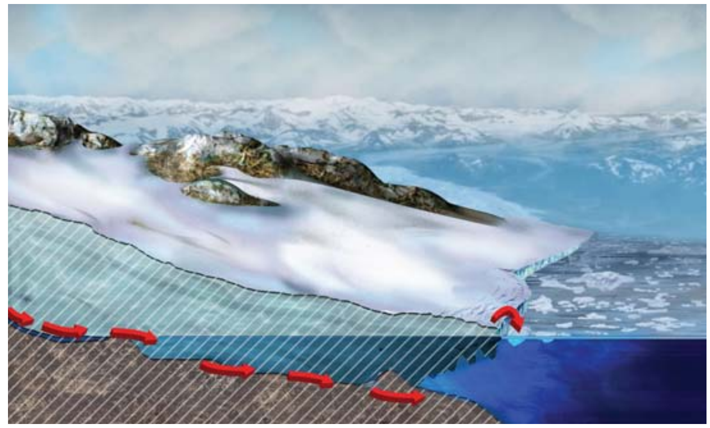
18 CReSIS Web site: www.cresis.ku.edu.

method can be used to measure ice thickness and characterize the underlying topography.[19] CReSIS will continue to make detailed measurements of ice sheets in both Greenland and Antarctica to improve ice sheet models and allow glaciologists to make better forecasts of glacier behavior.

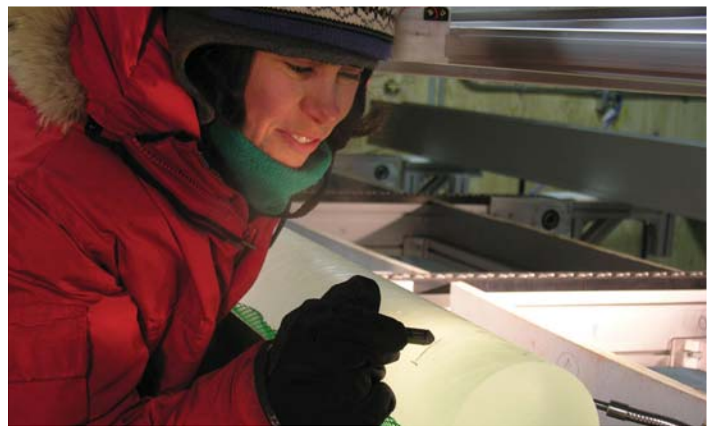
Earth's snow and ice deposits have proven to be rich sources of climate information from our planet's past. Glaciologists drill vertical cores deep into pristine ice layered like a birthday cake, the result of hard-packed snowfall accumulated over thousands of years. These layers preserve a wealth of information about the atmospheric composition and temperature when the snow first fell. In the polar regions, summer temperatures rarely exceed the freezing point of water, so the layers of snow are unperturbed by melting. Pockets of air among the snowflakes are buried below new layers; they become tiny atmospheric time capsules, preserved as microscopic bubbles in the compressed ice. Researchers are continuing to find new ways of extracting data about atmospheric composition, temperature, solar activity, volcanic eruptions, and other types of information from ice cores. In some regions of Antarctica and Greenland, ice has accumulated continuously for many millennia. The farther down scientists drill, the farther into the past they stretch the climate record. In one current NSF research project, researchers from Greenland and Antarctica are teamed up to drill ice cores from regions that experience similar snow accumulation.[20] In Antarctica in particular, annual precipitation rates are generally low, limiting the amount of ice, and therefore climate information, contained in an annual layer. In West Antarctica, however, precipitation rates are higher than the continental average, and scientists have already drilled cores containing more detailed information about past climate from this area. The scientists hope not only to develop a higher resolution climate record for Antarctica, but to compare this climate record to similar Greenland cores in an effort to reveal the climate relationship of the opposite ends of Earth over the millennia.

International Trans Antarctic Scientific Expedition

The International Trans Antarctic Scientific Expedition (ITASE) collects and interprets a continent-wide array of environmental parameters assembled through the coordinated efforts of scientists from 20 nations. Because of its



When a glacier with its "toe in the water" thins, a larger fraction of its weight is supported by water, causing it to slide faster, calving more ice into the sea at the glacier terminus. *Credit: Nicolle Rager Fuller, National Science Foundation*



Rebecca Anderson of the Desert Research Institute examines a section of West Antarctic Ice Sheet (WAIS) Divide ice core recovered from a depth of 500 meters. The WAIS Divide, located near West Antarctica's "ice divide" between the Amundsen and Ross seas, was chosen as a site for an ice core because of its smooth topography, ancient ice deposits, and relatively high accumulation rate. The WAIS Divide project will provide the Southern Hemisphere equivalent to a series of ice cores drilled in Greenland beginning in 1989 and will give researchers the opportunity to compare up to 80,000 years of regional climate trends between the two polar regions. *Credit: Courtesy of Kendrick Taylor*

U.S. International Trans Antarctic Scientific Expedition (ITASE) crewmembers Steve Arcone and James Laatsch return from a snow-penetrating radar test mission around Byrd Surface Camp. Arcone pilots the snowmobile while Laatsch rides the Nansen sled. ITASE researchers overcome the remoteness of the Antarctic continent to collect important information on environmental and climate change. *Credit: Dan Dixon, National Science Foundation*

19 NSF Highlight 13663: Center for Remote Sensing of Ice Sheets.

20 WAIS Divide Science: www.waisdivide.unh.edu/science.

remoteness, Antarctica is an ideal location to monitor biogeochemical cycles and climate change at the local and global scales.[21] ITASE is developing annually resolved, instrumentally calibrated records of climate over the past 200–1,000 years, including temperature, net ice mass balance, and atmospheric circulation and chemistry. The goal of ITASE is to develop a basis for understanding past, present, and future climate change over Antarctica and the adjacent Southern Ocean.[22]

National Ice Core Laboratory

The U.S. National Ice Core Laboratory (NICL) is a facility—jointly supported by NSF, USGS, and the Department of the Interior—for storing, curating, and studying ice cores recovered from the polar regions. NICL provides scientists with the capability to conduct examinations and measurements on ice cores, and it preserves the integrity of these ice cores in a long-term repository for current and future investigations.[23]

Eric Cravens, assistant curator at the National Ice Core Lab (NICL), holds up a piece of ice taken from above Lake Vostok, a remote region of Antarctica. The NICL is a facility for storing, curating, and studying ice cores. The facility currently houses more than 14,000 meters of ice cores from 34 drill sites in Greenland, Antarctica, and high mountain glaciers in the western United States. *Credit: Melanie Conner, National Science Foundation*

Glaciologists study not only the climate record contained in glaciers but the movement and behavior of the glaciers themselves. In a warming world, the complex interactions among atmosphere, sea, land, and ice may have profound implications for the amount of ice that will exist in the future. The vast reserves of water frozen above sea level on Antarctica and Greenland have grown and shrunk during previous episodes of climate change. Researchers are intently focused on the behavior of the ice sheets in both regions, particularly because of unexpected recent accelerations in melting and ice sheet collapse events.

Arctic Observing Network

The Arctic Observing Network (AON) is a new NSF-supported program that will encompass a system of atmospheric, land-based, and ocean-based observational capabilities, from ocean buoys to satellites. AON will enhance and expand our ability to monitor Arctic environmental conditions.

The Arctic Observing Network (AON) encompasses a system of atmospheric, land-based, and ocean-based environmental monitoring capabilities—from ocean buoys to satellites—that will significantly advance our observations of Arctic environmental conditions. Data from the AON will enable the interagency U.S. Government initiative—the Study of Environmental Arctic Change (SEARCH)—to gain an in-depth understanding of the wide-ranging and rapid changes that are occurring in the Arctic. *Credit: Nicolle Rager Fuller, National Science Foundation*

Data from AON will enable the U.S. Government initiative—the Study of Environmental Arctic Change (SEARCH)—to get a handle on the wide-ranging series of significant and rapid changes occurring in the Arctic.

21 http://www2.umaine.edu/itase

22 NSF Highlight 11564: ITASE (International Trans Antarctic Scientific Expedition).

23 http://nicl.usgs.gov

These changes include, for example, increasing average annual surface air temperatures, decreasing summer sea ice extent and sea ice mass, changing ocean circulation, migrating tree lines and vegetation zones, thawing glacial ice masses and permafrost, and changing socioeconomic dynamics.

Permanent NSF Arctic Research Facilities:

Toolik Field Station

The Toolik Field Station is part of the NSF-sponsored LTER network. The Toolik site enables researchers to study the ecology of one of Earth's important ecosystems—the frozen tundra landscapes of the far north. Toolik recently opened for continuous winter field study operations. While Arctic winters present significant logistical challenges, winter operations are essential to enable new observations such as the overwinter carbon dioxide flux of the surrounding tundra ecosystem.[24]

Toolik Field Station in an April 2002 snowstorm. The station is located in the northern foothills of the Brooks Range in northern Alaska, on the southeast shore of Toolik Lake. This location affords access to three major geographic regions in Alaska: the Brooks Range, the Arctic Foothills, and the Arctic Coastal Plain. *Credit: © 2002 James H. Barker and the Institute of Arctic Biology*

Summit Camp

NSF supports Summit Camp, a scientific research station in Greenland. The camp, located at the peak of the Greenland ice sheet (the largest ice sheet in the Northern Hemisphere) enables year-round operations to study air-snow interactions, which are crucial for interpreting data from ice cores drilled in the area and elsewhere. The site has proven to be a nearly ideal location for studies of climate change and snow chemistry.[25]

The late evening Arctic summer sun illuminates Summit Greenland Environmental Observatory, NSF's primary scientific station in Greenland. *Credit: Peter West, National Science Foundation*

Barrow

In Barrow, Alaska, NSF-funded researchers can take advantage of the laboratory facilities, researcher accommodations, and other research infrastructure of North America's northernmost community. Research conducted in Barrow includes studies of atmospheric composition, Bering Sea marine environment changes, terrestrial-atmospheric fluxes of greenhouse gases, permafrost melting, and many other topics. The scientific activities in Barrow also enrich the local economy and education system; researchers organize outreach programs for local students and include local people, including native Alaskans with cultural knowledge of the local ecosystems, in their research projects.

A "Welcome to Barrow" sign in Point Barrow, Alaska ("America's Northernmost City"). The Barrow Arctic Science Consortium is a nonprofit group that coordinates the research activities of a variety of NSF-funded researchers studying climate change and other areas of research in and around Barrow. *Credit: Anne M. Jensen, UIC Science*

24 NSF Highlight 14637: Winter Research Capability at Toolik Field Station, Alaska.

25 NSF-Supported Research Infrastructure: Enabling Discovery, Innovation, and Learning, 2008.

Continental Ice and Snow

In addition to ice at the poles, seasonal snow cover and high-altitude ice and glaciers figure in global and regional climate. Ice cores drilled in glaciers outside the Arctic and Antarctic Circles can be compared with other climate proxy data to show how the climates of different regions have correlated in the past. Researchers have determined that continental glaciers have been primarily involved in sea-level changes in the past, and much of the present rise in sea level may be attributable to glacial melt.[26,27]

And what about the climate effects of snow? In one example from an NSF-funded study, researchers found that seasonal snow cover can significantly change the amount of solar energy absorbed by the ground. The researchers discovered an important link between the albedo of North American winter snow cover and climate model forecasts. Through the incorporation of a realistic snow albedo feedback into climate models, the researchers found that they could substantially improve the accuracy of long-timescale predictions.[28]

Conclusion

Snow and ice are important influences in global climate. Earth's polar regions are experiencing swift and dramatic changes as a result of global climate change, with melting permafrost and rapidly shrinking sea- and land-based ice sheets being some of the most visible changes. The ancient ice reserves on Antarctica and Greenland store accumulated climate data that can help us forecast Earth's climate future; ironically, these stored records may be in danger of being lost because of the rapid warming, particularly in Greenland. The highlights that follow contain descriptions of some of the many research projects funded by NSF on snow and ice research. Many of the projects are connected with the IPY program and involve partnerships with researchers from around the world. These research efforts not only contribute to our current understanding of Earth's ice and snow, they also provide critical field experience and training for the next generation of glaciologists, paleoclimatologists, and geoscientists who will continue to monitor the cryosphere.

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26 Solomon, S., et al., Technical Summary, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 2007, p. 50.

27 News from the Field, "Glaciers and Ice Caps to Dominate Sea Level Rise This Century, Says CU-Boulder Study": www.nsf.gov/news/news_summ.jsp?cntn_id=109810.

28 NSF Highlight 15790: Improving Climate Model Predictions Through a Surprising Link to Snow Cover Simulations.

Ice Research Highlights

Understanding the Structure of Sea Ice

Arctic sea ice. *Credit: Martin Nweeia, Narwhal Tusk Research*

Ice plays an important role in both the current climate and climates of the past, influencing the amount of solar radiation reflected back to space, the exchange of heat between the polar ocean and the atmosphere, the amount of freshwater entering the ocean, and, indirectly, the strength of the global ocean's overturning circulation. Ice can be difficult for researchers to characterize, however, because it can exhibit different thermal behaviors, which depend on variables such as the number and size of air bubbles within it. Sea ice is a particularly complicated and dynamic porous composite of solid ice, brine, and gases. The microstructure of the ice depends on the temperature of the ice, the pressure to which it is subjected, and its history. Since the dynamics of climate depend strongly on land and sea ice, good models of the properties of ice are important for accurate climate predictions.

Ken Golden, a mathematician from the University of Utah, and Hajo Eicken, a sea ice specialist from the University of Alaska, Fairbanks, use computer models, laboratory experiments, field experiments, and 3-D data visualization techniques to study the influence of the microscale pore structure of sea ice, with the goal of developing a new generation of mathematical models of sea ice. These models will link the properties of the ice to large-scale parameters, such as temperature, to provide new tools for climate models, as well as new insight into the small-scale behavior of ice. **Highlight ID: 1992 GEO/OAD**

Center for Remote Sensing of Ice Sheets

Bruce Vaughn displays a segment of ice core retrieved by the Center for Remote Sensing of Ice Sheets project. Note the narrow bands of white firn (layers of incompletely melted winter snow accumulation) between thick layers of translucent solid ice. *Credit: Bruce Vaughn, Institute of Arctic and Alpine Research, University of Colorado*

The Center for Remote Sensing of Ice Sheets (CReSIS) is developing tools and techniques to determine the effect of climate change on polar ice sheets and the resulting impact on sea-level change. It is also training next-generation scientists and engineers, taking into account the diversity of the nation. Synthetic-aperture radars are revolutionizing the study of polar ice sheets. Satellite-based radars have shown that parts of ice sheets in Greenland and West Antarctica are undergoing rapid changes. However, what is causing these rapid changes is poorly understood. Constraining conditions at the bed is key to understanding the processes causing these changes and incorporating this knowledge into models. CReSIS has developed a very high frequency radar to simultaneously image the ice bed, measure ice thickness, and map internal layers. Its potential was demonstrated with field experiments in Greenland. This is the first successful measurement of ice thickness on this glacier, and clearly shows the deep and narrow channel through which the ice flows. The inset shows the deepest part of the channel in more detail and indicates an ice thickness of about 2.5 kilometers. The Jakobshavn Isbrae retreated and accelerated significantly over the past few years. Information about the bed topography and thickness is crucial to identify the causes of these changes and to model the glacier's response to a warming climate. **Highlight ID: 13663 OPP/ARC**

International Trans Antarctic Scientific Expedition

Crew member Betsy Youngman reels in the balloon while helping Markus Frey conduct atmospheric sampling experiments. The International Trans Antarctic Scientific Expedition (ITASE), under the leadership of Paul Mayewski, studies environmental change over the past 200 years. *Credit: Dan Dixon, National Science Foundation*

The International Trans Antarctic Scientific Expedition (ITASE) is a basis for understanding past, present, and future climate change over Antarctica and the adjacent Southern Ocean. ITASE, a 20-nation consortium, is developing a continent-wide array of annually resolved, instrumentally calibrated records of past climates (temperature, net mass-balance, atmospheric circulation, chemistry of the atmosphere, and forcing) covering the past 200–1,000 years. The initial phase of the U.S. contribution to ITASE (US ITASE) concentrated on West Antarctica. During the 2006–2008 austral field seasons, US ITASE planned to extend its traverses into East Antarctica. Several key results have emerged from the West Antarctic phase of US ITASE. Temperatures are still within the range of natural variability of the past 200 years, exclusive of the Antarctic Peninsula, and are closely associated with changes in major atmospheric circulation patterns. Mass balance variability is primarily controlled by surface/bed topography, with significant variability in regions displaying large gradients in topography. Initial phases of the inland migration of marine air masses can be detected along the Amundsen Sea coast. A significant portion of the natural variability in the strength of the westerlies surrounding Antarctica is attributed to decadal and longer scales of solar variability that affect the production of ozone and, as a consequence, the thermal gradient over Antarctica and the Southern Ocean. **Highlight ID: 11564 OPP/ANT**

Winter Research Capability at Toolik Field Station, Alaska

In early June, the covers for the Arctic Long Term Ecological Research (ARC LTER) greenhouse in the tall willow and birch shrub plot are rolled down. The greenhouses are used to increase the summer temperature for several ecosystems in near Toolik Field Station. The covers are rolled up again in mid-August. *Credit: Jim Laundre, Arctic LTER*

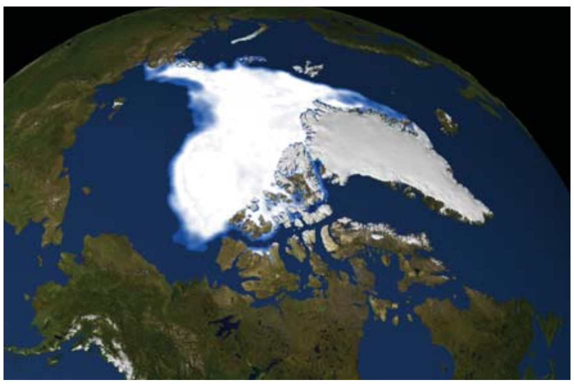
Winter lasts nearly three-quarters of the year in the Arctic, yet relatively few scientific studies have been carried out in the Arctic winter because of the significant challenges of conducting scientific research in the extreme cold and dark. Even access to automated measures of environmental parameters has been limited owing to a lack of continuous power and communications at major field sites. Recently, scientists have increasingly recognized the compelling need for winter studies, despite the logistical challenges. Important issues that can only be addressed by winter studies include (1) understanding the radiation balance in the winter and how it is changing, which is essential to understanding climate change in the Arctic; (2) understanding the role of snow and ground temperatures in overwinter carbon and nitrogen cycling, which affects summer growth of vegetation and feedback of greenhouse gases to the atmosphere (one of the principal ways that the Arctic affects global climate); and (3) understanding how animals and plants survive extreme winter conditions and how these adaptations may constrain their response to changing environmental conditions. Although many biological processes are slower in the winter because of low temperatures, microbes, plants, and animals continue to be active through the long winter night, and their activities establish a legacy that affects summer processes. For example, overwinter decomposition by soil microbes sets the conditions for summer uptake of nutrients and growth by plants.

The University of Alaska's Toolik Field Station (TFS) was open for continuous winter operations for the first time in 2006–2007. Science conducted there the first winter included studies of overwintering insects; studies of the patterns of snow accumulation and density behind snow fences and the effects on shrub mortality and overwinter carbon dioxide flux; winter meteorological measurements at a variety of newly established locations across the north slope; establishment of a snow-cover observation camera for long-term records of snow arrival and snowmelt; and studies of stream community ecology overwinter in unfrozen springs. Continuous relay and monitoring of existing meteorological stations operated by the Arctic Long Term Ecological Research Program were carried out. Baseline environmental observations were collected by TFS staff throughout the winter. These studies will advance our understanding of winter processes and their legacies for the summer. **Highlight ID: 14637 OPP/ARC**

Improving Climate Model Predictions Through a Surprising Link to Snow-Cover Simulation

See *Atmosphere* section.
Highlight ID: 15790 GEO/ATM

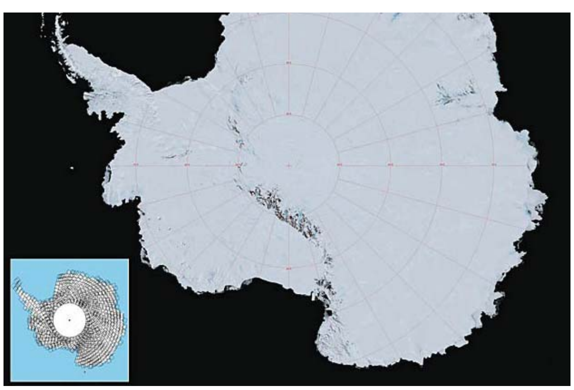
Loss of Arctic Sea Ice Observed in 2007



This image illustrates the record minimum sea ice in the Arctic Ocean, which occurred on September 14, 2007. *Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio*

In September 2007, the extent of sea ice in the Arctic Ocean was 23 percent less than the previous record set in 2005. Results from an array of buoys, deployed as part of the Arctic Observing Network, showed an extraordinarily large amount of bottom melting in the Beaufort Sea associated with this retreat. This observation indicates that local melting of sea ice was largely the result of excess heat in the ocean's surface waters, not excess heat in the atmosphere. A synthesis of satellite observations and weather forecast data is consistent with this conclusion. The conditions in the Beaufort Sea—more open water leading to more solar heat absorbed, resulting in more melting and more open water—is a classic ice-albedo feedback signature. Understanding the nature of changes in the Arctic sea ice cover is vital, since it is an indicator and amplifier of global climate change. **Highlight ID: 15844 OPP/ARC**

What Is Happening to the Antarctic Sea Ice Cover?



The Landsat Image Mosaic of Antarctica (LIMA). More than 1,000 Landsat satellite images were pieced together to construct LIMA. *Credit: USGS/ NASA*

We know that the area and thickness of the Arctic sea ice cover has been decreasing over the past few decades. What about the Antarctic? The media have been confused about why the Antarctic ice cover is not retreating in the same way as it is in the Arctic. Some reports have even suggested that increases of ice in areas of the Antarctic signal that global warming is a hoax. As in the Arctic, the Antarctic sea ice cover is affected by a complex combination of solar heating and atmospheric pressure patterns and ocean currents. Unlike the Arctic, until now at least, Antarctic sea ice largely disappears on a seasonal basis. The total amount of Antarctic sea ice in a given year doesn't seem to be changing dramatically, but there have been big changes in particular regions. Previous studies have shown pronounced contrasting trends in annual sea duration and monthly concentration in two regions of the Southern Ocean: decreases in the western

Antarctic Peninsula and southern Bellingshausen Sea, and increases in the Western Ross Sea region. The recent analysis of satellite observations from 1979–2004 shows that sea ice is retreating a month earlier and advancing a month and a half later in the former region and retreating a month later and advancing a month earlier in the latter region. These trends are strongly correlated with changes in atmospheric pressure patterns. A simple way to think about it is that there is a recurrent band of low pressure or "storminess" that affects the sea ice edge, particularly during spring and fall. Larger scale pressure systems push this band of low pressure around. When these larger scale systems are analyzed statistically, it appears that there is a hemispheric pressure pattern that changes on timescales of decades and is periodically perturbed by El Niño/La Niña climate patterns. Ozone losses and greenhouse gases—both of which affect Earth's interaction with sunlight—are thought to be driving changes in the Southern Hemisphere pressure patterns connected to the sea ice changes. On the basis of current understanding, continued greenhouse gas release would be expected to reinforce and perhaps expand these regional ice trends to larger areas. **Highlight ID: 16777 OPP/ANT**

Sea-Level Rise From Polar Ice Sheets: Societal Relevance and Broader Impacts

The southeastern United States, Florida in particular, contain densely populated coastal areas that could be vulnerable to sea-level rise. *Credit: Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE*

The Center for Remote Sensing of Ice Sheets (CReSIS) is an NSF-funded Science and Technology Center whose mission is to develop technologies, conduct field investigations, compile and analyze data to characterize ongoing rapid changes in polar ice sheets, and develop models that explain and predict ice sheet interactions with climate and sea-level rise. One of the goals of CReSIS is to contribute to the improvement of the Intergovernmental Panel on Climate Change assessment of future sea-level rise. Progress toward this goal has recently been made with research that simulated a theoretical global sea-level rise of 1 to 6 meters and developed a number of products for visualizing the coastal inundation and its effect.

Not only does the work have societal relevance because of the potential impacts on people living in coastal communities near sea level, but it was carried out by faculty and students involved in the center from the University of Kansas and the Haskell Indian Nations University. Through NSF funding, the lab has become a training ground not only for students but also for members of numerous American Indian tribes. Faculty and students at Haskell are training members of Native American tribes to use the techniques employed in the NSF-funded research. This contributes to the scientific literacy of citizens exercising stewardship over land and natural resources. **Highlight ID: 14730 OPP/ANT**

Connections: Sea-Level Rise, Climate Change, and the Dynamics of Glaciers

View of Kennicott Glacier, Alaska, looking toward 16,390-foot Mount Blackburn in its headwaters. Research on this Alaskan glacier by a small team of researchers from the University of Colorado, led by Robert and Suzanne Anderson and graduate student Tim Bartholomaus, takes advantage of the glacier's annual outburst flood event to study how the hydrologic system of a glacier influences its sliding speed, which governs how glaciers erode the landscape. *Credit: Robert Anderson, INSTAAR and Department of Geological Sciences, University of Colorado*

With global temperatures predicted to climb over the next century, the prediction is that ice will melt and the sea level will rise. But is the story as simple as that? The connection between these phenomena lies at the base of alpine-type glaciers, the tongues of ice that literally connect the ocean to the ice caps. It is the ability of these glaciers to slide that enables the ice caps to rejoin the ocean, causing the sea level to rise. Scientists from the University of Colorado at Boulder (UCB) have provided some of the first real-time sequences of glacial sliding and have demonstrated that the key to accelerations in glacial velocity is the dynamics of the basal plumbing system and the availability of melt water. Graduate student Tim Bartholomaus and his mentors from UCB have assembled high-resolution velocity, surface uplift, temperature, water pressure, and outlet water discharge data on the Kennicott Glacier in Alaska. These data reveal the intimate connection between water pressure and glacier sliding velocity, and enable Earth scientists to quantify the role of the subglacial plumbing system that at one moment provides safe passage for melt water and at another is overwhelmed and overpressured and enables rapid glacial sliding. Sea-level rise is linked to this dynamic behavior because the rate at which these glacial tongues slide will determine the principal rate at which ice mass is lost and, thus, the rate at which sea level will rise over the next few decades and centuries. **Highlight ID: 16095 GEO/EAR**

Ancient Glaciers in Antarctica Are Key to Understanding Climate Change

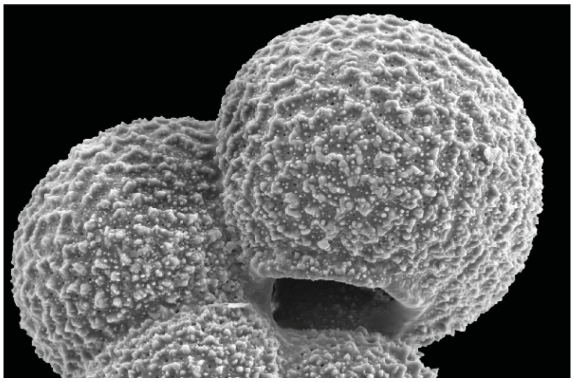
Permian glacial deposits exposed at Mount Ritchie, Antarctica. This image shows ice-proximal glaciomarine sedimentation from a Permian tidewater glacier. The large stones in the bottom half of the photo are interpreted as material that was either dumped off the surface of the glacier during iceberg calving or dumped from the surface of an iceberg. The light colored sandstone in the top of the photo may be the result of deposition of sand where subglacial streams emerged at the base of the glacier. *Credit: John Isbell, Department of Geosciences, University of Wisconsin-Milwaukee*

As Earth gets warmer, we look to the geologic record for examples of what the planet might become. The last time Earth transitioned from a glacial world like the present one to a "greenhouse world" (free of ice) was more than 250 million years ago. NSF researchers document the change using three lines of evidence: (1) chemical information that can tell us past temperatures; (2) fossil evidence of land plants; and (3) hard evidence from rocks in Antarctica that indicate whether or not there were ice sheets there at that time.

The results tell us two important things. First, atmospheric carbon dioxide content, global temperatures, and ice sheet occurrences are strongly correlated. This finding gives further credence to the idea that anthropogenic increases in atmospheric carbon dioxide will have major effects on global climate. Second, plants respond to climate change in a geologic instant. Europe went from warm, wet forests to dry, cold pine forests and then back again right along with climate change. All this was also accompanied by plant evolution.

This research suggests that if greenhouse gas emissions continue to increase, in addition to hotter temperatures and sea-level rise, we can expect big changes in the plants we're all familiar with, which would change everything about our crops, animals, and ecosystems in general. **Highlight ID: 14727 OPP/ANT**

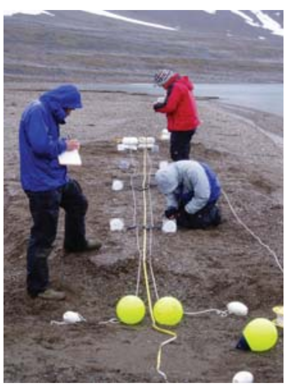
A Warming Climate Can Support Glacial Ice



Scanning electron microscope image of an Antarctic foraminifera. The fossilized remains of this type of organism are used to study climate conditions during the Cretaceous Thermal Maximum, 91 million years ago. *Credit: Scott McCallum and Scott Ishman*

A new research study challenges the generally accepted belief that substantial ice sheets could not have existed on Earth during past super-warm climate events. Researchers at Scripps Institution of Oceanography at the University of California-San Diego conducted the study, supported by the NSF-funded Integrated Ocean Drilling Program and the German Research Foundation. The study provides strong evidence that a glacial ice cap, about half the size of the modern-day glacial ice sheet, existed 91 million years ago during a period of intense global warming. The study examines chemical and sea-level data retrieved from marine microfossils deposited on the ocean floor 91 million years ago during a period known as the Cretaceous Thermal Maximum. This extreme warming event in Earth's history raised tropical ocean temperatures to 35–37 degrees Celsius (95–98.6 degrees Fahrenheit), about 10 degrees Celsius (18 degrees Fahrenheit) warmer than today, thus creating an intense greenhouse climate. It is likely that an ice sheet about 50–60 percent the size of the modern Antarctic ice cap existed for about 200,000 years, demonstrating that even the super-warm climates of the Cretaceous Thermal Maximum were not warm enough to prevent ice growth. The presence or absence of sea ice has major environmental implications, specifically in terms of sea-level rise and global circulation patterns. **Highlight ID: 16360 GEO/OCE**

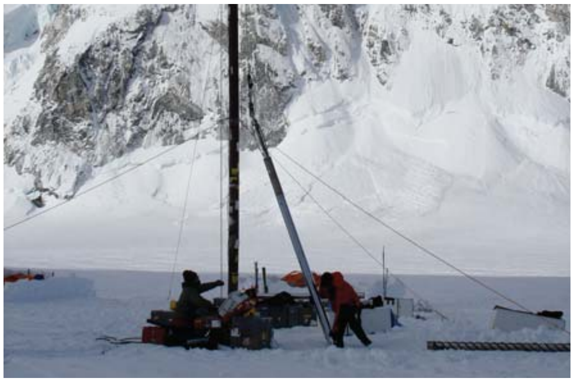
Calibrating Past Climate Change in the High Arctic: Svalbard, Norway, Research Experiences for Undergraduates



Research Experiences for Undergraduates (REU) participants lay out moorings for a research project. *Credit: Al Werner, Mount Holyoke College*

Svalbard, Norway, has warmed considerably over the past 90 years, and paleoclimate proxies indicate even greater climate change over the past 10,000 years. The objective of this Research Experiences for Undergraduates (REU) site program is to expose students to the challenges and rewards of polar research. Mount Holyoke College is the host institution, in collaboration with the Universities of Massachusetts and Northern Illinois, Bates College, and Hampshire College, as well as the Norwegian University system and the Norwegian Polar Institute. The Arctic is particularly sensitive to changes in climate, and climatically induced environmental changes in the region can trigger further changes of global consequence. Despite this, little is known of subcentury climate change, and virtually nothing is known of decadal-scale variability in this region. Undergraduate students conduct research on glacial lake and glaciomarine systems to establish links among climate, glacier mass balance, sediment transport, and lake and fjord sedimentation. Students, working closely with peers and faculty mentors, design their own research questions, collect field data, and formulate science hypotheses and conclusions during 5 weeks in Svalbard. **Highlight ID: 12614 GEO/ATM**

Novel Ice Core Drill Reveals Pacific Northwest's Climate Past



Driller Bella Bergeron (left, Ice Coring and Drilling Services) and Eric Steig (right, University of Washington) prepare to lower a 3-inch thermal core barrel into the glacier at Combatant Col, British Columbia Coast Range (July 22, 2006). The mountain in the background is Mount Waddington, the tallest peak in the Coast Range. Combatant Col is filled with a large, flat glacier that is about 200 meters (around 650 feet) deep. Because of its unusual thickness and altitude, Combatant Col is one of the best sites in western Canada to collect a deep ice core that records past climate changes in the region. *Credit: Douglas H. Clark, Geology Department, Western Washington University*

Some of the glaciers that hold the most promise for revealing Earth's climatic past are found in the most remote places. Eric Steig and Doug Clark took advantage of NSF's Small Grants for Exploratory Research program to develop an ice drill that is lighter and thus more portable than current drilling equipment. The team used this novel ice drill to recover an unprecedented ice core from an alpine glacier atop Mt. Waddington in the British Columbia Coast Range. The ice core revealed a record of the region's climate stretching more than 1,000 years into the past. The record included annual layers of atmospheric aerosols, such as soot and dust, preserved in the ice.

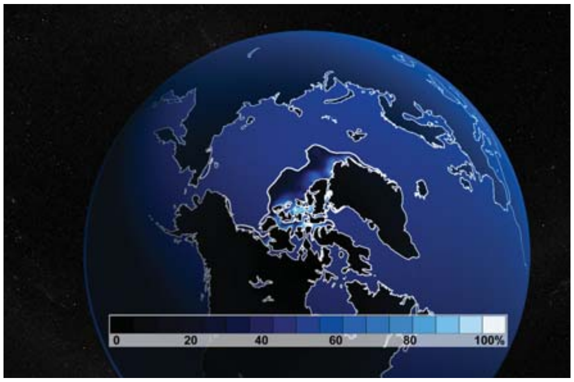
Annual snow accumulation records are useful quantitative indicators of large-scale atmospheric circulation patterns. Snow accumulation records from the North Pacific region are of particular interest because of their potential to contribute to the documentation and reconstruction of multidecadal climate variability.

Paleoclimate research is cross-disciplinary by nature and requires a multidisciplinary scientific strategy that integrates geology, biology, oceanography, chemistry, physics, and engineering to collect data and solve complex problems. Interpreting paleoclimatic data encourages a holistic approach to thinking about natural systems. At present, much paleoclimate research from ice cores is conducted from large base stations in polar regions. This new equipment and the recovered ice core help open up a new archive of paleoclimate data for use by climate researchers. **Highlight ID: 16324 GEO/ATM**

Studying Past Changes in Arctic Fossils

To understand the modern Arctic system, its current unprecedented change, and its future requires a long-term perspective on the natural variability intrinsic to the system. Because observational records of the Arctic are relatively brief, we must depend on proxy records for this perspective. This work is part of a larger NSF-sponsored project to obtain and synthesize climatic data from the Arctic over the past 2,000 years. Researchers are currently using assemblages of aquatic insect fossils from lake sediments to reconstruct past temperatures on Baffin Island, in the eastern Canadian Arctic, that will eventually be combined with many other similar records from across the Arctic to generate a broad understanding of past temperatures. This work contributes to understanding the Arctic system by placing 20th century climate change into a long-term context of interdecadal climatic variability spanning 2,000 years. **Highlight ID: 13785 OD/OCI**

Abrupt Ice Retreat Could Produce Ice-Free Arctic Summers by 2040



By about 2040, the Arctic may be nearly devoid of sea ice during the late summer unless greenhouse gas emissions are significantly curtailed. *Credit: © University Corporation for Atmospheric Research*

The recent retreat of Arctic sea ice is likely to accelerate so rapidly that the Arctic Ocean could become nearly devoid of ice during summertime as early as 2040, according to a study by a team of scientists from the National Center for Atmospheric Research (NCAR), the University of Washington, and McGill University. The team analyzed the impact of greenhouse gas emissions on the Arctic. Scenarios run on supercomputers showed that the extent of sea ice each September could be reduced so abruptly that, within about 20 years, it may begin retreating four times faster than at any time in the observed record.

Arctic sea ice has retreated in recent years, especially in the late summer, when ice thickness and area are at a minimum. To analyze how global warming will affect the ice in coming decades, the team studied a series of seven simulations run on the NCAR-based Community Climate System Model (CCSM), one of the world's leading tools for studying climate change. Having first tested the model to show that it closely matched observations of ice cover since 1870, the team simulated future conditions. The model results indicated that if greenhouse gases continue to build up in the atmosphere at the current rate, the Arctic's future ice cover will go through periods of relative stability followed by abrupt retreat. The research pointed to several reasons for the abrupt loss of ice in a gradually warming world. Open water absorbs more sunlight than does ice, meaning that the growing regions of ice-free water will accelerate the warming trend. In addition, global climate change is expected to influence ocean circulations and drive warmer ocean currents into the Arctic. **Highlight ID: 14113 GEO/ATM**

Antarctic Temperature Changes, 1958–2002

This project is the first to make a realistic estimate of Antarctic climate change through a quantitative trend assessment of observed surface temperatures in Antarctica since the International Geophysical Year in 1957. While Antarctic temperature changes have potentially major consequences for the global system, the large area and the highly heterogeneous network of surface stations in Antarctica had previously limited quantitative studies and had led to a mix of results reported to the public.

Using temperature time series from 21 Antarctic manned observing sites and 73 automated weather stations for which the record exceeded 2 years, together with cooperative ship reports from the surrounding oceans, the investigators produced an Antarctic temperature trend assessment that makes optimum use of the available information and is technically justified by the demonstrable statistical properties of the data.

The most prominent feature in the linear trends of annual surface air temperature for the period 1958–2002 is the significant warming over the Antarctic Peninsula. Other characteristics are slight warming in coastal Antarctica and actual cooling over regions of central Antarctica and parts of the Southern Ocean. The Antarctic Peninsula warming is strongest in autumn and winter but is apparent in all seasons. Results of the research are available at http://igloo.atmos.uiuc.edu/ANTARCTIC. **Highlight ID: 12271 OPP/ANT**

Arctic Cetaceans: Indicators of Climate Change

Kristin Laidre was supported for 22 months by a fellowship under the International Research Fellowship Program (IRFP) at the Greenland Institute of Natural Resources in Nuuk, Greenland. The IRFP is designed to launch young U.S. postdoctoral scientists and engineers into global engagement.

Laidre's research addresses questions concerning the vulnerability of Arctic cetaceans to climate change. The Arctic is currently experiencing dramatic changes in sea ice characteristics and marine productivity, which will have cascading effects on Arctic food webs. Three species of cetaceans (narwhal, beluga, and bowhead whale) inhabit the Arctic waters of West Greenland and are ideal indicator organisms for monitoring ongoing biophysical changes affected by a warming climate. Arctic cetaceans' seasonal movements, distribution, resource selection, and life history parameters are tightly linked with changes in the Arctic environment, making them both vulnerable to climate alterations and good indicators of cumulative changes.

The main purpose of the project has been to contrast Arctic species inhabiting different ecological niches with different life history strategies to support broader inferences regarding the effects of climate change in different habitats of the High Arctic. Laidre has quantified the trends in sea ice and primary production in focal areas using satellite telemetry data on whale movements and diving behavior and remotely sensed environmental data. This information has been used to examine resource selection and differential vulnerability using quantitative spatial modeling techniques. Results of this work have facilitated the understanding of the potential effects of climate change on High Arctic top predators and the sustainability of their exploitation by Inuit communities, linking scientific discovery to societal benefit.

The host institute—the Greenland Institute of Natural Resources (GINR) in Nuuk, Greenland—is the Greenland Home Rule Government's center for nature research focusing on conservation, climate change and human impacts, biological diversity, and sustainable use of living resources. Laidre has collaborated with senior scientist Mads Peter Heide-Jørgensen at GINR.

In addition to several peer-reviewed scientific manuscripts and a popular book published during the fellowship, Laidre's research has extended into an international review paper and a quantitative index developed by several top Arctic ecologists to rank the vulnerability of Arctic marine mammals to climate change. The international collaborative relationships Laidre formed in Denmark, Greenland, and elsewhere in Europe while on fellowship there, have been critical in her professional development and scientific progress. Her work has elucidated broad cetacean resource selection relationships and documented biocomplexity associated with changing climate. **Highlight ID: 12092 OD/OISE**