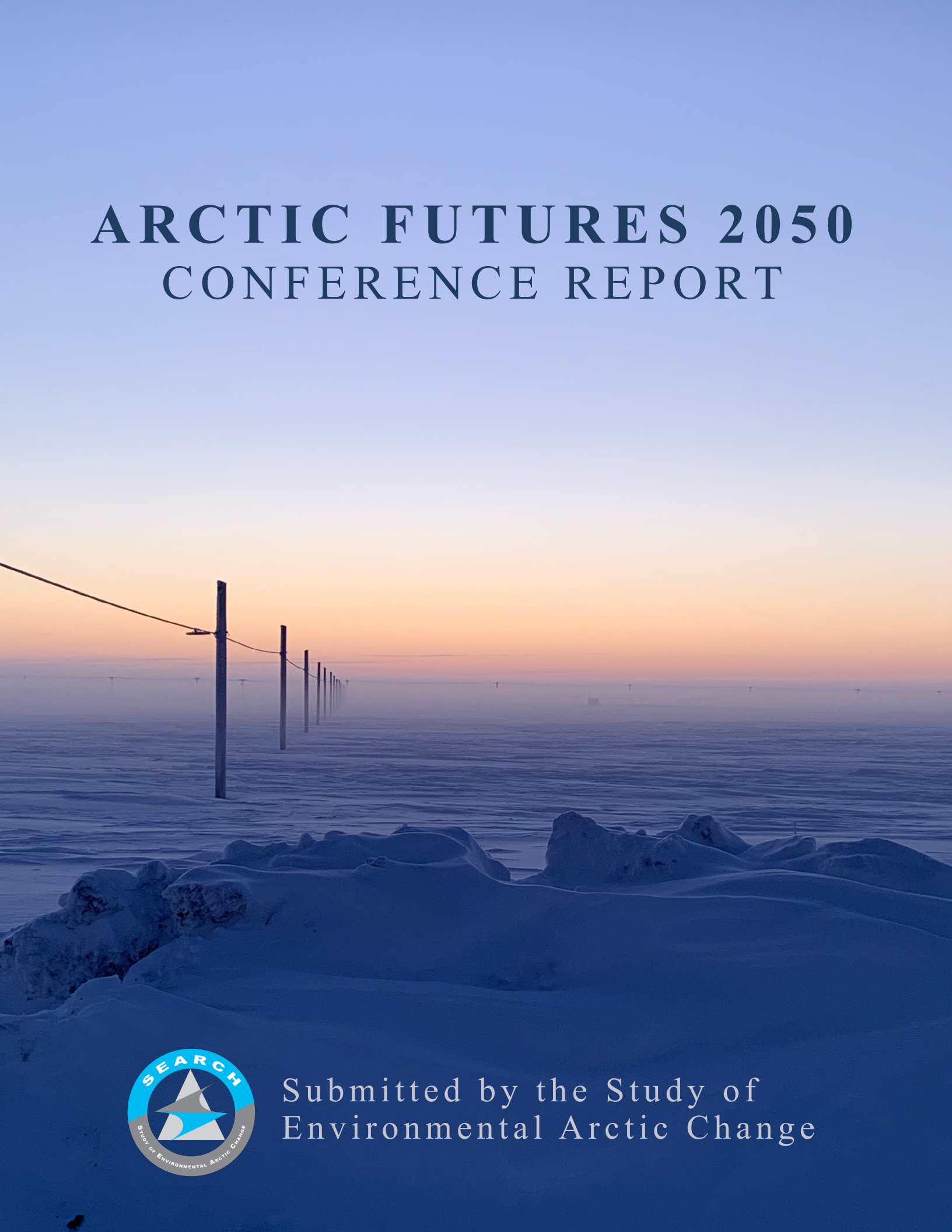
ARCTIC FUTURES 2050
CONFERENCE REPORT



Submitted by the Study of Environmental Arctic Change

"To us, when there's open water, it is not winter to us. Only when the whole of the Bering Sea is completely locked up, to us, that is winter. The winter we have now—three months—to us is not winter anymore because [the ice] doesn't fasten itself to our island. We haven't had shore fast ice within the last five years, and when the south wind blows that ice goes out. Our food security is at an imminent threat; we are losing our food security…"

Delbert Pungowiyi, Arctic Futures 2050 Conference, September 2019

ARCTIC FUTURES 2050

Conference Report to

National Science Foundation

U.S. Department of Energy

National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration

Gordon and Betty Moore Foundation

Pew Charitable Trusts

American Geophysical Union

Bureau of Ocean and Energy Management

International Arctic Science Committee

Submitted by the

Study of Environmental Arctic Change

April 16, 2020

Recommended citation: Fisher, A. M., B. P. Kelly, and G. W. Kling (eds.). 2020. Arctic Futures 2050 Conference Report. Study of Environmental Arctic Change. https://www.searcharcticscience.org/arctic-2050/conference-2019.

Conference photos by Joed Polly, ARCUS.

TABLE OF CONTENTS

ARCTIC FUTURES 2050 EXECUTIVE SUMMARY

In September 2019, the Study of Environmental Arctic Change (SEARCH) brought together nearly 400 scientists, Indigenous Knowledge holders and leaders, and policy makers from 15 countries to explore Arctic research needs. With the premise that policy responses to changing Arctic environments need to be informed by Indigenous and scientific knowledge, Arctic Futures 2050 relied on formats that emphasized collaboration and discussion.

Three keynote presentations set the stage: Past and Future Environments of the Arctic, Indigenous Peoples and Arctic Environmental Change, and What Policy Makers Will Need to Know in 2050. Most of the subsequent presentations were moderated discussions among an Indigenous leader, a scientist, and a policy maker. That format allowed for a holistic exploration of five conference questions.

The main conference conclusion is that **holistic understanding and useful adaptation to rapid Arctic change requires bringing together scientists, Indigenous Knowledge holders, and policy makers in all phases of defining the problems, conducting research, and sharing knowledge.**

Here, we summarize key takeaways from the spoken and poster presentations organized by the five conference questions.

WHAT DO WE CURRENTLY KNOW/ NOT KNOW ABOUT THE CHANGING ARCTIC AND WHY DOES IT MATTER?

The most immediate and consequential changes in the Arctic—diminishing sea ice, ice sheets, glaciers, and permafrost—have both local and global impacts. Widespread consequences include restructuring ecosystems, climate disruptions, and global sea level rise. Discussions highlighted the interlinked ecological and social implications of such changes, which included especially vivid descriptions of Arctic Indigenous People facing loss of life, tradition, and culture.

SEARCH scientists detailed some observed and predicted changes in the physical environment as the Arctic warms at more than twice the global rate:

A panel discussion on Implications of Changing Marine Ecosystems.

- Diminished **sea ice** over the past few decades is responsible for 50% of the warming observed in the Arctic and 17% of global warming. Sea ice is a defining characteristic of the Arctic and a potent force in regulating climate;[1]
- Thawing **permafrost**, accelerated by abrupt ground collapse in ice-rich soils, is on track to damage one third of the infrastructure in the northern permafrost region and add on the order of 75 ppm additional carbon dioxide to the atmosphere in this century;[2] and
- Greenland has lost more **land ice** than it accumulated over the past 20 years.[3]

Specific observations of environmental change from across the Arctic provided additional details and highlighted regional variations in the magnitude of change and its consequences. Arctic marine fisheries were described by several presenters in terms of local and national economies. Others emphasized that such climate impacts are taking place in the context of other pressures, including social and commercial disputes and government policies.

Panels also discussed how changes are engendering adaptive responses in policy, economics, and cultural practices. Discussions pointed to examples such as changes to fishing policies, subsistence whaling, food insecurity, the establishment of conservation areas, and control and remediation of erosion.

[1] Matthew Druckenmiller
[2] Ted Schuur
[3] Twila Moon

WHAT RESEARCH IS NEEDED TO INFORM RESPONSES TO ARCTIC CHANGE?

The scale and pace of environmental change was cited in numerous calls for accelerated Arctic research in the natural and social sciences. Specific research needs discussed included:

- predicting future states of sea ice, land ice, permafrost, and wildfires;
- mechanisms generating Arctic storms and predicting storms;
- bathymetric charting;
- pathways and risks of climate engineering;
- human health impacts of environmental change;
- impacts of environmental changes and harvests on fisheries; and
- impacts of increased Arctic shipping.

Many Indigenous presenters prioritized topics directly impacting the well-being of Arctic residents, such as air pollution, coastal erosion, increasing ship traffic, and food insecurity. Priorities of scientists included a greater emphasis on understanding Earth system processes and on forecasting future environmental states. Those making public policy decisions—such as planning mitigation and adaptation to rising sea levels—prioritized research that could narrow the range of future projections.

Co-production of knowledge by scientists, Indigenous Peoples, and policy makers will be necessary to focus priorities, and conference discussions recognized both the importance and the challenge of more meaningful co-production of knowledge. Four promising approaches discussed included:

1. collaboratively developing frameworks for communicating the confidence of predictions, especially those that would entail higher adaptation costs;
2. employing table-top and scenario exercises to clarify the research needed to address particular societal concerns;
3. collaboratively modeling the threats to communities and their consequences; and
4. a framework to evaluate the extent to which research is "new, urgent, and impactful."[4]

These approaches would all require or benefit from collaboration of scientists, Indigenous Peoples, and policy makers. Suggested pathways for collaboration included recognizing the value of Indigenous Knowledge to understand the Arctic environment; researchers working with local communities to identify research that is locally relevant and timely; framing research to consider social values; expanding environmental research that explicitly includes consideration of issues of human well-being; and building communities of practice that would link scientific, Indigenous, and policy experts together around shared interests and concerns. Barriers to collaboration between scientists, Indigenous Peoples, and policy makers include aspects of the academic reward system, inadequate compensation for Indigenous Knowledge holders, a lack of capacity in Indigenous communities, and the demands on the time of policy makers.

WHAT CHALLENGES CONFRONT POLICY MAKERS IN THE RAPIDLY CHANGING ARCTIC?

The pace of environmental change in the Arctic challenges government responses. Presenters noted that policy makers need assistance in making proper use of environmental data, and they need to be held accountable.

Presenters also considered the challenges of aligning policy decisions with a rapidly changing environment. Mitigation measures typically will take time to implement, whereas adaptation measures—including support for adaptation in Arctic communities—could happen more quickly. Experts with considerable experience at the science and policy interface emphasized the importance of policy makers appreciating the rapid pace and serious consequences of Arctic change. An Indigenous leader suggested that policy makers, scientists, and Indigenous People need to learn each other's terminology.[5] Policy makers and scientists agreed and gave the specific example of the varying uses of the term "uncertainty" with respect to scientific findings.

[4]Gerald Geernaert
[5]Rosemary Ahtuangaruak

Conference discussions brought to light impediments to informing policy with knowledge, including:

- inadequate appreciation for Indigenous Knowledge and rights;
- mismatches in communication styles;
- disparities in information needs of policy makers and what is known; and
- misalignment between the spatial and temporal scales at which decision makers need predictions versus what models are able to deliver.

Many policy issues identified by North American participants involved inadequate use of Indigenous Knowledge, however, European participants tended to focus more on challenges in transnational collaboration while still acknowledging tensions over Saami rights in Sweden, Norway, and Finland.

Collaboration in knowledge acquisition and policy making is hindered by tensions regarding Indigenous rights and international rivalries. Several presentations underscored the importance of rebuilding trust between policy makers, scientists, and Indigenous communities. Doing so will require honest and perhaps difficult discussions. The conference took tentative steps in that direction, but much more effort is needed.

Many posters were designed in a "big ideas" format to convey take-home messages clearly, succinctly, and in nontechnical language.

WHAT TOOLS CAN FACILITATE INFORMING DECISION MAKING?

To better inform decision making, participants identified tools relating to communication, co-production of knowledge, modeling, scenarios exercises, and remote sensing and other technologies.

Many presenters referred to the need for better **communication** between Indigenous Knowledge holders and scientists, and others addressed how knowledge holders could better communicate with policy makers. Developing effective and timely ways of communicating what is known about Arctic environmental change to policy makers was noted as essential.

Examples of Indigenous Knowledge informing policy included Inupiat whalers in Alaska informing management decisions by the International Whaling Commission, Inuit knowledge used in the delineation and establishment of a large marine protected area in Canada, and Saami herders informing ecological studies of reindeer. Those examples illustrated successes but also challenges of communication and, more fundamentally, building trusting relationships.

Conference attendees emphasized the importance of iterative discussions between researchers and those developing policies for adaptation. Such discussions can help policy makers distinguish new but not fully vetted research from research that is actionable by virtue of being broadly accepted or "settled" science. Conversely, dialogue can help researchers know where refinement of predictions will make significant differences in policy decisions.

Efforts on the part of the science community to better inform policy were described in spoken and poster presentations by academic, government, and boundary-spanning organizations. Examples included SEARCH's production of nontechnical briefs answering policy-relevant questions about environmental change in the Arctic; the German Arctic Office's "Dialogue Forums," where ministers in the German government are briefed on Arctic science; and Finland's Climate Panel, an independent group of scientists who inform the country's ministers on climate change science. One recommendation was

that an IPCC-like panel be created for Arctic change as a way to share knowledge and align Arctic policy internationally.[6]

Further, the importance of communicating what we know to the public at large was highlighted by several participants. Speakers suggested the need for public education and advancing science literacy.

Co-production of knowledge—combining Indigenous and scientific methods and engaging policy makers in framing questions—was embraced by many. Presenters emphasized that Indigenous Knowledge is distinct from scientific knowledge and should not be translated by scientists. A poster presentation elaborated on that point, highlighting that co-production of knowledge is distinct from multidisciplinary and multi-evidence-based approaches and also explained how co-production through equitable collaboration is important for "the holistic view needed to inform policy, resource management, and conservation."[7]

Spoken and poster presentations provided specific examples of how mathematical **models** extend the power of observations to predict future states of the Arctic. Presentations made clear the importance of models based on first principles in predicting the future of a system headed to a new state and pointed out that even the earliest versions of Earth system models predicted well the declines in sea ice that have since been observed. Improvements to climate models are ongoing and, in particular, could better incorporate Indigenous Knowledge.

The application of formal **scenarios exercises** for learning and informing decisions—including a table-top exercise—were demonstrated in presentations. One scenarios project presented took a pan-Arctic approach, while another focused on future scenarios in Arctic Russia. Other tools presented included structured decision-making approaches for considering social and economic implications.

The power of **remote sensing and other technologies** to track environmental change in the Arctic was emphasized in several presentations. Poster presentations described how remote sensing products are becoming more broadly accessible.

WHAT PARTNERSHIPS ARE POSSIBLE BETWEEN DECISION MAKERS AND KNOWLEDGE HOLDERS?

The importance of partnerships was a common conference theme. In an impassioned speech, Delbert Pungowiyi argued that the crisis of a rapidly changing Arctic requires "all hands on deck." He and many presenters emphasized the value of appropriate partnerships between Indigenous Peoples, scientists, and policy makers. Others outlined examples of past and present partnerships, as well as the need for new or improved partnerships crossing countries, disciplines, jurisdictions, and age groups. Those case histories suggested models for international cooperation and successful partnerships among Indigenous Knowledge holders, scientists, and policy makers.

CONCLUSIONS

Arctic Futures 2050 created a necessary opportunity for funders, researchers, Indigenous Knowledge holders and leaders, and policy makers to improve how Arctic policies are informed by scientific and Indigenous understanding. The conference was successful in providing that first opportunity, but ultimately it will have been successful to the degree to which it contributes to better and sustained co-production and use of knowledge. In a post-conference survey, about 90% of attendees rated the conference as very good to excellent, and many commented that the inclusion of scientists, Indigenous Knowledge holders, and policy makers was a powerful approach to understanding and responding to rapid Arctic change.

Find the conference program, posters, & session videos at
www.searcharcticscience.org

The conference was made possible with funding from the National Science Foundation; the U.S. Department of Energy; the National Aeronautics and Space Administration (Terrestrial Ecology and Cryospheric Science Programs); the National Oceanic and Atmospheric Administration; the Gordon and Betty Moore Foundation; Pew Charitable Trusts; the American Geophysical Union; the Bureau of Ocean Energy Management; and the International Arctic Science Committee.

[6]Markku Ollikainen
[7]Raychelle Aluaq Daniel, Carolina Behe, and Julie Raymond-Yakoubian

ORIGINS OF THE ARCTIC FUTURES 2050 CONFERENCE

In early 2013, the Study of Environmental Arctic Change (SEARCH) program proposed to the National Science Foundation (NSF) a five-year collaborative project of research, synthesis, and knowledge transfer. The proposal called for an Arctic Futures 2050 Open Science Meeting in the final year that would "lead to development of research products that address societal priorities and can help inform policy." The capstone conference was to be "patterned after the 2010 State of the Arctic Meeting and the 2003 SEARCH Open Science Meeting" to help identify future research directions.

EVOLUTION OF THE CONFERENCE FORMAT

Over the first three years of the current award, SEARCH came to see that while the previous open science meetings had advanced research in many important ways, the next meeting would benefit from more substantial involvement of Indigenous Peoples[8] and policy makers. SEARCH realized that policy responses to changing Arctic environments need to be informed by the knowledge of Indigenous Peoples and scientists. Therefore, in 2018, SEARCH re-envisioned the Arctic Futures 2050 conference as more than an open science meeting and began discussions with potential funders toward convening Indigenous People, policy makers, and Arctic researchers to collaboratively consider the knowledge needed to inform Arctic policies in the coming decades.

Expanding from a science conference to a convening of scientists, Indigenous Knowledge holders and leaders, and policy makers required broadening inputs, extensive outreach, and additional funding. A conference prospectus was drafted by the SEARCH executive director, Science Steering Committee, and action teams. The prospectus was modified in two convenings of the Arctic Futures Working Group (Appendix I), comprising representatives of potential funders and science organizations, and 15 meetings of the Indigenous Participation Working Group (Appendix I), comprising representatives of seven Indigenous organizations. A conference organizing committee (Appendix I) and SEARCH staff considered the inputs from funders and working groups to recommend a final program (Appendix II) to the SEARCH Science Steering Committee.

With considerable help from our funders and partner organizations (Appendix III) and especially the Indigenous Participation Working Group, we conducted extensive outreach to recruit diverse presenters and participants. From November 2017 through August 2019, we made over 40 presentations on the conference to Indigenous organizations, policy offices, and academic organizations (Appendix IV). We invited representatives from over 300 Indigenous organizations; solicited posters on informing policy from 66 organizations focused on the Arctic;

[8]This report follows the Native American Journalists Association and the University of British Columbia's Indigenous Foundations with respect to referencing Indigenous inhabitants of the Arctic. With the exception of direct quotes, *Indigenous Peoples* is used when referring to multiple Indigenous populations, and *Indigenous People* is used when referring to all Indigenous individuals.

and visited academic and government offices in the U.S., Canada, and Norway. We also received considerable help in recruiting presenters and participants from the U.S. Embassy in Canada; the Representative Office of Greenland in Washington, DC; as well as embassies to the United States of Canada, Denmark, Finland, Iceland, and Sweden. We reached out to Arctic scholars in Russia through email and in-person conversations at international meetings.

Given the varied audience, the conference format was modified from that typical of science meetings and included keynote talks; small panels made up of Indigenous, science, and policy voices; a panel focusing on Indigenous Knowledge; a demonstration of a scenario-based table-top exercise; and posters presenting new knowledge and descriptions of the work of Arctic researchers, Indigenous People, agencies, and institutions. All spoken presentations were part of plenary sessions, and long lunch breaks and evening receptions were designed to facilitate poster viewing and discussion among the diverse participants.

Opening session of Arctic Futures 2050 Conference.

Each session had a moderator, a rapporteur, and a question mediator (Appendix I). It was the moderator's responsibility to facilitate discussion among panelists and to help them address five key conference questions:

1. What do we currently know/not know about the changing Arctic and why does it matter?
2. What research is needed to inform responses to Arctic change?
3. What challenges confront policy makers in the rapidly changing Arctic?
4. What tools can facilitate informing decision making?
5. What partnerships are possible between decision makers and knowledge holders?

Most moderators were able to convene their panels for one, two, or three practice sessions in advance of the conference. Those sessions were intended to ensure that the presentations and discussions were accessible to the diverse audience.

A panel discussion on Emerging Research in the Arctic.

All sessions were video recorded, and the rapporteurs took notes designed to highlight especially salient points, particularly with respect to the five key questions. The notes were marked with time stamps to help refer back to the video.

Questions from the audience were relayed electronically to the moderators using the on-line tool Slido. The question mediator filtered out discourteous or off-topic questions and relayed the rest to the moderators on stage, who saw them on a tablet.

All spoken presentations were video recorded and are archived on the SEARCH website where they are organized by the program. Poster abstracts and, if provided, PDFs of the actual posters are also available on the website. In the text that follows, we have referenced specific statements from the spoken or poster presentations. Time stamps, in minutes and seconds, refer to specific locations in the conference videos and are provided to point readers directly to specific presentations. The citations are hyperlinks that will take you directly to the referenced video or poster (if no poster PDF was provided by the authors, the link will take you to the list of poster abstracts alphabetized by title). The conference program can be found in Appendix II. The program, posters, and videos are available online at www.searcharcticscience.org/arctic-2050/conference-2019.

This report, required of SEARCH by our funders, summarizes the conference proceedings with respect to the five key questions posed on the previous page. All conference participants were emailed a link to the draft of this report to review, and a subsequent reminder. Participants provided many helpful edits. Any conclusions or errors however, are attributable to SEARCH and do not necessarily represent the views of the diverse participants in the conference.

RESULTS

The conference was held at the National Academy of Sciences Building in Washington, DC, on 4–6 September 2019. Over 400 people registered, of which 393—representing 15 countries—participated in-person. The conference was live-streamed and viewed from the United States, Canada, United Kingdom, and Norway on 4 September (266 viewers), 5 September (242 viewers), and 6 September (143 viewers). Others viewed the archived video after the conference. Total views as of 17 September 2019 were 1,411. On Twitter, conference content (#AF2050) reached more than 61,496 users.

The in-person participants included 67 Indigenous People (Aleut, Athabascan, Haida, Inuit, Saami, Tlingit, and Yupik); 262 social and natural scientists; 87 policy makers from tribal, municipal, state/provincial, and national governments; and 18 policy influencers. Those numbers total somewhat more than the number of participants, because some participants identify with more than one category (e.g., Indigenous leaders who also are scientists or policy makers).

The diversity of participants and perspectives kept a focus on the human implications of Arctic environmental change as highlighted by Senator Lisa Murkowski (Welcome and Introductory Remarks, 5:03–9:21[9]), Maija Katak Lukin (Melting Ice and Thawing Permafrost, 2:29–15:58), David Behar (Melting Ice and Thawing Permafrost, 52:28–1:05:49), and others. Delbert Pungowiyi of the Native Village of Savoonga, Alaska, was especially eloquent in conveying how rapidly changing ecosystems are threatening the food security and culture of his community (Pungowiyi).

Considering Indigenous and scientific knowledge with specific reference to the human implications was widely—although not universally—appreciated by the participants (Appendix V, post-conference survey charts). Many comments expressed positive sentiments, such as: “The amount of knowledge shared at this conference was amazing! Everyone was experts in their studies or in their lives, and they were able to share their knowledge willingly.” Others commented on the continuing challenges of bringing Indigenous and scientific knowledge together. For example, “The gulf between the scientific community, Indigenous people, and policy makers is bigger than what I had imagined. At the same time, there is a clear indication that [the number of] researchers and practitioners who want to close that gulf and work at the interface is reaching critical mass to make a difference at the national scale.”

Arctic Futures 2050 generated subsequent invitations for follow-up presentations at conferences including the Arctic Domain Awareness Center’s Arctic Symposium (11–15 November 2019), ArcticNet’s Annual Science Meeting (2–6 December 2019), the National Council for Science and the Environment’s Annual Meeting (6–9 January 2020), the Arctic Frontiers (27–31 January 2020), the Alaska Business Forum (3 April 2020), and the Arctic Encounter Symposium (16–17 April 2020[10]).

Foundational Perspectives

Brendan Kelly introduced key topics of the conference before welcoming the three keynote speakers who set the stage by describing Arctic environmental change from evolutionary, Indigenous, and political perspectives (Welcome and Introductory Remarks).

[9]Throughout the report, time stamps show the time on the recording of specific talks or comments in the format HH:MM:SS.
[10]Postponed by pandemic.

Kirk Johnson described past climates and ecosystems of the Arctic in accessible terms and emphasized that we are headed toward a "hothouse world" not seen in the last 250 million years (Past and Future Environments of the Arctic). In a later presentation, Marika Holland added to this timeline emphasizing that change in the Arctic is especially rapid with profound reductions in the cryosphere (sea ice, land ice, and permafrost) concentrated in the past 30 years (How Predictions and Models Inform the Future).

Dalee Sambo Dorough summarized the implications of the geophysical changes in the context of social, cultural, and political conditions faced by Arctic Indigenous Peoples (Indigenous Peoples and Arctic Environmental Change). She highlighted the intricate environmental knowledge contained within the Inuit language. She noted that the rapid changes in the environment are challenging Indigenous food security, and she emphasized the importance of understanding and responding to these changes in the context of Indigenous sovereignty and with Indigenous Knowledge. Dorough defined Indigenous Knowledge as: "a systematic way of thinking applied to phenomena across biological, physical, cultural, and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons, and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation." Unless otherwise noted, we use that definition of Indigenous Knowledge throughout the report, whether referring to the knowledge of specific Indigenous groups or the aggregate knowledge of multiple Indigenous groups.

A keynote presentation on Indigenous Peoples and Arctic Environmental Change *by Dalee Sambo Dorough.*

A poster presentation by Raychelle Aluaq Daniel, Carolina Behe, and Julie Raymond-Yakoubian also characterized Indigenous Knowledge systems as encompassing "both cultural and ecological systems that interlink and support each other. They hold their own methodologies and evaluation processes" (Understanding the Arctic Through a Co-production of Knowledge). A panel on the second day focused on Indigenous Knowledge and emphasized the importance of bringing Indigenous worldviews to policy and science in equitable ways (Indigenous Knowledge Approaches to Inform Policy).

Heather Zichal described policy responses to environmental change with specific reference to institutional and leadership challenges (What Will Policy Makers Need to Know in 2050?). Zichal explained how governments, whether individually or collectively, will need to consider what institutions or actions are needed to keep pace with environmental change. She also pointed out the need to consider how policy makers will take into account data on climate change and how we will hold leaders accountable for collective action.

Answers to Key Questions

Here, we summarize answers to each of the five key questions, based on the spoken and poster presentations. Full details are available via the archived video recordings and posters, or at www.searcharcticscience.org/arctic-2050/conference-2019.

1. What do we currently know/not know about the changing Arctic and why does it matter?

The conference highlighted what we know and do not know about Arctic changes from the perspectives of Indigenous Knowledge holders, Indigenous community members, researchers, and policy makers. The consequences of environmental change in the Arctic were discussed both in terms of global implications and in terms of local impacts, especially for Indigenous communities. As Darcy Peter made clear, "everything impacts everything" (Modeling Risks in the Arctic System, 8:42–11:55).

Sea ice, ice sheets, glaciers, and permafrost are the elements of the Arctic environment most immediately responsive to a warming climate, and our current understanding of the processes and implications of those responses was detailed on the second morning of the conference in a series of talks connecting the local to global consequences. Maija Katak Lukin led off with a uniquely multidimensional perspective (Melting Ice and Thawing Permafrost, 2:29–15:58). She described the changing ecological, cultural, and social environment in northwestern Alaska from her perspectives as an Indigenous member of the community, a scientist, and a resource manager. In both personal and professional terms, Lukin explained the costs of thinning ice in terms of lost lives and increased operating costs to her agency. She contrasted the long history of acquired Indigenous Knowledge in the region with the very rapid loss of the archaeological record to permafrost thaw and coastal erosion.

Three scientists funded through SEARCH followed with overviews of scientific understanding and forecasts of the future of sea ice, land ice, and permafrost. Each summarized changes first at a local scale and then at the global scale. Matthew Druckenmiller summarized the consequences of rapid loss of sea ice, emphasizing impacts to hunters in the Arctic and to weather conditions outside of the Arctic (Melting Ice and Thawing Permafrost, 16:50–27:52). Druckenmiller also emphasized the impacts of diminishing sea ice to marine ecosystems, sea state, coastal erosion, global climate, and communities. Those impacts were detailed further in posters including Zdor, Local and Global: Globalization, Climate Change, and Identity of the Bering Strait Indigenous Communities and Aderhold et al. Sea Ice and the Alaska Transportable Array.

Ted Schuur summarized the work of the broad community of permafrost scientists in understanding and forecasting the future of permafrost in the Northern Hemisphere (Melting Ice and Thawing Permafrost, 30:54–40:20). He described the best estimates of permafrost emissions of carbon dioxide and methane in this century—approximately 150 million metric tons—as a potentially substantial amplifier of atmospheric warming and as needing considerable refinement. Turetsky and Gibson (poster, The Cultural and Climate Importance of Abrupt Permafrost Thaw) demonstrated "how scientific and local knowledge can work together to determine the risks associated with changing permafrost."

Schuur also outlined impacts to infrastructure and how an increase in forest fires affects permafrost ecosystems (Melting Ice and Thawing Permafrost, 30:54–40:20), while Farquharson et al. (poster, Long Term Monitoring of Permafrost Degradation Highlights Two Key Forms of Landscape Response) described the permafrost dynamics that influence damage to the built and natural environments. Douglas et al. (poster, Identifying Risk Factors for Permafrost Thaw and Degradation on U.S. Army Alaska Training Lands) described a framework to support decision making with respect to resource management and infrastructure development in interior Alaska. Turner et al. (poster, How Much Mercury Is in the Yukon-Kuskokwim Delta and Does Fire Influence Its Release?) quantified mercury in the terrestrial environment of western Alaska and examined the role of fire in the release of mercury.

Ted Schuur contributes to a panel discussion on Melting Ice and Thawing Permafrost: Local, Regional, Global Implications.

Twila Moon reviewed the highest level findings of the land ice research community with particular emphasis on current and future additions to sea level rise from melting ice sheets (Melting Ice and Thawing Permafrost, 40:22–52:18). At the same time, she pointed to impacts of ice sheet loss on marine ecosystem structure and ocean circulation patterns. Details of ice sheet melt were described by Leidman (poster, Hydrologic Modeling of Superglacial Streams and Their Impact on Albedo) and Navari et al. (poster, Quantifying Changes in the Surface Mass Balance of the Greenland Ice Sheet via a Novel Data Assimilation and Modeling Approach). A poster from SEARCH's Land Ice Action Team predicted regional variation in future sea level rise in the United States and emphasized heterogeneities related to the original location of ice loss (poster, Scambos et al., Arctic Land Ice Loss is Directly Affecting U.S. Coasts Now, with Growing Future Impacts).

The session ended with an in-depth example of how Arctic ice loss is affecting global society. David Behar focused on the future impacts of sea level rise on the San Francisco Bay region as an example of the still inadequately appreciated, nonlocal consequences of Arctic change. He also highlighted the progress and remaining challenges to making current scientific understanding accessible to resource managers and other decision makers (Melting Ice and Thawing Permafrost, 52:30–1:05:54).

Other Arctic system changes and their implications were illustrated in posters as well. For example, terrestrial changes (e.g., posters Yu et al., Understanding Peat Expansion in Arctic Tundra in a Warming Climate [TundraPEAT]; Zhou, Climate Change Increases Habitat Connectivity in Arctic Alaska); changes in air-ice-ocean interaction (poster, Dewey, Physical Changes in Air-Ice-Ocean Interaction in the Western Arctic); and freshwater changes in the Arctic Ocean (poster, Molodtsova et al., Tracing Freshwater in the Arctic Ocean).

With that common understanding of the drivers of Arctic change and its local and global implications, the conference further examined specific observations of Arctic change, gaps in our understanding of current and future change, and additional emphases on the consequences. The discussion of knowledge gaps addressed both what we do not know about Arctic change and the research needed to respond to the changes. The two related topics will be addressed together in the "What Research is Needed…" section starting on page 16.

Specific Observations of Arctic Change

The conference presenters were consistent in their understanding of increasing atmospheric greenhouse gas concentrations as the main driver of Arctic environmental change (e.g., Holland, How Predictions and Models Inform the Future; Rachold, Informing Arctic Policy). Their presentations also demonstrated, however, that the complexities of the Earth systems are such that the changes are heterogeneous across the Arctic, albeit in ways that are quantifiable and tractable (Holland, How Predictions and Models Inform the Future). Colleen Iversen pointed out that heterogeneous changes in atmospheric warming, terrestrial primary productivity, permafrost thaw, release of soil carbon, and infrastructure damage are well measured and reported (Implications of Changing Terrestrial Ecosystems). Specific local responses to climate warming discussed are summarized below.

While the seasonal duration and volume of sea ice is diminishing in the Arctic Ocean as a whole, rates of change are most dramatic in the marginal seas. In the Barents Sea, for example, comparisons of 2004 and 2012 data show cod have moved north and are using the entire Barents Sea (Reigstad, Barents Sea Fisheries, 5:28–6:21). Implications for the Arctic marine ecosystem include a reduction in Arctic fishes. The ecosystem is changing rapidly in ways that will require additional research and concerted shifts in management. Paul Wassmann emphasized that northward shifts in marine productivity are of immediate concern in Norway, given the tremendous value of Barents Sea fisheries to the Norwegian economy (Implications of Changing Marine Ecosystems).

In the Bering Sea, subsistence harvests have been adversely impacted by dramatic ice losses. Ice-free conditions in February 2018 and again in 2019 were unprecedented, and at least five communities in the northern Bering Sea are now considered to be in imminent danger from climate change (Ahmasuk, Indigenous Knowledge Approaches to Inform Policy; Druckenmiller, Melting Ice and Thawing Permafrost). Deenaalee Hodgdon described high Bering Sea temperatures killing Bristol Bay salmon (Indigenous Knowledge Approaches to Inform Policy). The possible economic impacts also were noted, since about half of U.S. fish landings are off the coast of Alaska (Balton, Barents Sea Fisheries; Noongwook, Indigenous Knowledge Approaches to Inform Policy).

Greenlanders also are experiencing and documenting environmental changes that impact their harvests of marine resources. Lene Holm also emphasized that those impacts are experienced in the context of other pressures such as global responses to the harvest practices of Greenlanders (Implications of Changing Marine Ecosystems).

Thinning of sea, lake, and river ice is also presenting new hazards to travel by Arctic residents, especially during subsistence hunting. Maija Katak Lukin, for example, related the loss in recent years of four family members—all experienced hunters and travelers—when they fell through the ice (Melting Ice and Thawing Permafrost, 2:29–15:58). Darcy Peter echoed safety concerns with the example of Beaver, Alaska, where later fall freeze-ups of the river create hazardous conditions and safety risks for community members hunting and seeking water and fuel (Modeling Risks in the Arctic System, 8:42–11:55).

Diminishing sea ice, combined with stronger and more frequent storms, also leaves Arctic coastal communities vulnerable to increased erosion. A panel on the third day of the conference illustrated the problem with an example from Alaska. Twyla Thurmond described growing up in Shishmaref, Alaska, with the specter of rising sea level and thawing permafrost contributing to the coastal erosion that this year washed out the road to the sanitation plant and, ultimately, may force relocation of the village (Social Implications of Arctic Change).

The panel emphasized that while erosion accelerated by climate change is a threat to the community, it is not happening in a vacuum, and policy approaches that focus only on climate change are likely to miss the importance to community well-being of the interrelated issues of environmental integrity, social well-being, cultural vitality, supportive policies, education, health, justice, and more (Social Implications of Arctic Change; poster, Huntington et al., Climate Change in Community Contexts). Moreover, Elizabeth Marino pointed out the importance of recognizing that the legacy of colonization is “stamped deeply” into scientific and political institutions (Social Implications of Arctic Change).

The problems are not unique to Shishmaref; 86% of Alaska Native communities are experiencing repetitive flooding and/or erosion (Marino, Social Implications of Arctic Change). Similarly, Romanovsky et al. described the potential for serious land subsidence on the North Slope of Alaska by the end of the 21st century, with two-thirds of the permafrost area developing taliks (layers of unfrozen ground surrounded by permafrost) of various depths (poster, Permafrost on the North Slope of Alaska May Start Thawing Much Earlier than Previously Expected).

Land-surface disturbances such as thermokarst failures and tundra fires also were discussed as likely effects of climate change (poster, Kling et al., Causes of Environmental Change Near Toolik Lake, Alaska). These disturbances have the potential to alter land and water makeup, thereby magnifying consequences of climate change. The authors noted that similar environmental changes may be occurring in unmonitored regions of the Arctic, even when the obvious drivers of climate such as air temperature have changed little over time.

Adaptive Responses

Adaptive responses to conserving commercial and subsistence harvests were described, with examples from Norway, the United States, and Canada. Norwegian participants described how scientists, policy makers, and international science bodies work together to ensure that fisheries in the Barents Sea are sustainable (Barents Sea Fisheries). The panelists highlighted that environmental changes are likely to demand greater research and management efforts to continue the sustainable harvests.

An Inupiaq whaling captain from Alaska, a marine resource manager for the U.S. government, and a research scientist presented a protracted—but ultimately successful—case of Indigenous and scientific knowledge informing international policy (Subsistence Whaling). Over decades, the Indigenous Knowledge of bowhead whale behavior and ecology came to be appreciated and incorporated in management decisions by the International Whaling Commission.

The Informing Marine Conservation Areas in the Arctic panel described how the Canadian government collaborated with Indigenous communities to establish a large marine protected area in the Lancaster Sound. The protected area originally proposed by the federal government was greatly expanded and refined through the consideration of Inuit *Qaujimajatuqangit* (traditional knowledge). The final area reflected the importance of protecting Inuit harvesting rights and species at risk, and negotiations took into account food security concerns and economic opportunity for communities (Inutiq, Informing Marine Conservation Areas in the Arctic).

George Noongwook described how Indigenous observations have allowed the people of St. Lawrence Island in the northern Bering Sea to adapt to a lack of winter sea ice (Indigenous Knowledge Approaches to Inform Policy). In the absence of that ice, the island's whalers have developed a successful winter whaling season that provides food and spiritual nourishment. Eduard Zdor also explained how the younger generation of hunters are able to adapt due to the combination of knowledge obtained through "traditional knowledge, personal observations, and globally accepted information" (poster, Local and Global: Globalization, Climate Change, and Identity of the Bering Strait Indigenous Communities).

Min Liew and Ming Xiao highlighted engineering challenges and solutions for permafrost erosion in the Arctic (poster, Permafrost Coastal Erosion Controls and Remediations in the Arctic). The authors noted that current Arctic permafrost erosion controls and remediations are short-term measures that are often ineffective. Their study considered what erosion control measures have been effective for non-Arctic coastlines and their applicability for areas of permafrost erosion along the Arctic coastline.

The full implications of environmental change on Arctic communities in the coming decades remains uncertain. Based on her life experience as a Haida in Alaska and as a policy maker with the state government, Barbara 'Wáahlaal Gíídaak Blake expressed concern that irreversible changes impacting Indigenous culture are close at hand (Implications of Changing Terrestrial Ecosystems). Maija Katak Lukin described environmental changes in northwestern Alaska as causing loss of life, tradition, and cultural heritage (Melting Ice and Thawing Permafrost, 2:29–15:58). Others emphasized the adaptability of Indigenous Arctic Peoples (Dorough, Indigenous Peoples and Arctic Environmental Change; Noongwook, Indigenous Knowledge Approaches to Inform Policy; Retter, Implications of Changing Terrestrial Ecosystems). Those optimistic views notwithstanding, Indigenous Knowledge holders expressed alarm at how fast the environment is changing and what it means for food security and other aspects of their well-being.

Why it Matters Emphasized

Conference speakers described the significance of Arctic environmental change in global and local terms. Global consequences highlighted included amplification of climate warming through reduced albedo (reflectivity of the Earth's surface) and increased carbon emissions from thawing

permafrost (Holland, How Predictions and Models Inform the Future; Melting Ice and Thawing Permafrost). Other global impacts include rising sea levels as ice sheets melt, potential shipping accidents in the Arctic (Inclusive Planning for Arctic Futures), and challenges to the global food supply (Wassmann, Implications of Changing Marine Ecosystems).

Our Resources, Our Home, Our Families, Our Future—posters produced by Indigenous People of Alaska—highlighted why understanding and responding to change matters (Erickson et al., Indigenous Participation Working Group Poster Series). Consequences of environmental change specific to the people living in the Arctic include reduced food security, the physical destruction of communities, and cultural disruptions. George Noongwook emphasized the importance of Indigenous Knowledge in minimizing the time and energy required to feed a community, optimizing social cohesion, and aiding the observation and protection of resources. He further explained the importance of ensuring children and grandchildren "can enjoy the same pride, energy, food that we experience right now" (Indigenous Knowledge Approaches to Inform Policy). Deenaalee Hodgdon expressed the concern that traditional food might not be available to future generations (Indigenous Knowledge Approaches to Inform Policy).

The plight of communities whose physical existence is threatened by climate change was emphasized by the panel discussing Shishmaref, Alaska (Social Implications of Arctic Change). That panel highlighted the cultural disruptions associated with forced displacements. Cultural disruption was further highlighted by Delbert Pungowiyi, who emphasized the relationships between the environment, spiritual beliefs, and cultural identity (Pungowiyi).

Several presenters cited the global nature of environmental change and the increasing impacts on people the world over in calling for collaborative responses (e.g., Behar, Melting Ice and Thawing Permafrost; Carlo, Ways Forward; Kelly, Next Steps; Noongwook, Indigenous Knowledge Approaches to Inform Policy). According to George Noongwook, working together is no longer optional; it is a social responsibility.

A panel discussion on Indigenous Knowledge Approaches to Inform Policy.

2. What research is needed to inform responses to Arctic change?

Information needs were referenced frequently, and the call for continued, new, and altered research was a common thread. Discussions focused on themes of prioritization, such as who should be involved and how research programs should be developed. Specific research needs were described, with several falling under the themes of human health, shipping, and fisheries.

Prioritizing Research Needed

The scale and pace of environmental change was cited in numerous calls for additional research in the natural and social sciences. However, speakers also pointed out the importance of prioritizing future research. In this sense, the answer to the question "what research is needed to inform responses to Arctic change?" hinges heavily on the audience for, and the urgency of, the research. The answers to those questions are important in terms of social justice and efficiency.

Rosemary Ahtuangaruak highlighted a weakness of the current scope of Arctic research by noting that urgent questions most relevant to Arctic communities are not being sufficiently studied (Emerging Research in the Arctic). Others highlighted the need to understand accelerated erosion (Social Implications of Arctic Change), impacts of increased shipping (Ahmasuk, Indigenous Knowledge Approaches to Inform Policy), and human well-being (Social Implications of Arctic Change; Emerging Research in the Arctic). Speakers highlighted such challenges as calling for more immediately relevant research (Bahnke, Urgency of Collaborating to Inform Arctic Policy; Erickson, Considerations for Emerging Research).

The issue of prioritization raised the inevitable tension between research that improves our understanding of the Earth system as a whole and research that addresses immediate challenges faced by people and communities. Gerald Geernaert suggested a framework for prioritizing future research: to what extent is the research new, urgent, and impactful (Emerging Research in the Arctic)? Evaluation of proposals for basic understanding (for example, by the National Science Foundation) typically favors "new" and "impactful" research. Additional consideration of the urgency, however, would place greater emphasis on research addressing immediate challenges. At the same time, addressing immediate challenges calls on knowledge of diverse experts accumulated over many years of basic research (Holland, How Predictions and Models Inform the Future).

In a climate system moving rapidly to a new state (Johnson, Past and Future Environments of the Arctic), observations of past conditions have limited predictive value, and models based on first principles are increasingly important (Holland, How Predictions and Models Inform the Future). Marika Holland highlighted the increasing skill of Earth system models in predicting future environmental states and, at the same time, the potential to further improve the models with inclusion of Indigenous Knowledge. Julie Loisel, Zenon Medina-Cetina, and Darcy Peter presented a risk assessment model using a Bayesian network to formally evaluate the array of interconnected threats and vulnerabilities in the Arctic system and the consequences for people (Modeling Risks in the Arctic System).

Policy makers demonstrated the application of a table-top exercise as a tool for identifying research needs based on specific scenarios (Goodman et al., Inclusive Planning for Arctic Futures). The panel of policy makers, scientists, and Indigenous Knowledge holders was presented with a scenario in which a shipping accident involving a nuclear-powered vessel takes place in the Bering Strait. The panelists' responses demonstrated how scientific and Indigenous Knowledge would be accessed to respond to such an emergency (Appendix VI).

Who Should Be Involved in Arctic Research?

Kaare Sikuaq Erickson considered what the research team of the future would look like and specifically focused on the question of composition: who will be involved and who will be fairly compensated (Considerations for Emerging Research)? Erickson called for a more inclusive and diverse research community in which traditional knowledge is valued intellectually and monetarily and acknowledgements in publications do not distinguish between scientists and Indigenous Knowledge holders.

Others also emphasized the importance of involvement of Indigenous People in research (e.g., Ahmasuk, Inclusive Planning for Arctic Futures; Carlo, Ways Forward; Strawhacker, Considerations for Emerging Research; Murkowski, Welcome and Introductory Remarks, 5:03–9:21). Dalee Sambo Dorough outlined how Inuit traditional knowledge and scientific research are both valid knowledge systems with regard to cooperative research (Indigenous Peoples and Arctic Environmental Change). Nikoosh Carlo also recommended there be more opportunities for Indigenous youth to be involved in Arctic research (Ways Forward).

Austin Ahmasuk offered two examples of research that should involve or be conducted by Indigenous People (Ahmasuk, Indigenous Knowledge Approaches to Inform Policy). As the Coast Guard leads efforts to define vessel routes in the Arctic and areas to be avoided, Indigenous People should consistently be involved in the process. For example, Indigenous People could provide important insight into wave and current patterns for determining where pollutants would be carried after a maritime shipping incident.

In the Barents Sea Fisheries panel, Alf Håkon Hoel called for science cooperation for Arctic matters. The panel highlighted the importance of scientific collaborations at the national level as well as the international level. The panelists also made clear that including international bodies (e.g., International Council for the Exploration of the Sea) in research and management activities can provide valuable scientific integrity and oversight.

The Considerations for Emerging Research panel also considered international cooperation and multidisciplinary research. Justiina Dahl specifically gave the example of MOSAIC—a research project with international researchers drifting with the sea ice for one year to better understand climatic changes. Other international research efforts and networks were highlighted by posters (e.g., Wassmann et al., ARCTOS; Pope and Hinzman, Society Benefits by Connecting Arctic Science Across Countries, Disciplines, Sectors and More (IASC)).

In determining who should be involved with Arctic research, it seems important to consider the end users and those being most affected by environmental change. Hajo Eicken argued that

Indigenous experts, social scientists, and others at a local level will be essential to defining the problems as well as conducting the ensuing research (Emerging Research in the Arctic). Partnerships with other jurisdictions with similar experiences or objectives (e.g., impacted coastal communities of Alaska partnering with impacted coastal towns of Louisiana) were also recommended (Huntington, Social Implications of Arctic Change).

How Should Research Programs Be Developed?

Melanie Bahnke urged researchers to work with communities to understand what research is locally relevant and useful (Urgency of Collaborating to Inform Arctic Policy). Not all research requires such collaboration, but mechanisms to consider and facilitate such collaboration are worth exploring further. It is also important to recognize where efforts to include communities in research, even with good intentions, become burdensome on communities in the Arctic (Erickson and Strawhacker, Considerations for Emerging Research).

The Informing Marine Conservation Areas in the Arctic panel highlighted the benefits of elevating social values. A poster also suggested that we reframe climate change research to also consider health, poverty, education, cultural vitality, equity, justice, and other topics highlighted by people impacted by changes (Huntington et al., Climate Change in Community Contexts). Hajo Eicken suggested a specific avenue for considering these values when he stated that "broader impacts" in National Science Foundation proposals should be a way of linking the social value to the science being done. He suggested that researchers, students, and villages come together to better co-produce the broader impacts (Emerging Research in the Arctic).

During the Emerging Research in the Arctic panel, ideas for creating partnerships and communities of experts were discussed. Hajo Eicken suggested building communities of practice that link different groups of experts. The need for partnerships was illustrated in an example of Japan's space-based CO_2 and CH_4 monitoring that can be deciphered and used by those affected on the ground.

The unintended consequences of funding and reward systems within research programs bears consideration. Lene Holm noted that funding agencies often constrain the types of science that needs to be conducted (Implications of Changing Marine Ecosystems) and thereby minimize support for other ways of knowing.

In the Ways Forward panel, Julienne Stroeve called for a new paradigm that facilitates scientists engaging with local communities, governments, and policy makers. Scientists need to be rewarded for community engagement. At the same time, compensation for Indigenous People sharing knowledge needs to be built into the new framework as well.

Specific Research Needs

Speakers and posters highlighted numerous research needs. Ann Robertson noted the urgent need to study the loss of the cold pool in the Bering Sea (Implications of Changing Marine Ecosystems). Gerald Geernaert made clear that we need to know more about sea ice and permafrost decay, as well as fires, in order to plan responses (Emerging Research in the Arctic).

The Inclusive Planning for Arctic Futures table-top exercise offered insight into research needs, including new mechanisms of storm generation and more basic bathymetric charts. Posters explored climate engineering pathways and the research needed to understand risks, especially to Arctic communities (Buck and Mettiäinen, Solar Geoengineering Could Keep Winters Cool in the European Arctic; Field, Working Together to Save Arctic Ice; Moore, Geoengineer the Ice Sheets to Stop Sea Level Rise).

Human health, fisheries, and shipping received considerable attention. Rosemary Ahtuangaruak outlined research needs for community health concerns, including the need to better understand the health effects of flaring of gas during inversions and the need to understand connections between increases in cases of asthma and oil and gas activities. Ahtuangaruak also asked for research that considers how changes to the land and waters are impacting human health. She specifically highlighted the importance of knowing what parts of animals are consumed by Arctic communities to better understand man-made pollutant concentrations and risks (Emerging Research in the Arctic).

A panel discussion on Social Implications of Arctic Change: The Example of Shishmaref, Alaska.

Arctic shipping was highlighted in panels and posters. Austin Ahmasuk explained the need to better understand the impacts of shipping on Arctic communities and how Arctic communities are being changed by shipping (Indigenous Knowledge Approaches to Inform Policy). Research needs regarding vessel discharge and invasive species were specifically explored through posters (Ahmasuk and Parks, Examining Alaska Native Concerns About Vessel Waste Discharges in the Northern Bering Sea and Bering Strait; Droghini et al., Are Invasive Species a Threat to the Bering Sea?). Other posters highlighted understanding and improving industry practices (Baroud, Infrastructure Development is Critical to Safely Navigating the Arctic; Robbins Gisclair et al., Now is the Time to Advance a Network of Safety Measures for Vessel Traffic in Alaskan Waters; Wilson III, Arctic Indigenous Voices Amidst Increased Polar North Shipping).

Discussion of fisheries also led to defined research needs. Marit Reigstad recommended building more established knowledge on the productivity and life cycles of organisms facing changing temperatures and additional impacts (Barents Sea Fisheries). The consequences of harvests in new areas, e.g., how new trawling will impact benthic communities, also will need attention. Others called for comprehensive ecosystem assessments and long-term time series to track developments in abundance and distributions for the sake of effectively managing fisheries in the Arctic (Balton and Brusendorff, Barents Sea Fisheries).

3. What challenges confront policy makers in the rapidly changing Arctic?

Policy makers will continue to face challenges in the rapidly changing Arctic. Speakers noted how difficult it is for policy makers to keep pace with the rapid and dramatic environmental changes in the Arctic. Other challenges include knowledge and policy alignment, working internationally, and addressing the lack of trust and inadequate representation in the policy making process.

Policy makers and others often find it daunting to navigate the alphabet soup of organizations working on some aspect of the Arctic. Twenty-nine posters presented Arctic organizations explaining their roles in science, policy, or advocacy. Some examples of posters illustrating an organization's role include Divine et al., Co-Production of Knowledge, Tools for Decision-Making...(The BeringWatch Indigenous Sentinels Network); McFarlane et al., Atmospheric Radiation Measurement (ARM) User Facility; Pomerance, The Arctic 21 Network: What is the Arctic We Have to Have to Sustain the Global Climate System?; Students on Ice Alumni Delegation, Students on Ice: Building the Next Generation of Leaders in the Arctic; and Retter, How the Saami Council Informs Arctic Policy.

Keeping Pace with Rapid and Extreme Changes

The changes in the Arctic are rapid and extreme and come with important implications for the people living there (Lukin, Melting Ice and Thawing Permafrost; Johnson, Past and Future Environments of the Arctic). Henry Huntington emphasized that a "climate crisis is here and now" (Social Implications of Arctic Change). Barbara 'Wáahlaal Gíídaak Blake emphasized that Arctic communities are at a tipping point (Implications of Changing Terrestrial Ecosystems).

Speakers observed that policy making is generally not keeping pace with changes in the Arctic (Robertson, Implications of Changing Marine Ecosystems; Zichal, What Will Policy Makers Need to Know in 2050?). Timely policy responses are hindered by political funding cycles (Urgency of Collaborating to Inform Arctic Policy), bureaucratic deliberation (Inutiq, Informing Marine Conservation Areas in the Arctic), and the need to compromise (Solie Jensen, Social Implications of Arctic Change). At the same time, it was noted that the speed with which policies can be implemented varies with their nature. For example, Kirk Johnson noted that climate mitigation will take time to implement, while adaptation measures—including support for adaptation in Arctic communities—can happen more quickly (Keynote Speaker Q&A).

Experts from the policy realm suggested that policy makers gain more awareness of the seriousness of the changes (Ulmer, Informing Arctic Policy) and consider and better understand the rapid pace (Ollikainen, Informing Arctic Policy). Institutional changes to streamline policy making were also suggested (Keynote Speaker Q&A). Creating new institutions to assist with timely responses was recommended (Clement, Informing Arctic Policy) but not uniformly embraced. Several panels instead emphasized making existing institutional efforts more coherent and streamlined (Dorough, Keynote Speaker Q&A; Inutiq, Informing Marine Conservation Areas in the Arctic; Geernaert, Emerging Research in the Arctic).

Knowledge and Policy Alignment

Senator Lisa Murkowski (Alaska) highlighted that policy makers need information from Indigenous People, scientists, and other experts (Welcome and Introductory Remarks). The Urgency of Collaborating to Inform Arctic Policy panel also described how policy alignment can be hampered by poor communication and timing mismatches, as well as gaps in information.

Communication between policy makers and knowledge holders was generally described as ineffective. Rosemary Ahtuangaruak suggested that policy makers, scientists, and Indigenous People need to learn each other's terminology (Emerging Research in the Arctic), and Dalee Sambo Dorough emphasized the need for a unified understanding of what Indigenous Knowledge entails and how it can inform policies (Indigenous Peoples and Arctic Environmental Change).

Respectfully including Indigenous Knowledge is both appropriate and challenging. The wealth of such knowledge systems makes the inclusion of Indigenous Peoples, as well as consent for how Indigenous Knowledge is incorporated, essential (Dorough, Indigenous Peoples and Arctic Environmental Change). At the same time, Gunn-Britt Retter explained that traditional knowledge is dynamic but cautioned that it can become static as soon as it is written (Implications of Changing Terrestrial Ecosystems).

Scientists and policy makers could also improve communication across their spheres. One example—the nature of "uncertainty" and the different uses of the term—was raised (Keynote Speaker Q&A; Robertson, Implications of Changing Marine Ecosystems; Ollikainen, Informing Arctic Policy). The term is often used by scientists in a statistical sense but without clearly distinguishing it from quite different colloquial usages. In everyday usage, "uncertainty" can be synonymous with "unreliability" and "unpredictability." Thus, it is not uncommon for policy makers to question the reliability of models about which they understand there is uncertainty (Robertson, Implications of Changing Marine Ecosystems). Ollikainen suggested scientists alter how they communicate levels of certainty to policy makers (Informing Arctic Policy).

Long coffee breaks and lunches provided time for discussions on topics of the conference, such as aligning knowledge and policy.

The diversity of participants in the conference made clear the demand on knowledge holders to communicate in a variety of ways appropriate to distinct audiences. The demand stems, in part, from geographic heterogeneity in projected environmental changes. Thus, conveying the significance of climate projections will vary from one jurisdiction to the next (Behar, Melting Ice and Thawing Permafrost). For example, the impacts of sea level rise will manifest differently in areas experiencing isostatic rebound than in areas of subsidence. Institutional mechanisms for sharing science with policy makers are fairly well established, but the same cannot be said for sharing

Indigenous Knowledge (Ahtuangaruak, Emerging Research in the Arctic; Ahmasuk, Indigenous Knowledge Approaches to Inform Policy; Carlo, Ways Forward). The need for additional communication pathways is clear; developing capacity for such pathways in Indigenous, policy, and scientific institutions will be an important challenge going forward.

Increased institutional capacity will need to consider gaps in available information and timing mismatches in what is known and what is needed by policy makers. The Sea Ice Prediction Network noted the "gap between what stakeholders find useful and what scientists can provide" (poster, Bhatt et al., Reduce the Gap Between Stakeholder Needs and Seasonal Sea Ice Outlooks). The spatial scale at which change in Arctic sea ice is predicted is coarse relative to the needs of local communities (Druckenmiller, Melting Ice and Thawing Permafrost, 16:50–27:52). Similarly, on the temporal axis, climate models can predict envelopes of future temperature (Holland, How Predictions and Models Inform the Future), but policy makers may seek climate information at finer resolutions (Ulmer, Informing Arctic Policy). Timing mismatches further challenge policy making. Policy may need knowledge input immediately, but the science may not be available (Urgency of Collaborating to Inform Arctic Policy).

Working Across Boundaries

Local impacts will need to be addressed, but the global nature of Arctic change asks policy makers to work across political and cultural boundaries. Justiina Dahl made the point that humankind requires international collaboration at different levels, from the local to the global (Considerations for Emerging Research). Markku Ollikainen noted that the biggest challenges for policy makers relate to international issues (Informing Arctic Policy). The question of how to bring varying international perspectives together was echoed in other sessions (e.g., Dahl, Considerations for Emerging Research; Wassmann, Implications of Changing Marine Ecosystems).

Panelists also highlighted the shortcomings of policies that do not consider specific scenarios or the people impacted. Elizabeth Marino highlighted that U.S. buy-out programs for repetitively flooded areas are designed for individual homeowners but not for communities at risk (Social Implications of Arctic Change). Thus, policy makers must be aware that policies that work in many parts of the world may not work for rural Arctic communities.

Trust and Addressing Justice Issues

A lack of trust in the policy making process can hinder the transfer of information and knowledge. Throughout the conference, there were calls for rebuilding trust between policy makers, scientists, and Indigenous communities (Urgency of Collaborating to Inform Arctic Policy; Ways Forward; Rachold, Informing Arctic Policy). Doing so will require honest and, perhaps, difficult discussions (Ways Forward).

Policy makers and scientists also face the challenge of reflecting on and correcting past wrongdoings. Thus, policy makers need to focus on equitable solutions (Urgency of Collaborating to Inform Arctic Policy) with a new focus on issues of justice (Kelly, Next Steps). Scientists need to acknowledge and compensate Indigenous Knowledge holders in research, and policy makers and scientists need to recognize that colonization is stamped deeply into our power structures (Marino, Social Implications of Arctic Change; Kelly, Next Steps).

4. What tools can facilitate informing decision making?

Presentations and discussions at the conference identified tools that Indigenous People, scientists, and/or policy makers could employ to better inform decision making. The tools that emerged fit into five broad categories: communication, co-production of knowledge, scenarios exercises, modeling, and advances in technology.

Communication

A key objective of the conference was developing more effective and timely ways of communicating what is known about environmental change in the Arctic to policy makers.

Many presenters referred to the need for better communication between Indigenous Knowledge holders and scientists, and others addressed how knowledge holders could better communicate with policy makers.

Examples of Indigenous Knowledge informing scientific research included Inupiaq whalers contributing their knowledge of sea-ice dynamics and whale behavior (Brower and George, Subsistence Whaling), Indigenous Knowledge of ocean circulation brought to scenario exercises (Ahmasuk, Inclusive Planning for Arctic Futures), and Saami knowledge of reindeer informing ecological studies (Retter, Implications of Changing Terrestrial Ecosystems).

The panel considering subsistence whaling in Alaska described Indigenous Knowledge holders and scientific researchers communicating and working well together, but panelists made clear that the current level of cooperation took many years to evolve (Subsistence Whaling). Communication may be key for knowledge exchange, but there are foundational steps, such as relationship building, that are necessary first.

While the benefits of bringing both knowledge systems to bear on understanding environmental change in the Arctic were broadly recognized, Indigenous participants repeatedly reported that Indigenous Knowledge remains undervalued in the scientific community (e.g., Bahnke, Urgency of Collaborating to Inform Arctic Policy; Daniel and Chase, Indigenous Knowledge Approaches to Inform Policy). At the same time, some panelists noted increasing appreciation for Indigenous Knowledge among Arctic researchers (e.g., Turetsky, Urgency of Collaborating to Inform Arctic Policy; Erickson and Strawhacker, Considerations for Emerging Research). While there are clear signs of increasing appreciation of Indigenous Knowledge among Arctic scientists, faster progress was deemed desirable, both as a matter of equity and for the purposes of optimizing our collective ability to inform policy making with knowledge (Melting Ice and Thawing Permafrost; Holm, Implications of Changing Marine Ecosystems).

Several discussions highlighted opportunities and challenges in terms of science informing Indigenous communities. Numerous speakers referenced a legacy of colonialism that contributes to skepticism toward science in some Arctic communities. The benefits of scientific knowledge seem to be better appreciated in communities where co-production of knowledge is practiced through the efforts of individual scientists (e.g., Turetsky, Urgency of Collaborating to Inform Arctic Policy; Marino, Social Implications of Arctic Change) or through locally established science

institutions (e.g., Lukin, Melting Ice and Thawing Permafrost; Ahmasuk, Indigenous Knowledge Approaches to Inform Policy; Brower and George, Subsistence Whaling). Collaborative, community-based coastal monitoring was offered as a mode of understanding and communicating risks and adaptation options for communities (poster, Ravens, Collaboration with Arctic Coastal Communities Facilitates the Determination and Communication of Risk, and Promotes Adaptation). Similarly, a collaborative effort to share weather information with communities was presented as an approach to communicating risk (poster, Hill, Collaboration of the NWS and Rural Communities to Improve Weather and Climate Decisions in Southwest Alaska).

The opportunities and challenges for Indigenous Knowledge holders informing policy makers were evident in several discussions. The Informing Marine Conservation Areas in the Arctic panel detailed the crucial role that traditional knowledge played in determining the boundaries of the protected area as well as establishing a management regime that will protect Inuit harvesting rights as well as species at risk.

Key to the substantial role of Inuit in establishing the protected areas was earnest communication in the form of negotiations between the Qikiqtani Inuit Association, the Government of Nunavut, and Parks Canada. The panel noted that successful negotiation benefitted from a whole-of-government effort mandated by the prime minister. Nonetheless, one of the negotiators noted that the temptation to be celebratory was tempered by the sense that "this system should already be in place in our communities; this economic system should have already been in communities" (Inutiq, Informing Marine Conservation Areas in the Arctic).

Nikoosh Carlo also highlighted the importance of high-level leadership for ensuring that Indigenous Knowledge informs policy (Ways Forward). Even when such leadership or a unified government approach is lacking, others pointed to the importance of increased dialogue between Indigenous People and decision makers (e.g., Thurmond, Social Implications of Arctic Change; Ahtuangaruak, Emerging Research in the Arctic).

The effectiveness of leaders receptive to including Indigenous Knowledge in policy making can also be hampered by less receptive electorates as described by Barbara 'Wáahlaal Gíídaak Blake (Implications of Changing Terrestrial Ecosystems). Therefore, Blake pointed out, communicating the value of Indigenous Knowledge needs to extend beyond elected leaders. Others pointed to the value of increasing youthful and Indigenous voices as participants and leaders of Arctic policy discussions in Alaska and Washington, DC (Hodgdon, Indigenous Knowledge Approaches to Inform Policy; Robertson, Implications of Changing Marine Ecosystems; Carlo, Ways Forward).

Barbara 'Wáahlaal Gíídaak Blake contributes to a panel discussion on Implications of Changing Terrestrial Ecosystems.

The importance of communicating scientific understanding of Arctic change in timely and effective ways to policy makers was emphasized at the outset of the conference (Kelly and Murkowski,

Welcome and Introductory Remarks; Zichal, What Will Policy Makers Need to Know in 2050?). Perhaps inevitably, subsequent discussions of science informing policy focused on how well scientists communicate and how well policy makers listen. Thus, Melanie Bahnke pointed out the wealth of knowledge about Arctic change among Indigenous People and scientists but wondered whether policy makers were listening (Urgency of Collaborating to Inform Arctic Policy). Gifford Wong offered some encouraging examples of the U.S. Congress paying attention to science findings (Urgency of Collaborating to Inform Arctic Policy). Similarly, participants on the panel on Barents Sea fisheries detailed effective use of knowledge to inform fisheries management in Norway (Barents Sea Fisheries). It was noted that often the receptivity of policy makers to Indigenous or scientific knowledge will vary depending on the regime (e.g., Blake, Implications of Changing Terrestrial Ecosystems; Erickson, Considerations for Emerging Research; Ollikainen and Rachold, Informing Arctic Policy).

Similar to the skepticism of Indigenous Knowledge pointed out by Blake, others pointed out that informing policy with science suffers from broadly insufficient science literacy (e.g., Wassmann, Implications of Changing Marine Ecosystems; Erickson, Considerations for Emerging Research). Ole Øvretveit also noted that the media can play a role in the miscommunication of science, especially when a simplified, sensational version of scientific knowledge is elevated (Continuing the Conversation).

Of course, a receptive audience is not sufficient; those presenting knowledge need to do so in ways effective for each audience. Incorporating storytelling was recommended during multiple panels (Urgency of Collaborating to Inform Arctic Policy; Chapin and Ulmer, Ways Forward). Other examples of efforts to communicate Arctic change effectively included posters from Aiken et al. (Arctic Answers: Informing Policy with Science in a Rapidly Changing Arctic); Richter-Menge et al. (NOAA's Arctic Report Card); Curry and Lopez (Context-Rich Images May Help Improve the Communication of Local Information to Outside Audiences); and LaValley et al. (Collaborating Across Boundaries Requires Innovative Tools: IARPC Collaborations as a Case Study).

Co-production of Knowledge

The premise of the conference was that scientists, Indigenous People, and policy makers should all be involved in co-producing the knowledge needed to respond to the changing Arctic environment (Welcome and Introductory Remarks). Policy making in the Arctic needs to be informed by the best available information from science and Indigenous Knowledge (Dorough, Indigenous Peoples and Arctic Environmental Change), and most of the discussions of co-production focused on combining Indigenous Knowledge and western science to bridge gaps in information (Zichal, What Will Policy Makers Need to Know in 2050?) and improve decision making (e.g., Informing Marine Conservation Areas in the Arctic). However, even when Indigenous Knowledge is made readily available, it can be overlooked, with substantial consequences for policy making and the well-being and livelihoods of Arctic Peoples (e.g., Subsistence Whaling).

Raychelle Aluaq Daniel, Carolina Behe, and Julie Raymond-Yakoubian recommended that "multiple knowledge systems and scientific disciplines should be advanced through a co-production of knowledge approach," which they differentiate from a multidisciplinary approach and multi-

evidence-based decision-making (poster, Understanding the Arctic Through a Co-Production of Knowledge). They emphasized that the co-production of knowledge approach requires the knowledge held by Arctic Indigenous Peoples, equitable collaboration, and ultimately "provides the holistic view needed to inform policy, resource management, and conservation."

Dalee Sambo Dorough echoed the sentiment that the approach hinges on the recognition of and respect for Indigenous Knowledge, which has its own methods and evaluation and validation processes (Indigenous Peoples and Arctic Environmental Change). She cautioned against devaluing the perspectives of knowledge holders, categorizing Indigenous Knowledge in strictly scientific terms, or having it translated by scientists. She also made the case that co-production of knowledge requires engagement at every stage of research.

Multiple poster presentations offered insights into co-production of knowledge. Darrel John and coauthors explained the importance of co-production of knowledge regarding community adaptation and relocation activities (poster, Right to Self Determination: Coproduction of Knowledge). Littell et al. pointed out that co-production is capacity and resource intensive and potentially leads to less proactive responses to climate change (poster, Climate Change Collaboration in Alaska: What if Coproduction is a Luxury?). They suggested less-strict co-production where collaborative teams of federal agencies and Alaska Native communities work on climate impacts and science translation. The Interagency Arctic Research Policy Committee outlined revised principles for conducting research in the Arctic that call for respect of culture and knowledge of Arctic communities (Bowden et al., poster, Revised Principles for Conducting Research in the Arctic: Respecting Local Culture and Knowledge). A Canadian approach to co-production of knowledge—with best practices that include meaningful engagement throughout the process, shared control of the process and outcome, and appropriate recognition of Indigenous Knowledge holders—was presented by Jennifer Sokol (poster, Co-Generation of Knowledge from Indigenous and Science Perspectives).

Specific Tools: Observations, Models, Scenarios Exercises, and Technologies

Remote sensing was considered by the panel on emerging research and by several posters. One panel highlighted the need for a better link between remote sensing and the people on the ground (Emerging Research in the Arctic). While the comments were made in relation to partnering more with Indigenous communities, Hajo Eicken pointed to the example of Japan having carbon dioxide and methane monitoring that can be used by people affected (Emerging Research in the Arctic). Craig Tweedie's team presented web-based tools for aggregating and sharing observations of the Arctic environment (posters, Tweedie et al., The Arctic Observing Viewer; Tweedie et al., *The Arctic Research*

Inclusive Planning for Arctic Futures *demonstrated a table-top exercise as a tool for informing decsion making.*

Mapping Application). Canadian scientists described a portal designed to accelerate the transfer of Arctic knowledge to policy makers and other audiences (poster, Lemay et al., *ArcticNet Iris Portal*). Observations in support of decision making were highlighted with specific reference to bathymetric mapping (Inclusive Planning for Arctic Futures), coastal resilience (poster, Brady, Eroding Arctic Coastlines Impact Alaska Native Land and Ocean Uses Beyond the Local Municipalities), breakup of sea ice (poster, Cooley et al., Combining Satellite Remote Sensing and Traditional Knowledge to Understand Mechanisms of Shorefast Ice Breakup in the Arctic), deconflicting maritime traffic (poster, McCammon et al., Using Real-Time Vessel Tracking Information and Subsistence Harvest Area Data for Decision Support), and NASA observations (poster, Delgado Arias et al., ICESat-2 for Arctic Applications).

Marika Holland offered an overview of how models can inform the future (How Predictions and Models Inform the Future). She emphasized the skill of modern models and that even the earliest Earth system models accurately predicted sea ice loss and the resulting amplification of warming. She described how current models can predict climate responses to emissions scenarios, improve understanding of Earth system processes, and quantify the limits of predictability. She also suggested that models could be further improved by including Indigenous Knowledge. Other panels offered insight on how to improve models (e.g., Urgency of Collaborating to Inform Arctic Policy; Emerging Research in the Arctic). Specific modeling efforts described opportunities to understand and predict changes in glaciers (poster, Leidman, Hydrologic Modeling of Supraglacial Streams and Their Impact on Albedo), permafrost degradation (poster, Nicolsky et al., High-Resolution Permafrost Modeling and Mapping in Alaska), and ocean chemistry (poster, Pilcher et al., Modeling Ocean Acidification in the Bering Sea). Loisel et al. also described a novel framework for assessing risks in the Arctic system (poster, Application of a Bayesian Network Framework for Assessing the Vulnerability of Integrated Arctic Systems).

Hajo Eicken spoke of scenarios exercises as effective for social learning and turning research into action (Emerging Research in the Arctic). The scenarios process can offer important insights, and the products can help decision makers consider and plan for plausible futures. Amy Lovecraft et al. described a workshop of diverse participants that considered the question “What information is needed to successfully respond to changes in Arctic environments by 2050?” (poster, Participatory Scenarios Methods and Outcomes: SEARCH Workshop April 2017). The workshop produced seven plausible futures in the Arctic. Petrov and Rozanova-Smith presented scenarios for Russia’s Arctic in 2050. Academics, local officials, Indigenous leaders, and business representatives were convened to produce those scenarios (poster, Russia’s Arctic Faces Uncertain Futures). Wee et al. illustrated the use of a structured decision-making approach to integrating “social, economic, and environmental dimensions of a climate adaptation plan” (poster, A Values-Focused Approach to Science-Informed Decision-Making for Arctic Communities).

Technologies already available or needed were discussed as pathways for improving decision making (e.g., Stroeve, Ways Forward). Tabisola et al. described novel technologies to supplement traditional ocean observational techniques (poster, Innovative Technologies to Advance Ocean Observation). The table-top exercise considering a plausible nuclear shipping incident highlighted gaps in knowledge and capabilities, including the need for response sensor technology (Inclusive Planning for Arctic Futures).

5. What partnerships are possible between decision makers and knowledge holders?

The importance of partnerships was a common conference theme. In an impassioned speech, Delbert Pungowiyi urged that the crisis requires "all hands on deck" (Pungowiyi, 15:20–15:46). George Noongwook explained that sharing resources and getting along with people is key to responding to change (Indigenous Knowledge Approaches to Inform Policy). Kevin McNamee highlighted the benefits of partnering with well-meaning, dedicated people (Informing Marine Conservation Areas in the Arctic). SEARCH demonstrated the power of partnering with policy makers to make science actionable at the local and federal levels (Melting Ice and Thawing Permafrost; poster, Aiken et al., Arctic Answers: Informing Policy with Science in a Rapidly Changing Arctic).

Others outlined examples of past and present partnerships, as well as the need for new or improved partnerships crossing countries, disciplines, jurisdictions, and age groups (Barents Sea Fisheries). There was an emphasis on the need to appropriately partner with Indigenous People (poster, Daniel et al., Understanding the Arctic Through a Co-Production of Knowledge); Subsistence Whaling; Informing Marine Conservation Areas in the Arctic; poster, Sokol, Co-Generation of Knowledge from Indigenous and Science Perspectives).

International Cooperation

The Barents Sea Fisheries panel illustrated the history of successful fisheries management in the Barents Sea while also exploring the current, climate-induced changes to those fisheries. Panelists discussed the fisheries management cooperation between Norway and Russia, as well as the role of the International Council for the Exploration of the Sea (ICES) in overseeing the science.

The panel's conclusions have implications for future fishing activity in the Arctic. Other regions are and will experience changes in species distributions and will need to ask questions of international cooperation, science, and management decisions. While the moratorium on Arctic fishing halts commercial activity in the Arctic Ocean for the time being, themes discussed during the Barents Sea Fisheries panel will be of interest, with international cooperation as a foundational focus.

In a later panel focused on marine change, Paul Wassmann again highlighted how Norway's and Russia's cooperation on fishing is working well but also suggested the need for more cooperation across the Arctic (Implications of Changing Marine Ecosystems). He specifically called for pan-Arctic integration of knowledge and cooperation (Wassmann, Implications of Changing Marine Ecosystems). Heather Zichal reminded the audience of the difficulty of having governments work together across boundaries (What Will Policy Makers Need to Know in 2050?). Others noted that, no matter the difficulty, international cooperation was essential to addressing environmental changes in the Arctic (Dahl, Considerations for Emerging Research).

Local to Global Exchange

Partnerships spanning the global to local level were discussed. Learning from other jurisdictions was a focus during the panel on Melting Ice and Thawing Permafrost. The notion that changes in

the Arctic will impact lower latitudes implied the need to partner and communicate with scientists and decision makers at different scales (Behar, Melting Ice and Thawing Permafrost). Twyla Thurmond and Henry Huntington discussed the possibility for the community of Shishmaref and people in Louisiana to jointly explore common experiences and community responses to climate change (Social Implications of Arctic Change).

Scientific and Indigenous Knowledge

Two case history panels explored partnerships between scientists, Indigenous Knowledge holders, and decision makers. One told the story of a whaling moratorium in the 1970s, which impacted the Inupiaq whalers living in northern Alaska who had been harvesting whales for more than 1,000 years prior to the moratorium decision (Subsistence Whaling). The Inupiaq harvest of bowhead whales is closely tied to cultural identity and food security, compounding the impact of the decision (Brower, Subsistence Whaling).

A panel discussion on Subsistence Whaling: Indigenous and Scientific Knowledge Informing Policy.

The Inupiaq whalers questioned the decision, believing that there were more bowhead whales than scientists had estimated. Leaders in the Indigenous and scientific communities, however, insisted on continuing dialogue. In those exchanges, the scientists learned much from the Indigenous Knowledge holders and eventually confirmed what the whalers already knew; there were 10 times as many whales as previously estimated (George, Subsistence Whaling). Ultimately, a memorandum of understanding between the federal government and Indigenous Knowledge holders allowed the Inupiaq to continue hunting and allowed for highly successful research collaborations between the whalers and research scientists that continue to this day (Tillman, Subsistence Whaling).

Other panels emphasized partnering with those who will be directly impacted by decisions and science. A basic improvement will come from researchers doing a better job of listening to Indigenous People (Strawhacker, Considerations for Emerging Research). Beyond this, there needs to be a recognition that Indigenous Peoples must play a direct role as knowledge holders in matters that will affect their integrity (Dorough, Indigenous Peoples and Arctic Environmental Change). Hajo Eicken recommended partnerships to find a better link between remote sensing science and the people on the ground (Emerging Research in the Arctic). The idea was further exemplified in the table-top exercise, with the need to include Indigenous People in the planning, discussions, and research regarding disasters (Ahmasuk and Schubert, Inclusive Planning for Arctic Futures).

The final case history panel described the establishment of *Tallurutiup Imanga*, a national marine conservation area in Canada. Sandra Inutiq explained that the conservation area had to be

negotiated with the Inuit and an impacts and benefits agreement had to be signed (Informing Marine Conservation Areas in the Arctic). The process officially included the Government of Canada, Qikiqtani Inuit Association, and the Government of Nunavut. Indigenous Knowledge and science were used to decide boundaries, and Inuit values such as food security and needs for infrastructure and job security were addressed. Kevin McNamee explained Prime Minister Justin Trudeau's administration's goal of reconciliation with the Inuit as key to the establishment of the protected area (Informing Marine Conservation Areas in the Arctic).

The mode of partnership could be better consultation, but generally, equity and balancing the decision-making power between entities will be necessary. There is a need for "genuine partnerships" (Dorough, Indigenous Peoples and Arctic Environmental Change). Partnerships can form easily and organically, but some will be shaped by necessity; a necessity to address new multifaceted concerns and do right by including those who have been historically excluded. The panels on subsistence whaling in Alaska and on establishing the marine conservation area in Canada highlighted that negotiations were not easy.

Including Youth

Multiple panelists spoke on the need to work with and elevate youth and highlighted the lack of youth on panels. As the generations to be inheriting much of the challenges stemming from climate change, it makes sense to increase their ability to engage. Delegates from the Students on Ice Foundation presented on these ideas, making clear that inclusion of youth in policy decisions will lead to richer, more effective policy (poster, Students on Ice Foundation, Are you Practicing Meaningful Youth Engagment?).

Youth need to know of opportunities and would benefit from being paired with mentors (Hodgdon, Indigenous Knowledge Approaches to Inform Policy). Increasing opportunities for Indigenous youth to engage in science was recommended (Carlo and Chapin, Ways Forward). Ann Robertson suggested exchanges whereby U.S. students, including Indigenous youth, could experience and contribute to policy making in Washington, DC (Implications of Changing Marine Ecosystems).

What Else is Needed to Better Inform Policy with Knowledge

Kaare Sikuaq Erickson also noted the importance of considering who was not part of the conference discussion (Considerations for Emerging Research). Speakers commented on the desirability of more participation by policy makers (Erickson, Considerations for Emerging Research), industry (Kelly, Next Steps), and others in the private sector (Informing Arctic Policy).

Panelists reflected on what is needed for partnerships. Some highlighted that relationship building can take time and trust (Urgency of Collaborating to Inform Arctic Policy; Carlo, Ways Forward). Reconciliation with Indigenous Peoples and equitably including Indigenous worldviews in policy making were also emphasized (Daniel, Indigenous Knowledge Approaches to Inform Policy).

The format and venue of collaborative convenings can also make a difference in reaching objectives and should be given adequate consideration (Carlo, Ways Forward). On a broader scale, there was a call for knowledge hubs to facilitate partnerships and a new paradigm that allows for engagement with local communities, governments, and policy makers (Chapin, Ways Forward).

TOPICS NOT ADDRESSED

Arctic Futures 2050 focused on how to enhance collaboration among Arctic scientists, Indigenous People, and policy makers in the context of rapid environmental change. Inevitably, some areas were inadequately addressed. For example, education plays a critical role in preparing scientists, Indigenous People, and policy makers. Education received some attention (Husebekk, Arctic Research and Education for the Future; poster, Singh et al., Smart Educative Tools for Climate Change Action: A Case Study), but less than deserved. Also, funding mechanisms to facilitate the tools and collaborations outlined were only generally discussed (Stroeve, Ways Forward). The recommendation to work with the private sector was made by one panel (Informing Arctic Policy) and participants commenting on the conference.

NEXT STEPS

Arctic Futures 2050 created a necessary but insufficient opportunity for funders and practitioners of Arctic research, Indigenous Knowledge holders and leaders, and policy makers from various levels of government to explore opportunities to better inform policies with scientific and Indigenous understanding. The conference will have been successful to the degree to which it contributes to better and sustained co-production and use of knowledge. These proceedings and the post-conference evaluation (Appendix V) make clear the will to advance co-production by scientists, Indigenous People, and policy makers. At the same time, it is clear that more difficult discussions are needed in the pressure of challenging times (Kelly, Next Steps).

By nature, new and uncertain conversations—such as are needed among Arctic scientists, Indigenous People, and policy makers—need to be balanced. Each party needs to convene some of the conversations in ways and venues that work best for them. Thus, SEARCH is eager to continue to be a part of the ongoing conversations while mindful that it needs to make room for others to lead.

SEARCH will extend the conversation through this report and reflections in future meetings and publications. In the short term, we are sharing lessons from Arctic Futures 2050 at other conferences. Already, we have responded to requests to discuss those lessons at the Bering Sea Elders Workshop in Nome, Alaska; the ArcticNet Annual Science Meeting in Halifax; the American Geophysical Union Annual Meeting in San Francisco; the National Council for Science and the Environment Annual Meeting in Washington, DC; Arctic Frontiers 2020 in Tromsø; the Alaska Forum on the Environment in Anchorage; the Alaska Business Forum; and the Arctic Encounter Symposium in Seattle. Those diverse meetings represent important opportunities to continue advancing toward true co-production of knowledge.

SEARCH hopes that the Indigenous and policy-making communities advance the conversations in fora appropriate to them. The Bering Sea Elders Workshop in September 2019 was a positive step in bringing Indigenous and scientific knowledge together, as demonstrated in a SEARCH produced video.

The Bering Sea Elders Workshop also led to publication of Voices from the Front Lines of a Changing Bering Sea: An Indigenous Perspective for the 2019 Arctic Report Card. We are aware of at least two publications on Arctic Futures 2050 planned by Indigenous participants. In 2020, SEARCH intends to publish a reflection on lessons learned on making science actionable and working with Indigenous communities.

LESSONS LEARNED

Bringing together nearly 400 Arctic scientists, Indigenous Knowledge holders and leaders, and policy makers from around the Arctic required a compelling intellectual premise and meeting considerable funding and logistical challenges. Because SEARCH hopes that others will choose to convene similar gatherings in the future, we offer here observations on some of the challenges.

Format of Meeting

Meeting formats vary widely within and between different disciplines of scientists, Indigenous Peoples, and policy makers. SEARCH and our partners explored formats that could effectively bridge the diversity of Arctic Futures 2050 participants and that might be appropriate to a three-day gathering of 400 or more people. It was obvious that no one format would suffice, so we focused on four modes, all in plenary sessions: (1) well-honed talks; (2) discussions within panels comprising an Indigenous Knowledge holder, a scientist, and a policy maker; (3) posters in a "big ideas" format designed to convey take-home messages clearly, succinctly, and in nontechnical language; and (4) unstructured but intentional discussions in breaks and receptions.

We limited traditional lecture-style presentations to a few topics necessary for common understanding, and we asked those speakers to hone their presentations with the diverse audience in mind. Responses from participants in formal and informal evaluations were overwhelmingly positive. Participants reported those talks were engaging and helpful for establishing common understanding. The limited number of lectures was appreciated by the audience, but it did require turning away a great many potential speakers. Another drawback to the approach was that it required considerable investment by the presenters in the form of preparation and practice. From an organizer's perspective, the approach was rewarded by the quality of presentations, but identifying, vetting, and working with the presenters in advance required considerable time and effort.

Small panels, each lasting 45 minutes, were the dominant mode of presentation. The panels were intentionally small, for the most part comprising three panelists and a moderator. That structure maximized the opportunity to hear scientific, Indigenous, and policy perspectives equally on each topic, and the audience found the conversational approach engaging and informative. Again, the preconference effort to identify panelists and convey what was required was substantial. Moreover, the moderators devoted substantial time and effort to convening the panelists for one to three practice sessions before the conference. Many panelists were obliging in finding the time for those sessions; others could not fit it into their schedules. Especially challenging was convening panelists who spanned 10 or more hours in time zones.

An additional challenge was that the small panels meant that some panelists felt burdened by a feeling that they had to represent large constituencies. In one instance, we combined what originally was conceived to be three panels into a single panel. The benefit was the opportunity to integrate across three related topics, but at the cost of more voices—five presenters and a moderator—and a longer overall duration (90 minutes). On the other hand, changing the mode of presentation from time to time seemed to help keep the audience's attention.

The amount of advance time and effort notwithstanding, we concluded that the panel approach was appropriate for our goals. Most important for Arctic Futures 2050, we believe, was balancing the voices of scientists, Indigenous People, and policy makers. It also was desirable to balance the panels in terms of gender, age, and nationality, and an additional challenge of small panels was that the number of panelists was less than the number of demographic categories over which we sought balance. As a practical matter, we found it important to continually revisit questions of balance. As the availability of individual moderators, panelists, and speakers inevitably changed, the balance shifted on multiple axes, and we would have to reconfigure the entire agenda. Our heavy demands on the time of moderators and panelists contributed, in some instances, to the inability of some to commit.

Receptions and poster viewing sessions were held to encourage conversations.

The emphasis on conversational panels limited the number of presenters that could speak in the plenary sessions. We accepted that limitation on the conviction that it would be compensated by the depth of interactions, and we believe that it was. Nonetheless, we also wanted to provide opportunity for specific knowledge to be presented, and we chose posters to meet that need. In recognition of the diverse backgrounds of conference participants, we asked presenters to employ the "big ideas" format that focused on conveying in accessible terms one or a few main ideas while eschewing the details of the research. The format proved useful for conveying Indigenous and scientific knowledge, and feedback on the format was largely positive. We and at least some of the poster presenters were disappointed in the engagement with the posters. To maximize opportunities for viewing, we intentionally displayed all posters throughout the conference and encouraged viewing during 90-minute lunch breaks as well as during two evening receptions. The lure of food, side meetings, and informal conversations, however, was strong and worked against visits to the poster rooms. We considered and rejected engineering participants' break times to more strongly encourage poster viewing. Such an effort probably would have been worthwhile. Nonetheless, the posters shared substantial knowledge that was important in informing the conference discussions and goals judging from participant comments.

An important goal of the conference was to initiate or extend relationships between scientists, Indigenous People, and policy makers, and we recognized the value of convenings (e.g.,

Gordon Conferences) that mix formal sessions with opportunities for unstructured conversations. Thus, we scheduled long lunch breaks and two evening receptions. For the most part, the strategy proved effective, and many reported having new insights based on those unstructured conversations. There were, however, unexpected challenges to maintaining those conversations. Miscommunication with the venue staff truncated one reception earlier than advertised. Several subgroups participating in the conference proposed to use the lunch periods and/or receptions for side meetings, as is common at large conferences. Most were dissuaded when we explained the intent of the "open" periods. Future convenings intending to maximize unstructured but important interactions might anticipate and identify times and venues for side meetings and be explicit about the intent of the built-in time for unstructured conversations.

Meeting Logistics

SEARCH chose the conference location and venue based on maximizing participation. We sought participation by scientists, Indigenous Peoples, and policy makers from all Arctic nations. Among the important policy makers sought were U.S. federal employees, most of whom are restricted in travel by funding and a prohibition on accepting outside travel support. Washington, DC offered a location that would maximize federal employee participation and minimize overall travel costs for participants coming from North America, Europe, and across the Arctic. We focused our fundraising on providing travel support for Arctic Indigenous and early career participants who otherwise could not have participated. The Polar Research Board of the National Academy of Sciences kindly arranged for the meeting space at no cost to the conference, further freeing funds to support travel for Indigenous and early career participants.

The venue had the additional advantages of easy access to international airports and public transportation. It also allowed us to arrange visits to congressional offices for some participants. At the same time, the meeting space was considered unwelcoming by some participants, and some participants expressed concerns about food waste and plastics associated with the catered meals.

SEARCH wanted to maximize the opportunity participants had to put questions to speakers and panelists. We considered three approaches: (1) passing microphones to people raising their hands, (2) having questions submitted on cards passed to the stage, and (3) having questions submitted via an internet-based application software. Past experience demonstrated that the microphone and handwritten questions minimize the number of questions being addressed for several reasons, so we used Slido, an online tool. As it turned out, the meeting hall's internet experienced interruptions during much of the conference, so we also employed handwritten questions. When the internet was fully functional, questions were immediately and legibly conveyed to the moderators via a question moderator who was tasked with filtering out disrespectful or off-topic questions. The handwritten questions were slower to convey than the internet questions but faster than would have been possible passing microphones among 400 people. Passing a microphone offers the potential for longer exchanges between a questioner and those on stage but at the cost of still fewer people being able to participate. The microphone approach offers advantages in smaller meetings.

Appendix I
Conference Contributors

The conference was made possible by many people who provided their expertise and time to planning and execution. SEARCH greatly appreciates their contributions.

Conference Organizing Committee
Erica Goldman, National Council for Science and the Environment
Marika Holland, National Center for Atmospheric Research
Brendan Kelly, SEARCH Executive Director (Conference Chair)
George Kling, University of Michigan
Francis Wiese, Stantec Inc.
Helen Wiggins, Arctic Research Consortium of the U.S.

Conference Support
Judy Fahnestock, Arctic Research Consortium of the U.S.
Andrea Fisher, SEARCH
Brit Myers, Arctic Research Consortium of the U.S.
Joed Polly, Arctic Research Consortium of the U.S.
Zeb Polly, Arctic Research Consortium of the U.S.
Tohru Saito, International Arctic Research Center, University of Alaska Fairbanks
Lisa Sheffield Guy, Arctic Research Consortium of the U.S.
Asma Shethwala, Arctic Research Consortium of the U.S.
Helen Wiggins, Arctic Research Consortium of the U.S.

Indigenous Participation Working Group
Rosemary Ahtuangaruak, Nuiqsut Council
Carolina Behe, Inuit Circumpolar Conference Alaska
Nikoosh Carlo, CNC North Consulting
Malinda Chase, Alaska Climate Adaptation Science Center; Aleutian Pribilof Islands Association
Raychelle Aluaq Daniel, SEARCH Science Steering Committee
Kaare Sikuaq Erickson, UIC Science
Andrea Fisher, SEARCH
Brendan Kelly, SEARCH
Julie Raymond-Yakoubian, Kawerak, Inc.

Arctic Futures Working Group
Waleed Abdalati, Cooperative Institute for Research in Environmental Studies
David Balton, Wilson Center
Leah Braithwaite, University Laval
Jennifer Francis, Woods Hole Research Center
Laurie Geller, National Academy of Sciences
Scott Gende, National Park Service
Erica Goldman, National Council for Science and the Environment

Sherri Goodman, Wilson Center
Marika Holland, National Center for Atmospheric Research
Stephanie Holthaus, The Nature Conservancy Alaska
Henry Huntington, Huntington Consulting
Brendan Kelly, SEARCH
George Kling, University of Michigan
Amy Lovecraft, University of Alaska Fairbanks
Emily Osborne, Arctic Program, NOAA
Lori Parrott, Sandia National Laboratory, U.S. Department of Energy
Theodore Scambos, National Snow and Ice Data Center
Christina Schädel, Northern Arizona University
Ted Schuur, Northern Arizona University
Mike Sfraga, Wilson Center
Amanda Staudt, National Academy of Sciences
Leigh Welling, National Park Service Alaska Region
Francis Wiese, Stantec
Helen Wiggins, Arctic Research Consortium of the U.S.
Cathy Wilson, Los Alamos National Laboratory, U.S. Department of Energy

Moderators

Betsy Baker, North Pacific Research Board
David Balton, Wilson Center
Malinda Chase, Alaska Climate Adaptation Science Center; Aleutian Pribilof Islands Association
Raychelle Daniel, SEARCH Science Steering Committee
Erica Goldman, National Council for Science and the Environment
Sherri Goodman, Wilson Center
Geoff Green, Students on Ice Foundation
Marika Holland, National Center for Science and the Environment
Priyanka Hooghan, Committee on Science, Space, & Technology, U.S. House of Representatives
Henry Huntington, Huntington Consulting
Brendan Kelly, SEARCH
George Kling, SEARCH Science Steering Committee
Julie Loisel, Texas A&M University
James Townsend, Center for a New American Security
Fran Ulmer, U.S. Arctic Research Commission
Francis Wiese, Stantec, Inc.
Gifford Wong, IDA Science and Technology Policy Institute

Rapporteurs

Betsy Baker, North Pacific Research Board
Sara Bowden, Interagency Arctic Research Policy Committee

(Rapporteurs continued from previous page)
Julie Brigham-Grette, Polar Research Board, U.S. National Academy of Sciences
Marika Holland, National Center for Science and the Environment
Igor Krupnik, Smithsonian Institution
Irina Overeem, SEARCH Science Steering Committee
Christina Schädel, Northern Arizona University
Sandy Starkweather, National Oceanic and Atmospheric Administration
Leigh Welling, National Park Service

Question Mediators

Kimberly Aiken, GRID-Arendal
Danielle Dickson, North Pacific Research Board
Andrea Fisher, SEARCH
Amy Kirkham, Senator Murkowski's Office
Twila Moon, National Snow and Ice Data Center
Darcy Peter, University of Alaska Fairbanks
Jen Pizza, National Oceanic and Atmospheric Administration
Allen Pope, International Arctic Science Committee
Julie Raymond-Yakobian, Kawerak, Inc.
Jessica Rhode, Interagency Arctic Research Policy Committee

Appendix II
Conference Program

Program Online:
https://www.searcharcticscience.org/arctic-2050/conference-2019/program

Day 1	WEDNESDAY, 4 SEPTEMBER
7:30 am	Registration (Lobby) and Light Breakfast (Great Hall)
SETTING THE STAGE (All plenary sessions will be held in the Auditorium)	
8:30 am	Welcome and Introductory Remarks *Brendan P. Kelly, SEARCH* *The Honorable Lisa Murkowski, U.S. Senator, Alaska (Video Remarks)*
8:55 am	Past and Future Environments of the Arctic *Kirk Johnson, Smithsonian's National Museum of Natural History*
9:15 am	Indigenous Peoples and Arctic Environmental Change *Dalee Sambo Dorough, Inuit Circumpolar Council*
9:35 am	What Will Policy Makers Need to Know in 2050? *Heather Zichal, Blue Prosperity Coalition*
9:55 am	Questions and Answers - All Keynote Speakers
10:15 am	**Break (Great Hall)**
10:45 am	Urgency of Collaborating to Inform Arctic Policy *Moderator: Brendan P. Kelly, SEARCH* *Panel: Melanie Bahnke, Kawerak, Inc* *Merritt Turetsky, University of Guelph and University of Colorado Boulder* *Gifford Wong, IDA Science and Technology Policy Institute* *A Native leader from Alaska, an Arctic ecologist, and a policy maker will discuss key challenges to knowledge holders informing policy and to policy makers informing research.*

MAKING SCIENCE AND INDIGENOUS KNOWLEDGE ACTIONABLE – I	
11:30 am	Implications of Changing Terrestrial Ecosystems *Moderator: George Kling, University of Michigan* *Panel: Barbara 'Wáahlaal Gîidaak Blake, First Alaskans Institute* *Colleen Iversen, Oak Ridge National Laboratory* *Gunn-Britt Retter, Saami Council* *A terrestrial ecologist, a member of the Saami Council, and a policy expert with the First Alaskans Institute (formerly with the State of Alaska Governor's office) describe changes in Arctic terrestrial ecosystems, policy implications, and information needs.*
12:15 pm	Guidance to posters and lunch (Francis Wiese)
12:30 pm	**Lunch and Posters (Boxed lunches available in the Great Hall; Posters displayed in the West Court, East Court, and Lecture Room)**
2:00 pm	Barents Sea Fisheries: Informing Management Under Rapid Change *Moderator: Ambassador David Balton, Wilson Center* *Panel: Anne Christine Brusendorff, International Council for the Exploration of the Sea* *Alf Håkon Hoel, UiT-The Arctic University of Norway* *Marit Reigstad, UiT - The Arctic University of Norway* *A case history illustrating how scientists and policy makers work together to ensure that fisheries in the Barents Sea are sustainable. The panelists will discuss how environmental changes are likely to demand greater research and management efforts to continue the sustainable harvests.*
2:45 pm	**Break (Great Hall)**
3:15 pm	How Predictions and Models Inform the Future *Marika Holland, National Center for Atmospheric Research* *How do we use mathematical models to predict future states of the environment? A description in plain English of how climate and sea ice models work, their power, and their limitations.*
4:00 pm	Modeling Risks in the Arctic System *Moderators: Julie Loisel, Texas A&M University & Zenon Medina Cetina, Texas A&M University* *Panel: Darcy Peter, University of Alaska Fairbanks* *The Arctic Bayesian Network is a model that integrates Indigenous knowledge, scientific data, engineering assessments, and the expert opinion of governance bodies. The model is intended to illuminate the interconnectedness of the Arctic System and assess risk of natural and anthropogenic systems.*
4:45 pm - 7:00 pm	**Reception (Hosted bar and light appetizers in the Great Hall) and Posters (Posters displayed in the West Court, East Court, and Lecture Room)**

Day 2	THURSDAY, 5 SEPTEMBER
7:30 am	Registration (Lobby) and Light Breakfast (Great Hall)
IMPLICATIONS OF CHANGE AND WHAT WE NEED TO KNOW	
8:30 am	Melting Ice and Thawing Permafrost: Local, Regional, and Global Implications *Moderator: Gifford Wong, IDA Science and Technology Policy Institute* *Panel: David Behar, San Francisco Public Utilities Commission* *Matthew Druckenmiller, National Snow and Ice Data Center* *Maija Katak Lukin, United States National Park Service* *Twila Moon, National Snow and Ice Data Center* *Ted Schuur, Northern Arizona University* *SEARCH scientists, an Arctic resident, and a public utilities program director from outside the Arctic will describe how and why sea ice, permafrost, and land ice are changing across the Arctic, as well as the consequences of these changes on local communities to global society.*
10:00 am	**Break (Great Hall)**
10:30 am	Indigenous Knowledge Approaches to Informing Policy *Moderators: Raychelle Aluaq Daniel, The Pew Charitable Trusts &* *Malinda Chase, Alaska Climate Science Center; Aleutian Pribilof Islands Association* *Panel: Austin Ahmasuk, Kawerak, Inc.* *Deenaalee Hodgdon, Brown University* *George Noongwook, Savoonga Whaling Captains Association* *This panel will describe the interconnected and holistic nature of Indigenous knowledge that includes people as part of the ecosystem. Embedded within these knowledge systems are frameworks for evaluating evidence.*
11:15 am	Implications of Changing Marine Ecosystems *Moderator: Francis Wiese, Stantec* *Panel: Lene Kielsen Holm, Greenland Institute of Natural Resources* *Ann Robertson, Office of U.S. Senator Murkowski (Alaska)* *Paul Wassmann, UiT - The Arctic University of Norway* *A resource manager, a policy staff member, and a marine ecologist describe the socioecological implications of a rapidly changing Arctic marine ecosystem. They will discuss information needs at different scales, lessons learned concerning informing policy with scientific and Indigenous knowledge, as well as shaping a conceptual model for the one Arctic Ocean ecosystem.*
12:00 pm	**Lunch and Posters (Boxed lunches available in the Great Hall; Posters displayed in the West Court, East Court, and Lecture Room)**

USING WHAT WE KNOW - I	
1:30 pm	Inclusive Planning for Arctic Futures: Demonstrating a Scenario-Based Table-Top Exercise *Moderators: Sherri Goodman, Wilson Center and James Townsend, Center for a New American Security* *Panel: Austin Ahmasuk, Kawerak, Inc.* *Lawson Brigham, University of Alaska Fairbanks* *Phil Brown, NORAD & USNORTHCOM J74* *Mike Farrar, Air Force Weather Operations* *Jennifer Francis, Woods Hole Research Center* *Randy Gauntt, Sandia National Laboratories (retired)* *Shannon Jenkins, U.S. Coast Guard* *David Kennedy, National Oceanic and Atmospheric Administration (NOAA)* *Randy "Church" Kee, Arctic Domain Awareness Center* *Rebecca Pincus, U.S. Naval War College* *Mark Rosen, The CNA Corporation* *Gail Schubert, Bering Straits Native Corporation* *Zachary Schulman, U.S. Coast Guard* *Phillip Thorne, U.S. Coast Guaard* *Jon White, Consortium for Ocean Leadership* *This session will demonstrate how a table-top exercise can be used to bring science, Indigenous, and policy communities together to develop information, ideas, and proposed actions to drive future research directions, policy initiatives, and planning for emergency response in the Arctic. Peter Davies, Sherri Goodman, and James Townsend collaboratively developed the table-top scenario for the session.*
3:00 pm	**Break (Great Hall)**
MAKING SCIENCE AND INDIGENOUS KNOWLEDGE ACTIONABLE – II	
3:30 pm	Arctic Research & Education for the Future *Anne Husebekk, UiT - The Arctic University of Norway*
3:40 pm	Subsistence Whaling: Indigenous & Scientific Knowledge Informing Policy *Moderator: Brendan P. Kelly, SEARCH* *Panel: The Honorable Harry Brower, Jr., Mayor of the The North Slope Borough, Alaska* *Craig George, Alaska North Slope Borough* *Michael Tillman, U.S. Marine Mammal Commission* *An Inupiaq whaling captain, a marine resource manager, and a research scientist present a case history of Indigenous and scientific knowledge informing international policy.*
4:25 pm - 7:00 pm	**Reception (Hosted bar and light appetizers in the Great Hall) and Posters (Posters displayed in the West Court, East Court, and Lecture Room)** • **Yupik drumming and singing by George Noongwook of Savoonga, Alaska**

Day 3	FRIDAY, 6 SEPTEMBER
7:30 am	Registration (Lobby) and Light Breakfast (Great Hall)
USING WHAT WE KNOW - II	
8:30 am	Informing Marine Conservation Areas in the Arctic *Moderator: Geoff Green, Students on Ice Foundation* *Panel: Sandra Inutiq, Qikiqtani Inuit Association* *Kevin McNamee, Parks Canada Agency* *This case history will describe how science and Inuit Qauijimajatuqangit (traditional knowledge) informed creation of large marine protected areas in the Canadian Arctic and will inform future management and protection of Inuit harvesting rights and species at risk.*
IMPLICATIONS OF CHANGE AND WHAT WE NEED TO KNOW - II	
9:15 am	Social Implications of Arctic Change: The Example of Shishmaref, Alaska *Moderator: Henry Huntington, Huntington Consulting* *Panel: Lindsay Solie Jensen, Office of U.S. Senator Dan Sullivan (Alaska)* *Elizabeth Marino, Oregon State University* *Twyla Thurmond, Native Village of Shishmaref* *Arctic change is not happening in a vacuum, and policy approaches that single out climate change are unlikely to succeed or to help Arctic peoples. The case of Shishmaref, Alaska, illustrates that community well-being is interconnected with environmental integrity, social well-being, cultural vitality, supportive policies, education, health, justice, and more.*
10:00 am	**Break (Great Hall)**
10:30 am	Emerging Research in the Arctic *Moderator: Betsy Baker, North Pacific Research Board* *Panel: Hajo Eicken, International Arctic Research Center, University of Alaska Fairbanks* *Gary Geernaert, Department of Energy* *Rosemary Ahtuangaruak, Nuiqsut* *In this forward-looking panel, natural and social scientists ask, "what will life be like in the Arctic and how will it change between 2025 and 2050?" What Earth systems science and resilience capacity building will be required?*
11:30 am	Considerations for Emerging Research: Capacity and Scale *Moderator: Priyanka Hooghan, Committee on Science, Space, & Technology* *Justiina Dahl, Swedish Polar Research Secretariat* *Kaare Sikuaq Erickson, Ukpeaġvik Iñupiat Corporation* *Colleen Strawhacker, U.S. National Science Foundation* *Following the discussions from the previous session, this panel further considers emerging research in the Arctic and asks how that research can best meet the needs of Arctic communities and policy makers.*

12:45 pm	*Delbert Pungowiyi, Native Village of Savoonga*
1:00 pm	**Lunch and Posters (Boxed lunches available in the Great Hall; Posters displayed in the West Court, East Court, and Lecture Room)**
TAKING STOCK	
2:00 pm	Continuing The Conversation *Ole Øvretveit, Arctic Frontiers, Akvaplan-niva*
2:10 pm	Informing Arctic Policy *Moderator: Erica Goldman, National Council for Science and the Environment* *Joel Clement, Harvard Kennedy School* *Markku Ollikainen, University of Helsinki* *Volker Rachold, Alfred Wegener Institute, German Arctic Office* *Frances Ulmer, U.S. Arctic Research Commission* *Three scientists with deep experience informing heads of state will discuss the common challenges and opportunities as well as those unique to their governments.*
3:10 pm	Ways Forward *Moderator: Fran Ulmer, U.S. Arctic Research Commission; Harvard's Belfer Center* *Panel: Nikoosh Carlo, CNC North Consulting* *Terry Chapin, University of Alaska Fairbanks* *Julienne Stroeve, University of Manitoba; National Snow and Ice Data Center* *This panel will review the conference discussions in the context of other programs and initiatives and explore ways to build on conference discussions.*
4:10 pm	Next Steps *Brendan P. Kelly, SEARCH*

Appendix III
Conference Funders and Partners

The Arctic Futures 2050 conference was funded with support to SEARCH and ARCUS from:

National Science Foundation (Arctic Sciences Section)
U.S. Department of Energy
National Aeronautics and Space Administration (Terrestrial Ecology and Cryospheric Science Programs)
National Oceanic and Atmospheric Administration
Gordon and Betty Moore Foundation
Pew Charitable Trusts
American Geophysical Union
Bureau of Ocean Energy Management
International Arctic Science Committee

In-kind support was provided by partner organizations:

Alaska Climate Center
Aleutian Pribilof Islands Association
Arctic Frontiers
ArcticNet
CNC North Consulting
Embassy of Canada, Washington, DC
Embassy of Denmark, Washington, DC
Embassy of Finland, Washington, DC
Embassy of Iceland, Washington, DC
Embassy of Sweden, Washington, DC
Greenland Representation in Washington, DC
Interagency Arctic Research Policy Committee
Inuit Circumpolar Council-Alaska
Kawerak, Inc.
National Council for Science and the Environment
Students on Ice Foundation
UIC Science
U.S. Park Service
Wilson Center's Polar Initiative

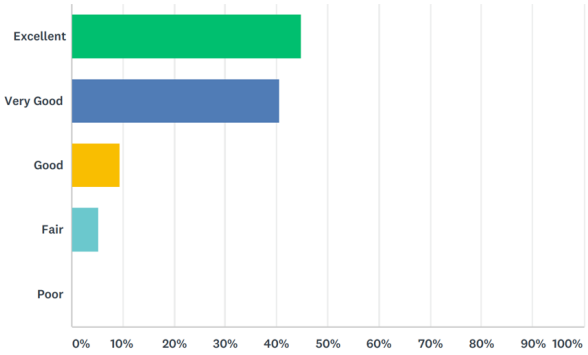
Appendix IV
Outreach Presentations in Advance of Arctic Futures 2050 Conference

DATE	AUDIENCE	LOCATION
1 Oct 2018	IARPC Staff Group	Washington, DC
5 Oct 2018	agencies, Indigenous, policy, public	webinar
9 Oct 2018	Senator Murkowski staff	U.S. Senate
9 Oct 2018	Senator Sullivan staff	U.S. Senate
9 Oct 2018	Congressman Young staff	U.S. House of Representatives
15 Nov 2018	agencies, Indigenous, policy, public	webinar
1 Dec 2018	AGU Fall Meeting town hall	Washington, DC
1 Dec 2018	ArcticNet Annual Meeting	Ottawa
14 Dec 2018	Senator Murkowski staff	U.S. Senate
9 Jan 2019	Natl Council for Sci. and Environ. Annual Conf.	Washington, DC
15 Jan 2019	Alaska Eskimo Whaling Commission	Anchorage
15 Jan 2019	International Arctic Research Center researchers	Fairbanks
21 Jan 2019	Community of Utqiagvik	Utqiagvik
22 Jan 2019	Mayor Brower (Utqiagvik) and staff	Utqiagvik
23 Jan 2019	Mayor Berkowitz (Anchorage) staff	Anchorage
25 Jan 2019	Kawerak president and staff	Nome
25 Jan 2019	Caleb Scholars staff	Nome
25 Jan 2019	Mayor Beneville (Nome)	Nome
7 Mar 2019	Arctic Frontiers	Tromsø
7 Mar 2019	UiT Arctic University of Norway	Tromsø
8 Mar 2019	Fram Centre	Tromsø
8 Mar 2019	Norwegian Polar Institute	Tromsø
11 Mar 2019	University of Oslo	Oslo
12 Mar 2019	Research Council of Norway	Oslo
15 Mar 2019	IARPC Permafrost Collaboration Team	Washington, DC
19 Mar 2019	Senator Murkowski and staff	U.S. Senate
20 Mar 2019	ArcticNet Board	Montreal, QC
21 Mar 2019	Polar Research Board	Washington, DC
22 Mar 2019	Science attaches for Canada, Iceland, Denmark, Finland, Greenland, Sweden	Finnish Embassy
22 Mar 2019	Senator Sullivan and staff	U.S. Senate
27 Mar 2019	IARPC Marine Ecosystems Group	webinar
1 May 2019	IASC Working Groups	Arkhangelsk, Russia
3 Jun 2019	IARPC Staff Group	Washington, DC
11 Jun 2019	Congressman Young and staff	U.S. House of Representatives
14 Jun 2019	Comm. on Sci., Space, & Tech., U.S. House of Representatives	Washington, DC
14 Jun 2019	Fran Ulmer, Arctic Research Commission	Washington, DC
24 Jul 2019	All IARPC meeting	Washington, DC

Appendix V
Post-Conference Survey Results

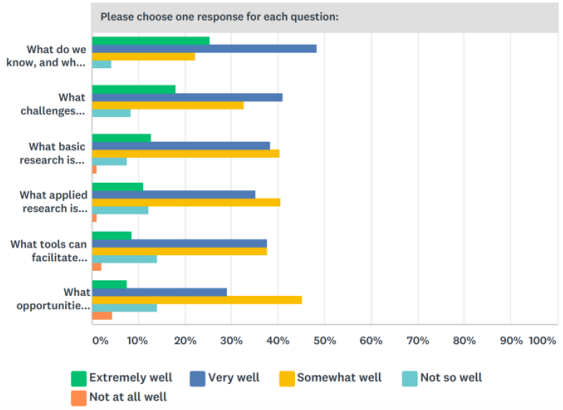
Overall, how would you rate the conference?

Answered: 96 Skipped: 0



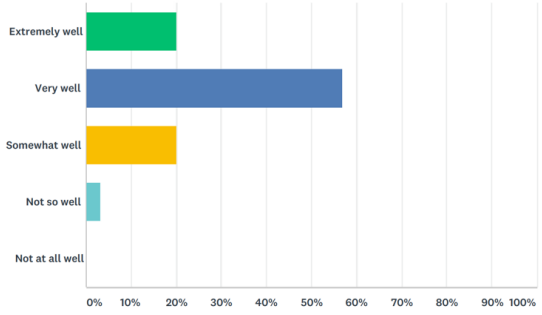
How well did the conference address the key conference questions:

Answered: 95 Skipped: 1



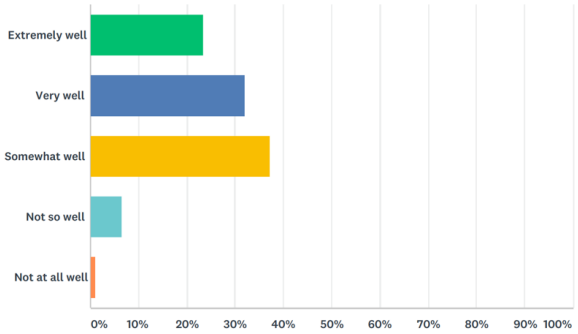
How well did the plenary sessions advance the conference discussions?

Answered: 95 Skipped: 1



How well did the poster sessions advance the conference discussions?

Answered: 94 Skipped: 2



Appendix VI
Table-Top Exercise Report

The Inclusive Planning for Arctic Futures*: Demonstrating a Scenario-Based Table-Top Exercise* session at Arctic Futures 2050 Conference was led by a Woodrow Wilson Center team. The team produced a report on the session:

Goodman, S., P. Davies, J. Townsend, and M. Maddox. 2019. Inclusive Planning for Changing Arctic Futures: Demonstrating a Scenario-Based Discussion. A Tabletop Exercise Demonstration at the Arctic Futures 2050 Conference.

Here, we offer an excerpt from the full report provided by Goodman, et al.

Key Takeaways:
The following key takeaways reflect six themes that emerged over the course of the tabletop exercise. These themes provide a potential framework for future work related to nuclear shipping incidents in the Arctic. In-depth information for each of these themes is contained in the detailed tabletop discussion notes in Appendix IV.

The initial operational response to any major Arctic shipping incident will follow well established search and rescue protocols, and will be led by the United States Coast Guard. Other cooperating agencies will be quickly brought into the response at local, regional, state and federal levels. Communications infrastructure in this region is, and will likely continue to be, quite sparse and communications effectiveness is likely to be an issue, unless communication infrastructure needs are addressed. The DoD response network is effective and has been exercised. However, exercise of DoD response capabilities for winter conditions has been very limited. Severe Arctic conditions, large distances and lack of communications and response infrastructure will present major challenges.

If a nuclear incident of this type occurs, it is likely to become an incident of national significance and an incident command structure will be established. A nuclear accident in shallow water has the potential to become a very serious incident. In a serious incident with a nuclear powered ship, losing cooling water circulation in the reactor with the ship in shallow water has the potential for very serious consequences. If there is a release, iodine and cesium-137 will be the major elements of concern, iodine in the near term and cesium in the long term. Cesium is important with respect to long term contamination of food sources etc. US nuclear plants conduct probabilistic risk assessments in order to develop an understanding of what could happen in incidents like this, and what is most important. In order to prepare for response to a nuclear shipping incident, some form of risk study for these scenarios should be completed.

Important predictive capabilities for situational awareness and informing response decisions does not currently exist for winter Arctic conditions. If a radioactive release were to occur, it will be important to quickly get trajectory analysis information for predictions of where wind and water currents could potentially carry contaminants. This capability must be in place long before an incident occurs. The climatology of Arctic storms is changing. The tracks of storms are changing. With more open water storms are behaving differently. The Arctic used to be a “graveyard for storms.” We are now seeing storms that not only not die but actually regenerate in Arctic waters because their warming allows the storm to gain energy. We need a better observation network. Modeling requires good data. This is beyond the capability of any single agency. There must be a single, common model.

The US Arctic currently lacks multiple facets of both operational and research infrastructure needed to provide key elements of both short and long-term response to a major winter-time incident. From an operational perspective, only 6% of Arctic waters are charted to modern standards. High quality charts will be very important to enable effective response. Other infrastructure will be important as well, including: an Arctic port, communications infrastructure, and other important maritime support capabilities. There are very few ways to bring in response teams and the support to sustain them, not to mention if there was a mass casualty incident. From a research perspective, both near- and long-term decisions must be based on solid science. Understanding the near-term states of winter atmospheric and ocean conditions will be very important. Currently we have very limited observation and research infrastructure capable of producing the kind of data required to build effective predictive atmospheric and ocean circulation models, especially under winter conditions. In order to have the information necessary to plan for and respond to a major contamination incident, we must have rigorous understanding of changing Arctic ecosystems, and the impacts on migrating species.

There must be a strong indigenous voice and participation in the response effort. Arctic indigenous communities have important knowledge to inform response decisions and must be part of response decisions. By 2050 there is a need to transform indigenous emergency response infrastructure so that is is integrated into other infrastructure elements. Indigenous communities have some of the highest percentages of former US military personnel. Local communities will be ready to step forward to assist with response and will be most directly affected. This kind of incident would potentially have impact on subsistence level food supplies. It is important that we understand the impact of indigenous peoples' experience of historical incidents will have on this situation. Radioactivity moves quickly into human population because the food chain is shorter. The legacy of US nuclear activity in the Arctic region needs to be remembered and there needs to be transparency. Project Chariot by the US government exposed indigenous people to radiation with a near total lack of transparency. Hence, planning for a response to such a future incident should recognize the need to build trust with local communities. Transparency will be key.

This incident has the potential to rapidly become a major international incident. Communication lines with Russian (and other country's) institutions will be important. Confidence Building Measures (CBM) could help to prepare both the US and Russia for a future contingency. Current US Coast Guard relationships and regular communications with the Russian coast guard equivalent addresses current states of shipping and navigation in the region. However, both the US and Russia would rise to a high level of decision making an incident with a nuclear component. As these channels of communication and decision making are not regularly needed today, they would benefit from planning and exercise for future contingencies. In the Cold War, this type of contingency planning with Russia took the form of "Confidence Building Measures". As the incident is elevated to the Russian military and other agencies,communications could be come very difficult. Multiple different and powerful parts of Russian government may become involved: For example, Yamal and Gazprom (very powerful); ROSATOMFLOT directs vessels; Ministry of Transport sets standards. Relationship with the Russian Coast Guard may not be adequate because they do not have the authority that our US Coast Guard does. The US and Russia should develop procedures and plans to exchange appropriate information and open needed communication channels.

ARCTIC FUTURES 2050

CONFERENCE REPORT