

With input from the scientific community, agency personnel, diplomats, and the citizens of the Arctic region, the report's authoring committee identified emerging research questions for study over the next two decades. These are questions that have arisen as rapid change has pervaded the Arctic system, have not yet received the attention they likely deserve, or can only now be addressed given technological or other advances. In other words, these are questions that in five or ten years' time we would kick ourselves for not asking now.

The report also assesses not only what is needed to address today's questions, but also what is needed to be ready for those questions that emerge in coming years. It underscores the importance of translating research findings into practical information that can help guide management and policy decisions.

EMERGING QUESTIONS

In each of the sections below, the report's authoring committee identified emerging research questions for the next 10 to 20 years of Arctic science.

Evolving Arctic

The rapid pace of Arctic change is raising new questions and driving new interactions. The *Evolving Arctic* focuses on the transition to the "new normal" of reduced ice and snow and the cascade of impacts this will have on systems that depend on frozen ground and water. Arctic societies are also changing rapidly, especially in the political realm as indigenous people achieve greater autonomy in some regions.

Hidden Arctic

The *Hidden Arctic* explores what could be found as ice barriers diminish—and what could be forever lost amid rapid change. Many aspects of the Arctic

What is the Anthropocene?

The changes taking place in the Arctic, such as physical and biological shifts driven by worldwide human activity including economic expansion and technological advances, are hallmarks of the **Anthropocene** epoch in which human activity is a dominant force on the global environment. Scientific research is crucial to understanding how rapid environmental and societal changes will affect the Arctic and the rest of the world.

Box 1. Evaluating Emerging Questions

In its deliberations, the committee considered four categories of knowledge that could be revealed through Arctic research:

What we know forms the foundation for what comes next. A great deal is known about how the Arctic is changing, along with extensive information about Arctic conditions in various disciplinary fields.

What we know we need to know includes key questions driving current research, enumerated in many planning documents and other places, and recognizing how much is at stake.

What we think we don't know is knowledge that is not shared and thus often overlooked. This includes traditional knowledge held by indigenous peoples, proprietary data, and discipline-specific information that has not yet carried over to inform other fields.

What we don't know we don't know is the realm of surprise.

have been unknowable, in large part because ice cover has blocked access and presented a major barrier to research. Loss of sea ice, the retreat of glaciers, and technological advances now allow research in new fields, new geographical areas, and throughout the year. At the same time, rapid change can lead to the loss of geological features or cultural sites.

Connected Arctic

The Arctic is connected to the rest of the world by air and water currents, by animal migrations and invasive species, and by societal interactions. Changes occurring in the Arctic do not stay in the Arctic, but affect the rest of the northern hemisphere and beyond. Climatic and meteorological connections in particular have far-reaching implications globally; for example, through rising sea level due to mass loss of the Greenland Ice Sheet and through weather patterns potentially affected by sea ice loss. Outside pressures influence Arctic residents and the experiences of Arctic cultures can inform and be informed by those of indigenous peoples elsewhere.

Managed Arctic

Questions of societal changes, conflict and cooperation, and proactive vs. reactive decision making are raised in the *Managed Arctic* section. Humans have lived in the Arctic for millennia, shaping their surroundings and making use of what the Arctic has to offer. In recent decades, the human environment has shifted greatly, including political and economic integration with nation-states and less obvious trends such as the urbanization of Arctic peoples. Looking forward, human activity and interventions are likely to increase in frequency, magnitude, and scale in the Arctic. Research is essential to understand the drivers of change, their implications, and options for response.



Aurora borealis, base camp, Baffin Island, Arctic Canada. Credit: M. Kennedy, Earth Vision Trust.

Undetermined Arctic

The *Undetermined Arctic* addresses how we can be prepared to detect and respond to the unexpected. Leaving room for new ideas and making it possible to identify new research directions when the need arises requires research to better assess new topics, long-term observations to identify changes and surprises without delay, and flexibility in funding to move quickly when a significant event occurs.

Meeting the Challenges

Meeting the Challenges addresses what is needed to leverage efficiencies in making Arctic research happen, from collaboration and coordination to sustained observations, building human and operational capacity, making information actionable as well as accessible, and possible changes in funding approaches.

Enhancing Cooperation

No single agency, organization, or country can take on all research topics in the Arctic. Some research questions are too broad or involve such extensive field efforts that they cannot be resolved solely by researchers from a single country or supported by a single funding source. In some cases comprehensive data sets of numerous field processes must be collected simultaneously in coordinated expeditions or cruises requiring collaboration among many nations. Cooperation is essential: among researchers, between agencies, among nations, across disciplines, between Arctic residents and visiting scientists, and with the private sector.

Sustaining Long-term Observations

Long-term observational data are essential for detecting change and for putting research findings into context. There are, however, insufficient long-term observation efforts underway and little coordination among those that do exist. Instead, available records are often a collection of ad hoc efforts conducted with different time scales, in different areas, and for different purposes. It is thus difficult to distinguish large-scale patterns from localized ones or to connect findings in one discipline to those in another.

Managing and Sharing Information

Data management requirements have often been underfunded, resulting in poor quality metadata, a lack of long-term archiving, or other shortcomings that greatly reduce the utility of data. Our understanding of the Arctic as a system has evolved through the ability to compare data sets from disparate fields and regions in order to see connections and commonalities. But data management is often left to individuals or to separate efforts depending on agency, program, discipline, or other parameters.

Maintaining and Building Operational Capacity

New technologies allow new approaches to research in many fields. Among the most promising recent developments is a host of autonomous mobile sensors for the ocean and atmosphere that can be deployed relatively easily and inexpensively. At the same time, it is critical that current capabilities are sustained, including ships, satellites, and research stations.

Growing Human Capacity

Arctic research depends on sufficient human capacity, including scientists trained in the necessary fields who are capable of interdisciplinary collaboration. During the International Polar Year, concerted efforts were made to involve young researchers, and those opportunities help to retain scientists in Arctic research. Additionally, Arctic residents can offer a great deal to research efforts. To avoid “research fatigue” it is important to make sure that Arctic residents have the chance to act on what is learned from research,



Supraglacial water channels and small surface ponds on the flanks of Russell glacier, a land terminating glacier on Southwest Greenland. Credit: Perry Spector

this report, pressures are growing for support of comprehensive systems and synthesis research, non-steady-state research, social science, stakeholder-initiated research, international research, and long-term observations. Other approaches are used in different countries, and the tradeoffs involved are worth considering to assess whether some of those approaches might be adopted or adapted in the United States.

Building Knowledge and Solving Problems

Getting more from Arctic research may best be pursued by enhancing the ways we make use of that research. Collaboration is needed—not just among scientific disciplines, or between scientists and those who

and to use knowledge gained to enhance the adaptive capacity of their community.

Investing in Research

Society's ability to address emerging research questions in the Arctic is closely tied to the way research funding is organized. Given the emerging research questions and implementation challenges identified in

live in the Arctic, but also with and between decision makers to better understand what they require and how scientific results are factored with other considerations to produce decision outcomes. Fostering a sense of shared purpose to manage change to the best of our abilities is essential, as is a continued commitment to studying what exists, what is emerging, and what awaits us in the Arctic.

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The National Academies appointed the above committee of experts to address the specific task requested by the Arctic Research Commission, Department of Energy; National Aeronautics and Space Administration; National Oceanic and Atmospheric Administration; National Science Foundation; and Smithsonian Institution. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

For more information, contact the Polar Research Board at (202) 334-3479 or visit <http://dels.nas.edu/prb>. Copies of *The Arctic in the Anthropocene: Emerging Research Questions* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.

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