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Preparing for a Northwest Passage: A Workshop on the Role of New England in Navigating the New Arctic

Katharine A. Duderstadt

The University of New Hampshire, katharine.duderstadt@unh.edu

Catherine M. Ashcraft

The University of New Hampshire, Catherine.Ashcraft@unh.edu

Jennifer F. Brewer

The University of New Hampshire, jennifer.brewer@unh.edu

Elizabeth Burakowski

University of New Hampshire, Durham

Jaed M. Coffin

The University of New Hampshire, Jaed.Coffin@unh.edu

See next page for additional authors

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Authors

Katharine A. Duderstadt, Catherine M. Ashcraft, Jennifer F. Brewer, Elizabeth Burakowski, Jaed M. Coffin, Jack E. Dibb, Lawrence C. Hamilton, Nancy E. Kinner, Larry A. Mayer, Jennifer L. Miksis-Olds, Joseph Salisbury, Kerri D. Seger, Ruth K. Varner, and Cameron P. Wake

The background of the slide is a photograph of an Arctic landscape. In the foreground, there are large, white icebergs floating in dark blue water. The middle ground shows a vast expanse of water with smaller ice floes. The sky in the background is a mix of light blue and yellow, suggesting a sunset or sunrise. The text is overlaid on a semi-transparent blue rectangle in the upper left portion of the image.

Summary Report

**Preparing for a Northwest Passage
A Workshop on the Role of New
England in Navigating the New Arctic**

The University of New Hampshire
March 25-27, 2018

Duderstadt, K. A., C. M. Ashcraft, J. F. Brewer, E. A. Burakowski, J. M. Coffin, J. E. Dibb, L. C. Hamilton, N. E. Kinner, L. A. Mayer, J. L. Miksis-Olds, J. E. Salisbury, K. D. Seger, R. K. Varner, C. P. Wake (2018), Summary Report: Preparing for a Northwest Passage, A Workshop on the Role of New England in Navigating the New Arctic, The University of New Hampshire, Durham, NH.

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Summary Report

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I. EXECUTIVE SUMMARY

The rapid warming of the Arctic and melting of Arctic sea and land ice has ramifications around the globe. Shipping routes through an ice-free Northwest Passage in combination with modifications to ocean circulation and regional climate patterns linked to Arctic ice melt affect trade, transportation, coastal ecology and hydrology, human-built infrastructure, demographics and cultural identities, fish and wildlife, energy resources, and air and water quality -- not only in the Arctic but also in mid-latitude coastal regions such as New England. With profound changes on the horizon, this is a critical opportunity for regions such as New England to prepare for the uncertain yet inevitable economic and environmental impacts of Arctic change.

A regional workshop, "NNA Convergence: Preparing for a Northwest Passage – the Role of New England in Navigating the New Arctic" (NSF #17443460), hosted by the University of New Hampshire (UNH) on March 25-27, 2018, gathered expertise and talent from academic and external partners throughout New England and beyond involved in Arctic research. The workshop paired two of NSF's 10 Big Ideas, [*Navigating the New Arctic*](#) and [*Growing Convergence Research at NSF*](#)¹, to discuss the socio-economic and environmental links between New England and the Arctic. The workshop adopted a convergent framework, considering the methods and conceptual frameworks from the social sciences, the experimental and modeling tools of the physical and life sciences, and the solution-driven problem solving of engineering.

I. Workshop Goals and Objectives

The goal of the workshop was to *assess the socio-economic and environmental links between Arctic change and New England, identifying transformational convergence research initiatives to anticipate, prepare for, and adapt to future impacts and opportunities*. The specific objectives of the workshop were to:

1. **DEVELOP A VISION** for how Arctic change might impact New England over the next several decades (opportunity, risks, and hazards) and recommend future convergent research priorities linking Arctic change and New England
2. **ESTABLISH A REGIONAL NETWORK** to encourage multi-institutional convergence research projects
3. **IDENTIFY SPECIFIC CONVERGENCE RESEARCH INITIATIVES**, core collaborative teams, topics for review papers, and follow-up plans in line with NSF Navigating the New Arctic (NNA).

Discussions were designed to develop strategies for conducting scientific research that will best inform decision-making and sustainable communities in anticipation of Arctic change. Particular emphasis was given to concerns unique to New England and its relationship with the Arctic. The anticipation was that identifying specific research problems ripe for convergent approaches will enable the development of innovations in observing systems and modeling efforts, as well as strategies for engaging a range of communities and interest groups throughout the planning, implementation, and evaluation of future research initiatives.

¹ NSF defines Convergence Research as research driven by a specific and compelling problem requiring a deep integration across disciplines.

II. Workshop Findings and Recommendations

i. Overarching Goals

Guest speakers, panel presentations, and round-table discussions focused on three broad topics: Transportation and Infrastructure, Living Resources, and Coastal Dynamics. Plenary discussions based on these sessions identified the following strategic imperatives to link New England and the Arctic through the convergence of knowledge, technology, and society:

- **PREDICT SCENARIOS** of viable regional economies in New England and in the Arctic under conditions of Arctic change, including what these new economies will provide for people on scales from small towns to cities and how they will change socio-ecological and cultural systems.
- **STRATEGICALLY BALANCE** the role of science in engaging with commercial interests as well as environmental ethics and social justice.
- **FULLY ENGAGE STAKEHOLDERS** in the design and execution of research. Include traditional knowledge and citizen science in an effort to understand the scale and rate of change of inter-linked systems in the Arctic and connected regions.
- **FORM A REGIONAL NETWORK** to provide distinctive leadership in supporting science and informed decision-making.
- **TRAIN THE NEXT GENERATION** of convergence researchers and Arctic leaders in twenty-first century skills that value diversity and inclusion.

ii. Establishing a New England Arctic Network (NEAN)

The consensus among workshop participants is that a regional, multi-institutional network based in New England can uniquely address links between Arctic change and the North Atlantic Arctic region. This *New England Arctic Network (NEAN)* will combine the wealth of academic expertise in Arctic research across New England with researchers, stakeholders, and external partners concerned with environmental, economic, and social impacts, providing an ideal community for anticipating and responding to Arctic change and its impacts on the eastern coast of North America. This regional network in affiliation with other nascent networks in Canada and Europe will foster connections and research collaborations among people living and working throughout the North Atlantic Arctic region. Participants identified the following characteristics and objectives for this network:

- **INCLUSIVE MEMBERSHIP**, engaging university researchers and a diversity of representation from businesses, governments, nonprofit organizations, and coastal and indigenous communities.
- **OPEN COMMUNICATION** and the exchange of information and resources, including online collaborative tools that foster new Arctic research collaborations based on community needs.
- **SOLUTIONS-ORIENTED APPROACH** for activities with an applied component, including participatory research methods.
- **HOLISTIC METHODOLOGY** involving research, scholarship, communication, and engagement that is international, interdisciplinary, and inclusive.
- **ENGAGE COASTAL COMMUNITIES** from New England to the Arctic, including indigenous groups. Recognizing a need to expand beyond New England to Canada and other countries around Atlantic, the anticipation is for New England network to grow into a *North Atlantic Arctic Network (NAAN)*.

iii. Themes and Initiatives for Research and Scholarship

The New England Arctic Network will bring researchers (physical and biological scientists, social scientists, engineers, and humanists), educators, artists, governments, businesses, and not-for-profits into the design, implementation, and communication of solutions-driven scientific research, enabling convergence research initiatives across disciplines, institutions, and sectors. Following are the mission, high-priority themes, educational initiatives, and some example convergence research projects to guide the development of this network:

MISSION

Study and respond to links between Arctic change and North America's East Coast, with a particular focus on the North Atlantic, New England, and the Gulf of Maine.

THEMES

1. Hazards related to increased shipping and resource extraction in the North Atlantic Arctic region (e.g., oil spills, disruption of ecosystems, and socio-economic and environmental shocks to coastal communities).
2. Socio-economic and environmental impacts of increased shipping and tourism on coastal communities with implications for environmental ethics and social justice.
3. Risk assessments for coastal communities, informing response to sea level rise and coastal erosion, adaptive management for fisheries and wildlife, and environmental and cultural stewardship.
4. Physical and social infrastructure needs, including the role of adaptive technologies such as smart sensors, scientific decision support, and collaborative governance.
5. Innovative strategies for data synthesis, information transfer, and co-learning among researchers, operators, and decision makers that incorporate traditional knowledge, citizen science, and participatory research.
6. Enhancement of quantitative and qualitative observations to fill data gaps, with a particular focus on biogeophysical marine observations as well as disruptions to socio-ecological systems from the Gulf of Maine to Baffin Bay.

EDUCATIONAL INITIATIVES

1. Design multi-institutional courses that adopt progressive problem-based pedagogy and blended learning.
2. Use the New England Arctic Network to expand student opportunities for field research throughout the North Atlantic Arctic Region.
3. Enhance diversity among the next generation of Arctic leaders, with a particular focus on providing educational opportunities for underrepresented groups and indigenous communities from both New England and the Arctic.
4. Collaborate on outreach activities to educate the “lower 48” about the global impacts of Arctic change.

EXAMPLE CONVERGENCE RESEARCH PROJECTS

1. Perform integrated assessments for socio-ecological scenarios associated with the expansion of ports, shipping, and tourism linking New England and the Arctic. Can strategic investments at local, state, and regional scales improve equitable distribution of benefits (e.g., the best location for ports)?
2. Develop the cyberinfrastructure necessary to anticipate and response to hazards from shipping and resource extraction that affect local communities and ecosystems. Promote efforts to link datasets from natural and social sciences to provide better options for decision-making.
3. Fill in gaps and synthesize datasets to understand how ocean circulation, salinity, and nutrient loading in the North Atlantic will change as a result of Arctic ice melt. Predict the impacts of the changing marine environment on biological productivity, fisheries, community resilience, livelihoods, and cultural heritage.
4. Prepare for real-time knowledge transfer from New England to Arctic communities on a variety of social, environmental, and technology issues. Use social network analysis, social media, and evolving technologies to enhance information transfer.
5. Conduct community-driven studies of coastal erosion and impacts to ecosystem services from permafrost thaw, sea level rise, and extreme weather. Bring together charting and ocean mapping, bioaccumulation, human censusing, displacement options, political consensus, satellite, remote and in situ monitoring on ocean and land. Pursue case study, comparative, and historical research to anticipate societal response. Develop low cost and autonomous sensors (remote observations) and low cost and robust tools (citizen science).

Chapter 4 of the workshop report presents a more comprehensive discussion of Findings and Recommendations. Table 4.2 catalogues an extensive list of specific and compelling science questions and societal challenges linking New England and the Arctic. Each initiative will require a deep integration across disciplines to design the objectives, methodology, implementation, and assessments needed to achieve solutions.

The complete workshop report along with contact information for the New England Arctic Network are available at the following website:

<https://mypages.unh.edu/ne-arctic-convergence>

2. INTRODUCTION

The Changing Arctic

The Arctic is a bellwether of climate and environmental change, with surface temperatures rising twice as fast as the global average [Serreze *et al.*, 2009; Screen and Simmonds, 2010; Cowtan and Way, 2013; Cohen *et al.*, 2014]. September sea ice extent in the Arctic has decreased by 40% since the 1970s and trends predict a nearly ice-free Arctic by mid-century [Smith and Stephenson, 2013; AMAP, 2017] (Figure 2.1). Summertime cruise ships are now voyaging through an open Northwest Passage and last January a commercial LNG tanker traversed the Northern Sea Route unassisted by an icebreaker vessel [Darby, 2018]. The amplification of warming in the Arctic is already having powerful impacts not only for the four million residents of the Arctic but also for non-Arctic populations around the world.

Nations around the world are enticed by the economic lure of new Arctic shipping routes. Russia and China are building fleets of ice-strengthened ships and ice-breakers and coastal communities such as Portland, Maine are transforming into Arctic shipping hubs. Melting Arctic sea ice raises the prospects for mineral and energy exploration, expanded fisheries, faster shipping routes, and an increase in tourism, with diplomats bracing for jurisdictional disputes over Arctic waters. In this rush to the north, dramatic

uncertainties prevail regarding the repercussions that Arctic ice melt and the opening of shipping routes such as the Northwest Passage will have on air and water pollution, migration routes, wildlife habitats, and coastal communities, not only in the Arctic but also at lower latitudes.

Hazards and risks accompany these new opportunities. Expanded access to Arctic regions requires emergency response mechanisms for disasters such as oil spills and shipwrecks. Thawing permafrost, combined with reduced seasonal ice cover along coastlines and rivers, leads to accelerated erosion, damage to fragile ecosystems, threats to human community safety and infrastructure, increased wildfire frequency and intensity, and the release of large stores of carbon dioxide (CO₂) and methane (CH₄) into the atmosphere [e.g., Kasischke and Turetsky, 2006; Flannigan *et al.*, 2009; Schuur *et al.*, 2015]. Melting Arctic ice sheets and glaciers contribute significantly to our rising seas and disrupt ocean circulation patterns. Ocean acidification, chemical pollution, and noise pollution stress marine ecosystems, and shifting migration patterns on both land and sea threaten biodiversity [e.g., Alerstam *et al.*, 2007; Wilcove and Wikelski, 2008)].

The opening of a Northwest Passage and the increase in ship traffic is still far enough in the future to develop a feasible strategic plan for New England. New ventures to enhance

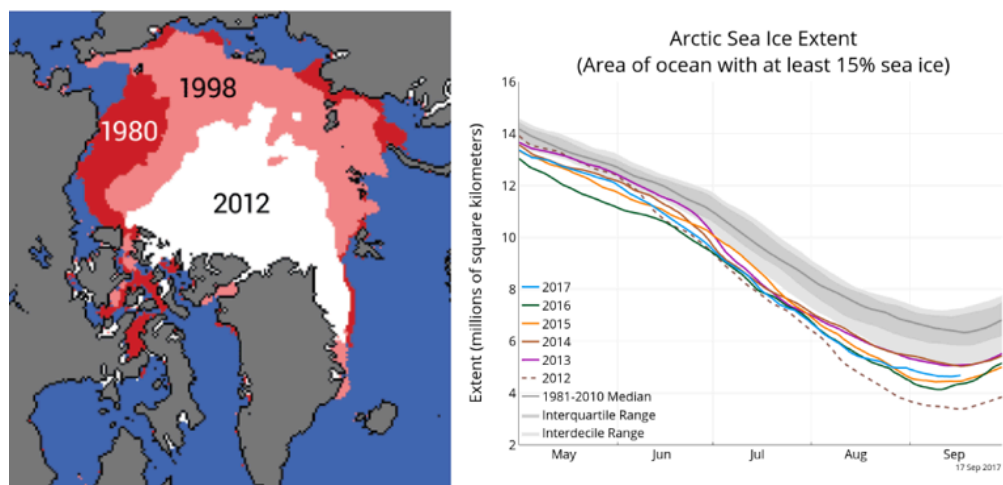


Figure 2.1. Trends in sea ice extent. The National Snow and Ice Data Center.

economic development and stimulate productivity must be accompanied by environmental and societal sustainability. The pursuit of innovation, solutions, new products, and increased productivity needs to also empower communities, improve lifestyles, and strive for social and economic equality.

The Role of New England in Navigating the New Arctic

The influences and human dimensions of Arctic change are global, impacting the well-being, resiliency and quality of life for people living in the Arctic as well as populations affected by Arctic change at lower latitudes, invoking the phrase, “What happens in the Arctic doesn't stay in the Arctic” [e.g., *Francis & Vavrus*, 2012; *Hamilton and Lemcke-Stampone*, 2014; *NRC*, 2015; *Kennedy et al.*, 2016]. Communities in the mid-latitudes must take into account Arctic change in preparing for sea-level rise, changes to regional weather patterns, displaced ocean currents, modifications to ecosystems, and new economic, cultural, and societal relationships [*Kopp et al.*, 2010; *Cohen et al.*, 2018; *Overland et al.*, 2016; *Singh et al.*, 2016; *Zhang et al.*, 2016; *Yang et al.*, 2016; *Koven et al.*, 2011; *Schuur et al.*, 2015]. Possible impacts from Arctic change on mid-latitude

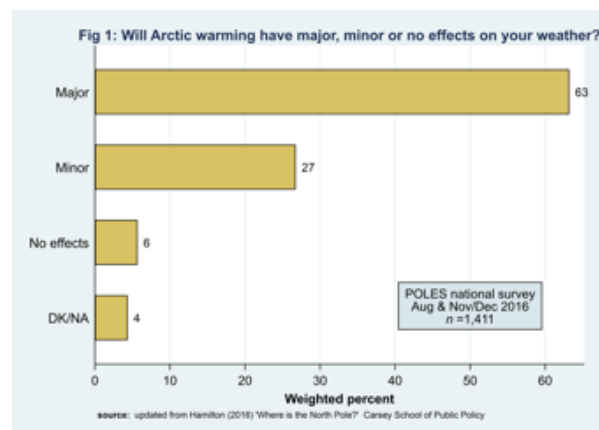


Figure 2.2. National survey on impacts of Arctic change on mid-latitude weather. Updated from Hamilton 2016.

The swell of commerce, tourism, and the quest for resources as Arctic ice melts will require innovative observations, models, and predictions throughout the Arctic and at lower latitude coastal regions such as New England [*Arctic Council*, 2009, 2015; *Ellis and Brigham*, 2009; *Transportation Research Board*, 2016]. Populations at lower latitudes bear much of the responsibility for Arctic change, enhancing concerns over future expectations, choices, and behaviors.



Figure 2.3. Left: Northwest Passage, Northern Sea Route, and future central Arctic shipping route (adapted from AMSA, Arctic Portal). Right: Route of the 2016 Crystal Serenity cruise (The Washington Post).

weather have already gained widespread public attention (Figure 2.2) [*Hamilton*, 2012, 2016].

FOCUS ON THE NORTH ATLANTIC ARCTIC

As an Arctic nation, the United States invests considerable resources in studying the impact of Arctic change on citizens of Alaska and on oil drilling and fishing in the Bering, Chukchi, and Beaufort seas. However, the rapid pace and broad scale of recent Arctic change necessitates studying and responding to links between the Arctic and North America's east coast (the North Atlantic, New England, and Gulf of Maine).

New England is home to the closest U.S. ports on the Atlantic side of the Northwest Passage, serving as the nation's "eastern gateway to the Arctic." Recent events such as the 2016 Arctic Council SAO hosted in Portland, Maine [Arctic Council, 2016b; Overton, 2016a] and the role of Senator Angus King from Maine in forming a US Senate Arctic Caucus with Senator Lisa Murkowski of Alaska highlight the growing relationship between New England and the Arctic.

Figure 2.3 shows new shipping routes anticipated from Arctic ice melt along with the route of the 2016 voyage of the 1500-passenger Crystal Serenity cruise ship. In addition to the economic benefits of tourism and the search for resources, the Northwest Passage will reduce transport times from Asia to eastern North America by several days compared to the route through the Panama Canal [Farré et al., 2014; Lu et al., 2014; Melia et al., 2016; Patel and Fountain, 2017].



Figure 2.4. Crystal Serenity anchored off Bar Harbor, Maine. (Bangor Daily News, Bill Trotter)



Figure 2.5. International Marine Terminal in Portland, Maine with Eimskip container ship. (Portland Press Herald, Carl D. Walsh)

Infrastructure for shipping and tourism will continue to become a priority, not only as a result of the Northwest Passage but also as links between New England, Iceland, Greenland, and Scandinavia strengthen and shipping through the Northern Sea Route grows. The Maine Port Authority in Portland has committed to becoming a leader in Arctic shipping, currently serving as the North American hub of the Icelandic shipping company Eimskip, launching a project to double the amount of cargo freight moving through the International Marine Terminal [Overton, 2016b].

Expanding Arctic shipping routes, in combination with changes to ocean circulation and regional climate patterns linked to Arctic ice melt, could have particularly strong influences on communities surrounding the Gulf of Maine. Modifications to traditional observational networks and predictive models will be necessary to detect and respond to changes to fisheries, tourism, coastal ecology, air quality, water quality, invasive species, animal migration, noise pollution, trade, job opportunities, and demographics.

An ice-free Northwest Passage will stimulate new trade markets, including the potential to transport fossil fuel from the Alaskan North Slope to U.S. East Coast refineries. Increased ship traffic will require shore-based infrastructure (e.g., docks, warehouses, and services) and provide job opportunities around the Gulf of Maine. Search and rescue capabilities must

expand, along with plans for responding to oil and container spills. Noise pollution will increase in coastal communities and underwater soundscapes, disturbing coastal and marine ecosystems. Navigation routes will likely intersect migratory paths of marine mammals such as whales and sea turtles. Ships will emit plumes of nitrogen oxides, sulfur dioxide, and persistent organic pollutants (POPs), affecting air quality as well as water quality and wildlife. There is also the threat of the transport of invasive species via ballast water. Understanding how new shipping routes will impact all of these sectors will be critical for guiding recommendations, procedures, and protocols for shipping.

ATMOSPHERIC AND OCEANIC IMPACTS

New England is uniquely affected by changes to global atmospheric circulation and ocean currents. Meltwater from sea ice and glaciers introduces vast amounts of fresh water into Baffin Bay, changing thermohaline circulation. This influx in turn modifies deep-water circulation, the Labrador Current, and the Atlantic sub-polar gyre, influencing regional climate patterns that affect New England [Yang *et al.*, 2016]. Paleoclimate proxy evidence of sea-ice cover from marine sediment cores west of Greenland studied in conjunction with stable isotopes in Greenland ice cores and historical records of temperatures over North America and Europe have provided insight into climate shifts such as the Medieval Climate Anomaly and Little Ice Age [Moffa-Sánchez *et al.*, 2014; Moreno-Chamarro *et al.*, 2016]. These correlations might also be used to project future impacts of melting sea ice on the regional climate of New England.

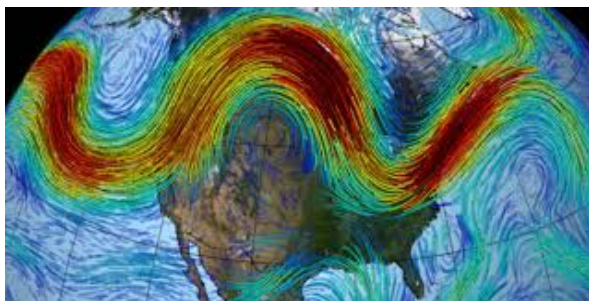


Figure 2.6. The meandering polar jet stream. (NASA)



Figure 2.7. Currents in western North Atlantic Arctic. Adapted from Seidenkrantz, 2013.

The oscillation of the atmospheric polar jet stream exerts a strong control on mid-latitude storm tracks and the speed of their propagation, especially over New England. As Mark Twain commented, "one of the brightest gems in the New England weather is the dazzling uncertainty of it" [as cited in Delbanco, 2001]. An ice-free Arctic will change albedo and sensible heat flux, reducing the meridional temperature gradient, resulting in a weaker, meandering jet stream that brings more persistent weather patterns to New England (Figures 2.4 and 2.5) [Kim *et al.*, 2014; NRC, 2014b; Francis and Vavrus, 2015; Overland *et al.*, 2016; Mills *et al.*, 2016]. Cold snaps and heat waves will last longer. Rain and droughts will be less frequent but more severe. Modifications to regional climate will have significant economic impacts on agriculture, infrastructure, commerce, and tourism. These atmospheric teleconnection might explain extended periods of low temperature and snow accumulation in the eastern US during the winters of 2013-14 and 2014-15 [Bellprat *et al.*, 2016]. A counter-argument reverses this cause and effect, asserting that it is the weaker, meandering jet

stream that amplifies Arctic sea ice melt [Ding *et al.*, 2017].

A modified jet stream can also steer ocean surface currents and create blocking patterns that impact ocean circulation. The evolving understanding of atmospheric teleconnections and atmosphere-ocean coupling adds complexity to regional climate predictions [NRC, 2014b]. The rate of Arctic ice melt is also uncertain, particularly with regard to the Greenland ice sheet, making regional climate predictions that inform economic, environmental, and social sectors correspondingly uncertain. The rapidly evolving understanding of the impact of Arctic ice melt on ocean and atmospheric circulation will require modifying assessments for regional climate change in New England. Studies at the University of New Hampshire show that the majority of the public concur that changes in the Arctic will affect weather in New England [Hamilton and Lemcke-Stampone, 2014]. From a public policy perspective, the region is ready to engage in a convergence research effort to develop strategies for addressing this connection.

THE RESEARCH CAPACITY OF NEW ENGLAND

New England is a powerhouse for academic research institutions and innovative enterprises that participate in field campaigns and modeling efforts throughout the Arctic, including NSF-sponsored projects in Greenland, Canada, and the Arctic-North Atlantic ocean. Figure 2.8 shows a selection of New England institutions involved in Arctic research. Collaboration across this corridor of research and excellence could activate economic, environmental, and social creativity needed to identify sustainable solutions.

There are many observational, modeling, and social structures within New England that could be updated and adapted to prepare New England for Arctic change. The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), part of the U.S. Integrated Ocean Observing System (IOOS), hosts an observational network for the coastal waters of the northeastern United States and Canada, providing data products from satellite, buoys, and surface stations (Figure 2.9). Satellite data is available

through the Satellite Oceanography Data Lab at the University of Maine and includes sea-surface temperature, chlorophyll, wind, and true color composites from AVHRR, SeaWiFS, MODIS, and SeaWinds. The Gulf of Maine Moored Buoy Program (UMOOS) and buoys and surface stations from the University of New Hampshire (including the former UNH Coastal Ocean Observing Center network), NOAA, NWS, and Environment Canada also participate in the NERACOOS network. The associated New England Ocean Science Education Collaborative (NEOSEC) engages the public with the goal of improving ocean literacy. Expanding and enhancing existing networks will aid in assessing the impacts of Arctic change.

The NSF-sponsored Arctic Observing Network (AON) provides a critical framework for current and future Arctic observations [NSF, 2007]. Established in conjunction with the International Polar Year (2007-2008) as part of the Study of Environmental Arctic Change (SEARCH) Program, this network along with synthesis activities such as Arctic Futures 2050 promises to greatly enhance the understanding of

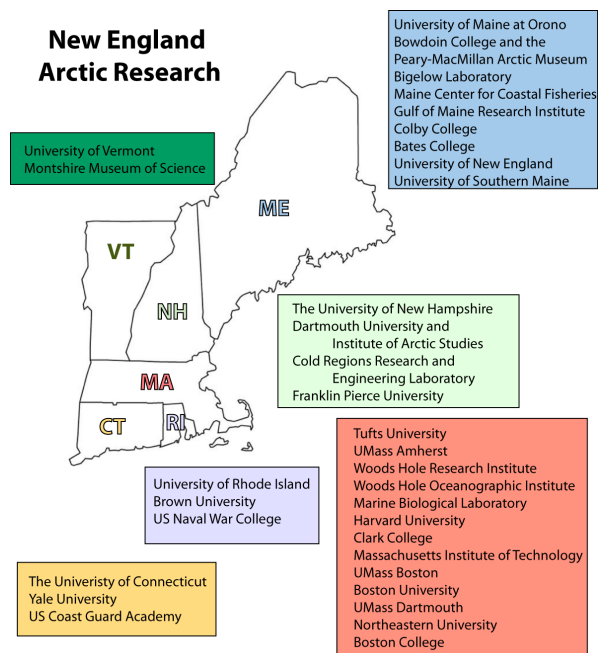


Figure 2.8. Examples of New England institutions involved in Arctic research or research on links between New England and the Arctic

Arctic ice melt. Additional observations are expected during the current Year of Polar Prediction sponsored by the World Weather Research Programme Polar Prediction Project.

UNH, the host of this workshop, is heavily engaged collecting observational data throughout the Arctic in ocean mapping, sea-floor properties, coastal processes, and acoustics [e.g., *Jakobsson et al.*, 2012, 2015; *Mayer*, 2016]. The Data Visualization Research Lab at the UNH Center for Coastal and Ocean Mapping (CCOM) develops unique tools to analyze, interpret, and disseminate these observations. UNH also participates in observation and modeling studies of terrestrial ecosystems and coastal watersheds in both the Arctic and New England, including using in situ and satellite observations to study changes to biological productivity and aquatic chemistry [e.g., *Mulukutla et al.*, 2012; *Hernes et al.*, 2014; *Salisbury et al.*, 2015].

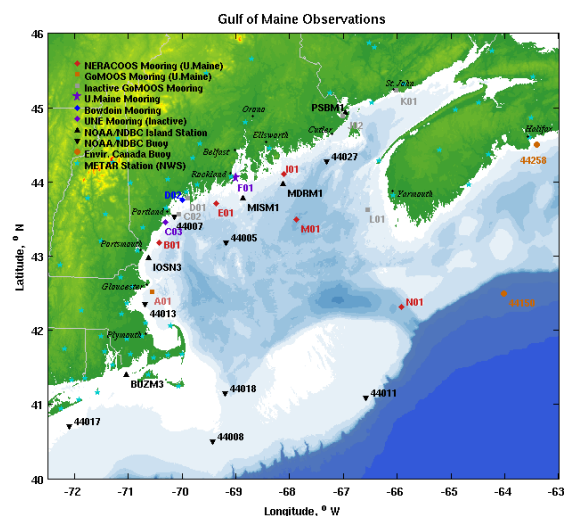


Figure 2.9. University of Maine Ocean Observing System (UMOOS)

In the Northern Atlantic, the Ocean Observatories Initiative (OOI) has installed platforms providing real-time data from arrays off of Martha's Vineyard in Massachusetts (Coastal Pioneer) and off the southeast coast of Greenland (Irminger Sea). The OOI data portal provides easy access to data from a large suite of instruments, including physical, chemical, and geological and biological properties and processes from the seafloor to the air-sea

interface. Institutions from across New England also participate in the NSF sponsored Coastal SEES projects, including the University of Maine and Gulf of Maine Research Institute (fisheries), Clark University and the Marine Biological Lab (coastal salt-marshes), and MIT (environmental flow associated with hazards). UNH provides datasets with observations of air-sea flux from ships and buoys in the Gulf of Maine. The Northeast Consortium, with administrative offices at UNH, supports monitoring projects such as the Fisheries and Ocean Data Management System comprised of commercial fishermen, scientists, and other stakeholders in the Gulf of Maine.

Data is available through the Marine Environmental Observation Prediction and Response (MEOPAR) Network, hosted by Dalhousie University in neighboring Halifax, Nova Scotia. MEOPAR is a large-scale Canadian effort designed to reduce vulnerability and strengthen opportunity in Canada's marine environment. The program studies marine hazards from storms, coastal erosion due to waves, chemical and biological change (ocean acidification), geophysical events (tsunamis), and direct human impacts (oil spills, ship accidents) [*Wallace et al.*, 2014].

As increasing numbers of ship plumes will impact air quality in the region, it is valuable to have access to historical region datasets, including the North Atlantic Regional Experiment (NARE), International Consortium for Atmospheric Research on Transport and Transformation (ICARTT), and the Atmospheric Investigation, Regional Modeling, Analysis and Prediction (AIRMAP) program [*Fehsenfeld et al.*, 1996; *Neuman et al.*, 2006; *Mao and Talbot*, 2004]. Pollutants from ship plumes result in spikes in nitrogen oxides and sulfur within the marine boundary layer, impacting ozone, aerosols, and the oxidation capacity of the atmosphere [*Eyring et al.*, 2010]. New England is influenced by a variety of air masses, including polluted air from the Northeastern Urban Corridor and Ohio River Valley, Arctic air masses from Canada impacted by wildfires, and the clean marine air masses from the western North Atlantic Ocean. The atmosphere off the

coast of New England remains a region dominated by net ozone production, emphasizing the significance of increased nitrogen oxide pollution from ship plumes.

Researchers throughout New England also participate in the collection and interpretation of long-term surface and ice core measurements in Alaska and Greenland, critical to understanding links between historical Arctic ice melt and changes in climate modes and weather patterns. The US Army Corps of Engineers Cold Region Research Lab (CRREL) in New Hampshire serves as the national center for cold regions science and engineering with substantial involvement in the cold and complex environments of both the Arctic and New England winter conditions. CRREL engineers engage in collaborative projects with academic and non-academic research institutes as well as communities in issues involving domain awareness, polar operations and infrastructure, and environmental protection.

HISTORICAL RELATIONSHIPS

New England holds unique historical narratives of "the North" and a relationship with the Arctic that has been evolving for centuries. From a social science and humanistic perspective, there are common challenges faced by postcolonial indigenous groups in the Arctic and New England (Figures 2.10 and 2.11) [e.g., *Howey* 2010, 2011; *Senier* 2014; *Senier et al.*, 2014]. New economic relations can trigger unprecedented rates of social change and



Figure 2.10. Supporting Penobscot Nation's ancestral rights (Bangor Daily News, Ashley L. Conti)



Figure 2.11.. Ceremony of the Founding of Nunavut, 1999. (Ansgar Walk)

challenge longstanding cultural identities and value systems, particularly in Native communities [*Steinberg and Tasch*, 2015].

Methods of cultural conservation and sharing of traditional knowledge through innovative story-mapping and digital humanities could help build and sustain collaborative relationships among indigenous communities in the Arctic and New England, thereby increasing the probability that scientific field studies will advance shared goals of social-ecological resilience. New England has also grappled with the successes and failures of coastal economic and social transformations for centuries, including the impacts of 20th-century ecosystem changes on fishing communities of Newfoundland, Greenland, Iceland and the Faroe Islands [e.g., *Brewer* 2012, 2013a, 2013b; *Brewer et al.*, 2017; *Feintuch and Watters*, 2005; *Hamilton*, 2007]. Given this rich history, New England is an ideal leader in preparing the "lower 48" for Arctic change.

Another strategy for deepening relationships with indigenous Arctic communities is to share scientific advances enabled by observations and measurements collected on their homelands over the past half century, including mapping of local waters and unprecedented advancements in the knowledge of the Earth's near and deep space environments from networks of ground-based monitors, balloons, and rockets launched from indigenous Arctic lands.

A convergent approach with stakeholder engagement

Convergence is “the merging of ideas, approaches and technologies from widely diverse fields of knowledge to stimulate innovation and discovery” [Mervis, 2016]. Convergence goes beyond traditional transdisciplinary collaboration by focusing on a purpose-driven (rather than curiosity-driven) problem that addresses a deep scientific question or societal need. Convergence tackles the technical, organizational, and logistical challenges to collaboration from the outset in order to enable sustained collaboration across disciplines [Roco *et al.*, 2013; NRC, 2014a; Mervis, 2016].

Studying the impact of the opening of the Northwest Passage in conjunction with changes to regional ocean circulation and climate on New England requires a convergence approach at all stages of development and implementation. This systems-level thinking will benefit research into links between Arctic change and New England by bringing together substantially different disciplines from physical and life sciences, social science, and engineering, while transcending barriers that might arise from disparate terminology and paradigms. Convergence will ensure that all disciplines participate from the onset, involved in the design and implementation of scientific research and overcoming the tendency to position social sciences and engineering as “end-users” of post-processed data. Convergence research will bring the tools and techniques from sociology, economics, and public policy into the experimental and modeling realm of biological and physical sciences and the solution-driven problem solving of engineering.

Observations, data analysis, and modeling efforts must be designed to evolve alongside changing societal goals as new understandings arise concerning the impacts of Arctic change on lower latitudes. For example, the strategic visions of sustainable fisheries in the Gulf of Maine, including fishing rules and innovative aquaculture, will inevitably adapt to constraints and opportunities from new shipping routes in conjunction with changes in regional climate and ocean currents. Including a variety of disciplines

and external partners in the design of observational platforms, data analyses, and models will ensure a focus on the most relevant science questions and societal concerns regarding fisheries. As another example, increased ship traffic will likely impact the feeding, behavior, and migration patterns of whales off the coast of North America through noise pollution, ship strikes, and accidental spills. In the Gulf of Maine, data related to whale migration is often collected by non-profit organizations and volunteers on commercial whale watch vessels [MacLaren *et al.*, 2012]. Acoustic detection, tracking technologies, satellite tags, and WhaleAlert apps have been developed to help avoid ship strikes and disturbances [Wiley *et al.*, 2016]. A convergence approach is allowing these organizations to minimize disturbances to migration patterns with the least amount of disruption to economic activity.

The issues associated with the changing Arctic are diverse. Solutions will require a systems understandings of biogeophysical and socioeconomic interactions. Consequently, *Navigating the New Arctic* and *Growing Convergence Research at NSF* are natural partners. Section 3 of this report describes the strategies used during the workshop to encourage convergent thinking linking New England and the Arctic. Section 4 lists specific convergent questions and ideas to propel future research initiatives. Section 5 summarizes the priorities. The Appendices provide additional information about the workshop and recommendations.

3. WORKSHOP NARRATIVE

This section presents the format, agenda, and detailed narrative of the events throughout the workshop. The intent is to remind participants of the topics and themes discussed, provide a synopsis for those who were unable to attend, and present a model for future workshops. Findings and recommendations are presented in the next section (Section 4).

This workshop convened Arctic researchers throughout New England (and beyond) to determine how to identify and respond to emergent problems resulting from Arctic change and the opening of the Northwest Passage. The goal was to capture the collective knowledge of participants from a variety of disciplines and sectors to assess economic, environmental, and social impacts of Arctic change on New England as well as to identify observations and indicators required to prepare for, adapt to, and respond to these influences. A series of panels, round-tables, and plenary discussions were designed to encourage the convergence of methods, tools, and ways of thinking.

The main goal of the workshop was to assess the economic, environmental, and social links between Arctic change and New England, identifying transformational convergence research initiatives to anticipate, prepare for, and adapt to future impacts and opportunities

The primary objectives were to

- Develop a vision for how Arctic change might impact New England over the next several decades and recommend future convergent research priorities linking Arctic change and New England.
- Establish a *New England Arctic Research Network* to encourage multi-institutional convergence research projects
- Identify specific convergence research initiatives, core collaborative teams, topics for review papers, and follow-up plans in line with the goals of NSF Navigating the New Arctic (NNA).

The expectation was that, by the end of the workshop, participants would:

- Be able to distinguish convergence research from traditional multidisciplinary, interdisciplinary, and transdisciplinary research. Be able to identify which areas lend themselves to convergence research.
- Understand how to merge current discipline-specific research into a convergent approach, advancing innovations in observations, data analysis, and modeling that link New England and Arctic change.
- Identify a strong set of specific issues relevant to New England and the Gulf of Maine where convergence research can identify viable solutions to emergent challenges.
- Have a clearer understanding for how to achieve a balanced integration of social sciences and biogeophysical sciences in solving Arctic issues as well as actions that encourage the participation of local and indigenous communities.
- Create a list of documents and action items for disseminating information on the impact of Arctic change on the "lower 48" states to the public, political representatives, and stakeholders.

The University of New Hampshire served as an ideal location for the workshop, centrally situated within the New England region and having a history of robust field research both throughout the Arctic and in New England. UNH also holds "A Deep Commitment to Interdisciplinarity" as one of the Six Visions and Values within its strategic plan [UNH, 2015], exemplified by the UNH Collaborative Research Excellence (CoRE) Initiative supporting innovative interdisciplinary research teams.

WORKSHOP FORMAT

The main workshop venue was a large conference hall with a panel-table, podium, banquet-tables for participants, and space for posters and informal discussions. Flip charts, writing materials, and multiple screens encouraged participants to interact and openly

share ideas. While much of the workshop was videotaped and extensive notes were taken, the consensus was to publically share only summary items in order to encourage unimpeded exploratory discussions.

Over 100 participants attended the workshop from 11 states and 4 countries, representing academia, industry, small business, government, and community organizations. There were 12 graduate students, 16 undergraduates, and over a dozen early career academic researchers. A complete list of participants is provided in Appendix D.

All presentations and materials with permission to share are available at the website <https://mypages.unh.edu/ne-arctic-convergence>. This site also archives workshop handouts, summary notes, external resources, and drafts of this report and will be continually updated as new activities and action items develop within the New England Arctic Network.

Appendix A provides the agenda for the workshop. A public lecture the evening of March 25th was followed by two full days of lectures, panels, discussions, and events, divided into four sessions: 1. Convergence and Arctic Research, 2. Transportation and Infrastructure, 3. Living Resources, and 4. Coastal Dynamics. Each session followed a similar format, beginning with a panel presentation, questions and answers, and small round-table discussions. Each day ended with late afternoon plenary deliberations, prioritizing the main ideas (Figure 3.3).

Appendix B summarizes the panel descriptions and biographies of the speakers and panelists. The composition of each panel was designed to be convergent, representative of academia, stakeholders, community members, and a diversity of disciplines. Prior to the workshop, each panel conducted telecons or group email exchanges to determine formats and content that were both informative and would inspire animated discourse during the question and answer sessions, round-table discussions, and facilitated large-group deliberations.

The primary focus of the round-table discussions was to identify emergent

transformational convergence research questions and to encourage co-development of techniques and strategies to address the impact of Arctic change. Participants were encouraged to identify areas of research where convergence is already beginning to happen, and to determine ways to strengthen these efforts and broaden participation. On the first day, seats were deliberately assigned (at banquet tables of 8) to ensure a diversity of disciplines and sectors. Each table had a Leader/Rapporteur (an Arctic researcher), Notetaker (graduate student), and Facilitator (undergraduate trainee from the UNH Civil Discourse Lab) This structure enabled the conversations to remain focused and inclusive while capturing a breadth and diversity of ideas. Appendix F provides the round-table guidelines used in these discussions.

The first round-table provided an opportunity for introductions as well as a forum to define Convergence in Arctic Research. The discussions involved brief introductions, visions of future scenarios, and questions or societal problems linking Arctic change and New England necessitate convergent approaches. For each subsequent session topic (Infrastructure & Transportation, Living Resources, and Coastal Dynamics), groups were asked to consider the following questions:

1. What are some existing or new convergence research ideas that come to mind based on the panel discussions?
2. How do these convergence research topics relate to broader societal impacts and solutions?
3. What currently exists or is emerging in your field that can contribute to convergence research (methods, techniques, programs, individuals, groups, tools)?

The leaders, note takers, and facilitators were also given the following questions to further propel the discussions, with the note takers asked to capture any information related these questions.

I. Vision:

- What is going to happen in New England as a result of Arctic Change?

- What are the emergent technologies, challenges, and solutions?

II. Network (identify interest in New England Research Network):

- How does your expertise contribute to a convergence research question?
- Who (individuals or groups) should be included in the discussion around a proposed convergence research topic?
- What networks already exist that can be tapped into? (Including international networks)
- How can cyberinfrastructure (networking, people, data, computational resources, and associated skill sets) help promote convergence?

III. Existing capacity:

- Modifications to traditional observational networks and research initiatives that will be necessary to detect and respond to emergent problems
- Observations and indicators required to prepare for, adapt to, and capitalize on economic, environmental, and social impacts.

The goal was to identify a comprehensive list of convergence research questions and emergent technologies, methods, and models that might lead to solutions.

At the end of these small-group discussions, each table uploaded onto a shared document their main ideas on "recommendations of future research priorities for convergent research linking Arctic change and New England." This document was shared on a large screen and used to guide the facilitated plenary deliberations at the end of each day. (Documents remain available on the workshop website).

WORKSHOP NARRATIVE

Jennifer Francis, Research Professor in the Department of Marine and Coastal Sciences from Rutgers University, kicked off the event with a public lecture on the evening of March 25th titled, "The Arctic Meltdown and Extreme Weather: How Are They Connected?" In this

presentation, Francis explained new research that links the increasing frequency of extreme weather events in the Northeast with the rapid melting of the Arctic. Evidence suggests that Arctic warming is causing weather patterns to become more persistent, leading to extremes such as droughts, cold spells, heat waves, snowy winters, and flooding [e.g., *Shepherd*, 2016; *Vavrus et al.*, 2017; *Francis et al.*, 2017]. Francis discussed the impact of Arctic amplification and sea-ice loss on intensifying ridges/troughs of planetary waves, weakening westerly winds, and disrupting the stratospheric polar vortex. She presented examples of the Eastern freeze of early January to mid-February of 2018 as well as the Eastern heat wave in late February 2018. Predictions of Arctic teleconnections are particularly critical in the eastern United States, where episodic and regional fluctuations in extreme winter weather can readily disrupt natural ecosystems and coupled human services.

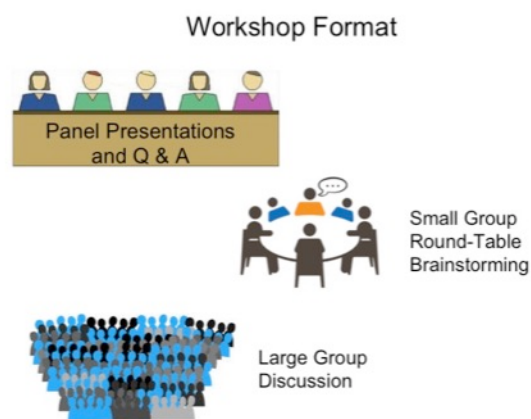


Figure 3.1. Format of workshop session

The morning of March 26th opened with a welcome by Jan Nisbet, the UNH Senior Vice Provost for Research, and a video address by Senator Angus King of Maine. Senator Jeanne Shaheen of NH provided a letter that was read to the audience and Senator Maggie Hassan of NH sent a letter following the workshop (see Appendix E for the congressional correspondence). Vice Provost Nisbet welcomed the group to UNH, praising the value of bringing together researchers and stakeholders from across New England for interdisciplinary collaboration in Arctic research. Senator King discussed the



Figure 3.2. Video address by Senator Angus King of Maine.

importance of scientific research and discovery in developing policy at the local, state, and national scale, in particular with regard to the peaceful development of trade, energy, and security in a way that respects indigenous peoples and the environment.

Mamadou Diallo (Director of Molecular Environmental Technology, Materials and Process Simulation Center, the California Institute of Technology) continued to set the tone for the workshop with a plenary talk titled, "Convergence Research and Education: Examples and Case Studies from Sustainability Science and Engineering." He began by describing Convergence Research as defined by NSF and outlined the theory of Convergence of Knowledge, Technology, and Society (CKTS) [Roco and Bainbridge, 2013]. Diallo provided an example of convergence research from his own work in Sustainable Desalination and Ocean Resource Recovery [Diallo *et al*, 2015]. Finally, he discussed Convergence in Education. He describes a Caltech course on "Fundamentals of Sustainability Science and Engineering" taught

by himself and Julie Kornfield that focuses on Literacy, Systems Thinking, Systems Analysis Frameworks and Tools, and Communication Skills. This introductory talk was crucial in providing a common understanding of the meaning of "convergence research" in relation to with multidisciplinary, interdisciplinary, and transdisciplinary research.

The morning panel on March 26th was moderated by Larry Hamilton, Professor of Sociology at the University of New Hampshire. Speakers provided examples of convergence research in the Arctic and included Paul Berkman (Director of the Science Diplomacy Center at the Fletcher School of Law and Diplomacy, Tufts University), Kim Juniper (Chief Scientist of Ocean Networks Canada, and Professor of Biology at the University of Victoria), and Elisabet Idermark (Senior Advisor on international relations at the Research Support Office, Stockholm University, Sweden). Descriptions of each talk are given below in the Panel 1 text box.

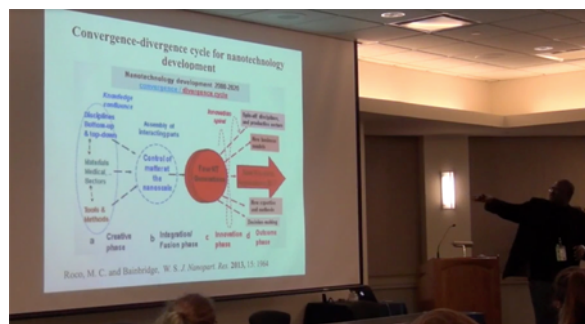


Figure 3.3. Plenary talk by Mamadou Diallo

Panel 1: Convergence in Arctic Research

This panel examined how to merge discipline-specific research into a convergence approach to advance innovations in observations, data analysis, and modeling. The goal was to demonstrate how a convergence approach will benefit research into links between Arctic change and New England by bringing together substantially different disciplines from natural science, social science, and engineering, while transcending barriers that might arise from disparate terminology and paradigms. The panel presentations provided examples of how convergence can tackle the technical, organizational, and logistical challenges to collaboration from the outset in order to enable sustained collaboration across disciplines.

Larry Hamilton, Professor of Sociology at the University of New Hampshire, (moderator) began this panel with a presentation titled, "Integrating Social and Natural Science Research." He first reminded the audience of two primary characteristics of NSF Convergence Research: 1. Driven by problems of societal importance and 2. Requires deep integration across disciplines. Given that the integration of social and natural science research is often an "unfamiliar, challenging terrain," Dr. Hamilton provided examples of integration of social and natural science research:

- Historical: Herring stock collapse of Siglufjörður in north Iceland [ref]
- Comparative: The potential relocation of Kivalina, an Inupiat village in NW Alaska threatened by coastal erosion [ref]
- Analytical: the Arctic Sea Ice Outlook predictions since 2008 [ref]
- Surveys: public opinion surveys inspired by Dr. Jennifer Francis' research on how Arctic change affects midlatitude weather [ref]

Paul Berkman, Director of the Science Diplomacy Center at the Fletcher School of Law and Diplomacy, Tufts University, presented a talk titled, "Science Diplomacy Navigating the New Arctic Across Generations." He discussed the role of science in Arctic diplomacy within the context of sustainable development. Berkman noted the simultaneous urgencies across security time scales (mitigating risks of political, economic, societal, and environmental instabilities) and sustainability time scales (balancing societal, economic, and environmental elements across generations) and the need for nations and peoples to address these urgencies both individually and collectively. He also provided an example based on operational and sustainable decision-making for ship traffic in the Arctic Ocean. He ended the talk with a discussion of how The Arctic Science Agreement ("The Agreement for Enhancing International Scientific Cooperation") will enable the natural sciences, social sciences, and indigenous knowledge to provide evidence-based options to propel diplomacy forward.

Panel 1 (cont.)

Kim Juniper, Chief Scientist of Ocean Networks Canada, and Professor of Biology at the University of Victoria, gave an overview of current efforts of Oceans Network Canada in establishing community-based and remote cabled observatories in Nunavut, Canada (Cambridge Bay, Gascoyne Inlet, and Churchill). The Cambridge Bay Observatory monitors ice growth and dissolved gases. Six years of community engagement include snow-depth measurements, a weather station, ice profiler data products, and an Automatic Identification System monitoring vessel traffic, all made available to the Arctic communities. He also described educational programs with local communities including collaborations with Nunavut Arctic College, Actua, and Let's Talk Science along with the programs "Ocean Sense" and the "Youth Science Ambassador Program." Juniper presented some of the protocols necessary for Arctic observational research, including how to work with knowledgeable hunters, Elders, youth, and other community members to identify changes in sea ice and the impact on community activities. Suggestions include oversight committees providing local partnership and guidance, dedicated funding for community involvement, on-going local participation and guidance with a long-term commitment, and projects that are useful to the community.

Elisabet Idermark, Senior Advisor on international relations at the Research Support Office, Stockholm University, Sweden, described the *Arctic Science IntegrAtion Quest (ASIAQ)*, an international, cross-disciplinary project designed to jointly advance research and education for a sustainable Arctic (<https://asiaq.org/>). The ASIAQ project is funded by The Swedish Foundation for International Cooperation in Research and Higher Education (STINT) and the participating universities. This effort is designed around the Global Goals for Sustainable Development with a focus on Arctic waters, both on land and in the ocean. The ASIAQ project unites six universities from three continents and four countries (US: UNH; Sweden: Stockholm University, Umeå University and KTH Royal Institute of Technology; Japan: University of Tokyo; Russia: Northern Arctic Federal University). It brings together researchers representing four disciplines: Arctic Engineering and Technology, Arctic Physical Sciences, Arctic Medicine and Health, Arctic Social Sciences. The goals of ASIAQ are to 1. inspire and provide support for the development of joint, cross-discipline research projects led by early career scientists; 2. provide early career researchers with a network supporting them in becoming future leaders in integrated Arctic science projects; 3. carry out synthesis and outreach activities to spread the knowledge within and across research communities, stakeholders and society. Idermark also discussed successful models of past international and interdisciplinary research efforts involving Stockholm University available as models, including SWERUS-C3, the Stockholm Resilience Center, the Baltic Sea Center, and Baltic Eye.

The afternoon session on March 26th began with an introduction from Nancy Kinner, University Professor of Civil and Environmental Engineering and co-Director of the Coastal Response Research Center at The University of New Hampshire. She read a letter from US Senator Jeanne Shaheen emphasizing the need to prepare for the economic, environmental, and social effects of Arctic warming on coastal regions of New England.

Kinner then introduced and moderated Panel 2 on "Transportation and Infrastructure" with

speakers David Kennedy (NOAA's Senior Advisor for the Arctic Region), Jeff Levine (Director of Planning and Urban Development of the City of Portland), and Rebecca Pincus (Professor in the Department of Humanities at the U.S. Coast Guard Academy) (See Text Box). A question and answer session following the panel and considered issues such as Search and Rescue (SAR), infrastructure needs in the Arctic given thawing permafrost and in New England given sea-level rise, and justice and equity in city planning and transportation infrastructure.

Panel 2: Infrastructure and Transportation

Nancy Kinner, University Professor of Civil and Environmental Engineering and co-Director of the Coastal Response Research Center at UNH, moderated this panel. The discussion focused on how an ice-free Arctic will stimulate new trade markets, impacting coastal regions and transforming coastal communities such as Portland, Maine into Arctic shipping hubs. This panel presented examples of new ventures to enhance economic development and stimulate productivity, while addressing the importance of environmental and societal sustainability. Participants considered how the pursuit of innovation, solutions, new products, and increased productivity can also empower communities, improve lifestyles, and contribute to social and economic equality.

David Kennedy, NOAA's Senior Advisor for the Arctic Region, began the discussion by noting that, while Alaska and the Pacific Northwest have organized networks to collaborate on research in the Pacific Arctic region, the US Northeast as a region has yet to organize in addressing North Atlantic Arctic issues. This workshop is a good opportunity to start. The Northeast needs to develop a better understanding of issues in Arctic, for example what's going to happen with oil and gas exploration, and development and contingency plans for managing spill response. He emphasized reaching out to indigenous cultures to establish relationships in which communities in the Arctic can be recipients of economic benefits. He also mentioned the value of the tourist industry in educating the "lower 48" about the Arctic, with educational resources about the Arctic provided at ports.

Jeff Levine, Director of Planning and Urban Development of the City of Portland, discussed the recent Portland Strategic Plan and the expansion of the Portland International Marine Terminal (IMT), one of the first deep water ports on the eastern side of the Northwest Passage. He discussed the division of the port into three sections: the Western Waterfront for container ships, Central Waterfront serving fisheries, and the Eastern Waterfront for tourism and cruise ships. Levine presented the challenges of developing infrastructure to respond to increases in shipping while also considering the increased flooding from sea level rise. This infrastructure includes the need for cold storage facilities and rail and truck access balanced with the city regulations for zoning and noise. The expansion of the IMT includes the additional goal of investing in human capital, requiring educational systems, affordable housing, and access to jobs.

Dr. Rebecca Pincus, Professor in the Department of Humanities at the U.S. Coast Guard Academy (currently Assistant Professor at the US Naval War College in Newport, RI), presented the challenges of Arctic change from the perspective of shipping, tourism, and security. She discussed the anticipated "known-unknowns" associated with hydrography/charting, search and rescue (SAR), the "tyranny of distance" (how technologies can break distance barriers), ice forecasting, and maritime domain awareness (MDA). She also mentioned unanticipated "unknown-unknowns," exemplified by the sudden increase in icebergs off the coast of Newfoundland and the unusual North Atlantic Right Whale mortality events. Dr. Pincus referenced the Canada-United States (CANUS) Joint Contingency Plan and the Arctic Coast Guard Forum as recent efforts by the US Coast Guard to address many of the challenges from Arctic change. She also stressed the need for convergence to support adaptation, informed opportunism, and cooperation. Pincus answered questions about the recent international agreements involving SAR and the role of the US Coast Guard, especially with regard to relationships between the US and Canada.

Following the second set of round-table discussions, participants joined in a facilitated group discussion, sharing and deliberating the main ideas encountered throughout the day.

The synopsis of the morning session emphasized the multiple spatial and time scales that are involved in responding to Arctic change. For example, economic analyses of the impacts of Arctic change on New England must extend from local through regional scales, and conducting science in a way that encourages collective thinking, builds bigger constituencies, and adopts adaptive, ecosystem-based management. Furthermore, the Gulf of Maine cannot be considered in isolation, as remote forcing is extremely important. The Gulf is the southern boundary for species like shrimp and keystone zooplankton, and a regional approach will be required in order to assess changes to fisheries along with changes in phenology. Historical experience of fisheries might be used as empirical models for change in the future.

While capitalization of the Arctic is rapid, participants noted the importance of remaining focused on long-term, broader social goals. Risk assessments, in collaboration with stakeholders, also need to take into account temporal and spatial scales in order to help train first responders and to prepare for pathogen/invasion vectors, toxicity and bioaccumulation, pollutant transport and effects on public health, changes to ecosystems, and the expansion of eco-tourism. With regard to the Northwest Passage, it was noted that cruise ship tourism will likely emerge before destination shipping, and the impacts from the opening of the Northern Sea Route will likely be felt first.

Reflections on the afternoon panel and round-table involved a great deal of discussion about permafrost. Although not obviously linked to New England, permafrost thaw has major implications for

infrastructure and transportation. On a pan-Arctic scale, there is a need to consider how datasets involving permafrost are shared and related to the carbon cycle, quantifying risks from erosion and hazards. Concerns were shared about the need to reach out to indigenous communities to learn about their needs and creating long-lasting partnerships between New England and local Arctic communities in order to inform decisions that involve social sciences and human health as well as the North-South dynamic. There was also a reminder that ideas must be supported by observation, a means to compile and share research data, and that link demographic changes with the location and types of hazards. Continuous monitoring and materials engineering will be crucial for providing the required information to develop solutions and understandings. All of these efforts will rely on social and economic analyses, not just technical solutions, in order to determine who will benefit or be disadvantaged. These comments reaffirm the need for research that involves convergence of knowledge, technology, and society.

The day concluded with a reception at the University Museum and the Dimond Library Special Collections featuring an exhibit titled, “To the Ends of the Earth: New Hampshire’s Connection to Polar Exploration. This exhibit centered around the collection of Robert Stephenson of Jaffrey, N.H., featuring artifacts, paintings, rare books, journals, videos, and stories from both Arctic and Antarctic exploration, including pieces from Admiral Richard E. Byrd, Ernest Shackleton, and Roald Admunsen. This exhibit linked New England to historical and contemporary polar exploration, providing an inspirational environment for more informal conversations expanding upon the ideas brought up during the day.

The morning of March 27th began with breakfast at the UNH Museum of Art amidst

an exhibit featuring interactive and multi-sensory installations, paintings, and videography of the Arctic and Antarctic titled, “Long Eye.” The early morning immersion within the museum exhibit opened minds to new ideas and different ways of thinking as participants returned to the conference venue (Figure 3.4).



Figure 3.4. Students viewing Arctic installation at the UNH Museum of Art, including works by Eric Aho, Resa Blatman, Wendy Jacobs, Andrea Juan, Anna McKee, Claudia O'Steen and Aly Ogasian.

In the main conference room, Siobhan Senier (UNH English Professor and author of *Dawnland Voices: An Anthology of Indigenous Writing from New England*) introduced Maria Girouard, tribal historian and a founder of the group Dawnland Environmental Defense representing the Penobscot Nation. Girouard has been very active around tribal sovereignty issues along the Penobscot River in Maine and around transnational resource extraction that is impacting tribal waterways and homelands. Her plenary talk helped set the tone for a day of discussions surrounding living resources and coastal dynamics, emphasizing the historical lessons of colonization and implications for environmental and cultural stewardship. (Figure 3.5)

Girouard provided a historical sketch of the Penobscot River and its people (Panawahpskek) and the disruption of ten thousand years of peaceful governance and tribal sovereignty of ancestral homelands by

the arrival of the European settlers 400 years ago (Figure 3.5). Girouard presented ideas of governance based and ways of knowing based on responsibilities toward the watershed and place names replete with traditional ecological knowledge..



Figure 3.5. Maria Girouard shares a historical sketch of the Penobscot River and its people.

Throughout the centuries and into contemporary times, treaties between the European settlers and the Penobscot people were negotiated and then broken. Industrialization (dams, sawmills, logging, mining) and governance based on rights instead of responsibilities destroyed crucial fisheries and decimated hunting grounds, leading to starvation of the Penobscot people. Girouard discussed the debate over restitution and justice surrounding the Maine Indian [Land] Claims Settlement Act of 1980. Consecutive interpretations of this and prior treaties, however, continue to diminish sovereign lands, including an ongoing legal debate over the 2012 redefinition of the Penobscot reservation by the State of Maine that excludes the river waters.

The question arose, "How do we reframe our discussion and approaches to environmental issues in terms of "responsibilities" instead of "rights?" Girouard optimistically suggested that appealing to humanity can overcome obstacles, and that interpreting law, history, and regulations in accordance with humanity and human emotion is critical to making progress. She pointed to positive examples of progress, such as the removal of the

Veazie Dam that is dramatically improving the fisheries in the Penobscot river.

The themes of indigenous sovereignty and traditional ecological knowledge echoed throughout the subsequent panels and round-table discussions. Interregional comparisons between native tribes in New England and local and indigenous communities in the Arctic were seen as having the potential to provide insight into responses to Arctic change. A coordinated response could be especially valuable with respect to the shocks of globalization and climate change to small, coastal communities both in the Arctic and in New England.

Jennifer Brewer, Associate Professor of Geography at the University of New

Hampshire, introduced and moderated Panel 3 on “Living Resources.” She transitioned into the panel presentations by pointing out that this session touched on several themes presented by Maria Girouard, including the depth of local knowledge and the impacts of multiple layers of policy jurisdiction. Speakers included Susan Kaplan (Professor of Anthropology and Director of the Peary-MacMillan Arctic Museum and Arctic Studies Center At Bowdoin College), Robin Alden (Founding Executive Director of Maine Center for Coastal Fisheries), and Tom Shyka (Product and Engagement Manager at the Northeastern Regional Association of Coastal Ocean Observing Systems, NERACOOS. (See text box.)

Panel 3: Living Resources

Jennifer Brewer, Associate Professor of Geography at the University of New Hampshire, introduced and moderated the panel on Living Resources, addressing the unprecedented change in environmental conditions on land and sea that trigger ecosystem change. Temperature increases, sea ice melt, ocean chemistry changes, thawing permafrost, and shifting weather patterns will affect species distributions, population dynamics, and trophic relations. This panel considered how policy can help sustain living resources and the communities reliant on them, taking into account social-ecological variability, alternative knowledge systems, and the environmental ethics of indigenous groups. This session also touched on several themes presented by Maria Girouard, including the depth of local knowledge and how it has been affected by multiple layers of policy jurisdiction.

Susan Kaplan, Professor of Anthropology and Director of the Peary-MacMillan Arctic Museum and Arctic Studies Center At Bowdoin College, presented a talk titled, "Considering Indigenous People and Other Northerners in a Changing Arctic." She discussed the demographics of the 13 million people living in the Arctic, 10% indigenous, representing eight nations. Kaplan stressed the importance of economic benefits to local Arctic communities as they respond to climate change and globalization. The subsistence hunt remains vital to northern communities, and they are already experiencing food insecurity as a result of changes in the Arctic. As shipping routes become ice-free and cargo ships, fossil fuel transport, and tourism more common, countries will have to ensure shared waterways by establishing shipping lanes that take into account local economic and wildlife activities. These considerations extend to New England, developing research and economic development partnerships of mutual benefit to Arctic and New England populations, including helping Arctic communities build capacity among their young people. Development of cross-cultural understanding, innovative thinking, and restraint will be needed to avoid repeating the history of outsiders' exploitation of the Arctic in response to new opportunities.

Panel 3 (cont.)

Robin Alden, Founding Executive Director of Maine Center for Coastal Fisheries, presented, "Fisheries: Arctic change presents a convergence opportunity." She focused on the idea that New England has a great deal of history, institutions, and expertise to contribute to the challenges that will face fisheries as the Arctic changes, particularly sustainable small scale fisheries both in New England and the Arctic. Alden suggested that the physical changes in the Arctic provide an opportunity to develop new thinking and policies to change the historical paradigm of overfishing that is pervasive worldwide. She gave participants a primer on current policy and management of fishing and emphasized that this rigid framework does not allow the learning and experimentation needed to adapt to change. Instead, she promotes Complex Adaptive Systems Theory that allows learning and feedback loops at multiple scales, with local science and local observation serving as a critical piece of the solution. Alden also provided examples of successful activities from the Maine Center for Coastal Fisheries, including the Community Fisheries Action Roundtable (C-FAR), Eastern Maine Skippers Program, and collaborative research with Gulf of Maine fishermen. Within collaborative research initiatives, she stressed the critical need for fishermen to originate the questions and to be engaged in analyzing the data. She also highlighted a recent agreement signed by the MCCF, NOAA, and State of Maine to pilot the science that would make possible ecosystem-based management from the Penobscot Bay to the Canadian border, extended the invitation to become a part of this effort and its future workshops.

Tom Shyka, Product and Engagement Manager at the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), described existing convergence research approaches at NERACOOS and opportunities for NERACOOS and its partners to support new research. The mission of NERACOOS is "produce, integrate, and communicate high-quality information that helps ensure safety, economic and environmental resilience, and sustainable use of the coastal ocean." NERACOOS is part of the NOAA Integrated Ocean Observing System (IOOS) representing the region of the Northeast downstream of the Arctic, with many partners and principle investigators at academic and research institutions around New England. Shyka pointed to the real time buoy map (http://neracoos.org/realtime_map) to show that the region between the Gulf of Maine and Nova Scotia is data poor and that expanding the network to obtain information in this area is critical for understanding the potential change in currents resulting from Arctic ice melt. The organization uses a variety of ocean observing technology as well as data management techniques to providing products that stakeholders request (they have a strong relationship with Gulf of Maine fishermen). The success of NERACOOS is driven by partnerships, high quality and reliable data streams, robust data management system, and ongoing communications programs. Shyka ended the talk by emphasizing once again the importance of communicating with stakeholders early on and throughout the process to understand how they use and value data.

The afternoon session began with Panel 4 on "Coastal Dynamics," moderated by Catherine Ashcraft, Professor of Natural Resources and the Environment at the University of New Hampshire. This panel discussed how changes in the Arctic will impact communities on and near the coast. Speakers included Kevin Knuuti (an independent consulting engineer and former technical director for Earth Sciences and Engineering at CRREL), Adam Parris (Executive Director, the Science and Resilience Institute, Jamaica Bay, NYC), Steve Couture (Administrator, NHDES Coastal Program), and a letter by Senator David Watters (NH Senator and former English professor at UNH) who was unable to attend (the letter is included in

Appendix E). Round-table discussions following this panel allowed participants to discuss new convergence research problems, societal impacts, and emerging tools and methods to address problems in coastal dynamics (Figure 3.6).



Figure 3.6. Round-table discussions

Panel 4: Coastal Dynamics

Catherine Ashcraft, Assistant Professor of Natural Resources and the Environment at UNH, moderated this discussion. The panel considered how changes in the Arctic will impact communities on and near the coast, including a discussion of both opportunities and risks resulting from changes currently being observed and changes projected over the next 20-50 years. While the focus included coastal communities in the Arctic and others around the world, this panel paid particular attention to coastal areas in the northeast US and Eastern Canada. This discussion helped explore convergent topics that will advance our understanding of how Eastern North America should prepare for and respond to these impacts over time.

Kevin Knuuti, currently an independent consulting engineer and former technical director for Earth Sciences and Engineering at CRREL, gave a talk on "Coastal Dynamics," considering observations of sea level rise in New England, and corresponding effects, risks and uncertainty and federal rules. He discussed trends and uncertainties in measurements of sea level rise using tidal datums and storm surge. Effects of mean sea level rise and storm surge include shoreline and beach erosion, navigation, flood risk, and impact on ecology. Knuuti talked about quantifying uncertainties and risks given multiple scenarios, and congressional rules. He discussed quantifying ecological value and communicating risk to the public, political officials, and decision makers. He also made the point that frequent "nuisances" have more impact in changing peoples minds than extreme events. That is, higher frequency, lower magnitude events are more likely to influence people's behavior and encourage retreat.

Panel 4 (cont.)

Adam Parris, Executive Director, the Science and Resilience Institute, Jamaica Bay, NYC, presented "Coastal Resilience – The Science and the Humanity of it all." He began by discussing the case of Jamaica Bay, NYC and the flooding associated with sea level rise, high tides, and storm surge. Communities around Jamaica Bay such as the Rockaways suffered enormous damage during Hurricane Sandy in 2012 and became a lesson for the imperative to prepare for sea level rise and the increase in coastal flooding. In this community, the conversation has changed from conservation and ecology to disaster and risk reduction. The communities are developing adaptive strategies that will provide 10-15 years of breathing room to allow them to make decisions for the future. Parris discussed two different decision timeframes for Jamaica Bay, now through 2030 and 2030 through 2080. The question is how much to invest in short term strategies and how to encourage proactive as opposed to reactive decision-making. The decisions made now determine the accumulated risk carried forward. There is also the need to balancing adaptation at nested scales of decision making. This hinges on risk awareness and understanding and on decision awareness and understanding. People understand the risks but do not necessarily understand the decisions. Finally, there is the question of equity. How we build a shared understanding, through humane approaches to engagement, could determine the equitable distribution of costs and benefits. Parris echoed Knuuti's point that people are most willing to relocate based on nuisance flooding, housing values, and what their neighbors do.

Steve Couture, Administrator, NHDES Coastal Program, provided a description of "NHDES Coastal Resilience – A Program Overview," discussing efforts by New Hampshire to prepare for and adapt to future sea level rise. He defined coastal resilience as, "the ability of a community or system to proactively prepare for and 'bounce back' from hazardous events such as hurricanes, coastal storms, and long-term sea-level rise and associated flooding, rather than simply react and respond to events." He outlined the program's activities to reach communities, advance state understanding and implementation, and translate the best-available science. NHDES has been involved with a variety of initiatives including co-founding the New Hampshire Coastal Adaptation Workgroup (CAW), launching the Coastal Resilience Program, completing a 2016 NH Coastal Risk and Hazard Commission Report, and assisting in the passage of state laws. Their efforts to reach communities have included the Climate Risk in the Seacoast (C-RiSe) assessments and assisting municipalities and the state through NH Setting SAIL program. Efforts to translate best-available science include the NH Coastal Viewer (allowing visualization of future scenarios), a model showing how sea level affects NH marshes, the Living Shorelines project, and collaboration on tidal culvert projects and dam removal projects. They have also put together reports that inform NH policy in preparation of sea level rise, storm surge, and flooding. The future focus in science will include groundwater rise mapping along with high resolution flood mapping and visualization.

Panel 4 (cont.)

Senator David Watters, NH Senator and former English professor at UNH, provided a letter read by Catherine Ashcraft to the audience (see Appendix E). Watters invokes a Passaconaway tale to introduce policy efforts to address the impacts of climate change and Arctic ice melt. Four years ago, Watters helped create the Coastal Risk and Hazards Commission which reported on sea level rise and extreme precipitation (described as well by Steve Couture). He introduced legislation to create a commission on ocean acidification and emerging environmental threats in the Great Bay and coastal waters and proposed bills to address the need for transportation and infrastructure to adapt to increased shipping and sea level rise. Senator Watters gave specific recommendations for research questions that have been incorporated into the tables in Section 4.

A facilitated plenary discussion presented and debated the major round-table big ideas. The goal once again was to arrive at ideas that could propel collaborative, multi-institutional research initiatives designed to respond to NSF's Navigating the New Arctic. The day ended by identifying next steps, with a particular focus on the development of a regional network of researchers, stakeholders, and external partners to begin to tackle the specific and compelling problems identified during this workshop. This new "New England Arctic Network (NEAN)" is outlined in the next section. Section 4 presents the conclusions and findings of the round-table discussions and plenary deliberations, presenting a large list of convergence research topics to grow the relationships developed at this workshop and propel a regional effort to pursue solutions.

4. FINDINGS AND RECOMMENDATIONS

This section describes findings and recommendations from the workshop given the goals to

1. **Develop a vision** for how Arctic change might impact New England
2. **Establish a regional network** to encourage multi-institutional, collaborative initiatives
3. **Identify specific convergence research ideas** linking New England and the Arctic.

These findings come from a synthesis of the round-table discussions, panel question and answer sessions, and facilitated large group deliberations. The goal of this section is to provide a comprehensive and thorough collection of research initiatives linking New England and the Arctic. Section 5 prioritizes the research questions and proposes an initial roadmap to guide the regional network.

Developing a Vision

Workshop participants acknowledge that understanding the links between Arctic change and New England requires a systems-level approach, integration across disciplines, and consideration of multiple spatial and temporal scales. They repeatedly emphasized the need for stakeholders and policymakers to be involved throughout the research process, including setting initial research goals. NSF's Convergence Research is viewed as a promising mechanism for bringing science to action, providing options to decision and policy makers. Figure 4.1 presents a conceptual diagram of the convergence/divergence process adapted from *Roco et al.* [2013] to represent recommendations for research linking New England and the Arctic.

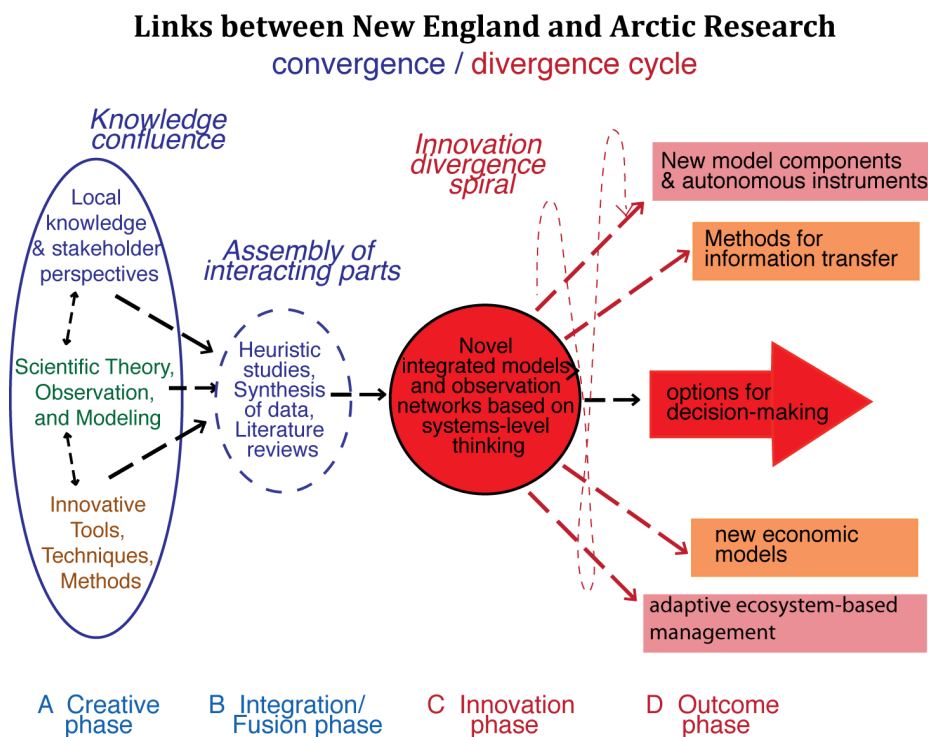


Figure 4.1. The convergence-divergence cycle applied to researching linking New England and the Arctic. Adapted from figure 7 of *Roco and Bainbridge* [2013].

Several themes permeated the panel, round-table, and plenary discussions. Table 4.1 describes these themes and a comprehensive list of questions that clarify their importance.

1. **PREDICT SCENARIOS** of viable regional economies in New England and in the Arctic under conditions of Arctic change, including what these new economies will provide for people on scales from small towns to cities and how they will change socio-ecological and cultural systems.
2. **STRATEGICALLY BALANCE** the role of science in serving commercial interests with environmental ethics and social justice.
3. **FULLY ENGAGE STAKEHOLDERS** in the design and execution of research. Include traditional knowledge and citizen science in an effort to understand the scale and rate of change of inter-linked systems in the Arctic and connected regions.
4. **FORM A REGIONAL NETWORK** that is free from geopolitics to provide distinctive leadership in supporting science and informed decision-making.
5. **TRAIN THE NEXT GENERATION** of convergence researchers and Arctic leaders in twenty-first century skills that value diversity and inclusion.

Table 4.1. Questions linking New England and the Arctic requiring Convergence

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| <p>What are VISIONARY PROJECTIONS of viable regional economies in New England and in the Arctic under conditions of Arctic change? What would these new economies provide for people from small towns to cities and how will they change socio-ecological and cultural systems?</p> <ul style="list-style-type: none"> • How will increased shipping traffic and faster travels times strengthen Arctic economies and open new trade markets for New England, including effects on demographics and job opportunities? • What is the economic impact across the North Atlantic region of projected changes in destination and trans-Arctic shipping, tourism, and resource extraction? Can ecosystem based management with public participation be balanced against this increased economic activity? • What is the current capacity to track social and ecological impacts of the changing Arctic economy? • How can research agendas anticipate the economic, developmental, and operational uncertainties of oil and gas exploration? • What ancillary data collection opportunities can smart infrastructure provide to study environmental and social change? • What impacts will climigration [Hamilton et al., 2016] have on New England and Arctic coastal communities? • How will tourism from New England affect socio-ecological systems in the Arctic? • How can New England participate in expanding Arctic fisheries (including in the Central Arctic Ocean) in ways that are socially and economically sustainable, and responsive to regional oceanographic changes? • How can we better understand how ocean circulation, salinity, and nutrient loading driven by ice melt impact biological productivity and fisheries? • How will regional climate patterns in New England change with Arctic amplification, including seasonal extent and extreme weather events? • What are the impacts of Arctic-induced weather variability and changing ocean circulation to key ecosystem services supporting the socio-economic-cultural identity of New England (cultural heritage such as lobsters, ice fishing, maple syrup, ski industry). |
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Table 4.1. (cont.)

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| <p>How do we STRATEGICALLY BALANCE how science serves both commercial interests and broad social goals that strive for environmental and social justice?</p> <ul style="list-style-type: none"> • Can sustainable, equitable development of shipping in the NW Passage be done in a way that does not disproportionately harm coastal communities and ecosystems? • How can sustainable, equitable development of shipping in the NW Passage and large ports in New England be done in a way that does not disproportionately harm indigenous communities and coastal ecology? • How do we achieve environmental and social justice through changes to transportation networks, resource extraction, and tourism? • How can economically underdeveloped communities be empowered by instead of exploited by interacting with the economically developed world, providing opportunities for future generations? • How do we study unexpected, uncertain, and abrupt responses of ecosystems to changing climate, ecosystem interactions, and human exploitation? • What cyberinfrastructure and data protocols are needed to openly share pan-Arctic research data, including data acquired on territories owned by indigenous peoples? • What are the best methods for increasing diversity among leaders in Arctic studies and enhancing STEM education about the Arctic and within the Arctic. |
| <p>How can traditional knowledge, citizen science, and fully ENGAGING STAKEHOLDERS in design and execution of research improve understanding of the scale and rate of change across all the inter-linked systems in the Arctic and connected regions?</p> <ul style="list-style-type: none"> • How can convergence research and strengthening the role of social science enable the cultural shifts needed to solve issues associated with Arctic change? • How do we ensure science is used for joint learning instead of as an adversarial process? • What is the economic impact across the North Atlantic region of projected changes in destination and trans-Arctic shipping, tourism, and resource extraction? Can ecosystem based management with public participation be balanced against this increased economic activity? • How can non-market valuation of ecosystem and cultural services be better factored into risk assessment? • Does education about risk-assessment for communities facing environmental change and development of contingency plans (including managed retreat) result in better outcomes? • How do we encourage collective, co-management to avoid cultural loss and discontinuity resulting from conflict between local autonomy and external control? Are local communities the appropriate focus or will collective/regional efforts be more effective? • How can we foster growth within existing citizen science activities such as backyard climate indicators, eco-tourism research, whale watches, and alert apps and link successes in citizen science in New England with initiatives in the Arctic. • What are best practices for communicating to local communities (esp. indigenous Arctic communities), including sharing the discoveries made in scientific research conducted on their lands? • How can story-telling and narrative help link the Arctic with regions such as New England? |

Table 4.1 (cont.)

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| <p>How can REGIONAL NETWORKS such as a "North Atlantic Arctic Network," free from geopolitics, provide leadership in supporting science and informed decision-making in the Arctic?</p> <ul style="list-style-type: none"> • How do we harness the brain power of a region such as New England to conduct both core and systems level research in the Arctic (paleoclimate, glaciology, space weather, astrophysics, ocean mapping, etc.) • How can the region develop a more comprehensive approach to scientific decision support for regional planning around coastal processes? • How do we increase understanding of environmental change as an issue of collective/regional adaptation, not just local impacts? • How can the Distributed Biological Observatory expand into the North Atlantic Arctic, including how a New England Arctic Network contribute to the current efforts of BBOS and FRAM as well as establishing a data synthesis efforts similar to PacMARS. • What are ways that New England can serve as an "outdoor laboratory" for testing new technologies for withstanding extreme Arctic conditions? • Increased awareness of Arctic changes seems to facilitate public understanding of New England climate change mitigation and adaptation needs. Why is this? Can we leverage this behavior to accelerate public commitments to scientific decision support around local and regional policy? • What historical comparative models can be used to assess and improve Arctic policy and regional management efforts? Can past gold rushes and similar bonanzas inform more sustainable oil, gas, and mineral exploration in the Arctic? Can lessons from the history of New England and North Atlantic fisheries be applied to new fisheries in the Arctic? |
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Establishing a Regional Network

Currently, much of the US Arctic focus is on Alaska and the North Pacific [e.g., *NRC*, 2003, 2004, 2014c; *IARPC*, 2016; *USARC*, 2017]. There is a clear need for a regional network that engages stakeholders from the northeastern United States in the broader international North Atlantic sector of the Arctic, fostering connections and research collaborations among people and institutions living and working in the North Atlantic Arctic (Figure 4.2).

To pursue convergence research, this network must develop a broad community of practice, including university researchers as well as representatives from businesses, governments, non profit organizations, and coastal and indigenous communities. The goal of this network will be to facilitate communication and the exchange of information and resources, develop a sense of community among participants, and foster new Arctic research collaborations based on

community needs across the North Atlantic sector of the Arctic.



Figure 4.2. The North Atlantic Arctic

On the basis of feedback from the workshop, the strategy will be to first solidify and grow a New England network and then reach internationally to build, support, and maintain a more expansive network.

Workshop participants also identified critical characteristics for this network described below.

INCLUSIVE MEMBERSHIP

A convergent approach requires membership from a diversity of public and private institutions that include academia, businesses, governments, nonprofit organizations, and coastal and indigenous communities. Diversity of perspective and expertise is essential for convergence, not only across disciplines and employment sectors, but also across socio-economic, cultural, and ethnic backgrounds [NAP, 2014a]. An inclusive attitude along with carefully-planned facilitation and management strategies can strengthen creativity and innovative problem-solving [Stahl *et al.*, 2010a, 2010b]. We also anticipate that by bringing together participants from many disciplines and sectors into a setting open to fostering collaboration, this convergence approach will inspire more individuals from underrepresented minority groups to pursue Arctic research and careers in STEM.

OPEN COMMUNICATION

In order to foster new Arctic research collaborations, the network requires robust communication tools. Workshops, virtual meetings, a website, online collaborative tools, and periodic electronic newsletters will enable the exchange of information and resources and develop a sense of community among participants.

Early on in the growth of the network, it will be necessary to compose norms and protocols for shared governance, management, equitable participation and communication to guide the activities, products, and expansion. Virtual meetings, seminars, and facilitated topical panel discussions focusing on individual convergence research questions will further strengthen relationships. Boundary objects such as maps, visualizations, and spreadsheets will enable participants from widely different disciplines to interact and exchange vocabulary and interpretations. Visual arts and visual anthropology are also

recognized to be powerful communication tools.

Participation at the international level will also be crucial for connecting with other networks around the North Atlantic Arctic. The NEAN will also benefit from representation and events at local, regional, national and international professional meetings.

SOLUTIONS-ORIENTED APPROACH

The ultimate goal of convergence research is to identify, understand, and communicate the critical science necessary to engage communities and pursue innovative solutions to emerging challenges. Developing solutions to complex problems requires a scientific approach that is solutions-based as opposed to curiosity-based, with projects having an applied component that brings science into action. Once again, it is crucial to involve local communities and stakeholders in the initial development of research initiatives, acknowledging that solutions can be based on geographic interest as well as a range of temporal scales.

HOLISTIC METHODOLOGY

Successful research, communication, and engagement, use holistic methods, defined as international, interdisciplinary, and inclusive. Figure 4.3, adapted from Berkman *et al.* [2017], shows the iterative decision-support process adopted by Pan-Arctic Options that integrates holistic evidence from the sciences with governance and stakeholder perspectives to enable science to provide well-conceived options to decision-makers.



Figure 4.3. Decision Support Process:
From *Berkman et al.*, 2017

ENGAGE COASTAL COMMUNITIES

As mentioned throughout this report, it is essential to include local communities in all stages of research, from defining the objectives to implementing solutions. This type of involvement will ensure that sustainable and equitable development does not disproportionately harm indigenous communities and coastal ecology. Identifying discrepancies between what we want to know scientifically and what communities want and need to know will enable adaptation and mitigation strategies for coastal resilience. While the initial networking of the NE Arctic Convergence Workshop serves as a solid foundation, we fully realize that to meet our goal we need to deliberately expand our geographic scope (from New England to the North Atlantic Arctic), our expertise, and most importantly our societal engagement.

Convergence Research Ideas

In order for convergence to thrive, specific and compelling problems need to be at the forefront. Within the New England Arctic effort, a strong set of specific and compelling convergence research problems will serve as seeds around which systems-thinking and synthesis can grow, feeding the convergent approaches of the larger network of regional collaborators. Tables 4.2a-d list numerous specific and compelling convergence research problems that will require deep integration across disciplines.

These tables are divided into sections roughly corresponding to the topics of the workshop:

- a) Sustainable Societies, Transportation, and Infrastructure
- b) Living Resource, subdivided into Marine and Terrestrial Ecosystems and Small and Remote Villages and Indigenous Communities
- c) Coastal Dynamics
- d) Global Scale Approaches to Arctic change.

Within this vast collection of convergence research ideas, there are several that must begin immediately in order to combat the rapid changes already being seen in New England. Chief among these priorities are:

- Oil spill response preparation
- Economic impacts of increased shipping and tourism on coastal communities.
- Infrastructure needs, smart sensors, and adaptive technologies
- Risk assessment for coastal communities, including fishing and adaptive ecosystem-based management.
- New methods for data synthesis and information transfer between researchers and stakeholders
- Observational data gaps in the marine region between the Gulf of Maine and Newfoundland.

These projects must all begin with stakeholder engagement. The challenge will be how to most efficiently engage existing groups and relationships that link stakeholders to researchers as well as to secure funding to enable these communities to adequately participate.

Appendix G lists some research ideas that specifically address within the priorities outlined the 22 Feb 2018 NSF NNA DCL. In addition, while Navigating the New Arctic is already partnering with Growing Convergence Research, the breadth of these topics demonstrate the potential for future partnerships with other NSF's 10 Big Ideas. (Appendix H).

Table 4.2a. Sustainable Societies, Transportation, and Infrastructure: Convergence Research Ideas

- Determining the timeline for shipping expansion. Increased shipping through Northern Sea Route will likely occur before the Northwest Passage. Both will also impact New England. Cruise ship tourism from New England to the Canadian Arctic may be the first to benefit from the opening of the Northwest Passage, with destination shipping coming later.
- Economic analysis comparing destination shipping, tourism, and large scale shipping.
- Economic analyses of ports and shipping to determine investment to respond to environmental change on scales of city, county, state, and New England region. Best location for ports (deep natural harbors or vibrant cities)
- Transportation and shipping port infrastructure needs such as railways, bridges, warehouses, docks as well as community infrastructure such as schools, hospitals, roads, etc. How can infrastructure plan for facilities that "can get wet" as sea levels rise and storm surge increases (floating docks, dikes, etc.)?
- Analysis of heavy metals and invasive species from ship ballast water and their impact on ecosystems and communities.
- Merge existing databases on sea ice, icebergs, ship traffic, marine species (all trophic levels) distributions to determine conflicts. Prepare for new models capable of forecasting impacts of Arctic change to anticipate future conflicts.
- Social, economic and political aspects of domestic and international manufacturing of heavy-duty ice breakers, smaller ice breakers, and ice-strengthened cargo and cruise ships. Analysis of investment needs for Bath Iron Works to be competitive in ship-building for the Arctic.
- Economic and logistical analysis of opportunities to increase air freight transport between New England and Greenland, Iceland, or Canadian Arctic.
- Determine what existing and new empirical, historical, regional, and comparative models will best address regional management efforts in the North Atlantic Arctic region.
- Predictions of how demographics will change. Will new opportunities counter current trends of aging population, drawing younger people to cities like Portland How to incentivize populating northern Maine. Impacts of global migration (refugee and immigrant influx).
- Needs for first response preparation in response to oil spills and accidents.
- Assess the scientific knowledge needed to train first responders for search and rescue and educated inexperienced eco-tourists in personal and environmental safety.
- Identify research opportunities, infrastructure needs, and environmental education needs associated with tourism, especially as links build between New England and Iceland and Greenland.
- How can Arctic civil infrastructure (roads, ports, telecommunications, buildings) be made more resilient in response to thawing permafrost, sea level rise, and eroding coastlines?
- Overlay permafrost data with coastal erosion, carbon and water cycles, and other hazards to quantify risks. Including infrastructure stability and impacts on transportation.
- Can redevelopment or replacement of these infrastructure assets on permafrost incorporate smart sensors to improve understanding of the rates and controlling processes putting communities at risk?
- What does our understanding of permafrost across the Arctic imply about projections for where the best locations will be for new coastal infrastructure to support the New Arctic?

Table 4.2a. (cont.)

- Predict infrastructure needs in an uncertain future. What is the fate of "abandoned infrastructure" when it fails or is underutilized? What types of continuous long-term monitoring of environmental change are required? What types of materials and structures from operations research in engineering can be adapted over time (as opposed to a static 10-20 year lifespan)?
- Predict toxic pollution from melting glaciers and thawing permafrost.
- What state-of-the-art sustainable energy development methods and technologies can be incorporated into new infrastructure and transportation projects?
- Impacts of changes in extreme weather events on infrastructure (e.g., trucks blown over on R.I. bridges during storms). How to include extreme weather in traffic analysis.
- As seasons change, re-examine work, school, and community calendars that impact work force development, education, recreation, tourism, and quality of life.
- Examine differing experiences between coastal and island communities, including sense of place. What factors inform decision to stay and build or to leave?
- Develop outreach programs to educate New England about linkages to the Arctic. Provide educational materials to New England ports to reach stakeholders in shipping, fishing, and tourism.

Table 4.2b. Living Resources: Convergence Research Ideas

Marine and Terrestrial Ecosystems

- Studies aimed at understanding and predicting how ocean circulation, salinity, and nutrient loading in the North Atlantic will change due to Arctic ice melt, and impact biological productivity and fisheries. Filling in data gaps (e.g., Between Gulf of Maine and Newfoundland)
- How to manage New England fisheries as populations change in distribution and range.
- Movement of species associated with sea ice using new technologies such as acoustics.
- How and where to establish new environmental preserves and sanctuaries.
- Studies involving changes in the physics and ecology of the Gulf of Maine from a regional (North Atlantic-Arctic) sense with remote forcing from the Arctic, especially considering that the Gulf of Maine is the southern boundary for many species (shrimp and keystone zooplankton). Can no longer consider Gulf of Maine in isolation.
- How will the continuing northern migration of Gulf of Maine fish species impact the fishing industry in Maine, and how will national and international regulations create a regime for Arctic fisheries?
- Can we forecast impacts of increased shipping on pollutants, marine sounds, invasive species, fishing, ecotourism, endangered species (right whale).
- What is the impact on human health of toxic pollution and "zombie" pathogens from melting glaciers and thawing permafrost re-entering ecosystems in the Arctic?
- Assess impact of dams (natural and manmade) and infrastructure on fish in estuarine systems.
- Observational initiatives to study terrestrial pathogens and invasive species.
- How will the atmospheric response to changes in Arctic ice and oceanic adjustments impact key ecosystems services in the North Atlantic region?
- How will late season Nor'easters (attributed by many to Arctic influences) impact Gulf of Maine / North Atlantic ecosystems?
- Forest fires and impacts on snow, soil, and microbes. What might be the impact on New England, due to wind currents, of smoke and soot deposition from large-scale fires in tundra and peat in the Arctic region?

Table 4.2b. (cont.)

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| <p>Small, remote villages and indigenous communities</p> <ul style="list-style-type: none"> • Design research agendas that begin with local community concerns, problems, values, and cultural practices. Explore what local and indigenous people envision for their future using social assessment surveys and tools, political clout, economic modeling, and epidemiology mapping tools. • Preparing for knowledge transfer from New England to Arctic communities on a variety of social, environmental, and technology issues. How to use social infrastructure and social media to enhance knowledge transfer. New paradigms for monitoring networks using technologies such as Skype or Facebook. • Integrative mapping of local mental maps and satellite imagery as boundary objects and communications. • Determine how the indigenous voice can enter into societal/policy decisions regarding infrastructure impacts on estuarine systems • Bringing an indigenous voice into all levels of planning/research will require a cultural shift, including away from quick-fix tech/engineering solutions. Ensure transparency and mutual benefit, including how to communicate, publicize, and archive scientific results. • Studies of how shipping, resource extraction, and tourism will impact the equitable distribution of economic benefits and empowerment of local communities. • Study the use of safe spaces to talk about values within communities and break through traditional power dynamics and assumption instead of articulation of values? • Explore creative ways to make fishing by non-Arctic communities more amenable to acknowledging concerns of local Arctic residents. Share personal narratives and stories more broadly. For example, connects can be made among fisherman from different regions. • Create an almanac of extreme weather including tradition and oral narrative to analyze past and present weather patterns (e.g., Fidelia Fieldings' diary). • How will climate and ocean researchers incorporate cultural systems in projecting the impacts of climate change, since the dynamic of cultural production, including landscapes, historical preservation, modes of memory, values, and arts, will be profoundly affected? • Studies of collective co-management to address crises versus cultural loss and discontinuity resulting from conflict between local autonomy and external control. Methods linking decision-makers with affected communities. Compile examples of what has worked and what has not worked in co-management of resources in small, rural communities around the globe. • Explore ecotourism as a potential sponsor of research, educational, and outreach activities, especially with the rise in visibility of northern coral reefs. • Study best practices for economic benefits of tourism to benefit local communities. Economic benefits of tourism in small Arctic communities will likely be dominated by smaller yachts and ships as larger ships keep proceeds for themselves. • What are the power relationships in Arctic communities (gender, age, etc.) and how does this inform sustainability as well as relationships with Arctic researchers? • Expand community-based monitoring networks in the North Atlantic Arctic region (similar to GLOBE for Arctic communities). For example, use "kits" and "drifters" for local observations of ocean temperature and salinity, sea level, and atmospheric and snow conditions. • Given that the majority of Arctic residents live in cities, how does the urban-rural relationship impact sustainable development? |
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Table 4.2c. Coastal Dynamics and Sea Level Rise: Convergence Research Ideas

- Study of coastal erosion from sea level rise and extreme weather that use convergent approaches, including charting and ocean mapping, bioaccumulation, human censusing, displacement options, political consensus, satellite, remote and in situ monitoring on ocean and land.
- How will an open Arctic intensify coastal storms? How can governments respond?
- How will the concentration of fresh water off of Greenland's melting ice cap affect the Atlantic meridional overturning circulation, and how will this overturning impact the Gulf of Maine and its fisheries?
- Develop new methods to identify ideal locations for new coastal infrastructure, such as remote sensing techniques and innovative risk assessment models.
- Create higher resolution sediment transport models to improve living shoreline stabilization efforts.
- What are the lessons learned from the University of the Atlantic and New England aquarium with respect to sea level rise that could apply to other areas of coastal New England ?
- Explore methods that would allow agencies such as USACE and NH DES to incorporate non-market values in mitigating risk involving sea level rise and extreme precipitation events.
- Determine how to best proactively protect archeological, cultural heritage, and paleo-environmental sites in response to long-term coastal stressors, and how to prioritize these efforts to address desires of the local communities as well as researchers.
- Compare threshold and triggers most likely to influence retreat decisions among New England and Arctic communities.
- Research on the psychology of change as it relates to sea level rise. What makes people react? Does 3D visualization of predictions help?
- Social and psychological challenges to migrating away from coasts, both in New England and in Arctic communities. Quantitative and qualitative studies of when individuals and various communities decide to retreat rather than continue to mitigate impacts of sea level rise.
- Teach risk-assessment to communities and encourage willingness to develop and proceed with contingency plans, including managed retreat.
- Studies addressing "elevation gentrification," the rise of younger more affluent communities at higher altitudes that are not as impacted by sea level rise.
- What does decommissioning a municipality look like? How can it be done equitably?

Table 4.2d. Global Scale Approaches to Arctic Change: Convergence Research Ideas

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| <ul style="list-style-type: none"> • Develop projections, predictions, and scenarios that better integrate causal relations across fields of study. • Conduct global life cycle and cost-benefit analyses of preserving the Arctic versus exploitation of resources, including exploration of global governance options. • How can knowledge co-production, social and ecological indicators development, and community-based research become more pervasive in biogeophysical Arctic research? What is the role of ecosystem-based management, adaptive management and public participation? (Use historical lessons from New England fisheries). • Adopt a New England regional approach to connect with other regional organizations in the Pan-Arctic. "Brain strength" of New England and good location to train future leaders. • Scholars and stakeholders must work together to avoid negatively framing problems in order to arrive at global solutions. • Create new migration models for human and animal populations to inform infrastructure planning and collecting ecological and environmental data. • Developing inexpensive and open source hardware sensors for use in remote sensing of the ocean and coasts to quantify threats to coastal communities (e.g., erosion, changes to water quantity and quality, permafrost degradation) • Novel opportunities for sea level and ocean chemistry measurements including new satellite assets, sub-orbital platforms, and even hydrographic sensors involving marine life. • Development of cyberinfrastructure to prepare for hazards, especially oil spills. Promote efforts to link datasets from natural and social sciences, so that observing capabilities can be used to provide options for decision-making. Open, linked, common format databases with layers of information to assess transportation and hazards and interactions with ecosystems. • Address gaps in education and workforce training. Improve educational curricula and methods to prepare society to better assess risk and uncertainty. (e.g. Eco-School) • How can science remain focused on broader societal goals as capitalization of the Arctic accelerates? Pursue private foundation funding sources as a means of connecting science and policy to communities. • How can New England's past engagement with the Arctic, including polar exploration, shipping, whaling, fur trading, art, and literature, from the 17th to the early 20th centuries, be used as a framework for understanding how the region will respond to a new Arctic? |
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Meeting the Workshop Objectives

The primary workshop objectives have been met. This gathering initiated a dialogue about complex impacts that Arctic change might have on New England over the next several decades and recommended a list of broad questions linking New England and the Arctic that require a convergence approach (Table 4.1). Plans are underway to form a New England Arctic Network (NEAN) following the recommendations and guidelines of workshop participants. A

core team submitted a proposal a month following the event to form an NSF Research Coordination Network to continue to build this network and eventually connect with international research networks surrounding the North Atlantic Arctic Region. Tables 4.2a-e demonstrate the vast number of specific convergence research initiatives identified at the workshop and the NEAN will help prioritize these research questions, form collaborative team to pursue these projects, and develop a more concise

vision for the future links between New England and the Arctic.

With regard to training a new generation of Arctic researchers, the workshop directly reached 12 undergraduate, 16 graduate, and over a dozen early career researchers. The involvement of graduate and undergraduate students as notetakers proved extremely valuable, capturing details from each round-table and engaging students with experts in Arctic research from a range of disciplines. The undergraduate facilitators from the recently established UNH Civil Discourse Lab brought the additional emphasis on equitable communication and deliberation skills that will be crucial for continued convergent studies.

One challenge encountered by workshop organizers was how to best including indigenous voices in the workshop, given the wide diversity of needs and challenges among tribes and communities. It was clear that inviting individual speakers would provide an incomplete picture of such a large and diverse region. Consultation with Arctic researchers who work directly with indigenous communities also warned of the dangers of outreach fatigue and recommended that carefully-planned and sustained efforts beyond the scope of this workshop were needed to establish and maintain relationships among individual Arctic communities to ensure mutual benefit. There was also the concern that inviting indigenous speakers from the Arctic without first acknowledging the concerns of native tribes of New England would neglect a history that is extremely relevant for how the globalization and environmental impacts of Arctic change will impact indigenous communities in both New England and the Arctic.

In the end, Susan Kaplan, Director of the Peary-MacMillan Arctic Museum and Arctic Studies Center At Bowdoin College, provided an overview of common challenges faced by both indigenous and non-indigenous communities in the Arctic. Kim Juniper of Ocean Networks Canada provided insight into collaboration with communities in Nunavut. And Maria Girouard from the Penobscot Nation and Dawnland Environmental Defense gave a plenary talk about the 400 year relationship between native tribes, settlers, and the environment of New England titled, "The Penobscot: Ancestral River, Contested Territory." All of these speakers stressed the need to work through established indigenous councils and organizations before beginning research in local communities.

The round-table discussions and facilitated large-group deliberations also emphasized the imperative and interest to include local and indigenous communities when planning and executing convergence research initiatives, with the goal of developing long-term, sustained relationships and sharing methodological innovations, findings, and data with the communities. As recommended by Arctic Horizons [Anderson *et al.*, 2018], research design must involve social scientists and consider ethics and information sovereignty of Arctic Indigenous communities.

Workshop materials, this report, related documents and action items are available and continually update on the website: <https://mypages.unh.edu/ne-arctic-convergence>, contributing toward the dissemination of information on the impact of Arctic change on the "lower 48" states to the public, political representatives, and stakeholders.

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6. APPENDICES

Appendix A. Workshop Agenda

Goal:

To assess the economic, environmental, and social links between Arctic change and New England, identifying transformational convergence research initiatives to anticipate, prepare for, and adapt to future impacts and opportunities.

Objectives:

- Develop a vision for how Arctic change might impact New England over the next several decades and recommend future convergent research priorities linking Arctic change and New England.
- Establish a *New England Arctic Research Network* to encourage multi-institutional convergence research projects
- Identify specific research initiatives, core collaborative teams, topics for review papers, and follow-up plans for proposing to future NSF NNA and other federal opportunities.

Sunday March 25

7:00 pm "The Arctic Meltdown and Extreme Weather: How Are They Connected?"

Dr. Jennifer Francis, Dept. of Marine and Coastal Sciences, Rutgers University
MUB (Memorial Union Building) Auditorium II

Monday March 26 – Squamscott, Holloway Commons

8:00 Breakfast and Registration

8:30 Introduction and Welcome

Katharine Duderstadt (workshop organizer)

Jan Nisbet, Senior Vice Provost for Research at the University of New Hampshire

US Senator Angus S. King, Jr. – video address

9:00 "Convergence in Research and Education" – Mamadou Diallo

9:50 Panel #1 Convergence and Arctic Research

Larry Hamilton (moderator), Paul Berkman, Kim Juniper,
Elisabet Idermark, Mamadou Diallo

11:00 Break

11:15 Round table discussions – Convergence in Arctic Research

12:00 Lunch

1:00 Panel #2 Infrastructure, Transportation, Opportunities, and Hazards

Nancy Kinner (moderator), David Kennedy, Rebecca Pincus, Jeff Levine

2:30 Break

2:45 Round table discussions – Convergence in Infrastructure and Transportation

3:30 Facilitated large group discussion on specific research initiatives,
core collaborative teams, and links to the NSF NNA Dear Colleague Letter

4:30 Reception at Dimond Library Special Collections & University Museum

"To the Ends of the Earth: New Hampshire's Connection to Polar Exploration
and Research"

Tuesday, March 27 (Breakfast at Museum of Art, Workshop at Squamscott, Holloway Commons)

- 8:00 Breakfast at UNH Museum of Art
Installations and paintings of the Arctic and Antarctic by artists
Anna McKee, Wendy Jacobs, Erik Aho, Resa Blatman, Andrea Juan,
Claudia O'Steen and Aly Ogasian.
- 8:45 Return to Squamscott Room, Holloway Commons
- 9:00 Welcome to day 2
- 9:05 "The Penobscot: Ancestral River, Contested Territory"
Maria Girouard, Dawnland Environmental Defense
- 10:00 Panel #3 Living Resources
Jennifer Brewer (moderator), Susan Kaplan, Robin Alden, Tom Shyka
- 11:00 Break
- 11:15 Round table discussions – Convergence in Living Resources
- 12:00 Lunch
- 1:00 Panel #4 Coastal Dynamics, Opportunities and Hazards
Catherine Ashcraft (moderator), Kevin Knuuti, Adam Parris, Steve Couture
- 2:30 Break
- 2:45 Round table discussions – Convergence in Coastal Dynamics
- 3:30 Facilitated large group discussion on specific research initiatives,
core collaborative teams, and links to the NSF NNA Dear Colleague Letter
- 4:20 Next steps and closure

POSTERS: Please visit posters around the conference room throughout the event.

Appendix B. Panel Descriptions and Biographies

Sunday, March 25th Evening Lecture



*Dr. Jennifer Francis
Research Professor
Institute of Marine and
Coastal Sciences
Rutgers University*

Jennifer Francis is a Research Professor in the Department of Marine and Coastal Sciences at Rutgers University, where she has taught courses in satellite remote sensing and climate-change issues, and is also co-founded and co-directed the Rutgers Climate and Environmental Change Initiative. Her research focuses on Arctic climate change and Arctic-global climate linkages. She and her husband circumnavigated the world in a sailboat from 1980-1985, including Cape Horn and the Arctic, during which her interest in weather and the Arctic began. She earned a B.S. in Meteorology from San Jose State University and a PhD in Atmospheric Sciences from the University of Washington.

Monday, March 26th Plenary Talk



*Dr. Mamadou S. Diallo
Director of Molecular
Environmental Technology
Materials and Process
Simulation Center
California Institute of
Technology*

Mamadou Diallo is Director of the Molecular Environmental Technology Materials and Process Simulation Center at CALTECH and Adjunct Professor of Civil Engineering at Howard University. He has great interest in utilizing sustainability science and engineering as a convergence platform to advance a broad range range of research and educational activities. His current research focuses on the preparation and characterization of multifunctional membranes for sustainable chemistry, engineering and materials, including water treatment and desalination, CO₂ capture and conversion, and critical metal and resource recovery. He recently served as Director of the Laboratory of Advanced Materials and Systems for Water Sustainability of the Graduate School of EEWS (Energy, Environment, Water and Sustainability) at the Korea Advanced Institute of Science and Technology (KAIST). He holds an Engineer Diploma in Mineral Engineering from Ecole Nationale de L' Industrie Minerale (Rabat, Morocco), a Master of Science in Chemical Engineering from Colorado School of Mines, a Master of Science in Chemistry and a Ph.D. in Environmental Engineering from the University of Michigan.

Panel 1: Convergence in Arctic Research

(Monday March 25th morning)

This panel will examine how to merge discipline-specific research into a convergence approach to advance innovations in observations, data analysis, and modeling. A convergence approach will benefit research into links between Arctic change and New England by bringing together substantially different disciplines from natural science, social science, and engineering, while transcending barriers that might arise from disparate terminology and paradigms. The panel will examine how convergence can tackle the technical, organizational, and logistical challenges to collaboration from the outset in order to enable sustained collaboration across disciplines. Panelists will discuss ways that convergence can extend beyond traditional multidisciplinary, interdisciplinary, and transdisciplinary research. Following this panel, researchers will be asked to identify research themes linking New England and Arctic Change that lend themselves to convergence research.



*Dr. Lawrence Hamilton
Department of Sociology
Carsey School of Public Policy
University of New Hampshire*

Larry Hamilton is Professor of sociology and senior fellow at the Carsey School of Public Policy, University of New Hampshire. Over the past 25 years he has studied human-environment interactions around the circumpolar North, from Alaska to Greenland and the northern Atlantic. Much of his research involves collaboration between social and natural scientists, to investigate topics such as fisheries crises in Greenland, Iceland and Newfoundland, or the accuracy of hundreds of predictions about sea ice. One recent article focused on “Climigration? Population and climate change in Arctic Alaska.” Dr. Hamilton also conducts large-scale surveys of U.S. public knowledge and perceptions about polar regions.



*Dr. Kim Juniper
Chief Scientist, Executive
Ocean Networks Canada
Professor of Biology
University of Victoria*

Kim Juniper has been a Professor in the School of Earth and Ocean Sciences and the Department of Biology at the University of Victoria, and holder of the BC Leadership Chair in Ocean Ecosystems and Global Change since 2006. He came to UVic from the Université du Québec à Montréal where he was Professor of Biology and Director of the GEOTOP Research Centre. He received his BSc from the University of Alberta (1976) and a PhD from Canterbury University in Christchurch, New Zealand (1982). The primary focus of his research has been the biogeochemistry and ecology of submarine hydrothermal systems. His interdisciplinary publications on deep-sea vents encompass the fields of microbial ecology, biomineralization and benthic ecology. Other research areas have included the microbial ecology of deep-sea sediments, and the seasonal dynamics of arctic sea-ice microbial communities. Juniper previously served the NEPTUNE Canada project as Co-Chief Scientist in 2004-2006, and was President of the Canadian Scientific Submersible Facility from 2001 to 2011.



*Dr. Paul Arthur Berkman
Director of the Science
Diplomacy Center
Fletcher School of Law and
Diplomacy
Tufts University*

Paul Arthur Berkman is building connections between science, diplomacy and information technology to promote cooperation and prevent discord, balancing national interests and common interests for the benefit of all on Earth. He was a visiting professor at the University of California at the age of 23, after wintering the previous year in Antarctica on a SCUBA research expedition, evolving two decades later into a textbook on *Science Into Policy*. He was a Fulbright Distinguished and Head of the Arctic Ocean Geopolitics Programme at the University of Cambridge, chairing the *Antarctic Treaty Summit* at the Smithsonian Institution in 2009 with legacy through the first book on *Science Diplomacy* and then the first formal NATO-Russia dialogue the following year regarding *Environmental Security in the Arctic Ocean* with legacy contributions through a successful Springer publication of the same name. He currently coordinates the *Arctic Options* and *Pan-Arctic Options* projects (involving support from national science agencies in the United States, Russian Federation, Norway, France, China and Canada from 2013-2020) as well as a Carnegie Corporation project on *US-Russia Relations*. In September 2015, he joined the Fletcher School of Law and Diplomacy at Tufts University as Professor of Practice in Science Diplomacy and is now Director of the Science Diplomacy Center as a university-wide initiative.



*Elisabet Idermark
Senior Advisor International
Relations
Research Support Office
Stockholm University*

Elisabet Idermark is Senior Advisor on international relations at Research Support Office, Stockholm University, Sweden, coordinating research projects and partnerships. She is the project manager for the Arctic Science IntegrAtion Quest (ASIAQ), uniting six universities from three continents and four countries (Russia, Japan, USA and Sweden) in an endeavour to jointly advance research and education for a sustainable Arctic.

Panel 2: Infrastructure and Transportation – Opportunities and Hazards

(Monday March 25th afternoon)

An ice-free Northwest Passage will stimulate new trade markets, including the potential to transport fossil fuel from the Alaskan North Slope and Canada to U.S. East Coast refineries. Coastal communities such as Portland, Maine are transforming into Arctic shipping hubs. Increased ship traffic will require shore-based infrastructure and provide job opportunities. Search and rescue capabilities will need to expand, along with plans for responding to oil and container spills. Air, water, and noise pollution may increase in coastal communities, disturbing terrestrial and marine ecosystems and migratory paths, and there is the potential of invasive species being transported via ballast water. This panel will present examples of new ventures to enhance economic development and stimulate productivity, while addressing the importance of environmental and societal sustainability. Participants will consider how the pursuit of innovation, solutions, new products, and increased productivity can also empower communities, improve lifestyles, and strive for social and economic equality.



*Dr. Nancy Kinner
University Professor
Civil and Environmental
Engineering
Coastal Response Research Center
The University of New Hampshire*

Nancy Kinner's main areas of research interest are oil spill response and restoration, bioremediation of contaminated subsurface environments and more generally, environmental microbiology. She is a member of the Environmental Research Group (ERG) at UNH and has conducted research on wastewater biofilm microbiology, the role of protists in subsurface and sea ice contaminant degradation, and petroleum and chlorinated solvent bioremediation. A professor of Civil and Environmental Engineering, Kinner has been co-director of the Coastal Response Research Center, a partnership between UNH and the National Oceanic and Atmospheric Administration (NOAA), since 2004. The center brings together the resources of a research-oriented university and the field expertise of NOAA's Office of Response and Restoration to conduct and oversee basic and applied research, conduct outreach, and encourage strategic partnerships in spill response, assessment and restoration.



*David Kennedy
Senior Advisor for the Arctic
Region
National Oceanic and Atmospheric
Administration (NOAA)*

David Kennedy is currently NOAA's Senior Advisor for the Arctic Region. He served as Deputy Undersecretary for Administration at NOAA as well as Assistant Administrator for NOAA Ocean Service and director of NOAA's Office of Ocean and Coastal Resource Management. He has more than two decades of experience leading hazardous materials management and response efforts, including coordinating federal scientific response to more than 100 oil and chemical spill incidents. Prior to 1976, Kennedy was director of the spilled oil research team at the University of Alaska Geophysical Institute. He is a native of Oskaloosa, Iowa, and received a Bachelor of Arts degree in anthropology from the University of Northern Colorado.



*Dr. Rebecca Pincus
Professor
Department of Humanities
U.S. Coast Guard Academy*

Rebecca Pincus is the Class of '65 Endowed Chair in Arctic Studies in the Department of Humanities at the U.S. Coast Guard Academy and leads research at the Academy's recently established Center for Arctic Study and Policy (CASP). Her research addresses security concerns in the Arctic region, broadly defined as encompassing national security as well as human and environmental security concepts. She earned a B.S. in Foreign Service from Georgetown University, an M.S. in Environmental Law from Vermont Law School, and an M.S. and Ph.D. in Natural Resources from the University of Vermont.



*Jeff Levine
Planning & Urban
Development Director
City of Portland*

Jeff Levine, AICP, has been involved with land use planning on the local and regional level for 20 years. Before coming to Portland, he was the Director of Planning & Community Development for Brookline, MA, where he managed the completion of the town's award-winning Comprehensive Plan and a public realm plan for the Route 9 corridor into Boston. Previously, he worked as the Director of Transportation & Long Range Planning for the City of Somerville, MA, and as a regional planner for the Cape Cod Commission. A New England native, he has been involved in a number of land use transformations, including the redevelopment of the Assembly Square district in Somerville; planning for the introduction of a new light rail transit line in Somerville; redevelopment of John Kennedy's boyhood church into a mixed-income housing development in Brookline; and the redevelopment of the Bayside district in Portland. Jeff has also been involved in Metropolitan Planning Organizations in Boston, on Cape Cod, and in Portland. Jeff is an adjunct faculty member at the Muskie School of Public Service, and was previously an adjunct at Tufts University, at the University of Massachusetts at Amherst, and at the APA Planning Leadership Institute. He has a degree in urban planning from the University of Minnesota and an undergraduate degree from Wesleyan University.

Tuesday March 26th Plenary Talk



Maria Girouard
Dawnland Environmental Defense
Penobscot Indian Nation

Maria Girouard of the Penobscot Indian Nation, Maine is an historian (M.A. History, University of Maine) with a particular expertise in the Maine Indian Land Claims. A longstanding community organizer, educator, and environmental activist Maria has spoken extensively on topics including Penobscot history, tribalstate relations, the Maine Indian Land Claims, food justice, and the current legal battle being waged over the Penobscots' ancestral river. She is a cofounder of the Sunlight Media Collective and of Alnabek Kkihkan The Peoples' Garden on Indian Island. She served her tribal community in the past as an elected member of the Penobscot Tribal Council and director of the Penobscot Cultural and Historic Preservation Department. In 2015 Maria was awarded the prestigious Maryann Hartman Award for her advocacy work in preserving the cultural heritage and rights of the Penobscot Nation. She currently works as a health and wellness coordinator for MaineWabanaki REACH.

Panel 3: Living Resources

(Tuesday, March 26th morning)

Unprecedented environmental conditions on land and sea trigger cascades of ecosystem change. Rising temperatures drive shifts in species distributions, population dynamics, and trophic relations. As sunlight reaches previously ice-covered waters, Arctic primary production is increasing, yet habitat loss, increased shipping, resource extraction, and commercial harvest of living resources may reduce some species populations. Meanwhile, temperature increases in the Gulf of Maine drive some species into deeper or more northern waters, stress other species and increase vulnerability to disease, while newly-arrived species populations may have economic value and/or compete against current species. Ocean acidification and other changes in ocean chemistry pose further challenges. In the face of such rapid change, how can policy sustain living resources and the human communities reliant on them? Some researchers and practitioners argue that current approaches have not accommodated existing levels of socio-ecological variability, and will surely fail as change accelerates. Others seek alternative knowledge systems and environmental ethics of indigenous groups. Many call for expanded data collection. To advance these lines of inquiry, this panel will initiate policy-relevant knowledge-sharing across marine science, social science, and resource management.



*Dr. Jennifer Brewer
Associate Professor of Geography
Carsey School of Public Policy
The University of New Hampshire*

Jennifer Brewer is an Associate Professor in the Department of Geography and Master in Public Policy Faculty in the Carsey School of Public Policy. As a political ecologist, her research focuses on human-environment relations and environmental governance, particularly in marine fisheries. Her research asks how decision processes can simultaneously sustain natural resources and augment public capacities for civic engagement. Her projects have spanned community- and market-based co-management models, incorporating field data collection with qualitative and quantitative analyses. Jennifer holds a doctorate in Human Geography from Clark Graduate School of Geography, a Master of Science in Marine Policy from the University of Maine School of Marine Sciences, and a Bachelor of Arts from the University of Michigan School of Liberal Arts and Sciences. She has also worked at the National Academy of Sciences, US House of Representatives, Alaska Department of Fish and Game, and in the non-profit sector.



*Robin Alden
Founding Executive Director
Maine Center for Coastal
Fisheries (retired)*

Robin Alden has dedicated her career to linking ecological knowledge of fishermen with marine science and effective fisheries policy. She retired in January 2018 from Maine Center for Coastal Fisheries (MCCF) in Stonington, Maine where she was Founding Executive Director. Founded in 2003, its mission is to secure a sustainable future for fisheries and fishing communities in Eastern Maine and beyond. Alden served as Maine Commissioner of Marine Resources under Governor Angus King, where she initiated the Maine lobster zones, an example of fisheries co-management. She also founded, published, and edited the regional trade fishing newspaper, Commercial Fisheries News for 20 years. She cofounded the Maine Fisherman's Forum, served two terms on the New England Fishery Management Council, and worked with Maine Sea Grant. In 2017, Alden received the Peter Benchley Hero of the Seas award for her grassroots work integrating fishermen's knowledge into science and policy and in 2016, was honored as a White House Champion of Change for Sustainable Seafood. She is a 1998 Gulf of Maine Visionary Award recipient. She holds a B.A. in Economics from the University of Maine.



*Dr. Susan A. Kaplan
Director of Peary-MacMillan Arctic
Museum and Arctic Studies Center
Professor of Anthropology
Bowdoin College*

Susan Kaplan, a professor of anthropology and director of the Peary-MacMillan Arctic Museum and Arctic Studies Center at Bowdoin College, is an Arctic anthropologist and archaeologist. Working primarily in Labrador, Canada, she studies prehistoric and historic Inuit responses to environmental change and contact with the West using archaeology, ethnohistory, visual anthropology, and paleoenvironmental data. She studies the history of Arctic exploration using the same investigative tools. Finally, she works with material culture, using museum collections to develop exhibitions for the public and to reach out to the northern communities from which artifacts were collected.



*Tom Shyka
Product and Engagement
Manager
NERACOOS*

Tom Shyka is the Product and Engagement Manager at the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS). Tom works with NERACOOS end users and stakeholders to help educate and communicate about the information and the value NERACOOS provides. In this role, Tom works with NERACOOS end users to understand their information needs and help develop products and services to meet those needs. Tom's work with stakeholders has led to the expansion of the observing system including the development of a Cape Cod PORTS (Physical Oceanographic Real-Time System) that supports safe and efficient navigation. Additionally, Tom has led the communications program at NERACOOS, helping it evolve to integrate new media channels and broaden the outreach. In his previous roles, Tom led the Gulf of Maine Research Institute's Ocean Data Products team, which developed NERACOOS' first web site and data management system. Tom also served as the COO at GoMOOS (Gulf of Maine Ocean Observing System) where he oversaw many aspects of the non-profit including product development, communications, and grants management. Tom was the recipient of a Sea Grant Knauss Marine Policy Fellowship and has also worked as an environmental consultant, a marine ecologist for NOAA's National Marine Sanctuary Program and as an environmental chemist. He received a MS in Marine Estuarine and Environmental Science from the University of Maryland.

Panel 4: Coastal Dynamics, Opportunities and Hazards

(Tuesday, March 26th afternoon)

A central goal of the entire workshop is to identify challenges and opportunities created by Arctic change that extend beyond clear and present threats (e.g., rising seas redefining where the coast is), and consider how possible societal responses may have wide reaching geographic and socio-economic consequences, both intended and unintended. This panel is intended to spark deep and wide ranging discussion about how changes in the Arctic will impact communities on and near the coast, including a discussion of both opportunities and risks resulting from changes currently being observed and changes projected over the next 20-50 years. While the focus includes coastal communities in the Arctic and others around the world, this panel will pay particular attention to coastal areas in the northeast US and eastern Canada. This discussion will help us explore convergent topics that will advance our understanding of how eastern north America should prepare for and respond to these impacts over time.



*Kevin Knuuti
Independent
Consulting Engineer*

Kevin Knuuti is an independent consulting engineer whose work focuses on risk assessment and communication; climate change (sea-level change); datums; and physical processes in coastal, estuarine and fluvial environments. Prior to working as a consulting engineer, Kevin had a career in Army Corps of Engineers with positions that included Technical Director, Cold Regions Research and Engineering Laboratory (Hanover, NH); Chief Engineer, southwestern United States (Sacramento, CA); Research Engineer, Coastal and Hydraulics Laboratory (Vicksburg, MS); and Chief of Water Resources and Coastal Engineering, northern California (San Francisco, CA). During his career in the Army Corps of Engineers, Kevin's work included planning, analysis, design and construction associated with coastal and riverine flood risk reduction; ecosystem restoration; environmental remediation; and infrastructure for Army and Air Force installations. Kevin also led the water level analysis assessment of the post-Hurricane Katrina investigation of Louisiana and Mississippi; was the lead author for the Army Corps of Engineers sea-level rise policy; and has contributed to sea-level rise work for several states and Federal agencies, for the National Climate Assessment, and for the IPCC. Kevin has a bachelor's degree in civil engineering from the United States Military Academy at West Point, master's degrees in civil and environmental engineering from the University of California at Berkeley, and will complete his PhD in civil engineering from Colorado State University this year. He is also an Army combat veteran who retired from the Army as a Colonel.



*Adam Parris
Executive Director
Science and Resilience Institute
Jamaica Bay, NYC*

Adam Parris. Having lived near estuaries all his life, Adam Parris is passionate about positive change where people, waters, and diverse species converge at the coast and about making science more relevant and useful. Currently, he leads the Science and Resilience Institute at Jamaica Bay in New York City, a partnership between governmental, research, and community organizations aimed at improving resilience in the region's coastal waters. Previously, he helped develop the Sea Level Rise Tool for Sandy Recovery, an effort to integrate science on future sea level rise with flood insurance information for rebuilding and recovery efforts. He has been involved in integrating sea level rise information into the coastal planning efforts of a number of Federal agencies, as well as the states of California, Maryland, New York, and New Jersey. From 2010 – 2015, Mr. Parris directed NOAA's Regional Integrated Sciences and Assessments (RISA) program, a national effort to connect science to climate adaptation and preparedness decisions in different regions across the US. He holds a Bachelor's degree in English Literature and Environmental Geology from Bucknell University and a Master of Science in Geology from the University of Vermont.



*Dr. Catherine Ashcraft
Assistant Professor
Department of Natural Resources and the
Environment
Carsey School of Public Policy*

Catherine Ashcraft is an Assistant Professor of Natural Resources and the Environment and Master in Public Policy Faculty of the Carsey School of Public Policy at the University of New Hampshire. She is interested in the human dimensions of ecological systems and focuses on how environmental policies and institutions are negotiated and designed, how they respond to change, and are renegotiated. Her current research projects include adaptive and integrated approaches to flood risk management in Europe and New England, institutions for managing conflict and uncertainty in the Danube and Nile Rivers, and international water diplomacy.



Steve Couture
Administrator
NHDES Coastal Program
NH Dept. of Environmental Services

Steve Couture, MPA, CPM, serves as Coastal Program Administrator for the NH Department of Environmental Services (NHDES) where he oversees the technical assistance services provided to NH's coastal communities as well as providing direction for state coastal policy. He has worked for NHDES for 18 years, with a focus on watershed management policy and implementation, including watershed hazards. Steve previously served for eight years as the NHDES Rivers Coordinator and has represented NHDES on NH's legislatively enacted Flood Study Commission and served as the NHDES alternate on the NH Coastal Risk and Hazards Commission.

Appendix C. Posters (missing several...need to find titles)

Claire Eaton and Catherine M. Ashcraft, The University of New Hampshire **"Science Diplomacy in the Atlantic Arctic: Assessing Potential Expansion of the Distributed Biological Observatory (DBO) to the Baffin Bay-Davis Strait Area."**

Christina Herrick, Martin Wik, Michael W. Palace, Ruth K. Varner, Patrick M. Crill, The University of New Hampshire, **"Using Landsat to relate waterbody surface temperature to greenhouse gas emissions across a subarctic landscape."**

Clarice R. Perryman, Natalie N. Kashi, Carmody M. McCalley, Avni Malhotra, M. Florencia Fahnestock, Julie G. Bryce, Reiner Giesler, Ruth K. Varner, The University of New Hampshire, **"Illuminating Geochemical Correlates of Methane Oxidation Across a Gradient of Permafrost Thaw."**

Jessica DelGreco, Christina Herrick, Kellen McArthur, Ruth Varner, Anthony John Garnello, Daniel Finnelli, Carmody McCalley, Michael W Palace, The University of New Hampshire, **"Four Years of UAS Imagery Reveals Vegetation Change Due to Permafrost Thaw."**

Paige Clarizia, Duc Nguyen, Nathan Cleveland, Andrew Robison, Wilfred Wollheim, David Bastvikeri, Ruth K. Varner, The University of New Hampshire, **"Trace gas emissions from fluvial wetlands in the Ipswich River, Massachusetts."**

Ruth K. Varner, Michael W. Palace, Scott R. Saleska, Benjamin Bolduc, Bobby H Braswell, Patrick Crill, Jeff Chanton, Jessica DelGreco, Jia Deng, Steve Frolking, Chirstina Herrick, Mark E. Hines, L Jamie Lamis, Changsheng Li, Kellen McArthur, Caromdy McCalley, Andreas Persson, Nigel T Roulet, Joanne Shorter, Nathan Torbick, Gene Tyson, Virginia I Rich, The University of New Hampshire, **"From archaea to the atmosphere: scaling methane emissions across a thawing permafrost landscape."**

Kerri D. Seger and Jennifer L. Misksis-Olds, The University of New Hampshire, **"An acoustical survey of odontocetes in the Bering Sea from 2008-2017."**

Appendix D. Participants

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| Robin Alden | Maine Center for Coastal Fisheries |
| Ted Ames | Maine Center for Coastal Fisheries Bowdoin College |
| Catherine Ashcraft | Natural Resources and the Environment, UNH |
| Vidya Balasubramanyam | New Hampshire Coastal Program |
| Paul Arthur Berkman | Science Diplomacy Center, Fletcher School of Law and Diplomacy, Tufts University |
| Julie Hambrook Berkman | Our Spaces |
| Jennifer Brewer | Geography, UNH |
| Julia Bryce | Earth Sciences, UNH |
| Elizabeth Burakowski | Earth Systems Research Center, UNH |
| Sophie Burke | Natural Resources and Earth Systems Science, UNH |
| Jaed Coffin | English, UNH |
| Alix Contosta | Earth Systems Research Center, UNH |
| Zoe Courville | Cold Regions Research and Engineering Laboratory |
| Steve Couture | Administrator, NHDES Coastal Program |
| Brigt Dale | Nordland Research Institute, Norway Brown Institute for Environment and Society |
| William Daniels | University of Massachusetts, Amherst |
| Marcos Del Hierro | English, UNH |
| Mamadou Diallo | California Institute of Technology |
| Jack Dobb | Earth Systems Research Center, UNH |
| Jenn Dijkstra | School of Marine Science and Ocean Engineering, UNH |
| David Divins | School of Marine Science and Ocean Engineering, UNH |
| Katharine Duderstadt | Earth Systems Research Center, UNH |
| Claire Eaton | Natural Resources and the Environment, UNH |
| Jessica Ernakovich | Natural Resources and the Environment, UNH |
| Mark Fahnestock | University of Alaska Fairbanks, Geophysical Institute |
| John Farrell | United States Arctic Research Commission |
| Jennifer Francis | Rutgers |

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| Bradley Franklin | Gulf of Maine Research Institute |
| Sawyer Gardner | Undergraduate Student, UNH |
| Parker Gassett | University of Maine, Marine Policy |
| Maria Girouard | Dawnland Environmental Defense |
| Melissa Gloekler | Coastal Response Research Center, UNH |
| Eli Gould | STIX, L3C |
| Jessica Graybill | Colgate University |
| Breezy Grenier | Sedna Epic |
| Alyssa Hall | Nuka Research and Planning Group |
| Hannah Hamalainen | Dimond Library, UNH |
| Eric Heim | Earth Sciences, UNH |
| Erik Hobbie | Earth Systems Research Center, UNH |
| Larry Hamilton | Sociology, UNH |
| Meghan Howie | Anthropology, UNH |
| Elisabet Idermark | Stockholm University |
| Kim Juniper | Ocean Networks Canada |
| Susan A. Kaplan | Arctic Museum/Arctic Studies, Bowdoin College |
| David Kennedy | NOAA |
| Gail Kezer | Office of US Senator Angus King |
| Nancy Kinner | Civil and Environmental Engineering, UNH |
| Kevin Knuuti | Independent Consulting Engineer |
| Bess Koffman | Colby College |
| Karl Kreutz | Climate Change Institute, The University of Maine |
| Natallia Leuchanka | Natural Resources and Earth Systems Science, UNH |
| Jeff Levine | City of Portland, ME |
| Thomas Lippmann | Center for Coastal and Ocean Mapping, UNH |
| Larry Mayer | School of Marine Science and Ocean Engineering, Center for Coastal and Ocean Mapping, UNH |
| Alexandra Melnyk | Undergraduate Student, UNH |
| Jennifer Miksis-Olds | School of Marine Science and Ocean Engineering, UNH |
| Mark Milutinovich | Research Office, UNH |
| Hannah Munro | Earth Sciences, UNH |

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|------------------------|---|
| Stephen Sam Newell | Passamaquoddy Tribe of Maine |
| Jan Nisbet | Senior Vice Provost for Research, UNH |
| Andrew Ouimette | Earth Systems Research Center, UNH |
| Adam Parris | Science and Resilience Institute, Jamaica Bay, NYC |
| Suellen Peluso | Advancement, UNH |
| Clarice Perryman | Natural Resources and Earth Systems Science, UNH |
| Neal Pettigrew | School of Marine Sciences, University of Maine |
| Rebecca Pincus | US Coast Guard Academy |
| Bonita Pothier | U S Senator Angus S. King, Jr. |
| Jesse Ross | Coastal Response Research Center, UNH |
| Jonathan Rubin | University of Maine |
| Joe Salisbury | Ocean Process Analysis Lab, UNH |
| Rebecca Sanders-DeMott | Natural Resources and the Environment, UNH |
| Kerri Seger | School of Marine Science and Ocean Engineering, UNH |
| Siobhan Senior | English and Women's Studies, UNH |
| Alexander Shiklomanov | Earth Systems Research Center, UNH |
| Tom Shyka | NERACOOS |
| Justine Stadler | EPSCoR |
| Roger Stephenson | Union of Concerned Scientists |
| Robin Tyner | United States Navy USN(ret) |
| Ruth Varner | Earth Systems Research Center, UNH |
| Cameron Wake | Earth Systems Research Center, UNH |
| Zhaojun Wang | University of Delaware |
| David Watters | New Hampshire Senate |
| Alison Watts | Civil and Environmental Engineering, UNH |
| Jingfeng Xiao | Earth Systems Research Center, UNH |

Undergraduate “Junior Facilitators”
UNH Civil Discourse Lab

Ashley Stratton
Brianna Belley
Lucy Klemarczyk
Maria Harmon
Marlo Ellis
Caitlin Magowan
Victoria Gleixner
Jocelyn Vierzen
Becca Barton
Sara Faucher
Julia Bobeck
Eddy White
Megan Ross
Pop Lacey
Katie Holden

Faculty Advisor: Dr. Renee Heath, Department of Communication

Appendix E. Congressional Videos and Letters

United States Senator Angus S. King, Jr

Transcript of Video Address for the event “Preparing for a Northwest Passage
A Workshop on the Role of New England in Navigating the New Arctic”

March 26, 2018
The University of New Hampshire

Good morning.

My introduction to Arctic related issues was literally an immersion. Four years ago this week I was four hundred feet under the ice in the Arctic Ocean on the U.S.S. New Mexico, United States nuclear attack submarine. We'd flown out over the ice to the ICEX experimental station, and the nuclear submarine came up through the ice. We boarded, spent a day and a night on the submarine, and saw the Arctic from a unique perspective -- both above the ice and below it. That was the beginning of an engagement that I've had since I've been here in the Senate with Arctic related issues.

Shortly thereafter, I was going up to the Senate floor following Senator Lisa Murkowski of Alaska. I said Lisa I want to be the Arctic senator, and she said no, you can be the assistant Arctic senator. That day the Senate Arctic caucus was born, and we have members from across the country that realize the strategic, the economic, and the trade implications of the changing Arctic.

Flash forward to today. I saw a headline just in the last couple of days that last week the temperature in the Arctic was sixty degrees above normal. I made a speech on the Senate floor couple of days ago where I had a chart that showed since nineteen seventy nine ice in the Arctic Ocean has decreased by two thirds. This is enormously significant for our country and for the world. The Arctic essentially has been locked up and unavailable to human habitation other than the native people who live up there, but it has generally been inaccessible to the world since virtually all of human history. Now it's suddenly opening up. What does this mean and what are the implications for our country and for the world?

As you know, and as I think you've already learned, there are tremendous climate implications in terms of what happens in the Arctic. There are recent studies that indicate that the warming of the Arctic is having an effect on the storm systems that have been battering the United States over the next several years and the predictions are that's going to continue and perhaps even get worse.

From the point of view of the state of Maine one of the things that interests us is that as trade and commerce go through an increasingly open Arctic Ocean, the United States is a trade destination and Maine possesses the first set of ports that are available for those ships transiting from Asia to the East Coast of the United States. The trip, by the way, is somewhere between five and eight days, perhaps even more, shorter going through the northern pass then through the Panama Canal. Now it's going to be a while. I've heard predictions of twenty to thirty years before the ice is sufficiently clear that that kind of transit will be easy. It's still very challenging, but last year the crystal Serenity, a cruise ship, went through the through the Arctic Ocean, west to east, and I think that's just something that's going to be happening more and more frequently.

So we're talking about trade opportunities. We're talking about the possibility of energy. The challenge with energy of course is that extraction in that very difficult environment is going to be dangerous and threatening to the environment. So that's going to be an issue. And the third issue is strategic. We know that the Russians are in effect militarizing a lot of their share of the Arctic along...I don't know whether to call it north or south...but along their shoreline and they have a great deal of military activity in that area in terms of bases and also shipping. It's a very, very complicated situation. The good news is that thus far this is one of the areas where we are working cooperatively with the rest of the world, including the Russians, in order to try to work through these kinds of issues -- whether it's energy or economics, indigenous people, strategic issues -- to work through those issues in a cooperative and peaceful way. We have international organizations that are in place that are already working on these issues and that's very positive.

But I think the main message I want to share with you today is how important what you're doing is. This I believe is one of the most important regions in the world, especially because of the fact that this is a newly available part of our ocean environment that has simply not been open to human utilization for virtually all of human history. Imagine if you will...it's like discovering the Mediterranean Sea, an important body of water that is bordered by a whole lot of countries. Hopefully we're going to be able to manage this new asset, if you will, for humankind more peacefully than the history of the development of the Mediterranean Sea over the last several thousand years. So a tremendously important subject.

You've pulled together, I know, people from around the world and around the country to discuss these issues, and I want you to know that there are people here in Washington who are thinking about this who are trying to be sure that this is something that's done peacefully, that the opening up of the Arctic can be a positive development and not a negative one for our country and the people of the world. We have a great opportunity here but we need your help. We need the science. We need the data. We need to understand what's going on. We need to understand the relationship of Arctic climate with climate and currents in the Atlantic, for example, and that's where participants in this conference and the good thinking that you're going to be doing can really make a difference.

So congratulations for pulling this together. All the best on the deliberations. And please share what you're learning and what you discover so that we can have the best possible policy down here and we can make good decisions on behalf of the indigenous people, the people of the countries that border the Arctic, but also the people of the United States and the world.

Thanks for what you're doing and congratulations.

United States Senate

WASHINGTON, DC 20510

March 26, 2018

Dear Friends,

Thank you for the invitation to join you for this week's workshop on 'Navigating the New Arctic.' I wish I could be with you as develop partnerships and approaches to address a complex issue: the melting of the Arctic Sea.

The diversity of disciplines here today reveals just how far-reaching the effects of Arctic change can be. It is crucial that we come together to prepare for the impacts of rapid Arctic warming on the coastal regions of New England. To adapt to these changes and take advantage of new possibilities, we need to have a proper understanding of the economic, environmental and social effects and how they influence international trade, coastal ecology, air and water quality, demographics and a variety of other issues. That's why your participation in the *New England Arctic Research Network* is so important. Your collaborative work will give region the information it needs to confront the challenges and capitalize on the new possibilities of an open Arctic.

I hope this workshop sparks lively discussion and a clearer path forward in addressing this important regional concern. Thank you to the University of New Hampshire, the National Science Foundation and all who bring their wisdom, experiences and perspectives to this initiative. I wish you all the best as you continue your good work.

Sincerely,



Jeanne Shaheen
United States Senator

United States Senate

March 25, 2018

Dear Friends,

I regret that I cannot be with you today to welcome you to this important workshop on the changing Arctic climate, and the impact that it will have on New England's climate and economy.

New Hampshire's beautiful natural resources are a treasured and integral part of our way of life and our economy. We are already seeing the real impacts of climate change in our state, and as Arctic ice continues to melt, we will keep seeing changes in our oceans and climate.

Many Granite Staters are concerned about what these impacts – particularly stronger and more frequent storms – will mean for their families, their homes, and their businesses.

We have an imperative to act as we see more extreme natural disasters across the world damaging economies and threatening people and their way of life and we need to help people adapt to these changes and the direct threats that they face. This begins with focusing on efforts like improving our infrastructure and developing resilience strategies to help plan ahead of storms and extreme weather events.

We must also keep working to mitigate climate change, which is why I am continuing to push to cut carbon emissions, conserve and protect our natural resources, and to build a stronger, clean energy future.

I want to thank the UNH Collaborative Research Excellence Institute and the National Science Foundation for sponsoring these conferences and workshops. I look forward to working with you to protect New Hampshire, New England, and the world from climate change.

With every good wish,



Margaret Wood Hassan
United States Senator

Senator David Watters
New Hampshire States Senate

William Wood, in New Englands Prospect, published in 1634, describes a powerful Native leader of the Piscataqua region, “If we may believe the Indians who report of one Passaconaway that he can make the water burn, the rocks move, the trees dance, metamorphize himself into a flaming man.” Our modern Passaconaways with the magic of CO₂, have given us warming waters, coastal storms, extreme winds, and a carbonized society. We now face consequences and a new New England prospect with the coming ice-free Arctic and rapid ice-cap decline.

As a legislator, I have been concerned with planning for these changes and with the capacity of our political system to cope with them. Four years ago, my legislation created the Coastal Risk and Hazards Commission, which reported on sea level rise and extreme precipitation. My legislation created a commission on ocean acidification and emerging environmental threats in the Great Bay and coastal waters. As New Hampshire’s legislative commissioner on the Atlantic States Marine Fisheries Commission, I am concerned with changing ocean temperature, acidity, and currents, in part related to changes in the Arctic region. As a member of the Senate Transportation Committee, which legislates the NH Ten Year transportation plan, issues of sea-level rise may outstrip our capacity to plan and fund the coastal transportation system, or account for the potential of increased container shipping. A recommendation of the CRHC was a bill to task relevant state agencies to review existing statutes, rules, and practices in light of its projections. Another bill passed last year enabled municipalities to use the local tax code to encourage mitigation for sea level rise and to create Coastal Resilience Incentive Zones (C-RIZ) to address large changes, such as coastal retreat.

There is also the potential of disruption to fisheries by increased shipping, and environmental concerns over possible oil spills related to tankers (the oil spill in the Piscataqua some 35 years ago is a foretaste of impacts). Changes in the Arctic climate will accelerate local impacts. The process of establishing the Coastal Risk and Hazards Commission revealed how difficult it was to overcome political/ideological positions on climate change, but the resulting report gives hope for bipartisan, multi-level governmental action. However, the report also reveals the limitations of cooperation among municipalities, county and regional planning groups, state agencies and the legislature, and the Federal government.

Here are a few issues for research:

- How will an open Arctic intensify coastal storms, and how can governments respond?
- How will the concentration of fresh water off of Greenland’s melting ice cap affect the Atlantic overturning, and how will this impact the Gulf of Maine and its fisheries?
- How will the continuing northern migration of Gulf of Maine fish species impact the fishing industry in Maine, and how will national and international regulator create a regime for Arctic fisheries?
- What might be the impact on New England, due to wind currents, of smoke and soot deposition from large-scale fires in tundra and peat in the Arctic region?
- How will climate and ocean researchers incorporate cultural systems in projecting the impacts of climate change, since the dynamic of cultural production, including landscapes, historical preservation, modes of memory, values, and arts, will be profoundly affected?
- How will cultural systems be engaged for societies and political subdivisions to respond to climate change?
- How can New England’s past engagement with the Arctic, from polar exploration, shipping, whaling, fur trading, art, and literature, from the 17th to the early 20th centuries, be used as a framework for understanding how the region will respond to a new Arctic?

Appendix F. Round-Table Guidelines

Introduction: Identify rapporteurs, facilitators, and notetakers at each table. Review Goals, Objective, Groundrules, and Logistics:

1. Everyone's perspective is valuable
2. Everyone has a chance to speak. Be concise.
3. Only one person speaks at a time
4. There are no bad ideas
5. The goal is convergence of our best research ideas

Logistics

- Banquet tables of 8 (anticipate 7-8 tables...but 9-10 will be available)
- Flip-charts available for facilitators; Notetakers asked to use computer
- Facilitator (student and/or Arctic Working Group member)
- Rapporteur (Arctic Working Group member)
- Notetaker (graduate student or UNH recruit) at each table
- Table-tent with groundrules. Sheet on table with Main 3 Questions
- 40 minute discussion, 5 minutes reciting big ideas

Facilitators/Rapporteur (might be same person if no student facilitator)

- Facilitator Introduction
 - Welcome.
 - Identify Rapporteur (Arctic Working Group leader)
 - Identify Notetaker– who will capture all details
 - Point to Groundrules (listed on “table tents”)
 - Remind everyone of 3 main questions (on screen, table handout, and in folders)
 - 40 minutes for discussion.
 - Rapporteur will briefly recite 1-2 main ideas (in depth discussion at end of day).
- Role of Facilitator
 - Make sure everyone is clear on instructions and has met each other
 - Keep group focused on the three main questions
 - Provide everyone an opportunity to speak
 - Refer to information in folders or pull in a panelist/expert to answer questions
 - *Ensure 1-2 big ideas are achieved by end of 40 minutes*
- Role of Rapporteur (UNH Arctic Working Group Member)
 - Participate in group discussion and listen for top 1-2 ideas.
 - Recommendations for future research priorities for convergent research linking Arctic change and New England.
 - Let student facilitator (if present) and note-takers “do their job”
 - But help clarify issues involving content and keep discussion focused on convergence research
 - Identify and clarify wording of top 1-2 big ideas and type into shared Google Doc (or give to Kathy to type in)
 - *Read* (don't elaborate on) 1-2 big ideas to audience at end of discussion
 - Will be discussed in detail at end of day

Notetakers

- Captured details (on computer) to use in workshop product development and follow-up
 - also captured and projected on live Twitter feed
 - Important for specific research ideas – tools, methods, networks, etc.
 - Note: A major objective from our proposal is to assess future observational, data, and modeling needs for the region...so we need these details!
- Use Secondary Questions as guide for what to record.

General Questions

Main Synthesizing Questions

(main drivers of discussion for reporting back to larger group)

1. What are some examples of existing and new convergence research projects that come to mind based on the panel discussion?
2. How do these convergence research topics relate to broader societal impact and solutions?
3. What currently exists or is emerging in your field that can contribute to convergence research on these topics (methods, techniques, programs, individuals, groups, tools)?

Secondary Questions

(captured by notetakers for workshop report)

Vision:

- What is going to happen in NE as a result of Arctic Change?
- What are the emergent technologies, emergent challenges, emergent solutions? (e.g., autonomous sensors).

Network (identify interest in New England Research Network):

- How does your expertise contribute to a convergence research idea?
- Who (individuals or groups) should also be included in the discussion around a proposed convergence research topic?
- What networks already exist that can be tapped into? (Including international networks)
- How can cyberinfrastructure (networking, people, data, computational resources, and associated skill sets) help promote convergence?

Existing capacity:

- Modifications to traditional observational networks and research initiatives that will be necessary to detect and respond to emergent problems
- Observations and indicators required to prepare for, adapt to, and capitalize on economic, environmental, and social impacts.

Specific Panel Questions

Panel #1 – Convergence Research

1. *Brief Introductions - Who are you and what do you hope to get out of this workshop? (1 min each)*
2. *Visions of future scenarios -- What will New England, the Gulf of Maine, and the Western North Atlantic Ocean look like as the Arctic changes over the next several decades?*
3. *Which questions or societal problems linking Arctic change and New England necessitate convergent approaches?*

Panel #2 -- Infrastructure and Transportation

1. *What are some existing or new convergence research ideas that come to mind based on the discussion of transportation and infrastructure?*
2. *How do these convergence research topics relate to broader societal impacts and solutions?*
3. *What currently exists or is emerging in your field that can contribute to convergence research on transportation and infrastructure (methods, techniques, programs, individuals, groups, tools)?*

Panel #3 – Living Resources

1. *What are some existing or new convergence research ideas that come to mind based on the discussion of living resources and indigenous communities?*
2. *How do these convergence research topics relate to broader societal impacts and solutions?*
3. *What currently exists or is emerging in your field that can contribute to convergence research of living resources (methods, techniques, programs, individuals, groups, tools)?*

Panel #4 – Coastal Dynamics

1. *What are some existing or new convergence research ideas that come to mind based on the discussion Coastal Dynamics?*
2. *How do these convergence research topics relate to broader societal impacts and solutions?*
3. *What currently exists or is emerging in your field that can contribute to convergence research of coastal dynamics (methods, techniques, programs, individuals, groups, tools)?*

Appendix G. NSF NNA 2018 DCL

The following recommended research topics address some of the priorities outline in the 22 February 2018 NSF Navigating the New Arctic Dear Colleague Letter:

1. Innovative cyber-physical observing systems and data protocols for knowledge and information transfer between New England and Arctic communities on a variety of social, environmental, and technology issues, with particular urgency to prepare for oil spills and shipping accidents.
2. Identify what new materials, technologies, and smart sensors (in social, physical, life sciences) can help adapt infrastructure (roads, ports, telecommunications, buildings) to Arctic change, including thawing permafrost, sea level rise, eroding coastlines, changes to atmospheric and ocean circulation, and economic development.
3. Develop integrated models to better anticipate and prepare for unexpected and abrupt responses of ecosystems to changing climate, northward shifts of species ranges, and human exploitation of natural and biotic resources. What types of risk assessment models can bring social, physical, and life science together to inform decision-making on both local and regional scales?
4. Increasing diversity among leaders in Arctic studies and enhancing STEM education about the Arctic and within the Arctic. This includes increasing teaching and learning of local and traditional knowledge in academia, attracting and retaining STEM scholars from coastal and indigenous communities with a vested interest in the problems researchers are striving to solve.
5. Explore what coastal and indigenous people in New England envision for their future with regard to economic impacts across the North Atlantic Arctic region and projected changes in trans-Arctic shipping, tourism, fisheries, and resource extraction. Find out community concerns, problems, values, and cultural practices to frame initial research agendas aimed at co-production of knowledge, seeking solutions, and providing viable options for decision-makers.

Appendix H. NSF's 10 Big Ideas

The following convergence research topics have the potential for developing future partnerships with other projects associated with NSF's 10 Big Ideas.

Harnessing the Data Revolution (HDR)

1. Determine the critical data needed to track social and ecological impacts of the changing Arctic. What is missing? What analysis methods will be most useful with these large dataset (e.g., statistical analysis, machine learning, social network analysis)? How can qualitative research be integrated into this analysis?
2. Compiling a central database to aide in the response to oil spills and shipping accidents off the East Coast of North America.
3. New cyberinfrastructure and data protocols for knowledge and information transfer between New England and Arctic communities on a variety of social, environmental, and technology issues. How to use social infrastructure and social media to enhance knowledge transfer, including new paradigms for monitoring networks using technologies such as Skype, Twitter, and Facebook. It would be useful to have a database of existing communications networks, such as how local residents share and receive information.
4. Overlay permafrost data with coastal erosion, carbon and water cycles, and other hazards to quantify risks, including infrastructure stability and impacts on transportation. Developing new methods for using remote sensing to identify ideal locations for new coastal infrastructure. Determine how smart infrastructure can provide ancillary data collection opportunities, such as continuous monitoring of environmental change.
5. Merge existing databases on sea ice, icebergs, ship traffic, and marine species (all trophic levels) in preparation for new models capable of forecasting impacts of Arctic change and anticipate future conflicts.

The Future of Work at the Human-Technology Frontier (FW-HTF)

1. Human-technology interactions in cold, dark, remote environments, including collaborations among scientists, healthcare providers, and educators with Arctic communities.
2. Explore cutting-edge technologies (e.g., autonomous sensors and IoT) to help fishermen manage changing fisheries from New England to the Arctic in ways that are socially, economically, and environmentally sustainable. Which of these tools can help shipping companies and oil and mining industries coordinate their activities with local indigenous hunters? Will internet connectivity enable distant fishing villages to collaborate with each other and share knowledge?
3. Determine how human interaction with smart infrastructure and smart sensors can improve the safety and efficiency of workers in various sectors as they adapt to Arctic change? What are best practices for introducing new technologies to Arctic communities?
4. Study how machine learning and artificial intelligence can improve risk assessments associated with the hazards of Arctic change, including sea level rise. Can human-technology interactions advance environmental and social justice issues?
5. Develop new technologies to help train first responders for search and rescue in North Atlantic Arctic and as well as train inexperienced eco-tourists and their guides. Can robots help perform search and rescue tasks in remote, difficult to reach Arctic environments?

Windows on the Universe (WoU): The Era of Multi-messenger Astrophysics

1. Conduct new astrophysical and space science observations in the high magnetic latitude, Arctic regions, including telescopes, neutron monitors, magnetometers, rocket launches, and balloon observations. What are best practices for communicating to local communities (esp. indigenous Arctic communities) the discoveries and conclusions from scientific observations conducted on, or launched from, their lands?
2. Learn about the history of astronomical events impacting Earth through ice core and geological paleoclimate data (e.g., cosmogenic isotopes).
3. Innovative networks of ground-based (or underground) magnetometers with community involvement and citizen science.

Understanding the Rules of Life (URoL): Predicting Phenotype

1. Studies involving unexpected, uncertain, and abrupt responses of ecosystems to changing climate, ecosystem interactions, and human exploitation as a result of Arctic change.
2. Observational initiatives studying trends in terrestrial pathogens and invasive species as a result of Arctic amplification, including the impact on human health of “zombie” pathogens and toxins from melting glaciers and thawing permafrost re-entering ecosystems in the Arctic?
3. Methods to proactively preserve paleo-environmental Arctic sites, enabling the study of environmental changes in the Arctic now and throughout history that impact phenotype and phenology, northward migration, and population genetics.

The Quantum Leap (QL): Leading the Next Quantum Revolution

1. New quantum materials and quantum communication methods that improve the resilience of Arctic civil infrastructure (roads, ports, telecommunications, buildings) to thawing permafrost, sea level rise, and eroding coastlines.
2. Enabling communication among swarms of remote sensors (ocean gliders, drones, CubeSats), and coordination of in situ sensors.

NSF 2026

1. Use input from the New England Arctic Network to identify new fields of research (both Arctic and non-Arctic) that do not fit into NSF’s current programs.
2. Capture ideas from critical stakeholders about new opportunities for scientific research beyond Arctic issues.
3. Identify gaps in knowledge and needs of coastal communities not emphasized in NSF’s current programs, including the NSF Coastlines and People (CoPe) initiative

NSF Includes

1. Increasing diversity among leaders in Arctic studies and enhancing STEM education about the Arctic and within the Arctic. This includes increasing teaching and learning of local and traditional knowledge in academia, attracting and retaining STEM scholars from coastal and indigenous communities with a vested interest in the problems researchers are striving to solve.
2. Studies of how an equitable distribution of economic benefits and empowerment of local communities through new Arctic opportunities in shipping, resources extraction, and tourism can improve access to STEM education and STEM job opportunities.
3. Developing methods of improving curricula in education and workforce training in order to prepare society to better assess risk and uncertainty, skills that will fortify lower socio-economic and minorities populations against the dangers and hazards associated with Arctic change (especially indigenous communities and their lands).
4. Determining how convergence methods that reach across both STEM and non-STEM disciplines can broaden participation in a New England Arctic Network and entice more people from underrepresented groups to participate in STEM fields and Arctic leadership.
5. Exploring what coastal and indigenous people envision for their future. Determine how local community concerns, problems, values, cultural practices, and indigenous voices can help create scientific research agendas aimed at finding solutions and providing viable options for decision-makers.

Mid-scale Research Infrastructure

1. Infrastructure necessary for data transfer and real-time sharing of pan-Arctic observation and modeling data with operators, stakeholders, and communities, including smart sensors and cyberinfrastructure. This capability is particularly critical for oil spill response and search and rescue.
2. In situ observational solutions (e.g., buoy networks, autonomous or remotely operated underwater vehicles, acoustic sensors) to fill critical data gaps between the Gulf of Maine and Newfoundland in order to understand how ocean circulation, salinity, and nutrient loading will change due to Arctic ice melt, and impact biological productivity and fisheries.
3. Expansion of the Distributed Biological Observatory into the North Atlantic Arctic.
4. Novel opportunities for sea level, coastal bathymetry and erosion, and ocean chemistry measurements including in situ sensors and instruments on CubeSats, drones, autonomous gliders, and hydrographic sensors involving marine life.
5. Research infrastructure needs for New England to serve as an "outdoor laboratory" for testing new technologies for withstanding extreme Arctic conditions.

Appendix I. Acronyms and Terms

| | |
|---------|---|
| AICP | American Institute of Certified Planners |
| AIRMAP | Atmospheric Investigation, Regional Modeling, Analysis and Prediction |
| AON | Arctic Observing Network |
| APA | American Planning Association |
| ASIAQ | The Arctic Science Integration Quest |
| AVHRR | Advanced Very High Resolution Radiometer |
| BBOS | Baffin Bay Observing System |
| C-FAR | Community Fisheries Action Roundtable |
| C-RiSe | Climate Risk in the Seacoast |
| CALTECH | California Institute of Technology |
| CANUS | Canada-United States |
| CASP | Center for Arctic Study and Policy (US Coast Guard Academy) |
| CAW | Coastal Adaptation Workgroup (NH) |
| CCOM | Center for Coastal and Ocean Mapping (UNH) |
| CKTS | Convergence of Knowledge, Technology, and Society |
| COO | Chief Operating Officer |
| CoRE | Collaborative Research Excellence Initiative (UNH) |
| CRREL | Cold Regions Research Lab |
| DBO | Distributed Biological Observatory |
| DCL | Dear Colleague Letter |
| EEWS | Energy, Environment, Water and Sustainability |
| EPSCoR | Established Program to Stimulate Competitive Research |
| ERG | Environmental Research Group |
| FRAM | FRontiers in Arctic marine Monitoring |
| GoM | Gulf of Maine |
| GoMOOS | Gulf of Maine Ocean Observing System |
| GLOBE | Global Learning and Observations to Benefit the Environment |
| IARPC | Interagency Arctic Research Policy Committee |
| ICARTT | International Consortium for Atmospheric Research on Transport and Transformation |
| IMT | International Marine Terminal (Portland) |
| IOOS | Integrated Ocean Observing System |
| IoT | Internet of Things |
| IPCC | Intergovernmental Panel of Climate Change |
| KAIST | Korea Advanced Institute of Science & Technology |
| LNG | Liquefied Natural Gas |
| MCCF | Maine Center for Coastal Fisheries |
| MDA | Maritime Domain Awareness |
| MEOPAR | Marine Environmental Observation, Prediction and Response Network |

| | |
|-----------|--|
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NAAN | North Atlantic Arctic Network |
| NAP | National Academies Press |
| NASA | National Aeronautics and Space Administration |
| NARE | North Atlantic Regional Experiment |
| NATO | North Atlantic Treaty Organization |
| NEAN | New England Arctic Network |
| NEOSEC | New England Ocean Science Education Collaborative |
| NEPTUNE | North-East Pacific Time-series Undersea Networked Experiments |
| NERACOOS | Northeastern Regional Association of Coastal Ocean Observing Systems |
| NHDES | New Hampshire Department of Environmental Services |
| NNA | Navigating the New Arctic |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | National Research Council |
| NSF | National Science Foundation |
| NWS | National Weather Service |
| NYC | New York City |
| PacMARS | Pacific Marine Arctic Regional Synthesis |
| PORTS | North-East Pacific Time-series Undersea Networked Experiments |
| REACH | Reconciliation-Engagement-Advocacy-Change-Healing |
| RISA | Regional Integrated Sciences and Assessments |
| SAO | Senior Arctic Officials (Arctic Council) |
| SAR | Search and Rescue |
| SEARCH | Study of Environmental Arctic Change |
| SeaWiFS | Sea-Viewing Wide Field-of-View Sensor |
| STEM | Science, Technology, Engineering, and Math |
| SWERUS-C3 | Swedish-Russian-US Climate-Cryosphere-Carbon |
| UNH | The University of New Hampshire |
| UMOOS | University of Maine Ocean Observing System |
| USACE | United States Army Corps of Engineers |
| USARC | United States Arctic Research Commission |
| UVic | University of Victoria |