



IARPC envisions a prosperous, sustainable, and healthy Arctic understood through innovative and collaborative research coordinated among Federal agencies and domestic and international partners.

Interagency Arctic Research Policy Committee

2015 Biennial Report

Interagency Arctic Research Policy Committee

2015 BIENNIAL REPORT

Committee on Environment, Natural Resources, and Sustainability

National Science and Technology Council

OCTOBER 2015

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive branch coordinates science and technology policy across the diverse entities that make up the Federal research and development enterprise. A primary objective of the NSTC is establishing clear national goals for Federal science and technology investments. The NSTC prepares research and development strategies that are coordinated across Federal agencies to form investment packages aimed at accomplishing multiple national goals. The work of the NSTC is organized under five committees: Environment, Natural Resources and Sustainability; Homeland and National Security; Science, Technology, Engineering, and Math (STEM) Education; Science; and Technology. Each of these committees oversees subcommittees and working groups focused on different aspects of science and technology. More information is available at www.WhiteHouse.gov/administration/eop/ostp/nstc

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC. More information is available at www.WhiteHouse.gov/administration/eop/ostp

About the Interagency Arctic Research Policy Committee

The Arctic Research and Policy Act of 1984 (ARPA), Public Law 98-373, July 31, 1984, as amended by Public Law 101-609, November 16, 1990, provides for a comprehensive national policy dealing with national research needs and objectives in the Arctic. The ARPA establishes an Arctic Research Commission (ARC) and an Interagency Arctic Research Policy Committee (IARPC) to help implement the Act. IARPC was formally created by Executive Order 12501. Its activities have been coordinated by the National Science Foundation (NSF), with the Director of the NSF as chair. On July 22, 2010, President Obama issued a Memorandum for the Director of OSTP making NSTC responsible for IARPC with the Director of the NSF remaining as chair of the committee.

About this Document

This report was developed by the IARPC Collaboration Teams as a summary of accomplishments since the release by the NSTC of the *Arctic Research Plan: FY2013-2017*. It is intended to inform the NSTC, Congress, and the public about progress in implementing the research plan. This report is published by OSTP.

Copyright Information

Cover: A fishing boat passes in front of an iceberg calved from Jakobshavn Glacier, Ilulissat, Greenland (Photo: Nick Salava). Top Left: Anthropologist Stephen J. Langdon with George Ramos Sr., Tlingit elder and science project adviser, en route to visit traditional seal camp locations in Disenchantment Bay, neat Yakutat, Alaska. (Photo: Aron Crowell, Copyright 2011, Smithsonian Institution). Researchers prepare for an early spring snowmobile traverse (Photo: UMIAQ, LLC). The USCGC R/V HEALY works alongside the Canadian Coast Guard cutter *Louis S. St-Laurent* (Photo: USCG). Walruses near Svalbard Archipelago, Norway (Photo: Roy Stehle).

Members of Congress, the Arctic Research Community, and Interested Parties:

We are pleased to forward the Interagency Arctic Research Policy Committee (IARPC) 2015 Biennial Report. This report, called for in the Arctic Research Policy Act of 1984 (15 U.S.C. § 1408), highlights progress on implementing the five-year Arctic research plan released by the Office of Science and Technology Policy in February 2013. Sixteen Federal agencies collaborated through IARPC to implement the Arctic research plan and to enhance interagency communication and coordination to leverage emerging research and data to greatest effect. This report describes important knowledge gained through IARPC-enabled work conducted over a two-year period ending in autumn 2014. The report also forecasts activities to be addressed through the IARPC framework over the next several years.

The rapid pace of change in the North has tremendous implications for human well-being, national security, transportation, and economic development well beyond the Arctic Circle. Having entered a two-year chairmanship of the Arctic Council in late spring 2015, the United States has an opportunity to establish scientific research priorities for the Arctic region that will enhance our ability to forecast change and to support policy and management decisions based upon solid scientific findings.

IARPC's Federal agencies collaborate with partners in the State of Alaska, local communities, indigenous groups, academia, and the private sector to facilitate implementation of the plan. The effort ensures that scientific research in the Arctic addresses the interests and needs of those communities, and that scientific talent wherever it exists is tapped to provide the global community with the best information about this rapidly transforming region of our planet.

This IARPC Biennial report does not cover all Federally-funded research activities carried out in the Arctic, but rather provides a snapshot of the programs undertaken to implement the five-year research plan. These efforts ranged from improving access to scientific data to conducting field studies of the Arctic marine ecosystem in the Beaufort Sea north of Alaska.

We appreciate your support as we continue to implement the plan and coordinate our broad Federal research efforts in the Arctic region.

Thomas Burke	Tamara Dickinson	Kathryn Sullivan
EPA	OSTP	NOAA
Co-Chair, CENRS	Interim Co-Chair, CENRS	Co-Chair, CENRS

Blank, back of letter

Table of Contents

Acknowledgements

Simon Stephenson, Executive Director IARPC, defined the vision for this report and inspired the team's efforts to communicate it. Brendan C. Kelly, Former Executive Director IARPC, provided guidance from 2010 to 2014. NSF Division of Polar Programs provided financial support for the development and printing of this report.

Sincere thanks are due to the IARPC team members for their contributions to enhancing interagency research collaborations and also to the IARPC team leads who helped focus the considerable energy produced by collaboration team activities. Named writers within this document generated and reviewed content.

Editorial team: Sara Bowden, Executive Secretary IARPC; Sandy Starkweather, Implementation Scientist IARPC; and Anjuli Bamzai, Program Director, Climate and Large-Scale Dynamics, Geosciences Directorate, NSF

Additional writing, editing and conceptual development: Penelope (Kip) Rithner

Graphic design: Stacie McMullen, Edge Design Studio, Inc., with contributions from Mark Lesh Design

For centuries, Alaskans have navigated coastal waters in skin-covered boats called umiaqs, hunting for sea life. How is the warming Arctic changing marine ecosystems, and what impacts can be expected for Arctic communities that rely on these waters for sustenance? IARPC encourages research collaborations to advance Arctic knowledge. Better understanding may help people predict and prepare for the future. Photo: Faustine Bernadac

IARPC: Setting a Coordinated Research Agenda

The Arctic environment is undergoing rapid transition as sea and land ice diminish, with tremendous implications for natural environments, human well-being, national security, transportation, and economic development. The United States and the other Arctic nations require strong, coordinated research efforts to understand and forecast changes in the Arctic.
—John P. Holdren, Letter to Congress presenting *Arctic Research Plan: FY2013–2017*[1]

In the 2 years since Dr. Holdren, Director of the White House Office of Science and Technology Policy, called for "strong, coordinated research efforts" in the Arctic, scientists have gained new understanding of rapid Arctic change—and of the "tremendous implications" thereof.

The Arctic Report Card for 2014[2] describes significant climate and environmental change in the Arctic: for example, increases in air and sea temperatures, with accompanying changes in sea ice cover. The report includes impacts to animals adapted to living in the polar habitat.

Implications for people living in the changing Arctic are, not surprisingly, significant. Some living south of the Arctic Circle may perceive the region as a beautiful and isolated place, a closed landscape with little impact on theirs. The distance allows the Arctic to become "like a snow globe on a shelf," as Senator Lisa Murkowski (Alaska) offered in a

[1] This plan was developed by the Interagency Arctic Research Policy Committee, which reports to the NSTC Committee on Environment, Natural Resources, and Sustainability (CENRS), Office of Science and Technology Policy, Executive Office of the President.
[2] "The Arctic Report Card: Update for 2014." www.arctic.noaa.gov/reportcard

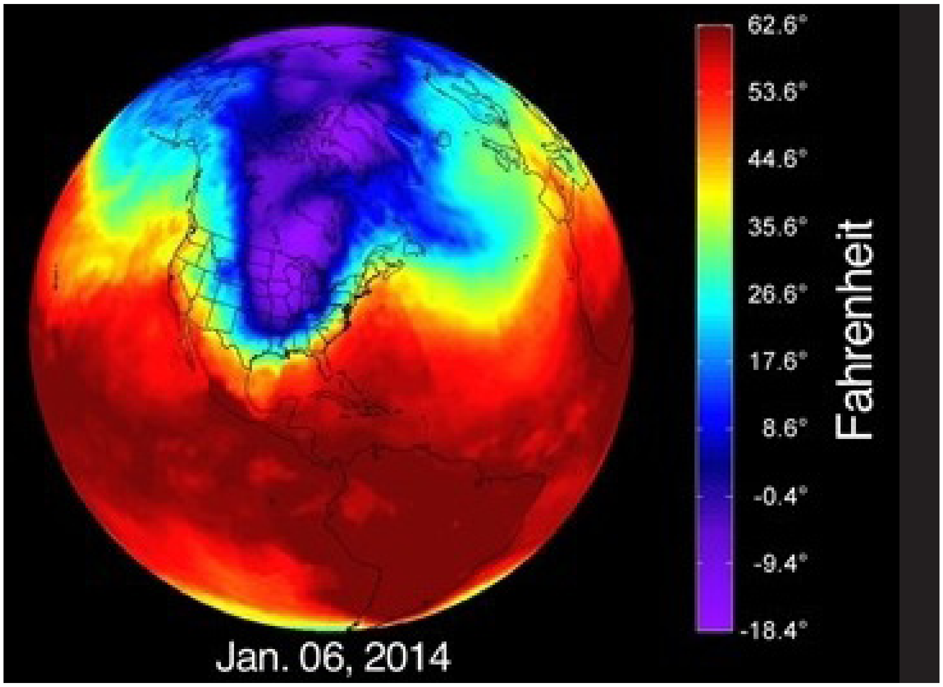


FIGURE 1
A GLOBAL SYSTEM
Big temperature differences between the mid-latitudes and the Arctic keep a cold air current circling the North Pole in winter, locking cold air over the pole. Scientists are studying whether warming temperatures in the Arctic can weaken that stream, causing it to wobble and spill frigid air into lower latitudes, as indicated by dark blue and purple areas, above. Low temperature records in the United States during the winter of 2014—including over 50 such records on January 6 alone—may have been caused by the dipping jet stream. SOURCE: NASA's Goddard Space Flight Center

recent article encouraging economic development for Arctic states.[3] But the scientific consensus suggests that the Arctic system is part of a global system—and so what happens in the Arctic impacts us all on time scales of days to decades (FIGURE 1).

Federal agencies providing national security, resource management, human services, and scientific discovery are challenged by the prevailing shift to a warmer, ice-diminished Arctic. They are galvanized by rapid environmental changes to accelerate the pace of research and knowledge growth through cooperation, data sharing, and the use of a variety of methods and tools.

Promoting such cooperation is the aim of the Interagency Arctic Research Policy Committee, or IARPC. Congress created IARPC to strategically enhance the effectiveness of Federal Arctic research efforts through interagency collaboration and cooperation with the state of Alaska and other relevant participants. IARPC is composed of principal members from 16 Federal agencies or offices[4] working in the Arctic. Through meetings, webinars, workshops, and an interactive website, IARPC provides a forum to leverage resources and maximize research outcomes.

IARPC helps the Federal Government coordinate a response to emerging opportunities in the Arctic. The United States chairmanship of the Arctic Council, lasting from May 2015 until April 2017, is one such opportunity. The Council was created in 1996 as a forum to promote cooperation and dialogue among the eight countries whose territories extend into the Arctic (Canada, Denmark [via Greenland], Finland, Iceland, Norway, Russia, Sweden, and the United States). The Arctic Council primarily focuses on fostering environmental stewardship and sustainable development. Chairmanship from 2015 to 2017 gives the United States a unique opportunity to shape the agenda and direction of the Arctic Council's work.

This biennial report describes how IARPC-enabled activities have addressed research ranging from coordinated field deployments to data sharing and interoperability. These activities generate knowledge that will inform key national priorities such as homeland security; energy, water, and food security; transportation infrastructure maintenance; and natural resources protection.

This report presents current progress on implementing a cross-agency Arctic research plan, developed by IARPC. The plan is informed by the 2013-2014 U.S. Arctic Research Commission's[5] Goals Report,[6] which focuses on the following goals:

1. Observe, understand, and respond to environmental change
2. Improve Arctic people's health
3. Understand natural resources
4. Advance civil infrastructure research
5. Assess indigenous languages, identities, and cultures

Published by the Office of Science and Technology Policy (OSTP) in February 2013, IARPC's *Arctic Research Plan FY13-17*[7] describes a vigorous research agenda to understand the Arctic's most vulnerable systems.

[3] www.adn.com/article/20141119/lisa-murkowski-alaska-must-lead-us-takes-arctic-council-chair

[4] These agencies are: Office of Science and Technology Policy (OSTP), Department of Commerce (DOC), Department of Defense (DOD), Department of Energy (DOE), Department of Health and Human Services (HHS), Department of Homeland Security (DHS), Department of Interior (DOI), Department of State (DOS), Department of Transportation (DOT), Environmental Protection Agency (EPA), Marine Mammal Commission (MMC), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF, Chair), Office of Management and Budget (OMB), Smithsonian Institution (SI), and United States Department of Agriculture (USDA). United States Arctic Research Commission (USARC), ex-officio.

[5] www.arctic.gov/index.html
[6] www.arctic.gov/reports_goals.html
[7] www.WhiteHouse.gov/sites/default/files/microsites/ostp/2013_arctic_research_plan.pdf

Who's Participating in IARPC Implementation?

NON-LEAD AGENCY | **LEAD AGENCY** (shown in bold)

Collaboration Team	Participating U.S. Federal Agencies																Non-Federal Partners
	DHS	DOC	DOD	DOE	DOI	DOS	DOT	EPA	HHS	MMC	NASA	NSF	OSTP	SI	USARC	USDA	
Arctic Communities	1	3	1		7	2			1		2	4	1	**4**		4	29
Arctic Data		7	4	1	14			1			**6**	3	1		2	2	15
Arctic Observing Systems	1	7	3	2	11						**2**	3	1		1		29
Atmosphere		9	1	**3**			1	1			6	2	1				13
Chukchi & Beaufort Seas		18	4	1	**10**					1	3	2	1		2		**15**
Distributed Biological Observatory		**9**	5		5					1	4	2	1		2		**14**
Glaciers & Fjords		2	1	3	1						3	**5**	1				8
Human Health	6	1	1		2			1	**7**		2	2	1		1		12
Modeling		7	2	**4**	6		1				6	2	1			2	9
Sea Ice	1	16	**7**	2	3						3	3	1				19
Terrestrial Ecosystems		1	1	3	**11**						5	2	1				16
Wildfires		2	1	1	**9**						3	1	1			1	**9**

FIGURE 2
TEAM EFFORTS
IARPC's 12 collaboration teams focus on research areas identified in the 5-year plan that involve interinstitutional and interdisciplinary cooperation. To achieve the richest perspective available, IARPC welcomes diverse input from State, local, and tribal entities, as well as academia, nongovernmental institutions, and industry. Each collaboration team is headed by a Federal agency or agencies, which report(s) back to the IARPC on progress. Some teams (Chukchi & Beaufort, DBO, and Wildfires) are co-chaired with external parties. The number of people from each agency participating on a team are shown in the boxes. These numbers indicate participation as of January 2015; they change as collaboration teams gain new people.

The report focuses on seven research themes: sea ice and marine ecosystems; terrestrial ice and ecosystems; atmospheric studies of surface heat, energy, and mass balances; observing systems; regional climate models; adaptation tools for sustaining communities; and human health. Instead of describing all federally funded research in the Arctic, the IARPC plan includes efforts that benefit most from collaboration. In addition to describing urgent research needs, the plan specifies the network of agency activities that will support them.

To assure rapid implementation, in 2013 IARPC created an association of 12 collaboration teams (FIGURE 2), each led by an IARPC member agency. In 2014, the teams opened to non-Federal partners such as universities and private agencies. This collaboration structure reflects the mandate of IARPC's enabling legislation[8] and provides a means for harnessing the talent of the broader scientific community. It creates a virtual public commons where a growing network of Federal funders, Federal researchers, and outside partners discover information, develop new research ideas, and build strategic alliances (FIGURE 3).

These research efforts support IARPC's vision of a prosperous, sustainable, and healthy Arctic understood through innovative and collaborative research coordinated among Federal agencies and domestic and international partners. They reflect our growing grasp of the vast network of activities and individuals with a stake in Arctic research. Thus, whether they are land managers, Alaska infrastructure planners, global environmental change researchers, indigenous hunters, or taxpayers, all Arctic stakeholders may find evidence in this report of the progress made by IARPC and its new collaboration structure.

[8] "Arctic Research and Policy Act of 1984, as amended," www.nsf.gov/geo/plr/arctic/iarpc/arc_res_pol_act.jsp

IARPC by the numbers

16 Federal agencies provide principal leaders

12 Collaboration Teams focus on an area of study supporting...

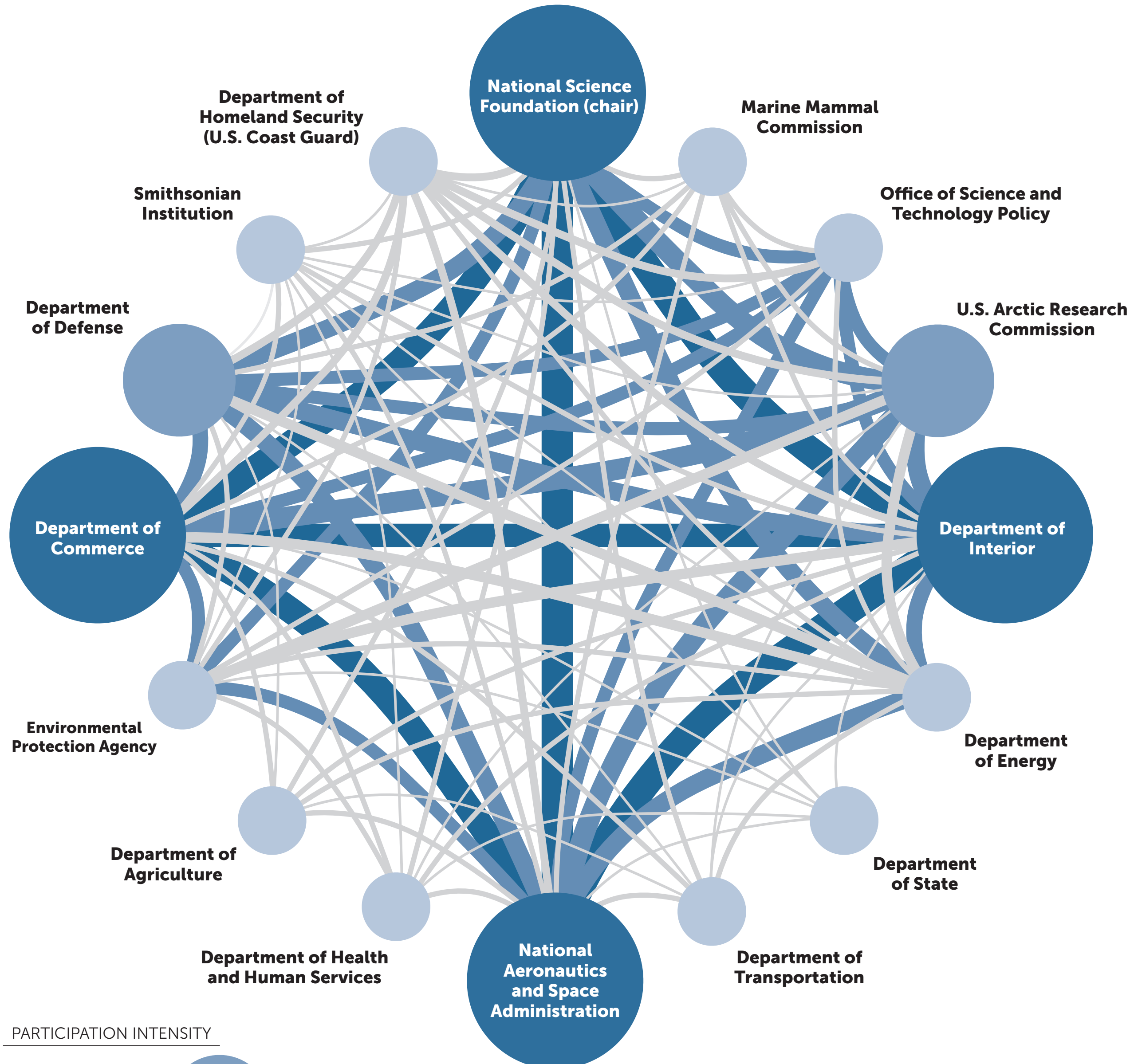
7 major research themes

145 milestones to organize Collaboration Team activities

With IARPC encouragement, scientists representing diverse disciplines collaborate on Arctic research. Photo: Stan Wullschleger

Who's Talking to Whom?

A Visualization of Federal Arctic Research Coordination



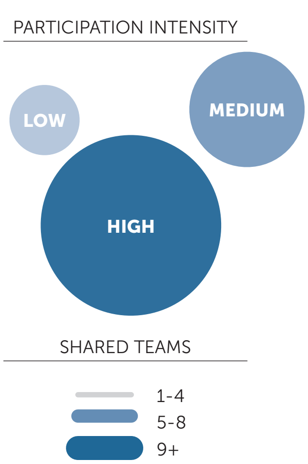


FIGURE 3
IARPC COLLABORATIONS
When IARPC Federal agencies team with knowledge leaders from Alaska, indigenous organizations, academic institutions, nongovernmental organizations, the Arctic Council, and international partners, results equal more than the sum of the parts. Synergies, connections, data exchange, and resource coordination: all of these help focus our efforts to advance understanding of the Arctic. Source: Sandy Starkweather, IARPC. *Compiled from information contained on the IARPC Collaborations website as of November 2014.*

Arctic Executive Steering Committee

In January 2015, President Obama issued an Executive Order* establishing an Arctic Executive Steering Committee (AESC) to augment Arctic policy coordination across the Federal Government. OSTP Director John Holdren chairs the committee, which includes Deputy Secretary or equivalent personnel with Arctic interests from all quarters of the Federal Government. This body provides cohesive guidance to Federal departments and agencies, and it also seeks to enhance collaboration with State, local, and Alaska Native organizations and tribal governments, academic and research institutions, and the private and nonprofit sectors. IARPC contributes to the AESC in areas related to coordination of federally funded research in the Arctic.

The AESC calls attention to the President's priorities, as described in the *National Strategy for the Arctic Region (NSAR)*:** advancing U.S. security interests; pursuing responsible Arctic region stewardship; and strengthening international cooperation. The importance of IARPC's efforts is recognized in the implementation plan for the NSAR. The IARPC research plan is fully embedded in the NSAR implementation plan, ensuring that IARPC efforts are contributing to the overall Federal Arctic effort. A working group reviewed ongoing Federal activities to identify possible areas of overlap or gaps in implementation; this group's recommendations will help to maximize resource investments (e.g., expert talent, dollars, and activities).

President Barack Obama visited Alaska, including areas north of the Arctic Circle, in late summer 2015. Photo: Jonathan Ernst/Reuters

* "Executive Order: Enhancing Coordination of National Efforts in the Arctic." The White House, Office of the Press Secretary. January 21, 2015, www.WhiteHouse.gov/the-press-office/2015/01/21/executive-order-enhancing-coordination-national-efforts-arctic

** *National Strategy for the Arctic Region*. Office of the President of the United States. May 2013, www.WhiteHouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf

IARPC's Communication Tools Encourage Cooperation

IARPC Toolbox

IARPC Collaborations   www.iarpccollaborations.org

Distinctly Innovative Ways of Doing Business, Not Business as Usual

The website is an experiment in new ways to "do" science, an effort to help funders and researchers work together across agencies, sectors and disciplines. Users can post their own content about IARPC collaboration team activities, as updates, documents, and events. Users also can comment on posts about the research being done, opening the conversation to new talent that may be missing on established email lists.

IARPC Collaborations takes the best part of social media—the ability to connect people—and leverages it to:

- Let new people contribute to the conversation—unlike email or phone calls
- Help users keep the community updated—no waiting for the webmaster
- Provide access to information all in one place—go beyond Google!
- Keep people connected through contact information, user profiles, and topical groups
- Track progress on NSAR milestones
- Filter milestones by agency—see each agency's work!

IARPC Collaborations: Join the conversation!

Scientists study melt-water channels ribboning Greenland's ice cap as part of a broader effort to understand regional warming and the complex ways in which the Arctic is changing. IARPC's collaboration teams help focus our efforts and resources to accelerate knowledge gain—and, ultimately, future preparedness. Photo: Sarah Das, Woods Hole Oceanographic Institution

2: Addressing Scientific Challenges through Collaboration

Understanding Sea Ice, Glacier-Ocean Interactions, and Marine Ecosystems

Diminishing sea ice cover and increasing open water in the summertime Arctic Ocean raise questions about the region's future—and the severity of global impacts. Some speculate that changes will bring more commercial activity in the Arctic: offshore oil and gas development, mining, shipping, fishing, and tourism.[9]

For Arctic coastal community members whose traditional way of life depends on sea ice, changes present both challenges and opportunities. The rapid pace of environmental change has ramifications for homeland and national security, public policy, and decision-making at all levels of government.

In this section, efforts to address a number of scientific questions laid out in the 5-year plan are reported: a series of experiments in the Marginal Ice Zone (MIZ) north of Alaska; field investigations in Greenland to better understand marine-terminating glaciers; and the launch of an IARPC-inspired Marine Arctic Ecosystem Study. These topics require large, coordinated efforts to examine complex components of the Arctic system (FIGURE 4). IARPC collaboration teams successfully contributed to research on these issues.

[9] For more on potential increases in commercial activities in the Arctic, see: Clement et al (2013). "Managing for the future in a rapidly changing Arctic. A report to the President." Interagency Working Group on Coordination of Domestic Energy Development and Permitting in Alaska (D. J. Hayes, Chair). www.doi.gov/sites/doi.gov/files/migrated/news/upload/ArcticReport-03April2013PMsm.pdf

The Arctic System

Understanding the connections between physical, biological, chemical, and human processes

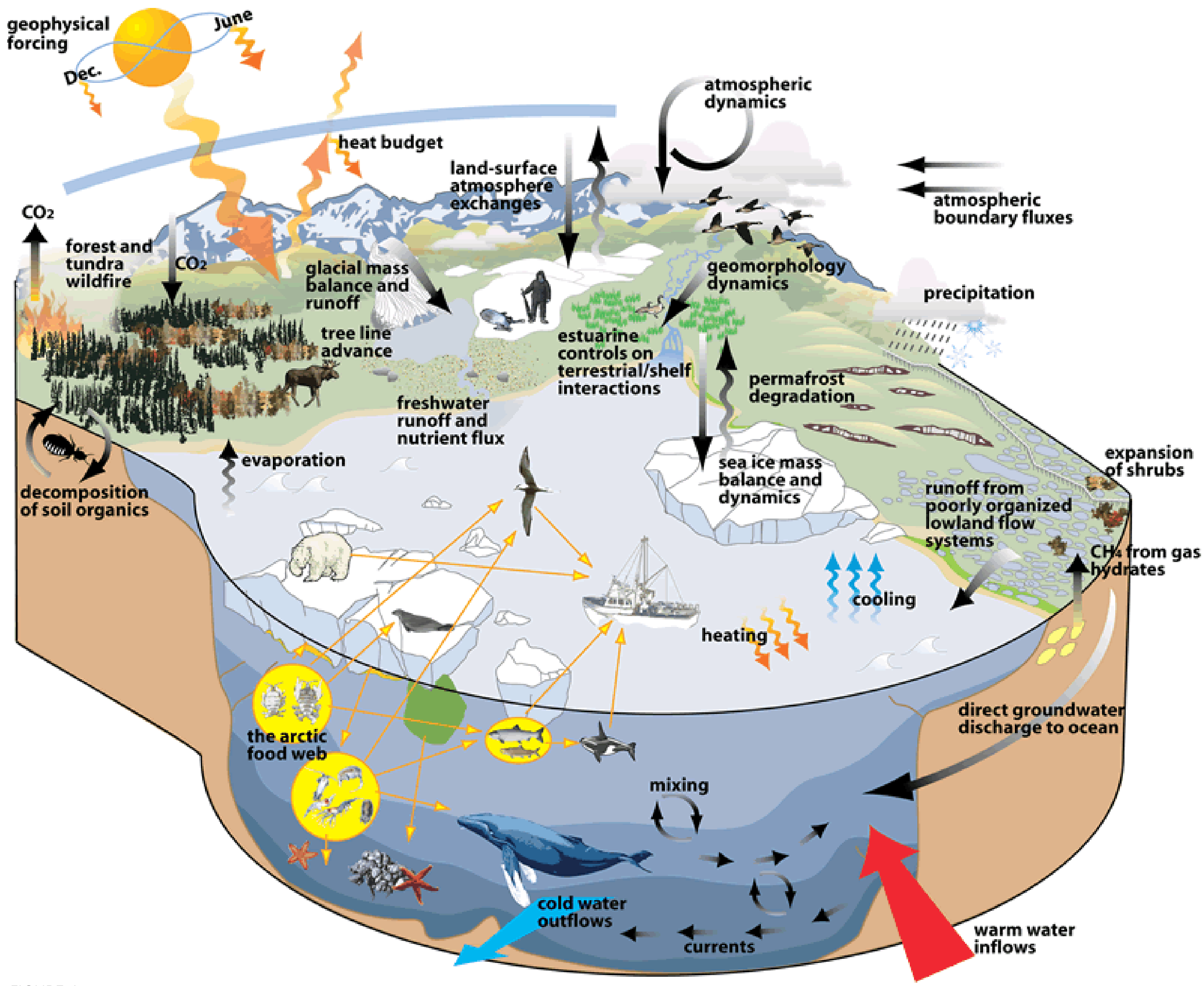


FIGURE 4

COMPLEX INTERACTIONS

This schematic describes the Arctic system and demonstrates the interconnections among components. Important changes in one component may influence other parts of the system. To accurately predict how the Arctic system will evolve with a changing climate, the linkages and feedbacks among systems must be understood. IARPC coordinates activities of U.S. Federal agencies to maximize the science investment in progressing toward this goal. Source: Study of Environmental Change (IARC, 2014).

Marginal Ice Zone Research

Declining summer sea ice extent off the northern coast of Alaska is leading to the emergence of a full MIZ, an area where consolidated pack ice meets the open ocean and has increased exposure to waves and swells. The MIZ is a complex and dynamic region of interactions and feedbacks among the atmosphere, ice, ocean, and ocean surface waves that affect the rate of ice advance and retreat.

Scientists must understand physical processes in the MIZ to explain the observed decline in sea ice extent and to improve sea ice prediction. This knowledge is critical for agencies operating in the maritime Arctic and for weighing potential risks and benefits of increased ship traffic in the region.

The MIZ is an inherently challenging place to conduct traditional field work due to unstable ice, wave action, and poor weather. The IARPC Sea Ice Collaboration Team has coordinated multi-agency sea ice research and technology demonstrations focused on the MIZ to increase knowledge, understanding, and predictive capabilities.

Ice reflects solar radiation, isolates water from wind currents, and calms waves, processes that can break up ice. MIZ research can help people make knowledge-based decisions to prepare (for example) for increased vessel traffic resulting from a more open ocean. Photo: US Fish & Wildlife Service

MIZOPEX

In the summers of 2012 and 2013, NASA and National Oceanic and Atmospheric Administration (NOAA) researchers collaborated on a field program called The Marginal Ice Zone Observations and Processes Experiment (MIZOPEX). The main aim of the program was to evaluate unmanned aerial systems (UAS) or "drones" for science in the MIZ of the Beaufort Sea off the northern coast of Alaska. These systems have the potential to greatly expand observational capabilities in the MIZ, complementing in situ instruments and remote sensing from space.

Based from Oliktok Point, Alaska, the MIZOPEX team launched a variety of UAS, including a tiny drone that could land on a surface and collect ground-based information. Each UAS was equipped with instruments, including visible and infrared cameras and a lightweight synthetic aperture radar (SAR). These instruments collected information on sea ice surface topography, melt pond size and distributions, and ice floe size and number (FIGURE 5). The UAS was also outfitted to drop small buoys to measure salinity and temperature in the uppermost ocean layer.

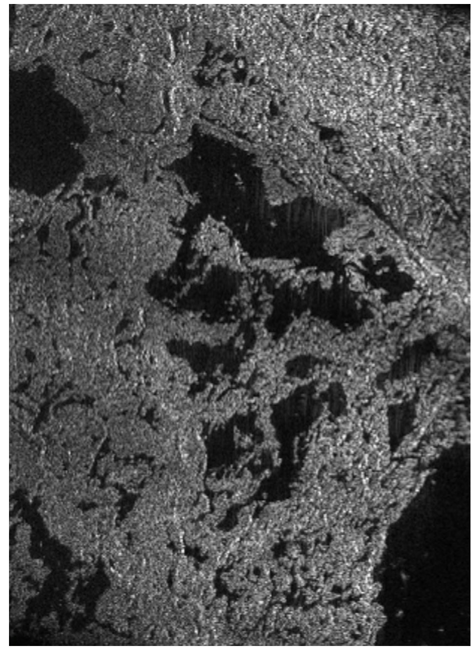


FIGURE 5
SAR IMAGERY
Water (dark tone) and ice floes (lighter tones) are shown in the MIZ taken from a Sierra UAS during MIZOPEX. Source: Jim Maslanik, University of Colorado Boulder

MIZOPEX demonstrated that UAS are a viable means to collect detailed data on multiple points of interest in an Arctic marine setting. This work also showed that pairing air-dropped instruments drifting in the ocean with high-resolution, repeated satellite coverage, is a powerful approach to investigating ice-ocean interactions in the dynamic MIZ.

ONR Marginal Ice Zone Departmental Research Initiative (MIZ DRI)

In 2014, the United States Department of the Navy's Office of Naval Research (ONR) led a 6-month Beaufort Sea MIZ field study. The experiment was part of a multi-institution, multi-nation, 5-year (2012-2016) investigation to improve understanding of the physics of atmosphere-ice-ocean-wave interactions and feedbacks in the summer MIZ. The research team also planned to develop and demonstrate new robotic networks for making observations in environments that present severe challenges for people-centric field investigations.

Operating from two small ice camps with fixed-wing aircraft and helicopter support in March 2014, the ONR team deployed an initial array of over 50 autonomous instruments and platforms on, in, and under the multiyear pack ice of the eastern Beaufort Sea. The array included automatic weather stations; ice-mass-balance, wave and ocean-flux buoys; ice-tethered profilers; polar-profiling floats; and acoustic sources. The acoustic sources provided navigation and communication services for Seagliders and polar-profiling floats deployed in July.

The initial array was supplemented during two summer field operations. In late July, scientists deployed Seagliders, Wavegliders, and a moored wave buoy and free-drifting wave floats from a small research vessel, the *Ukpik,* out of Prudhoe Bay. Then, in mid-August, an international collaboration with the Korea Polar Research Institute (KOPRI) allowed the deployment of additional weather stations, ice mass balance and wave buoys, and an ice-tethered profiler from the R/V *Araon*. An early result of this project was the discovery of an underwater acoustic channel between 50 m and 200 m below the ice in which acoustic signals travelled as much as 500 km to serve the Seagliders and Polar Profiling Floats and provided underwater positioning accuracy of 100 m. This has exciting implications for future sustained autonomous observing under the Arctic pack ice.

As the ice-based instrument array (FIGURE 6) drifted westward through the Beaufort Sea, it was imaged regularly from space by SAR[10] and, in an unprecedented Arctic collaboration with the intelligence community, by National Technical Means (NTM).[11] Scientists studying the SAR data and the 2014 NTM high-resolution, electro-optical image collections are measuring ocean surface waves, ice floe size, melt pond size and number, and ice fractures.

[10] The ONR array was seen by RADARSAT-2 and TerraSAR-X.

[11] Declassified visible band NTM images are publicly available at the United States Geological Survey (USGS) Global Fiducials Library www.gfl.usgs.gov

A wave buoy sits on the sea ice. It was deployed from the R/V *Araon* (in the background) of the Korea Polar Research Institute (KOPRI). Photo: Martin Doble (Villefranche Oceanographic Laboratory, France)

Additional campaigns

NASA's Operation IceBridge and the European Space Agency's CryoVEX projects placed scientists on the ice in March 2014 to take advantage of the ONR MIZ camps in the eastern Beaufort Sea. The scientists measured snow depth and ice thickness in situ, while aircraft overhead measured the same properties remotely. The data will improve algorithms for deriving sea ice information from instruments aboard the CryoSat-2 and ICESat-2 satellites. NASA's Operation IceBridge also sped up its data delivery by developing a quick-look snow depth and ice thickness product available as soon as possible after data collection from the National Snow and Ice Data Center. Such rapid data access allows the research community to assess the response of the pack ice to the 2014 summer minimum extent and to project pack ice behavior as it retreats in the upcoming summer. The experiment will improve computer models simulating ice advance, retreat, extent and volume.

NASA returned to the Beaufort and Chukchi seas in September 2014 when the ARISE (Arctic Radiation and IceBridge Sea and Ice Experiment) project flew a C-130 to investigate Arctic sea ice change and cloud radiative properties. ARISE will improve our understanding of the regional energy budget (i.e., how much energy is received from the Sun, and how much is reflected and radiated back into space). An October NOAA/ONR project used a P-3 research aircraft to investigate the impact of the advancing pack ice on ocean-to-atmosphere heat transfer, atmospheric temperature and pressure fields, and atmospheric circulation. The 2014 campaign repeated measurements made in the same region the previous fall.

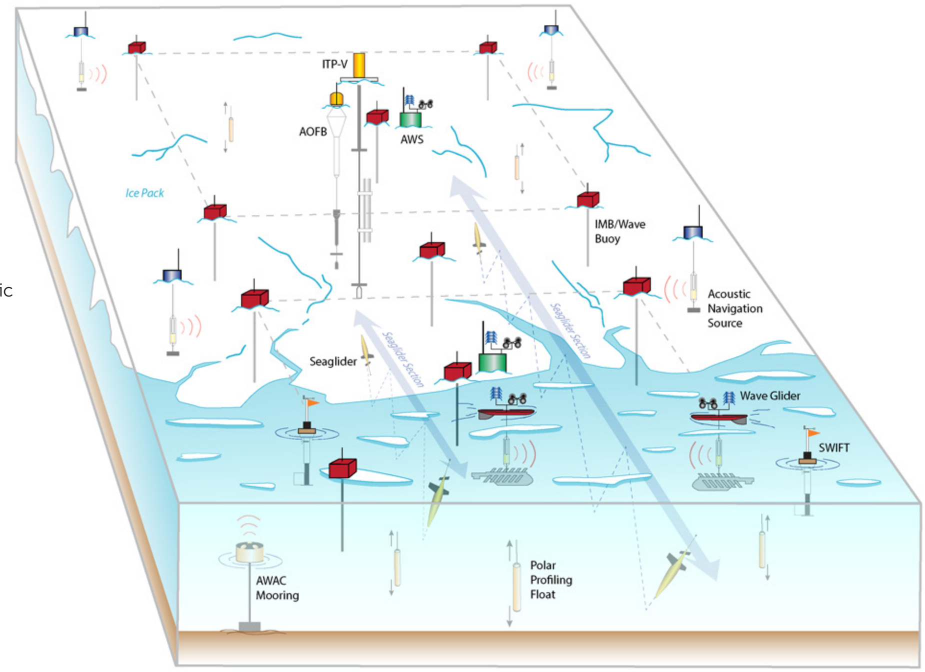


FIGURE 6
MARGINAL ICE ZONE SENSORS
This illustration depicts sensors installed in the Marginal Ice Zone of the Arctic Ocean. By the end of summer 2014 the ONR marginal ice zone observing array, consisting of almost 100 autonomous instruments and platforms, was demonstrating the value of robotic technology for scientific investigation of complex processes in a challenging environment. Credit: UW Applied Physics Laboratory

Greenland Ice Sheet Studies

Global sea level is rising due to the expansion of ocean water as it warms, and the melting of mountain glaciers and ice sheets.[12] Sea level rise has consequences for the 123 million people in the United States who dwell along the coasts, and for many more coastal residents around the globe. Should some sea-level predictions bear out, many Americans may be displaced or subject to increasing storm-related flooding and other associated problems. In addition, the release of freshwater into the Arctic Ocean and subarctic seas due to glacier and ice sheet melting will impact ocean circulation and climate.

To prepare for this future, scientists need to understand the processes by which ice is lost, and also how much is being lost, from the Greenland Ice Sheet and Arctic glaciers. DOE, NASA, and NSF are supporting research projects, field campaigns, satellite missions, and modeling to answer these questions and improve estimates of current and future contributions from Arctic land ice to sea level rise. A key uncertainty is the fate of marine-terminating Arctic outlet glaciers that transport ice from land to the ocean. The processes controlling ice transport at the ice sheet margins are poorly understood and are not well represented in current climate models[13] (FIGURE 7).

IARPC's Glacier-Fjord Collaboration Team (GFCT) was formed in 2012 by members[14] already engaged in efforts to coordinate Greenland Ice Sheet research *via* US CLIVAR (United States Climate Variability and Predictability Program), a Federal interagency effort to coordinate U.S. research on global climate variability and predictability.

The US CLIVAR Working Group on Greenland Ice Sheet Ocean Interactions (GRISO) published recommendations in 2012 that highlighted the need for research on glacier/ocean interactions and became a touchstone for the IARPC team's efforts. A key international workshop was held in June 2013 in Beverly, MA involving 90 stakeholders, including 47 U.S. scientists, 3 Federal agency program officers, and 40 international experts from 10 different countries. The workshop identified ways to reduce uncertainties in the ice/ocean/atmosphere interactions influencing the evolution of the Greenland ice sheet, including observational, synthesis, and modeling strategies; communication, coordination, and collaboration between diverse communities (e.g., oceanography, geology, glaciology, climatology, and paleoclimatology); synergies between national and international projects; and capacity-building with specific focus on advanced graduate students and early career scientists. Attendees discussed plans for a long-term Greenland observing system.[15] The workshop resulted in one funded research project and detailed planning for future projects, including a meeting in Europe for logistics in September, 2014.

[12] NOAA's State of the Coast. www.stateofthecoast.noaa.gov

[13] Stocker et al. (eds.). *Climate Change 2013: The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 1535 pp, doi: 10.1017/CBO9781107415324

[14] Four IARPC agencies also participate in U.S. CLIVAR: DOE, NASA, NOAA, and NSF.

[15] Heimbach et al. (eds.). *International Workshop on Understanding the Response of Greenland's Marine-terminating Glaciers to Oceanic and Atmospheric Forcing: Challenges to Improving Observations, Process Understanding and Modeling.* Report 2014-1, US CLIVAR Project. doi: 10.1017/CBO9781107415324. www.usclivar.org/sites/default/files/documents/2014/2013GRISOWorkshopReport_v2_0.pdf

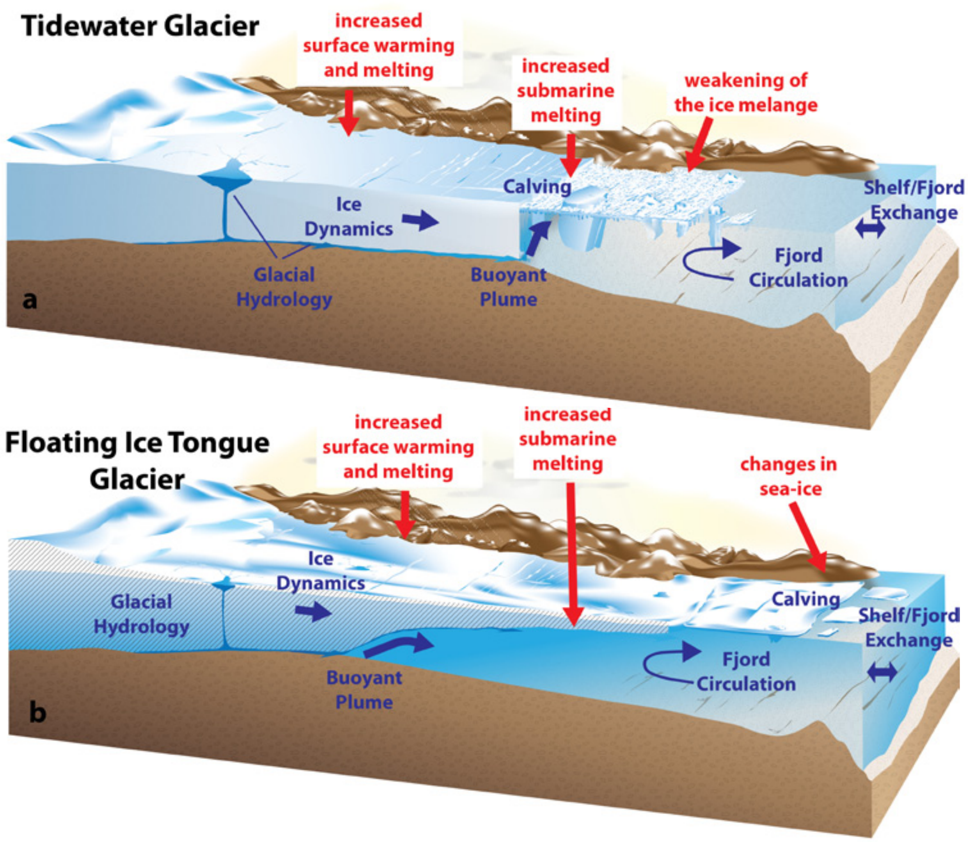


FIGURE 7
GLACIER MODELS
Glaciers that end in the ocean deliver both runoff (as do land-terminating glaciers) and solid ice, which later melts, to the ocean. Greenland has many such glaciers—and they are melting at accelerated rates. IARPC's GFC team coordinates efforts to accelerate our understanding of marine-terminating glaciers, a significant area of uncertainty for those predicting sea-level rise. Source: Straneo et al. (2013): "Challenges to Understanding the Dynamic Response of Greenland's Marine Terminating Glaciers to Oceanic and Atmospheric Forcing." *Bull. Amer. Meteor. Soc.*, 4, 1131–1144. doi: 10.1175/bams-d-12-00100.1

Chukchi and Beaufort Sea Studies

As IARPC developed its 5-year research plan, members identified the Chukchi Sea and Beaufort Sea ecosystems as areas of critical importance to U.S. national interests that would benefit from coordinated, interagency collaboration in association with non-Federal entities. IARPC's Chukchi-Beaufort Ecosystem Collaboration Team (CBCT) tackled this complex issue.

The Chukchi and Beaufort Seas border Alaska's northwestern and northern coasts and comprise the United States' Arctic Ocean holdings. They are biologically productive and diverse, as well as important to U.S. national security and economic interests for oil, and potentially to U.S. mineral and commercial fishing. These waters represent a vital component of traditional life for Alaskan communities (e.g., as a source of nutritional, cultural and spiritual sustenance).

Conceptual Development

The CBCT started by organizing a workshop[16] that involved international experts from academia, industry, and traditional communities in activities aimed at assessing the state of knowledge. The CBCT viewed the activity as a first step in studying how the Chukchi and Beaufort ecosystems may respond to climate change.

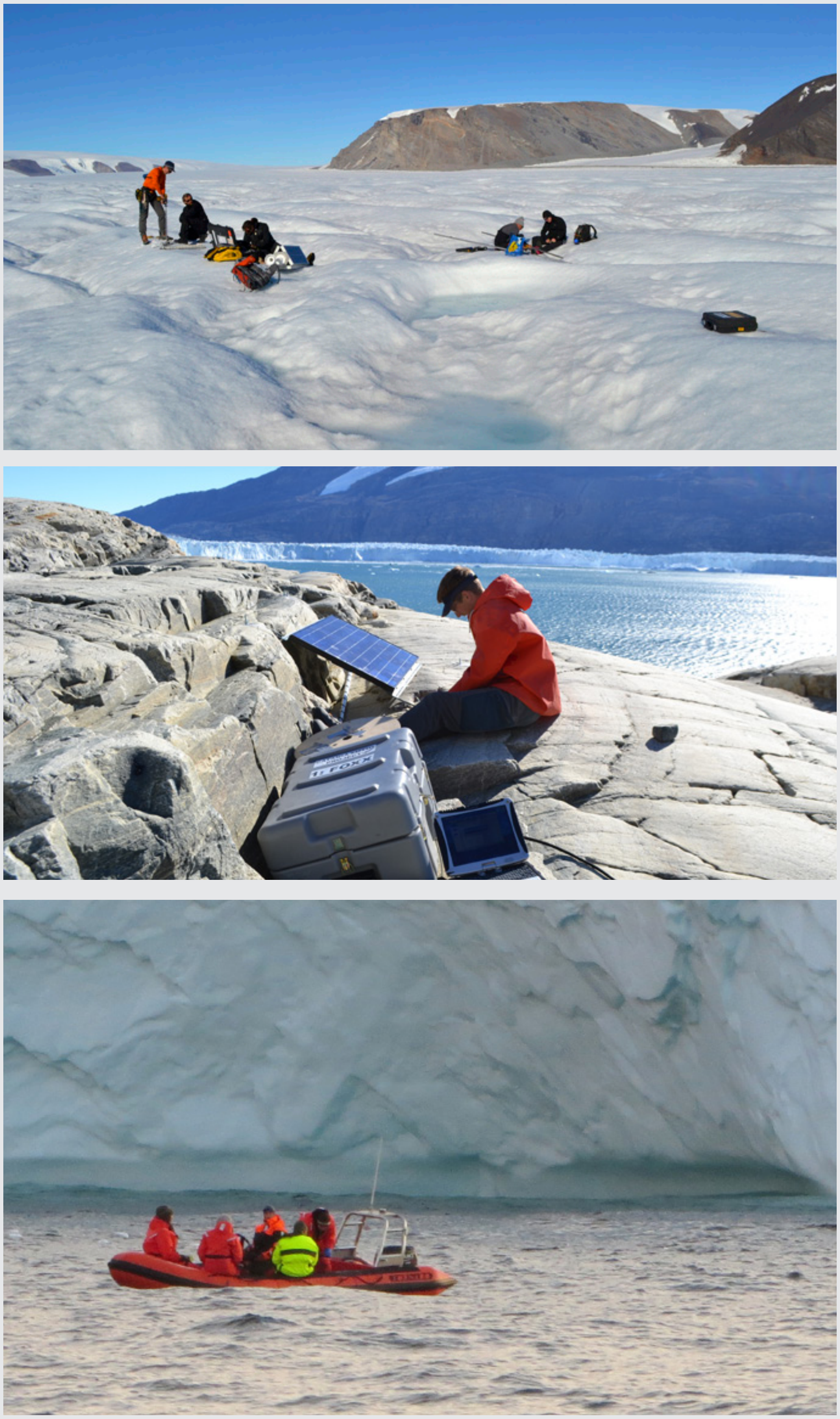
To this end, the CBCT encouraged development of a "framework document[17]" to foster and guide the scientific collaboration needed to achieve a common understanding of the U.S. Arctic marine ecosystem and its likely changes in coming decades. The CBCT developed a conceptual model that described the physical, biological, chemical and human aspects of the Arctic marine ecosystem.

The framework document brings together the thinking of academic and industry leaders, indigenous communities, conservation organizations, and government scientists to describe an intellectual and organizational approach to the research.

The document provides examples of ongoing and new affiliations, highlighting their different scopes, approaches and durations. It is aligned with several national plans, such as the *National Ocean Policy-Implementation Plan*[18] and the *Implementation Plan for the National Strategy for the Arctic Region.*[19]

[16] "Developing a Conceptual Model of the Arctic Marine Ecosystem. April 30 – May 2, 2013, Washington, DC." www.nprb.org/news/detail/arctic-conceptual-model-workshop-report-available
[17] www.iarpccollaborations.org/uploads/cms/documents/framing_arctic_marine_research_initiatives_report_p2b_lowres.pdf

[18] www.WhiteHouse.gov/administration/eop/oceans/policy
[19] www.WhiteHouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf



NASA-funded researchers collect information on atmospheric, glaciological, and ocean processes. To understand how an outlet glacier interacts with the fjord into which it terminates, team place global positioning instruments up on the ice sheet for information about the glacier's movement (top panel); install instruments (e.g., the solar-powered tide gauge near the glacier's face) to record information about calving events (middle panel); and collect water samples in the fjord as they drift by a melting iceberg (bottom panel). Photos: 1&2: Lauren Andrews, UTIG Photo 3: Dustin Carroll, University of Oregon

Marine Arctic Ecosystem Study

The Marine Arctic Ecosystem Study is led by Bureau of Ocean Energy Management (BOEM). MARES scientists aim to identify areas of increased productivity and different ecosystem dynamics (e.g., inner shelf versus outer shelf), and provide a better understanding of intra- and intersystem feedbacks, an important goal noted in IARPC's 5-year research plan. The CBCT provided coordination, ensuring that the MARES request for proposals supported the high level of integration, cooperation, and flexibility required for this complex undertaking.

Once the MARES organizers released a request for proposals in mid-June 2014, the team moved swiftly and announced an award in November. The compressed timeline demonstrates the effectiveness of the CBCT in coordinating interagency activity and illustrates IARPC's commitment to accelerate understanding of the Arctic marine environment (FIGURE 8).

MARES is relevant to the missions of many of the IARPC agencies and to our National priorities because it addresses energy security, climate change and monitoring, oil spill risk analysis, fundamental scientific questions on ecosystem structure and function, environmental protection, and exploration and discovery.

Contributing writers: Guillermo Auad, Danielle Dickson, Martin Jeffries, Bill Wiseman

Collaboration Team Meetings

Through Collaboration Teams, IARPC has enabled the engagement of the research community, as well as leveraged Federal investments through assocations that maximize scientific outcomes. Collaboration Teams meet regularly to discuss progress towards milestones that support the goals identified in IARPC's 5-year plan. Most meetings are open to the Arctic research community.

IARPC Toolbox

MARES

An Integrated-Science Approach

FIGURE 8

ACCELERATING RESEARCH THROUGH COOPERATION

The Marine Arctic Ecosystem Study was organized and championed by IARPC because the subject area is:

- **Vast** – involving most U.S. Arctic Ocean holdings north of Alaska
- **Complex** – involving land, ocean, atmosphere, ice, animals, traditional communities
- **Important** – to tribal, Alaska, U.S., and international interests
- **Precious** – one of the most biologically diverse and productive regions in the world
- **Changing** – disappearing sea ice, changing ecosystems bring opportunities and risks
- **Difficult** – a remote and fragile region with little infrastructure, dangerous ice cover, changing ecosystems that are difficult to study without impact

MARES agencies developed the science plan using concepts from a framework document established by the IARPC collaboration team. Refer to “The Common Objective” (see right). They also defined the process by which they would continue to advance group goals using a single contractor to conduct the work. Refer to “Getting it Done: Partnership Decision Model” (see below).

THE COMMON OBJECTIVE

INTEGRATED PERSPECTIVE OF THE OCEANIC-ATMOSPHERIC-SEA ICE-LAND SYSTEM FEEDBACKS

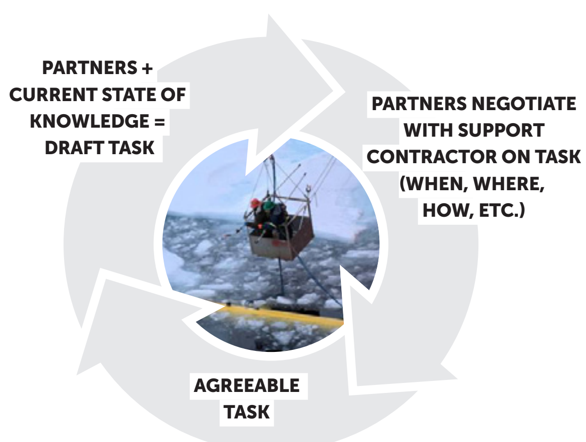
BIOLOGICAL
Ecosystem structure and functioning, emerging hotspots, resilience and sensitivities, ice algae studies

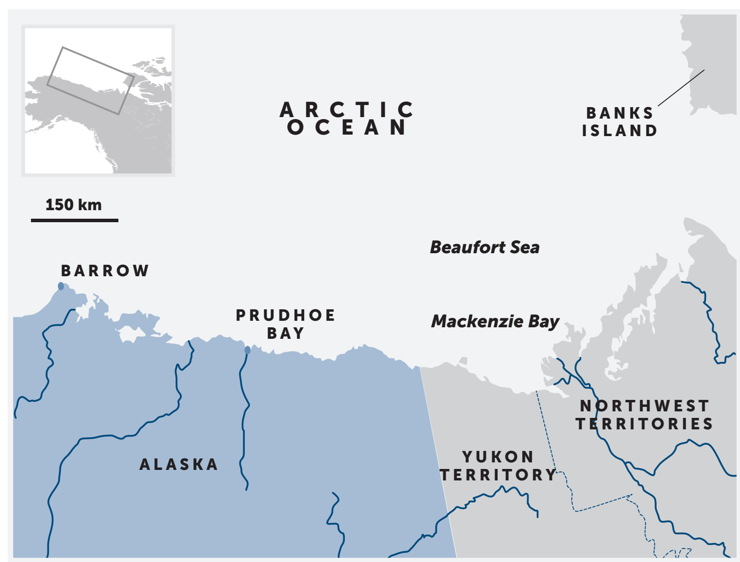
PHYSICAL
Circulation, sea ice and snow, river runoff and external drivers

SOCIAL
Subsistence, traditional environmental knowledge

CHEMICAL
Ocean acidification, biogeochemical impact of Mackenzie River Plume

GETTING IT DONE: PARTNERSHIP DECISION MODEL





The MARES study area

Leading up to 2011:	2011-2013:	2014:	2015:	2016 – 2019:	2019
• Consideration of common and complementary information needs and National policies	• Conceptual framework developed • Identify opportunities: Integration starts • Planning & alignment of common objectives	• Identify MARES implementation team • Identify procurement vehicle • Issue request for proposal (June) • Proposal review panels (August/September) • Single award to contractor	• Begin science program • Task 1: Determine next steps meeting • Task 2: Marine tagging pilot program	• Continue science program • Science review board feedback • MARES colleagues feedback • Participants jointly develop subsequent task orders based on current state of knowledge; then they negotiate with input from MARES contractor • Tasks: TBD	• Results • Identify next steps

The aurora borealis rises over Summit Station on the peak of Greenland's ice cap. Sponsored by the NSF, Summit is home to year-round, long-term measurements for monitoring and investigations of the Arctic environment. In addition to NSF studies, NOAA maintains a suite of measurements, as do European collaborators. Photo: Ed Stockard, Blue Marble Photography

3: Building Networks for Observing, Data, and Modeling

IARPC's cross-cutting efforts promote data integrity, exchange, and accelerated knowledge gain.

The activities within IARPC's *Plan for Arctic Research (FY 2013-2017)* encourage research integration—that is, efforts that cut across science from different fields (e.g., atmospheric science, terrestrial ecology, social science); geographic contexts (e.g., single field sites to pan-Arctic studies); and/or tools and practices (e.g., modeling, field observations, satellite observations, physical process studies). Such efforts merge what often might be isolated efforts.

There is a need to integrate diverse contributions. IARPC's collaboration teams have focused on enhancing tools that allow agencies to combine complementary observing, data collection, and modeling efforts.

In most cases, IARPC collaboration teams build on and broaden participation in existing integration efforts, rather than create new ones. This section describes IARPC contributions to an atmosphere observing portal, an Alaska-focused data collaboration, the Sea Ice Prediction Network, and ways to assess and access information needed by people living in the Arctic and other stakeholders.

IARPC Aids Data-Sharing Among Atmosphere Observatories

Modifying an existing data-access portal improves access for all

FIGURE 9
COMPATIBLE METADATA
As an important step toward scientific collaboration, the International Arctic Systems for Observing the Atmosphere (IASOA) portal stored information about data sets collected by 10 independent Arctic atmosphere observatories. But each collection had its own identifying information—metadata—which hampered access and use by others. IARPC collaboration team efforts to standardize metadata improved access and usability. Further, an innovative process developed through the IARPC collaboration automates the way information on additional data sets is collected, facilitating future "crowd-sourced" data collection.

Piecing Together Atmosphere Studies

DOE, NASA, NOAA, NSF, and many international groups collect long-term atmospheric observations in the Arctic. To advance Arctic atmospheric science, researchers must combine all these data to test models, establish climatologies, and detect change. Automated data discovery is critically needed but is impeded by the many incompatible standards used for describing and archiving data.

IARPC's Atmosphere Collaboration Team (ACT) tackled this challenge by encouraging agency participation in the International Arctic Systems for Observing the Atmosphere (IASOA) data portal funded by NOAA and NSF. The IASOA portal provides access to metadata from a consortium of 10 independently funded Arctic atmospheric observatories (FIGURE 9).

Most IASOA observatories are already active participants in global networks with robust data management capabilities, such as Global Atmosphere Watch and the Baseline Surface Radiation Network.[20] IASOA observatories also are funded and maintained by sponsor agencies with their own long-term repositories.

Automated data discovery, or harvesting, hits roadblocks when repositories use incompatible metadata formats and keyword vocabularies. IASOA worked across global, institutional, and project-level repositories to identify and

[20] www.wmo.int/gaw; www.bsrn.awi.de/

integrate common descriptors into its data harvesting process. A metadata design based on the International Standards Organization format, ISO-19115, was adopted. This was already in use by most global networks, though U.S. agencies had yet to migrate.

The IARPC ACT helped IASOA clear the roadblocks. NSF funded the initial concept design and development of IASOA's data portal. NOAA developed an authoring tool for ISO-19115 metadata, identifying compatible keyword vocabularies and creating 150 structured metadata records for its observations. DOE's Atmospheric Radiation Measurement (ARM) program and the NSF-funded Advanced Cooperative Arctic Data and Information Service (ACADIS) translated existing metadata into the ISO-19115 format. IASOA rapidly assembled metadata for nearly 1000 datasets,[21] an accomplishment that benefits the entire Arctic atmospheric science community.

Alaska Data Integration Working Group

IARPC's Terrestrial Ecosystems Collaboration Team (TECT) adopted an existing process that Alaskan managers have developed to share metadata for information related to Federal research activities within the state of Alaska.

The Alaska Data Integration Workgroup[22] (ADIwg) was created to allow program and project managers from participating groups[23] to share information about their funded activities in standard format.

Enabling discussions on project tracking and metadata across multiple agencies, ADIwg allows participants to examine and address technical barriers to efficient integration and sharing of data within and among member organizations. ADIwg then developed a set of dynamic tools for data-sharing as well.

With IARPC's help, ADIwg developed tools to expand the exchange of project and data information throughout Alaska. These include broader sharing of information on research projects across multiple agencies using standardized protocols. Like IASOA, ADIwg identified ISO 19115-2 International Standard for Geospatial Data (2009) to facilitate metadata exchange with local and international colleagues, to conform to metadata trends, and to allow for a broader participation from the ADIwg organizations

ADIwg recently developed a set of flexible, open-source tools allowing organizations to generate ISO metadata without having to learn the ISO standard. These tools will support additional metadata standards in the future, such as that of the Federal Geographic Data Committee. Another tool allows independent researchers to create ISO metadata themselves, reducing the delay associated with making data broadly available.

Several IARPC collaboration teams, including the Arctic Data Collaboration Team, adopted ADIwg tools to help increase agency involvement in their use.

Coordinating Ecosystem Science

Understanding Arctic ecosystems and how they are changing is a multidisciplinary challenge involving biology, geology, anthropology, chemistry, hydrology, and other disciplines. Collaboration among agencies leverages knowledge, expertise, and capabilities and distributes the costs of ecosystem research. This is particularly important in the Arctic given the logistical difficulty and expense of working in remote locations. IARPC enables a coordinated Federal investment to improve predictive understanding of Arctic ecosystems.

Recognizing the need for improved coordination, DOE and NASA used the IARPC network to exchange information and to identify other Federal offices (e.g., DOI, USDA, and USGS) with a stake in terrestrial ecosystem science. Agencies worked together through IARPC to coordinate programs such as NASA's Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE),[24] Arctic-Boreal Vulnerability Experiment (ABoVE),[25] and DOE's Next-Generation Ecosystem Experiment-Arctic (NGEE-Arctic).[26]

Launching an instrumented balloon to collect weather information. Photo: Kevin Hammonds

NASA's CARVE and ABoVE programs are large-scale activities to study ecosystem responses to environmental change. CARVE is an airborne campaign to collect and quantify greenhouse gases in the Alaskan Arctic using new remote sensing and improved modeling capabilities. CARVE coordinates closely with NGEE-Arctic and other Federal research activities so that the airborne data can be compared with ground-based measurements. ABoVE will utilize NASA's field, aircraft, and satellite remote-sensing capabilities, coupled with in situ activities, to study the vulnerability and resilience of ecosystems and society to environmental change in the Arctic. An emerging NASA campaign that integrates field and airborne activities will be carried out over an 8-to 10-year period. The initial ABoVE science team will be selected in 2015, and ABoVE solicitations will emphasize field and process understanding of ecosystem and societal vulnerabilities to environmental change. Airborne campaigns are envisioned in 2017 and 2019.

21 www.esrl.noaa.gov/psd/iasoa
22 www.aoos.org/adiwg
23 North Slope Science Initiative Oversight Group (NSSI); Alaska Ocean Observing System Board (AOOS); North Pacific Research Board (NPRB); Alaska Climate Change Executive Roundtable (ACCER)
24 www.science.jpl.nasa.gov/projects/CARVE
25 www.above.nasa.gov
26 www.ngee-arctic.ornl.gov

NGEE-Arctic engages DOE's modeling capabilities to help scientists explore the future of permafrost carbon in a warming Arctic. NGEE-Arctic combines field and laboratory process research to improve the representation of ecosystem processes in Earth system models. Now completing its third year of operation, NGEE-Arctic expects to extend for a decade and bring unprecedented insights to how climate change affects permafrost landscapes—and how permafrost landscape changes are in turn affecting climate (FIGURE 11).

ABoVE will leverage the DOE investment in NGEE-Arctic's Barrow location and use DOE's Earth system modeling capabilities, using ABoVE sites as test beds for testing NGEE-Arctic's improved representations of Arctic ecological processes in Earth system models. NGEE-Arctic scientists joined the ABoVE Science Definition Team and helped develop a science plan synergistic with NGEE-Arctic.

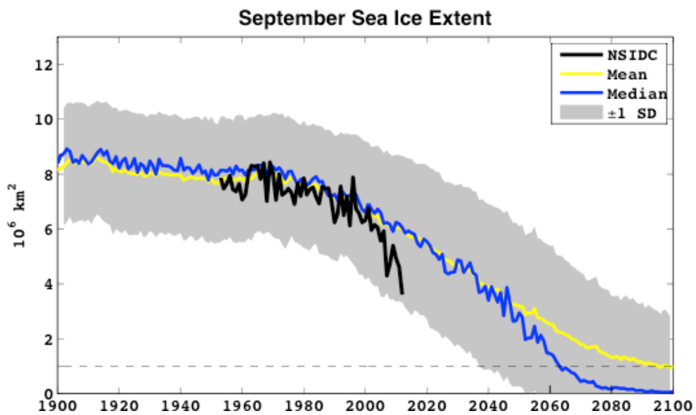


FIGURE 10

SIPN PREDICTION SUMMARY

Eighty-four sea ice extent predictions to the year 2100 by 36 different computer models. Clear differences between actual observations (black line) and predictions (the blue and yellow lines) point to the need to increase observations and process understanding to help improve models. Source: M. Jeffries, J. Overland and D. Perovich (2013)

Sea Ice Prediction Network

Forecasts of increased economic activity in the Arctic are based on recent declines and future projections of sea ice extent. But sea ice extent varies significantly year to year, and model simulations do not match recent observations well. There is high uncertainty about the future state of the sea ice cover, stemming from the challenge of modelling complex interactions and feedbacks in the atmosphere-ice-ocean-waves system.

Sea ice prediction is needed by a broad spectrum of users (e.g., Federal policy makers, community leaders, wildlife managers, hunters, etc.) for planning support and policy-making. Improved predictive skill is required on time scales ranging from hours to decades, and on spatial scales ranging from local to regional. How can scientists improve predictions to meet these growing and varied needs?

The Sea Ice Prediction Network (SIPN) is a response to this challenge. Initiated in 2013 by IARPC's Sea Ice Collaboration Team and funded by DOE, NASA, NOAA, NSF, and ONR, SIPN focuses on seasonal prediction. This is particularly challenging due to high variability in weather and ocean influences, limited instrumental observations, current model limitations, and an Arctic that is changing in ways unseen in recent history (FIGURE 10).

SIPN organized an open meeting at a December 2013, American Geophysical Union conference in San Francisco to engage the broader research community. Attended by 40 people, the meeting contributed to a doubling of inputs to the 2014 SEARCH[27] Sea Ice Outlook (SIO).

In April 2014, SIPN organized its first workshop, hosted by the National Center for Atmospheric Research[28] in Boulder, Colorado. The meeting planned for the 2014 SEARCH Sea Ice Outlook and advanced the science of sea ice prediction by coordinating model experiments; developing data sets for model initialization and validation; and improving metrics for evaluating model skill.

In June 2014, the National Snow and Ice Data Center released a new compilation of Arctic Ocean sea ice data sets. This valuable product offers scientists undertaking sea ice predictions easy access to the same data sets, enabling meaningful model intercomparisons and evaluations.

A busy year for SIPN culminated in a session at the December 2014 AGU Fall Meeting. The session, "Polar Climate: Processes and Predictability," addressed the processes that govern seasonal to multi-decadal polar climate variability; sources of polar climate predictability; uncertainty in polar climate prediction; model errors related to polar predictability; reanalysis data; and links between polar climate predictability and mid-latitude phenomena (e.g., Arctic amplification of climate change and its impact on the polar vortex and mid-latitude weather extremes).

SIPN leverages a decade of independently funded agency activities and is well-connected to international sea ice and polar prediction efforts.[29] Through SIPN, the Arctic modeling community maintains a vibrant and productive interchange. SIPN activities advance the state of knowledge about Arctic system processes that inform regional climate models.

Assessing and Sustaining Observations in the Arctic

Given the urgent need for improved societal resilience to Arctic change, strong linkages between information providers, interpreters, and users are critical. Web-based tools and visualization packages make Arctic observations more

[27] SEARCH is the Study of Environmental Arctic Change. www.arcus.org/search-program

[28] www.ncar.ucar.edu

[29] An IPY-like effort, the Year of Polar Prediction, is discussed in the last section.

IARPC Enhances Research to Clarify Permafrost Impacts in Earth System Models

The question: How do thawing permafrost and associated changes to the landscape, water, soil, and plant community affect the climate system?

FIGURE 11

NGEE-ARCTIC

Department of Energy (DOE) scientists at Oak Ridge National Laboratory are leading the Next-Generation Ecosystem Experiment – Arctic Landscapes (NGEE-Arctic) project. With support from IARPC, NGEE-Arctic draws on a myriad of talent funded by additional agencies, including NSF and NASA. Together, field and laboratory scientists and mathematicians develop studies to provide new information about permafrost ecosystems. Improved models can help community leaders and others better understand Arctic change and how to address uncertain futures.

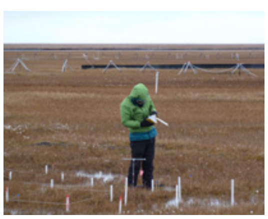
NGEE-ARCTIC'S TWO LINES OF INQUIRY:

THE CARBON DEPOT: Frozen plant material in permafrost holds rich stores of carbon. What happens when the permafrost thaws?

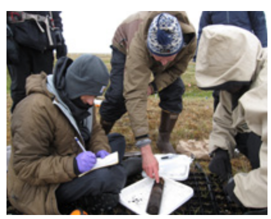
LANDSCAPE TRANSFORMATION: Thawing of Ice-rich permafrost can start a cascade of interacting processes, including changes in topography (collapsed ground), water distribution across the landscape (new lakes and streams), and impacts on plants. These interactions will determine the role of Arctic ecosystems in future climate. What are they?

Left: Different research disciplines work on the Barrow Environmental Observatory (BEO). Top right: Polygon wedges like these on the BEO are sensitive to permafrost thaw, potentially releasing stored carbon and reshaping Arctic landscapes. Bottom right: A wider view showing polygons and water after snowmelt in the spring. All photos on this page: Roy Kaltschmidt, Richard Norby, Cathy Wilson, and Stan Wullschleger

SCIENTISTS AT WORK



HYDROLOGY: Measuring thaw depth in field plots.

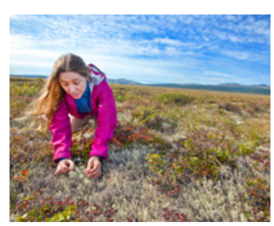


MODELING: An ecosystem modeler examines organic layers preserved in a permafrost core.

LABORATORY STUDIES: Analyzing permafrost cores using computer tomography.

BIOGEOCHEMISTRY: Coring tundra samples for biomass and carbon-nitrogen measurements.

GEOPHYSICS: Exploring subsurface characteristics using ground-penetrating radar.



ECOLOGY: Harvesting plant material from a plot to understand species composition.

COLLABORATION

NGEE team members discuss possible field sites.

High school students participating in a biology field course visit NGEE in Barrow.

accessible to a broad user base, encourage collaboration and coordination, and help identify areas where stronger partnerships are needed to improve the delivery to Arctic communities of basic and actionable information. Information needs include community-based monitoring programs to track changes in food resources, biodiversity, cultural identity, health, language, livelihoods, and traditional knowledge.

Building off complementary White House efforts (i.e., U.S. Group on Earth Observations),[30] IARPC's Arctic Observing Systems Collaboration Team (AOSCT) developed an Arctic Observing Assessment process allowing groups throughout the Arctic to identify information priorities at local, regional, national, and international levels.

This process identified 13 major priorities, which form the basis for a relational database of existing Arctic information. Analysis of this database shows how informational needs intersect between priorities. For example, common information resources serve the goals of three of the priorities, i.e., food security, ecosystem health, and climate change adaptation and mitigation (FIGURE 13). Data sources meeting multiple priorities are identified, as well as gaps where information products are lacking. The developing database is available through an online search and visualization tool located on the Arctic Hub.[31]

The Arctic Hub also has news, opportunities, and collaborative tools to advance observing design and implementation. The team completed the Arctic Observing Assessment in spring/summer 2015, using metadata techniques that support complex user searches and a visualization and export interface. Crowd-sourcing will support the continued build-out of the assessment and keep it "living" for years to come.

Activities of the Sustaining Arctic Observing Network (SAON) coordinate pan-Arctic observing systems for environmental, social, economic and cultural issues. The Arctic Council

[30] www.WhiteHouse.gov/administration/eop/ostp/nstc/committees/cenrs/usgeo

[31] www.arctichub.net

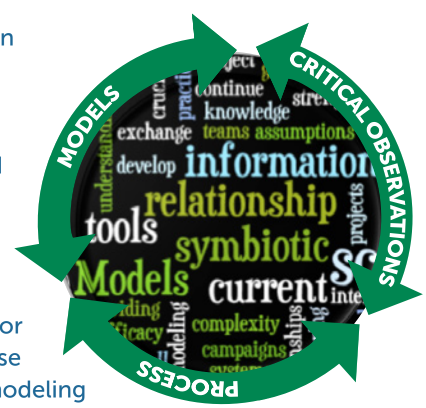
CARVE uses instruments aboard a NASA C-23 Sherpa aircraft to measure air and surface conditions and concentrations of greenhouse gases (carbon dioxide, methane, etc.). See page 17 for a description of the CARVE field campaign. Photo: NASA/Wallops

From Measurements to Process Understanding to Modeling

Earth System Models are tools that incorporate our state-of-the-science understanding of processes operating in nature. The science of climate and Earth system modeling has matured through finer spatial resolution, the inclusion of a greater number of physical and biogeochemical processes, and comparison to a rapidly expanding array of observations. Simulations of the Arctic from models have not converged, however, since different groups approach uncertain model aspects in distinctive ways.

Ideally, the relationship between model development and field work is symbiotic. Models are based on knowledge of process understanding from observations. In turn, models can guide the development of field campaigns to target and gather crucial observations—which can further advance the fidelity of model simulations.

In practice, the relationship between model development and field work has oftentimes been disconnected. Given the complexity of model development, there is a need to continue and strengthen collaboration amongst model developers, and between model developers and observational scientists. These opportunities include establishing intercomparison projects and providing an exchange of knowledge between modelers and field scientists.



IARPC's collaboration teams create a space for symbiotic relationships to develop between these groups; this bodes well for the efficacy of our modeling tools and for the scientific field work that informs them.

established two committees to provide leadership to implement SAON. The Committee on Observations and Networks focuses on collecting data and information on all observing capabilities, including access to platforms and geographical areas to present options for long-term funding. The committee will also develop a set of early warning indicators—the indicators network—initially focusing on climate change. This network will use existing and ongoing assessments to provide a status of the health of specific natural and human systems in the Arctic.

The Committee on Information and Data Services focuses on ensuring free and easy access to data and information in the SAON network. The Circum-Arctic Information System is responsible for integration and dissemination of data and information with guidance from the Committee. Through these and other activities, SAON will continue to develop the network of observations and make these observations available and applicable to environmental and societal issues.

Contributing writers: Kathy Coon, Renée Crain, Martin Jeffries, Erica Key, Mike Kuperberg, Sandy Starkweather, Stan Wullschleger

Focus on the Sea Ice Outlook

In response to the dramatic loss of Arctic summer sea ice in 2007, the research community initiated the Sea Ice Outlook (SIO) effort in 2008 under the umbrella of SEARCH.*

On a voluntary basis, each June the science community takes available information and populates models to predict the size of the lowest extent of sea ice (marked in September each year), and the lowest extent for the current month. This exercise is repeated each month through the summer.

In April 2014, four SIPN investigators published results of an analysis of more than 300 contributions to 6 years of sea ice outlook calls (Figure 12). The report summarized the findings as follows:

> Individuals and teams employ a variety of modeling, statistical, and heuristic approaches to make these predictions. Viewed as monthly ensembles, each with one or two dozen individual predictions, they display a bimodal pattern of success. In years when observed ice extent is near its trend [or long-term decline], the median predictions tend to be accurate, but in years when the observed extent is anomalous, the median and most individual predictions are less accurate. The latter at least partly reflect weather events, such as summer temperatures and wind conditions, which are much harder to forecast. Statistical analysis suggests that year-to-year variability, rather than methods, dominate the variation in ensemble prediction success. Furthermore, ensemble predictions do not improve as the season evolves.

In other words, a limitation to obtaining accurate sea ice predictions is the inherent uncertainty in the prediction of atmospheric and oceanic conditions. About a half-dozen models have evaluated skill in retrospective forecasts prior to 2007, with a much greater level of success than was found in the assessment of SIO contributions. Further, idealized studies also show much greater promise. More research is needed to understand whether skill is lower in the SIO contributions because ice is greatly diminished in recent years or if there is another explanation.

A month after the report was published, the first call for contributions to the SEARCH/SIPN Sea Ice Outlook for 2014 was issued. Between June and August, with contributions from 28 different groups, the SIO received a total of 88 outlooks, i.e., predictions of the sea ice extent to occur in mid-September 2014. The large number of outlooks and contributing groups reflects the growing value of the SIO as a forum for discussion of the challenges of sea ice prediction and how to overcome them.

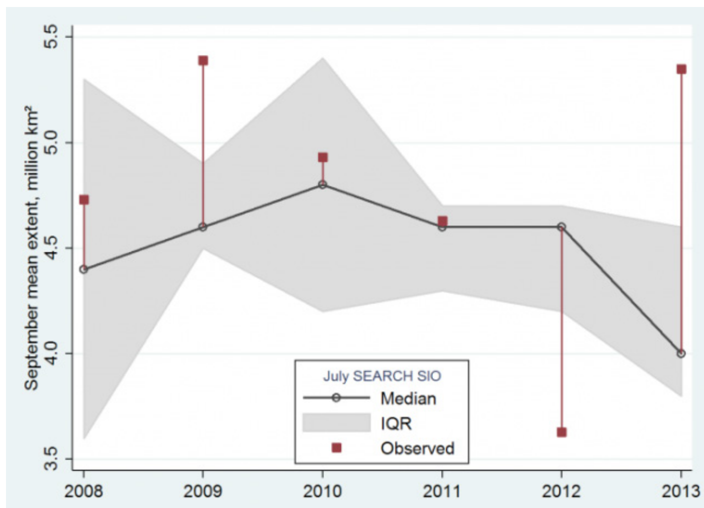


FIGURE 12
SEA ICE OUTLOOK
Median and interquartile range (IQR) of Sea Ice Outlook predictions made in July compared with observed mean sea ice extent in September. In years when observed ice extent is near its trend, the median predictions tend to be accurate (2008, 2010, 2011), but in years when the observed extent is anomalous, the median and most individual predictions are less accurate (2009, 2012, 2013). Source: Stroeve et al. (2014). "Predicting September sea ice: Ensemble skill of the SEARCH Sea Ice Outlook 2008–2013," *Geophys. Res. Lett.*, 41, 2411–2418, doi: 10.1002/2014GL059388

*Study of Environmental Arctic Change, a multi-agency/institutional collaboration formed in 1999 to study system-scale Arctic change.

The Changing Seasonal Wheel

Knowledge of Traditional Subsistence Activities Can Enhance Observations of Changing Seasonality

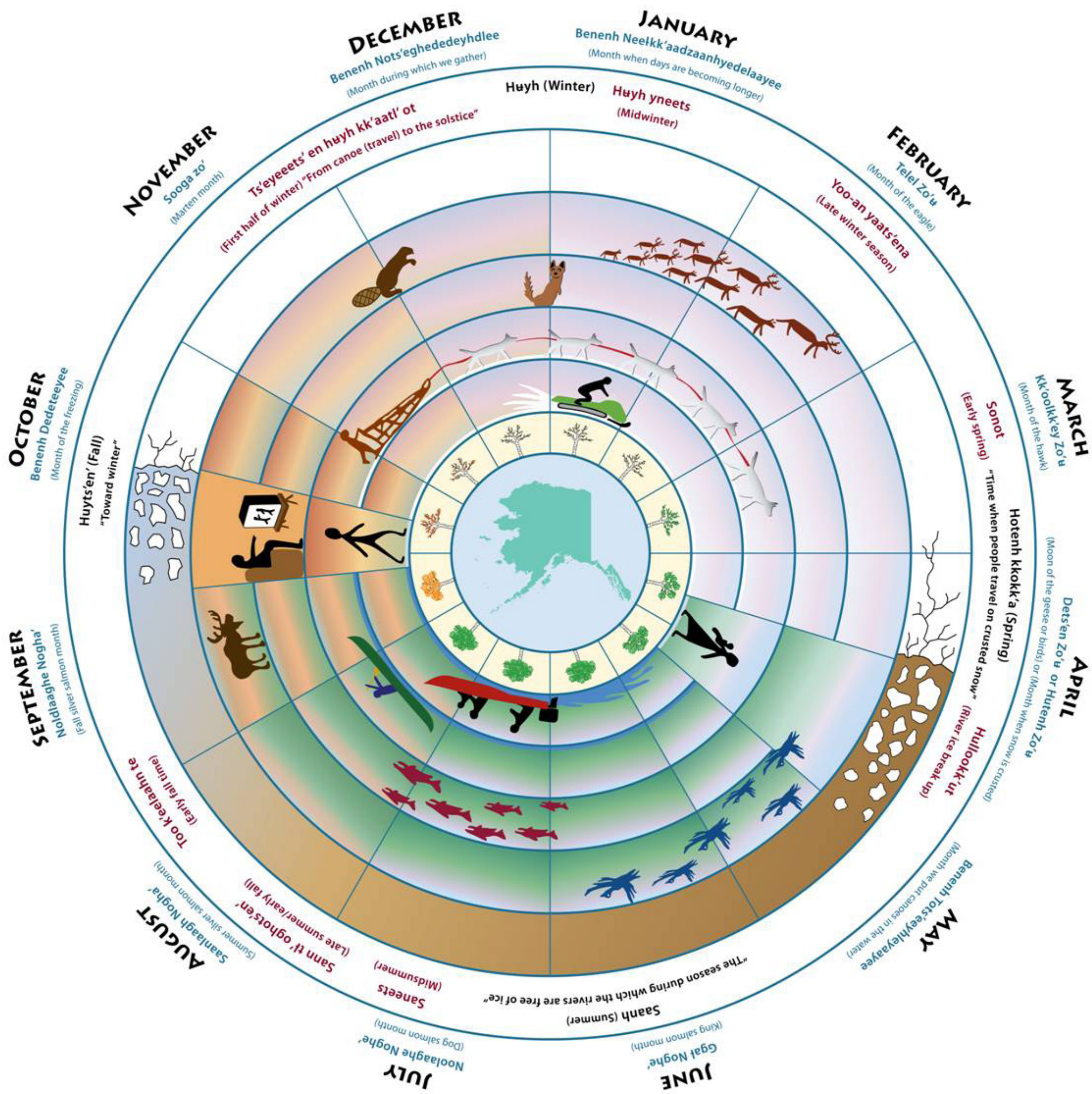


FIGURE 13

THREE KEY PRIORITIES

How will hunting, gathering, and harvesting activities, depicted in seasonal context for communities in Alaska's interior, be impacted by changing seasonality? While completing her Ph.D. dissertation at University of Alaska, scientist Shannon McNeeley (Colorado State University) developed this wheel with community members from Hughes, Huslia, and Koyukuk, Alaska, to help scientists understand local observations and understanding of seasons and seasonal change.

The wheel demonstrates the interconnectedness of three key priorities identified in the Arctic Observing Assessment: food security, ecosystem health, and climate change adaptation and mitigation. Information such as this can inform research to make it more salient to the needs of local people. Source: "The Koyukon. Seasonal Round," Original artwork by Shannon McNeeley, Travis Cole, and Michael Shibao. *Seasons out of Balance: Climate Change Impacts, Vulnerability, and Sustainable Adaptation in Interior Alaska: A Dissertation.* Shannon McNeeley, University of Alaska, Fairbanks, August, 2009, page 61

A young resident of Shishmaref, Alaska, enjoys some outdoor play during recess. Photo: "Kanigruaq" courtesy of Alaska Teacher/flickr/CC BY 2.0

4: New Tools to Support Arctic Research and Community Resilience

IARPC helps policy makers, community leaders, and residents adjust to the new Arctic.

Traditional Arctic communities are tied closely to the polar environment. In the past, these communities have adapted to change through age-old practices, for example, relocating or hunting different wildlife. But rapid Arctic change may challenge these communities in ways that require new adaptive responses. More broadly, State and Federal agencies will need resources with which to make knowledge-based decisions about transportation, resource management, and infrastructure as these are affected by the changing Arctic.

One of IARPC's focus areas is to provide the basic scientific knowledge necessary for community leaders and government agencies to develop sustainable pathways for successful adaptation amid rapid environmental change and a variety of other stressors—all while juggling diverse Federal, State, and local interests.

In this section, several examples are offered of how the IARPC has helped develop tools that provide decision support to policy makers and community leaders as they help residents adjust to the new Arctic.

Monitoring Ecosystem Health

Climate change is altering the incidence of disease among people and wildlife in the Arctic. Higher temperatures increase risks of disease from food poisoning; contaminated water; illness passed between humans and animals; and

Case Study: Local Environmental Observer Network

While harvesting a bearded seal, a Shishmaref resident noticed the animal had suffered unusual hair loss. The resident took a picture and reported the event.

Her photo and observation were posted to a public map on the Internet, and the observer was directed to the marine mammal stranding coordinator in Nome for more information.

That's Alaska's Local Environmental Observer (LEO) Network in action.

The LEO network provides rural communities with tools to improve monitoring for events such as extreme weather, damage to infrastructure, invasive species, and outbreaks of illness in wildlife included in subsistence diets (such as the bearded seal with hair loss in this example).

Through LEO, Alaskans become reporters bearing witness to change when they contribute their observations *via* a simple webpage maintained by LEO.

LEO distributes these reports to traditional knowledge experts, scientists, and others (in this case, NOAA and the SeaGrant Marine Advisory Program specialists) who then provide information and resources about the event to the original reporter *via* a monthly Google Map tool.

LEO archives the reports and the expert feedback to provide a lasting record. In addition to documenting change across Alaska, the LEO network improves communication and connects local environmental and health managers with organizations that can provide technical assistance and resources.

"Bearded Seal" courtesy of Gonzalo Malpartida/flickr/ CC BY 2.0

accelerated mobilization and biological amplification of toxic chemical contaminants such as mercury, and persistent organic pollutants circulating within terrestrial and aquatic ecosystems.

Because disease can spread through the food chain, traditional subsistence communities—i.e., those which hunt, harvest and produce most of their own food instead of purchasing it from grocery stores[32] — are particularly vulnerable to changes in wildlife resources and in the shared environment.

In addition to disease transmitted from animals or caused by contaminants, important emerging challenges include the overall health, abundance and availability of subsistence resources. Food security is becoming a challenge in much of the North. While traditional foods are nutritional and integral to healthy lifestyles, store-bought foods meant to augment or replace subsistence diets can be costly, highly processed, and/or nutrient-poor. All of these issues cause concern.

They also make the Arctic a region uniquely suited to a "one health" approach to public health—an interdisciplinary collaboration between medical providers (i.e., doctors, nurses, osteopaths, dentists, etc.) and experts in other health and environmental sciences-related disciplines—to sustain the health and resilience of landscapes, seascapes, wildlife, and human inhabitants.[33]

To help advance this approach, IARPC's Human Health Collaboration Team (HHCT) participates in Alaska's One Health working group. The group was formed in 2013 and is hosted by the Alaska Native Tribal Health Consortium and the U.S. Centers for Disease Control and Prevention (CDC). Participants include public health officials, veterinarians, farmers, environmental managers, wildlife harvesters, researchers, and resource managers. HHCT meets quarterly to share updates on activities, to discuss emerging issues, to consider events that are indicative of environmental and climate change, and to provide a forum for identifying areas of common interest.

The Alaska One Health Working Group uses interagency, interdisciplinary, and community-based collaborations to monitor the impacts of climate/ environmental change and environmental contaminants on human health in the Arctic, and to implement adaptive measures.

Elements of the approach include:

- Conducting community health assessments
- Initiating training and deployment of monitoring technology
- Developing a web-based monitoring network to assess environmental and health impacts and to provide feedback and adaption strategies to tribal leaders, tribes and tribal organizations
- Developing, deploying, and assessing a surveillance and response toolkit to promote community-based adaptation planning for climate change

The group uses a Google mapping tool to review and share recent environmental health events. Map posts include articles scanned from Alaska news media, observations provided by community-based members of the Local Environmental Observer (LEO) Network, as well as

[32] Subsistence goes beyond food provision to include important resources for living, cultural activities, and local economy.

[33] The broader definition of One Health is based on the premise that human health is connected with the health of the environment and that of wildlife and livestock health.

content provided by One Health group members themselves.

These inputs result in a tracking system for current and emerging events: a comprehensive environment, wildlife, and public health information fusion tool; and a constructive network for raising awareness and enhancing interagency collaboration.

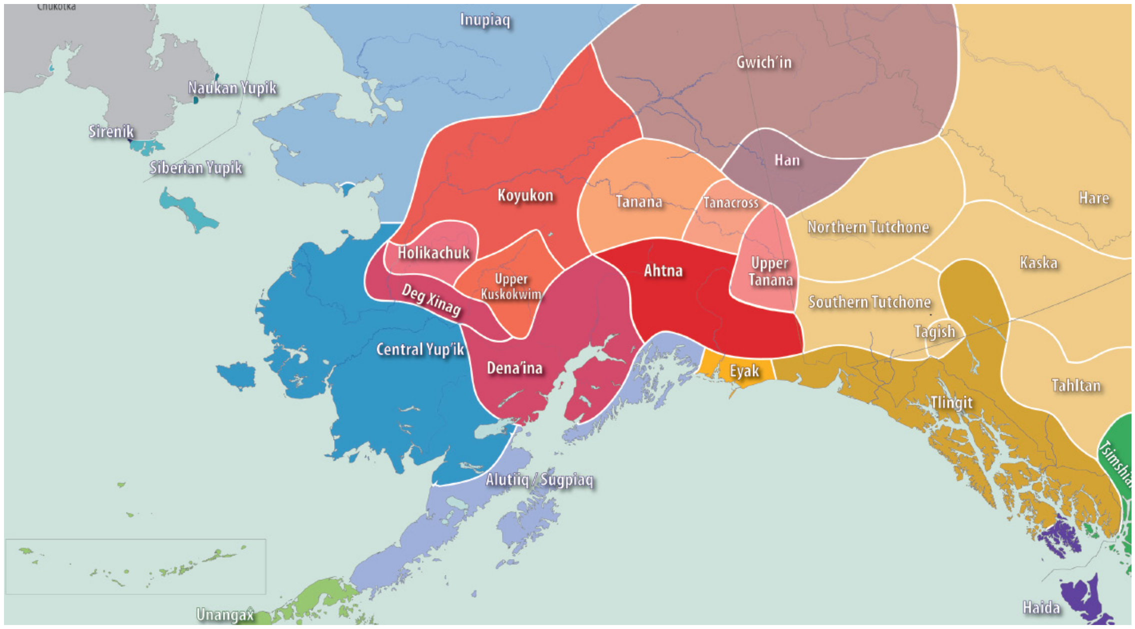


FIGURE 14
TWO MAIN BRANCHES
Map showing indigenous language distribution in Alaska. Source: University of Alaska, Fairbanks

Documenting Endangered Languages

Alaska is home to about 20 distinct indigenous languages primarily belonging to 1 of 2 main language branches: Eskimo-Aleut and Athabascan-Eyak-Tlingit (FIGURE 14). Except for Central Alaskan Yup'ik, only a small number of Alaskan children learn to speak a language other than English.[34] Because traditional communities tend to pass culture, subsistence practices, and language through story-telling and song, many of the indigenous languages are endangered. To support preservation, IARPC's Arctic Communities Collaboration Team (ACCT) is working with Federal and local agencies to develop tools that Arctic and Alaska Native communities can use to develop new indigenous language preservation strategies.

The ACCT promotes activities that support all cultural aspects of Arctic societies. Specifically for language preservation, the team focuses on encouraging the Documenting Endangered Languages (DEL) program, a partnership between the National Endowment for the Humanities, the Smithsonian, and the NSF to develop and advance knowledge concerning endangered human languages.

The DEL program uses information technologies and supports a range of field work and other activities to record, document, and archive endangered languages. Activities include preparing lexicons, grammars, text samples, and digital databases.

A unique achievement for Arctic language preservation is the development of a digital repository providing access to a world-renowned collection of Native American language documentation housed at the University of Alaska, Fairbanks' Alaska Native Language Archive. ACCT discussions on Arctic languages helped to focus Federal agency efforts on this topic and encouraged funding for the archiving project. When completed, the digital archive will provide the foundation for a new era of language and culture scholarship in the Arctic. To date, digitization efforts have already been undertaken in tandem with build-out of the necessary digital repository infrastructure. A local digital mass storage server resides at the Alaska Native Language Archive[35] hosted by the Arctic Region Supercomputing Center. The University of Alaska's Office of Information Technology hosts and maintains a web-based catalog and document-retrieval interface.

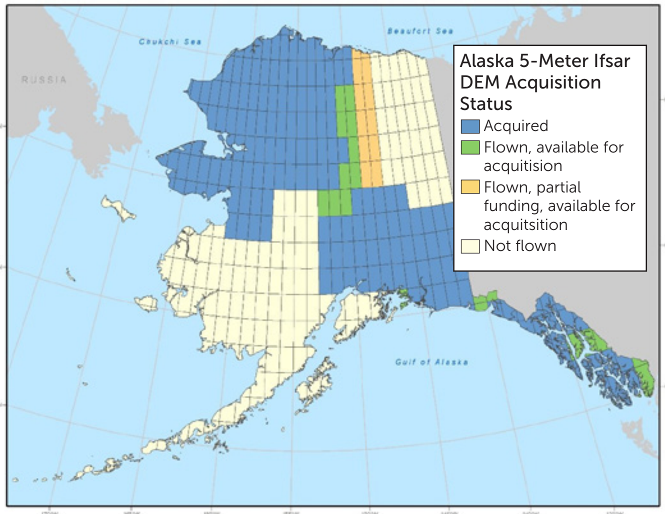
High-Resolution Digital Elevation Models for Alaska

Collaboration with the state of Alaska is called out in IARPC's enabling legislation. One area of successful collaboration is acquisition of high-resolution digital elevation models for Alaska. In early summer 2012, Federal and State experts met to review and address the state of Alaska's mapping documents. Because maps inform many government interests (e.g., land management, air and marine traffic control, resource development, etc.), agency managers wanted to assess best approaches to updating the largely outdated inventory.

To help address the issue, the IARPC Terrestrial Ecosystem Collaboration Team is working with members of the Alaska Mapping Executive Committee, which draws on members from State and Federal departments and agencies including Executive Office of the President, DHS, DOE, DOI, DOT, EPA,

[34] Alaska Native Language Center, University of Alaska, Fairbanks. www.uaf.edu/danl/about/index.xml?__noframe=2882

[35] www.uaf.edu/anlc



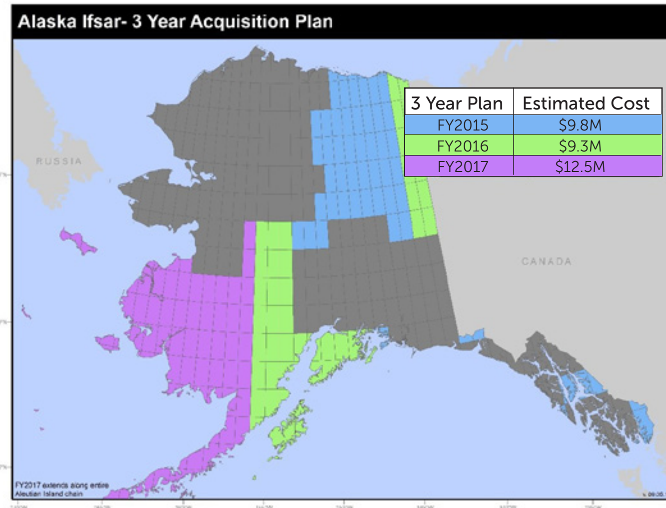


FIGURE 15

IMPROVED MAPS TO TRACK LANDSCAPE CHANGES

The status of Alaska interferometric synthetic aperture radar (IfSAR) Elevation Data Collection as of September, 2014 (left); Alaska Mapping Executive Committee IfSAR Elevation Data Collection showing areas covered by the 3-year Aquisition Plan as of July 2014.

NOAA and USDA. The committee intends to develop improved mapping for Alaska, producing high-resolution Digital Elevation Models for the entire state, including the coastal areas.

The Alaska Mapping Executive Committee coordinated the collection and purchase of new statewide 5-meter resolution digital-elevation data for Alaska using radar technologies that can penetrate the cloud cover persistent in many areas of Alaska. The data products include a Digital Terrain Model portraying the bare surface of the Earth, a Digital Surface Model depicting the highest features on the landscape (such as trees), and a terrain-corrected radar reflectance image.

This enhanced data collection greatly improves the existing Alaska statewide National Elevation Dataset, at 60-meter resolution, which was created from information on 1950s- and 1960s-era topographic maps.

The digital elevation models provide a baseline for current elevations and thus, are important data for use in better understanding coastal erosion, storm surges, vegetation communities, and sea-level rise—all of which are expected consequences of climate change. Digital elevation models can be used to delineate coastlines for maps, and, if repeated at time intervals, can elucidate changes in coastline. These data can be used to anticipate inundation and high elevation areas during storm surges and are helpful in tracking changes in flora and fauna communities, as well as impacts to human settlements. Additionally, the models are valuable to baseline vegetation mapping, and have been used in wetland mapping on the Seward Peninsula by the U.S. Fish and Wildlife Service, National Wetlands Inventory.

As of September 2014, 5-meter resolution elevation data was funded for over 50 percent of Alaska, including over 113,000 square miles of the Arctic (FIGURE 15). In line with the Alaska Mapping Executive Committee's 3-year plan, near-term elevation data acquisitions and purchases will most likely continue to concentrate on the Arctic and southeast Alaska, moving to south-central and southwestern Alaska in subsequent years.

Contributing writers: Mike Brubaker, Roberto Delgado, Alan Parkinson

Kivalina, Alaska, is located on a barrier island. Loss of sea ice has exposed the coast to bashing waves during storms, and threats to the community are worsened by sea-level rise. If not relocated, Kivalina likely will be inundated by 2025. Photo: "Kivalina, a village facing coastal erosion" courtesy of ShoreZone/flickr/CC BY 2.O

Spectacled eiders use openings in sea ice cover in the northern Bering Sea to reach clam populations on the sea floor. These birds are listed as threatened species under the Endangered Species Act. Photo: Matt Sexson, USGS

5: Developing International Research Networks

By promoting international activities, IARPC helps accelerate progress on issues of common concern through scientific research and traditional knowledge.

Many of the accomplishments described in this report draw on international cooperation. For example, atmosphere observatory network IASOA could not provide pan-Arctic observations without the participation of our Canadian, Danish, Greenlandic, Norwegian and Russian colleagues. Others, such as the MARES project or the SIPN, are now expanding international collaboration elements to enrich their activities. In this section, an activity critically dependent on international associations is described: the Distributed Biological Observatory (DBO) of the Pacific Arctic.

The Distributed Biological Observatory

Among IARPC's science themes is a commitment to advance research related to the influence of sea ice and other physical parameters on marine ecosystems. Over the last 2 years, IARPC has focused on enabling the DBO[36] of the international Pacific Arctic Group (PAG).

[36] www.arctic.noaa.gov/dbo

Early efforts

In 2009, in response to significant physical changes in the region, notably record seasonal sea ice retreats, ocean freshening, and warming, an international group of researchers formed the DBO. Their goal is to make sustained and consistent observations of the biophysical environment in five regions extending from the Northern Bering Sea to the Beaufort Sea (FIGURE 16).

Through coordinated planning, systematic observations, and data-sharing, the DBO pilot study (2010-2014) focused on five "hot spots" of high productivity and rich biodiversity along a latitudinal gradient in the Pacific Arctic. The scientific community vetted the DBO concept; subsequently, multiple Federal agencies, including BOEM, NASA, NOAA, and NSF, sponsored the activities. Internationally, Canadian, Chinese, Japanese, Korean and Russian agencies contributed as well, *via* the PAG and national agency support.

After a successful start, IARPC included the DBO in its 5-year plan in 2012, forming a collaboration team from among participating agencies. In 2012, the NSF Arctic Observing Network (AON) program awarded a 5-year collaborative grant.[37] Since forming, the IARPC DBO collaboration team has held regular teleconferences to achieve the overarching goal of routine sampling in all five DBO regions by 2015.

Interagency Collaborations and Achievements

The DBO collaboration team has received strong support and collaboration from a number of U.S. agencies and academic institutions (FIGURE 17).

[37] www.arctic.cbl.umces.edu/#_DBO
This website describes the DBO, lists the collaborators, and links to the NSF award page.

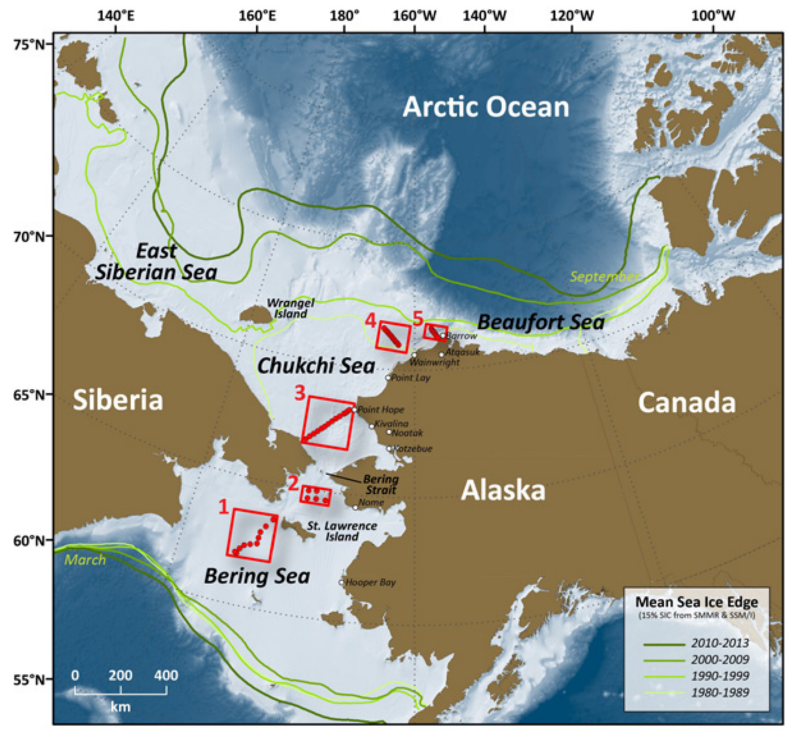


FIGURE 16
FIVE HOT SPOTS
The Distributed Biological Observatory (DBO) focuses multidisciplinary sampling at oceanographic stations across a latitudinal gradient from the northern Bering Sea to the Beaufort Sea; map is updated from Grebmeier 2012.

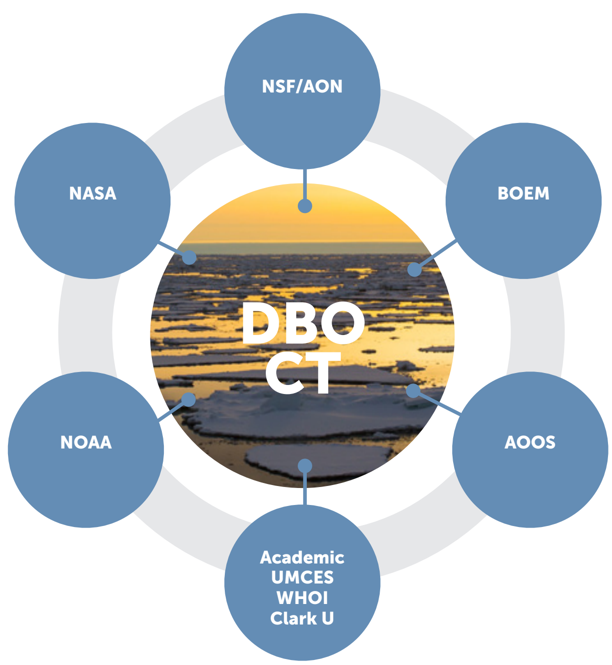


FIGURE 17
IARPC COLLABORATORS
U.S. agencies and academic allies comprising the DBO Collaboration Team.

Participants at academic institutions and Federal agencies[38] provide a synergistic flow of data and expertise. Examples of key contributions include:

- Annual ship-based sampling and the provision of a physical oceanographic data portal (WHOI) to enhance data access and coordination
- Development of a DBO specific portal by NASA to facilitate researcher access to regional satellite products[39]
- Sampling during the RUSALCA[40] program (the only program to sample in Russian waters), and coordination of national and international contributions to the DBO, *via* the PAG
- Contribution to sampling during various multidisciplinary research programs in the Chukchi Sea
- Provision of web-based assets mapping and a password-protected data workspace, and an open-web data portal

The DBO provides a framework to focus and coordinate standardized sampling and analytical efforts that link biological changes to physical drivers. A key DBO science achievement has been the ability to track shifts in benthic community biomass and structure concomitant with measures of annual sea ice persistence in the five DBO regions. These observations build upon research initiated in the 1980s, where decadal patterns, shifts in species composition, and northward faunal range were identified.[41] In addition, scientists are observing an east-to-west gradient in zooplankton populations that vary with water mass type through the season,[42] and more frequent occurrence of temperate whale species in DBO region 3.[43]

An important physical oceanographic achievement through observation of the DBO5 (Barrow Canyon) line (FIGURE 15) has been to observe the seasonal seawater freshening and warming of water transiting northward on the eastern and surface layers of the Chukchi Sea, with the maximum temperature observed in September.[44] Upwelling events are observed roughly one-third of the time (7 of 24 occupations), which significantly alter hydrography in the canyon.

The DBO International Network

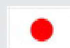
	COUNTRY	SHIP NAME
	Russia	*Professor Khromov*
	Korea	*Araon*
	China	*Xueê Lóng*
	Japan	*Oshoru-Maru, Mirai*
	Canada	*Sir Wilfrid Laurier, Louis S. St-Laurent, Amundsen*
	USA	HEALY, *Oscar Dyson, Aquila, Annika Marie*
INDUSTRY	Shell, ConocoPhillips	*Norseman ll, Westward Wind*

FIGURE 18
SHIP SUPPORT
Summary of international entities coordinated through Pacific Arctic Group (PAG) and industry agencies working on the Distributed Biological Observatory (DBO) program.

International and Industry Collaborators

The PAG is a consortium of institutions and individuals having a Pacific perspective on Arctic science. Organized under the International Arctic Science Committee (IASC), the PAG has as its central mission to serve as a Pacific Arctic regional organization to plan, coordinate, and cooperate on science activities of mutual interest. The four principal science themes of PAG are climate, contaminants, human dimensions, and structure and function of Arctic ecosystems.

With reference to the fourth theme, the PAG assumed a leadership role in coordinating international contributions to DBO sampling during the pilot-study program, including linking projects for sampling the DBO lines. These international contributions to DBO sampling provide an unprecedented capability to track inter- and intra-annual variability in DBO regions (FIGURE 18). An annual listing of DBO cruises undertaken through the PAG network is available on the PAG and DBO websites.

38 These institutions include Clark University (Clark U); University of Alaska, Fairbanks (UAF); University of Florida (UF); University of Maryland, Center for Environmental Science (UMCES); University of Texas (UT); and Woods Hole Oceanographic Institution (WHOI).

39 www.neptune.gsfc.nasa.gov/csb/index.php?section=270

40 Russian-American Long-term Census of the Arctic. www.arctic.noaa.gov/aro/russian-american

41 Grebmeier, J.M. "Shifting Patterns of Life in the Pacific Arctic and Sub-Arctic Seas." *Annual Review of Marine Science,* Vol. 4 (2012): 63-78. doi: 10.1146/annurev-marine-120710-100926

42 Pomerleau et al. (2014). "Spatial Patterns in Zooplankton Communities and Stable Isotope Ratios (13C and 15N) in Relation to Oceanographic Conditions in the Sub-Arctic Pacific and Western Arctic Regions during the Summer of 2008." *Journal of Plankton Research.* doi: 10.1093/plankt/fbt129

43 Clarke et al. (2014). "Subarctic Cetaceans in the Southern Chukchi Sea: Evidence of Recovery or Response to a Changing Ecosystem." *Oceanography* 26(4): 136-149. doi: 10.5670/oceanog.2013.81

44 Nobre et al. (2014). "Evolution of Water Masses in Barrow Canyon during Summer/Fall." AGU Ocean Sciences Meeting, Honolulu HI

Future Directions

The DBO CT is now focused on compiling data from the pilot study sampling period, to demonstrate the value of this national and international shared-data approach to the investigation of biological responses to a rapidly changing Arctic marine ecosystem.

Three goals included in both the DBO CT activities table, and the National Strategy for the Arctic Region work plan[45] are to publish an updated national/international DBO concept plan for decadal-scale implementation by the end of 2015; prepare periodic assessments on the physical and ecological state of the Pacific Arctic marine environment; and integrate DBO data with that from collaborating agencies and other sources by the end of 2016.

The DBO CT is on track to accomplish these goals, drawing upon outcomes of international meetings such as discussions of the DBO held at the 2014 Arctic Science Summit Week in Helsinki, Finland, and the second DBO Data Workshop in October 2014. Expanding from the Pacific Arctic sector, the DBO also serves as a framework for international research coordination *via* the Arctic Council Circumpolar Biodiversity Monitoring Program, and is recognized as a task of the pan-Arctic Sustaining Arctic Observing Network program.

Additional discussions are ongoing to expand the DBO concept to the pan-Arctic scale as part of the Norwegian Strategic Initiative-Arctic for placing DBO-transect lines in the northern Barents Sea and through National Oceanographic Partnership Program for placing additional DBO-transect lines in both the U.S. and Canadian Beaufort Sea.

Contributing writers: Jacqueline Grebmeier, Sue Moore

[45] www.WhiteHouse.gov/sites/default/files/docs/nat_arctic_strategy.pdf

A herd of walrus rest on patchy sea ice. Photo: Karen Frey, Clark U

The Pacific Arctic: Why it Matters

The region is home to animals thought vulnerable to sea ice loss, notably walruses, ice seals, polar bears, and ocean-going bird species, which feed and breed on sea ice. Sea ice habitat loss impacts both walrus and diving sea ducks who use it as a resting platform between feeding periods. These animals lose more energy in the ocean than they do when resting on ice. Seasonal sea ice loss in the region increases access for ships and for those seeking natural resource extraction. Given these potentially competing interests—and the unknown potential for cascading impacts—scientists seek to understand the relationships between physical and biological systems in the Pacific Arctic. Improved understanding of the marine ecosystem would support information-based decisions for local, State, and Federal managers.

Next-generation scientists plan their field work in Alaska's Brooks Range (the opportunity) while garbed in head-nets to protect against swarms of mosquitoes (a challenge). Photo: Jason Briner, State University of New York at Buffalo

6: Looking Forward

The best scientists in the world are all telling us that our activities are changing the climate, and if we do not act forcefully, we'll continue to see rising oceans, longer, hotter heat waves, dangerous droughts and floods, and massive disruptions that can trigger greater migration, conflict, and hunger around the globe. The Pentagon says that climate change poses immediate risks to our national security. We should act like it.
—President Barack Obama, State of the Union Address. January 20, 2015

IARPC's expanding collaborations will help policy-makers develop informed approaches to meet challenges and opportunities arising in the new Arctic.

IARPC's next course is an exciting one, with challenges and opportunities centered around people. Arctic residents must adapt to rapid change in social and natural systems. People living below the Circle are increasingly aware of the linkages between the region and their weather, water supply, the changing prices of food, fuel, and other goods, and of issues such as coastal vulnerability and wildfire expansion. Rapid change may also alter people's perceptions of the Arctic itself—its innate beauty, and the indigenous heritage Arctic Nations share.

Improving knowledge of Arctic systems will remain a vital centerpiece of the U.S. research agenda, even as Federal budget managers strain to address broad challenges of national security, energy independence, food and water security, health care, and more. Strong agency coordination

Ride-Sharing in the Arctic

Arctic field work frequently calls for specialized support (e.g., ice-strengthened vessels, ruggedized field gear, and expensive air support). Sharing logistics resources when possible allows scientists and Federal funding agencies to stretch logistics dollars—and pays big benefits in terms of research collaboration as well.

The NSF's Division of Polar Programs manages the Arctic research support and logistics (RSL) program, working through agreements and contracts with a variety of organizations that provide services and infrastructure to researchers. Through economies of scale and efficiencies gained through years of experience, the RSL program leverages its investment to provide camps, ships, aircraft, risk management, environmental compliance, and proposal estimates. RSL funds the operation of facilities, including Summit Station in Greenland, and Toolik Field Station on Alaska's North Slope; and it maintains the science capability on the United States Coast Guard Cutter HEALY. RSL extends these resources, on a reimbursable basis, to other agencies and organizations. U.S. and international organizations can and should do more to share resources, coordinate field campaigns, and utilize best practices developed by one another.

At a 2013 RSL workshop, stakeholders and providers met to explore the logistic infrastructure that needs to be in place to facilitate Arctic research over the next 20 years. Key workshop themes acknowledged that science needs must drive logistics requirements; that research, and therefore logistics, needs to be Arctic-wide and year-round; and that logistics capabilities need to be flexible and agile, leveraging existing capabilities, emerging technologies, and the desire and willingness of the next generation of researcher and logistician to learn and succeed.

Specifically, workshop participants suggested IARPC as a forum for U.S. agencies to better coordinate logistics resources in support of research. NSF is working with other agencies towards a sustained dialogue regarding logistical needs and resources, so as to improve both coordination and collaboration.

At an international level, collaborations continue. The Swedish Polar Research Secretariat (SPRS) approached NSF in 2014 to discuss using the Swedish research icebreaker *Oden* in the Arctic on a more regular basis. In 2015 and 2017, NSF and SPRS intend to implement a pilot arrangement to support projects led by researchers from each country. In winter of 2015, researchers from both countries attended a workshop to discuss potential collaborations that could result in a long-term arrangement.

The arrangement would allow funding agencies to alert the research community in advance of the ship's availability so they may propose to use it. If proposals are funded through the merit review processes of both countries, coordinated cruises would emerge. The discussion is on-going and will be informed by an NSF-funded research project onboard *Oden* in 2015 in the Nares Strait region of Greenland.

RSL is active in the Forum of Arctic Research Operators (FARO), a body to discuss facilities and infrastructure in an international setting. FARO meets annually at Arctic Science Summit Week. RSL has taken the lead in facilitating information-sharing on field safety risk management in the Arctic, enabling each country to share best practices and possibly share opportunities for field safety training and other expertise. FARO is an opportunity for each country to discuss field research plans to improve coordination and collaboration, particularly among research vessels, ecological research stations, and other areas of emphasis, such as the upcoming Year of Polar Prediction.

Two small helicopters move scientists to field sites on Alaska's North Slope. Photo: Nancy Brandt is more important than ever before, not simply from the standpoint of leveraging resources, but because the problem is complex. This complexity moves IARPC forward.

Year of Polar Prediction

Future internationally coordinated activities present opportunities for U.S. agencies to cooperate in productive ways with other nations. One such example is the proposed Year of Polar Prediction (YOPP), developing under the auspices of the World Meteorological Organization's Polar Prediction Project[46] , and commencing in 2017,' YOPP is a centerpiece activity—similar in nature to the International Polar Year[47]—intended to coordinate broad international polar observing activities with the aim to improve weather and climate model predictions for polar environments.

YOPP has the potential to improve weather predictions in polar environments by reducing uncertainty due to poor process understanding and sparse observational networks. The research program will also improve seasonal forecasts of Arctic sea ice concentrations, which would support safer transportation and development in the region, and help scientists understand the polar vortex and cold-air outbreaks that wreak havoc with mid-latitude winter weather. YOPP's success will rely on well-coordinated observations targeted at specific model-improvement opportunities.

Well-coordinated U.S. participation in YOPP is a challenge because it requires both mission-based agencies and competitive-funding agencies to recognize and support their unique roles, while working together in a mutually beneficial way. A series of planned U.S.-specific discussions will lead to more unified U.S. participation on the international stage—and IARPC will enhance this cooperation *via* collaboration teams and net-working tools.

[46] www.polarprediction.net/yopp.html

[47] A coordinated pulse of polar research activity, 2007-2008. www.ipy.org

NOAA measures key atmospheric indicators of global climate from Greenland's Summit Station. The NSF funds the station in cooperation with the Government of Greenland. Photo: Ed Stockard, Blue Marble Photography

U.S. Chairmanship of the Arctic Council

In May 2015, the United States assumed chairmanship of the Arctic Council for a 2-year period. The council was formed in 1996 as a forum to promote cooperation and dialogue among the eight countries whose territories extend into the Arctic (Canada, Denmark [via Greenland], Finland, Iceland, Norway, Russia, Sweden, and the United States). The council is unique as an international forum in that it also includes representation from six indigenous peoples' organizations. An "observer" category includes non-Arctic nations, intergovernmental organizations, and nongovernmental organizations that have been granted accreditation through an application process. The most recently accredited observers were approved in 2013, and included six nations—China, India, Italy, Japan, Singapore, and South Korea.

The Arctic Council primarily focuses on fostering environmental stewardship and sustainable development. Chairmanship from 2015 to 2017 gives the United States more opportunity to influence the direction of the council's work while focusing on three overarching goals for its term: continue strengthening the Arctic Council as an intergovernmental forum; introduce new long-term priorities into the Arctic Council; and raise U.S. and global awareness of the Arctic and climate change.

Along with these goals, the United States will focus Arctic Council activities on the following three organizational themes:

- **Improving Arctic Ocean Safety, Security, and Stewardship** by promoting search-and-rescue exercises; coordinating marine environmental protection research and information, including that related to oil-spills; enhancing activities to develop a Pan-Arctic network of marine protected areas; and expanding the monitoring coverage of ocean acidification in the Arctic Ocean.
- **Improving Economic and Living Conditions for Arctic Peoples** by demonstrating the potential of renewable energy to replace expensive diesel sources; internationalizing efforts to improve access to clean drinking

water, reliable sanitation and freshwater supplies; developing telecommunications infrastructure; and adapting suicide / mental illness prevention research and resources to suit the unique circumstances of Arctic communities.

- **Addressing the Impacts of Climate Change** by implementing efforts to reduce, monitor, and study short-lived climate pollutants; promoting and evaluating recommendations for climate adaptation and resilience for Arctic residents; and enhancing Arctic climate science.

Through its collaboration teams, IARPC contributes to the research components of these themes and ensures coordination across Federal agencies. These themes each benefit Arctic residents while helping to promote a considered approach to the new Arctic that emphasizes environmental stewardship. Another area of focus will be public outreach—that is, efforts to educate the general public about the Arctic, why it matters, and how the effects of climate change in the Arctic impact other areas of the planet. The U.S. chairmanship of the Arctic Council provides a seat from which the United States can promote its strategic national interests in the Arctic, as well as make the American public aware that these national interests exist.

Emerging Science Questions and Expanding Networks

IARPC set out in 2013 to provide guidance on future Arctic research over the next 10 to 20 years. Multiple IARPC agencies (DOE, NASA, NOAA, NSF, the Smithsonian Institution, and USARC) sponsored a committee under the Polar Research Board (PRB) of the National Academy of Sciences to develop and issue the report. The resulting study, *The Arctic in the Anthropocene: Emerging Research Questions*,[48] was issued in April 2014. It addresses the urgent need to understand the rapidly changing Arctic by defining the current state of knowledge and connecting the dots among emerging science questions to guide future science opportunities. The goal: to leverage science talent and agency resources, thus maximizing opportunities to fill in critical knowledge gaps.

IARPC encouraged contributions from the science community, agency personnel, international colleagues, and Arctic residents. With input from this constituency, the report identified questions that have arisen as rapid change has pervaded the Arctic system, questions that have yet to receive the

[48] Available for download on the IARPC Collaborations website: www.iarpccollaborations.org

Barrow, Alaska: a person flings treats to the crowd below as he rides on the blanket toss, a traditional game celebrating a successful community harvest. Photo: Faustine Bernadac

Strategies for Addressing Future Research Challenges

As described in *The Arctic in the Anthropocene*

Enhance Cooperation. No single entity can address all Arctic research topics. Cooperation is essential among researchers, between agencies, among nations, across disciplines, between Arctic residents and visiting scientists, and within the private sector.

Sustain Long-term Observations. Long-term observational data are essential for detecting change and for putting research findings into context.

Manage and Share Information. Understanding the Arctic system will continue to evolve through the ability to compare data sets from disparate fields and regions to see connections and commonalities.

Maintain and Build Operational Capacity. Technology advances allow new approaches to research in many fields. At the same time, decisions-makers must sustain current capabilities, including ships, satellites, and research stations.

Grow Human Capacity. Arctic research depends on sufficient human capacity, including scientists trained in the necessary fields who are capable of interdisciplinary collaboration, and Arctic residents who can offer a great deal to research efforts.

Invest in Research. Given the emerging research questions, pressures are growing for comprehensive systems and synthesis efforts, research on rapid changes, social science, stakeholder-initiated research, international research, and long-term observations.

attention they require, and/or that can only now be addressed given technological or other advances.

The report reveals a future Arctic research agenda that will challenge existing practices to bridge disciplinary and functional gaps. In particular, the ground for collaboration between natural, social, and human health sciences will grow as will the need to translate scientific knowledge into decision-relevant contexts (e.g., scientists advancing sustainability research working with those planning infrastructure development). Research sponsorship will need to adapt to meet these challenges, and IARPC is positioned to lead.

As the Arctic research 5-year plan is updated, IARPC will explore opportunities more broadly in the context of the National Strategy for the Arctic Region, the Arctic Council chairmanship, and the new Arctic Executive Steering Committee. IARPC will work with the state of Alaska, Arctic communities, and other interagency committees to cooperatively address research priorities. With all these imperatives, IARPC is well-placed to continue and expand its efforts to create networks of collaborators to tackle urgent research questions that must be addressed as the Arctic undergoes rapid climate and environmental change.

The call for collaboration points back to IARPC's enabling legislation.[49] What happens in the Arctic has far-reaching implications for the entire planet. Fostering a sense of shared purpose among different stakeholders—from U.S. Federal, State, and international organizations to private industry and other non-governmental entities—to manage change is essential. So is a continued commitment to study what exists, what is emerging, and what awaits us in the Arctic through activities that have been and will continue to be addressed by IARPC and its collaboration teams.

Contributing writers: Sara Bowden, Renée Crain, Lauren Everett, Sandy Starkweather, Michael Young

[49] www.WhiteHouse.gov/sites/default/files/microsites/ostp/ARPA.pdf

New Webinar Series

IARPC webinars often cut across teams and themes, acting as a node in the network that encourages communities to get to know and understand potential collaborators' activities.

In addition to webinars hosted by collaboration teams, IARPC launched a series of webinars in 2015 to engage and inform people on a broader range of topics, including research questions, new technologies, and questions related to science policy. IARPC encourages the community to offer webinar suggestions.

IARPC Toolbox

Photo: Faustine Bernadac

Interagency Arctic Research Policy Committee
Sara Bowden, Executive Secretary
bowden@arcus.org
(703) 447-7828