

REPORT OF THE ARCTIC MARINE RESEARCH CAPABILITIES COMMITTEE



A UNOLS SPECIAL COMMITTEE



ON THE FRONT COVER

USCGC *Healy* in the ice with scientists working in the foreground. Photo credit: David Forcucci

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A UNOLS SPECIAL COMMITTEE

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CONTENTS

| | |
|--|------|
| Executive Summary | 1 |
| 1. Background and Approach..... | 4 |
| 2. The Case for US Preeminence in Arctic Science..... | 6 |
| 3. The Future of US Icebreaking Capability and Arctic Research | 8 |
| 4. Current Fleet Status | 9 |
| 5. Limitations to Science Using Current Icebreaker/Ice Capable Fleet..... | 11 |
| 6. Future US Fleet Outlook..... | 12 |
| 7. International Research Fleet and How US Assets Compare | 14 |
| 8. Results of Community Survey | 17 |
| 9. The Need for Icebreakers to Support Future Arctic Research | 19 |
| 10. Science Missions | 20 |
| 11. Ship Capabilities Needed to Enable Envisioned Future Arctic Marine Research..... | 21 |
| 12. Ships Categorized by Science Mission Capabilities..... | 27 |
| 13. Mapping Science Missions onto Ship Categories | 28 |
| 14. Intersection of Science Needs with USCG Statutory Missions..... | 29 |
| | |
| Appendix 1. Statement of Task..... | A1-1 |
| Appendix 2. Community Survey Questions..... | A2-1 |
| Appendix 3. Community Survey Results..... | A3-1 |
| Appendix 4. STORIS Letter..... | A4-1 |
| Appendix 5. Mission Scenarios..... | A5-1 |

EXECUTIVE SUMMARY

The present geopolitical moment and rapid environmental changes in the Arctic Ocean have made it clear that the United States must advance efforts for scientific operations in this strategic region to protect vital national interests. International interest in waterways, mineral resources, and fisheries, as well as security, is increasing as the Arctic Ocean becomes more accessible. Yet, the United States currently has few assets with which to maintain an operational presence for these interests; national prominence in Arctic marine research is at stake.

Over past decades, advances in polar science have been directly linked to improvements in logistics support. The operational knowledge and capabilities provided via successive generations of US polar-capable ships, most recently USCGC *Healy* and R/V *Sikuliaq*, have led to fundamental scientific discoveries and breakthroughs in understanding of Arctic ecosystems, ocean physics and circulation, climate-atmosphere interactions, sea ice processes, biogeochemical cycling, and geologic formation and evolution of basins and shelves. Improvements to polar-capable research vessels will increase understanding of short- and long-term environmental processes that impact Arctic, and US, economic resources and US sovereignty and national defense, including domain awareness, and meet top scientific and national priorities.

The Arctic Marine Research Capabilities Committee (AMRCC) was convened in June 2024 at the request of the US National Science Foundation, the Office of Naval Research, and the US Arctic Research Commission and tasked to review and refresh science missions (SMs) and associated science mission requirements (SMRs) for future federal icebreakers operating in the Arctic Ocean and other northern polar regions to meet the research needs of the science community for the next 30 years (see [Appendix 1: Statement of Task](#)). The AMRCC examined the entire spectrum of Arctic marine research, both

present and envisioned over the next several decades, and embraced the fundamental question: what kinds of ship-based (and related) capabilities are needed to support cutting-edge US Arctic research?

To assess future needs and develop potential science mission scenarios and related requirements, the AMRCC conducted a review of existing studies on Arctic marine research directions and potential science missions; met remotely and in person at workshops; reviewed US Executive Office Orders, Memoranda, and Fact Sheets; and solicited ideas from the national and international scientific communities at three public-facing meetings and through a survey of current and prospective Arctic vessel users ([Appendices 2 and 3](#)). The AMRCC also drew substantially on the 2019 *Report of the Ad Hoc Subcommittee on the US Antarctic Program's Research Vessel Procurement*.¹ Both the leadership of the University National Oceanographic Laboratory System (UNOLS) and the US Coast Guard (USCG) were included in the AMRCC's discussions. A general assumption was that the provision of future seagoing platforms for Arctic research would depend primarily on these two entities.

CRITICAL FINDINGS AND OBSERVATIONS

- The US position at the forefront of Arctic scientific research is fading as the US ice-capable fleet ages. Advances in US Arctic operational capacity and regional knowledge are directly linked to growth of the US polar, ice-capable fleet; outside of limited USCG assets, that capability presently consists of a single Academic Research Fleet vessel (R/V *Sikuliaq*) that is incapable of operating in heavy ice. By contrast, other nations, including Canada, Norway, China, Japan, Korea, United Kingdom, Sweden, and Germany, are building, or have built, icebreakers or icebreaker fleets that can conduct marine research in low-to-heavy ice conditions. For example, Canada's Coast Guard alone, as part of their national ship-building

¹ <https://nsf.gov-resources.nsf.gov/files/RV-Subcommittee-final-report-14AUG2019.pdf>

strategy, is expected to receive up to 16 multi-purpose icebreakers, six program icebreakers, and two polar icebreakers, all to be delivered within the next two decades and to be extensively outfitted with science research capabilities.² To maintain prominence in Arctic marine research, the United States needs to dedicate similar resources. **When USCGC Healy retires (2040s), the US's polar science capability will be severely diminished without these new investments.**

- Ongoing, past, and future US Arctic scientific research contributes critically to US maritime capabilities and interests in the Arctic, including economic benefits, safe navigation, national security and defense, national sovereignty, and long-term strategies.
- For the foreseeable future, vitally needed advances in research and understanding of the year-round Arctic marine environment will require appropriate science support on USCG icebreakers. Fortunately, the USCG at present is poised to expand its fleet of polar icebreakers with three heavy icebreakers (Polar Security Cutters [PSCs]) and up to 11 medium icebreakers (Arctic Security Cutters [ASCs]). Following a formal competitive process, two alternate designs for the ASCs have been selected by the USCG for implementation: the Seaspans/Aker/Rauma Multi-Purpose Icebreaker (MPI) and the Davie/Helsinki Multi-Purpose Polar Support Ship (MPPS-100). If appropriately configured, these ships will provide opportunities to support Arctic marine research. Of the two published ASC designs, the MPPS-100 appears better suited to support science infrastructure given its higher icebreaking rating, modular mission configurable design, placement of the working deck, and larger berthing capacity.
- Ship-based research will continue to be a core requirement for Arctic marine science over the next 30 years, providing an essential platform for well-developed sampling technologies and for more recently developing, and to be developed, autonomous assets (e.g., autonomous underwater vehicles [AUVs], uncrewed aerial systems [UASs], remotely operated vehicles [ROVs]). Icebreaker-based, science-equipped small boats will also become more import-

ant to support near-surface measurements in undisturbed water and to work in nearshore, shallow water environments.

- Modular equipment can expand the capabilities of a ship with only minimal permanent science equipment, especially if modularity is inherent to the initial ship design.
- Thirteen potential science missions (see Section 10 and Appendix 5) requiring capabilities ranging from the very basic (meteorological sensors and data systems) to the complex (multidisciplinary, multi-investigator, bio-chemical-physical basin-scale surveys) were used to identify appropriate ship-based requirements. These requirements were grouped into three categories:
 - Science Enabling Capabilities – mostly permanent infrastructure or modular equipment enabling
 - Research Capabilities – types of data or samples that a vessel needs to be able to collect, many through modular or non-permanent equipment
 - Small Boat Capabilities
- All the science missions can be supported in terms of science mission requirements by at least one category of ships being planned for construction.
- Many of the science mission requirement capabilities contribute to fulfilling the USCG's statutory missions.
- At all possible occasions, US ice-capable vessels should be constructed with hull-mounted acoustic systems; reinforced decks for heavy equipment such as A-frames, modular labs, and winches; digital infrastructure for large-scale, real-time data transfer and remote communications for science; and berthing capacity for a multidisciplinary science team. These core capabilities will enable any such equipped ship to be modified to support science or to take on modular equipment to support a specific science mission.
- Investing in vessels capable of fulfilling the science mission requirements for the next 30 years of US science is consistent with the aims of the President's

² <https://www.canada.ca/en/public-services-procurement/services/acquisitions/defence-marine/national-shipbuilding-strategy/projects/large-vessels.html>

Research and Development Budget Priorities³ that state that the United States must enhance its strategic posture and scientific capabilities in the Arctic. The capabilities identified in the AMRCC report are equally applicable to the conduct of marine research in Arctic and Antarctic regions.

Determining, documenting, and understanding ongoing changes across nearly every aspect of the Arctic today and in the past, and anticipating the relationship of these changes to and upon human activities, are the primary aims of planned and future Arctic marine research. Scientific questions span many disciplines—water masses and circulation, the carbon cycle, geochemistry, biology/ecology, ice transport and mass balance, weather and atmospheric transport processes of snow and rain, expansion of fisheries and other resource use, human activity and transportation, water fluxes through and between basins, shelf-basin exchanges, structural and stratigraphic evolution, and more.

Among other capabilities, the scientific community emphasized the need for winch and over-the-side load handling, state-of-the-art acoustic sensors, science spaces (such as built-in and/or modular lab spaces), deck space for modular equipment, drone and aircraft launch capabilities, science berthing, and heavy-ice breaking capabilities for year-round access (Appendix 5). Looking to the future, the community commented on the paramount importance of mapping, remotely or autonomously operated vehicles, unmanned aerial vehicles, robust off-ship data transfer, remote communications capabilities, and state-of-the-art, in situ ocean and air measurement capacity. These advancing technologies are critical to maintain competitive capabilities in Arctic system science and domain awareness.

This report reviews existing research capabilities, national and international capacities, and science mission scenarios to evaluate current and future needs. The report also follows from some initial recommendations made to the USCG for outfitting of the newly acquired USCGC *Storis* (Appendix 4) to help transition it to being an effective Coast Guard asset with research capabilities on par with USCGC *Healy*.

Building additional research-capable icebreakers ensures secure navigation, protects national interests, and sustains a strong US scientific presence in the polar regions. These ships will enable critical observation and research on rapidly changing environments and emerging economic opportunities, reinforcing US national security, prosperity, and global scientific leadership.

³ <https://www.whitehouse.gov/wp-content/uploads/2025/09/M-25-34-NSTM-2-Fiscal-Year-FY-2027-Administration-Research-and-Development-Budget-Priorities-and-Cross-Cutting-Actions.pdf>

1. BACKGROUND AND APPROACH

The University National Oceanographic Laboratory System (UNOLS) created the Special Purpose Arctic Marine Research Capabilities Committee (AMRCC) in June 2024 at the request of the US National Science Foundation (NSF), the Office of Naval Research, and the US Arctic Research Commission (USARC) and was tasked to review and refresh science missions (SMs) and associated science mission requirements (SMRs) for future federal icebreakers operating in the Arctic Ocean and other northern polar regions, in order to meet the research needs of the science community for the next 30 years (see [Appendix 1: Statement of Task](#)).

The AMRCC is composed of experienced Arctic professionals representing a range of different oceanographic seagoing science disciplines, varied career stages (i.e., senior, mid-level, and early career), marine technician/engineering science support staff, and United States Coast Guard (USCG) operators ([Table 1](#)). All members of the AMRCC are familiar with Arctic science operations successfully supported by the icebreaker USCGC *Healy*. The AMRCC benefited also from the participation of liaisons representing the USCG and USARC and was supported by the UNOLS office, especially the UNOLS Executive Secretary.

TABLE 1. AMRCC Team

AMRCC MEMBERS

- **Dr. Carin J. Ashjian**, Chair, Woods Hole Oceanographic Institution
- **Dr. Bernard Coakley**, University of Alaska Fairbanks
- **Dr. Lee W. Cooper**, University of Maryland Center for Environmental Science
- **Dr. Christopher J. Cox**, National Oceanic and Atmospheric Administration
- **Dr. Emily Eidam**, Oregon State University
- **Dr. Lauren Juranek**, Oregon State University
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- **Dr. James A. Austin Jr.**, The University of Texas at Austin and US Arctic Research Commission
- **Dr. John Farrell**, US Arctic Research Commission
- **LT Christine C. McCulla**, US Coast Guard

UNOLS OFFICE

- **Mr. Douglas Russell**, UNOLS Executive Secretary
 - **Ms. Bridget Harrell-Donze**, UNOLS
 - **Ms. Stefani Martynenko**, UNOLS
-

The AMRCC developed this report during remote meetings via the Zoom video platform and two in-person gatherings (November 2024 and April 2025, both in Seattle, Washington). The approach was largely prescribed by the statement of task and included collecting and evaluating appropriate documentation (e.g., SMs and SMRs for the academic fleet, Requests for Information and Requests for Proposals for USCG ships, US Arctic policy documents, US National Academies reports). During the period of the committee's work, the National Oceanic and Atmospheric Administration (NOAA) also conducted a science mission needs assessment for capabilities on icebreakers to meet that agency's science operations requirements. Because of the timing, the AMRCC did not have the opportunity to review the NOAA report as part of their work. Additional information was collected directly from the scientific community, including potential future SMs and SMRs that took into consideration the needs for emerging and to-be-developed technologies and anticipated technological developments. To collect this input, the AMRCC created an online questionnaire that surveyed the community for current and future ship-based research requirements. The AMRCC held two in-person community workshops (in December 2024 at the fall meeting of the American Geophysical Union in Washington, DC, and in January 2025 at the Alaska Marine Science Symposium in Anchorage, Alaska) at which input from the scientific community was solicited. The results of the community survey are shared ([Appendix 2](#)) and discussed in context

of the AMRCC's activities at a third conference (Arctic Science Summit Week) at the University of Colorado Boulder in March 2025.

On December 20, 2024, during the period of this report construction, the USCG acquired *M/V Aiviq*, a Polar Class 3 icebreaker that had been owned by Edison Chouest Offshore.⁴ *M/V Aiviq*, which has been renamed USCGC *Storis*, required modifications to bring the vessel to USCG operational readiness. The Congressional appropriation for the purchase of the vessel stipulated that the ship should have science capabilities comparable to USCGC *Healy*. UNOLS, through the work accomplished by the AMRCC, provided the USCG with a letter identifying core science enabling capacities that the AMRCC recommended the USCG consider as they retrofitted the ship for Coast Guard service ([Appendix 3](#)).

⁴ <https://www.news.uscg.mil/Press-Releases/Article/4015778/coast-guard-accepts-ownership-of-commercially-available-polar-icebreaker/>

2. THE CASE FOR US PREEMINENCE IN ARCTIC SCIENCE

Understanding and quantifying the rapid changes that are underway in the Arctic system are of critical importance to US national interests, influencing military strategy, disaster response, future shipping lanes, natural resource utilization, and relationships with international partners as well as potential adversaries. As an Arctic nation, citizens of the United States are also being affected by dramatic environmental changes that influence lifestyles, economic development, and opportunities.

Scientific research is the essential means for understanding the Arctic as a bio-geophysical system and the interactions of this system with global human activities. Much like the Antarctic and the deep ocean, the Arctic is a shared international space where national interests can compete but also where cooperation has been fundamental to advancing science since the World War II period. Successful international cooperation in the Arctic is demonstrated historically by collaborative efforts among countries going back decades, including efforts such as the International Polar Years (1882-1883, 1932-1933, 1957-1958, 2007-2008), the Arctic Ocean Section (1994), Arctic Mid-Ocean Ridge Expedition (2001), and Arctic Coring Expedition (2004). More recently, collaborative efforts among countries include the deployment of ships across the pan-Arctic domain (e.g., GEOTRACES 2015 and the Synoptic Arctic Survey 2020-2022), the long-term observation of oceanographic properties through cooperative deployment of moorings and routine surveys in the Siberian sector of the Arctic Ocean (Nansen and Amundsen Basins Observational System [NABOS], 2002-present), the use of the German icebreaker R/V *Polarstern* as a floating science platform by multiple countries (the Multidisciplinary drifting Observatory for the Study of Arctic Climate [MOSAiC], 2019-2020), and the cooperation of multiple countries in sampling the changing Bering and Chukchi ecosystem in US, Russian, and international waters (the Distributed Biological Observatory [DBO], 2010-present).

In addition, USCGC *Healy* has been instrumental in developing new scientific tools that have direct applications to the USCG through its Research and Development Center cruises such as that in 2015 to northern Alaska. USCGC *Healy* has also served the nation by collecting multibeam, gravity anomaly, and sub-bottom profiler data on multiple cruises from 2004 to 2012 to establish the full extent of the US Extended Continental Shelf in the Arctic Ocean based on criteria identified under the United Nations Convention on the Law of the Sea (UNCLOS). These data are also important to safety of navigation and to US economic interests such as benthic fisheries and petroleum or mineral extraction. Data collected during the ongoing NABOS project not only increases understanding of the ongoing environmental evolution of the Arctic Ocean but also provides rare, high-latitude ocean and sea-ice data that could directly contribute to USCG and US Navy operations, such as environmental mitigation, search and rescue, and risk reduction.

US scientists have played leading roles in Arctic scientific coordination, setting high standards that promote benefits outside of scientific knowledge, such as supporting commerce in our country's most economically important fisheries, providing platforms for evaluating the potential for economic resource development, and expanding national defense capabilities as sea ice retreats across the Arctic seascape. Without regular access to capable, well-equipped ice-breaking vessels, American scientists' ability to participate in the international conversation and contribute to the agenda for future research will be diminished. Given the limited availability of US flagged ice-capable research vessels, US-based scientists often rely on collaboration with international scientists and icebreakers to conduct their Arctic research.

The primary Arctic-related scientific challenges identified by the AMRCC through community surveys, public meetings, and deliberations that need to be addressed

in the coming years include: closing gaps in terrestrial, ocean, and atmosphere research at scales from local to global; improving remote/autonomous/semi-autonomous sensing; providing resources for more sampling in more areas at more times of year (including in heavy ice, during shoulder seasons, and in winter); collecting data that will support potential resource extraction as well as establish the geologic history of the Arctic Ocean and, indirectly, the adjacent continents; advancing fully coupled Earth system modeling; adapting observing strategies that are appropriate to changing Arctic conditions; and sustaining (or regaining) our preeminence in Arctic research and technology.

The scientific topics that need to be addressed include many scientific disciplines: oceanic water masses and circulation, bathymetry and continental shelf mapping, carbon and water cycles, geochemistry, biology/ecology, sea ice, snow, atmosphere, fisheries and other resource use, human activity and transportation, changes in freshwater input and Atlantic water fluxes, shelf-basin exchanges, seafloor and sub-seafloor sampling, including potential for and impacts of deep-sea mineral extraction, and more. Environmental intelligence and domain awareness to support safe and sustainable operations is necessary, as access to the Arctic and geopolitical and economic interests increase.

Advances in polar science have relied on improvements to polar logistic operations and capabilities. Remote sensing, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), uncrewed aerial systems (UASs), and submarine platforms are growing in sophistication and data-gathering capabilities. A better appreciation is also being gained for the value provided by Indigenous knowledge holders who are present in the Arctic throughout the year and who have knowledge gained over centuries. Arctic science advances are occurring through the inclusion of Indigenous knowledge, with programs such as Alaska's

Arctic Observatory and Knowledge Hub and Respectful Research paving the way. However, the research, training, and support provided to US marine research by polar-capable, surface research ships, including those from which the new advances in remote and autonomous sensing are deployed, remains critical for understanding the dynamics of many processes of importance to the national interest of the United States in the Arctic. New operational knowledge and capabilities provided by a new fleet of polar-capable ships will enable significant research advances that meet the geopolitical needs of the United States, while furthering scientific understanding of Earth's high-latitude regions to the benefit of all.

3. THE FUTURE OF US ICEBREAKING CAPABILITY AND ARCTIC RESEARCH

In this assessment of the long-term future of Arctic scientific research, the AMRCC makes two assumptions:

1. The effort will involve a continuing cooperative relationship between the USCG and academic institutions and federal science agencies, as well as scientific support organizations, both US-led and including one or more international partners.
2. Icebreaking and associated challenges to navigation in seasonally ice-covered seas will continue to be essential and play an increasingly prominent role, even as the Arctic pack sea ice cover diminishes in coming decades.

4. CURRENT FLEET STATUS

The US government’s polar icebreaking capability currently consists of the heavy icebreaker USCGC *Polar Star* and medium icebreaker USCGC *Healy*. The Coast Guard also recently acquired USCGC *Storis* (Table 2). The University of Alaska Fairbanks operates the ice-capable research vessel *Sikuliaq*, owned by NSF. NSF recently terminated the lease of RVIB *Nathaniel B. Palmer* that had been used for Antarctic research, including light icebreaking as part of its science support function.⁵

USCGC *Polar Star* was commissioned in 1976. It is capable of breaking through ice up to 21-feet thick with its 75,000 horsepower and 12,500-ton displacement. The ship’s primary mission is conducting the annual break-out of McMurdo Station in Antarctica. Doing so enables the annual resupply of McMurdo Station and other US science installations in Antarctica. While the ship has operated in the Arctic in support of science missions in the past, the ages of the ship and its systems now

TABLE 2. Existing, future, and recent US polar icebreakers or ice-capable ships. Information on future icebreakers was collected from Requests for Information, presentations to the AMRCC, national and international committee reports, and the media. Note that the contract to use RVIB *Nathaniel B. Palmer* was terminated by NSF in 2025. MPI ASC = Multi-Purpose Icebreaker Arctic Security Cutter. MPPS-100 ASC = Multi-Purpose Polar Support Ship Arctic Security Cutter.

| | USCGC <i>Polar Star</i> | RVIB <i>Nathaniel B. Palmer</i> | USCGC <i>Healy</i> | R/V <i>Sikuliaq</i> | USCGC <i>Storis</i> | Polar Security Cutter | MPI ASC | MPPS-100 ASC | Antarctic Research Vessel |
|--------------------------------|-------------------------|---------------------------------|----------------------|---------------------|----------------------|-----------------------|--------------------|---|---------------------------|
| Length | 399' | 305.8' | 420' | 261' | 360' | 460' | 328' | 328' | 365' |
| Beam | 84' | 60' | 82' | 52' | 24' | 88' | 67' | 69' | 80' |
| Draft | 31' | 22.5' | 29.3' | 28' | 28.25' | 36' | 21' | 22-25' | 32.5' |
| Icebreaking | 6' @ 3 kts | 3' @ 3 kts | 4.5' @ 3 kts | 2.5' @ 2 kts | 3.3' @ 3-5 kts | 6-8' @ 3 kts | 3.3' @ 4 kts | 5' @ 3 kts | ≥4.5' @ 3 kts |
| Range | 28,275 nm @ 13 kts | 15,000 nm @ 12 kts | 16,000 nm @ 12.5 kts | 18,000 nm @ 10 kts | 15,500 nm @ 10 kts | 6,500 nm @ 12 kts | 12,000 nm @ 10 kts | 6,500 nm @ 12 kts or 12,000 nm @ 12 kts | 17,000 nm |
| Endurance (Days) | 90 | 65 | 90-100 | 45 | n/a | 90 | n/a | 90 | 90 |
| Power | 75,000 hp | 12,700 hp | 30,000 hp | 16,000 hp | 22,000 hp | 45,200 hp | 9,655 hp | 17,400 hp | |
| Crew | 145 | 22 | 85 | 22 | 28 | 186 (total) | 50 (total) | 124 (total) | 29 |
| Science Party | ~18 | 45 | 51 | 24 | 36 | (?) | (?) | (?) | 55 |
| Country of Construction | USA | USA | USA | USA | USA | USA | Finland and USA | Finland and USA | TBD |
| In Service and Flagging | 1976, USA | 1992, USA | 1999, USA | 2014, USA | 2025, USA (as USCGC) | TBD, USA | late 2020s?, USA | late 2020s?, USA | TBD, USA |
| Moon Pool | No | Yes | No | No | No | TBD | No | Yes | Yes |

⁵ Voosen, P. 2025. NSF plans abrupt end to lone US Antarctic icebreaker. Science Insider, <https://doi.org/10.1126/science.z6ggq8y>

require annual heavy shipyard maintenance as part of a service life extension program when not engaged in its primary Antarctic mission. USCGC *Polar Star* has limited science support opportunities given its focus on icebreaking, ice escort of supply ships into and out of McMurdo Sound, and Antarctic logistics support. USCGC *Polar Star* is homeported in Seattle, Washington.

USCGC *Healy* was commissioned in 1999 and conducted its first dedicated science deployment in mid-2001. As a “medium” icebreaker, USCGC *Healy* can break 4.5 feet of ice at 3 knots continuously. It can also break ice up to 10 feet thick when backing and ramming. USCGC *Healy* is designed for and incorporates significant science support capabilities that have enabled the ship to provide extensive support of science missions throughout its history. USCGC *Healy* is America’s primary means for conducting high-latitude science across the Arctic. USCG plans are in place to conduct a service life extension of USCGC *Healy* via a series of five annual major maintenance periods starting in 2026. This will allow the ship to operate into the 2040s. USCGC *Healy* is homeported in Seattle, Washington.

The USCG recently acquired USCGC *Storis* (previously M/V *Aiviq*)—classified nautically as an Anchor Handling Tug Supply (AHTS) vessel that was designed and built in 2012 to support oil exploration and drilling in the Chukchi Sea. The Congressional authorization for the purchase of USCGC *Storis* stipulated that the USCG is required to outfit the ship for science operations equivalent to the capabilities of USCGC *Healy*.⁶ Because such a comprehensive refit of the ship will require significant planning and resources, it is recognized that fully developing USCGC *Storis*’ capabilities will take place over an extended time frame across numerous dry-dock and dockside maintenance availability periods. The ship was commissioned as a Coast Guard cutter in Juneau, Alaska, on August 10, 2025, and conducted her first patrol into the Arctic Ocean from August until early October, spending 112 days in the Bering and Chukchi Seas and over the Chukchi Cap.⁷ This initial patrol lays the groundwork for the USCG to transform the ship to a highly capable high-latitude Coast Guard cutter and icebreaker capable of supporting all the USCG statutory

missions, while also being capable of supporting Arctic research. USCGC *Storis*’ home port will be Juneau, Alaska, once adequate shore facilities there have been developed.

The United States also has an ice-capable research vessel, *Sikuliaq*, that is owned by NSF and operated by the University of Alaska Fairbanks (UAF) as part of the US Academic Research Fleet. This ship was delivered to UAF in 2014 and has provided excellent science support since, averaging 259 days of science mission time per year. R/V *Sikuliaq* is designed to operate in the marginal ice zone around Alaska and other Arctic regions where marginal ice zones are prevalent, such as summer in the Northwest Passage and in Baffin Bay. R/V *Sikuliaq* is ice strengthened to ABS Ice Class AI standards. It can break through 2.5 feet of first-year sea ice at 2 knots. R/V *Sikuliaq* is well equipped for science in the Arctic Ocean both in terms of permanently installed instrumentation and through flexible support for temporary augmentation by portable instruments. While designed for science support in ice-covered waters, the ship is classed by UNOLS as a Global Class Oceanographic Research Vessel and has also supported NSF-funded missions in non-polar waters across the Pacific. With the termination of the lease for the Antarctic icebreaker RVIB *Nathaniel B. Palmer* (see below), R/V *Sikuliaq* has been called upon to do research cruises in Antarctica. R/V *Sikuliaq* is homeported in Seward, Alaska.

RVIB *Nathaniel B. Palmer* was leased by NSF from Offshore Service Vessels LLC, doing business as Edison Chouest Offshore Inc. The ship conducted research in Antarctica from 1992 to 2025, averaging 240 days of service per year. It can break 3 feet of ice at 3 knots. While primarily used in the Antarctic, in 2003 RVIB *Nathaniel B. Palmer* conducted a science cruise in the Chukchi and Beaufort Seas as part of the NSF-funded Shelf Basin Interactions Program. The contract for the lease of RVIB *Nathaniel B. Palmer* was terminated by NSF in 2025 due to budget constraints.

⁶ <https://www.congress.gov/bill/117th-congress/house-bill/7776/text>

⁷ <https://www.highnorthnews.com/en/us-icebreaker-healy-wraps-four-month-patrol-arctic-countering-growing-chinese-presence>

5. LIMITATIONS TO SCIENCE USING CURRENT ICEBREAKER/ICE CAPABLE FLEET

Here, we discuss the practical operational constraints for each of the routinely used (for Arctic marine research) vessels. These limitations were used to identify existing unmet needs that may be addressed by future vessels. At present, the small fleet of ice-capable vessels creates practical seasonal and geographic restrictions to operational access.

R/V *Sikuliaq* is not sufficiently ice-hardened to fully meet the needs of the US Arctic marine science community. Because it does not operate much beyond the marginal ice zone, its use in the Arctic is restricted to summer-early fall months and to geographic regions with limited ice presence. Compared to other Arctic marine research platforms, R/V *Sikuliaq* has limited berth availability, which has restricted the breadth of science that can be accomplished on multidisciplinary Arctic research expeditions (see [Appendix 5](#)).

USCGC *Healy* is currently the only federal icebreaker that may be capable of supporting scientific operations in the Arctic during winter or early spring (e.g., December–April). However, winter and spring observations have been rare owing to USCGC *Healy*'s traditional, summer-focused deployments. The small size of the current federal icebreaking fleet and the need to provide for domain presence during the open water season limits the extent to which USCGC *Healy* can deploy during shoulder seasons (or be available for an entirely winter deployment). Additionally, USCGC *Healy* already has one of the longest continuous deployment periods in the USCG, with the ship often away from home port for up to six months. That extended deployment, together with drydock maintenance that often occurs away from home port, leads to restrictions on its operational window to maintain the USCG-required minimum five-year average time in home port.

The present deployable icebreaking capacity also limits access to portions of the Arctic; science mission profiles that require heavy icebreaking in multiyear ice (Polar Class 2 or above), including work in the Lincoln Sea and northern Greenland, are presently not feasible. Science in the Eastern Hemisphere of the Arctic requires long transits and complicated logistic support and, as a result, has been restricted to favorable ice conditions.

Such constraints on seasonal and geographic availability impose complications when planning joint icebreaker missions (see [Appendix 5](#)), which require international partnerships due to the small size of the US icebreaker fleet. For example, observations envisioned for the Fifth International Polar Year (2032–2033) rely on multi-ship campaigns in the Arctic; these missions are challenging to plan due to differing priorities for USCG and international vessels and can present scheduling challenges due to different planning horizons for USCG and international vessels.

The limitations of the fleet restrict the scope of Arctic observations that can be undertaken and dramatically curtails the ability of the United States to develop a full perspective on the behavior, complexity, and changes in atmospheric-sea ice-ocean systems and adjoining land interactions. The impacts of these limitations are not exclusive to scientific research, but also impact geopolitics, societal growth, military operations, and the potential for commercial enterprise. Having more research-capable icebreakers in the fleet would alleviate these gaps in coverage and permit more continuous US presence at high latitudes. Many countries are currently investing in new icebreakers with extensive scientific capabilities (e.g., Japan, Korea, China, Canada). For the United States to retain its leadership in Arctic science, appropriate icebreaking platforms must be available beyond the current seasonal and geographic scope provided by the existing fleet (USCGC *Healy*).

6. FUTURE US FLEET OUTLOOK

The USCG currently is revitalizing its icebreaker fleet (Table 2). Appropriations approved in 2025 will facilitate the USCG acquiring up to six new heavy Polar Security Cutters (PSCs) and up to 11 medium-class Arctic Security Cutters (ASCs). The design and construction process for these vessels will advance over multiple years. Thus, it is timely to now specify capabilities that can be designed into these new classes of icebreakers and to identify modular or portable capabilities that could be deployed on any of the ships for mission-specific work.

A parallel science requirement analysis has already been considered for Antarctic science needs, including the development of SMRs for an Antarctic research vessel.⁸ The AMRCC took advantage of this scientific specification process, even though funding for such a vessel has not yet been included in the current Major Equipment and Facilities Construction fund that is used by NSF to support ship construction. The AMRCC drew on the existing SMRs developed for the Antarctic as it developed input to the USCG on desired science mission capabilities for the new USCG vessels, based on projected needs of the Arctic science community for the next 30 years.

POLAR SECURITY CUTTERS (PSCs)

The PSCs will be the first new heavy (i.e., USCGC *Polar Star*-like capabilities) icebreakers built by the United States in 50 years. The ships are based on a modified design for the future German icebreaker *Polarstern II* and will be built by Bollinger Shipyards in Pascagoula, Mississippi. Construction of the first PSC has commenced after several years of delays in finalizing the ship's detailed design to meet US Coast Guard requirements and creating new icebreaker methods construction. The first PSC is expected to be delivered at the end

of this decade. Currently, two PSCs are under contract, although the USCG is expected to contract for the building of at least three of these ships. The primary mission of the first PSC will be to support Antarctic icebreaking and logistical support missions similar to those carried out by USCGC *Polar Star*. Multiple PSCs assure that the USCG will have the flexibility and fleet redundancy to carry out research missions and navigate in the thick Antarctic ice, leading supply ships and tankers and thus providing for re-supply of fuel and supplies to McMurdo Station, and by land-transfer to the South Pole. The PSCs will likely have some science capability when they are commissioned (i.e., multibeam, conductivity-temperature-depth sensor package [CTD], meteorological data), with the potential to increase those capabilities as the ships become fully operational. The PSCs will be homeported in Seattle, Washington.

ARCTIC SECURITY CUTTERS (ASCs)

A fleet of ASCs (medium icebreakers) is anticipated to provide a persistent US presence in the Arctic with the capability to execute all USCG statutory missions, including Arctic research and development missions. A Request for Information (RFI) for construction-ready icebreaking capable vessels or vessel designs appropriate for the ASCs that could be delivered within 36 months of contract award was issued by the USCG on April 11, 2025, with a required response date of April 25, 2025; the RFI included preliminary capability parameters. On October 9, 2025, US President Donald Trump and Finland President Alexander Stubb signed memorandum of understanding under which four ASCs would be built in Finland to facilitate faster delivery. President Trump also signed a Presidential Memorandum on the Construction of Arctic Security Cutters that authorizes and enables the construction of four ASCs outside of

⁸ <https://nsf.gov/resources.nsf.gov/files/RV-Subcommittee-final-report-14AUG2019.pdf>

⁹ https://www.whitehouse.gov/presidential-actions/2025/10/construction-of-arctic-security-cutters/?utm_source=substack&utm_medium=email

¹⁰ <https://www.whitehouse.gov/fact-sheets/2025/10/fact-sheet-president-donald-j-trump-authorizes-construction-of-arctic-security-cutters/>

¹¹ <https://www.madeinamerica.gov/waivers/nonavailability/69470a05dad97124a5220c4b>

the United States.^{9,10} A waiver to Made In America laws¹¹ has been approved and published by the US General Services Administration (GSA), allowing the construction of the four ASCs, as well as additional procurement of highly specialized equipment to outfit the future domestically constructed ASCs with similar equipment as their sister ships constructed in Finland.

Two designs have been contracted for construction.^{12,13,14} The first design is termed the Multi-Purpose Icebreaker (MPI) and is based upon a design by Aker Arctic for the Canadian Coast Guard in which the working deck is located amidships, with ship structures (the “house”) forward and aft of that deck; this design provides for little capability for towing off the stern. A consortium of Bollinger Shipyards (Louisiana, USA), Seaspan Shipyards (Vancouver, Canada), Aker Arctic Technology (Finland), and Rauma Marine Construction (Finland) will build the first two MPIs in Finland and the remainder at Bollinger in the United States.

The second design, the Multi-Purpose Polar Support Ship (MPPS-100), would be built by Davie Defense and Helsinki Shipyard and follows a more standard layout that would be better suited to scientific deployments with a working deck on the stern (and thus the capability to tow and deploy equipment while underway from the stern). Because of deck configuration, icebreaking capability, and potential inclusion of a moon pool, this design may better support the science infrastructure required for several of the SMs than will the MPI design. The first two MPPS-100s will be built in Finland and the remaining three at Gulf Copper shipyard Galveston, Texas, which was recently acquired by Davie Defense. Delivery of the first ships is expected within three years of the signed contract. At present, homeport(s) for the ASCs is/are unassigned. The AMRCC suggests that homeporting at least one ASC on the East Coast of the United States could support research activities in the eastern Arctic. Due to their shallower draft, additional higher latitude homeports would also be worth considering.

ADDITIONAL CONSIDERATIONS

During the (evolving) PSC and ASC construction and delivery timelines, USCGC *Healy* will be retired from service, which is anticipated to be in the 2040s if the planned service life extensions are completed and no major equipment failures occur. The retirement of USCGC *Healy* will leave a critical gap in icebreaking capability and the support of Arctic scientific research, including USCG research and development missions. The need for the icebreaking capabilities of USCGC *Healy* or better icebreaking capabilities will continue to be required to reach areas in the Central Arctic Basin, especially during winter, and to work in areas of multiyear ice. However, based on what is known of USCGC *Storis* and the ASC RFI, those ships’ hull characteristics, endurance, and icebreaking may not be as capable as USCGC *Healy*. That icebreaking role will ultimately be filled by the PSC(s), heavy icebreaking vessels, the first of which may be delivered in time to precede the retirement of USCGC *Healy*. While the USCG has already made it clear that the role of PSCs will not be to support scientific research, the possibility exists that the PSCs will play an escort role for ASCs to access portions of the Arctic that they themselves will not be able to reach alone. Typically, most ships collect data that can support some science (e.g., bathymetry, meteorology). Because the PSCs will have some limited science capabilities, opportunistic science may be possible, as it has been on USCGC *Polar Star*.

USCGC *Storis* may well be suited to serve as a bridging strategy until the heavy PSCs and ASCs are commissioned, serving as a backup to USCGC *Healy* and supporting USCG mission requirements, although the icebreaking capacity of USCGC *Storis* is significantly less than that of USCGC *Healy*, and opportunities to support certain types of science will be entirely dependent on retrofits for science equipment.

¹² <https://www.news.uscg.mil/Press-Releases/Article/4403354/us-coast-guard-completes-the-presidents-contract-awards-for-11-arctic-security/>

¹³ <https://www.navalnews.com/naval-news/2026/02/davie-defense-awarded-uscg-contract-to-build-five-arctic-security-cutters/>

¹⁴ <https://www.navalnews.com/naval-news/2025/10/white-house-selects-bollinger-led-international-team-to-build-six-u-s-coast-guard-arctic-security-cutters/>

7. INTERNATIONAL RESEARCH FLEET AND HOW US ASSETS COMPARE

Multiple nations have polar research icebreakers with a range of ice capabilities, enabling differential access to the Arctic Ocean and thus supporting distinct subsets of Arctic science. The operational specifications (e.g., size, icebreaking capability, power, endurance) of the existing and planned US polar icebreakers fall within the range of specifications of international peers (Table 3). The specifications for several of these ships are more completely described in the 2019 report on the requirements for a new Antarctic science icebreaker.¹⁵ Note also that most international icebreakers are now also being constructed with moon pools, which are open water access points within the interior of the ship where gear, AUVs, ROVs, divers, and other deployments can be managed without interference from sea ice (or surveillance).

Science party capacities for the existing and future international icebreakers presented here are sufficiently large to support interdisciplinary research programs and range from 35 (R/V *Kronprins Haakon*) to 117 (RSV *Nuyina*) berths (excluding *Le Commandant Charcot*

because most of those berths are reserved for tourism). (Note that for some international research icebreakers, the extended berthing capacity is designed to provide transportation for personnel embarking to land-based research stations, for example, in Antarctica.) The historical capacity of USCGC *Healy* (51 berths) is within this range. At present, the potential science party capacities of the upcoming USCG PSC and ASCs and of USCGC *Storis* are unknown. However, a reduction in science party size relative to that of USCGC *Healy* for those ships could limit the scope of the science programs that can be supported.

Many nations have dedicated resources to expanding research capability and national presence in the Arctic Ocean (Table 3). For example, Canada has plans to revitalize the Canadian Coast Guard fleet with the construction of two heavy icebreakers. One (CCGS *Imnaryuaq*) is being built in Vancouver, British Columbia, Canada by Seaspan's Vancouver Shipyards. The second (CCGS *Arpatuuq* using the Polar Max design) is being

BOX 1. SCIENCE CAPABILITY VIDEOS AND WEB PAGES

USCGC *Healy*: <https://www.youtube.com/watch?v=eIGt0HNhyOX9Y>

R/V *Sikuliaq*: <https://www.youtube.com/watch?v=Z3ln9zLtyHk>

***Xue Long 2*:** <https://www.youtube.com/watch?v=m5kCdTCLLxQ>

RSV *Nuyina*: <https://www.antarctica.gov.au/science/technology/marine-science/>

SA *Algulhas II*: <https://www.youtube.com/watch?v=s4EHZ9-kNWc>

R/V *Kronprins Haakon*: <https://www.youtube.com/watch?v=eS3UWV0zVA0>

RRS *Sir David Attenborough*: <https://www.youtube.com/watch?v=0EVPUCHdK08>

R/V *Polarstern*: <https://www.youtube.com/watch?v=w1gO3sD-Q6g>

***Le Commandant Charcot*:** <https://us.ponant.com/le-commandant-charcot>; <https://www.youtube.com/watch?v=pjve3PZih6s>

***Oden Replacement*:** <https://www.polar.se/media/a3wk0lud/technical-requirement-240613-rev-4-2025-06-24.pdf>

¹⁵ <https://www.whitehouse.gov/wp-content/uploads/2025/09/M-25-34-NSTM-2-Fiscal-Year-FY-2027-Administration-Research-and-Development-Budget-Priorities-and-Cross-Cutting-Actions.pdf>

TABLE 3. Selected international icebreakers, including those under construction. Power estimates are approximate for the under-construction ships.

| | CCGS Amundsen | R/V Polarstern | Oden | IBRV Araon | SA Algulhas II | Xue Long 2 | RSV Nuyina | R/V Kronprins Haakon |
|------------------------------------|--------------------------|---------------------------|-----------------------|-----------------------|---------------------------|-----------------------|-----------------------|---------------------------------|
| Length | 323' | 387' | 351' | 364' | 440' | 402' | 526' | 329' |
| Beam | 65' | 72' | 102' | 62' | 71' | 73' | 84' | 69' |
| Draft | 23' | 37' | 23'-27.9' | 22' | 25' | 26' | 31' | 34' |
| Icebreaking | 3.3' @ 3 kts | 4.9' @ 3 kts | 6.2 @ 3 kts | 3' @ 3 kts | 3' @ 5 kts | 5' @ 3 kts | 5' @3 kts | 3' @ 5 kts |
| Range | 35,000 nm @ 14 kts | 19,000 nm @ 10.5 kts | 30,000 nm @ 13 kts | 20,000 nm @ 12 kts | 15,000 nm @ 14 kts | 20,000 nm @ 12 kts | 16,000 nm @ 12 kts | 15,000 nm @ 12 kts |
| Endurance (Days) | 100 | 75 | 100 | 75 | 90 | 60 | 90 | 65 |
| Power | 17,700 hp | 18,940 hp | 7,242 hp | 18,774 hp | 12,000 hp | 20,000 hp | 26,000 hp | 15,000 hp |
| Crew | 41 | 44 | 22 | 25 | 45 | 30 | 32 | 15-17 |
| Science Party | 39 | 55 | 45 | 60 | 100 | 60 | 117 | 35 |
| Country of Construction | Canada | Germany | Sweden | Korea | Finland | China | Romania | Italy |
| In Service and Flagging | 1978, Canada | 1982, Germany | 1988, Sweden | 2010, Korea | 2012, South Africa | 2018, China | 2018, Australia | 2018, Norway |
| Moon Pool | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

| | RRS Sir David Attenborough | Le Commandant Charcot | Mirai II | CCGS Imnaryuaq | CCGS Arpatuuq | Polarstern II | Oden Replacement |
|------------------------------------|---------------------------------------|----------------------------------|------------------|---------------------------|--------------------------|-----------------------|-----------------------------|
| Length | 423' | 492' | 420' | 518' | 454.5' | 470' | 459' |
| Beam | 79' | 92' | 75' | 92' | 96.5' | 89.5' | 92' |
| Draft | 23' | 33' | 26' | 32' | 34' | 36.4' | 33' |
| Icebreaking | 3' @ 3 kts | PC2 | 4' @ 3 kts | 6.6' @ 3 kts | 6.6' @ 3 kts | 6' @ 3 kts | 6' @ 5 kts |
| Range | 19,000 nm @ 13 kts | TBD | 80,000 nm @ ? | 26,200 nm @ 12 kts | 26,200 nm @ 12 kts | 30,000 nm @ 13 kts | TBD |
| Endurance (Days) | 60 | ~120 | TBD | 25 (270°) | 25 (270°) | 90 | 100 |
| Power | 15,000 hp | 45,600 hp | 22,500 hp | 62,000 hp | 45,600 hp | 37,000 hp | ~46,000 hp |
| Crew | 30 | 215 | 34 | 60 | 60 | 50 | 32 |
| Science Party | 60 | 245 | 63 | 40 | 40 | 60 (90°) | 88 |
| Country of Construction | UK | Romania | Japan | Canada | Finland, Canada | Germany | South Korea ^b |
| In Service and Flagging | 2018, United Kingdom | 2020, France | 2026, Japan | ~2030, Canada | ~2030, Canada | ~2030, Germany | 2028 (?), Sweden |
| Moon Pool | Yes | No | Yes | Yes | Yes | Yes | Yes |

^a Logistic endurance (not underway)

^b Hyundai Heavy Industries in South Korea has been awarded the contract but this decision has been appealed by Davie/Helsinki Shipyard

built by Chantier Davie Canada Inc. (CDCI) starting at its Helsinki, Finland, shipyard with later work in CDCI's shipyard in Lévis, Québec, Canada.^{16,17} Canada also plans to construct six medium-heavy icebreakers (program icebreakers) and up to 16 multi-purpose icebreakers.¹⁸ Korea is planning the construction of a Next Generation Icebreaker. Sweden has contracted with Hyundai in Korea for the construction of a replacement for *Oden*. Germany is constructing *Polarstern II*.^{19,20} China has also greatly expanded its presence in the Arctic Ocean with the operation of five research icebreakers in the Arctic Ocean²¹ in 2025, including the deployment of 43 crewed submersible dives in the summer of 2025.²²

¹⁶ https://www.marinelog.com/shipbuilding/shipyards/shipyard-news/construction-of-canadas-polar-max-heavy-icebreaker-starts-in-finland/?utm_source=&utm_medium=email&utm_campaign=53186

¹⁷ <https://www.canada.ca/en/public-services-procurement/services/acquisitions/defence-marine/national-shipbuilding-strategy/projects/large-vessels/polar-icebreakers.html>

¹⁸ <https://www.canada.ca/en/public-services-procurement/services/acquisitions/defence-marine/national-shipbuilding-strategy/projects/large-vessels.html>

¹⁹ <https://sixtydegreesnorth.substack.com/p/european-icebreaker-update>

²⁰ <https://www.awi.de/en/about-us/service/press/single-view/polarstern-neubau-auftrag-fuer-deutschen-forschungseisbrecher-vergeben.html>

²¹ <https://gcaptain.com/china-deploys-five-icebreakers-near-alaska-in-unprecedented-arctic-move/>

²² https://gcaptain.com/china-completes-43-manned-arctic-dives-in-2025-demonstrates-dual-submersible-operations-under-ice/?subscriber=true&goal=0_f50174ef03-9cae9dcd40-169908901&mc_cid=9cae9dcd40&mc_eid=3384892a96

8. RESULTS OF COMMUNITY SURVEY

BACKGROUND

The community survey was developed by a subgroup of the AMRCC in November 2024. The survey was drafted in mid-November and reviewed and finalized in early December. The survey was released to the community on December 10, 2024, coinciding with and announced at the Community Meeting held at the 2024 fall meeting of the American Geophysical Union in Washington, DC. The survey was publicized through mailing lists, including UNOLS lists, the Interagency Arctic Research Policy Committee, the now discontinued ArcticInfo, and early career lists. Initially the survey was to close on February 7, 2025, but the deadline was extended until March 1, 2025. The survey consisted of 40 questions to be answered either with quantifiable metrics (e.g., rate from 1 to 5) or with comments. Focus areas included: current Arctic research of respondent; future Arctic research of respondent; scientific support, facilities, and infrastructure needs for respondent's current and future research; and important scientific questions driving research into the next 50 years. Thirty-nine members of the community provided responses to the survey: 18% were early career researchers who had been in the field for 0-5 years, 33% had been in the field for 6-15 years, and 39% had been in the field for 15+ years. Most respondents had earned PhD degrees.

The data and comprehensive synopsis of the comments are available in [Appendix 3](#). Some caution in interpreting some of the survey results is required. For example, the level of support for some capabilities was likely influenced by the number of responders whose area of research would require a particular capability (e.g., there are very few responses from marine mammal or bird scientists; thus, the ability to conduct mammal/bird observations from the bridge does not stand out as an important need).

FUTURE SCIENCE AREAS AND CHALLENGES

The common thread envisioned by the community for future Arctic marine research is to document the recent changes across nearly every aspect of the Arctic environment and the history of those changes, understand the forces driving the changes and the relationship of these changes to past and present human activities, and anticipate future change. These goals were envisioned for multiple research areas, including water masses and circulation; the carbon cycle; geochemistry, biology, and ecology; ice; fisheries and other resource harvesting; human activity and transportation; fresh water and Atlantic water fluxes; shelf-basin exchanges; and more.

Specific scientific research challenges cited by respondents include closing gaps in terrestrial, ocean, and atmosphere research at scales from local to global, improving remote/autonomous/semi-autonomous sensing, providing resources for more sampling in wider geographic areas at more times of year (including in heavy ice, during shoulder seasons, and in winter), finding ways to collect data related to the effects of industrial scale resource extraction, and adapting observing strategies to the changing Arctic.

Access to the Arctic is prioritized by the community. It is recognized as a challenge due to ships' icebreaking capabilities that could limit access to regions with persistent heavy ice cover and during the shoulder seasons and the winter, and to political challenges across international boundaries. For example, one respondent noted that "A lack of cooperation across nations to conduct Arctic research will be very challenging in the next decade(s), and without international cooperation, we will not be able move forward with critical Arctic science."

NEEDED FUTURE SCIENCE CAPABILITIES

All respondents stated that their future research will require the use of icebreaking ships. Even if future summer Arctic marine science support requires less icebreaking capability for a particular mission or region, year-round icebreaker support will be required during winter and shoulder seasons, during ice pack breakup and freeze-up, and for accessing persistently ice-covered locations. Icebreakers provide crucial flexibility in station planning and cruise tracks and a broader temporal operational window.

Respondents recognized that with a larger fleet of icebreakers, total science berthing capacity could be equivalent or greater to that available at present, but that large, multi- or interdisciplinary programs or efforts requiring large technical teams to deploy modern instrumentation (e.g., complex ROVs) will be difficult to support without a ship that has a large science berthing capacity or that can participate in a two-ship operation. Respondents recognize that there will be gaps in research capability once USCGC *Healy* is decommissioned prior to availability of alternate science-ready platforms; both the loss of access to Arctic regions with substantial ice cover and reduced ship-time availability are concerns.

The most important basic infrastructure components of an icebreaker that undertakes scientific missions include sufficient deck space for science activities, modular equipment (e.g., portable A-frames and winches), and science gear; room for dedicated and specialized laboratories; an onboard computer network with high internet bandwidth; sufficient cargo capacity to store samples that is also accessible, and care taken regarding habitability, as the science missions are long.

In addition to the basic infrastructure needs, the most desirable science capabilities, systems, and equipment cited by respondents are the ability to deploy equipment overboard; meteorological systems; in-hull acoustics; data systems; science seawater circulation systems; and small boats. The survey ranked a moon pool and a flight deck as less critical to future research needs (although the AMRCC notes that there is a compelling need for a flight deck for UAS and helicopter deployment/recovery). Moon pools are advantageous

for deploying equipment in ice and in cases where surveillance of equipment deployment might compromise operational security. The AMRCC also noted that almost all new icebreaker platforms constructed in the past decade have moon pool deployment capabilities; however, many US researchers have not had experience working with moon pools, so their ranking of this icebreaker feature as less critical may reflect a lack of familiarity with its advantages.

Future research will require the use of new technologies, including sampling and observing (e.g., AUVs, UASs, ROVs), long-term moorings, helicopter-based operations (for access to ice camps and deployments of helicopter-towed atmospheric chemistry sampling systems), and advanced data capabilities (e.g., high network/internet bandwidth, large data storage capacity, virtual communications, incorporating use of artificial intelligence, and keeping separate science and USCG computer networks to preserve security). Respondents note that traditional sampling approaches will continue to be critical, particularly to biological/chemical/ecosystem measurements that cannot easily be sensed autonomously.

Frequent and easy access to shallow water, estuaries, fjords, and river channels also was identified as a science need that could be accommodated either through smaller icebreaking vessels or through the use of science-capable small boats (e.g., a 45-foot vessel with space for science crews of up to six to eight and science capabilities, such as a small Niskin rosette to collect water samples) that can be launched from a larger icebreaker.

9. THE NEED FOR ICEBREAKERS TO SUPPORT FUTURE ARCTIC RESEARCH

The scientific community, including sea ice modeling specialists, expects that icebreakers will remain essential for scientific research for the next 30 years. Even if, in the future, late summer Arctic marine science support may require less icebreaking capability, icebreakers will be required for the other 310 days per year (i.e., winter and shoulder seasons), including during breakup and freeze-up. Increased availability of icebreaking capabilities means increased potential for conducting station work and ship course planning, and operations will be possible during a broader temporal window. Projections of a “Last Ice Area” north of Greenland and the Canadian Archipelago mean that there will likely be some ice in regions important to research throughout the time when icebreakers are being constructed in this decade or next and can be expected to be operational. More extreme environmental conditions are expected during this time period, and, with ice conditions less predictable and spatially and temporally complex and variable, access to ice-safe research ships will be essential for safety and planning for coming decades. There is also interest in winter science missions for which appropriate icebreakers will be needed. This need is especially critical, as some of the major changes in the Arctic that impact lower latitudes are cold air outbreaks that direct heavy snow to the south and atmospheric rivers that bring warm, moist air northward. Another consideration is that summer operations may require the ability to carry out research activities in open seas, potentially with large significant wave/swell height and winds.

Scientific challenges can be met if logistical challenges in Arctic marine research are resolved. Access for US scientists to the Atlantic-influenced Arctic is also limited in all seasons, as is access to shallow, nearshore areas (estuaries, deltas, and shoreline) that cannot be occupied by existing icebreakers such as USCGC *Healy*. Furthermore, many biological, ecological, and physical measurements require human occupation of ice-covered seas and of sea ice systems to generate data, including such potential changes as the development of new fisheries. Logistical support is expensive and difficult

to schedule, and it can be hard to obtain the needed project-dedicated time for a field program. Transit distances from embarkation and disembarkation ports to distant research sites, and from the continental United States, present additional challenges.

The polar science community also anticipates the need for interdisciplinary research onboard the new icebreaker platforms, with specific needs for more research during spring, autumn, and winter (in both ice and open water), and the capability of working in heavier ice than has been feasible in the past. Conducting extensive interdisciplinary research in relatively remote Arctic waters, for example, north of Greenland in the Lincoln Sea, argues for greater vessel endurance and capabilities in multiyear ice. Notably, the capabilities identified in this report can equally support marine research in the Antarctic where longer cruise lengths are the norm.

10. SCIENCE MISSIONS

The AMRCC identified 13 science missions as representative of possible types of projects or programs in the Arctic for the next 30 years (Table 4, Appendix 5) with which to help define the SMRs. Although many of the approaches are similar to those used today, it is envisioned also that the missions increasingly will use autonomous platforms, such as UASs or drones and AUVs, as well as emergent technologies such as robotic lander drills. Novel instrumentation and sensors will also be incorporated on traditional platforms, such as on a CTD rosette.

The science missions range from small, focused science projects (SM6, SM13) that could be conducted on an opportunistic basis from a ship with a non-science

primary mission or by joining a different dedicated science cruise, to single-project missions with space and time for other projects to join (SM1), to single disciplinary, small-large team missions (SM3, SM4, SM5, SM8, SM9, SM11, SM12, SM13), or to large, interdisciplinary missions including a two-ship effort (SM2, SM5, SM7, SM10). The SMs are examples requiring science or science-enabling capabilities that encompass a wide range of needs. However, they are not an exhaustive survey of the potential science projects and missions of the future. The examples also focus on different ocean regions, from fjords and nearshore studies to shelf-break work to deep-basin work, and encompass the entire range of seasons, including winter.

TABLE 4. Science missions (SMs) used to identify science mission requirements (SMRs). Complete descriptions of these example missions can be found in Appendix 5.

| Mission Scenarios | |
|-------------------|---|
| SM1 | Single PI Project with Space for Others |
| SM2 | Internationally Coordinated Basin-Scale Survey Cruise |
| SM3 | Marine Geology and Geophysics – Lander Drilling and Giant Piston Coring |
| SM4 | Marine Geology and Geophysics – Multibeam and Seismic Mapping, Rock Dredging, Sediment Coring |
| SM5 | Winter Ecosystem Study |
| SM6 | Science of Opportunity |
| SM7 | Ocean Exploration |
| SM8 | GO-SHIP* – Including BIO GO-SHIP or Geochemistry Options |
| SM9 | Physical Oceanography – Arctic Mobile Observing System |
| SM10 | Multi-Ship Multidisciplinary Arctic Basin Studies |
| SM11 | Near Shore Coastal and/or Rapid Response Mission |
| SM12 | Fjord Survey |
| SM13 | Air-Sea-Ice Interactions |

*Global Ocean Ship-Based Hydrographic Investigations Program

11. SHIP CAPABILITIES NEEDED TO ENABLE ENVISIONED FUTURE ARCTIC MARINE RESEARCH

Specialized scientific equipment and novel sampling approaches are fundamental to interdisciplinary research. Consequently, research cruises require vessels with modularity, deck space, and multi-purpose laboratories, including the use of portable vans. Fundamental, core measurements of ocean-ice-atmosphere interactions (measurements may include atmospheric properties, surface currents, bathymetry, sea surface temperature, ice properties, upper ocean water mass properties, energy transfer, and others) augment situational awareness, are necessary for developing and evaluating coupled numerical weather and sea ice prediction models, and are important for understanding the coupled cryosphere-atmosphere-ocean system. The capacity to deploy complex underwater profiling systems and robotic vehicles as well as UASs are essential for pushing the boundaries of knowledge in the Arctic domain. Geotechnical drilling, dredging, and seismic reflection operations can support better understanding of seafloor characteristics, including the presence of methane hydrates and availability of critical minerals as well as deeper understanding of the history of the ocean basin at timescales greater than one million years. Accommodating small boat operations from icebreakers allows for a fuller understanding of the water mass linkages between nearshore and inland fjord systems that are becoming increasingly interconnected under the influence of glacier ice melt. Putting people and equipment on the ice via helicopter or transporting instrumentation using the vessel's cargo cranes are also key capabilities. Having the network and cyber-infrastructure to acquire and store large datasets from shipboard mounted sensors (e.g., broadband acoustics or X-band radar) is essential sophistication for modern science needs. In aggregate, these research needs direct desired vessel characteristics.

The ability to add modular scientific capabilities (e.g., containerized labs) on an as-needed basis is identified as a key attribute for a range of ship sizes and icebreaking capabilities. Modularity and the accom-

panying needed flexibility in working deck areas will be critical as new icebreakers are designed and constructed. This will allow for ships to accommodate specialized equipment, some of which is only in the developmental stages today, and to devise laboratory spaces that meet foreseen and unforeseen project needs. Some modular applications are expected to have location requirements on the vessel. For example, aerosol sampling or atmospheric remote sensing is preferentially made forward of vessel exhaust sources while ROV/UAS operations may require support vans to be accessible from where the equipment is to be deployed.

Additional improvements could be incorporated with purpose-built systems and specialized platforms, such as a piston coring launch-and-recovery system for efficient seafloor sampling and remote-sensing methods to sample characteristics of the upper 10 m of the water column and to measure shallow water currents (e.g., pyrometer, LiDAR, X-band radar). Other shipboard deployment methods of potential benefit include a moon pool to safely launch and recover equipment in heavy ice conditions, and resident helicopter support for operations.

In addition, the mothership concept will be paramount for the next generation of icebreakers, whereby features such as launch pads, moon pools, and command centers will streamline and maximize the use of AUVs and UASs during transits and while conducting station work, thereby fully exploiting the vessel's presence within the Arctic operating domain. Persistent aircraft observations are highly sought after by the atmospheric, sea ice, and trace gas communities in the United States and globally. These drone systems will be capable of housing a suite of in situ atmospheric sensing, radiometric, and sea ice imaging devices simultaneously, including sampling aerosols and trace gas measurements (water vapor, carbon dioxide, methane) and their sources (based upon isotopic properties) within a 5-20 mile radius of the ship, and measurements in vertical profiles

up to a mile or more. Such UASs are in direct communication and operated by trained staff and/or military personnel with expertise in UAS operations, and are based on the icebreaker during the entire operation.

The AMRCC assembled two types of capabilities based on input from the community and the needs of the example SM scenarios: *Science Enabling Capabilities* (Table 5) and *Research Capabilities* (Table 6). The SMRs following from these SM scenarios also identified access to shallow coastal regions and fjords, and sampling of the upper water column or sea ice near but away from the ship as a required capability. This would be accomplished by small boats deployed from the icebreaker that can support scientific instrumentation (Table 7).

As the AMRCC identified needed capabilities, they were categorized as to whether that capability could be accommodated through modularity (i.e., bringing equipment on board for a specific mission) or whether it required permanently installed facilities. The AMRCC also identified a core set of capabilities that should be installed/available on all these vessels as a minimum to accommodate science missions, including those that enhance ship capabilities through modular installations.

As additional background and further description, a simplified version of the science mission requirements/capabilities for a new Antarctic Research Vessel, adapted from the 2019 *Report of the Ad Hoc Subcommittee on the US Antarctic Program’s Research Vessel Procurement*,²³ are posted on the UNOLS web site. The AMRCC notes that these descriptions are not recommendations for future Arctic federal icebreakers but rather provided for convenience.

SCIENCE-ENABLING CAPABILITIES

Science-enabling capabilities (Table 5) are those that enable scientific work on a ship, even if the ship is not a dedicated research vessel. They may not be used for all the ship’s missions but generally are necessary to conduct science missions or missions that include a scientific work component. These capabilities are for the most part provided by permanent equipment on the ship, although additional equipment can be brought aboard for a specific science mission. Examples include hull-mounted acoustic sensors, flow-through ambient seawater system, berthing and hotel services, lab and storage spaces, an independent science network and data storage systems (air-gapped from secure Coast

TABLE 5. Science-enabling capabilities critical to science observations and national security applications that should be incorporated into ship designs. Potential for capability to be accomplished using modular equipment and required supporting systems also identified. For some capabilities, specific operational security needs to which a capability contributes are noted.

| | Science-Enabling Capability | Modular Potential | Required Supporting Systems | Specific Additional National Security Needs |
|-------------|--|-------------------|---|---|
| Core | Hull-mounted transducers | No | Cable conduits, space above water line for transceivers, anti-freeze flooded tanks, ice windows | |
| | Berthing and hotel services: Accommodations for minimum 25-26, goal 35 including science techs | No | | |
| | Permanent interior lab space | No | Flexible chemical/flame resistant work surfaces, network connections, clean power, comms, network, fume hoods, UPS, compressed air, sinks, deionized water, segregated hazmat storage | |
| | Moon pool | No | Gear-handling equipment | Deploy subsurface gear, such as AUVs, without detection |

Table continued on next page...

²³ <https://nsf.gov/resources.nsf.gov/files/RV-Subcommittee-final-report-14AUG2019.pdf>

TABLE 5, continued. Science-enabling capabilities critical to science observations and national security applications that should be incorporated into ship designs. Potential for capability to be accomplished using modular equipment and required supporting systems also identified. For some capabilities, specific operational security needs to which a capability contributes are noted.

| | Science Enabling Capability | Modular Potential | Required Supporting Systems | Specific Additional National Security Needs |
|--|--|-----------------------|--|--|
| Overboarding and Ship Handling | Dynamic positioning | No | | |
| | High capacity stern A-frame | No | | |
| | Oceanographic winches | No | | |
| | Ability to tow packages from the stern in ice | No | | |
| Meteorological and Underway Observing | Flow through science seawater with capacity for multiple permanent and temporary sensors | No | Navigation, data infrastructure | Pollutants, contaminants, HABs, surface sound speed |
| | Platforms for meteorological sensors | Yes | Foremast 16-20 m above mean water line (ideally forward-tilting); climbable; ability to mount auxiliary equipment; access to 110/220 VAC, freshwater source on bow for cleaning, science network | Situational awareness (e.g., Row 16 AWS), atmospheric/ice observations including those assimilated into forecast models for sea ice prediction and weather |
| Science Network and Data | Independent science network and data storage system | No | Navigation, SATCOMS, UPS, airgapped unclassified network | Inputs to forecast models, including sea ice prediction and weather; enables participation of non-USCG personnel on deployments |
| | High bandwidth satellite comms system, internet, telepresence | Yes | Power, undisturbed field of view for science antennas | |
| | Access to ice radar (X-band) data feed (archived is OK) | NA | Navigation, networked data storage (see <i>Healy</i> system) | Situational awareness, sea ice drift analysis |
| | Onboard situational awareness system (e.g., shipwide GIS system, ice products, bathymetry, remote sensing) accessible to both operators and scientists | Yes | Simultaneous access to data and imagery products for operators and scientists, including navigation data, science network connectivity and computer for bridge | |
| | CCTV systems to monitor decks, winches, etc. | Yes but not desirable | Networking and/or dedicated cable runs to relay data, power | |
| Modular Capabilities | Modular specialized lab capability | Yes | Tie down, power/water/HVAC/comms/on-deck plumbing that doesn't freeze for modular labs. | |
| | Capability to install modular equipment (e.g., winches, launch/recovery systems, compressors) | Yes | Sufficient deck strength, deck bolt pattern, appropriate electrical power to support modules | |
| | Heated, weather-protected staging area with deck access for other science equipment (e.g., AUV, ROV, electronic equipment) | Yes | Freshwater, drains, electricity, deck bolt pattern, compressed air, wide door deck access | |
| | Heated, weather-protected staging area for CTD | No | Freshwater, drains, electricity, deck bolt pattern, compressed air, wide door deck access | |

Guard networks), access to the ship's navigation data, a suite of meteorological sensors and platform meeting research-grade requirements, and the space, deck strength, and tie-down capabilities to accommodate portable equipment such as winches and lab vans. The AMRCC recognizes that not all federally owned/operated Arctic icebreakers of the future will feature all science-enabling capabilities but recommends that, as possible, they be included (or at least the ability to add them) in ship design (space-weight-power considerations) or refit planning.

RESEARCH CAPABILITIES

Table 6 identifies the types of data or samples to be collected and associated equipment to be deployed from or installed on a ship to enable future Arctic Ocean

research. Many of these measurements can be accomplished using equipment brought on board (modular), usually by researchers or logistics providers, but that requires support from the science team aboard the ship.

The AMRCC recognized that there are synergies between future science findings and national security needs in the Arctic and identified these connections for each science measurement. The AMRCC also recognized that the science measurements/findings contribute to the USCG's ability to fulfill many of their statutory missions (see also Section 14). Note also that hull-mounted acoustic transducers are included as both science-enabling and research capabilities because of the substantial hull modifications required to accommodate such sensors and the difficulty in achieving these measurements at scale using portable equipment.

TABLE 6. Research capabilities/science measurements required to accomplish future Arctic research, potential for that research to be accommodated with modular equipment on a science enabled ship, required supporting systems or science-enabling capabilities of the ship, and national security needs and USCG statutory missions (see key at bottom) to which the science measurements can contribute.

| Science Measurements | | Modular Potential | Required Supporting Systems | National Security Need | USCG Statutory Missions Supported |
|-----------------------------------|--|-------------------|---|--|-----------------------------------|
| Hull-Mounted Acoustic Instruments | Modern multibeam seafloor mapping (deeper water) | No | Navigation, data infrastructure, sound speed profiles (from CTD and flow-through) | Bathymetric charting, safety of navigation, subsurface obs (water column), geohazards, SAR, infrastructure analysis, backscatter | PWS, ATON, SAR, LMR, DR, IO, MEP |
| | Water-column acoustics (i.e., EK80) | No | Navigation, data infrastructure | Scattering layers, thermohaline structure, subsurface object detection (e.g., mooring balls, mines) support of fisheries and international agreement obligations | PWS, ATON, SAR, LMR, DR, IO, MEP |
| | Water column velocity | No | Navigation, data infrastructure | Understanding sound propagation, submarine detection, ship navigation | PWS, ATON, SAR, LMR, DR, IO, MEP |
| | Reference hydrophones | No | Navigation, data infrastructure | Ship generated noise signature | PWS, ATON, SAR, LMR, DR, IO, MEP |
| | Modern sub-bottom profiling | No | Navigation, data, sound speed profiles (from CTD and flow-through) | Mineral/resource identification, subsurface obs, detecting buried objects, geohazards, infrastructure analysis, sediment classification | PWS, ATON, SAR, LMR, DR, IO, MEP |
| | Ultrashort baseline (USBL) | No | Navigation, seavalue/gatevalue and power to retract above hull when not in use | Navigating mid-water assets for SAR, hazards to navigation, pollution and contaminants, infrastructure, minerals and other extraction, methane detection | SAR, ATON, DR, MEP, LMR, IO |

ATON = Aids to Navigation. DI = Drug Interdiction. DR = Defense Readiness. IO = Ice Operations. LMR = Living Marine Resources. MEP = Marine Environmental Protection. MLE = Other Law Enforcement. MI = Migrant Interdiction. MS = Marine Safety. PWS = Port, Waterways, and Coastal Security. SAR = Search and Rescue.

Table continued on next page...

TABLE 6, continued. Research capabilities/science measurements required to accomplish future Arctic research, potential for that research to be accommodated with modular equipment on a science enabled ship, required supporting systems or science-enabling capabilities of the ship, and national security needs and USCG statutory missions (see key at bottom) to which the science measurements can contribute.

| Science Measurements | Modular Potential | Required Supporting Systems | National Security Need | USCG Statutory Missions Supported |
|--|-------------------|---|---|-----------------------------------|
| Water column hydrography and other sensor measured characteristics (e.g., dissolved oxygen) and water sampling (CTD and rosette) | Maybe | Navigation, data infrastructure | Subsurface obs (water column), sound speed profiles | LMR, MEP |
| Meteorological data collection (sensors) | No | Navigation, data infrastructure, power, supporting infrastructure | Domain awareness, weather forecasting, situational awareness, real-time meteorological conditions, SAR, large scale weather forecasting, sea icing warnings | SAR, DR, IO, ATON, MEP |
| Seafloor sampling with grabs and small corers (including multicore and box core) | Yes | Winch, A-frame, ambient seawater for hoses, refrigerated van, dynamic positioning | Validation of multibeam/backscatter measurements, detection of pollutants/contaminants in seabed, support of fisheries, HABs detection | ATON, LMR, MEP |
| Mooring, buoy, ROV, AUV, drifter, gliders, floats, Saildrone, or other vehicle deployment and recovery | Yes | Navigation, crane, winch, space | Subsurface observations, seafloor acoustic sensors, submarine detection, acoustic moorings, infrastructure, under-ice navigation, contaminant monitoring, marine mammal detection | ATON, SAR, LMR, MS, MEP |
| Water column sampling other than with rosette (e.g., nets, pumps, cameras) | Yes | Winch, A-frame, ambient seawater for hoses, refrigerated van, dynamic positioning | Support of fisheries, detection of pollutants/contaminants, HAB detection, subsurface observations | LMR, MEP |
| Clean atmosphere sampling | Yes | Bow mast, navigation, data, space for instruments | Detection of pollution, detection of noble gas isotopes for nuclear weapon testing detection | LMR, MEP, |
| Deployment of personnel and equipment on ice | NA | Crane, gangplank/brow, small boat | SAR and presence, contaminants of sea ice | IO, SAR, MEP |
| UAS (drone) launch and recovery | Varies | Navigation, data infrastructure, satellite/internet connectivity | Ice conditions, surveillance outside of science, SAR, satellite validation | SAR, MEP, IO, MLE, PWS |
| Lander-style drilling capability | Yes | Crane, 30+ ton A-frame, portable winch, deck space and strength (heavy equipment), vessel stability | Mineral/resource identification, subsurface obs, sediment classification, methane fluxes (seafloor stability) | LMR, ATON |
| Large-scale coring | Yes | Crane, A-frame, winch, deck space, DP, rail length, refrigerated van | Seabed surface characterization, surveying for mineral resource mapping, contaminants for some coring applications | LMR, MEP |
| Gravimetry | Yes | Power, space location | Subsurface observations | ATON, DR |
| Cold/freezer storage | Yes | Power, space | Subsurface observations | LMR |
| Visual research observations from the bridge | NA | Space on bridge with window and small desk space for laptop | Enforcement of national and international laws and regulations; treaty obligations | SAR, MEP, MS, DR, IO, PWS |

ATON = Aids to Navigation. DI = Drug Interdiction. DR = Defense Readiness. IO = Ice Operations. LMR = Living Marine Resources. MEP = Marine Environmental Protection. MLE = Other Law Enforcement. MI = Migrant Interdiction. MS = Marine Safety. PWS = Port, Waterway, and Coastal Security. SAR = Search and Rescue.

SMALL BOAT CAPABILITIES

Small boat capabilities (Table 7) include both permanent installations, such as a heated cabin for personnel and permanently fixed instrumentation, as well as the infrastructure such as clean power or a small davit or winch to accommodate researcher-supplied equipment. The boat should be capable of working in Arctic icy conditions, for example, be constructed out of aluminum rather than fiberglass with a keel-cooled rather than

water-cooled engine (to avoid overheating following ice ingestion). Instrumentation such as a depth finder or multibeam capable of data export, AIS system, and hull-mounted acoustic Doppler current profiler (ADCP) would provide for robust research capability. A small amount of deck space to allow up to three people to work to recover autonomous profilers, small ROVs, drifters, or other sampling devices would greatly expand the utility of this vessel. The small boat should be easily deployed by a Miranda-type davit to facilitate frequent use.

TABLE 7. Science equipment and instrumentation needed for small boats that can be deployed from the large icebreaker.

| Equipment and Instrumentation | Related Research Goals | Modular Potential |
|---|---|-------------------|
| Hull-mounted multibeam system | Mapping, personnel | No |
| Hull-mounted ADCP | Mapping, sampling | No |
| Gyro stabilization | Mapping, personnel, sampling, deployments | No |
| Integrated nav/GPS system | Mapping, personnel, deployments | Yes |
| Small davit | Deployments | Yes |
| Small winch/capstan system | Deployments | Yes |
| Small met sensor | Sampling | Yes |
| Shelter/cabin for equipment and personnel | Mapping, personnel, sampling, deployments | No |
| Deck with space for 3 people to work | Sampling, deployments, recoveries | No |

12. SHIPS CATEGORIZED BY SCIENCE MISSION CAPABILITIES

In considering the science mission capabilities requirements, the AMRCC recognized that there could be multiple types of US federally flagged and owned icebreakers with varying intrinsic science mission capabilities. The AMRCC considered it important to identify how these multiple types of ships could conduct valuable science with different suites of capabilities. Therefore, the AMRCC identified six categories of ships with varying potential science capabilities:

1. Minimal science capability – a vessel with a primary mission other than science that could accommodate certain types of research. Capabilities could be enhanced with the installation of modular in situ equipment. Could be a smaller vessel.
2. Moderate science capability – a vessel with a primary mission other than science but that has greater capabilities or capacity to expand capabilities through modular in situ equipment.
3. Science capability consistent with that of USCGC *Healy* or of US UNOLS Global Class Vessels – a multi-mission vessel that has permanent science capabilities and can expand capabilities further through modular infrastructure.
4. Capabilities for USCGC *Storis* – as the vessel undergoes outfitting appropriate for a USCG cutter, there may be opportunities to incorporate infrastructure-dependent capabilities (e.g., strength support for an A-frame, networking, cable runs, hull-mounted sonars) that would support later incorporation of a broader range of science capability. The AMRCC recognized that: (a) the legislative charge is for USCGC *Storis* to be as science capable as USCGC *Healy*, and (b) that this transformation is likely to be a long-term process similar to USCGC *Healy*'s service life extension program.
5. Capabilities for the ASCs with the Davie Defense/Helsinki Shipyard Design (MPPS-100) that has the working deck aft and that may have moderate science capability achieved in part through modular equipment. Deployments would occur over the stern. It is not clear if there would be capability to deploy over the side, although Davie Defense advertises modular mission space as integral to the initial design.
6. Capabilities for the ASCs with the Seaspan-Aker MPI design that has the working deck near the bow and a helicopter deck over the stern and that may have moderate science capability achieved in part through modular equipment. Most deployments could occur over the side from the working deck.

Note that these categories are based only on science capabilities and are not considering icebreaking capability.

13. MAPPING SCIENCE MISSIONS ONTO SHIP CATEGORIES

The ability of different ships to support the SMs depends on the characteristics of the ship (e.g., hull design, deck space, overboard handling equipment, berthing and lab space, flight deck), the permanent science infrastructure (e.g., hull-mounted acoustic sensors, science network, science seawater that is uncontaminated by contact with ship plumbing), and, because many of the science requirements can be satisfied with modular equipment, the space to accommodate and the means to secure temporary equipment on the deck, to the superstructure, and inside the deck house. The use of modular equipment expands the possible suite of ships that can support science.

There is a large amount of uncertainty associated with this analysis. Much of the ASCs' science capability remains unidentified, minimal and moderate science capability ships are only loosely defined, with many relying on modularity to conduct science missions, and

the timeline and certainty of the USCGC *Storis* evolution to USCGC *Healy* science capabilities are unknown. However, all the SMs can be supported by at least one category of ships being considered (Table 8).

Six of the SMRs may not be able to be supported if USCGC *Healy* is decommissioned prior to deployment of suitable replacement platforms, depending on when (and if) USCGC *Storis* has USCGC *Healy*-equivalent science capabilities and on the science capabilities of the ASCs. Those missions include basin-scale survey (SM 2), winter ecosystem study (SM 5), geophysical missions (SMs 3,4), GO-SHIP (SM 8), and multi-ship, multidisciplinary, basin-wide studies (SM10). Limiting factors include science berthing capacity, deck space, over-boarding capability (e.g., locations of deployments, types of cranes and winches), and icebreaking capability, as well as potential limitations of permanent or modular science instrumentation and facilities.

TABLE 8. Science missions that can be accommodated on the six categories of ships based on their science capabilities. Note, icebreaking capability is not considered.

| Ship Science Capability | Mission Scenarios | | | | | | | | | | | | |
|------------------------------------|-------------------|-----|------------------|------------------|-----|----------------|----------------|---|----------------|------------------|-----|------------------|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Minimal | x | | | | | x | | | | | | | x |
| Moderate | x | | | x ^a | | x | x | x | x ^b | x ^a | | | x |
| <i>Healy</i> or UNOLS Global Class | x | x | x | x | x | x | x | x | x | x | x | x | x |
| USCGC <i>Storis</i> | x | (x) | (x) | (x) | (x) | x | x | x | (x) | (x) | (x) | x | x |
| Davie/Helsinki ASC (MPPS-100) | x | | x ^{a,d} | x ^{a,d} | | x | x | | x ^a | x ^{a,d} | x | x ^d | x |
| Seaspan/Aker ASC (MPI) | x ^c | | | | | x ^c | x ^c | | x ^a | | x | x ^{c,d} | x |

() Science capabilities should be phased in with time and more missions accommodated

^a If sufficient deck space and overboarding equipment

^b If equipped with stern A-frame and crane

^c If ice-free region can be maintained along side of ship

^d If science party complement is sufficient

14. INTERSECTION OF SCIENCE NEEDS WITH USCG STATUTORY MISSIONS

Arctic marine research capabilities defined by the polar science community and the USCG's 11 statutory missions complement each other with a suite of shared infrastructure requirements that may be met with the USCG fleet, including access to ice-covered regions, water column and seafloor sampling, acoustic measurements, meteorological data collection, deployment of airborne and in-ocean autonomous assets (e.g., AUVs, UASs), robust communication, and data acquisition capacity (Figure 1). The synergies between the scientific community's science missions and the Coast Guard's statutory missions allow the USCG to leverage an enormous academic, intellectual, and instrumental resource base provided by the universities, research institutions, and other federal agencies. For example, drone and UAV capabilities offer opportunity for synergistic R&D in technologies of shared interest between the USCG and the research community. More generally, a wide swath of environmental intelligence data collected from the vessel—interpreted, processed, and supported with input from subject matter experts—directly supports all statutory missions by enhancing domain awareness for navigation and other Coast Guard operations, as well as feeding back into weather and ice forecasts used by the vessel operators.

Some of these synergistic opportunities are paramount to addressing marine safety and national security. For example, the USCG weekly online publication "Notice to Mariners" includes aids to navigation information for Arctic waters. The USCG also contributes data to the National Weather Service Coastal Hazard Messages and Marine Forecasts for the Arctic Ocean. With changes in sea ice extent, and potential associated changes in extreme weather, the attention to hazards associated with, for example, sea state, ice dynamics, sea ice freeze onset,²⁴ and freezing sea spray, are of paramount importance. Also, support by multibeam and water column/water mass sampling, as well as ship-mounted meteorological devices and in situ trace

gas measurements, provide needed data for real-time awareness, yield short-term benefits for forecast accuracy, and enable long-term benefits for development of improved forecast models and environmental warnings. These data also contribute seasonal-scale information for strategic planning related to "defense readiness," "coastal security," "marine environmental protection," and "living marine resources" missions.

Consider a search and rescue (S&R) mission as a use case. In such a situation, scientific research seamlessly strengthens and complements the USCG capabilities. Forecast confidence is higher *a priori* because of data and research supported previously by the vessel. Drone and UAV operations provide situational awareness in real time and can assure the success of S&R activities, all while providing environmental awareness. Mounted sensors may be repurposed to detect atmospheric trace gases and provide imagery that offers important information for the USCG operation. And the USCG benefits from access to and relationships with subject matter experts on topics ranging from safe travel on sea ice and ice dynamics to impacts on living marine resources and oil spill response.

Crucially, the capabilities defined and sought after by the scientific research community better allow for the assessment of and provide quantitative evidence for defining territorial boundaries, because the Extended Continental Shelf (ECS) is defined by geologic features. Multibeam mapping sonars, seismic exploration, sediment coring, dredging, and drilling all are tools used to refine the understanding of offshore marine geology. A prime example is the mapping and dredging survey conducted by USCGC *Healy* to resolve the disputed maritime boundary between Canada and Denmark/Greenland. Without research-capable icebreakers, the United States would be unable to independently verify or refute claims of territorial sovereignty in the Arctic.

²⁴ <https://www.thebarentsobserver.com/arctic/two-icebreakers-are-on-the-way-to-rescue-icelocked-ships-on-northern-sea-route/107740>

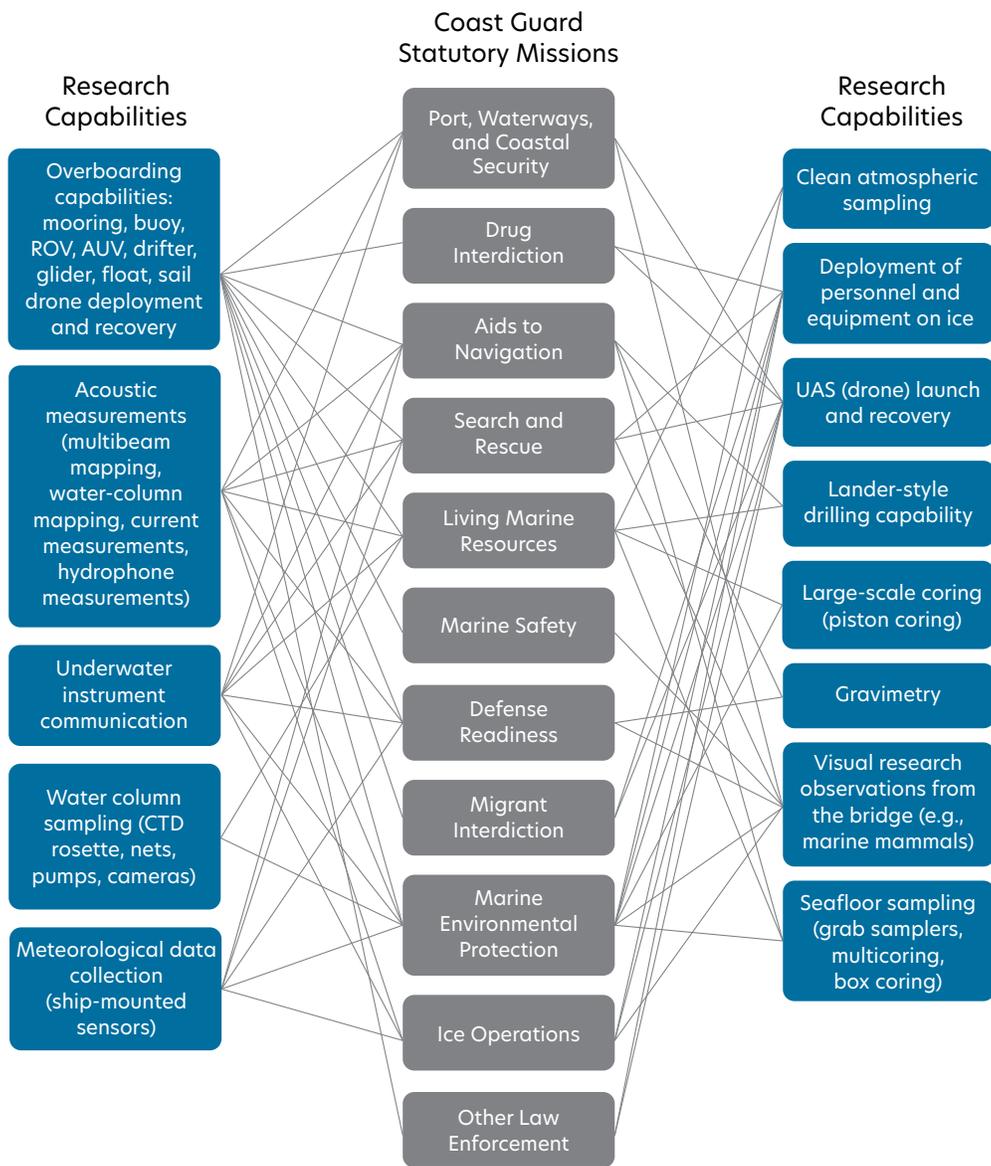


FIGURE 1. Contributions of Arctic icebreaker research capabilities to the USCG's 11 statutory missions.

APPENDIX 1. STATEMENT OF TASK

Arctic Marine Research Capabilities Committee

Statement of Task

Purpose: Review and refresh science missions and affiliated science mission requirements of future Federal icebreakers operating in the Arctic Ocean and other northern polar regions

Tasking:

Federal agencies, including the National Science Foundation (NSF), the Office of Naval Research (ONR), and the U.S. Arctic Research Commission (USARC) request that the UNOLS Chair and Council establish a *Special Purpose* Arctic Marine Research Capabilities Committee (AMRCC) to review and refresh the anticipated science missions (SMs) and affiliated science mission requirements (SMRs) for: (a) any commercially available polar icebreaker that may be acquired or procured and refit for operation by the Federal government; and (b) the conceptual design of future “medium”¹ or “heavy”² federal-flagged and owned icebreakers that will operate in the Arctic Ocean and other northern polar regions including, but not limited to, the approximate extent of the area described in the international [“Agreement on Enhancing International Arctic Scientific Cooperation.”](#)³

In so doing, the committee will consider, among other documents, the SMs and SMRs identified during a prior UNOLS Polar Research Vessel Study completed in 2011⁴, the 2017 report by the National Academies of Sciences, Engineering, and Medicine, *Acquisition and Operation of Polar Icebreakers: Fulfilling the Nation’s Needs*⁵, SMRs identified for the National Science Foundation’s Antarctic Research Vessel completed in 2022⁶, and UNOLS reports such as the SMRs documents published for Regional Class, and Global Class Research Vessels.

During this effort, the AMRCC may also consider the security or “dual use” aspects of data collection from shipboard observational systems. For example, bathymetry, backscatter, and water column structure are not only fundamental to addressing basic science questions, but also contain critical operational environmental information that may inform decisions on potential cable routes, detection of infrastructure, and other matters.

¹ According to the USCG, a “medium” icebreaker has the ability to break through 4.5 feet of ice at 3 knots, and can back and ram through at least eight feet of ice. See here:

<https://crsreports.congress.gov/product/pdf/RL/RL34391/250>

² The operational classification of “heavy” is defined by the USCG and the Office of Science and Technology Policy as vessels that have icebreaking capability of six feet of ice continuously at three knots, and can back and ram through at least 20 feet of ice. See here: <https://nap.nationalacademies.org/read/11525/chapter/5>

³ Arctic science cooperation agreement: <https://www.arctic.gov/science-agreement/>

⁴ https://www.unols.org/sites/default/files/PRV_SMR_FinalReport_Feb2012.pdf

⁵ <https://doi.org/10.17226/24834>

⁶ <https://future.usap.gov/ARV/ARV-Science-Mission-Requirements.pdf?348213888206>

The AMRCC will also consider the “lessons learned” from operation of the *R/V Sikuliaq* and how they may translate to the conceptual design of future Federal icebreakers. Similarly, innovations adopted in the designs and operations of other Arctic research vessels, such as, but not limited to *Polarstern II*, *Aaron*, *Oden*, and *Kronprinz Haakon* should be considered.

Through consultation with the research community, the committee will assess whether existing SMs and SMRs meet current and emerging needs for Arctic research on Federal icebreakers. The committee is also asked to identify any additional SMRs required to ensure that Federal icebreakers will meet the needs of the Arctic marine research community for the next 30 years, which is especially important given the pace of technological advancements in data collection and processing.

It is anticipated that a report from this activity will be transmitted to the federal agencies requesting this report in the second quarter of 2025.

Actions:

1. Create AMRCC
 - a. UNOLS - develop Charter from Council
 - i. Up to 12 people
 - ii. Chair – academic researcher
 - iii. 8-9 members from research vessel user community (international membership, disciplinary balance).
 - iv. 3-4 Technical / Operational Experts (naval architects, R/V operators, and R/V Technical Support personnel).
2. Nominations
 - a. Nominations to the AMRCC and for the AMRCC Chair will be solicited from the research community and other organizations with relevant expertise. Candidates will be asked to submit their vitae and letters of interest.
 - b. Applications for membership to the AMRCC and the AMRCC Chair will be reviewed by a AMRCC selection group that includes:
 - i. UNOLS Chair,
 - ii. UNOLS Immediate Past Chair,
 - iii. Fleet Improvement Committee Chair, and
 - iv. Arctic Icebreaker Coordinating Committee Chair.
 - c. The UNOLS Chair shall appoint AMRCC members and the Chair from the nominations put forward by the AMRCC selection group.
 - d. Members of the AMRCC will be appointed for the duration of the task that has an expected completion date of June 30, 2025.
 - e. UNOLS draft & release announcement soliciting nominations.

- f. UNOLS receive nominations & share with AMRCC Selection Group.
 - g. UNOLS host AMRCC Selection Group Virtual Meeting.
 - h. UNOLS Notify AMRCC selectees.
3. Meetings:
- a. The AMRCC will meet three times in addition to the AMRCC workshop. The meeting schedule is indicated below.
 - i. The first meeting will focus on reviewing existing icebreaker research vessel documents, developing science mission scenarios and draft SMRs, determining whether a community workshop would be beneficial and planning for it.
 - ii. The second and third meetings will be devoted to drafting and finalizing the SMR document.
 - iii. Meeting logistics and travel arrangements will be coordinated by the UNOLS Office.
4. Workshop (optional):
- a. One community workshop is a possibility, if determined to be appropriate by the AMRCC. If so, the workshop will present mission scenarios, review community input to the AMRCC SMR survey, and gather additional community feedback.
 - b. The workshop date is tentatively planned for the last quarter of CY 2024.
 - c. The UNOLS Office will coordinate all logistics and travel arrangements for such a Workshop.
5. Charge to the AMRCC
- a. Review SMRs identified in other documents, such as those in a UNOLS Polar Research Vessel Study,⁷ completed in 2011, and those identified for the NSF Antarctic Research Vessel⁸, completed in 2022.
 - b. Consult existing UNOLS reports such as the SMRs documents published for Regional Class⁹, and Global Class¹⁰ Research Vessels for guidance on the process and structure of this activity.
 - c. Develop an online survey to gather feedback from the Arctic marine research community on the anticipated SMs and the capabilities that will be required by future federal icebreakers operating in the Arctic to carry out these missions. The

⁷ https://www.unols.org/sites/default/files/PRV_SMR_FinalReport_Feb2012.pdf

⁸ <https://future.usap.gov/ARV/ARV-Science-Mission-Requirements.pdf?348213888206>

⁹ https://www.unols.org/sites/default/files/rcsmr_version1_0.pdf

¹⁰ https://www.unols.org/sites/default/files/Global_Class_SMR_March_2022.pdf

UNOLS Office will assist by publishing the survey online and compiling responses that are submitted.

- d. Plan and hold a community workshop (optional) to discuss mission scenarios, review community input to the AMRCC SMR survey, and gather additional community feedback.
- e. Through consultation with the research community, the AMRCC will:
 - i. Assess whether the existing icebreaker SMRs meet current and emerging needs for polar research.
 - ii. Identify any additional SMRs required to ensure that the future federal icebreakers operating in the Arctic will meet the needs of the polar marine research community for the next 30 years.
- f. Prepare a report to the federal agencies affiliated with UNOLS that shows a clear connection between critical science questions and the SMRs identified. The format of the final report should be consistent with available UNOLS SMRs documents for Regional and Global Class vessels.
- g. Transmit the final report to the UNOLS Office in early June 30, 2025.
- h. The timeline for the actions discussed above is as follows:

| Date | Activity |
|-------------|--|
| 4/1/2024 | Post Call for Nominations |
| 4/28/2024 | Deadline for Submitting Nominations |
| May 2024 | AMRCC Selection Group finalizes membership and appoint Chair |
| June 2024 | Finalize online survey |
| June 2024 | Open online survey for public comment |
| June 2024 | Committee Meeting 1 |
| | Plan Activity |
| | Plan Workshop |
| | Review icebreaker documents |
| | Develop mission scenarios with input from AICC and others |
| | Strawman Science Mission Requirements |
| | Identify areas requiring additional information |
| Late May | Invite workshop participants |
| July 2024 | Close online survey |
| Oct/Nov | Workshop |
| | Present use case scenarios and online survey results |
| | Gather additional input |
| Jan 2025 | Committee Meeting 2 |
| | Draft Science Mission Requirements |
| March 2025 | Committee Meeting 3 |
| | Finalize Science Mission Requirements |
| April 2025 | Post Science Mission Requirements for public comment |
| May 2025 | Close public comments |
| 6/30/25 | Submit Final Science Mission Requirements to UNOLS |

APPENDIX 2. COMMUNITY SURVEY QUESTIONS

UNOLS Arctic Marine Research Capabilities Committee (AMRCC) Community Survey

Federal agencies are working to acquire future icebreaking capability to support U.S. priorities and missions in the Arctic. The scientific community has been offered the opportunity to provide input to the federal agencies that may influence the capabilities to be incorporated into any future icebreakers to enable support for Arctic science for the next 30+ years.

The AMRCC was established with support from the federal funding agencies to develop Science Missions and Science Mission Requirements to provide guidance to U.S. federal agencies regarding icebreaker support for Arctic marine research. The Statement of Task for the AMRCC and other related information can be found [here](#).

To collect input from the community, we are circulating this survey broadly to request your thoughts and ideas on *future* U.S. icebreakers that, as one of their missions, would carry out Arctic marine and interdisciplinary science support. We will share the survey results with the community shortly after the survey is completed through community meetings and email communication. We anticipate there will be additional opportunities for the community to provide input via these means. **Please complete and submit your survey responses by Friday, 7 February 2024.**

As a community member in polar marine and interdisciplinary sciences, or a person who uses US ships to support other science in Arctic regions, please respond from the standpoint of your own field of research from these two perspectives as you complete the survey:

- a) Have the **current** US ships operating in the Arctic regions met the needs of your research objectives? If not, what additional capability or capacity is desirable in the near term?

- b) How do you expect **future** research priorities and infrastructure requirements for your work to change over a 10 to 30-year timeframe? Are the current specifications and capabilities of the U.S. Arctic-operating ships sufficient for these needs? If not, what additional capability or capacity is desirable? Have you seen or know of advanced capabilities that other countries are planning, have operational today that you deem suitable for the U.S. Arctic vessels?

The second perspective is necessarily speculative, but critical for the evaluation of future fleet capacity and capability. Please consider how *evolving research priorities* and how *emerging measurement systems and technology* will create new research opportunities and shape future demand for icebreaker infrastructure in your field.

For this purpose, we ask you to describe your ideal science mission requiring icebreaker support. This will help the AMRCC to identify community-desired scenarios for future science missions requiring Arctic icebreaker support.

The results of this survey will be used by the UNOLS Arctic Marine Research Capabilities Committee (AMRCC) to develop the recommendations. Please complete as much of the survey as is practicable for you. Response to all questions is not required for submitting your response to the survey. However, the more questions you can reply to - the more helpful your feedback will be to the AMRCC.

Please complete and submit your survey responses by Friday, 7 February 2024.

We strongly encourage you to complete this whole form, but you can choose to complete your desired sections. Please select a section to jump to.

Mark only one oval.

A) Your Future Arctic Research > *Skip to question 3*

B) Scientific Support, Facilities and Infrastructure > *Skip to question 8*

C) Important Scientific Questions Driving Research into the Next 50 Years > *Skip to question 58*

D) Your Current Arctic Research > *Skip to question 62*

A) Your Future Arctic Research Section

The following questions are centered on your planned future research and will provide the AMRCC with a broader understanding of your future research needs.

1. Please select the broad geographical region/s of the Arctic where you would like to focus your future research. (If "Other", please specify.)

Check all that apply.

- Bering Sea
- Chukchi Sea
- Chukchi Borderland
- Beaufort Sea
- Canadian Arctic Archipelago
- Baffin Bay
- Greenland
- Svalbard
- Barents Sea
- Nordic Seas
- Russian Shelf Seas and Slopes
- Central Arctic Ocean
- Coastal [within 200 mi from coastline]
- Shelf
- Basins
- Other:

2. Will your future Arctic research require icebreaking ships? *

Mark only one oval.

Yes No

If yes, briefly describe your intended use of icebreakers in the Arctic.

3. What gaps do you see in our ability to conduct important Arctic science once *Healy* retires?

4. Describe your ideal science mission requiring icebreaker support.

B) Scientific Support, Facilities and Infrastructure

The following questions focus on your scientific support, facilities and infrastructure needs for your current and future research. Some questions use USCGC *Healy* as a point of reference.

5. The current non-crew berthing capacity of the *Healy* is 35, with surge capacity up to 51 (includes science support technicians).

a) To date, is this range in berthing capacity sufficient for your work?

Mark only one oval.

Yes No

b) Will this range in berthing capacity be sufficient in the future?

Mark only one oval.

Yes No

c) What science berthing capacity (including science support technicians) would be sufficient in the future?

6. What top 5 scientific capabilities would you like on a future arctic research vessel to support your science?
(Please prioritize from 1 to 5 with 1 being the most important.)

- Over the side handling (cranes, winches, A-frame(s), LARS)
- Lab space
- Deck space
- In-hull acoustic sensors (e.g. multibeam, sub bottom profiler, ADCP)
- Science seawater system(s)
- Meteorological systems
- Flight deck for aerial systems / helicopters
- Real time data presence
- Small boats
- Science & other vans
- Moonpool
- User supplied overboarding systems / portable equipment
- Interior science cargo storage
- Refrigerated, freezer & hazmat storage
- Climate Controlled Lab Space
- Mission hangar on Main Deck
- Marine Mammal / Bird Observing

Type in additional categories that were not captured in our list.

7. Please review these particular core capabilities for incorporation into a new polar research vessel, listed below.
Rate the importance of each for your research on a scale of 1-3.

- Acoustically quiet ship with minimal underwater-radiated noise
- Habitability
- Geotechnical drilling
- Moon pool operations
- Helicopter operations
- Seismic capability
- Cargo capacity and accessibility
- Bandwidth, connectivity for science
- Deck space
- Laboratory capacity (including temperature-controlled spaces and storage)

8. Is the available laboratory space, deck area and science storage space on the *Healy* sufficient for your work now?

Mark only one oval.

Yes No

b.) In the future?

Mark only one oval.

Yes No

c.) Please describe how laboratory space could be improved and what capabilities would be gained by improvements.

9. Is the suite of scientific support instrumentation on the *Healy* sufficient for your current and/or future work (e.g. acoustical profiling & mapping systems, meteorological instruments, underway seawater measurements, CTD or other lowered instrument packages, sample collection and storage facilities, etc.)?

a.) Current work?

Mark only one oval.

Yes No

b) Future work?

Mark only one oval.

Yes No

c.) Please describe how this could be improved and what capabilities would be gained from improvements.

10. Are the network and other technical systems on the *Healy* sufficient for your work now and in the future (e.g. intra-net connectivity on the ship, internet connectivity and bandwidth to external sites, satellite communications, mapping and GIS capabilities, desk space and support for personal workstations, navigation systems, time servers, clean power, etc.)?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe how this could be improved and what capabilities would be gained from improvements.

11. Are the winch, A-frame, crane and small-boat operations capabilities of the *Healy* sufficient for your work now and in the future?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe how this could be improved and what capabilities would be gained from improvements.

12. Are the general handling characteristics of the *Healy* with respect to dynamic positioning for over-the-side operations and stability in heavy seas and/or sea ice sufficient for your work now and in the future? [y/n; choose one option]:

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe how this could be improved and what capabilities would be gained from improvements.

13.) Are the in-ice operation capabilities of the *Healy* sufficient for your science now and in the future?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe how this could be improved and what capabilities would be gained from improvements.

14. Does your research require helicopter support?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for helicopter support.

15. Does your research require small boat support?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for small boat support.

16. Does your research require support from other airborne assets? (e.g., AAVs or Drones)

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for support for airborne assets.

17. Does your research require support from in-water autonomous assets (AUVs, ROVs)?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for support for in-water autonomous assets.

18. Does your research require towing gear through the ice pack or elsewhere in the Arctic Ocean?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for support for towing gear.

19. Does your research involve data presence that requires high bandwidth communications, including but not limited to conducting research remotely using high bandwidth communications?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for support for high bandwidth communications.

20. Does your research require support which minimizes science impacts from light, noise, and other aspects of operating an icebreaker?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe your requirements for support related to minimizing light, noise, and other impacts associated with operating an icebreaker.

21. Are there ways in which a new U.S. icebreaker could better facilitate research by and/or in service to indigenous communities?

a.) Current work?

Mark only one oval.

Yes No

b.) Future work?

Mark only one oval.

Yes No

c.) Please describe what type of ship capabilities could better facilitate research by and/or in service to indigenous communities.

22. What additional capacity or capability do you feel is lacking in the existing vessels that may be required in the future to meet future scientific objectives in your field?

23. How do you envision projected climate/weather shifts over the next 30+ years affecting your science support needs from icebreakers?

C) Important Scientific Questions Driving Research into the Next 50 Years

24. What are the major scientific challenges faced by your research and how are these related to the science mission requirements for icebreakers operating in the Arctic regions?

25. Please list the primary Arctic-related scientific challenges you foresee needing to be addressed in the coming years.

26. Please list research questions you foresee needing to be addressed in the coming years.

27. How do you see Arctic research contributing to national and international interests in the future?

D) Your Current Arctic Research

The following questions are centered on your current research and experience in the Arctic regions and will provide the AMRCC with a broader understanding of your current research needs.

28. How many years of experience do you have in your field of science since your last degree?

(If you choose Other, please specify.)

Mark only one oval.

- Current student
- 0-5 years
- 6-15 years
- 16+ years
- Other:

29. What is your highest degree earned?

Mark only one oval.

- N/A
- High School
- Bachelor
- Masters
- Doctorate
- Other Training

If you chose Other Training, please specify.

30. What is your job category?

(If you choose Other, please specify.)

Mark only one oval.

- Student
- Post-doctorate researcher
- Scientist (project leader)
- Technician
- Other:

31. Please identify your field of study, if not captured in the selection boxes, please provide a short description.

(If you choose Other, please specify.)

Mark only one oval.

- Marine Ecosystem Science
- Chemical Oceanography
- Geological Oceanography
- Atmospheric Sciences
- Sea-ice System Science
- Indigenous Knowledge
- Other:

32. Are you a US-based researcher?

Mark only one oval.

- Yes No

If No, where are you based?

33. Does your work involve:

(If you choose Other, please specify.)

Check all that apply.

- Field-going operations
- Laboratory-based field-going science
- Data from field operations
- No field work necessary
- Other:

34. Do you currently or plan to conduct ship-based oceanographic research in the Arctic?

Select one or more from:

Check all that apply.

- I have conducted ship-based oceanographic research in the Arctic
- I plan to conduct ship-based oceanographic research in the Arctic
- Neither description works for me

If you chose "Neither", please specify.

35. Do you plan to conduct ship-based oceanographic research in the Arctic in the future?

(If you choose Other, please specify.)

Mark only one oval.

- Yes
- No
- Other:

36. Please select the broad geographical region/s of the Arctic *
where your research has been focused.

(If you chose Other, please specify.)

Check all that apply.

- Bering Sea
- Chukchi Sea
- Chukchi Borderland
- Beaufort Sea
- Canadian Arctic Archipelago
- Baffin Bay
- Greenland
- Svalbard
- Barents Sea
- Nordic Seas
- Russian Shelf Seas and Slopes
- Central Arctic Ocean
- Coastal [within 200 mi from coastline]
- Shelf
- Basins
- Other:

37. In what season/s do you (or would you) prefer to primarily focus your research?

a.) I currently conduct field work in: (Select one or more)

Check all that apply.

Spring (Mar - Jun) Summer (Jun-Sept) Fall (Sept-Dec) Winter (Dec -Mar)

b.) I'd like to conduct field work in: (Select one or more)

Check all that apply.

Spring (Mar - Jun) Summer (Jun-Sept) Fall (Sept-Dec) Winter (Dec -Mar)

c.) Is the season you currently conduct field work in limited by ship capacity?

38. Briefly describe how you have used ships to support your Arctic research.

Thank you for completing this survey, your input will be extremely valuable in planning the future of icebreaker support for the U.S. Arctic marine sciences.

APPENDIX 3. COMMUNITY SURVEY RESULTS

Note: Answers likely depend on field or approach of respondent's research.

1. Broad geographical region/s of the Arctic where past research has been focused.

Most respondents have worked in the Pacific Arctic Region, the Central Arctic Ocean and basins, in coastal regions, near Greenland, and in shelf regions. Fewer have worked in the Atlantic Arctic, Nordic Seas, and Russian Seas and Slopes.

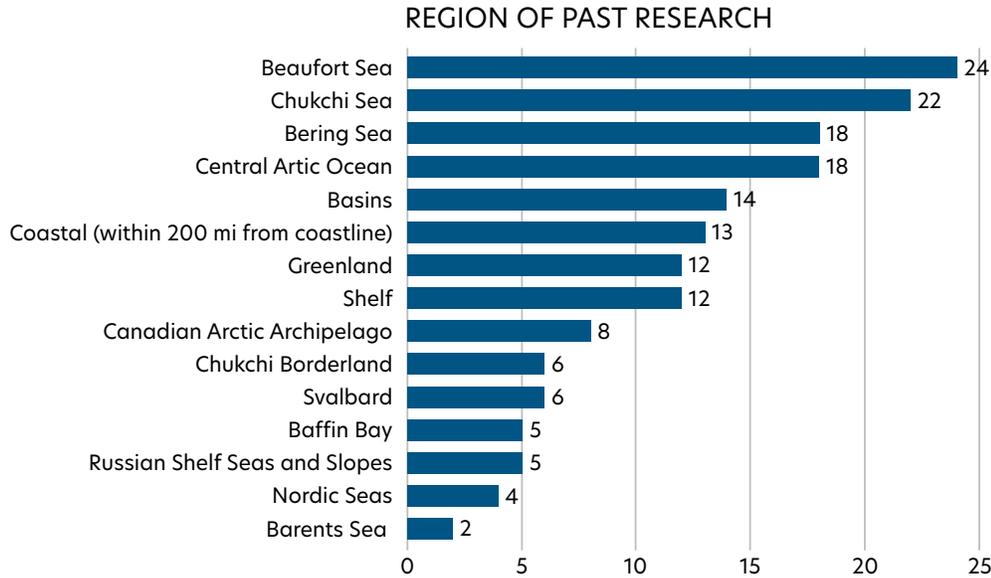


FIGURE A3-1. Number of responses for each Arctic geographic region.

2. Requirement for icebreaking ships for future research.

All respondents (31) replied that yes, their future research would require the use of icebreaking ships.

There was strong interest in using icebreakers to access challenging locations, including expanded use in shoulder seasons (spring and fall) as well as mid-winter. For example, researchers wish to access the North Pole more regularly, maintain year-round operations in the Arctic, access central basins for deep submergence work, and access shallow coastal areas, which present their own unique access challenges.

Several key areas of research were identified. Mapping and marine geology ranked highly, including efforts to map unexplored regions (using a multibeam echosounder), conduct sediment coring and lander drilling operations (including at depths >1,000 m), survey for mineral deposits, study mid-ocean ridge evolution, and study glacial outlets. This interest extended onto land as well (e.g., using helicopters to access remote uplifted marine sedimentary deposits). In terms of physical oceanography, there was interest in CTD profiling, mooring deployment and retrieval, glider and drifter deployment, and deployment of thermometry moorings under the ice. Specific scientific interests included topics such as studying the connection between the Beaufort Gyre and Atlantic Ocean circulation. Atmosphere and coupled atmosphere-ice measurements were also included (including vertical profiles of atmospheric properties). In the biology sphere, there was interest in studying pelagic communities (including in zones of ice and ice melt), collecting water-column biogeochemical data, and conducting ecological and biologic studies from sea ice. One respondent highlighted a need to conduct fisheries stock assessments. Several respondents emphasized certain technological needs, including the ability to deploy/service/recover moorings, deploy UAVs (drones), deploy ice stations (including meteorological stations), deploy drifting platforms, and deploy autonomous (and semi-autonomous) vehicles to extend sampling ranges. One respondent highlighted the interdisciplinary nature of such work, which strengthens national research interests.

SPECIFIC COMMENTS BROKEN DOWN BY CATEGORY

TYPE OF ACCESS/LOCATIONS

- Access to ice-infested waters, particularly in the shoulder seasons and even in the dead of winter
- Reach areas of the Arctic traditionally covered by ice (central basins and shelf and slope regions) in order to collect water chemistry samples and to deploy/recover moorings
- Hydrography in and around pack ice
- Reach difficult-to-access coastal regions, deltas, and estuaries
- Deploy instrumentation away from coastlines to obtain measurements in the central Arctic; serve as an operations base for such measurement activities
- Ice breaking in central Arctic and ice-hardened capability in Bering Sea and Greenland
- Access to the Arctic Ocean during summer and fall seasons; ideally would be able to access in spring as well, but US icebreaking capacity cannot do this
- Sample areas covered by ice
- For central Arctic Ocean work in the summer, we currently need icebreaking ships, and that is expected for the near future. As summer conditions require less strong ice-breaking requirements, fully capable icebreakers will be required for a presence in the Arctic year-round or even just in the shoulder seasons
- To breakthrough ice in order to do seasonal operations that are not just in summer
- Going to areas that have historically been ice covered, including the North Pole
- Oceanographic sampling
- US/USCG polar icebreakers must support a broad range of US national interests in a future Arctic Ocean. Future US icebreakers are required to support three research functions: hydrography/charting in remote Arctic waters (with installed multibeam sonars); environmental observations (critical oceanographic and atmospheric observations) for climate change research and national security concerns; and interdisciplinary science and engineering

MAPPING AND GEOLOGY

- Geophysical mapping and sediment coring
- Looking for mineral deposits
- Mapping unmapped regions, looking at melting processes of Greenland ice cap, looking at evolution of Alpha-Mendelev Ridge, examining anomalous seafloor features
- Access to Nares Strait, Lincoln Sea, North Greenland, and Canada fjords and offshore, sediment coring and lander drilling, multibeam mapping, helicopter access to land for uplifted marine sediments
- Sediment coring/lander drilling in the Arctic basins (below 1,000 m water depth)

PHYSICAL OCEANOGRAPHY AND RELATED

- Physical oceanography including CTDs, mooring deployment and retrieval, glider and drifter deployment
- Monitoring the strength of the Beaufort Gyre and its changing water mass properties; identifying linkages between Beaufort Gyre freshwater and Atlantic circulation
- Deploy acoustic thermometry moorings in the Arctic

MOORINGS, AUVs, GLIDERS, ETC.

- Support of annual turn-arounds of oceanographic moorings and multidisciplinary surveys and process studies
- Deployments of opportunity for drifting platforms (ITPs)
- In situ process observations using deployment of autonomous systems (buoys, moorings, UAVs), in situ observations (met stations and ice stations), focusing both on shelf and central basin
- Mooring operations; deployments and recoveries of AUVs

ATMOSPHERE

- As a platform for as-long-as-possible observations of the atmosphere, especially vertically
- Transportation to specific sites in the sea ice, operation of equipment for observing the atmosphere and sea ice

BIOLOGY, BIOGEOCHEMISTRY, ECOLOGY

- Get into areas of the Arctic early in the season where there is still ice cover; study ice-associated processes and the influence on ice and ice melt to the pelagic community
- Access to ice-edge and iced-over regions in the locations mentioned above to collect hydrographic/biogeochemical data and samples from ice/water column/sediments during different seasons
- Access beyond the shallow shelves and into basins, and more importantly, into the CAO will continue to require dedicated icebreakers for research. Deployments of (semi) autonomous instrumentation to these regions for higher-frequency, longer-term data collection require getting equipment and personnel into the field. More critically, many ecological and biological measurements require sea ice occupation for longer periods to conduct process studies, and these activities requires having ship-based platforms available for such work.

FISHERIES

- Gain a comprehensive stock assessment of required fisheries

3. Gaps in our ability to conduct important Arctic science once *Healy* retires.

The main comments center around:

ACCESS TO THE FULL AND ENTIRE ARCTIC BASIN

- Sampling the deep ocean
- Sampling in thick ice regions
- Ship-time availability

OBSERVATIONAL LOSSES

- Mapping and environmental awareness
- Continuation of time series: for example, water masses, and biological, atmospheric, sea ice conditions
- Development of innovations for Arctic research and observations

4. Describe your ideal science mission requiring icebreaker support.

- First-year ice, marginal ice zone studies, multi-year ice
- Central Arctic
- Multi-mission support, interdisciplinary science
- ROVs, autonomous instrument deployment
- Winter observations!! Shoulder seasons
- (Fast) Small boat deployments for nearshore surveys
- Multibeam, coring, lander drill deployment (requires capable A-frame)
- Two-month deployments (three months?)
- Lagrangian tracking + coupling to surface ice deployments (MOSAIC-like)
- Capabilities: Sufficient lab space, over-the-side handling, storage, underway sampling
- Ice stations
- Paired concurrent studies (basin + shelf) on two vessels
- Mooring deployments in ice

5. Healy's current non-crew berthing capacity is 35, with surge capacity up to 51 (includes science support technicians). Is this range sufficient at present, will it be in the future, and if not, what would be sufficient?

The community survey received 27 substantive responses to the question concerning berthing capacity for embarked scientists and technicians. These responses ranged from 10 to 80, with an average of 39 and standard deviation of 17. Excluding outliers, 70% of the responses were between 25 and 50. The single most common response was "the same as *Healy*," which pulled the average up toward the 50-berth capacity. Of the respondents who provided reasoned justification for the number, the general sense was that smaller science parties were more conducive for quality of science. Respondents noted a requirement for up to five berths for non-science members of the science party to include educators, community members, journalists, and other outreach. A common theme of the responses was that a larger fleet of icebreakers would decrease the total number of berths required on any individual platform as the demand for science could be distributed across the fleet. As the United States considers the science requirements for new icebreakers, this committee recommends a minimum threshold of 25 berths for scientists, technicians, and other non-mission personnel. The committee views *Healy's* 50 science berths as an objective requirement for future platforms. This upper number could potentially include mission-support personnel such as aircrew, divers, or UAS operators.

6. Top scientific capabilities desired on a future Arctic research vessel to support science, ranked highest to lowest.

The most desired scientific capability was over-the-side (OTS) handling equipment. However, many capabilities were thought desirable. The least desirable capabilities were a moon pool and a flight deck.

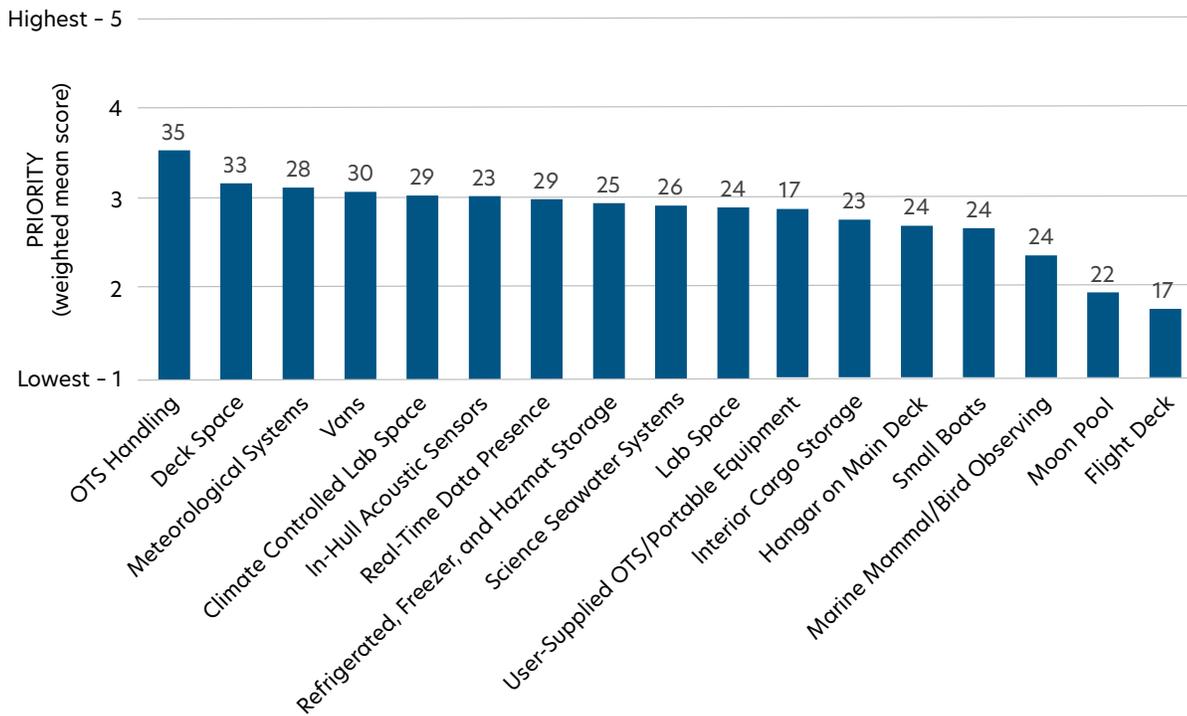


FIGURE A3-2. Priority of scientific capabilities desired, with "5" indicating highest priority and "1" indicating lowest priority. For each capability, the height of the bar shows the weighted mean score, and the number above the bar shows the number of responses for that capability. Capability ordered in descending order of priority (left to right).

7. Importance of core capabilities for incorporation into a new polar research vessel.

Deck space, laboratory capacity, network/internet bandwidth, cargo capacity and accessibility, and habitability were thought the most important core capabilities. Of lower importance were helicopter, moon pool, geotechnical drilling, and seismic operations. An acoustically quiet ship was of mid-importance.

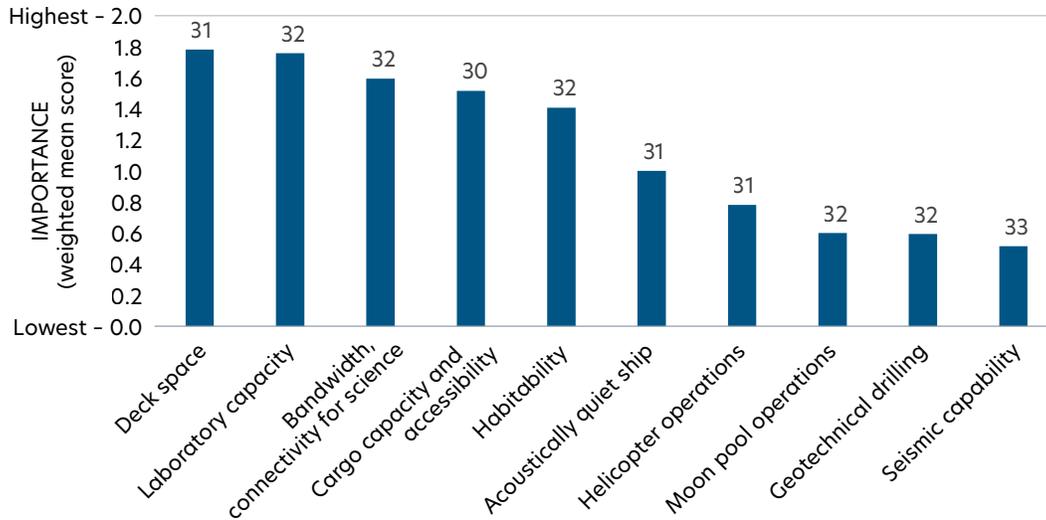


FIGURE A3-3. Importance of some core capabilities for incorporation into a new polar research vessel rated on a scale of 3 (critical) to 1 (not necessary). For each capability, the height of the bar shows the weighted mean score, and the number above the bar shows the number of responses for that capability. Not all respondents scored each capability.

8a,b to 13a,b. Are the facilities or capabilities on *Healy* sufficient for your work now and in the future?

Healy facilities or capabilities were deemed sufficient for respondents' present work (over-the-side equipment and small boats were thought the least useful). However, all facilities/capabilities on *Healy* were thought insufficient for future work.

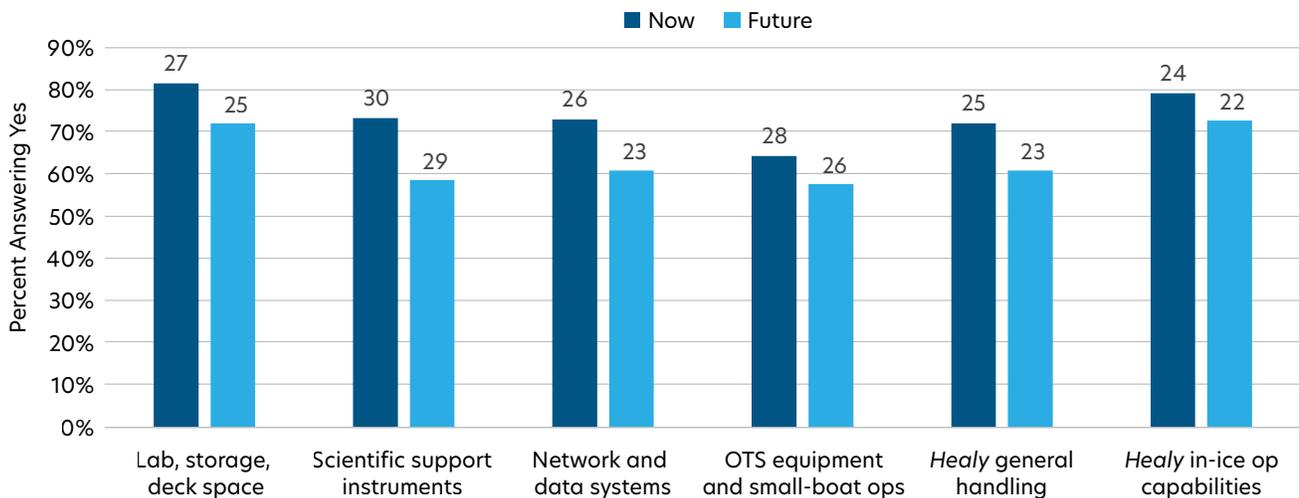


FIGURE A3-4. Percentage of responses agreeing that *Healy* facilities/capabilities are sufficient now and in the future. Total number of responses (yes and no) noted above each bar.

8c to 13c. Describe how the facilities or capabilities on *Healy* could be improved and what would be gained by improvements.

8c. LABORATORY, STORAGE, AND DECK SPACE

Overall, the community requests more lab and deck space, with intentional planning made for modular and configurable layouts. Better access between sampling stations, lab spaces, sample storage, and climate control chambers was highlighted. The main deck is small and becomes cramped with equipment especially during mooring missions, which impacts the available space for lab vans and winches often requiring sacrifices be made. Sheltered staging spaces on *Healy* are often cluttered and are challenging to use by all parties. Requests have been made for larger heated facilities to prepare heavy oceanographic equipment such as mooring and gliders, which are difficult to move from the main lab onto the aft deck.

- Bigger main lab
- Deck space is a bit tight for equipment-heavy operations. Easier access to a “wet lab” for staging large equipment (e.g., buoys, vehicles) would be useful.
- Allows number of scientists from different disciplines to set up their research station to conduct ship-based experiments and to have enough space to not be on top of others, which plays into morale; more science can be conducted with more space as additional equipment and people can be on board
- More deck space needed for coring / lander drilling options
- The spaces on the ship cannot be only accessed by high-angle hatchways. Safety alone requires that future ships have proper stairwell and not ladder-ways.
- Not enough space for wet chemistry. Have to rely on vans which are not ideal and often have insufficient space and capabilities.
- With a full complement (51), the science space on the *Healy* is not sufficient. However, with a partial complement, the lab space is generally sufficient, especially where vans can fill in any gaps. In the future, the need for more scientists/science team members will also necessitate an increase in laboratory space and/or modular laboratory options. In the case of modular laboratories—if a ship is well built to handle lab vans, the ship may be able to be more flexible in what services it offers to scientists. The vans have to be in a reasonably accessible location for science as well (e.g., not through a dozen water-tight doors and up a flights of stairs) because transporting seawater from the main deck to other decks can be a safety concern.
- Lab space needs to be designed at the same time as the ship, not added later during the build
- Cannot remember if this problem arises with *Healy* or not, but sometimes ability to get gear from a rear container to the bow of the ship or vice versa is needed. These details matter!
- It would be nice to have a more open laboratory space as with most modern vessels that allows for modular design of lab spaces to accommodate a range of missions. Access to clean science water and clean spaces and temperature control “Baltic rooms” are critical.
- It might be good to have more “wet bay” storage—not exposed to the elements, but easy access to the deck.
- Lab space could use better access to main deck for large packages (e.g., pallet jack). Large mooring packages, for example, could be fully prepped in the lab space and then wheeled onto deck at the appropriate time.
- Not really critical; a small electronics lab is all needed, for repairs.
- Improved verticality or compartmentalization
- Better comms between bridge and geophysical stations (mapping, etc.).
- Large open areas with tables for sediment core processing. Useful to have geophysical controls in the main lab so running instruments and core processing can occur simultaneously in the same space. Dedicated space and system for foul weather gear (mud room) so it isn’t tracked into the ship.
- Climate control in the hangers could be improved—this would allow for more water processing to occur in the hanger rather than having to route sampling into the wet lab. As it stands now, there is a risk of water freezing if it stays in the hanger. I realize there are heaters in there, but they are never working at capacity. An expansion of wet

- lab space would also be an improvement—there is currently a lot of bench space in the main lab but the wet lab is always in higher demand. Adding drains into the wet lab would also be useful—this would allow us to potentially drain water into a floor drain rather than into a sink, which would free up valuable real estate near the sink. Having a freezer on the main lab level would be helpful and reduce the risk of going up/down the stairs to the cargo hold.
- I think that the present lab space is sufficient

9c. SCIENCE SUPPORT INSTRUMENTATION

While many of the responses acknowledged *Healy's* capabilities are generally adequate there are many areas identified for improvement. The surface waters are difficult to sample due to the disturbed water column and depth of water intake for the science seawater flow through system. Remote sensing is powerful for long-term studies but requires in situ observations to calibrate remote observations, using the CTD, underway seawater sensors, and the addition of an eddy covariance flux tower to measure the gas exchange between the surface waters and atmosphere. Sensor requests include updating the multibeam, expanding the ADCP and fisheries sonars (e.g., EK80) as well as providing for additional sensors and cameras on the CTD. Sediment sampling remains an important capability to maintain, with requests for various solutions being available and supported such as mud grabs, kasten cores, gravity cores. Deeper coring and seafloor drilling will be a critical capability in the Arctic, utilizing jumbo piston cores, vibracores, and potentially lander drills. More workspaces are needed proximal to the laboratory sinks. Additional needs are for a true Launch and Recovery System (LARS) deployed an enclosed Baltic room, and a larger working deck to accommodate more oceanographic equipment such as moorings and winches. Current and future research requires immediate access to data and metadata, both onboard and remotely for expedited expert analysis utilizing a dedicated science network, high bandwidth internet, and data presence tools.

- A fish capable mission set
- The underway systems pull water in that is too deep. It does not pull near surface water. This is not only important for shallow surface work, but is also critical for all the validations being done for remote-sensing work. For validating satellite measurements in particular, the vessel mixes the water and produces garbage data sometimes that is so widely used by people in the remote sensing community and they are clueless about it.
- Could also use more small quick CTD capabilities
- Near surface ADCP measurements would also be great.
- Further improvements in hull-mounted sensors, attention to bubble sweep noise, support for ROV/AUV operations, more flexible helicopter support (see how done on Swedish icebreakers where helicopter work is much more flexible)
- Not sure *Healy* is a great ship to compare against for scientific needs. It's a highly specialized ship built on compromises between what the military wanted and what science needed.
- More storage facilities for samples that are easily accessible while underway
- I think the biggest improvement could be ensuring access to datasets that technical science teams maintain has a clear pathway for science teams to download, clearly outlined metadata, and clearly outlined quality control pipelines. This needs to be accessible during and post-cruise (i.e., ensuring the enough staffing for the science technical team).
- Access to geotechnical drilling capabilities would greatly expand *Healy's* functionality
- The support instrumentation is a moving target as technology changes. It is important to set up a flexible system that can be modified in the future. The Coast Guard is the least flexible organization I have ever worked with.
- A key capability in this category is the availability of satellite data to aid in finding suitable ice floes for on-ice deployment of instruments.
- Upgraded and state-of-the art instruments in CTD/surface underway systems is critical. State-of-the art coring—grab/multicore, kasten/gravity corer—equipment should be part of the ships capability to collect seabed sediments without needing to engage MARSSAMs coring facility.

- Additional operational meteorological equipment for routinely observing basic properties of clouds and the atmosphere above the vessel. This would yield much needed statistical information on cloudiness and atmospheric composition that serves as important context for any other measurement activities.
- Larger back deck (for mooring ops) would be nice
- The underway system and the CTD system would benefit from a larger suite of standard instruments. Put a SUNA onto the CTD and the waterwall. The CTD would benefit from options for various camera systems.
- Permanent remote sensing and eddy-covariance flux tower would make characterization of atmosphere and surface energy budgets possible. Single short periods are insufficient; need large ensembles of data.
- MET systems have been down for long periods
- Upgraded MBES, full suite of scientific (fisheries) sounders, better underway seawater system
- Newest instrument technologies with highest resolutions at the time
- Some storage or workspace near the underway system would be helpful to allow folks who are taking underway samples to have a place to store their equipment, datasheets, etc.
- Enhanced meteorological support instruments required; continuous water sampling required; advanced multi-team sonar critical
- There is strong need for a LARS CTD system like that on R/V *Sikuliaq*, with a large Baltic room. Three SADC systems would be great.
- Add higher frequency ADCP (e.g., WH300) that is better suited for the relatively shallow Chukchi Sea

10c. NETWORK AND DATA SYSTEMS

Most responses indicate the network on *Healy* can be improved upon, with stand-alone infrastructure and high-speed satellite internet dedicated to science users for internal and off ship data presence. High bandwidth will become increasingly necessary for real-time data analyses and processing. For mapping and geophysical surveys, the network must be able to support remote displays allowing the helmsman and scientists to monitor the data being collected to inform course adjustments. The computer lab should be larger and more available for science users. Separating servers from users would vastly improve the habitability of that space; future designs should include a dedicated climate-controlled server room physically isolated from the science and technician monitoring workstations.

- The science computer lab could be expanded somewhat. The fast internet from Starlink is a huge leg up.
- I have not been on *Healy* in 8 years so I do not know what their current capabilities are but many ships now have Starlink internet, which has allowed for stable and fast internet connectivity. It has also allowed for live video streaming to shore for outreach work.
- For survey/mapping work, consider putting scientific workstation on the bridge or adjacent to facilitate communications between scientists and helmsman. Put real-time bathymetry readout at helm station so that helmsman can steer ship to cover multibeam swaths. This setup on I/B *Oden* is extremely effective and efficient. In my recent experience, digital clocks for science operations and ship operations were not synched, making it hard to merge navigation files with science instrument operation files, so make sure all data flows can be synched precisely and accurately.
- Continuous, high speed internet is a standard now. I can do real-time data processing remotely from many UNOLS vessels, but this would not be possible for when *Healy* decides that the internet should be disabled. Again, military vessels are not science vessels.
- I enjoy the limited internet availability on the ships.
- The cruises I have participated on *Healy* have had poor connectivity, even while testing starlink capabilities. The ability to interface with onshore teams, and real or near realtime data processing would be some immediate capabilities gained.
- Arctic work suffers from a lack of satellite coverage, little can be done about that in ship design.
- A key capability in this category is the availability of satellite data to aid in finding suitable ice floes for on-ice deployment of instruments.

- A science-only internet system that is 100% disconnected from the ship's internet would allow greater flexibility for science and potentially avoid many security issues. If the ship needs to get science data, then those computers could have some secure system for pushing data over to the ship's internet.
- Possibility to transfer reasonably large amounts of data to shore would be a great advancement
- We've had issues before with networking from machine to machine on the ship's network.
- Will be more dependent on higher bandwidth comms—and real-time inputs
- Currently, the internet is not reliable (Starlink has been a huge improvement but it's not clear how good the connectivity will be on any given cruise) so it is difficult to plan for how much communication we can have with external sites. Improving the reliability/better communication of what internet speeds to expect would help with planning activities like outreach, exchange of data in real time, and troubleshooting with colleagues on land.
- The IT support on the ship could be improved in the future.
- Near-real-time data exchange with shore is possible now, but sometimes cumbersome.

11c. WINCH, A-FRAME, CRANE, AND SMALL-BOAT OPERATIONS

Numerous responses indicate the need to increase the load handling capacity on *Healy* to allow for the deployment of heavy equipment (30 tons) through the aft A-frame, and the addition of increased strength members to allow for higher tensions to support deep sediment coring and drilling operations. The cranes and winches have often been troublesome, indicating the need for more consistent off-season maintenance to ensure operational readiness. The expansion of small boat capabilities was also highlighted, allowing for extended surface and shallow water sampling away from the larger vessel. A future workboat should have significant range, room for scientists, a climate-controlled workspace, and be designed to support ADCP, fisheries, and mapping sonars as well as load handling equipment. This would provide a platform for scientist to better access waters currently restricted to *Healy*, as well as the ability to measure variables within the first 10 meters of the water column, which are often disturbed and contaminated by *Healy's* hull displacement and prop wash.

- Need 30-ton stern A-frame that folds down for maintenance, need dedicated CTD LARS
- Expanding small-boat operations helps us reach areas that are currently inaccessible.
- Quick, easy, and more capabilities of small boats are needed.
- 30-ton over-the-side lift capacity minimum
- Not sure it's possible to do hand-deployment/recovery on *Healy* given its freeboard. This is something I can and do on all other UNOLS vessels.
- The winch systems need to be updated to the most robust systems possible. In the future we may expect different deployments, weights, etc. The winch and cable systems need to be ready to handle heavier science gear and increased data transfer.
- An A-frame that can tow plankton nets behind the back of the boat would be ideal.
- Can the existing A-frame deploy an instrument like MEBO?
- Again, it is more of a problem with the way operations are handled than the equipment itself. The Coast Guard is a risk-averse organization that believes it knows everything about handling equipment (it does not).
- Cannot remember if this problem arises with *Healy* or not, but sometimes ability to get gear from a rear container to the bow of the ship or vice versa is needed. These details matter!
- Ensure the A-frame/crane systems are rated to highest capacity and have large enough dimensions to allow deployment/recovery of large equipment—e.g., moorings, towed vehicles, large coring equipment.
- Having a fast, light work board (e.g., 40' coastal vessel with A-frame) that could be deployed to work near the big ship could provide a huge up-scaling of the amount of science done on a cruise. It would require a dedicated captain/crew (2-3 people) and could ideally bring another 3-4 scientists on board. A small vessel like this could be deployed up to a few days at a time.
- Modest winching needs only when working on the ice
- Less reluctance to use (but this may vary from crew to crew)

- The trawl winch could only use 500 m of wire last time I was on *Healy*. They have never used the small boat to recover instruments, only to take science parties to shore. They need to be better able to use the small boat.
- Handling system to allow for longer sediment core collection—higher allowable pullout tensions
- More deck space to enhance safety and provide more areas for buoy, submersible, and large equipment deployment.
- Redundancy in the hydro winch would be awesome.
- The cranes on *Healy* are very large and have failed on a number of cruises I was on. They are sufficient, though sometimes “overkill,” when they are operational.

12c. GENERAL HANDLING CHARACTERISTICS OF HEALY WITH RESPECT TO DYNAMIC POSITIONING FOR OVER-THE-SIDE OPERATIONS AND STABILITY IN HEAVY SEAS AND/OR SEA ICE

Fourteen respondents commented on the desired handling characteristics of a new platform. The responses ran the gamut, from praising *Healy's* seakeeping abilities to complaining about the size of the ship and disruptions to the water column that introduce mixing to water. Responses called for both LARGER and SMALLER ships than *Healy*, citing the disruption to the water column and seakeeping ability as conflicting demands. One persistent concern was the amount of time required to establish station and transition from transit to deployment of sampling instruments. This can be addressed in two ways. First, include a dynamic positioning system with azimuthal thrusters and a sufficiently powered bow thruster. Second (and outside the scope of this committee) enact a training program that builds appropriate expertise on the bridge and on deck to proficiently and safely deploy gear over the side. This committee recommends dynamic positioning (DP) as a threshold requirement for new icebreaking platforms. DP is a standard capability of research vessels and increases the safety factor when deploying instruments and gear into the water.

- *Healy* is sufficient but could be better. She rides great in big seas.
- The boat is huge and mixes all the water that I want to measure. We need more smaller vessels.
- Not sure about current heavy-seas capability, but good dynamic positioning is essential
- Too much setup time between operations
- It's good as long as it actually works and is used.
- *Healy* currently takes about an hour to set up on station—this disturbs the water column. It also reduces the amount of science that can be conducted per cruise.
- A ship needs to be designed for research from the beginning, not as an add on later, this is the *Healy* problem
- Improved DP capabilities should be included in the new vessel using latest technology
- Training protocols and oversight that resulted in a 2022 loss of *Healy's* CTD clearly were insufficiently matched to the science operations and expectations. Safely deploying a CTD in 25- to 30-knot winds should not be outside the bounds of operational limits. I would like to see a design requirement for continued CTD operations in a full sea state associated with 35 kt winds.
- Don't need positioning
- Would like to see better DP
- It is difficult for them to hold position sometimes to deploy a full-depth CTD.
- Would the option of running CTD casts off the stern (rather than the side) allow for more casts to proceed in heavier seas? I don't know enough about deployment in high seas to know if that would help, but this might be something we could consider in the placement of the CTD rosette hanger on future ships.
- Latest, most advanced dynamic positioning system available for the first USCG PSC

13c. IN-ICE OPERATIONS

- Vessel with heavier icebreaking capability
- Thruster arrangement for better ice management while station keeping or towing
- Continuity with crewing and ice pilot experience to fully exploit the vessel's capabilities and better facilitate access
- Potentially allows for more work during shoulder seasons, wintertime, year-round access, etc.

14a,b to 20a,b. Does your research require support from helicopters, small boats, other airborne assets, in-water autonomous assets, towing gear, high bandwidth communications, or protection from light or noise impacts, now or in the future?

Almost all listed capabilities would be required more in the future than at present. This was particularly notable for the use of remotely operated equipment such as drones/UASs and AUVs/ROVs. Towing gear was also thought to be more important for future research. Only small boats were thought to be less important in the future than at present.

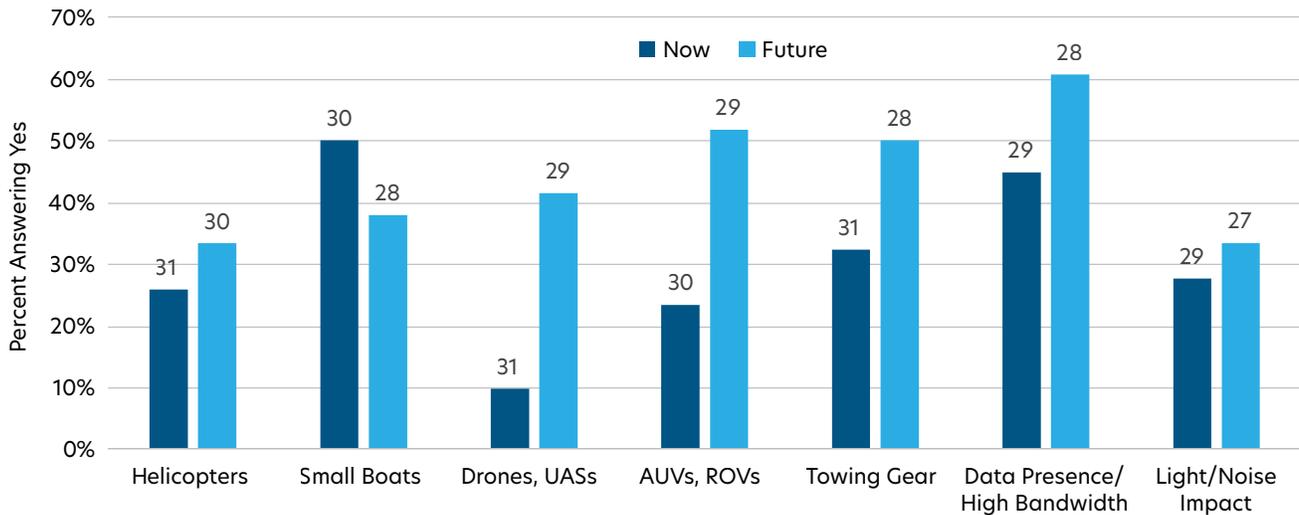


FIGURE A3-5. Percentage of responses that facilities/capabilities are sufficient now and in the future. Number of responses is noted above each bar.

14c to 20c. Describe your requirements for each.

14c. HELICOPTERS

Of 32 respondents, roughly one-third indicated that aviation support was required for their current or future studies. Twelve respondents indicated specific functions for aviation platforms. Some noted more than one requirement. The results can be summarized thus: roughly half (six of twelve) desired the ability to land the helicopter on ice floes away from the ship to deploy instruments or collect samples. Four respondents noted the need for logistical support: transportation of personnel or gear to/from shore-side locations. Three respondents expressed a desire for the helicopter to be outfitted with sampling instruments for atmospheric profiles and radiation properties. Three respondents suggested the utility of helicopter for ice reconnaissance.

From these data, the committee does not recommend a science-derived aviation platform requirement for new ice-breakers. Should agency requirements provide such a platform, this committee strongly recommends “skis” or other landing gear mechanism that will enable the aircraft to land safely on ice floes, potentially in some depth of powder snow. A well-established and documented process to approve instrumentation for installation on aircraft is desired.

- Not specifically, but if winter operations become more possible a helicopter would be useful to support remote equipment installations (away from the vessel) in thicker ice.
- Large lifting capability helicopters specifically support for a K-MAX
- Access to land for uplifted marine sediments and glacial features
- Helicopter support isn’t strictly needed but can be very useful. It helps with ice floe identification, and is also useful for getting things done efficiently (work on an ice floe while ship does something else).

- Access to remote/iced stations for sampling/deployment as a means to broaden range of scientists
- Transportation of people and equipment to remote sites away from the vessel. Sling loading of cargo. Operation of equipment for measuring atmospheric and radiation properties.
- Helicopters could provide some novel science sampling opportunities but in general mission's helicopter maintenance and crew wind up being more of a distraction to the core science from my experience.
- Ideally, instrument helicopters for atmospheric profiling
- Ice recon, instrument deployment
- Pack ice deployment of CTD
- Access to ice floes further away from the ship; aerial surveys of sea ice concentration
- I don't need a helicopter for the science I do, by ice reconnaissance would be awesome (like some foreign icebreakers have).

15c. SMALL BOATS

Roughly half of respondents indicated a current mission requirement for small boat support. Two-thirds anticipated a need for small boat support in the future. Small boat mission needs can be sorted into four categories. Most simply, three respondents indicated a requirement to transfer personnel to/from ice floes. This indicates a small boat that is capable of operating in icy waters with appropriate propulsion and hull design for contacting ice. It further requires operating parameters of 30°F water temperature and 0°F air temperature. Five more respondents described a need to deploy or recover instruments from the small boat. This might include subsea moorings or AUVs that are not easily deployed or recovered from the ship. Dynamic positioning and a recovery deck at/near the water line could mitigate this requirement. Seven respondents voiced a requirement to collect samples from the small boat that could not be collected from the ship (for two particular reasons: contamination, shallow water). These respondents also indicated a requirement to install sampling instruments on to the small boat. Finally, two respondents expressed a desire for an acoustic package on the small boat to include an acoustic Doppler current profiler and shallow water multibeam sonar to enable data collection in shallow water. In view of the previous requirement, it is conceivable that such acoustics systems could be modular and added and removed from the small boat, if such technology exists.

- Ease of deployment and recovery is critical to keep operations that require small boat efficient. Ability to install instruments on the small boat (e.g., small winch, cameras, etc.).
- Please get more small boats that can be quickly and easily deployed for operations. They also need to have plenty of deck space and it would be nice if they had operations to let them be operated independent from main vessel operations for a day or more. Berths not needed. ADCPs would be great.
- Access to shallow water, nearshore regions. Small boat should have multibeam, and small winch/wire with davit or light-duty A-frame for (for example) CTD operations, water sampling (can use discrete bottles rather than large rosette), or small grab or gravity coring to characterize seafloor
- Make over-the-side sampling of surface water possible.
- Potential need for doing on-ice sampling
- Small boat support to ice floes may be necessary—especially in late summer as ice continues to deteriorate.
- Trace metal work requires sampling away from the contaminating influence of the ship. Small boat operations are one way of doing this in open water, but in ice a more rational approach to exiting the ship on to the ice is needed.
- Small boat work in near shore and/or ice-edge regions is key to sample these areas. A system for small boat launch/recovery that incorporates new techniques and equipment should facilitate small boat ops and minimize disruption of other activities on the ship.
- Deployment and recovery of AUVs; sampling small-scale features
- Recovery of moorings using small boats can be very time efficient and provide the CG with useful training scenarios.
- Instrument deployment and recovery
- My work doesn't require a small boat. But a small boat operation could facilitate mooring recoveries because *Healy* seems to have limited ability to maneuver in high winds.

- Access to sea ice floes. Small instrument sampling, which cannot be done from the main vessel, proximal sampling to ice floes and ice floe edges.
- Small boat deployments may be necessary for collecting trace-metal clean water samples away from the ship.
- To help with mooring operations; to sample in near-shore waters

16c. OTHER AIRBORNE ASSETS

Capabilities to use drones and autonomous aerial vehicles (AAVs) were seen as very important for future research and 21st century polar operations. Respondents identified several logistic and research needs that could be fulfilled using such assets including aerial surveys (e.g., of ice, surface roughness, imaging, topographic mapping, marine mammal distributions) and for media production. In support of the use of drones/AAVs, adequate launch and recovery space with support systems including heated indoor laboratory/maintenance/storage/charging space, good communications (no interfering systems such as radio noise) and visibility are desirable.

- Drones for reconnaissance imaging coastal areas, sea ice, shelf ice would be very useful.
- Drones are becoming increasingly important for making aerial photography and doing spatial surveys of, for example, surface roughness.
- The ability to fly drones is likely to be important in the future, to increase the footprint of the ship-based sampling.
- Drone flights for aerial surveys and media production
- Launch/recovery space. Indoor lab space for working on systems. Good communications and visibility. Lack of interfering systems (radio noise). Charging and storage space.
- A good deck space with climate-controlled space nearby for pilot standby would be helpful.
- AAV mapping of the area is of interest for physics, marine mammal research and more
- Great area of advancement, still underutilized. There is a great need for detailed profiling and clouds and icing conditions is a big problem.
- Topographic and ice mapping
- Helo ops and capacity to support a full range of future AAVs and drones required for 21st century polar operations.

17c. IN-WATER AUTONOMOUS ASSETS

Respondents are interested in using AUVs, ASVs, hybrid vehicles, autonomous floats, and/or ROVs to map under-ice environments (including under ice shelves and hazardous areas near glacial grounding zones). Researchers are interested in visually documenting conditions and collecting samples and related measurements. Interests include using deep submergence AUVs/ROVs (which may impose additional considerations on winch and A-frame capabilities). These assets are of interest for accessing challenging and/or high-hazard areas. Some of these deployments could be facilitated by a small boat. Some respondents also noted a desire to deploy/recover oceanographic moorings and gliders and to tow an imaging system.

AUVs, ROVs

- AUV or hybrid vehicle for mapping and if possible sampling under ice shelf or grounding zones, or access to hazardous ice front areas would be very useful.
- AUVs and ROVs provide ability to scout/sample regions that otherwise are challenging to access.
- Potential use of WHOI Deep Submergence Facility AUV and ROV
- Small ROVs that can access under-ice environments for visual documentation and sample collection

Floats

- Deploy and recover autonomous floats.

ASVs

- Ice margin, ice front measurements with ASVs!!!!

Moorings/gliders

- Deployment/recovery of oceanographic moorings and gliders

Other

- Fiber-optic cables are necessary for our towed imaging system.

All/generic

- Ability to position the ship nimbly, or quickly deploy small boats in various conditions
- Again, for successful 21st century operations, supporting in-water autonomous assets is critical and must be considered in the final ship design process.

18c. TOWING GEAR

Respondents were interested in towing devices such as an uCTD system, SeaSoar, Acrobat, MOCNESS, imaging system, or even a mooring, including where sea ice is present. There was also interest in towing seismic gear, including using down-rigging equipment for operations under ice.

For some devices, deployment could happen from *Healy* or from a small boat. Speeds of 3-6 kts are ideal for some instruments, and some instruments require that the vessel be nimble (i.e., ability to speed up or slow down quickly). Some equipment requires the use of fiber-optic cables. The ability to install and operate a winch on the back deck of *Healy* (or similar vessel) and use the A-frame to manage these operations is critical.

- A towed CTD system would be tremendous, particularly when there is some ice present.
- Towed profilers (uCTD, SeaSear, Acrobat, etc). from either small boats, or large vessels. Requires flexibility in how the ship is driven (ability to slow down or speed up quickly).
- Fiber-optic cables
- Seismic operations with down-rigging for operating under the sea ice would be useful.
- Seismic gear
- Ability to tow a 1 m MOCNESS through the ice would be awesome!!!
- 3-6 kts through water are ideal towing speeds for some instrumentation.

Generic

- Over-the-side deployments involve a short period (hours) of towing a mooring.
- Towed vehicles are key to detailed profile of water column and currently *Healy* presents multiple challenges to utilizing these platforms/equipment. Ability to install/operate winch/towed vehicle packages is critical to design of back deck/A-frame.

19c. HIGH BANDWIDTH COMMUNICATIONS

- Ability to transfer large datasets for processing on shore
- Wireless communications with on-ice instrumentation
- Remote piloting and communications with AUVs and drones
- Telepresence
- Satellite Imagery

20c. MINIMIZING LIGHT, NOISE, AND OTHER IMPACTS ASSOCIATED WITH OPERATING AN ICEBREAKER

- Measure ship motion
- Minimize underwater acoustic radiation
- Only operate transducers as needed.
- Compartmentalization of labs to mitigate conflicts
- Minimize light and air pollution. One solution is a small sampling platform that can operate some distance away from mothership.

21. Ways in which a new US icebreaker could better facilitate research by and/or in service to Indigenous communities now and in the future.

Approximately 60% of respondents thought US icebreakers could facilitate research by and/or in service to Indigenous communities now and in the future.

Type of ship capabilities that could better facilitate research by and/or in service to Indigenous communities.

- Important to engage communities
- Continuity of engagement
- Landing craft, port call visits to communities
- Coastal research capabilities
- Bunk space for Indigenous participation
- Sound/light concerns
- Communications infrastructure for communities is important

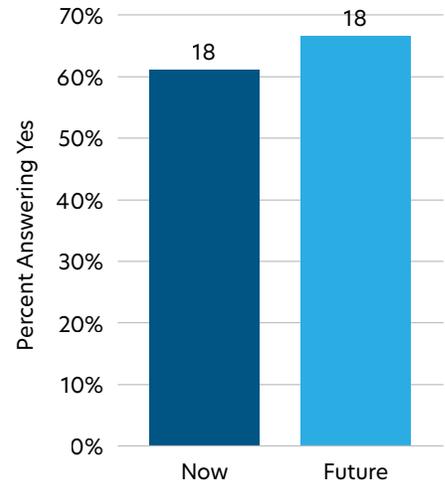


FIGURE A3-6. Percentage of responses agreeing that a new US icebreaker could facilitate research by and/or in service to Indigenous communities. Total number of responses (yes and no) shown above each bar.

22. Additional capacities or capabilities that respondents felt was lacking in the existing vessels that may be required in the future to meet future scientific objectives in their field.

Respondents noted that additional/lacking capacities or capabilities in existing Arctic marine science support include the need for a science-oriented heavy icebreaker, not only to improve early and late-season science access (including to shelf areas), but also to address year-round science. It was also noted that there is science need on the other end of the ship scale to improve access to shallow water, estuaries, and river channels, which would require a different vessel (hence the note “need more vessels”).

Attention to modularity and flexibility in science deck areas, specialized equipment, and laboratory spaces was noted. Cited examples of specific science areas needing improved attention include seafloor sampling operations, improved ability to do science work in the upper 10 m of the water column, and improved ability to measure shallow water currents (with ADCP). There was also mention of provisions for a moon pool, and also improved helicopter support for science operations.

Specific Responses

- Smaller boats that can access shallow water, estuaries, and river channels
- Large open flexible deck space that can be re-configured for a variety of uses.
- Science-oriented heavy icebreaker

- Need more vessels
- Modularity in ship design for deck layout, specialized equipment (e.g., winches), storage and or/lab vans, deck-based incubations, etc.
- Seafloor sampling operations do not appear to be a priority. *Healy* is effectively the only vessel by which US academic researchers obtain access to Arctic sediments and subseafloor science.
- The basic problem with US Arctic research is that it is run by the Coast Guard who, despite being well meaning, are structurally completely at odds with a science-based mission. Military type units want complete order in everything. Science needs flexibility as situations and findings dictate, the Coast Guard is structurally unable to deal with this.
- What is lacking the most is improvements in ship scheduling; final decisions on cruise length and dates are made too late to allow for deployments of opportunity in many cases. Final decision in January for shipping in March is not optimal.
- Sufficient deck space for underway UAS operations
- I think we need better access to the shelves. *R/V Sikuliaq* is a good model, but something a bit more ice capable (for early and late season) would be good.
- We do not well sample the upper 10 m of the water column. This is partly due to our instrumentation but also partly due to CG protocols for sampling or stopping sampling packages when above 20 m depth. The near-surface is a critical place for biology, air-sea gas transfers, and stratification due to ice melt. We spend so much effort in getting to the Arctic, it is really too bad that we don't routinely measure the upper water column structure more accurately.
- Year-round icebreaking capacity and sufficient ship time/number of vessels for year-around activity
- Moon pool would be nice. Limited, if any, helo support has been frustrating.
- Dedicated US research icebreaker polar class 2
- The ability to do science in heavy ice and in winter conditions
- Better shallow-water ADCP

23. How do you envision projected long-term weather trends or shifts over the next 30+ years affecting your science support needs from icebreakers?

Respondents note that “ice breakers will still be essential 30 years from now and will have a longer operating season because of reduced ice cover.” Even if future summer Arctic marine science support requires less icebreaking capability for a particular mission, icebreaker support will be required for winter and shoulder seasons, including ice pack breakup and freeze-up. Icebreakers provide crucial flexibility in station planning and cruise tracks, and a broader temporal operational window. There will be some ice in regions important to research even in much of the summer. With reduced sea ice, biogeographic regimes are shifting north, including commercially important fish species. More extreme conditions are expected, and with ice conditions less predictable, access to ice-safe research ships is essential for safety and planning for the coming decades. There is also interest in winter science missions, for which appropriate icebreakers will be needed. A side note is that summer operations may require the ability to carry out research activities in rougher seas.

Specific Responses

- With changing temperatures and reduced ice, fish populations are moving. This will require ships to go further north to get a true population count of fish. This will require being able to get into ice packs to observe and survey below them.
- Long duration (further north), increased comfort for working in winter/shoulder seasons. More autonomous system support (e.g., through computer resources, etc.).

- Weather more variable and extreme
- Increased studies in the High Arctic are likely due to the projected increase in ship traffic and southern expatriate species move northward and start to become a permanent component of the arctic ecosystem.
- Will still need winter/shoulder-season icebreaking and helicopter support even if the Arctic becomes relatively ice-free in summer.
- None. I want to be in the Arctic during breakup and freeze-up, if those times/locations change then my science would move with them.
- Need more vessels
- While summer support may require less icebreaking capability, we will be entering an era where access is possible in wintertime/year round. Icebreaking presence will continue to be important for the next 30 years simply for safe accessibility to Arctic Ocean regions.
- I don't think they will. There will always be ice in the Arctic Ocean during winter. If anything, ice conditions may become less predictable, and safety planning requires that a future ship maintains a similar ice capabilities to *Healy*.
- The time of very thick rafted ice floes is probably over soon, so the need for really powerful breaking capacity is not paramount. Much of the "action" in the Arctic is near the edges of the basin, which less powerful icebreakers can reach.
- Icebreakers will still be essential 30 years from now and will have a longer operating season because of reduced ice cover. Ability to operating in significant surface waves alongside performance in the sea ice will have to be balanced.
- Longer and large open water seasons will likely mean the ship will need to be able to operate under a broader range of wind/wave conditions. Anti-roll technologies may be need to be incorporated into the design to facilitate operations under conditions similar to (those of) full open ocean.
- As the sea ice continues to decline, ships will need to be present as a stable platform for operations that might have previously been conducted on the sea ice. Ships will also be needed to deploy and retrieve equipment that has been installed in/on the sea ice and ocean.
- I think that icebreakers will become more critical as ice stability is reduced.
- Perhaps higher sea state, and questions that will require earlier and later access
- Thinner, more mobile ice may create more deformed ridges. The annual duration of open water will further increase, so having ships that are stable in open seas is also key.
- Less and thinner ice/more volatile weather
- Yes, but still need to design for current conditions
- Icebreakers will always be necessary because there will be seasonal ice cover for the next 30+ years.
- While sea ice continues to diminish, in the near future, we need to measure existing changes to sea ice environments, especially the CAO. Without sufficient icebreaker capacity, the United States cannot lead these efforts.
- As sea ice declines I suspect that more cruises will be able to take place on ships that are ice strengthened but not icebreakers, but I am concerned about the possibility of this dictating where sampling can occur. For example, if we plan to go to a shelf region where there is likely to be minimal sea ice and we are put on a non-icebreaking ship, but then we do run into sea ice, we won't be able to complete the planned stations. I will always be more comfortable working in the high Arctic on icebreakers because this gives us more flexibility in station planning and cruise tracks.
- Greater needs for continuous and more comprehensive observations during deployments
- With a projected stormier Arctic and shrinking ice, the icebreakers of the future must also be very seaworthy in open water rough seas.

24. Major scientific challenges faced by research and how these relate to the science mission requirements for icebreakers operating in the Arctic regions.

The principal scientific challenge is access. Even with international politics aside, scientific challenges are closely related to logistical challenges in Arctic marine research in nearly all seasons and areas. Support from appropriate ships is crucial to enable science. For example, the need for winter data (of types requiring on-site presence) points to the need for a winter-capable Arctic research ship; work in shallow waters requires a ship different from USCGC *Healy*; and the United States does not regularly operate an Arctic-ice-capable research ship in the eastern Arctic region. As noted by one respondent, "most biological and ecological measurement[s] still and will require human occupation of sea ice environments to generate vital data." Logistical support is expensive and difficult to schedule (with delays in getting to the field that can pose special difficulties for early-career researchers), and it can be hard to obtain the needed project-dedicated time for a field program. Also, working in a military environment from ports distant from research areas presents additional challenges.

Specific Responses

- Lack of winter sea ice and upper ocean observations; capturing interfaces in system (e.g., ice-ocean, ocean bottom); ability to operation in winter and in shallow environments (small boat)
- Coastal processes and how to link what is changing on land and rivers with that in estuaries and high-latitude oceans
- Ship availability and cost (non-NSF funded research)
- Shedding of ice and/or liquid water from Greenland to the Arctic Ocean and GIN/Labrador Seas, Baffin Bay, Nares Strait; impact on ocean circulation, chemistry, and ecosystems
- Availability of ship days, shipment of cargo to ship other than in Seattle
- Accessing the central Arctic, having enough ships to support the ship time needed
- Access and capacity in terms of ship availability AND space for participation. Also, by interlinking science with US military priorities it makes science a secondary priority to any military needs rather than a primary need for US involvement in understanding the Arctic Ocean and the US Arctic waters along our own coastline.
- Climate change studies using CTDs and optical sensors and in-line system
- The major challenge of observing the Arctic Ocean and air-ice-ocean interactions will remain for the next 50 years and beyond. Icebreakers similar to or more capable than *Healy* will still be necessary to accomplish this challenge.
- Biggest challenge is associated with availability and costs of securing appropriate vessels to work in Arctic region. Highly competitive proposals are delayed and/or denied because of issues of costs and vessel availability (imho).
- The high-level topics are related to change in the Arctic cryosphere, how these feedback on the climate system, and the implications on human communities, sea level, ecosystems, and more. One of the related challenges for the atmospheric components of these problems is the spatial and seasonal representativeness of existing and future measurements. Measurements of the surface energy budget, clouds, and atmospheric composition have only been made at a few locations in the central Arctic and rarely in winter. It is important and necessarily to make these measurements in more locations to understand how representative individual measurements are and to detect changes in these properties in response to an evolving Arctic system.
- Access to shelves; access to early and late season
- We need to keep tabs on the health of the Pacific Arctic ecosystem; this can only be done through regular observations.
- A lack of fundamental understanding of small-scale (unresolved in models) processes unique to the Arctic that hinders improvement in models. This understanding can only be addressed by observations and measurements of sufficient quantity and quality, and in the Arctic the deployment of the necessary instruments is the main challenge.
- Incomplete mapping of Arctic, understanding causes of rapid melting of Greenland ice cap
- Access! There should be a dedicated medium/heavy duty icebreaker for science in the Arctic. They should be able to operate out of Nome or Longyearbyen to save on transits.

- Funding for basic science
- No icebreakers operating in the Atlantic, so no icebreakers for Baffin Bay
- Insufficient ecological and biological data on fundamental ecological processes in the CAO and large Arctic basins as we observe greater variability in sea ice thickness and concentration from year to year. Technological developments for bio and eco sensors for (semi) autonomous platforms lags greatly behind physical and chemical sensor development and will not soon be better. Therefore, most biological and ecological measurement still and will require human occupation of sea ice environments to generate vital data. Icebreakers are essential for getting people into the remote regions and serving as a safe base to conduct long-term studies.
- My research interests lie in the changes occurring on the Siberian Seas, so the geopolitical climate can impact cruises (e.g., we can no longer collaborate with Russian colleagues or use Russian ships, we have had to change station locations to keep them farther from the Russian EEZ). I don't foresee this being too big of an issue because the United States will want to continue to have a presence in this region, but I worry about science time being co-opted for military ops. I would feel less concerned about this if there are icebreakers that are dedicated to doing science, rather than having polar security cutters that periodically allow scientists on board.
- Understanding the physical circulation of the Arctic Ocean to support US national security. Understanding the Arctic Ocean and its critical roles in climate change and impacts on the entire planet.
- Perhaps the biggest challenge is simply access to icebreakers—we don't have enough of them. This means delays in getting to the field, and not enough dedicated time for different components of a field program.

25. Primary Arctic-related scientific challenges foreseen to be addressed in the coming years.

Scientific challenges cited by respondents include closing gaps in terrestrial, ocean, and atmospheric research at scales from local to global, improving remote/autonomous/semi-autonomous sensing, providing resources for more sampling in more areas at more times of year (including heavy ice, shoulder seasons, and winter), finding ways to collect data related to industrial scale resource extraction, and adapting observing strategies to the changing Arctic. Political concerns were noted: "A lack of cooperation across nations to conduct Arctic research will be very challenging in the next decade(s), and without international cooperation, we will not be able move forward with critical Arctic science."

Specific Responses

- Oceanographic physical drivers of harmful algal bloom distribution in the Arctic
- Fish migration north
- Close the terrestrial-ocean gaps in local and global scales. Quantify friction of ice on water and air. Validate remote sensing.
- More vessels to support more ship time.
- Year-round accessibility for research to better understand the ecological and physical structure of the Arctic
- Sampling in the ice
- How fast, where, and why is the Arctic Ocean warming? How fast, where, and why are freshwater and stratification changing? What are the circulation pathways and variability and are these changing? What impact does this have on ecosystems, Arctic environment, and global climate?
- Arctic change impacts on the biogeochemistry and ecology of Arctic regions
- Adapting observing strategies to the new Arctic system. The system is changing faster in some ways than our ability to observe it. Need to develop improved autonomous / semi-autonomous observing systems and networks.
- Influence of leads in the ice. Evolving boundary layer structure and associated impact on clouds. Cloud-surface feedbacks. Studies related to radiation management in the Arctic.

- The science community needs to use its voice to inform discussions of the potential opening of the high Arctic to fisheries as we approach the end of the fishing moratorium. We need to collect data that will show the sensitivity of this system to industrial-scale resource extraction and show the risks associated with an extractive approach.
- The coupling between atmosphere, sea ice and ocean (surface energy budgets), lower troposphere vertical mixing, and general air mass transformation.
- As above
- We need to measure the interior of the Arctic better. There are very few platforms that can get to the interior of the Central Arctic.
- Same as above
- Icebreaking ships for May-August Baffin Bay work
- How will primary productivity change in response to changes to sea ice, and how are these changes connected across different regions of the CAO and shelves? How will community composition at lower trophic levels shift and what implications will this have for fisheries? How and who will construct governance of Arctic waters and resources as more of the Arctic Ocean becomes accessible? How will international diplomacy concerning Arctic issues affect Arctic science and cooperation? A lack of cooperation across nations to conduct Arctic research will be very challenging in the next decade(s), and without international cooperation, we will not be able move forward with critical Arctic science.
- Understanding Arctic sea ice changes (retreat in all seasons) and the implications for increasing marine use. How changing Arctic biological-physical-chemical changes impact regional and global ecosystems.
- The ability to carry out programs in the shoulder seasons and winter, often in extreme-cold conditions. The ability to work in heavy ice, such as north of Greenland.

26. Research questions needed to be addressed in the coming years.

The common, strong thread in anticipated future Arctic marine research themes is to determine and understand changes across nearly every aspect of the Arctic, recent and anticipated, and the relationship of these changes to and upon human activities. Respondents mentioned many aspects—water masses and circulation, carbon cycle, geochemistry, biology/ecology, ice, fisheries and other resource harvesting, human activity and transportation, fresh water and Atlantic water fluxes, shelf-basin exchanges, and more.

Specific Responses

- Changes to deep water mass properties and drivers of such changes
- Fish sustainability
- Fisheries becoming established in the Arctic; change in carbon movement as the pelagic and benthic ecosystems change; increased anthropogenic noise from ship traffic that will affect marine mammals; increased predation on marine mammals by apex predators that move northward
- Occupation of region during a time of changing sea-ice conditions...including non-summer time.
- All aspects of a changing climate and changes in sea ice including impacts on chemistry, physics, and biology
- In what ways will the Arctic ocean restructure as ice loss continues and becomes a more seasonal feature—does physical restructuring drive changes in ecological structure?
- How fast, where, and why is the Arctic Ocean warming? How fast, where, and why are fresh water and stratification changing? What are the circulation pathways and variability and are these changing? What impact does this have on ecosystems, Arctic environment, and global climate?
- Long-term impacts of sea ice, temperature, and hydrographic changes in Arctic Ocean regions—coasts/shelves/basins—with focus on the carbon cycle and biogeochemistry
- Impacts of increased human activities as Arctic "opens" up to trade, natural resource harvesting, transportation, tourism, etc.

- How does the declining sea ice impact large-scale energy budgets that can impact circulation patterns? What are the implications of sea-level rise on coastal systems?
- Can the Arctic Ocean ecosystem absorb the impacts of commercial fishing and other vessel activity without causing catastrophic stress in the upper trophic level animals that live here?
- The COUPLED climate system
- There is a lack of data collected in the Arctic. These data can be used to monitor the stratification of the ocean as is subjected to increased atmospheric exposure. More heat, momentum exchange, will drive the salinity stratification to a thermal stratification.
- Changing circulation and freshwater fluxes
- Greenland ice sheet behavior
- How will primary productivity change in response to changes to sea ice, and how are these changes connected across different regions of the CAO and shelves?
- How will community composition at lower trophic levels shift and what implications will this have for fisheries?
- How do changes in freeze-up conditions and processes impact spring- and summertime observations of ecosystem functions?
- How is climate change (e.g., loss of sea ice, Atlantification, increased coastal erosion) impacting Arctic oceanography?
- A key research arena is the changing Central Arctic Ocean and how it relates to global climate change. Understanding the CAO will provide the CAO Fisheries (treaty) Agreement members nations to better manage and regulate the region.
- Air-sea interaction and water mass transformation during the winter months. High-resolution measurements of boundary currents, including shelf-basin exchange. Studies of the impacts of storms in different ice conditions.

27. Arctic research and contributions to national and international interests.

Monitoring and measuring natural resources: For example, fisheries, seafloor minerals, marine mammals; sea ice spatial and temporal patterns—thickness and distributions and their trajectories and linkages to interannual weather patterns and continued warming of the ocean.

Security and leadership: Providing a presence to assure laws of the sea and national boundaries are respected, especially with increasing foreign vessels in the north. Leadership in a sustained Arctic presence and support of communities of the north.

International collaborations: Joint Coast Guard exercises for preparedness; joint and coordinated research missions, for example, IPY 2031-2032, Synoptic Arctic Survey, GO Ship, Oden 2025-early career Swedish-Canadian collaborations.

28 to 32. Demographics of respondents.

The majority (94%) of the respondents had received a PhD. Most respondents had more than six years of experience, but there were some who were early career. Most identified as being a scientist. One postdoctoral researcher had experience in offshore wind. One scientist had 14 years of experience in USCG ship operations, including with ice-breakers. Most respondents specified only one field of study, but a few identified two as being their focus. Physical oceanographers provided the most responses by far (14/41) followed by chemical (6/41) and geological (5/41) oceanographers. Several responses also were received from biological oceanographers and ecosystem scientists, biogeochemists, and sea ice and atmospheric scientists. The majority of respondents were from the United States (31/35 who answered), with four responses from scientists from India, United Kingdom, Sweden, and Bermuda.

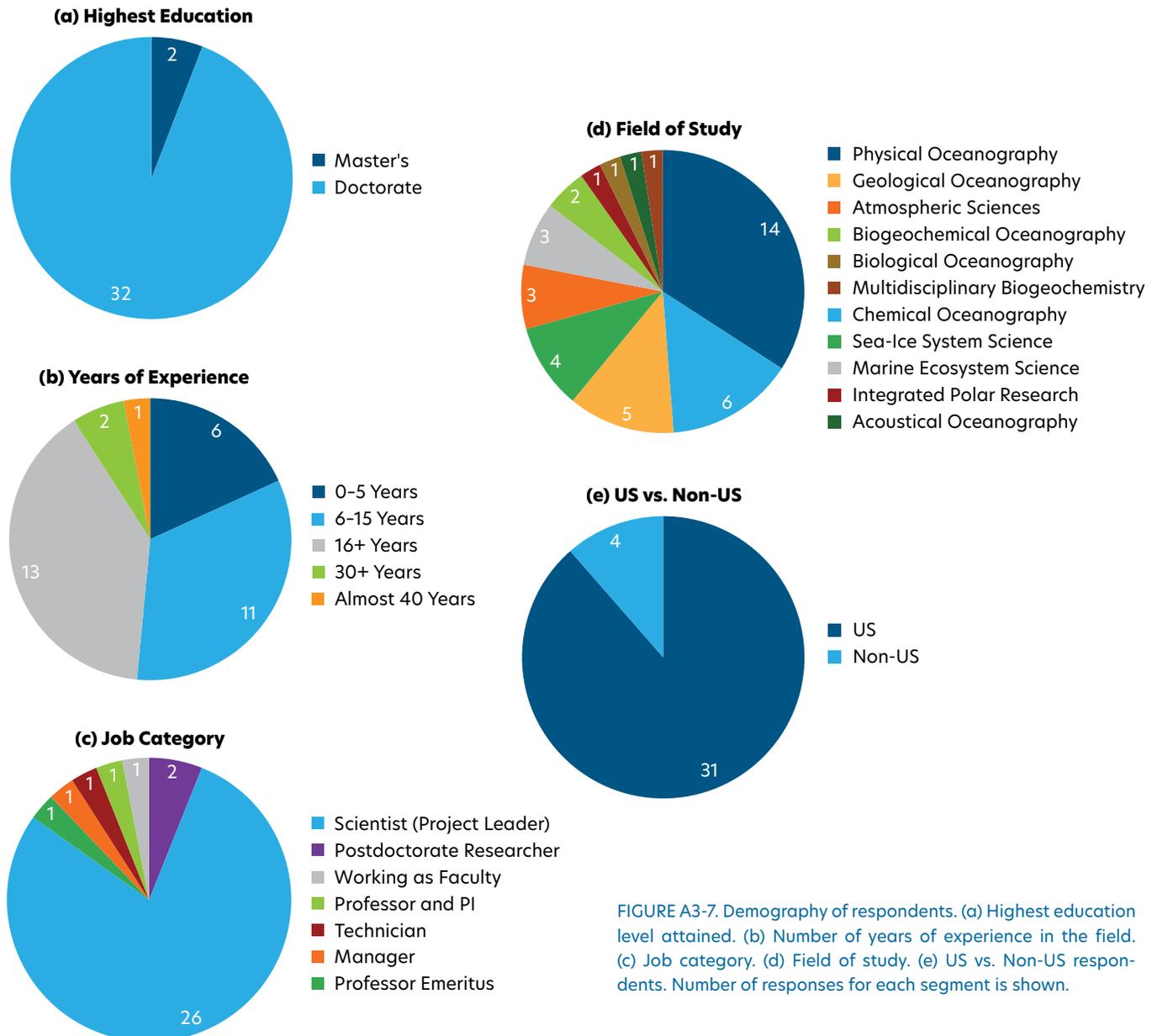


FIGURE A3-7. Demography of respondents. (a) Highest education level attained. (b) Number of years of experience in the field. (c) Job category. (d) Field of study. (e) US vs. Non-US respondents. Number of responses for each segment is shown.

33 to 35. Type of fieldwork.

Most respondents used fieldwork in their research. Two-thirds of the respondents plan to use ships in their future research. Of those who were not planning to use ships in the future, three were retired or soon-to-retire, one provided shipboard support, and several planned to use data collected from ships but not use the ships themselves.

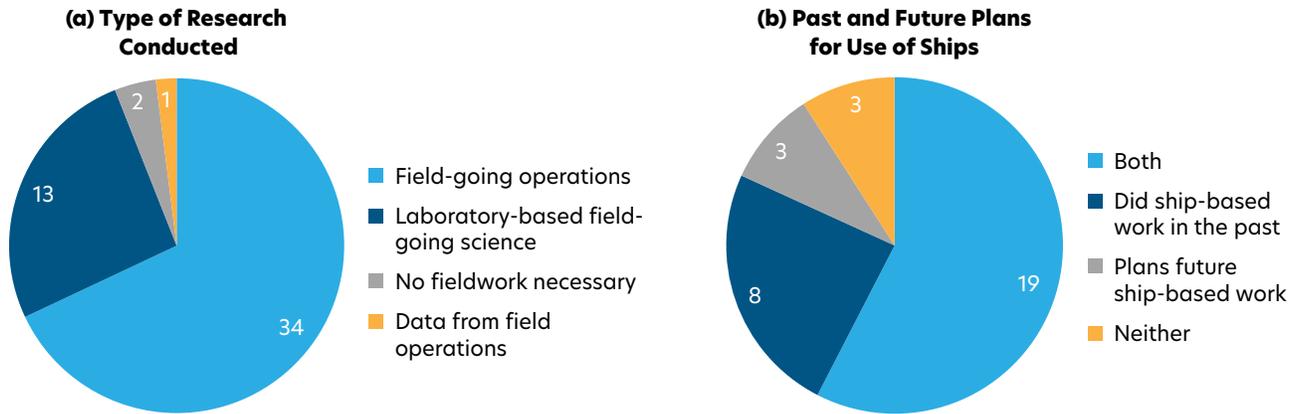


FIGURE A3-8. Ship use in research. (a) Type of research conducted by respondents. (b) Past and anticipated future use of ships in research. Number of responses for each segment is shown.

36. Broad geographic region/s of the Arctic where respondents want to focus future research.

Similar to where respondents had worked in the past, the Pacific Arctic, shelf, and Greenland were regions of future research. Notably, the Bering Sea was much less frequently identified as a location for future research than had been identified as a location of past research.

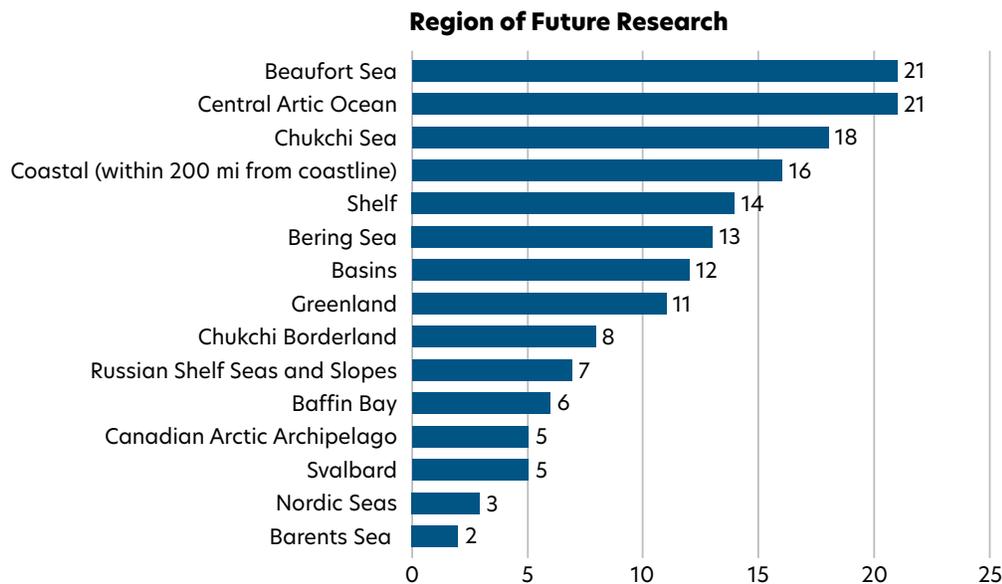
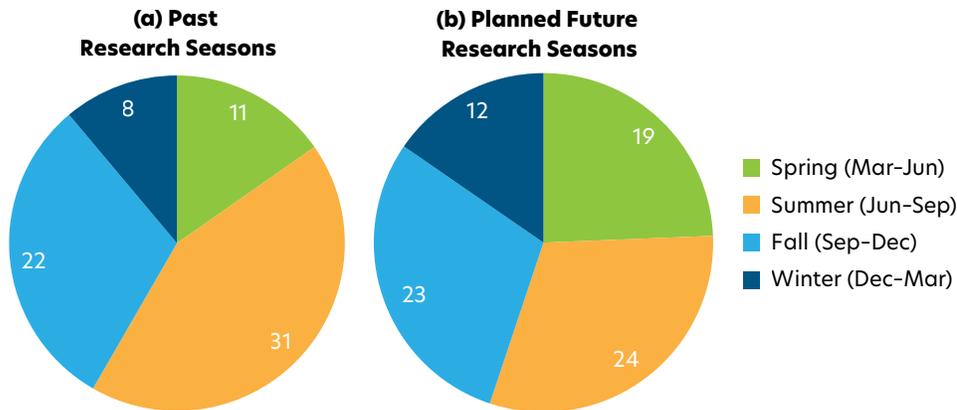


FIGURE A3-9. Number of responses for each Arctic geographic region.

37. Season/s in which respondents prefer to primarily focus research.

Most respondents have worked previously during summer and fall (74% of responses). In the future, more respondents would like to work during winter and spring (40%). Most respondents said that the season(s) in which they focus their research is dictated by ship capability. One person said that the *Healy* schedule dictates their research timing.



(c) Is the season you work in limited by ship capability?

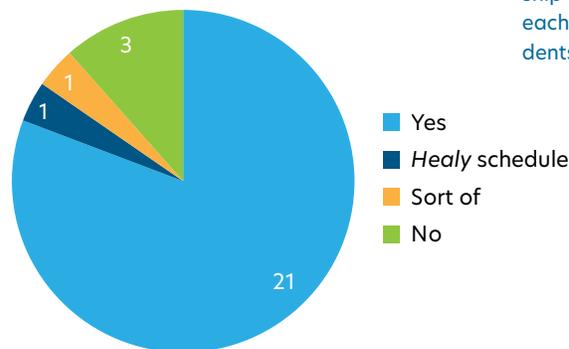


FIGURE A3-10. Season in which research is primarily focused. (a) Past research. (b) Future research. (c) Research limited by ship capability. Number of responses for each segment is shown. Note that respondents could select more than one season.

38. Use of icebreakers for research.

- Deployment activities: moorings, wave gliders, atmospheric devices
- In situ measurements: hydrographic, seafloor mapping, oceanographic, ocean water chemistry (T, Sal, CDOM, water isotopes-¹⁸O, ²H), pCO₂, water vapor isotopes, marine boundary air ¹³C-CO₂ and ¹³C-CH₄
- On site (ice stations) measurements and collections: sea ice coring, melt pond measurements
- Station measurements: CTD casts: nutrients, isotopes, ancient C, water masses, harmful algal bloom, seafloor sampling-biological, sediment properties

APPENDIX 4. STORIS LETTER



Date: 15 July 2025

From: University-National Oceanographic Laboratory System (UNOLS)

To: Commandant (CG-751), U.S. Coast Guard

Copy: National Science Foundation (Office of Polar Programs)
Office of Naval Research (Code 32)
Arctic Research Commission

The University National Oceanographic Laboratory System (UNOLS) chartered the Arctic Marine Research Capabilities Committee (AMRCC) in June 2024 with support from the National Science Foundation, the Office of Naval Research, and the Arctic Research Commission. The AMRCC's purpose is to review and refresh anticipated science missions and affiliated science mission requirements for future Federal icebreakers operating in the Arctic Ocean and other northern polar regions, including any commercially available icebreaker acquired by the Federal government and future "medium" or "heavy" federally flagged and owned icebreakers.

The AMRCC is composed of experienced Arctic scientists that represent the range of different oceanographic science disciplines, different career stages of working in Arctic science (i.e., senior, mid-level, and early career), marine technician / science support, and USCG operational experience. All members of the Committee are very familiar with Arctic science operations successfully supported by USCGC *Healy*.

The Committee is working on a final report with recommendations for scientific capabilities that would be ideally designed for implementation in the enlarged USCG icebreaker fleet. However, the Committee recognizes that the USCG is more immediately preparing to commission USCGC *Storis* in August and is identifying the modifications required to prepare the ship to be fully in service as a USCG cutter. In the legislation authorizing the purchase of the ship, it was stipulated that any icebreaker acquired or procured have scientific research capabilities comparable to those of USCGC *Healy*. This is consistent with the Coast Guard's seven statutory duties (14 USC 102) that include the responsibility to "engage in oceanographic research of the high seas and in waters subject to the jurisdiction of the United States." The AMRCC has identified core enabling capabilities (Table 1) that they recommend the USCG consider as they prepare *Storis* for cutter service.

The identified capabilities are grouped into categories based on function or category and are: Highest Priority Infrastructure, Overboard Handling, Meteorological and Underway Observing, Laboratory and Staging, and Science Network and Data. Each grouping includes two or more specific capabilities. Those that can be accommodated using modular or portable assets are identified. The scope of modifications anticipated to achieve each capability and the type of science research that would be enabled also are noted. It is worth noting that the AMRCC recognizes that while its members are experienced ship-based scientists and technicians, they are not marine architects or engineers and cannot definitively identify the scope of any specific desired modification. The supporting systems required for each enabling capability also have been identified to the best of our ability. The integration of these science

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capabilities and how they contribute to US national interests, including national security needs across the whole Coast Guard icebreaker fleet will be further elaborated in the upcoming Committee report.

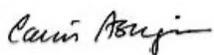
In these interim recommendations specific to USCGC *Storis*, the AMRCC has identified capabilities that are most important to implement early to be able to conduct science from the ship in the near future. Included with the identified capabilities are the Committee's recommendation on short-term to long-term phasing of each capability. Many of the short-term phasing capabilities require only minor modifications and can be accomplished using modular equipment. Note that the phasing identified here is not an evaluation of the value of the different types of science measurements but rather a recognition that some capabilities can more easily be achieved because they require only minor changes or because they can be modular.

Two substantial high-priority infrastructure recommendations are for hull-mounted transducers and for berthing and hotel services for scientists/science technicians. Any work to install hull-mounted transducers would require a dry-docking period as well as hull modifications. Whether hull-mounted acoustic instrumentation will be able to collect high-quality data from *Storis* is unknown, given the ship's hull configuration and the likelihood of bubble generation that interferes with such instrumentation. This instrumentation is highly desired, however, both by the USCG and the science community and the AMRCC recommends that the USCG research the feasibility of a successful installation.

Support of some science capabilities may require substantial modifications to the ship infrastructure, such as plumbing for ambient seawater, cable runs for hull-mounted acoustic sensors, and deck strength to accommodate over-boarding equipment or science vans, that will require vessel stability, deck strength, weight, space, and volume analyses. For example, the Committee recommends that *Storis* carry hull-mounted sensors such as a multibeam echosounder for bathymetric mapping. Identifying and constructing the cable runs for such sensors might most efficiently be accomplished during other, cutter-readiness ship modifications and could save time and expense later. Likewise, the piping for a science seawater system could be installed alongside other, non-science modifications. Other recommendations require specific adjustments that might not coincide with other non-science modifications. All over-boarding capabilities require lower rails than presently exist on the ship, particularly on the stern where a science A-frame for deploying instrumentation could be installed. Installation of a meteorological mast on the bow may be impractical because of the current flight deck configuration.

The AMRCC hopes that these recommendations are useful and stands ready to answer any questions elaborating on them. Please contact the AMRCC Chair Carin Ashjian (cashjian@whoi.edu) or the UNOLS Executive Secretary, Doug Russell (doug@unols.org) to start the conversation.

Best regards,



Carin Ashjian, Ph.D.
Chair, AMRCC



Bruce Appelgate, Ph.D.
UNOLS Chair

Encl: Table 1 – AMRCC Science Mission Capabilities Recommendations for USCGC *Storis*

Table 1 - AMRCC Science Mission Capabilities Recommendations for USCGC Storis

| | Enabling Capability | Modification | | | Supporting Systems | National Security Needs | Science Enabled |
|--|--|--------------|----------------------------------|-----------------------|--|-------------------------|-----------------|
| | | Phasing | Scope | Portability | | | |
| Highest Priority Infrastructure | Hull Mounted Transducers | Short | Extensive | No | Conduits for cables and space above water line for transceivers, anti-freeze flooded tanks, ice windows. Also motion sensor, GNSS system, surface water sound speed sensor, XBT system | A | b |
| | Berthing and Hotel Services - Minimum 25-26, Goal 35 including Science Techs | Short - Long | Minimum - Maximum* | No | Appropriate for needs | A | a |
| Overboard Handling | Dynamic Positioning | Short | Existing | No | | A | c |
| | High Capacity (15-ton minimum, 30 ton preferred) Stern A-frame | Medium | Major | No | Deck strength, electrical and hydraulic. Removable low stern rails to permit overboarding. | A | c |
| | Installation of Modular Equipment (e.g., Winches, launch/recovery systems, compressors) | Medium | Minor | No | 2-foot on center tie down reinforced deck, appropriate high voltage/amperage power for equipment, high-volume seawater cooling | A | c |
| | Side or Portable Launch and Recovery System | Short | Major | Yes | Deck strength, electrical and hydraulic. Low or removable ship rails / bulwarks. | A | c |
| | Oceanographic Winches (Replacing existing winches) | Medium | Extensive | No | Electrical and hydraulic power, cable runs, sheaves and overboarding systems (crane, A-Frame), control system | A | c |
| Meteorological and Underway Observing | Flow through Uncontaminated Science Seawater System to which Instruments can be added | Short | Minor | No | Navigation, data infrastructure | A, B | d |
| | Platforms for Meteorological Sensors | Short | Minor | Yes | 10-m above mean water line at bow (ideally forward-tilting); climbable; ability to mount auxiliary equipment; access to power, freshwater source on bow to enable use of hose for cleaning, science network | A, C | e |
| Laboratory and Staging | Permanent Interior Lab Space | Short | Extensive | No | Flexible chemical/flammable resistant work surfaces, network connections, clean power, comms, network, fume hoods, UPS, compressed air, sinks, deionized water, hazmat lockers, space/power for freezers (-80 °C and -20 °C)/refrigerators/portable incubators | A | a |
| | Modular Specialized Laboratories | Short | Minor | Yes | 1-foot on center deck bolt pattern in lab spaces, power/water/HVAC/comms/on-deck plumbing that doesn't freeze for modular labs. | A | a |
| | Modular Specialized Science Equipment (e.g., Compressors) | Short | Minor | Yes | Tie down reinforced deck, appropriate high voltage/amperage power for equipment, high-volume seawater cooling | A | f |
| | Heated, Weather Protected Staging Area with Deck Access for other Science Equipment (e.g., AUV, ROV, Electronic equipment) | Short | Minor | Yes | Freshwater, drains, electricity, 2-foot on center deck bolt pattern, compressed air, wide door deck access | A | g |
| | Heated, Weather Protected Staging Area for CTD | Short | major | No | Freshwater, drains, electricity, 2-foot on center deck bolt pattern, compressed air, wide door deck access | A | h |
| | Scientific Cargo Hold | Short | Interior-Major; Portable - Minor | Yes | Tie down for portable solutions | A | a |
| Science Network and Data | Independent Science Network & Data Storage System | Short | Minor | No | Navigation, SATCOMS, UPS, airgapped unclassified network | A, D | a |
| | High Bandwidth Satellite Comms System, Internet, Telepresence | Short | Minor | Yes | Power, undisturbed field of view for science antennas, | A | a |
| | Access to Ice Radar (X-band) Data Feed (archived is OK) | Medium | Minor | NA | Navigation, networked data storage (see Healy system) | A, E | a, i |
| | Situational Awareness System (e.g., Shipwide GIS System, Ice Products, Bathymetry, Remote Sensing) Accessible to both Operators and Scientists | Short | Minor | Yes | Simultaneous access to data and imagery products for operators and scientists, including navigation data, science network connectivity and computer for bridge | A | a |
| | CCTV Systems to Monitor Decks, Winches, etc. | Short | Minor | Yes but not desirable | Networking and/or dedicated cable runs to relay data, power | A | j |

Table 1 - AMRCC Science Mission Capabilities Recommendations for USCGC *Storis*

* Scope depends on number of science berths

Key to National Security Needs

A: Enabling capability that is critical to all observations

B: Pollutants, contaminants, HABS, surface sound speed

C: Supports observations for situational awareness, critical to atmospheric/ice observing science capabilities, including those that could be directly assimilated into forecast models for sea ice prediction and weather, or improve those capabilities.

D: Critical to all listed science capabilities, feeds into forecast models including sea ice prediction and weather, enables participation of non-USCG personnel on deployments

E: Situational awareness, enables sea ice drift analysis

Key to Enabled Science

a. All science

b. Multibeam and sub-bottom bathymetry, water column velocity and bioacoustic measurements

c. Seafloor sampling, water column sampling, mooring and/or asset deployments/recoveries

d. Pollutants, contaminants, HABS, surface sound speed, nutrients, microbial composition

e. Atmospheric observations, weather and real-time state analysis, heat fluxes, air-sea exchange

f. Seismics, future large instrumentation

g. ROV/AUV/UAS based observations, large volume pumping, storage of equipment that cannot freeze

h. CTD measurements, water column sampling, other rosette-based instrumentation

i. Cruise track and sampling planning, sea ice observations

Date: 7/15/2025

APPENDIX 5. MISSION SCENARIOS

Mission Scenario 1. Single PI Project with Space for Others

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| TYPE OF WORK | <ul style="list-style-type: none"> • PRIMARY PROJECT. High resolution CTD transects across the shelf-slope transition. • OTHER PROJECTS. Zooplankton net tows and benthic grabs or cores at a subset of stations across the transects; use of an instrument to measure SW chemistry from underway SW system (if available on ship); marine mammal and bird observations during daylight hours from bridge; additional sensors on CTD rosette (e.g., LADCP, UVP); remote observations (e.g., marine mammals) from UAS. |
| SCIENCE PARTY | 6-8 people plus at least 2 for activities 3-5; 5 people for activity 2; 1 person for activity 6; 2-4 marine technicians. TOTAL: ~8-25 |
| TIME OF YEAR | Any |
| AREA OF OPERATIONS | Chukchi and Beaufort shelves and slopes |
| TRANSIT | Distance from nearest port: ~800 nm Speed: 15 kts |
| TOWING/SURVEY | Distance: Speed: Best depending on ice conditions |
| DAYS | On station: 25 (including transits) Towing/survey: Transit: 10 TOTAL DAYS: 35 |
| MAJOR OR SPECIAL EQUIPMENT | Vessel-supplied CTD rosette and associated LARS, winch, conducting cable. Alternatively, a modular CTD system could be temporarily mounted on the deck, requiring space, sufficient deck support strength, and capability to secure the system. Optimally, a hull-mounted ADCP. Permanent or portable A-frame and winch optimally with conducting wire but non-conducting could be possible as well. Access to navigation (for data logging computers), and bathymetry (hopefully multibeam) data and to internet (a portable internet system such as Starlink could be used). Space with a counter and sink next to underway ambient running seawater for instrument. Fume hood for hazardous materials (hazmat) such as preservatives (could be portable). Hazmat locker. Lab space and office space. Interior storage for samples. Ambient seawater on deck to wash nets and to process benthic samples. Potentially internal storage for nets, depending on air temperature. Use of a small, science-supplied UAS. |
| SCIENTIFIC OBJECTIVES | <ul style="list-style-type: none"> • PRIMARY. Conduct a series of high-resolution (5 km spacing) CTD stations across the shelf-slope interface (30-1,000 m bottom depth) as quickly as possible while also collecting acoustic (multibeam, ADCP) data. • OTHER. Zooplankton, benthic, and seabird/marine mammal composition and abundance and near-surface chemical concentrations associated with hydrography across the shelf-slope basin transition. |

Mission Scenario 2. Internationally Coordinated Basin-Scale Survey Cruise

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| TYPE OF WORK | Physical-biological-chemical Arctic Basin survey |
| SCIENCE PARTY | 35-50 |
| TIME OF YEAR | Late summer/early fall (sea ice minimum) |
| AREA OF OPERATIONS | Central Arctic (off-shelf to North Pole) |
| TRANSIT | Distance from nearest port: 500-2,000 nm Speed: 12 kts in open water; 3 kts in ice |
| TOWING/ SURVEY | Distance: 6,000 nm Speed: n/a |
| DAYS | On station: 20-25 Towing/survey: n/a Transit: 35-40 TOTAL DAYS: 55-65 |
| MAJOR OR SPECIAL EQUIPMENT | 1-2 science vans; A-frame, CTD with rosette; in situ pump deployments; bongo and multinet sampling; ambient seawater and freshwater to fantail for rinses; multicore-type surface sediment sampling; atmospheric sampling, flow through seawater sampling; on ice sampling (limited). Heated staging areas for preparation of equipment and/or processing of water and sediment samples. On-board laboratory space requirements include flexible lab bench space, fume hoods, freezers (-20°C and -80°C), climate-controlled chambers. Ship icebreaking capability sufficient to conduct survey to North Pole and return in desired timeframe. UASs for sea ice conditions, marine mammal distributions, and small volume or shallow sampling away from ship. Ability to launch and recover UASs, AUVs, small ROVs. |
| SCIENTIFIC OBJECTIVES | <ul style="list-style-type: none"> • Internationally coordinated basin-scale survey cruise. Ability to conduct hydrographic sampling in a wide variety of sea ice conditions. Emphasis on international data sharing and synoptic Arctic interpretations of conditions, assessed on decadal timescales with other observation platforms deployed in all Arctic shelves and basins. • Sampling of the water column (upper 1,000 m, with occasional full-depth casts) for standard hydrography (salinity, temperature, nutrients, dissolved oxygen), mixing tracers, dissolved and particulate organic carbon and trace elements, and plankton (phyto-, micro-, and zoo-). Particles and trace element collection in water column using in situ pumps and from the underlying sediments using grabs or corers for these same parameters and for benthic organisms. Sampling of atmospheric trace gases, water vapor, aerosols, and surface and in water optical conditions. All cruises are highly interdisciplinary, require large amounts of deck and lab space utilizing special sampling equipment, and have a large science party scaled to ship capabilities and capacity. |

Mission Scenario 3. Geological Drilling and Coring

| | |
|-----------------------------------|---|
| TYPE OF WORK | Lander drilling and giant piston coring |
| SCIENCE PARTY | 35-40 |
| TIME OF YEAR | September (sea ice minimum) |
| AREA OF OPERATIONS | Basins or fjords |
| TRANSIT | Distance from nearest port: Entire ocean basin Speed: 3-10 kts |
| TOWING/ SURVEY | Distance: n/a Speed: n/a |
| DAYS | On station: 30-40 Towing/survey: Transit: 10-20 TOTAL DAYS: 40-60 |
| MAJOR OR SPECIAL EQUIPMENT | <ul style="list-style-type: none"> • The Lander Drill requires heavy lift capability and overboard handling via stern A-frame (SWL = 30 T or greater), and 400 ft² of deck space for a custom deck-mounted LARS track, portable winch (operation of winch and drill from control van like ROV ops), and multiple vans. Requires 480VAC with up to 400 amps electrical power from vessel. Deck space for control, lab, workshop/tool, and drill pipe vans, with CT scanner and multisensing core track equipment. • OSIL 50-meter Giant Piston Coring System with side rail and transfer bucket, along with gravity and multi-coring, adequate vessel winch to support 32 mm synthetic rope, adequate length clear side deck for deployment and recovery, lab space for core splitting, core description lab or science vans for multi-sensor track, camera, and geochemistry. • Multibeam mapping and sub-bottom profiling for detailed site characterization prior to landing drill or core. Dynamic positioning and ice management from thrusters is critical because lander or core is tethered to ship. |

**SCIENTIFIC
OBJECTIVES**

- Projects of this type support the study of Earth history and dynamics as recorded in the chemical, mineralogical, geological, and physical properties of ocean sediment samples. Sediment records are used for studies of temporal evolution of ocean chemistry, ocean circulation, sea level, Earth processes such as reversals in Earth's magnetic field, and history and nature of geologic events including volcanic eruptions, earthquakes, and submarine landslides.
- High-priority targets for future drilling include shallow waters on the continental margins of high economic interest for offshore energy and for geohazards such as earthquake-generated tsunamis in polar regions where ice-ocean interactions are key to understanding sea level change and subsurface ocean circulation, and rocky systems in the deep sea to understand tectonic forces and processes related to formation of strategic minerals and volcanic hazards.
- Critical research objectives consistent with NASEM (2025) for which the US science community currently lacks any means of getting samples. All could be enabled by lander drilling.
 - Sub-seafloor fluids and deep biosphere
 - The coastal transition zone, offshore energy, and geohazards
 - Volcanic systems
 - Sea level change
 - Past ice sheet growth/retreat
 - Past changes in the ocean and carbon-cycle processes

Mission Scenario 4. Geology and Geophysics Surveying and Sampling

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| TYPE OF WORK | Mapping followed by seismic/dredging/coring |
| SCIENCE PARTY | Mapping: 8 Seismic: 12 Dredging/coring: 10 TOTAL: 30 |
| TIME OF YEAR | Three seasons (towed seismic unlikely anywhere in winter) |
| AREA OF OPERATIONS | Everywhere except areas of multi-year ice (CAB, nearshore) |
| TRANSIT | Distance from nearest port: Variable Speed: 12 kts |
| TOWING/SURVEY | Distance: 3,000 nm (seismic); 3,000 mi (multibeam) Speed: 5 kts (seismic); 10 kts (mapping) |
| DAYS | On station: 10 (dredging/coring) Towing/survey: 15 (multibeam); 30 (seismic); 10 (sampling) Transit: variable TOTAL DAYS: 55-65 |
| MAJOR OR SPECIAL EQUIPMENT | Hull-mounted multibeam; underway seismic reflection systems (variable size, depending on objectives) - modular (van housed) winches + sound sources; compressors (variable size, depending on objectives); need to mate winches to vessel's power systems (electric and or hydraulic). Strengthened deck space to install/mount array/sound source winches, accommodate integration of seismic compressors (electric or diesel driven, high volume raw seawater available for cooling, control cables, high pressure air lines); A-frame deployment of both hydrophone array + sound sources. A-frame deployment of dredge - permanent deck-mounted winch could be used for dredging, assuming wire strength sufficient. Dynamic positioning. Potential use of UAS for ice reconnaissance. |
| SCIENTIFIC OBJECTIVES | The primary objective would be to identify and characterize geologic features and natural resources along or across Arctic basins. Multibeam mapping of selected area(s) should ideally be done first; 100% coverage ideal. Underway seismic along transects, likely onshore/offshore, with connecting profiles to assure 3D characterization of targeted bottom/sub-bottom features would follow. Dredging and coring to corroborate geologic identity of seafloor features identified by multibeam mapping and seismic sub-bottom profiles. Would inform future drilling missions that require significant mapping and survey efforts be performed in advance. |

Mission Scenario 5. Winter Ecosystem Study

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| TYPE OF WORK | Winter ecosystem study |
| SCIENCE PARTY | 35-50 |
| TIME OF YEAR | Polar night (winter) |
| AREA OF OPERATIONS | Chukchi Sea (as an example, other locations also desirable) |
| TRANSIT | Distance from nearest port: Assume Dutch Speed: 4-6 kts |
| TOWING/ SURVEY | Distance: n/a Speed: n/a |
| DAYS | On station: 30 Towing/survey: n/a Transit: 12 TOTAL DAYS: 42 |
| MAJOR OR SPECIAL EQUIPMENT | Water sampling with CTD/rosette; ADCP; vertical casts of nets; benthic samplers; camera systems; ROV and AUV (including gliders) sampling under ice, in the water column, and on the seafloor; UASs for marine mammal quantification and sea ice characterization; underway seawater sampling; observations by science party on bridge; atmospheric sampling of trace gases, aerosols, and energy fluxes (see also Mission Scenario 13). Support for on ice work, including manual sampling and deployment of equipment. Warm staging areas equipped with drains that do not freeze. Heated working decks. Ambient seawater on deck for rinsing. Accommodation on rosette for additional user-supplied instruments. Onboard laboratory requirements include flexible lab bench space, environmental chambers, fume hoods, freezers (-20°C and -80°C), science reefer, ice, access to flow-through seawater for user-supplied instrumentation, hazardous materials storage, deionized water. High-bandwidth networking and internet access. Velocity, bioacoustics, and bathymetry data. Accommodation for multiple science vans on deck operating active remote sensors (e.g., radar/lidar) or air sampling. |
| SCIENTIFIC OBJECTIVES | Describe abundance, biomass, composition, and critical rates multiple ecosystem components in the context of physical and chemical environment (microbes, phytoplankton, microzooplankton, meso/macro zooplankton-fish, and upper trophic levels in the water column, benthos, and sea ice). Assessment of ship-generated lighting on organism behavior. Characterize atmospheric properties and constituents; observe heat, momentum, and gaseous transfer across the coupled ocean-ice-atmosphere interfaces. |

Mission Scenario 6. Science of Opportunity

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| TYPE OF WORK | Science of opportunity on USCG mission to Chukchi and Beaufort shelves and slopes. High resolution CTD transects across the shelf-slope transition, continuous meteorological measurements of air-sea interactions, use of an instrument to measure seawater chemistry from underway seawater system (if available on ship). Over-the-side sampling using an instrument or sampling device (type not specified). Marine mammal and bird observations during daylight hours from bridge and/or from UAS. |
| SCIENCE PARTY | 10 (depends on number of projects) |
| TIME OF YEAR | August-September |
| AREA OF OPERATIONS | Chukchi and Beaufort shelves and slopes |
| TRANSIT | Distance from nearest port: ~800 nm Speed: 15 kts |
| TOWING/SURVEY | Distance: Speed: |
| DAYS | On station: TBD Towing/survey: Transit: 10 TOTAL DAYS: TBD |
| MAJOR OR SPECIAL EQUIPMENT | Vessel-supplied CTD rosette and associated LARS, winch, conducting cable. Alternatively, a modular CTD system could be temporarily mounted on the deck, requiring space, sufficient deck support strength, and capability to secure the system. Use of a permanently installed stern A-frame with winch or ability to mount a portable A-frame on the stern or on the side with winch on deck to deploy equipment over the side/stern. Access to shipboard meteorological instrument data and/or space for temporary installation of additional meteorological sensors. Real-time access to navigation and bathymetry (hopefully multibeam) data and to internet (alternatively, a portable internet system such as Starlink could be used). Space with a counter and sink next to underway ambient running seawater for instrument. Depending on the opportunistic research, a fume hood and hazmat storage. Lab and office space. (See Mission Scenario 13 for air-sea-ice interactions equipment needs). Ability to launch/recover small UAS. |
| SCIENTIFIC OBJECTIVES | Conduct a series of high-resolution (5 km spacing) CTD stations across the shelf-slope interface (30-1,000 m bottom depth) as quickly as possible. Transects can be conducted at night to best coordinate with USCG mission requirements for over-the-side work during the day. Seabird/mammal observations when ship is underway; drone surveys during daylight. Continuous sampling of meteorological parameters and water chemistry. |

Mission Scenario 7. Ocean Exploration

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|---|---|
| TYPE OF WORK | Ocean exploration (Arctic Basin/flanking seas, >200 m water depths) |
| SCIENCE PARTY | 20-25 research/15-20 technical support (perhaps more, if showcasing/testing new technologies is an objective) |
| TIME OF YEAR | Generally spring/summer/fall (minimal ice required, for large package deployments) |
| AREA OF OPERATIONS | Deep water—central Arctic Basin, flanking seas (e.g., Greenland) |
| TRANSIT | Distance from nearest port: variable Speed: Ice-dependent (5 kts in ice, 12 kts in open water) |
| TOWING/ SURVEY | Distance: ~500-1,000 nm (multibeam); 5-10 nm/location (ROV/AUV towing) Speed: 5 kts (multibeam); <1 kt (ROV/AUV towing) |
| DAYS | On station: 25-35 Towing/survey: 10-15 (multibeam), 15-20 (ROV/AUV towing) Transit: ~10-20 days (depending on ports) TOTAL DAYS: 35-55 (depending on remoteness) |
| MAJOR OR SPECIAL EQUIPMENT | Pre-surveying (primarily multibeam) for situational awareness of (primarily) seafloor, water column. Vans for ROVs/AUVs (at least 2/survey; additional vans may be needed for housing new technologies/engineering tests of new bottom/water column survey equipment [ROVs/AUVs, etc.] |
| SCIENTIFIC OBJECTIVES | Surveys would target one or more seafloor features (e.g., wrecks, seamounts, trenches, portions of seafloor spreading ridges). Each survey might also include one or more locations for water column observations at various depths by ROV/AUV and future technologies (TBD) as well as surveying the seafloor using photography and/or acoustics. Sampling (water column, plankton, benthos) would take place at selected locations. Science objectives could include: <ul style="list-style-type: none"> • Marine archaeology – wreck characterization, visual mapping, identification of encrusting biology (including selective sampling) • Marine ecology – deep-sea, near-bottom, and benthic biology • Geologic features – visual mapping, selective sampling • Water column studies – visual characterization of planktonic biology (including selective sampling, if possible), collection of temperature and salinity data and chemical, dissolved gases, etc. samples. • Deployment/testing of new visualization/mapping technologies |

Mission Scenario 8. GO-SHIP

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| TYPE OF WORK | GO-SHIP (optional/desirable: include BIO GO-SHIP component or include a geochemistry component) |
| SCIENCE PARTY | 28-30 without BIO; 35+ with BIO; up to 50 with geochemistry |
| TIME OF YEAR | Not seasonally dependent (“best for expected sea and ice conditions”) |
| AREA OF OPERATIONS | Trans-Arctic Ocean: Beaufort shelf and slope, Canada Basin, Alpha Ridge, northern Makarov Basin, Lomonosov Ridge, Amundsen Basin, Gakkel Ridge, Nansen Basin, Barents Sea slope and shelf (or opposite direction) |
| TRANSIT | Distance from nearest port: Up to ≈2,000+ nm Speed: 11-12 kts |
| TOWING/SURVEY | Distance: n/a Speed: n/a |
| DAYS | On station: 40 GO-SHIP; add 2-4 days for BIO; add 10 days for geochemistry Towing/survey: n/a Transit: Typically 4+ (very port dependent) TOTAL DAYS: ~44-58 |
| MAJOR OR SPECIAL EQUIPMENT | GO-SHIP: 2-3+ science vans; A-frame or boom; large 36-place rosette with ancillary instruments; underway seawater system with ancillary measurements; ADCP; ARF global ship standard met package; BIO adds upper ocean net tows; geochemistry adds special “trace metal clean” rosette for dedicated casts. Laboratory space for extensive onboard water sample processing and analyses for a variety of parameters; lab space can be augmented using additional laboratory vans. Uncontaminated underway seawater system available in all ice conditions. Sample storage for both frozen and never-frozen samples. Use of small boat to conduct shallow (~30 m) sampling away from ship in undisturbed water. Ability to launch/recover UASs. |
| SCIENTIFIC OBJECTIVES | The primary GO-SHIP objectives are to provide the highest accuracy measurements covering the Arctic Ocean from coast to coast and top to bottom, with approximately decadal resolution of the changes in inventories of heat, freshwater, carbon, oxygen, nutrients, and transient tracers so that climate and associated biogeochemical changes can be tracked with sufficient parameter and spatial coverage to constrain state estimation and inform predictive modeling of Earth’s climate. The BIO component aims to measure, understand, and predict the biodiversity and biogeochemical role of pelagic communities in tandem with and leveraging the GO-SHIP hydrographic measurements. A geochemical (“GEOTRACES”) component would identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean, and to establish the sensitivity of these distributions to changing environmental conditions. Air-sea chemical fluxes surveyed using drones. |

Mission Scenario 9. Arctic Mobile Observing System

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| TYPE OF WORK | Physical oceanography – Arctic Mobile Observing System |
| SCIENCE PARTY | 10 |
| TIME OF YEAR | September (sea ice minimum) |
| AREA OF OPERATIONS | Beaufort Sea |
| TRANSIT | Distance from nearest port: ~800 nm Speed: 3-10 kts |
| TOWING/ SURVEY | Distance: n/a Speed: n/a |
| DAYS | On station: 20-25 Towing/survey: n/a Transit: 10 TOTAL DAYS: 30-35 |
| MAJOR OR SPECIAL EQUIPMENT | <ul style="list-style-type: none"> • Dynamic positioning, ice management, stern A-frame, and crane are all critical for equipment deployment/recoveries. • Vessel-supplied CTD rosette and associated LARS, winch, and conducting cable. • Sufficient deck space for multiple 20' ISO containers and science-supplied mooring winch. • Vessel-supplied sensors: navigation (heading/position), meteorology, ADCPs, mid-water multibeam, ice radar • On-ice operations for buoy deployments • UAS deployments for spatial surveys of surface properties and upper water column hydrography. • ROV/AUV deployments |
| SCIENTIFIC OBJECTIVES | <ul style="list-style-type: none"> • Characterizing Arctic ocean-ice-atmosphere variability and predicting the system's evolution on synoptic to seasonal timescales requires observations that span a broad range of spatial and temporal scales. Forecast quality depends on observations for initialization, assimilation, and for informing how the simulations represent unresolved physics. Data intended for use in nowcast/forecast efforts must be delivered in a timely fashion—a challenging requirement for polar regions where ice blocks access to satellite services. Vessel coordination allows for opportunities to cross-validate buoy sensor packages. Air-sea interaction measurements using dedicated packages. • To support Navy missions in the ice-covered Arctic, the Arctic Mobile Observing Innovative Naval Prototype (AMOS INP) is developing a mobile observing capability composed of ice-based Gateway Nodes and an array of complementary autonomous platforms (gliders, floats, AUVs), networked together through acoustic navigation and communication to enable coordinated, cooperative sampling and efficient data relay. Ability to launch/recover drones, ROVs, and AUVs. |

Mission Scenario 10. Multi-Ship Multidisciplinary Arctic Basin Studies

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| TYPE OF WORK | Multi-ship mission to conduct Arctic basin physical-biological-chemical study (see Missions 2 and 5) coupled together with geophysical study (see Missions 3 and 4). Space permitting, might also accommodate air-sea-ice interactions work of Mission Scenario 13. |
| SCIENCE PARTY | Ship 1: 35-50; Ship 2: 30 |
| TIME OF YEAR | Spring-summer-fall |
| AREA OF OPERATIONS | Arctic Basin (and some margins, depending on actual location). Some work in permanent sea ice. |
| TRANSIT | Distance from nearest port: thousands of km Speed: 3-12 kts (ice-dependent) |
| TOWING/SURVEY | Distance: thousands of km Speed: 5-10 kts (seismic and multibeam only) |
| DAYS | On station: 35-40 Towing/survey: TBD Transit: TBD TOTAL DAYS: 40-60 |
| MAJOR OR SPECIAL EQUIPMENT | <p>See Mission Scenarios 2-5 and 13 for more details and for information on ship-supplied equipment.</p> <p>Major user supplied equipment that needs to be accommodated on the deck includes the following (by ship).</p> <ul style="list-style-type: none"> • GEOPHYSICAL SHIP: 400 m² of deck space for a custom deck-mounted LARS track, portable winch, multiple vans, adequate vessel winch to support 32 mm synthetic rope, adequate length clear side deck for deployment and recovery of 50 Giant Piston Coring System with side rail and transfer bucket, compressors for seismics (variable size, depending on objectives), deck space to install/mount array/sound source winches, winch for dredging winch. • INTERDISCIPLINARY SHIP (assumes <i>Healy</i>-like science capabilities): science vans, user-supplied sampling gear including plankton nets, pump systems, optical instruments, and benthic samplers (grabs, corers). ROVs/AUVs and UASs. Potentially, mooring deployment and recovery gear. |
| SCIENTIFIC OBJECTIVES | The primary objective of the geophysical ship would be to identify and characterize geologic features and natural resources along or across Arctic basins using multibeam mapping and seismic surveys and dredging, drilling, and coring to corroborate geologic identity of seafloor features identified by the multibeam mapping and seismic sub-bottom profiles. The primary objective of the interdisciplinary ship is to obtain a comprehensive understanding of the state of the Arctic basin physical-biological-chemical (carbon) system, preferably during late summer to coincide with the sampling period of the International Synoptic Arctic Survey program. |

Mission Scenario 11. Nearshore Coastal and/or Rapid Response Mission

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| TYPE OF WORK | Nearshore coastal mission and/or rapid response mission |
| SCIENCE PARTY | 6 or more (rapid response); 10–25 for nearshore coastal work |
| TIME OF YEAR | Year-round (rapid response); spring, summer, fall (nearshore work) |
| AREA OF OPERATIONS | Pacific, southern Alaska, Bering/Beaufort/Chukchi Seas, North Atlantic (Greenland region), Northwest Passage/Canadian Archipelago |
| TRANSIT | Distance from nearest port: 5–2,000 nm Speed: Ice-dependent (5 kts in ice, 12 kts in open water) |
| TOWING/SURVEY | Distance: Variable; could be measured in area instead of distance (e.g., for emergency response survey/SAR) Speed: 0–10 kts |
| DAYS | On station: 3–21 Towing/survey: Included in days on station Transit: 0–14 days (depends on location and ice conditions) TOTAL DAYS: 3–35 days (depending on remoteness) |
| MAJOR OR SPECIAL EQUIPMENT | <ul style="list-style-type: none"> • SMALL BOAT (landing craft): Craft sized for 6 people (2 operators and 4 research personnel), sensors and satcom (multibeam, subbottom profiler, nav system, Starlink, small flow-through system, ADCP, davit or small A-frame, small electric winch, heated cabin, available power for add-on sensors (i.e., needs stand-alone gen-set), gyrostabilization. May need water-making capability. • SHIP: Navigation and mapping systems (including 30 kHz or mid-range multibeam), drone launch and recovery capability, small boat deployment system (for rapid deployments and recoveries of personnel and equipment), helicopter capability, overboarding capability for autonomous vehicles and related assets (e.g., coring devices, seismometers for shelf coring and exploration), all standard meteorological, underway, and survey gear outlined in the SMR as part of the ship's basic suite of research equipment. |

**SCIENTIFIC
OBJECTIVES**

- **RAPID RESPONSE:** Example trip could include ~6 people mobilizing to an Alaskan port to survey in response to an environmental disaster, infrastructure damage, etc. (e.g., from an earthquake, oil spill, or other natural or human disaster). Other example missions include search and rescue response, for example, rescue of personnel from a grounded or sunken vessel. Example missions could also include conducting rapid environmental monitoring in response to an international incident (e.g., foreign oil pipeline break that causes water and atmospheric contamination) or severe HAB outbreak.
- **NEARSHORE COASTAL SURVEY:** Science goals could include
 - Mapping hydrodynamics and biogeochemical properties from the middle shelf into river mouths, including pollutants and contaminants if relevant. Extend survey range of ship into nearshore environments and river mouths by deploying small boats. Small boat should have robust high-resolution mapping and sub-bottom profiling and deployment capability (e.g., for sediment grab samplers, small CTD packages, other hand-deployable instruments). Small boat should have 12-hr range.
 - Surveying fall-season freeze-up processes (ice/wave interactions, other physical dynamics) in the nearshore zone for improvement of high-resolution coupled models
 - Deploy science parties on shore in remote regions (by small boat and/or helicopter) to survey properties that have connections to the continental shelf (e.g., nutrient contents in permafrost, terrestrial connections to marine sediment deposits, sampling of organisms, for example, for DNA analyses with connections to marine measurements)
- For both types (rapid response, nearshore sampling): need small boat capability (see above); drone launch and recovery capability; satcoms (on ship and small boat, i.e., small boat should have Starlink)

Mission Scenario 12. Fjord Survey

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| TYPE OF WORK | Fjord survey |
| SCIENCE PARTY | 35+ researchers |
| TIME OF YEAR | Year-round, but generally in spring/summer/fall |
| AREA OF OPERATIONS | Coastal Greenland, Canadian Archipelago, Southeast Alaska |
| TRANSIT | Distance from nearest port: 50-1,000 nm Speed: Ice-dependent (5 kts in ice, 12 kts in open water) |
| TOWING/ SURVEY | Distance: 1,000 nm Speed: 0-10 kts |
| DAYS | On station: 35 Towing/survey: Included in days on station Transit: 7-18 (depending on ice) TOTAL DAYS: 42-53 (depending on remoteness) |
| MAJOR OR SPECIAL EQUIPMENT | Small-boat launch capabilities; robust acoustic and mapping instrumentation on vessel and small boat (e.g., EK80 on ship; multibeam, sub-bottom profiler, ADCP on both); USBL, helicopter capabilities; UAS deployment capabilities; vans for storing cores/hazmat/PI-supplied seismic capabilities, vans for ROV/UAS (1-5 vans per survey depending on survey type); drop keel for protection of instruments from ice; UAS surveys for ice, near-surface, and near-glacial hydrographic or chemical surveys. |

**SCIENTIFIC
OBJECTIVES**

An example survey would include visiting a series of five fjords along the southwest coast or northwest coast of Greenland. Research objectives could include:

- Studies of biogeochemistry and ecosystem dynamics, for example, identifying carbon-water interactions that include freshening of the fjord systems and injections of ancient carbon from permafrost or other sources, and their contributions to the food webs. This would require water sampling from a small boat in the upper fjord (near the ice), CTD rosette casts from the ship in the middle to outer fjord (and inner shelf), fjord water chemistry (from underway systems on the ship and small boat and water profiles; radiocarbon, stable water isotope values), phytoplankton and zooplankton collections. Could also include sampling of fish.
- Geophysical and coring survey of fjord sediments (surface and subsurface) using multibeam, sub-bottom profiler as well as seabed coring and/or drilling and related seabed sediment sampling. Vessel- and small-boat-based water sampling to look at related water-column properties (e.g., suspended sediments)
- Physical oceanographic survey—mooring deployment/recovery, AUV deployment to sample hydrographic and other properties near the glacier terminus, vessel-based hydrographic measurements (ADCP, EK80, hydrophones), autonomous mapping assets (ROV/USBL). AUVs may also be used to map the ice face and seabed. AUSs also may be used for hydrography.
- Mapping of ice-ocean-land interactions and ice extents/calving using drones and/or helicopter; helicopter deployment of personnel and equipment on the ice (and nearby landscape)
- Marine mammal surveys (whales, polar bears, seals, narwhals) using drones, AUVs, hydrophones, small boat work, helicopter
- Interdisciplinary combinations of the above efforts, for example, marine mammal surveys combined with studies of ocean physics and acoustics, or studies of food webs and biogeochemistry (meaning combined AUV, small boat, mooring, drone work)

Mission Scenario 13. Air-Sea-Ice Interactions

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|---|---|
| TYPE OF WORK | Underway air-sea-ice interactions |
| SCIENCE PARTY | 0-2 |
| TIME OF YEAR | Autumn (freeze-up, marginal ice zone), winter (pack ice), summer (marginal ice zone, melting pack) |
| AREA OF OPERATIONS | Pan-Arctic |
| TRANSIT | Distance from nearest port: Assume Dutch Speed: 0-12 kts |
| TOWING/ SURVEY | Distance: n/a Speed: n/a |
| DAYS | On station: n/a Towing/survey: n/a Transit: Variable TOTAL DAYS: Variable |
| MAJOR OR SPECIAL EQUIPMENT | Bow mast outfitted with micrometeorological measurements 15-20 m above ice/water surface: basic meteorology (1 min means, T, p, q); ultrasonic anemometer (20 Hz u, v, w, T); open-path infrared gas analyzer (H ₂ O, CO ₂); IMU (10 Hz); laser or microwave height sensor; downward-facing narrow-band infrared thermometer; upward-facing broadband pyrometer, pyranometer, diffuse partitioning. Additional useful observations include underway bulk seawater temperature and salinity, ADCP, X-band ice radar. UASs for surface property heterogeneity surveys. |
| SCIENTIFIC OBJECTIVES | Calculate heat and momentum energy fluxes between air and ice to advance bulk aerodynamic representation of air-surface processes in coupled sea ice forecast models (e.g., NOAA UFS, Navy ESPC). This will help improve sea ice forecasts relevant for vessel operations, including ice growth/initiation of growth, ice drift, ice stress/pressure, and lead/ridge formation. |



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USCGC Healy (WAGB 20) crew members and the science team gather for a group photo at the North Pole, October 2, 2022. US Coast Guard photo by Deborah Heldt Cordone, Auxiliary Public Affairs Specialist 1