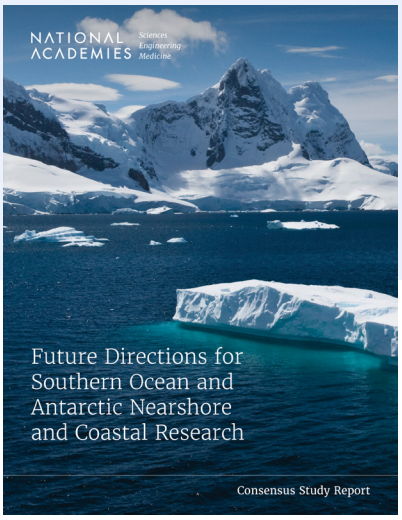
Future Directions for Southern Ocean and Antarctic Nearshore and Coastal Research



Antarctica hosts some of the harshest and most remote environments on Earth—and it is a region of vital importance for scientific research. Antarctica's environment and position on the globe mean that research conducted there can offer unique insights on important Earth processes, including rising sea level, the carbon cycle, and ecosystem structure. As the climate warms, data gathered from Antarctic research will be essential to understanding how Earth processes are changing and how those changes could affect the welfare of global populations.

The National Science Foundation's Office of Polar Programs supports Antarctic science and logistical operations through its U.S. Antarctic Program (USAP). However, the science infrastructure that enables research in the region is aging. At the request of the National Science Foundation, this report identifies the highest priorities for research in the Southern Ocean and nearshore and coastal Antarctica, as well as gaps in current capabilities to support this research. Given that U.S. Antarctic research provides data that are critical to addressing societally and economically urgent issues, the report concludes that investments in the USAP and its research platforms, including the development of new technologies and the replacement of aging research vessels, are justified.

SCIENCE DRIVERS FOR ANTARCTIC RESEARCH

The report identifies the following three thematic areas that represent the highest priority science drivers for Southern Ocean and Antarctic nearshore and coastal research: global sea-level rise, heat and carbon budgets, and changing ecosystems. A list of priority science questions to advance each of the science drivers is listed in Table 1.

Global Sea-Level Rise

Antarctica's ice sheets, which contain approximately 58 meters of sea level rise potential, may be approaching a dangerous tipping point toward major ice loss that is potentially irreversible on human timescales. Sea-level rise due to greenhouse gas emissions will last centuries to millennia and affect the entire global

Global Sea Level Rise	Global Heat and Carbon Budgets	Changing Ecosystems
How much and how fast will ocean warming raise sea level?	What determines the net uptake and release of carbon dioxide in the Southern Ocean and how will it change in the future?	What are the feedbacks between changing ecosystems and biogeochemistry that drive the carbon cycle?
How much and how fast will atmospheric warming raise sea level?	What are the key temporal and spatial scales of upper ocean processes that influence air-sea exchange?	How have biota adapted and evolved and what is their resilience to change?
How will floating ice processes impact the rate of ice sheet loss?	What are the pathways of ocean heat and biogeochemical properties between the open Southern Ocean and the Antarctic coast?	How can the study of global connections and ecosystem services inform evidence-based conservation and management?
Will grounding zone instabilities create tipping points of irreversible ice loss?	How can understanding past changes in the Southern Ocean heat and carbon dioxide budgets elucidate the future?	
Will geological and geophysical properties and processes exacerbate or moderate sea level rise?	What processes will impact Antarctic sea-ice extent and thickness on decadal timescales?	

Table 1: Priority science questions identified under each science driver for nearshore Antarctic and Southern Ocean research. Questions are not in order of priority.

community and economy, especially the approximately 1 billion people who live in low-lying coastal zones. Ocean forcing of the Antarctic ice sheets, through heat delivery and erosion, is expected to be the dominant source of ice mass loss in the next century, with atmospheric forcing also causing major ice mass loss. However, major uncertainties remain about the rates and extent of ocean warming, transport of heat through ocean in the sub-ice shelf cavities, and the sensitivity of the surface mass balance of ice sheets to increasing global temperatures.

Global Heat and Carbon Budgets

The global ocean has so far absorbed more than 90 percent of the excess heat from humanity's input of greenhouse gases to the atmosphere, thus mediating the rate of atmospheric warming—and two-thirds of that heat absorption has been in the waters of the Southern Ocean. The Southern Ocean plays an outsized role in the climate system because of its role in the global deep overturning circulation, which allows cold, deep waters to rise to the surface and exchange heat and carbon with the atmosphere. To better understand how the Southern Ocean carbon and heat reservoirs may change as climate warms, research is needed on the chemical and physical processes that govern the relationship between ocean, atmosphere, sea ice, and ice shelves.

Changing Ecosystems

The Southern Ocean and nearshore Antarctic ecosystem is uniquely adapted to its extreme environment and is rich in important ecosystem functions that regulate the exchange of energy, nutrients, and carbon throughout the food chain. However, considerable uncertainty remains about the role of different marine organisms in mediating the cycles of key elements (e.g., carbon, iron) in the Southern Ocean, and the feedbacks of these elements into Antarctic ecosystems. Much can be learned about how Southern Ocean biota will respond to continued and accelerating climate change, and how their responses may impact important natural systems that directly or indirectly benefit humans.

CAPABILITIES FOR U.S. ANTARCTIC RESEARCH

The capabilities needed to support Antarctic research include those hosted on USAP platforms, emerging tools and technologies, and programmatic approaches and partnerships that will advance research (see Figure 1).

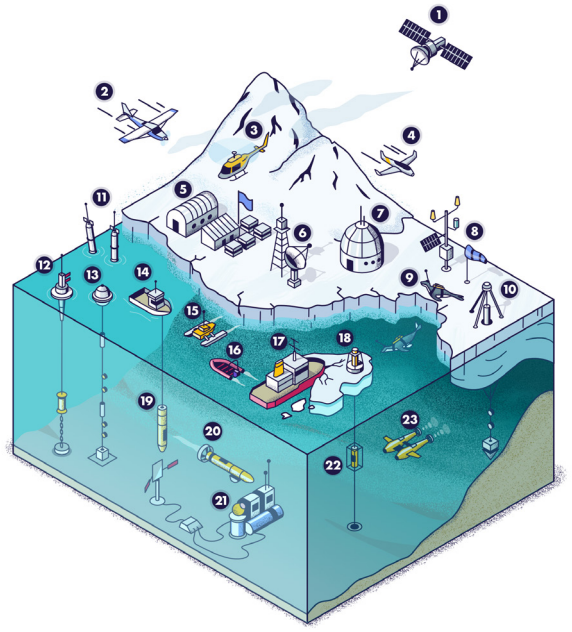


Figure 1. Capabilities for Southern Ocean and nearshore research identified in this report. (1) satellite; (2) fixed-wing aircraft; (3) helicopters; (4) uncrewed aerial systems; (5) research station; (6-7) autonomous land-based stations; (8) instrumented animals; (9) drilling and coring; (10) buoys; (11) ocean moorings; (12) autonomous surface vehicle; (13) small coastal vessel (with hull-mounted sensors); (14) rigid hull inflatable boat; (15) icebreaker (with seafloor sampler); (16) sea ice-tethered mooring and profiler; (17) autonomous ocean-based stations; (18) cabled observations; (19) autonomous underwater vehicle.

Vessel Capabilities

Both USAP vessels—the research vessels Nathaniel B. Palmer and Laurence M. Gould—are approaching or have exceeded their 30-year design service life. The near-term prioritization of the design and construction of a Polar Class 3 Antarctic Research Vessel (ARV) is essential for supporting U.S. national interests in use-inspired research (see Figure 2). The report lists high priority capabilities that scientists will need, either on the ARV or on partner vessels.

Figure 2. The proposed design for a new U.S. Antarctic Research Vessel
SOURCE: NSF, illustrated by Gibbs & Cox, a Leidos Company

Full helicopter support on the icebreaker would enable scientists to deploy heavy equipment and people for gathering critical data in heavily crevassed areas that do not accommodate fixed-wing aircraft. However, helicopter capability was removed from the ARV conceptual design in 2020, requiring that another solution be developed to address this gap and ensure access to these important regions.

> **Recommendation: The Office of Polar Programs (OPP) should release a request for information to develop innovative solutions for supporting U.S.-led expeditions to remote, heavily crevassed, and rapidly thinning glaciers and ice shelves to enable critical research into sea level rise. Some potential solutions may include international partner agreements, commercial leasing options, a cost-effective solution for supporting two light helicopters on the ARV that could be incorporated without delaying progression through the Final Design Stage, combined fixed wing and helicopter modes of operation, or some combination of these options.**

The USAP has indicated that it is planning to transition its dedicated Antarctic fleet from a two-vessel to a one-vessel program, which would allow for more cost-effective operations. However, this may have implications for the research community, for example by decreasing equity in field participation.

> **Recommendation: To foster the next generation of polar leadership, the National Science Foundation (NSF) should complete impact assessments on the planned transition to a one-vessel program, communicate their results, and implement actions to mitigate possible impacts from the transition. Impacts may include changes to the diversity of OPP's funded project portfolio and the diversity (e.g., career stage, race, gender) of the Chief Scientists on USAP vessels.**

Small, individual primary investigator-driven research projects have a long history of advancing Antarctic research and should continue to be supported. However—given the logistical constraints of working in the region under a planned one-vessel program and the interdisciplinary nature of many research questions—large, interdisciplinary field projects may help to accelerate discoveries.

> **Recommendation: NSF should regularly convene community workshops to identify cost-effective, directed, and interdisciplinary field programs focused on specific regions and integrated science questions.**

Tools and Technologies

Investments in new tools and technologies will be necessary for progress toward each of the science drivers. For example, there is currently an unmet need for a small coastal vessel that can operate independently of icebreakers and provide safe and nimble access to the shallow coastal zone for research on ecosystem resilience.

> **Recommendation: In consultation with the research community, NSF should consider investing in the lease or purchase of small coastal vessel(s) (e.g., 15 – 50 meters length), which could operate independently of icebreakers or other larger vessels, for cost-effective research access in the relatively ice-free shallow waters of the Antarctic Peninsula region.**

A recurring theme in this report is interest in localized regions of the Southern Ocean and the nearshore Antarctic, including the ice-shelf face and grounding line, which are important for many of the priority research questions identified in the report. Innovative, multi-platform observations can help bridge the gap between the needed measurements at these key locations and the limited availability of USAP vessels.

Recommendation: NSF should support the development of new and innovative observing systems—such as fiber optic cables, autonomous underwater vehicles, drones, and other potential platforms—that will collect sustained data at key locations (e.g., polynyas, ice-shelf face, rifted ice shelves, and grounding line) even in the absence of icebreaker support.

Research on the effects of multiple stressors on Antarctic and Southern Ocean ecosystems requires facilities that can accommodate multifactorial experiments in the manipulation of seawater temperature, dissolved oxygen, and pH. These capabilities are not adequately supported by the aquarium facilities at Palmer and McMurdo Stations.

Recommendation: OPP should convene a community workshop to consider needed upgrades to the aquarium and other laboratory facilities at both Palmer and McMurdo Stations.

Partnerships

OPP regularly collaborates within NSF and with other U.S. agencies. Closer engagement between these partners will maximize the resources and expertise of the Southern Ocean and Antarctic science community. Further, partnerships with commercial organizations, non-governmental organizations and international organizations are essential to advancing research questions and addressing logistical and resource constraints, although the U.S. should prioritize investments in its own infrastructure where possible.

Recommendation: NSF should strengthen existing, and identify new, strategic opportunities for lead agency agreements with countries that can help support the essential science priorities identified in this report. This is particularly important for those nations with year-round stations and vessel capabilities that are complementary to those of the United States.

Recommendation: NSF should explore the creation and expansion of shared instrument and equipment pools to support cost-effective and equitable access.

COMMITTEE ON FUTURE DIRECTIONS FOR SOUTHERN OCEAN AND ANTARCTIC NEARSHORE AND COASTAL RESEARCH

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