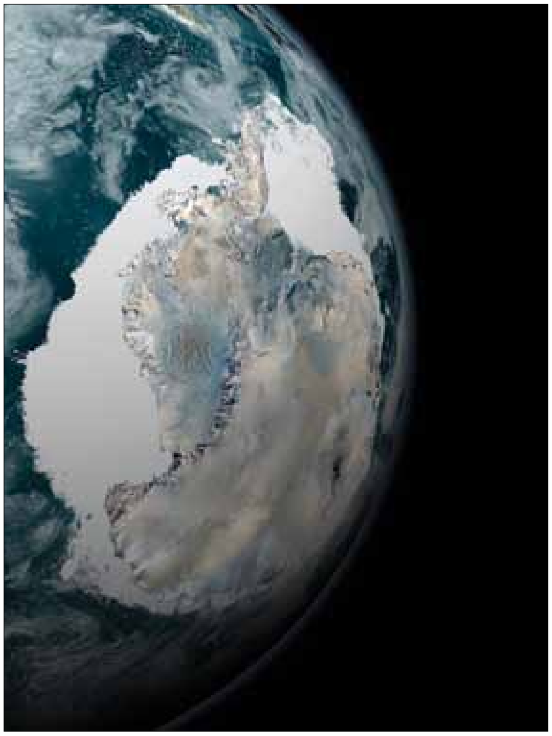
REPORT IN BRIEF

Future Science Opportunities in Antarctica and the Southern Ocean

Although the icy landscape of Antarctica and the Southern Ocean may seem distant, scientific research in this region can yield insights on changes that are important to the entire planet. The Antarctic region also holds the promise of novel discovery: ice and sediment records contain clues to Earth's history, the region's living organisms may hold genetic secrets to surviving in extreme environments, and the Antarctic plateau offers an unparalleled platform for observing the solar system and the Universe beyond. Looking out over the next couple of decades, this report identifies key questions that will drive scientific research in Antarctica and the Southern Ocean, and presents opportunities to be leveraged to sustain and improve the science program. The development of a large-scale observing network and a new generation of models has the potential to expand scientific understanding and ensure the continuing success of research in the Antarctic region.

The Antarctic region is like no other place on Earth. Covering nearly 14 million square kilometers—approximately 1.4 times the size of the United States—Antarctica is the planet's coldest, windiest, and driest continent. This extreme environment provides great opportunities for advancing scientific understanding of the planet: the climate and geography of the region are important players in many of Earth's global processes, including the circulation of the oceans and atmosphere, and the cycling of carbon dioxide through the ocean. A more complete understanding of the Antarctic region will allow scientists to better predict how these processes might change as Earth continues to warm, and how this change will affect the rest of the planet.



In addition to providing information on global change that is already occurring, Antarctica and the Southern Ocean also offer opportunities for novel discoveries. The remarkable clarity and relative stability of the atmosphere above the continent allows scientists to examine the upper atmosphere and beyond, observations that could help answer fundamental questions about the origins of the Universe and the nature of the solar system.

In the United States, the U.S. Antarctic Program of the National Science Foundation (NSF) holds the primary responsibility for supporting science in Antarctica and the Southern Ocean. At the request of the NSF Office of Polar Programs and the Office of

Science and Technology Policy in the White House, the National Research Council convened a committee of experts to identify the major science questions that will drive research in Antarctica and the Southern Ocean over the next 10 to 20 years. The Committee identified key scientific questions that fall within two broad themes: those related to global change, and those related to fundamental discoveries. In addition, the Committee identified several opportunities to broadly advance Antarctic and Southern Ocean research in the process of answering these questions. The information in the report is intended to inform a subsequent NSF Blue Ribbon Panel that will examine logistical operations in Antarctica and the Southern Ocean to ensure they are capable of supporting vital research in the Antarctic region over the coming two decades.

Global Change

Over the past century, temperatures on land and in the ocean have started to increase. Sea level is rising and global weather patterns are shifting, altering the chemical and biological systems of the planet. The climate and geography of Antarctica are important influences on these processes and provide a unique environment in which to monitor change. The Committee highlighted several areas of science that will be important in research on global change in Antarctica and the Southern Ocean over the next two decades.

How will Antarctica contribute to changes in global sea level?

Antarctica's ice sheets exist in a state of dynamic equilibrium. Snow and ice accumulate over the continent and slowly flow to the coasts by movement of glaciers and ice sheets; when these enormous ice shelves come into contact with the warming ocean, huge chunks break off and are lost to the sea. When ice sheets collapse, often explosively, they uncork the flow of glaciers behind them and accelerate the progress of these glaciers toward the sea.

Rising global temperatures now threaten to push the system out of equilibrium by making the ice sheets melt more quickly, increasing the volume of the world ocean and pushing global sea level higher. Antarctica's ice sheets hold about 90 percent of the world's ice and fresh water, and if all this ice were to melt, global sea levels would rise by more than 60 meters. Therefore, scientists need to understand how rapidly the world is warming, if Antarctic ice loss will accelerate, and how quickly sea level will rise. To reach this goal, increased observations of Antarctic ice sheet melting are needed, particularly at the ice/ocean and ice/bedrock interfaces, as well as improved models to better predict the rate of ice sheet loss.

What is the role of Antarctica and the Southern Ocean in the global climate system?

The ocean currents and air circulation of the Antarctic region are inextricably linked to those on the rest of the planet. More information on Antarctica's influence over globally interacting systems will allow scientists to better understand the global climate system and predict how it will change in the future. A systems approach, with increased observations and improved modeling, is critical to improving understanding of the climate system over the next 20 years.

For example, the strong westerly winds that circle the Antarctic continent influence global atmospheric circulation. To improve projections of future changes in atmospheric circulation, enhanced observations and modeling capacity are needed—especially to understand the role of the Antarctic ozone hole and the influence of global climate change.

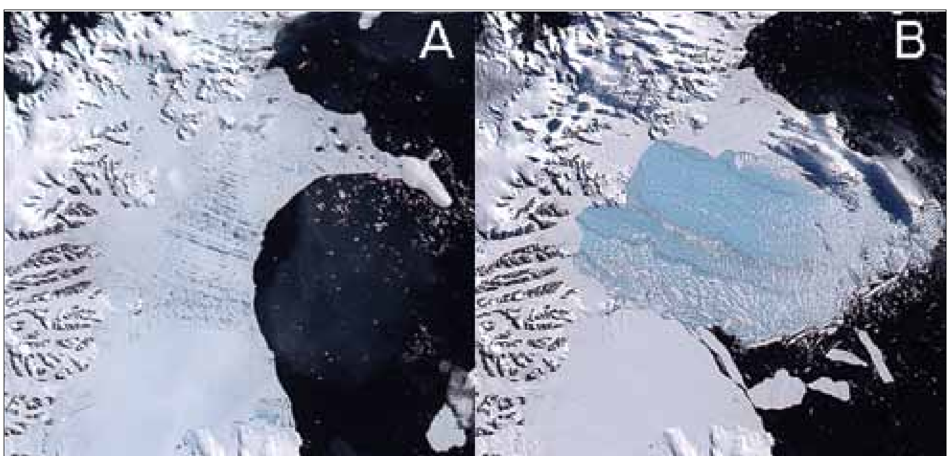


Figure 1. The Larsen Ice Shelf extends along the east coast of the Antarctic Peninsula (Image A). In 2002, the Larsen B ice shelf suddenly collapsed, delivering 3,250 km^2 of ice into the ocean (Image B). Better predictions of the effects of warming climate on ice shelves could help prevent similar occurrences from being surprises in the future.

Source: Cavalieri et al., 2008, National Snow and Ice Data Center, University of Colorado, Boulder.

Similarly, the circulation of the Southern Ocean is central to the global ocean circulation and plays an important role in the absorption of carbon dioxide from the atmosphere, a critical step in the global carbon cycle. Changing patterns of annual sea ice in the Southern Ocean could strongly affect atmospheric and oceanic circulation. Improved monitoring and modeling will allow scientists to better understand the role of the Southern Ocean in the global ocean system.

What is the response of Antarctic biota and ecosystems to change?

Although recent research has revealed a surprising diversity of life forms in Antarctica, even in habitats once considered lifeless, Antarctic ecosystems are relatively simple compared to those in other areas of the globe. This makes it easier to detect the impacts of global climate change and other environmental changes in Antarctic ecosystems than it is elsewhere on the planet.

Furthermore, Antarctic ecosystems are particularly vulnerable to change. The marine and land-based ecosystems of Antarctica and the Southern Ocean evolved in isolation from the rest of the planet, but recent factors such as the global transport of pollutants, ocean acidification, the introduction of invasive species, and increases in UV radiation are altering these communities. Increasing human presence, due to fishing, tourism, and research, has brought concerns about habitat destruction, overfishing, pollution, and other toxic effects on the environment.

Figure 2. Visiting scientists examine ongoing experiments at the McMurdo Dry Valleys Long Term Ecological Research Site.
Source: Chris Elfring

Of all the human influences, human-induced climate change may have the largest impact on the Antarctic region. On land and sea, warming and ice melt will increase the area of surfaces exposed to the elements, providing new habitats for colonization by organisms, and potentially altering the functioning and structure of ecosystems. For example the recent warming of the Antarctic Peninsula has caused changes in penguin populations. As warming continues, factors such as predation, competition, and pathogens may have a greater influence on ecosystem functioning than the physical processes that have, until now, dominated the region's ecosystems. Increased acidification of the oceans may affect marine organisms that build calcium carbonate shells. Changes in the ecosystems of the Antarctic region may be a harbinger of the changes to come elsewhere, and therefore monitoring Antarctic change could allow scientists to better predict future global change.

Figure 2. An Adélie Penguin.
Source: Edward Dunlea

What role has Antarctica played in changing the planet in the past?

The movement, fragmentation, and collision of Earth's tectonic plates can have dramatic consequences, causing earthquakes and volcanoes, constructing new mountain ranges, opening gateways between oceans, and triggering global climate shifts. Evidence from Earth's past indicates that the Antarctic continent played a central role in previous changes in Earth's climate and in atmospheric and oceanic circulation.

About 180 million years ago, Gondwana—a massive supercontinent consisting of Antarctica, India, Australia, South America, and Africa—began to break apart. Antarctica, which at the time was covered with dense forests inhabited by dinosaurs and mammals, started to move toward its present, polar position, opening up new ocean passages and causing great shifts in the circulation of the ocean and atmosphere (see Figure 3). These shifts reduced the amount of heat turning Antarctica from a lush, green continent to a white continent encased in ice. Understanding the opening of the Southern Ocean as Gondwana fragmented is critical to understanding how the global climate came to be in its present state.

Figure 3. The Gondwana supercontinent 150 million years ago (*left*), the transition and opening of the oceanic passageway around Antarctica 75 million years ago (*middle*), and present day geography (*right*). Source: ODSN-Geomar.

Discovery

Antarctica and the Southern Ocean provide a natural laboratory for scientific discovery. The tiny air bubbles trapped within the ice hold a record of the planet's atmosphere through time, the living things in the ocean and on land can teach scientists about survival strategies in extreme environments, and Antarctica provides an excellent platform for looking out to the solar system and the Universe beyond. The Committee highlighted several areas of science that will be important in discovery-driven scientific research in Antarctica and the Southern Ocean over the next two decades.

What can records preserved in Antarctica and the Southern Ocean reveal about past and future climates?

The rocks, sediments, and ice of the Antarctic region hold a trove of information about the history of Earth and its climate. Scientists gather records of the Antarctic region's past conditions by drilling into rocks, sediments, and ice, and by examining geological features. The fossil records in rocks and sediments can tell scientists the geographical range of an organism's habitat and the timeline of its existence. Physical and chemical analyses of cores drilled into the sediments at the bottom of the Southern Ocean can provide records of ocean temperatures, salinity, circulation, and biological productivity through time. Studying the composition ice cores, and the impurities and gases trapped in ice sheets, has yielded information on past climate conditions and atmospheric greenhouse gas concentrations. This information could enhance understanding of the regular cycles and processes that affect Earth's climate, as well as uncover details of abrupt climate change events in Earth's history that may provide insight on how Earth's climate may change in the future.

Figure 4. A one meter long section of ice core from the West Antarctic Ice Sheet Divide Ice Core. The visible dark layer shows deposits of ash. Measurements of air trapped in ice cores are used to create records of past temperatures and concentrations of atmospheric gases. Source: Heidi Roop

How has life adapted to the Antarctic and Southern Ocean environments?

Organisms native to Antarctica, such as seals, whales, and penguins, have evolved characteristics that allow them to thrive in the region's harsh conditions. These adaptations include changes in body shape, cardiovascular control, and metabolism that allow organisms to avoid hypothermia or hypoxia (low oxygen levels). For example, since prey is available at great depths in the Southern Ocean, many of the mammal and bird species that are able to survive in the harsh climate of the Antarctic region have developed excellent diving skills and the ability to swim underwater for long periods without suffering damage from low oxygen levels.

More information about these specialized biochemical and physiological adaptations could hold the key to understanding and preventing a host of illnesses and conditions that plague humans, such as heart attacks, strokes, and decompression sickness. In addition, learning how life tolerates the extremes of Antarctica could also help scientists engineer frost-resistant plants and develop an array of temperature stable products, from ice cream to vaccines. New tools are emerging that will allow scientists to study the genomics, metagenomics, and proteomics of how life has adapted to survive and prosper in the frigid and inhospitable Antarctic and Southern Ocean environments.

Seals and Penguins Aid Research

In addition to providing insight into human health, the birds and mammals of the Antarctic region can also provide information on ocean conditions. Some seals and penguins can be fitted with miniaturized sensors that obtain environmental data at locations and depths that submarines would have difficulty reaching. For example, Southern Elephant seals wearing sensors can obtain environmental data at depths of more than 900 meters. The sensors can record data on ocean variables such as temperature and salinity, and transmit the information to polar orbiting satellites when the animal surfaces.

Figure 5. Southern Elephant Seal.
Source: Steven H. Untracht, M.D., National Science Foundation

The Power of Space Weather

In 1859, the most powerful solar storm in recorded history caused visible auroras all over the globe and made telegraph systems all over Europe and the United States fail, spark, and catch fire. If such an event were to occur today, it would cause trillions of dollars worth of damage and many areas of the United States and the rest of the world could be without electrical power and communications for several months.

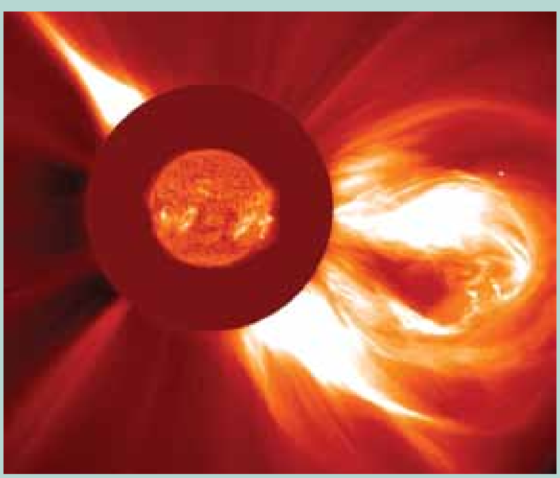


Figure 6. A composite image from the Solar & Heliospheric Observatory satellite showing a coronal mass ejection blasting out into space. Such events produce environmental changes termed “space weather.” Source: NASA

What can the Antarctic platform reveal about the interactions between the Earth and the space environment?

As society becomes more dependent on space-based technologies such as satellites for communications and navigation, it is becoming more vulnerable to space weather—magnetic storms on the sun that can spew high energy particles toward Earth and disrupt the proper functioning of satellites in orbit and electrical power distribution systems at Earth’s surface. Better monitoring of space weather could allow scientists to better predict space storms and limit their negative impacts.

For example, the Global Positioning System (GPS) has emerged as a major component of technological infrastructure over recent years. Many people use GPS as a tool for navigation, but the technology is also used for drilling for oil, tracking livestock, and guiding missiles. Space weather events can disrupt GPS functioning, leading to significant errors in positioning data.

The alignment of Earth’s magnetic field means that both of the planet’s poles lie in an optimal position to monitor space weather. The region around the South Pole is an ideal location to monitor changes in space weather, as compared to the North Pole where shifting sea ice makes building a permanent research station impractical. Over the next two decades, increased observations of space weather from Antarctica could hold the key to improving abilities to predict potentially catastrophic space weather events.

How did the Universe begin, what is it made of, and what determines its evolution?

Antarctica's atmospheric conditions of cold and stable temperatures, low levels of water vapor, and high altitude allow scientists to view far out into the cosmos. Using measurements of cosmic microwave background radiation made in the Antarctic region, scientists are testing theories of how the Universe formed (such as the Big Bang theory) and how it evolves. Ordinary matter makes up less than five percent of the Universe and very little is known about the dark matter and dark energy that constitutes the rest. Astrophysical measurements from Antarctica can provide insights into some of these fundamental questions about the composition of the Universe.

Figure 7: Telescopes can exploit the extraordinary transparent and stable atmosphere of Antarctica to map the intensity and polarization of cosmic microwave background radiation. Source: Edward Dunlea

In addition, Antarctica's vast supply of homogenous and transparent ice has allowed scientists at the South Pole to build a detector for neutrinos—high-energy, nearly mass-less particles that are very difficult to detect. The IceCube Neutrino Observatory, completed in December 2010, consists of thousands of photodetectors embedded in a cubic-kilometer of the clear ice deep below the South Pole station. More information on neutrinos could provide insight into the long-standing mystery of the origin of the ultra high-energy cosmic rays, a key piece of understanding how the Universe works.

Opportunities to Enhance Research in Antarctica and the Southern Ocean

Conducting research in the harsh environmental conditions of Antarctica is logistically challenging. Substantial resources are needed to establish and maintain the infrastructure needed to provide heat, light, transportation, and drinking water, while at the same time minimizing pollution of the environment and ensuring the safety of researchers. The Committee identified several opportunities to sustain and improve the science program in Antarctic and Southern Ocean in the coming two decades.

Collaboration

Over the past half century, collaborations between nations, across disciplinary boundaries, between public and private sector entities, and between science and logistics personnel have helped research in Antarctica become a large and successful international scientific enterprise. The International Polar Year, held from 2007-2008, demonstrated how successful international collaboration can facilitate research that no nation could complete alone This report examines opportunities to enhance each of these types of collaboration, with the overall conclusion that by working together, scientists can reach their goals more quickly and more affordably.

Energy, Technology, and Infrastructure

Advances in energy and technology can make scientific research in the Antarctic region more cost effective, allowing a greater proportion of funds to be used to support research rather than to establish and maintain infrastructure.

For example, most of the energy required to power research stations and field camps and to transport people and materials comes from burning fossil fuels. In addition to the cost of the fuel, the combustion of fossil fuels pollutes the air, and fuel leaks during storage and transport have the potential to contaminate the surrounding environment. Innovations such as more cost-effective overland transportation systems for fuel, or the use of wind-power generators, promise to reduce the cost and pollution associated with fuel transport.

Icebreakers

Source: U.S. Coast Guard

Icebreakers are essential to the conduct of science in Antarctica and the Southern Ocean. Some of these ships provide access for ocean and coastal research in full and partially ice covered seas and others break ice to clear out harbors and channels, which allows fuel and supplies to reach research stations (such as the McMurdo Research Station).

A number of previous reports have concluded that there is a critical shortage of U.S. icebreaking capacity in Antarctica and the Southern Ocean. The two large U.S. Coast Guard icebreakers, Polar Sea and Polar Star, are more than 30 years old and have exceeded their service lives. Although the purchase of any new polar class icebreakers by the United States will be expensive, there are strong national security and operational reasons for the nation to develop its own icebreaking capability. Alternative options include partnerships with other countries and leasing icebreakers flagged by other countries, such as the successful collaboration between the United States and Sweden using the icebreaker Oden, but such arrangements are not entirely dependable.

Based on the scientific research needs outlined in this report, the Committee on Future Science Opportunities in the Antarctic and Southern Ocean strongly supports the conclusion that the United States should develop sufficient icebreaking capacity, either on a national or international basis, to ensure that the scientific needs in Antarctica and the Southern Ocean—both for research and for the annual break-in supplying McMurdo Station— can be met by secure and reliable icebreaking capacity.

Education

Antarctica and the Southern Ocean offer great opportunities for inspiring popular interest in science in much the same way as space exploration did in the latter half of the 20th century. The National Science Foundation has supported a broad range of educational efforts to spark interest in polar science, including television specials, radio programs, and a multimedia presentation that toured U.S. science centers, museums, and schools. These efforts not only increase public awareness and understanding of the research taking place in Antarctica, but can help to inspire future generations of polar scientists. Building upon existing educational activities to develop a more integrated polar educational program, which would encompass all learners including K-12, undergraduates, graduate students, early career investigators, and life-long learners, would help engage the next generation of scientists and engineers required to support an economically competitive nation and foster a scientifically literate U.S. public.

Observing Network with Data Integration and Scientific Modeling

To better predict future conditions, scientists need a network of observing systems that can collect and record data on the ongoing changes in the Antarctic region's atmosphere, ice sheets, oceans, and ecosystems. This network should be able to measure and record ongoing changes to develop an understanding of the causes of change and to provide inputs for models that will enable U.S. scientists to better project the global impacts of a changing Antarctic environment. The envisioned observing network shares many characteristics of previous initiatives, such as the Arctic Observing Network (AON) or the proposed Pan-Antarctic Observing System (PAntOS). There is also an inherent need for improved sharing of data and information. Improvements in the collection, management, archiving, and exchange of information will allow data to be used for multiple purposes by a variety of stakeholders.

In addition, improvements in scientific models of the Antarctic region are urgently needed to strengthen the simulation and prediction of future global climate patterns. These initiatives will require interdisciplinary approaches at the system scale that would be best addressed with a coordinated, long-term, international effort. Given the scope of the research program and support infrastructure in the Antarctic region, the United States has the opportunity to play a leading role in developing a large scale, interdisciplinary observing network and robust earth system models that can accurately simulate the conditions of the Antarctic region.

Future Directions in Antarctic and Southern Ocean Science

This report identifies key scientific questions that will drive research in Antarctica and the Southern Ocean for the next two decades and highlights opportunities to help sustain and improve U.S. research efforts in the Antarctic region. From this, the Committee suggests actions for the United States to achieve success in the next generation of Antarctic and the Southern Ocean science projects.

- Lead the development of a large-scale, interdisciplinary observing network and support a new generation of robust earth system models
- Continue to support a wide variety of basic research in Antarctica and the Southern Ocean to yield a new generation of discoveries
- Design and implement improved mechanisms for international collaboration
- Exploit the host of emerging technologies including cyberinfrastructure and novel and robust sensors
- Coordinate an integrated polar educational program
- Continue strong logistical support for Antarctic science. The Committee encourages the National Science Foundation-led Blue Ribbon Panel to develop a plan to support Antarctic science over the next two decades with the following goals:
  - Improve the efficiency of the support provided by contractors and enhance the oversight and management of contractors by the scientific community
  - Increase the flexibility and mobility of the support system to work in a continent- and ocean-wide manner, utilizing as much of the year and continent as possible, and fostering innovative "cutting-edge" science
  - Maintain, develop, and enhance the unique logistical assets of the U.S., including the research stations, aircraft, research vessels, and icebreakers.

Closing Thoughts

Despite the challenges of working in the harsh environment of Antarctica and the Southern Ocean, the region offers great insight into the changing planet and is an invaluable platform for scientists to make new discoveries. Preserving the unique environment of the Antarctic region for new observations and experimental science requires a continued commitment to stewardship.

Making use of international and multidisciplinary collaboration, emerging technologies and sensors, and educational opportunities, the next 20 years of Antarctic and Southern Ocean research have the potential to advance understanding of this planet, and beyond. A robust and efficient U.S. Antarctic Program is needed to realize this potential.

Read or purchase this report and locate information on related reports at
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The National Academies appointed the above committee of experts to address the specific task requested by the National Science Foundation. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

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For more information, contact the Polar Research Board at (202) 334-3479 or visit http://dels.nas.edu/prb. Copies of *Future Science Opportunities in Antarctica and the Southern Ocean* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.