REPORT IN BRIEF

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A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research

RESEARCH IN ANTARCTICA AND THE SOUTHERN OCEAN has yielded tremendous insights into the workings of our planet and the universe beyond. Much of this research is now becoming increasingly urgent as scientists seek to understand how the region may affect sea-level rise and other global-scale environmental changes. Building on input from across the scientific community, this report identifies key priorities for Antarctic and Southern Ocean research over the coming decade, along with the infrastructure and logistical needs most critical for supporting this research.

As the planet's coldest and windiest continent containing 90% of the world's ice, Antarctica is like no other place on Earth. This unique environment provides an array of valuable opportunities for scientific research: for instance, ice and sediment cores provide a record of Earth's climate history, the region's varied ecosystems hold secrets to life in extreme environments, and the dry, stable atmosphere over Antarctica provides optimal conditions for studying the solar system and the universe beyond. Advancing our understanding of Antarctica and the Southern Ocean is becoming more urgent due to the region's important roles in circulation of the oceans and atmosphere, cycling of carbon dioxide and heat through the ocean, and global sea level rise from melting ice sheets.

The U.S. Antarctic Program of the National Science Foundation (NSF) supports U.S. scientific research in Antarctica and the Southern Ocean. At the request of the NSF Division of Polar Programs, the National Academies of Sciences, Engineering, and Medicine convened a committee to develop a strategic vision for NSF-supported Antarctic and Southern Ocean research for the coming decade. This report builds on a series of advisory efforts over recent years, including the Academies' report *Future Science Opportunities in the Antarctic and Southern Ocean,* and a special Blue Ribbon Panel study that examined capabilities and needs for logistical support of Antarctic research. Informed by extensive input from across the community of scientists who conduct Antarctic and Southern Ocean research, this report presents specific priorities for research investments, and identifies infrastructure most critical for supporting this work.

Scientists install cameras to document how Antarctic glaciers are changing over time. Source: Erin Pettit

MAINTAINING A BALANCED RESEARCH PORTFOLIO

Investment in a broad portfolio of research is essential for maintaining U.S. leadership in Antarctic and Southern Ocean science and for ensuring that NSF is well-positioned to respond to new breakthroughs and new environmental challenges. The NSF model of supporting research across the spectrum of disciplinary areas, in response to proposals from the research community, has proven effective for fostering innovation and discovery.

In the Antarctic, however, even small-scale research can have significant logistical requirements. It is therefore important for NSF to identify opportunities for efficiencies and coordination that best leverage logistical investments. For example, many studies require similar observations of basic physical parameters such as oceanic or atmospheric conditions. Efficiencies could be gained if this data collection was better integrated among teams working in regions that have a high level of inter-related research activity, such as the Ross Sea/McMurdo Sound area.

Recommendation: NSF should continue to support a core program of broad-based, investigator-driven research and actively look for opportunities to gain efficiencies and improve coordination and data sharing among independent studies.

STRATEGIC PRIORITIES FOR ANTARCTIC SCIENCE

Given the costs and logistical challenges of accessing remote Antarctic and Southern Ocean regions, balancing the broad base of smaller-scale research with a few larger-scale, more directed efforts would focus a critical mass of resources toward key research goals. Through an online forum and 14 outreach sessions held around the country, the report's authoring committee gathered ideas from the research community for priority large-scale initiatives. The Committee applied a set of evaluation criteria to these ideas to select three broad areas of research as priorities (Box 1).

Recommendation: NSF should pursue the following as strategic research priorities for the coming decade:

1. How fast and how far will sea level rise? The Changing Antarctic Ice Sheets Initiative

As the oceans and atmosphere warm, melting of ice shelves in key areas around the edges of the Antarctic ice sheet could trigger a runaway collapse process known as Marine Ice Sheet Instability. If this were to occur, the collapse of the West Antarctic Ice Sheet (WAIS) could potentially contribute 2 to 4 meters (6.5 to 13 feet) of global sea level rise within just a few centuries. Contributions from the East Antarctic Ice Sheet are unknown, but could be even larger.

Satellite observations confirm that certain areas of the WAIS are already becoming unstable, and that the pace of change has accelerated in recent years. Understanding the detailed dynamics of changes taking place in this region will help scientists better assess the likely rate and magnitude of future sea level rise. This in turn will help inform the societal responses that will be required to protect coastal regions around the world. With a primary focus around the Amundsen Sea region of West Antarctica (see Figure 1), this effort would include the following main activities:

- *A multidisciplinary campaign to understand why the Antarctic ice sheets are changing now and how they will change in the future.*

Much remains to be understood about the complex interactions among ice, ocean, atmosphere, and climate that drive Antarctic ice sheet changes (see Figure 2). Advancing this understanding will require a coordinated campaign of focused process studies, sustained observations, and mapping of unknown terrains in critical regions of the ocean, ice surface, and sub-ice environment, along with advancement of the models used to study ice sheet changes.

- *Using multiple records of past ice sheet change to understand rates and processes.*

The rocks, sediments, and ice of Antarctica hold a wealth of information about the rates and processes of past ice sheet collapse—data that could help inform and test models used to project future changes.

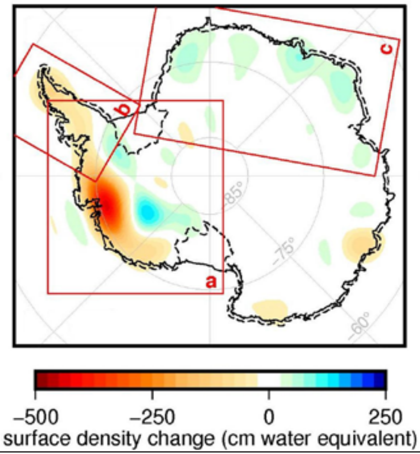

Figure 1. The mass of the Antarctic ice sheet declined by 92 billion tons per year from 2003 to 2014. The color scale indicates change in land ice mass (equivalent to centimeters of water), with red denoting the largest loss, and blue the largest gain. Most ice was lost from West Antarctica's Amundsen Sea region (box a) and the Antarctic Peninsula (box b). The East Antarctic (box c) primarily thickened during that time. Source: Harig and Simons, 2015.

Box 1. The Committee's Evaluation Criteria

The committee developed criteria to evaluate research ideas gathered through the community engagement process:

- Compelling science
- Potential for societal impact
- Time-sensitive in nature
- Readiness/feasibility
- Key area for U.S./NSF leadership

Additional factors considered:

- Partnership potential
- Impacts on program balance

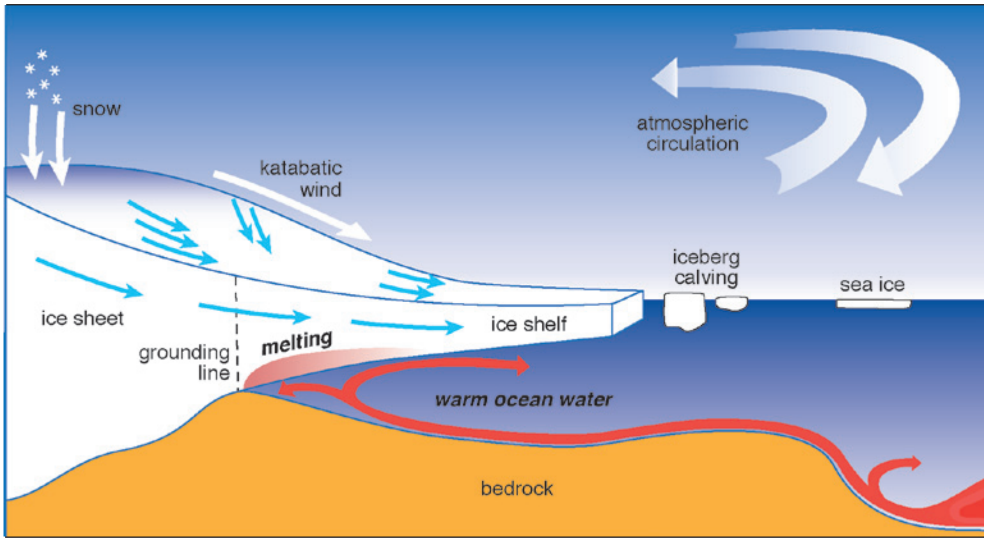

Figure 2. An array of forces affect growth and loss of an ice shelf, including: ice that flows from the ice sheet, warm ocean water that melts the underside of the ice shelf, and wind patterns that affect ocean and sea ice dynamics. In places where bedrock slopes downward behind the grounding line, the influx of warm ocean water underneath the ice sheet can potentially trigger a runaway collapse process known as Marine Ice Sheet Instability.

Studies of ice cores from the last interglacial period (roughly 125,000 years ago) that can resolve year-by-year variations in key indicators are likely most useful for elucidating how fast ice sheets can collapse. Marine sediment cores collected from around the WAIS collapse region may also yield new insights on how fast ice has melted in the past. New techniques that determine how long an area was ice-free could help scientists map the areal extent of past collapse, and thus the total volume of ice that contributed to sea level rise.

2. *How do Antarctic biota evolve and adapt to the changing environment? Decoding the genomic and transcriptomic bases of biological adaptation and response across Antarctic organisms and ecosystems*

More than 30 million years ago, Antarctica was cut off from the rest of the world with the opening of Drake Passage, the body of water between Antarctica and the southern tip of South America. Since then, Antarctic ecosystems have evolved in near-isolation, enduring extreme conditions and major climatic transitions (see Figure 3). Antarctic species currently face new challenges of adapting to changes such as a warming climate, ocean acidification, invasive species, and expansion of commercial fisheries. While the biology and ecology of Antarctic life is actively studied, a relatively unexplored research frontier is the information encoded within species' DNA.

Dramatic technical advances have made genome sequencing faster and less expensive in recent years. Such advances can be harnessed to gain new insight into the biological diversity that has evolved in the Antarctic environment, and the capacity for species to adapt to current and future environmental changes. This initiative proposes a coordinated effort to sequence the genomes and transcriptomes of key species, from mammals to microbes, as well as metagenomes and metatranscriptomes of the communities of species in environmental samples from soils, ice sheets, lakes and ocean water.

3. *How did our Universe begin and what are the underlying physical laws that govern its evolution and ultimate fate? A next generation cosmic microwave background program.*

The dry, stable atmosphere above the South Pole offers an ideal environment for astrophysical observations that help us understand the evolution and structure of the universe. One such area of research involves observations of the cosmic microwave background (CMB) radiation, the fossil light from the early universe nearly 14 billion years ago.

Measurements of the CMB have already provided remarkable insights into the make-up of the universe, and the presence of the cosmic neutrino background. Now researchers are proposing a next generation of

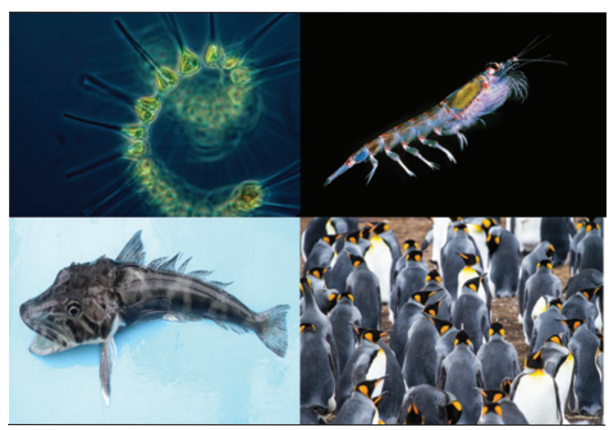

Figure 3. The diversity of Antarctic ecosystems offers insights into evolution and adaption in extreme environments. Clockwise from top left: phytoplankton (source: NOAA), krill (source: Biopics); king penguins (source: iStock), icefish (source: NOAA).

CMB studies to explore the origins of the universe, in particular a process known as inflation. Detecting the imprint on the CMB of gravitational waves generated during the first moments of the universe would be a key test of inflation, and would provide evidence of the quantum nature of gravity.

A next generation CMB experimental program would include an installation of new telescopes at the South Pole (as part of a larger global telescope array) to gather sensitive measurements that would help address fundamental questions about the origins and workings of the natural world—questions that cannot be explained within our current understanding of physics.

FOUNDATIONS FOR A ROBUST ANTARCTIC AND SOUTHERN OCEAN RESEARCH PROGRAM

The Committee identified infrastructure and logistical support needs, and other foundational elements most critical for advancing Antarctic and Southern Ocean research—in particular for supporting the priority research initiatives. These include:

Access to Remote Field Sites. Key future needs for West Antarctic research in particular include a deep field camp and logistics hub, over-snow science traverse capabilities, ship support for research in ice-covered Southern Ocean coastal areas, all-weather aircraft access to McMurdo, and improved aircraft access to remote field locations.

Ship Support. The U.S. has very limited icebreaker support in Antarctic waters, which constrains where scientists can conduct research and increases dependence on foreign vessels. To advance the science priorities and Antarctic research overall, NSF will need to support the Coast Guard's efforts to design and acquire a new polar-class icebreaker. With the assistance of other partners, NSF should also design and acquire a next-generation polar research vessel. In the near term, NSF should work with foreign research vessel operators to assure adequate field opportunities for U.S. scientists.

Sustained Observations. Long-term observations are essential for improving understanding of the natural environment and human influences on that environment. NSF can take many relatively low-cost steps to advance sustained observations, by better coordinating, integrating and strategically augmenting data collection and management being carried out by different research groups, and different nations' research programs.

Communication and Data Transmission. The proposed research priorities bring new requirements to increase bulk data transmission capacity, and to advance communications support for deep-field camps and for autonomous instruments operating under the ice shelf.

Data Management. NSF should identify specific archives to manage and preserve data, encourage all funded projects to include personnel trained in data management needs, and continue to advance both Antarctic-specific and broader, NSF-wide initiatives to encourage more coordinated data collection and sharing, better use of existing data, and more integration of data across nations, disciplines, and data types.

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The National Academies of Sciences, Engineering, and Medicine 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 Academies. This report brief was prepared by the Academies based on the committee's report. For more information, contact the Polar Research Board at (202) 334-2187 or visit http://dels.nas.edu/prb. Copies of *A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.