Sub-theme 1. The need for Observing System.
Sub-theme 2. Implementing and Optimizing a Pan-Arctic Observing System

MONITORING THE ARCTIC ACOUSTIC ENVIRONMENTS

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Abstract—Marine ecosystems are increasingly affected by underwater sounds. Growing scientific and societal concerns have led to several international initiatives to measure the environmental impact of ocean noise at a variety of spatial and temporal scales. The following statements are formulated around the terms of reference of the International Quiet Ocean Experiment (IQOE) for its working group on Arctic Acoustic Environments. It addresses knowledge gaps in long-term trends in soundscape characteristics, research priorities (transnational programs, equipment/infrastructure sharing), and other issues such as long-term data archiving and data access policies.

INTRODUCTION

The northern high-latitude regions, including the Arctic Ocean, are becoming increasingly important as a result of global warming and their growing economic and political interests. Sea ice reduction is facilitating resource exploration, marine transport and other economic activities in the regions. Warming waters lead to shifts in marine ecosystems and in soundscapes.

Exploitation of resources in the Arctic is expected to grow in the coming decades, offering new opportunities for marine and maritime industries. For example, the Barents Sea is the most important fishery area in Europe, and because of global warming there is a large potential for increased exploitation of living marine resources in the Arctic seas. Other regions, including the Northern Sea Route, will see increasing shipping, in particular from the Chinese One Belt One Road Initiative, and Russia aims to open the Bering Strait for large tankers. Due to the expected increase in exploitation of the Arctic marine resources, it is expected that ambient noise levels will increase in the Arctic in the coming years.

ACOUSTIC POLLUTION OF THE ARCTIC OCEAN AND SEAS

Ambient noise in the ocean is recognized as a pressing environmental and societal concern; the European Union uses it as one of its key descriptors of Good Environmental Status, as defined in the 2014 Marine Strategy Framework Directive (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010D0477(01)&from=EN). Shipping levels have already increased ambient noise underwater by 12 dB relative to 1960s levels in other parts of the world (e.g., Hildebrand, 2009), and similar effects can be expected in the Arctic region (e.g. Blondel et al., 2015). Other sources of human-generated sounds already include seismic exploration, either for delineation of Exclusive Economic Zones or for resource mapping (e.g., Geyer et al. 2016; Blackwell et al., 2015). These sounds, observed at frequencies of 10–200 Hz, can be detected as far as 1,400 km from the actual surveys, and are predicted to become louder as the Arctic Ocean warms up. Increased tourism, from large vessels and small craft, will increase sound levels both at lower frequencies (e.g., the 63 Hz and 125 Hz used by the European Marine Strategy Framework Directive for assessing noise pollution from shipping (MSFD, 2014)) and at higher frequencies, particularly in coastal waters (e.g., Stafford, 2013). Resource extraction, with drilling and large offshore structures, will contribute to the ambient noise. Increased naval activity by neighbouring countries might also add to the general acoustic budget. Evidence-based monitoring and management of the Arctic environments requires a diversity of baseline measurements of different acoustic metrics, for noise pollution and as proxies for other processes, and a good physical grounding of current and expected changes.

INTERNATIONAL COLLABORATIONS AND IQOE

Several actors, academic, governmental and commercial, are already collecting passive acoustic data in the many marine environments making the Arctic region, but the different activities are not coordinated and communication is not very developed. It is therefore imperative to increase collaboration in the Arctic in order to obtain a better knowledge of current noise status and more coordinated observing programs in this harsh environment. This is the goal of the International Quite Ocean Experiment (http://iqoe.org/), which has established a working group on the Arctic Acoustic Environment. This working group aims to produce an acoustic baseline against which future sound increases can be compared. There is a lack of consistent data management and data-access policies for scientists and data centers in the field of passive acoustics, and IQOE has established a working group to improve collaboration within this field. Furthermore, standardization of experimental protocols and observational techniques, and calibration of instrumentation (such as acoustic recorders) are essential to enable comparison of results. Another IQOE working group will aim to recommend best practices for experiments, observation, reporting, and other means to ensure that results are comparable and can be integrated to standardize data across large spatial and long-time scales.

FINAL STATEMENT

The IQOE Working Group on “Arctic Acoustic Environments” hopes to get the approval and support from AOS 2018 for its work on conducting the following activities:

- Identify locations of existing acoustic receivers in the Arctic Ocean
- Identify potential sources of historic acoustic data from the Arctic Ocean
- Inform the IQOE Data Management and Standardization working groups of historic and current data sources in the Arctic Ocean
- Compile existing acoustic data to determine whether time series showing evolution and future trends of relevant acoustic metrics can be created and report to Data Management and Data Access WGs
- Create a synthesis of research papers and state-of-the-art knowledge on the effects of sound on organisms in the Arctic Ocean
- Identify data/research conducted on the effects of permafrost and gas-saturated sediments on Arctic Ocean soundscapes
- Identify an ideal receiver array (location, number of receivers, types of receivers) to observe the baseline acoustic environment for the Arctic Ocean
- Identify ongoing going and planned experiments for which passive acoustics are planned or could be added
- Conduct/Support endorsement processes for passive acoustic projects with the Arctic Council

REFERENCES

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, D. Mathias, K.H. Kim, C.R. Jr. Greene, A.M. Macrander, "Effects of Airgun Sounds on Bowhead Whale Calling Rates: Evidence for Two Behavioral Thresholds", PLOS One, 10(6):e0125720, doi: 10.1371/journal.pone.0125720, 2015

Blondel, P., Sagen, H., Martin, B., Pettit, E.C., Tegowski, J., Thodes, A., Tollefsen, D. and Worcester, P.; "Report of the Polar Session, Oceanoise2015", Vilanova i la Geltrú, Barcelona, Spain, 10-15 May. (Editors Michel André & Peter Sigray), http://oceanoise2015.com/?page_id=789, 2015

Geyer, F., Sagen, H., Hope, G., Babiker, M., Worcester, P. F., Identification a quantification of soundscape components in the Marginal Ice Zone, Journal of Acoustical Society of America 139, 4, 2016

Hildebrand, J. A., Anthropogenic and natural sources of ambient noise in the ocean, Marine Ecology Progress Series, 395, 5-20, 2009

Stafford, K., "Anthropogenic sound and marine mammals in the Arctic: increases in man-made noises pose new challenges", The Pew Charitable Trust, 20 pp., http://ww.oceansnorth.us, 2013

Coastal sea ice: a case study in observing system analysis

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A study of coastal sea ice conditions highlighted both certain gaps in the Arctic Observing system and the potential for different types of observational techniques to fill in those needs.

Motivating problem:

In preparation for a Fall 2017 field campaign based around freeze-up near Utqiagvik (formerly Barrow), Alaska, our research group was having a hard time finding information on the timing of sea ice formation in the region. Questions regarding freeze-up dates, the stability of the initial ice cover, and the frequency of open water events were critical to our planning purposes, and the lack of available observations to address these questions highlighted specific gaps in the observational system.

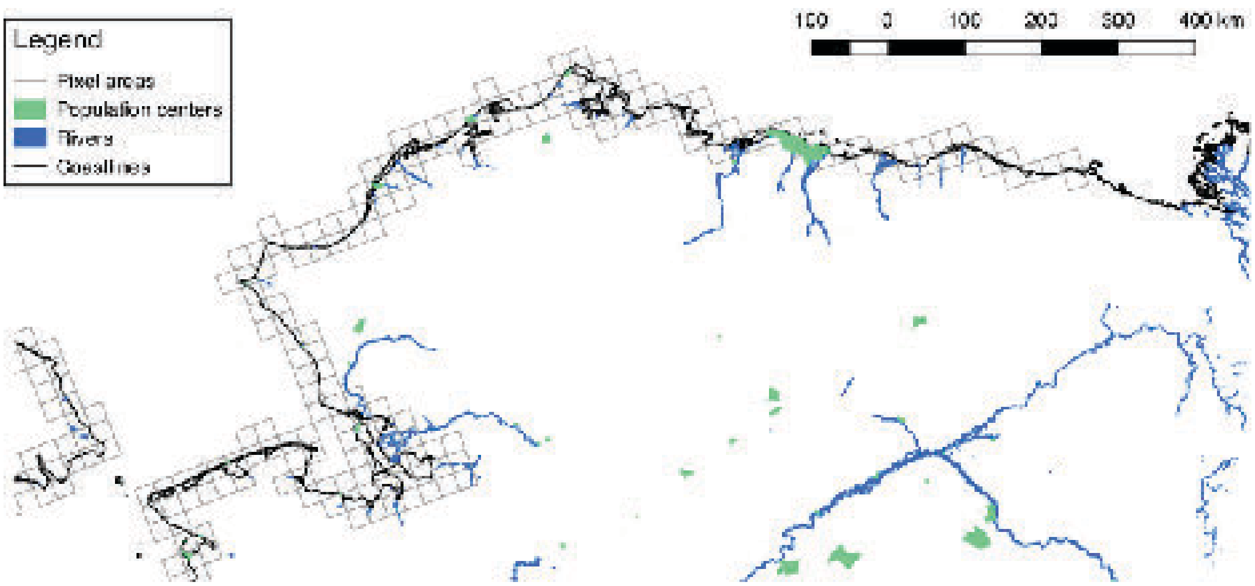
General concept:

While little of the Arctic can be said to be throughly monitored, some locations, seasons, and conditions are better monitored than others. Investing in platforms to fill in existing gaps in the observation network is necessary to improving the overall observational system. Remote sensing resources offer remarkable geographic coverage and often frequent temporal repeat, but have physical limitations that mean that certain locations and certain times of year are not well studied. Just as the IceBridge campaigns provide some continuity between satellite operations, well-placed observational systems can bridge gaps between remote sensing approaches across geography and season. The approach used in this case study illustrates how complimentary observational techniques can fill gaps in the observing system, leveraging available resources and opportunities to better understand the changing Arctic environment. An optimized Arctic Observing System will place special care to identify observing needs around the edges of the scope of remote sensing and in situ observational platforms and strategically fill those gaps wherever possible.

Observing system analysis:

To address the question regarding historical timing of freeze-up in the area surrounding the field sites, we first accessed remote sensing data. Passive microwave sea ice extent datasets, which provide daily repeat frequency in the Arctic, have been used to study freeze-up timing in the central Arctic [Stroeve 2014]. Unfortunately, these retrievals are undefined near shorelines [Cavalieri 1996], leaving a line of missing pixels surrounding the areas of interest. Visible imagery is particularly limited during the freeze-up season, when lack of sunlight and frequent cloud cover make for few images between October and February [e.g., Hall 2015]. SAR satellite coverage is extremely limited, though the extant data is of high spatial resolution and extends right up to shore.

Figure 1 shows a map of the northern Alaska coastline, with major rivers and population centers noted in blue and green respectively. Coastal pixel areas are shown in gray boxes, dividing space between the pixel centers evenly to define the grid [Maslanik 2004]. These pixels contain both a non-zero area of land and a non-zero area of ocean, and are therefore undefined in the passive-microwave sea ice extent records. These areas are a particular challenge to observe, especially in the winter season when visible imagery is unavailable to supplement the lower-resolution passive microwave retrievals. These areas include a number of shoreline types, including river outlets, permafrost bluffs, and rocky cliffs. Sea ice is an integral part of the ecosystem, but without better data regarding the presence of ice in these areas, the research on coastal ice interactions is limited. Population centers are marked in green, which are both locations where reliable sea ice extent information would be most



valuable for human activity and locations that would be easiest to gather additional information.

Because the area of interest for our study was near Utqiagvik (formerly Barrow), Alaska, the research questions could be addressed using a combination of archived webcam images (http://seaice.alaska.edu/gi/observatories/barrow_webcam) shore-based sea ice radar (http://seaice.alaska.edu/gi/observatories/barrow_radar), and local records of ice conditions archived through the ELOKA (eloka-arctic.org). These resources proved invaluable to working around an observation bias towards clear days that resulted in working from the limited visible imagery.

Known observing system needs and opportunities:
Coastal sea ice remains under-observed, especially in the freeze-up season where darkness and persistent cloud cover obscures satellite-based visible imagery. While in-situ assets are difficult to maintain in remote locations, strategic placement of several sea ice observing stations would extend the sea ice extent record to the shoreline. Communities along the Arctic coastline reduce the logistical cost of these investments, as even simple notes of sea ice conditions near shore dramatically improve the available information on the subject. Investing in training and compensating local reporters, and supplementing their notes with a few webcams and/or sea ice radars at locations with regionally representative sea ice conditions, would go a long ways towards improving the observing system's coverage of a scientifically, economically, and ecologically dynamic environment.

References:
Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. J. Zwally. 1996, updated yearly. *Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/8GQ8LZQVL0VL

Hall, D. K. and G. A. Riggs. 2015. *MODIS/Aqua Sea Ice Extent 5-Min L2 Swath 1km, Version 6*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/MODIS/MYD29.006.

Stroeve, J. C., Markus, T., Boisvert, L., Miller, J., & Barrett, A. 2014. Changes in Arctic melt season and implications for sea ice loss. *Geophysical Research Letters*, *41*(4), 1216-1225.

Maslanik, J. and J. Stroeve. 2004, updated 2017. *DMSP SSM/I-SSMIS Daily Polar Gridded Brightness Temperatures, User guide*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/AN9AI8EO7PX0.

ARCTIC GOOS

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The Arctic Observing Summit is invited to endorse and promote the idea to establish a Regional alliance for the Arctic Ocean – an Arctic GOOS under the UNESCO/IOC led Global Ocean Observing System (GOOS) with the goal to ensure a sustained fit-for purpose ocean observing system in the Arctic Ocean.

The rapid transformations occurring in the Arctic are affecting the entire Earth system, including its climate and weather extremes, through increased temperatures and the continuing loss of ice, glaciers, snow and permafrost. New economic interests in the Arctic have established the region as a larger player in the global economy, but also with very significant local effects. In spite of rapid environmental and social change, the Arctic remains a region of geopolitical stability that is a pre-condition for sustaining Arctic research. Changes in the Arctic are challenging our understanding of their consequences and our ability to provide knowledge for decision-makers. It is critical to anticipate changes in the Arctic rather than respond to them, but to do this requires sustained observations and improved understanding of local, regional and global processes. These research and operational service challenges must be addressed in a coordinated and timely manner to ensure sustainable development and resilient Arctic communities and ecosystems. Understanding the vulnerability and resilience of Arctic environments and societies requires increased international cooperation, including contributions from non-Arctic states. The Global Ocean Observing System (GOOS) is well-suited to foster such international cooperation and coordination regarding ocean observations and operational service provision.

GOOS is a permanent global system for observations, modelling and analysis of marine and ocean variables to support a better understanding of ocean climate and ecosystems, as well as human impacts and vulnerabilities. In this context GOOS coordinates observations around the global ocean for three critical themes:

- **Climate** - a changing climate is linked to a changing ocean. Warming results in land and sea ice melt, and increased carbon uptake is causing ocean acidification, both at alarming rates. The accurate modeling of global climate change and variability, and the monitoring of impacts of climate change mitigation programs, require sustained and extended observations, including those in the deep ocean and in remote regions.
- **Ocean Health** - the global ocean offers a variety of social, economic, cultural and environmental benefits to human livelihoods. Scientific evidence shows that ocean health, measured in terms of productivity, species diversity and resilience, is both impacted by and a threat to human activities. GOOS contributes to the ocean health theme by facilitating ocean monitoring for the conservation of biodiversity and the maintenance of sustainable ocean ecosystem services.
- **Real-time Services -** Real-time ocean data services provide improved weather forecasts and early warning for ocean-related hazards at the coast. This enhances the safety and efficiency of all ocean industries strengthening the global maritime economy. Societies and economies also benefit from this near-term ocean and climate information, such as El Niño forecasts, that are essential to global agriculture, water management, and disaster risk reduction.

These themes correspond to the GOOS mandate to contribute to the UN Framework Convention on climate change, the UN convention on biodiversity and the IOC/WMO mandates to provide operational ocean services, respectively.

GOOS is organised in GOOS Regional Alliances (GRA's) – the GRA's promote implementation of GOOS, both regionally and globally, adapt existing observing systems and integrate them into a common system, survey the users to determine their needs, and increase awareness, build support and develop capacity. At present 13 GRA's exist but none for the Arctic Ocean.

EuroGOOS has over the past 20 years established a coordinated ocean observation effort in the European part of the Arctic Ocean via its Arctic Regional Operational Oceanographic System (Arctic ROOS). Due to the Challenges in the Arctic as described above it has however become clear to us that international cooperation and coordination for the entire Arctic Ocean is needed. EuroGOOS therefore have taken the initiative to start a dialog within IOC on the idea of establishing a GOOS Regional Alliance for the Arctic – **Arctic GOOS**.

Arctic Futures 2050; Advancing Arctic Observing in an Open Science/Policy meeting

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The U.S. Study of Environmental Arctic Change (SEARCH) in collaboration with partners will convene an open science and policy meeting in 2019. Like the SEARCH Open Science Meeting in 2003, the State of the Arctic Meeting in 2010, and the AON Open Science Meeting in 2015, *Arctic Futures 2050* is intended to identify future directions for Arctic observing and research. Like the previous meetings, *Arctic Futures 2050*, will bring together scientists to share the latest understanding and emerging science concerning environmental change in the Arctic. *Arctic Futures 2050*, however, will go further in identifying future research directions by expanding participation to include policy-makers. The goal is to inform policy with science, and doing so effectively will require lasting collaborations between researchers and policy-makers. Policy-makers will be active participants in the meeting to ensure that research intended to inform policy is framed and executed to maximize its utility. Active collaboration by scientists and policy makers will be required to identify and prioritize actionable research. This approach is part of a broader SEARCH initiative to establish a community of practice that can help guide and prioritize research directions.

The challenge of designing research to meet society's needs is not unique to the Arctic or environmental studies. Ioannidis (2016), for example, argued that in medicine, most clinical research fails to be useful "not because of its findings but because of its design."

A major design flaw identified by Ioannidis (2016) is a failure to involve patients in setting research agendas that align with patient priorities. Along similar lines, policy-makers have rarely been given the necessary context and involvement to guide research in directions most useful to policy development, review, and implementation.

Engaging policy-makers as active participants in *Arctic Futures 2050* will require building relationships with members of that community early in the planning process. Further, the participants in the 2019 open science and policy meeting will need well-defined goal posts for addressing policy needs. Those goals should be rigorously framed within the constraints of realistic assessments of governance and management activities. *Ad hoc* descriptions of such needs are unlikely to produce actionable science. In April 2018, SEARCH will convene a workshop in which Arctic researchers and policy makers will use scenarios to identify plausible futures and the science questions they will present for policy makers. The scenarios approach we use provides a formal approach to strategic planning used by industry (Bentham 2014; Cann 2010), military planners (Davis et al. 2007), conservation planners (Peterson et al. 2003), and Arctic communities responding to environmental change (Walsh et al. 2011; Lovecraft and Preston, 2017). The scenarios workshop will identify the science needed to inform policy in coming decades, which will help frame the themes of the *Arctic Futures 2050* Open Science/Policy Meeting.

The 2016 AOS conference statement encourages contributions to what is described as the "Business Case for Arctic Observing," which requires systematic means to assess "needed resources including infrastructure, instrumentation, human capacity, the pathways to financing, and a strategy for sustained financing" (2016, AOS Conference Statement). The Scenarios model provides an unique means for considering 'plausible futures' and the requisite future research needs, including sustained observing infrastructure. Such a future-oriented perspective has been missing from other systematic approaches to advance integrated and multi-purpose observing infrastructure. The April 2018 SEARCH scenarios workshop will generate input to the AOS 2018; in turn, we anticipate that the Observing Summit will help ensure observing needs are well addressed in the *Arctic Futures 2050* Open Science/Policy Meeting.

LITERATURE CITED

Bentham, J. 2014. The scenario approach to possible futures for oil and natural gas, Energy Policy 64:87-92, ISSN 0301-4215.

Cann, A. 2010. Scenario-based strategic planning in the U.S. Army Corps of Engineers Civil Works Program. Institute for Water Resources, U.S. Army Corps of Engineers. http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/Scenario-BasedStrategicPlanning.pdf.

Davis, P. K., Bankes, S. C., and Egner, M. 2007. Enhancing strategic planning with massive scenario generation; theory and experiments. RAND Corporation 1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138. https://www.rand.org/content/dam/rand/pubs/technical_reports/2007/RAND_TR392.pdf.

Ioannidis, J.P.A. 2016. Why most clinical research is not useful. PLOS Medicine 13(6): e1002049. doi:10.1371/journal.pmed.1002049.

Lovecraft, A.L. and Preston, B. 2017. Chapter 8 Scenarios *in* Adaptation actions for a changing Arctic - perspectives from the Bering/Chukchi/Beaufort Region. Arctic Monitoring and Assessment Programme (AMAP), Arctic Council, Oslo, Norway.

Müller-Stoffels, M., and Eicken, H. 2011. Futures of Arctic marine transport 2030: An explorative scenario approach. Pages 477-489 in North by 2020: Perspectives on Alaska's changing social-ecological systems. University of Alaska Press.

Peterson, G. D., Cumming, G. S., and Carpenter, S. R. 2003. Scenario planning: a tool for conservation in an uncertain world. Conservation Biology, 17(2):358–366.

Walsh, J.E., Müller-Stoffels, M., and Larsen, P. H. 2011. Scenarios as tools to understand and respond to change. Pages 19-40 in North by 2020: Perspectives on Alaska's changing social-ecological systems. University of Alaska Press.

Marine and Coastal Safety and Security Infrastructure for the New Arctic Marine Highway

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As the climate warms, there is likely to be a nearly ice-free Arctic in this century. Already we are seeing extremely low sea ice extent in the winter, particularly in the Bering Strait and Chukchi Sea, as well as later freeze-up dates in the fall, thus paving the way for longer – and potentially riskier - Arctic navigation seasons. The U.S. and other nations such as Russia, China, Korea, and Japan are eyeing increased access and use of this new Arctic Marine Highway for shipping, offshore oil and gas and mining activities, commercial fishing and competition for subsistence activities and indigenous food security and other interests. For that reason, the marine waters and coastlines of the Beaufort, Chukchi and Bering Seas, which comprise the entirety of the U.S. Arctic, makes this region of great importance to national and international security. The U.S. Arctic in Alaska needs a robust marine and coastal observing infrastructure to support national interests in this region.

Similar to many regions of the world that lack power, easy road access and robust communication systems, the Alaska Arctic is a challenging environment for obtaining sustained observations, especially in real-time. However, the need exists for this information for forecasting and reporting on ocean conditions to improve navigation safety, assessing and planning for risks and incident response, and responding to coastal hazards such as longer periods of mobile ice and increased impacts of waves and storms on coastlines and communities. The Alaska Ocean Observing System (AOOS), the Alaska regional component of the national Integrated Ocean Observing System (IOOS), has partnered with the Bureau of Ocean Energy Management, the University of Alaska, the National Weather Service, the Marine Exchange of Alaska and the Arctic Domain Awareness Center to demonstrate new observing technologies and infrastructure support data products and applications that address this need. AOOS and partners are delivering real-time surface current, sea ice, water level and weather data in areas which were off limits 10 years ago, supporting high performance data computing, integration and synthesis to generate new data products and decision-support tools, and engaging with the stakeholders who will use and benefit from them. Some examples are described here that could be used in other remote regions of the Arctic.

High Frequency (HF) radars & remote power modules: Since 2009 during ice-free seasons, shore-based HF radars have been used to record real-time hourly surface currents by processing the Doppler spectrum from transmitted radar waves backscattered by ocean waves along the Chukchi and Beaufort coasts. For the past five years, these power-hungry radars have been sustained by remote power modules developed by the University of Alaska Fairbanks for remote, “off-the-grid” use. The coverage capability varies with sea ice cover, calm sea conditions, and/or ionospheric interference (see www.aoos.org/hfradar). The products can be used operationally for sea state conditions, search and rescue operations, navigation and oil spill response. Data are also crucial inputs into circulation models and forecasts.

X-band radars have been operating continuously since 2007 in Utqiaġvik (formerly known as Barrow) to monitor near-shore ice conditions (up to approximately 20 km or 11 nautical miles) and evaluate the stability of landfast sea ice. Images are recorded every 4 minutes and are sent via internet to the University of Alaska, where they are processed to derive maps of ice velocity, divergence and convergence. Local subsistence hunters and analysts at the National Weather Service's Anchorage Ice Desk have regularly used the sea ice radar to assess ice conditions in the Utqiaġvik area. Commercial and civilian mariners use the imagery and animations for navigational purposes when mobile sea ice poses a potential threat to their vessels.

Wave buoys measure and transmit data on surface currents, waves and sea surface temperatures – all critical data for safe navigation, and validating models and forecasts. Season sea ice has restricted use of wave buoys in the past, although seasonal deployments have occurred in the Bering Strait and Chukchi Sea. With longer periods of ice-free seasons, usage of these buoys becomes more realistic, with a new buoy planned outside the Port of Nome in summer 2018.

Real-time ice observations are typically restricted to seasonal mooring operations that can only be conducted with a ship during ice-free conditions. However, it is exactly during the breakup and freeze-up transitions when observations are most needed for accurate ice forecasting and modeling efforts. An ice detection buoy system has been piloted for two seasons recently to provide real-time temperature and salinity data throughout the water column running up to the day of freeze-up or use by sea ice forecasters. The mooring remains in the water without recovery while the surface buoy detaches on command at freeze-up, allowing this system to remain in place throughout the freeze-up process. With increased ship traffic, deployment of these buoys becomes increasingly realistic, and could significantly lengthen the period of real-time ocean observations during the late fall and early winter in the Arctic.

Accurate water level observations are fundamental for storm-surge forecasting, informed emergency response, ecosystem management, safe navigation, and mapping and charting. Alaska's extensive and remote shorelines are especially under-instrumented for water level observations, limiting Alaska's ability to provide useful marine forecasts and leaving exposed coastal populations and infrastructure. This is in part because of obstacles including seasonal ice, lack of coastal infrastructure and rapid coastal erosion, all which render conventional water level sensing technologies inapplicable. AOOS is piloting the use of water level/GPS receivers to measure water levels at accuracy levels necessary for computing principal tidal constituents (+/- 5 cm), estimating tidal datums, and providing observations needed to improve storm surge and inundation forecasts. These systems are low-maintenance, power-stingy, and easier and less expensive to install and maintain compared to traditional water level gages.

Weather forecasters and mariners alike are benefitting from numerous Automatic Identification System (AIS) stations across Alaska, now equipped with weather sensors that report localized wind conditions alongside vessel tracking information. These stations could be further enhanced to report local subsistence activity or other community observations to vessels transiting nearby. AOOS is working with the Marine Exchange of Alaska to develop a historic database of vessel traffic data providing a synthesis, archive, and display of a variety of associated decision-support tools. The goal is to enhance usability of this increasingly valuable dataset for analyzing potential oil spill impacts from vessel groundings and collisions, risk management measures, subsistence use avoidance, and planning and prioritization for hydrographic surveys.

Arctic Observing Summit

Short Statement

The Canadian Arctic Monitoring and Prediction System (CAMPS) – A Coordinated Knowledge Network to Understand and Anticipate Change in Canada's Northern Ecosystems

2. Implementing and Optimizing a Pan-Arctic Observing System

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A Changing Arctic

It is well acknowledged that climate is warming much more rapidly in the Arctic and Subarctic than in southern latitudes (IPCC, 2014; Serreze et al., 2009) – warming that is driving important changes in the interacting abiotic factors that in large part determine the abundance and health of many northern species. In Arctic coastal-marine systems a decreased sea ice season and warmer seawater are directly impacting sea ice-dependent biota (Eamer et al., 2013; AMAP, 2017), while sea level rise and increased rates of coastal erosion (Forbes, 2011; Gunther et al., 2015; Lantuit et al, 2015) are impacting vulnerable coastal wetlands that provide critical staging and nesting habitats for many migratory shorebird and waterfowl species (Provencher et al. 2018). The degradation of permafrost on exposed lakeshores and riverbanks, and the deepening of soil active layers are impacting biota in freshwater systems (Balzer et al., 2014; Sniderhan and Balzer, 2016), and are changing the quality and quality of river discharge to coastal marine ecosystems - a key determinant of physical processes that directly and indirectly affect coastal marine species (Carmack et al., 2016; Frey et al., 2009; Alkire et al., 2017). In terrestrial ecosystems, warming air and soil temperatures, degrading permafrost, and reduced snow season are causing infilling and changes in the relative dominance of shrubs, with unknown habitat effects (Myers-Smith et al. 2011; Tape et al., 2006; 2012). In some areas historical lemming cycling is reduced or has crashed, with potentially cascading effects on the many species that prey on them (Schmidt et al., 2014). Northern caribou populations are at historic lows (Gunn et al., 2010; Parlee et al., 2018; CARMA, 2018), and disease-driven muskoxen diebacks are occurring in the western Arctic – trends at this time that are largely unexplained (Kutz et al., 2015). Other factors such as ocean acidification (Steinacher et al., 2009; Yamamoto-Kawai, 2009), increased contaminants (Schuster et al., 2018), inevitable invasion by southern species (Lawler et al., 2009), and increased tourism, military activity and development all have the potential to significantly impact northern biota. Taken together, these ongoing changes interact in complex ways across scales to create high levels of uncertainty for government and regional agencies with biodiversity conservation mandates, for communities dependent on country food, and for industrial proponents and operators charged with minimizing and mitigating potential impacts of ongoing and proposed developments.

At the present time in northern Canada, monitoring and research that could contribute effectively to our understanding of these myriad changes is fragmented and uncoordinated. For example, many government departments conduct excellent monitoring programs that are implemented to fulfill their stated mandates, but are not linked to monitoring by academic organizations or communities. Canada is fortunate to have a culture of world-class northern scientists, and, although some academic researchers have managed to maintain long-term, research-level monitoring programs, they are by necessity limited temporally due to funding arrangements, and spatially due to the limited geographic scope of their research areas. Community-based monitoring is occurring in many communities across the Arctic and Subarctic, but they also lack long term sustainability and regional linkages. We propose here that what is needed is a long-term experimental approach that coordinates initiatives, methods and protocols to optimize present programs and attract new investments to support a long term, sustained national (and eventually international) approach to monitoring and research.

The Canadian Arctic Monitoring and Prediction System (CAMPS)

The Canadian Arctic Monitoring and Prediction System (CAMPS) is a proposal to begin to measure, understand and predict biodiversity change and associated abiotic drivers and ecological processes in the Arctic and Subarctic landscapes of Canada. The approach is to use CAMPS to initiate a national dialogue among all northern actors towards the development of a strategic northern knowledge system that coordinates ongoing science initiatives to optimize and coordinate present investments, proposes new science investments as needed, and mobilizes the intellectual capital of Indigenous Knowledge present in northern communities. Key elements of CAOPS include 1) long-term investment to sustain northern research infrastructure utilizing and supporting the present array of research sites to establish and maintain coordinated, long term monitoring experiments, and develop and refine regional predictive models; 2) long-term investment in northern communities to build local capacity, and access Indigenous Knowledge, to establish science-community partnerships that would implement a network of northern community observatories; and 3) coordination of these new initiatives with ongoing surveillance monitoring by agencies, universities, land claim bodies, communities and industry to report the state of Arctic and Subarctic ecosystems, and to make predictions on near- and long-term change.

CAMPS as it stands now has 3 main components (Figure 1). The foundation of the system is a network of monitoring and prediction observatories, with a Flagship Monitoring Site at the Canadian High Arctic Research Station (CHARS) as the hub. The observatory network would be initiated with existing northern research sites (e.g., research stations organized under the Canadian Network of Northern Research Operators, and the Changing Cold Regions Network, among others) for monitoring terrestrial and freshwater systems, and would be piloted in selected coastal communities, with supporting coastal boats (e.g., with the Arctic Research Foundation) and larger ships (e.g., Canadian Coast Guard icebreakers), for monitoring coastal and ocean ecosystems. Based on the input and direction of relevant science teams and IK experts, each site would implement and maintain co-ordinated, long-term monitoring experiments that link abiotic drivers and ecological processes to biodiversity outcomes in terrestrial, freshwater and coastal/marine ecosystems.

The intermediate level of the system would work to access and incorporate monitoring data from the wide variety of mandate-based monitoring programs conducted by various northern federal and territorial government agencies, land claim co-management boards, academic organizations and community-based monitoring programs (Figure 1). In many cases results from these programs could be used to calibrate and validate regional-scale, remote-sensing based models that reach out from long-term monitoring experiments conducted at the observatory network.

A final level of CAMPS (Figure 1) would use data and models from the observatory network, and data from the intermediate level of mandate-based monitoring programs to develop remote sensing-based models to extrapolate local results to reach out to regional and national scales to make predictions of change in appropriate monitoring measures (e.g., changes in vegetation composition, structure and productivity caused by climate-driven change in soil and site drivers, changes in sea ice biota resulting from sea ice changes and warming water) based on a range of climate scenarios.

The proposal at this time is that CHARS science staff will work with science and community partners to implement a proof-of-concept of CAMPS in the CHARS Experimental and Reference Area (CHARS ERA) in the Kitikmeot Region of Nunavut. This proof-of-concept follows monitoring approaches outlined in more detail in McLennan et al. (in prep). An ecological inventory and mapping system based on a nationally- and internationally- standardized nomenclature for arctic and sub-arctic ecological communities is seen as a critical component that can link monitoring across the North, permitting the broad extrapolation of monitoring and research results, and permitting the development of a national experimental design for the terrestrial components of CAMPNet observatories (McLennan et al., in press). We are beginning to seek input from northern scientists and Kitikmeot communities to develop consensus on appropriate experimental designs and protocols for implementing the intensive long term experiments in the CHARS Intensive Monitoring Area, and for designing the extensive calibration-validation monitoring aspects of the CAMPS in Kitikmeot communities. The long term outcome is that the proof-of-concept will demonstrate the usefulness of CAMPS for predicting likely outcomes and reducing ecological surprise to support decision-making and proactive adaptation approaches, and that this will in turn attract the required investments to implement the system nationally.

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References

Alkire, M. B., Jacobson, A. D., Lehn, G. O., Macdonald, R. W., and M.W. Rossi. 2017. On the geochemical heterogeneity of rivers draining into the straits and channels of the Canadian Arctic Archipelago. *Journal of Geophysical Research: Biogeosciences*, *122*(10), 2527–2547. http://doi.org/10.1002/2016JG003723

AMAP. 2017. Snow, water, ice and permafrost in the Arctic (SWIPA). Arctic Monitoring anfd Assessment Programme (AMAP). Oslo, Norway. Xiv + 269 pp.

Baltzer, J. L., Veness, T., Chasmer, L. E., Sniderhan, A. E. and Quinton, W. L. (2014), Forests on thawing permafrost: fragmentation, edge effects, and net forest loss. Glob Change Biol, 20: 824–834. doi:10.1111/gcb.12349.

CARMA Network. Accessed March 2018. https://carma.caff.is/herds.

Carmack, E. C., Yamamoto-Kawai, M., Haine, T. W. N., Bacon, S., Bluhm, B. A., Lique, C., … Williams, W. J. 2016. Freshwater and its role in the Arctic Marine System: Sources, disposition, storage, export, and physical and biogeochemical consequences in the Arctic and global oceans. *Journal of Geophysical Research G: Biogeosciences*, *121*(3), 675–717. http://doi.org/10.1002/2015JG003140

IPCC. 2014. Climate change 2014. Synthesis report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report on the Intergovernmental Panel on Climate Change. [Core writing team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 151 pp.

Eamer, J., G.M. Donaldson, A.J. Gaston, K.N. Kosobokova, K.F. Lárusson, I.A. Melnikov, J.D. Reist, E. Richardson, L. Staples, L., and C.H. von Quillfeldt. 2013. Life Linked to Ice: A guide to sea-ice-associated biodiversity in this time of rapid change. CAFF Assessment Series No. 10. Conservation of Arctic Flora and Fauna, Iceland. ISBN: 978-9935-431-25-7.

Forbes, D.L. (editor). 2011. State of the Arctic Coast 2010 – Scientific Review and Outlook. International Arctic Science Committee, Land-Ocean Interactions in the Coastal Zone, Arctic Monitoring and Assessment Programme, International Permafrost Association. Helmholtz-Zentrum, Geesthacht, Germany, 178 p. http://arcticcoasts.org

Frey, K. E., and J.W. McClelland. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrological Processes*, *23*(1), 169–182. http://doi.org/10.1002/hyp.7196

Gunn, A., D. Russell, and J. Eamer, Northern Caribou Population Trends in Canada. Canadian Biodiversity: Ecosystem Status and Trends. 2010. Technical Thematic Report No. 10, Canadian Councils of Resource Ministers, 2011).

Günther, F., P. P. Overduin, I. A. Yakshina, T. Opel, A. V. Baranskaya, and M. N. Grigoriev. 2015. Observing Muostakh disappear: permafrost thaw subsidence and erosion of a ground-ice-rich island in response to arctic summer warming and sea ice reduction. The Cryosphere, 9, 151–178.

Kutz, S., T. Bollinger, M. Branigan et al. 2015. *Erysipelothrix rhusiopathiae* associated with recent widespread muskox mortalities in the Canadian Arctic. *The Canadian Veterinary Journal*. 56 (6):560-563.

Lantuit, H., P. Overduin, N. Couture, S. Wetterich, F. Aré, D. Atkinson, J. Brown, G. Cherkashov, D. Drozdov, D. Forbes, A. Graves-Gaylord, M. Grigoriev, H. –W Hubberten, J. Jordan, T. Jorgenson, R. Ødegård, S. Ogorodov, W. Pollard, V. Rachold, S. Sedenko, S. Solomon, F. Steenhuisen, T.C. Lantz, and S.V. Kokelj. 2008. Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, Canada, Geophys. Res. Lett., 35, L06502, doi:10.1029/2007GL032433

Lawler, J.L, Shafer, S.L., White, D., Kareiva, P., Maurer, E.P., Blaustein, A.R., and Bartlein, P.J. 2009. Projected climate-induced faunal change in the Western Hemisphere. Ecology, 90(3), 2009, pp. 588–597.

McLennan, D.S., W.H. Mackenzie, D.V Meidinger, J. Wagner and C. Arko. In press. A Standardized Ecosystem Classification for the Coordination and Design of Long-term Terrestrial Ecosystem Monitoring in Arctic-Subarctic Biomes. Arctic.

McLennan, D.S., and Wagner, J. in prep. The Canadian High Arctic Research Station Monitoring Plan - Pilot Phase for Terrestrial Ecosystems. CAFF Report, CAFF International Secretariat, Akureyri, Iceland.

Myers-Smith, I.H., Forbes, B.C., Wilmking, M., Hallinger, M., Lantz, T., Blok, D., Tape, K.D., Macias-Fauria, M., Sass-Klaassen, U., Levesque, E., Boudreau, S., Ropars, P., Hermanutz, L., Trant, A., Siegwart Collier, L., Weijers, S., Rozema, J., Rayback, S.A., Schmidt, N.M., Schaepman-Strub, G., Wip, S., Rixen, C., Menard, C.B., Venn, S., Goetz, S., Andreu-Hayles, L., Elmendorf, S., Ravolainen, V., Welker, J., Grogan, P., Epstein, H.E., and Hik, D.S.. 2011. Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. Environ. Res. Lett. 6 (2011) 045509 (15pp). doi:10.1088/1748-9326/6/4/045509

Parlee, B.L., J. Sandlos, and D.C. Natcher. 2018. Undermining subsistence: Barren-ground caribou in a "tragedy of open access". Sci. Adv. 4: e1701611

Provencher, J. V., E. Johnston, N. Syroechkovskiy, N. Crockford, R.B. Lanctot, S. Millington, R. Clay, G. Donaldson, M. Ekker, G. Gilchrist, A. Black, R. Crawford, C. Price and T. Barry. 2018. Arctic Migratory Birds Initiative (AMBI): Revised Workplan 2015-2019. CAFF Strategies Series No. 6. Conservation of Arctic Flora and Fauna, Akureyri, Iceland. ISBN 978-9935-431-72-1.

N. M. Schmidt, R. A. Ims, T. T. Høye, O. Gilg , L. H. Hansen, J. Hansen, M. Lund, E. Fuglei, M. C. Forchhammer, and B. Sittler. 2012. Response of an arctic predator guild to collapsing lemming cycles Proc. R. Soc. B (2012) 279, 4417–4422 doi:10.1098/rspb.2012.1490.

Schuster, P. F., K.M. Schaefer, G.R. Aiken, R.C. Antweiler, J.F. Dewild, J.D. Gryziec, and T. Zhang. 2018. Permafrost stores a globally significant amount of mercury. Geophysical Research Letters, 45. https://doi.org/ 10.1002/2017GL075571

Serreze, M.C., A.P. Barrett, J.C. Stroeve, D.N. Kindig, and M.M. Holland. 2009. The emergence of surface-based Arctic amplification. The Cryosphere (3), 11-19.

Sniderhan, A. E., and J. L. Baltzer. 2016. Growth dynamics of black spruce (*Picea mariana*) in a rapidly thawing discontinuous permafrost peatland. J. Geophys. Res. Biogeosci.,121,2988–3000, doi:10.1002/2016JG003528

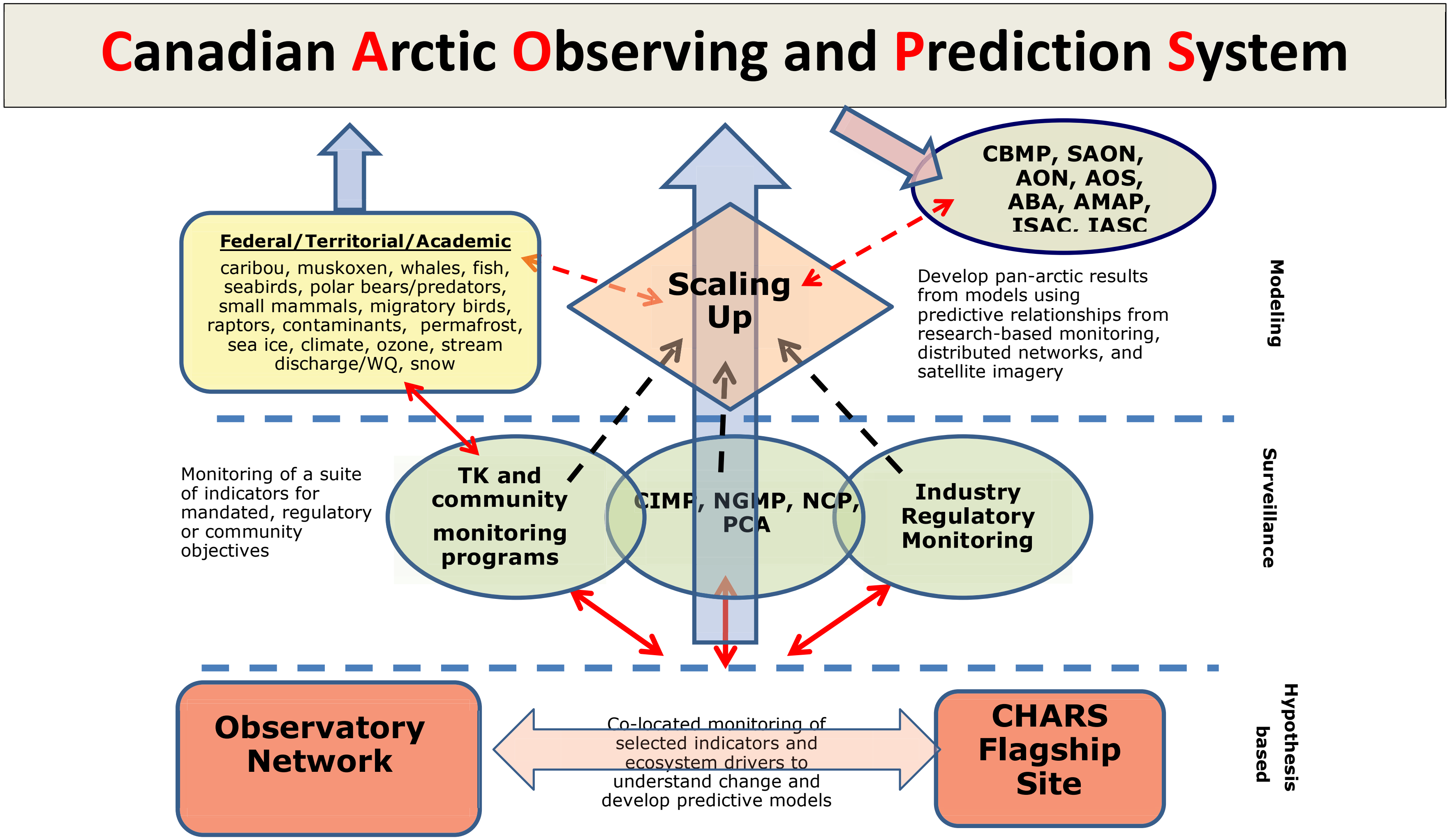
Streletskaya, I., and A. Vasiliev. 2015. The Arctic Coastal Dynamics Database: A New Classification Scheme and Statistics on Arctic Permafrost Coastlines, Estuar. Coasts, 35, 383–400, doi:10.1007/s12237-010-9362-6, 2011a.

Steinacher, M., F. Joos, T. L. Frolicher , G.-K. Plattner, and S. C. Doney. 2009. Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. Biogeosciences, 6, 515-533.

Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. Glob. Change Biol. 12, 686-702.

Tape, K.D., M. Hallinger, J.M. Welker, and R.W. Ruess. 2012. Landscape heterogeneity of shrub expansion in Arctic Alaska. Ecosystems 15: 711–724. DOI: 10.1007/s10021-012-9540-4

Yamamoto-Kawai, M., F.A. McLaughlin, E. C. Carmack, S. Nishino, and K. Shimada. 2009. Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt. Science, Vol. 326, Issue 5956, pp. 1098-1100


Canadian Arctic Observing and Prediction System
Federal/Territorial/Academic
caribou, muskoxen, whales, fish, seabirds, polar bears/predators, small mammals, migratory birds, raptors, contaminants, permafrost, sea ice, climate, ozone, stream discharge/WQ, snow
Scaling Up
CBMP, SAON, AON, AOS, ABA, AMAP, ISAC, IASC
Develop pan-arctic results from models using predictive relationships from research-based monitoring, distributed networks, and satellite imagery
Modeling
Monitoring of a suite of indicators for mandated, regulatory or community objectives
TK and community monitoring programs
CIMP, NGMP, NCP, PCA
Industry Regulatory Monitoring
Surveillance
Observatory Network
Co-located monitoring of selected indicators and ecosystem drivers to understand change and develop predictive models
CHARS Flagship Site
Hypothesis based

The Atmospheric Imaging Mission for Northern Regions: AIM-North

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Overview

AIM-North (www.aim-north.ca) is a proposed satellite mission that would provide observations of unprecedented frequency, density and quality for monitoring greenhouse gases (GHGs), air quality (AQ) and vegetation in the Arctic and boreal regions using two satellites in a highly elliptical orbit (HEO) configuration. Atmospheric species and vegetation would be spectroscopically imaged over land from ~40-80°N, multiple times per day. Enhancing the mission with additional spectral bands could provide complementary data for weather, climate and AQ research and operations. Canada has studied HEO mission concepts for communications and Earth observation for about a decade and AIM-North has evolved from these earlier proposals (*Garand et al.*, 2014). AIM-North is currently under consideration by the Canadian Space Agency, but since its pan-Arctic data would be of value to other northern countries, an international partnership is one way to facilitate sharing of AIM-North's costs and benefits.

Scientific Motivation and Technical Approach

Boreal forests are an important global carbon sink, but it is unclear how climate change will alter their net carbon balance in the future. Permafrost is vulnerable to warming, but it is uncertain how much carbon could be released as CO_2 or CH_4 and this uncertainty is coupled with the offset of some CO_2 by uptake from increased Arctic vegetation density. Dense and frequent satellite observations of northern CO_2 and CH_4 from AIM-North would help to reduce these uncertainties (*Nassar et al.*, 2014). Solar Induced Fluorescence (SIF) is as an indicator of photosynthetic intensity, the start, end and intensity of the growing season, provides information on vegetation stress and relates to gross primary production (GPP). Diurnal imaging of SIF would enhance our ability to assess boreal and Arctic vegetation, including their net carbon balance at various space/time scales. Anthropogenic activity and vegetation fires at high latitudes impact air quality. Geostationary (GEO) air quality satellites are planned over the U.S., Europe and East Asia, but coverage over Canada will be limited. AIM-North could provide comparable coverage to these GEO satellites over the high latitudes. Modern weather forecasting also relies on GEO satellites up to latitudes of ~55-60°. Enhancing AIM-North to provide geostationary-like weather observations could significantly improve forecasts at northern high latitudes, with benefits extending to densely populated regions of Canada or Europe.

AIM-North's most unique feature is the use of a highly elliptical orbit (HEO). With two satellites in HEOs inclined at ~63.44°, each satellite would dwell over the Arctic for many hours, enabling quasi-continuous coverage of northern regions. The exact HEO for AIM-North is still to be determined, with multiple options and variations available (*Trichtchenko et al.* 2014; *Garand et al.* 2014, *Trishchenko et al.* 2016). AIM-North would use a dispersive ultraviolet-visible spectrometer (UVS) to measure reflected sunlight to retrieve trace gas species and aerosols for AQ research and operational forecasting (see Table 1). The UVS would span 290-780 nm with a spectral sampling of ~0.4 nm and use push-broom scanning to image northern regions with 3x3 km^2 pixels every ~60-90 minutes of daylight (Fig. 1). AIM-North would use an imaging Fourier Transform Spectrometer (IFTS) to record spectra of reflected shortwave infrared (SWIR) and near infrared (NIR) solar radiation in 4 spectral bands (~0.25 cm^{-1} sampling). The IFTS would image column CO_2, CH_4, CO and O_2 on detector arrays for the four bands in Table 1, to give 3x3 km^2 ground pixels every ~60-90 minutes of daylight. A few isolated lines for SIF retrieval would be included in the IFTS 760-nm band, while the UVS would observe SIF over a broad spectral range. Although both the UVS and IFTS interferometer have heritage in successful Low Earth Orbit (LEO) satellites, imaging from HEO would be a novel application of these technologies.

Table 1. Spectral bands, spectral sampling and target species.

	Band (nm)	**Band (cm^{-1})**	**Spectral Sampling**	**Target Species**
UV-vis grating	280-780	12820-35714	~0.4 nm	O_3, NO_2, BrO, HCHO, SO_2, SIF aerosols and more
NIR & SWIR IFTS	758-762	13118-13192	0.25 cm^{-1}	O_2 A band: p_{surf}, aerosol, SIF
	1570-1587	6300-6370	0.25 cm^{-1}	CO_2 columns
	2042-2079	4810-4897	0.25 cm^{-1}	CO_2 columns
	2301-2380	4195-4345	0.25 cm^{-1}	CH_4 and CO columns
IFTS enhancement	Mid-wave IR (MWIR)		0.25-1.25 cm^{-1}	T, H_2O, O_3, CO, CO_2, CH_4, HNO_3, CH_3OH, HCOOH, PAN, HCN, NH_3, SO_2…
	Longwave IR (LWIR)		0.25-0.50 cm^{-1}	

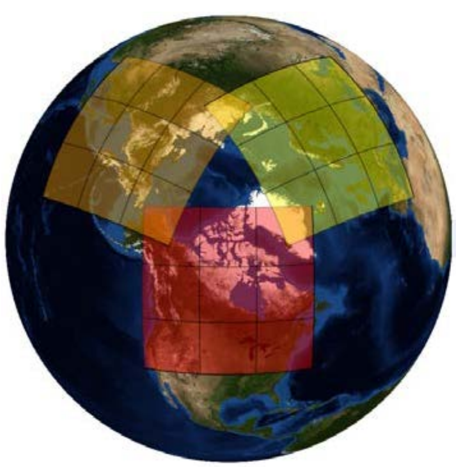

Figure 1. Potential AIM-North imaging approach. Each colored region would be scanned every ~60-90 minutes during daylight.

Adding LWIR/MWIR bands to the IFTS would enable northern measurements of temperature, water vapour and atmospheric motion vectors (for weather forecasts) along with numerous AQ species, and upper tropospheric CO_2 and CH_4 during days, nights and all seasons, but this would increase mass and cost. Other potential enhancements include a cloud imager to improve pointing strategies or a small dedicated aerosol instrument for improved AQ health forecasts.

AIM-North accuracy and precision targets are aligned with international GEO missions. Existing northern validation sites along with some new sites will be required to assess data quality and ensure that accuracy targets are met. Spatially and/or temporally averaging AIM-North data can improve precision beyond target values for some applications. Alternatively, sequentially combining multiple images can yield movie-like views of evolving atmospheric composition.

International and Societal Relevance

The Committee on Earth Observation Satellites (CEOS) Atmospheric Composition Virtual Constellation (AC-VC) group is coordinating a virtual constellation of three GEO satellites complemented by LEO satellites for air quality and a constellation for GHGs is now also beginning to form. AIM-North could observe the same species (many of which are considered Essential Climate Variables or ECVs) in a quasi-geostationary manner over the Arctic and adjacent high latitude land regions. This would extend the constellation for science, to support policy and to contribute to the intercalibration of GEO missions.

Quantification of anthropogenic CO_2 emissions from space (*Nassar et al.*, 2017) is of high interest internationally, but more extensive imaging with a shorter revisit than currently available is needed for all regions of the world. Over 60 space and related member agencies of CEOS agreed to the *New Delhi Declaration* in 2016, which identified the need for better GHG observations to support emission reduction goals under the UN's *Paris Agreement*. Countries are moving forward with LEO and GEO missions to support this goal, but cite a HEO mission to address high latitude regions, as part of the long-term vision (*Pinty et al.*, 2017).

Science Ministers of the 8 Arctic countries and 14 others plus the European Union issued a *Joint Statement on Arctic Science* in 2016 and one of the four themes was *Strengthening and Integrating Arctic Observations and Data Sharing*. Foreign Ministers of the 8 Arctic states signed *The Arctic Science Agreement* in 2017 pledging to develop and expand international scientific co-operation. Finland is chairing the Arctic Council (2017-2019) under the theme *Exploring Common Solutions*, with priorities including *Environmental Protection* and *Meteorological Cooperation*. Since AIM-North's unique northern coverage, spanning all longitudes, would generate valuable data over all Arctic countries, an international partnership, consistent with the high-level aspirations identified above, is one potential way forward to enable sharing of AIM-North's costs and benefits.

References

Garand, L., Trishchenko, A.P., Trichtchenko, L., Nassar, R. (2014), The Polar Communications and Weather Mission: Addressing remaining gaps in the Earth Observing System, Physics in Canada, 70(4), 247-254.

Nassar, R., Sioris, C.E., Jones, D.B.A., McConnell, J.C. (2014), Satellite observations of CO_2 from a Highly Elliptical Orbit (HEO) for studies of the Arctic and boreal carbon cycle, Journal of Geophysical Research Atmospheres, 119, 2654-2673.

Nassar, R., Hill, T., McLinden, C.A., Wunch, D., Jones, D.B.A., Crisp, D. (2017), Quantifying CO_2 Emissions from Individual Power Plants from Space, Geophysical Research Letters, 44 (19) 10,045-10,053. https://doi.org/10.1002/2017GL074702.

Pinty B., Janssens-Maenhout, G., Dowell, M., Zunker, H., Brunhes, T., Ciais, P., Dee, D., et al. (2017), An Operational Anthropogenic CO_2 Emissions Monitoring & Verification Support capacity - Baseline Requirements, Model Components and Functional Architecture, doi: 10.2760/08644, European Commission Joint Research Centre, EUR 28736 EN.

Trichtchenko, L.D., Nikitina, L.V., Trishchenko, A.P., Garand, L. (2014), Highly Elliptical Orbits for Arctic observations: Assessment of ionizing radiation, Advances in Space Research, 54, 2398-2414, http://dx.doi.org/10.1016/j.asr.2014.09.012.

Trishchenko, A.P., Garand, L., Trichtchenko, L.D. Nikitina, L.V. (2016), Multi-Apogee Highly Elliptical Orbits for Continuous Meteorological Imaging of Polar Regions, Bulletin of the American Meteorological Society, January 2016, 19-24, doi:10.1175/BAMS-D-14-00251.1.

Sub-theme 2. Implementing and Optimizing a Pan-Arctic Observing System

Evolution of Multipurpose Acoustic Observatories in the Arctic.

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ABSTRACT: This paper addresses the gap in ocean in situ observations in the Arctic. We describe how multipurpose acoustic systems can contribute to an optimized Pan Arctic Ocean Observing System. The upcoming pan-arctic Coordinated Arctic Acoustic Thermometry Experiment are described as well as how this can be used to create a multipurpose Arctic observation system for the future. It is a major problem that in situ observing systems lack sustainability. Accordingly, our main statement is that sustainable ocean observing systems in the Arctic depend on long-term funding, and we argue for that funding mechanisms other than research programs should be used for this.

INTRODUCTION.

It is of high priority to develop and implement research infrastructures to monitor changes in the Arctic environment on seasonal, annual, and decadal scales. Satellite observations are now under rapid development and plays a major role in Arctic monitoring, while there are large gaps in the in-situ ocean observing system. Various technologies are under development. Ice-ocean buoys drifting with the ice can provide multi-disciplinary data in near real time, but very few institutions have long-term funding to deploy and replace the buoys. Bottom-anchored moorings are well-established multi-disciplinary platforms, but very few in the Arctic with long-term funding e.g. Hausgarten and the Fram Strait array of oceanographic moorings.

Profiling floats, frequently used in open ocean, have to surface to transmit data, update their clocks, and geo-position via satellite. In ice covered regions floats may not be able to surface for many months. During this time, the sensors will collect data, but the positions where the data are taken will be unknown and the clocks will not be accurate. Cheaper floats combined with installation of an underwater acoustic geo-positioning system can make a significant contribution to the observation of the Arctic ocean. A network of fixed mooring systems with acoustic transceivers in the Arctic Ocean will provide an underwater geo-positioning system for all users in direct analogy with GPS positioning. The same system will provide ocean observation through acoustic thermometry, passive acoustic monitoring, and oceanographic point measurements.

PAN ACOUSTIC MULTIPURPOSE NETWORKS IN PROGRESS

Moored multipurpose acoustic networks have been implemented in a sequence of year-long research experiments in the Fram Strait and in the Beaufort Sea (Mikhalevsky et al. 2015). The *technological readiness level* is high, while the data management of passive acoustics and acoustic thermometry is not very well developed. The acoustic data has not yet been included in the common data repositories because standards and formats have been missing. This is currently addressed and under development within the INTAROS project (Integrated Arctic Observation System).

The previous experiments have all been implemented in the Marginal Ice Zone, but new initiatives for establishing acoustic networks in the interior of the Arctic have begun. Recently the Research Council of Norway and Office of Naval Research funded the Coordinated Arctic Acoustic Thermometry Experiment (CAATEX). A sketch of the planned configuration of the acoustic network and the drifting acoustic source is shown in Figure 1. The primary objective of CAATEX is to use acoustic thermometry to estimate the heat content of the Arctic Ocean to benchmark how warm the Arctic Ocean is and to improve our understanding of uncertainties in ocean heat content estimates from climate models. The CAATEX experiment will start in September 2019 and recovered in 2020 as part of the MOSAIC program.

The approach is to let a low frequency sound source drift with the ice across the Arctic Ocean as part of the MOSAiC. A sequence of 5-6 moorings will be installed from north of Svalbard and across the Arctic Basin using icebreakers. The acoustic moorings will be deployed in coordination oceanographic mooring arrays implemented by INTAROS project. The acoustic moorings will receive signals from the drifting source from different positions. Acoustic travel times between each source and receiver pair will be used to estimate mean ocean temperature along the section. In this way, a large part of the Arctic Ocean will be scanned through the "moving ship tomography" technique. This is the first time that the mean ocean temperature of the Arctic Ocean is scanned. Some of the new observations will be comparable to trans-Arctic measurements in 1994 and 1999. Thereby, it will be possible to document changes in mean ocean temperature over two decades. CAATEX will serve as a pilot for development of a network of fixed moorings network with acoustic transceivers in the Arctic Ocean for acoustic thermometry, UW-GPS, and passive acoustics. The CAATEX network can be extended by other national or international programs by more receivers and sources. In this way, the coverage and regional resolution can be improved.

OUTLOOK

As a follow-up of CAATEX we propose that well proven and robust instrumentation mounted in sea floor installations, bottom anchored oceanographic moorings, and drifting ice-tethered platforms should be combined with the multi-purpose acoustic networks. The system will enable year-round observations of ocean heat content, ocean acidification, sea level measurements, sea ice thickness, vocalizing marine life, acoustic impact of human activities, and geophysical hazards (e.g. earthquakes, landslides, tsunamis). This would establish a multi-disciplinary observatory in the central Arctic. To proceed it is essential that long-term funding mechanisms for ocean observatories in the Arctic are made available outside the research programmes for example through national, European and international infrastructure initiatives (Sandven et al. 2018).

REFERENCES.

Mikhalevsky, P. N.; Sagen, H.; Worcester, P. F.; Baggeroer, A. B.; Orcutt, J.; Moore, S. E.; Lee, . M.; Vigness-Raposa, K. J.; Freitag, L.; Arrott, M.; Atakan, K.t; Beszczynska-Möller, A; Duda, T. F.; **Dushaw, B.** D.; Gascard, J. C.; Gavrilov, A. N.; Keers, H.; Morozov, A. K.; Munk, W. H.; Rixen, M.; **Sandven, S.**; Skarsoulis, E.; Stafford, K. M.; Vernon, F.; Yuen, M. Y. *Multipurpose Acoustic Networks in the Integrated Arctic Ocean Observing System*. Arctic 2015 ;Volum 68.(5) s.1-17.

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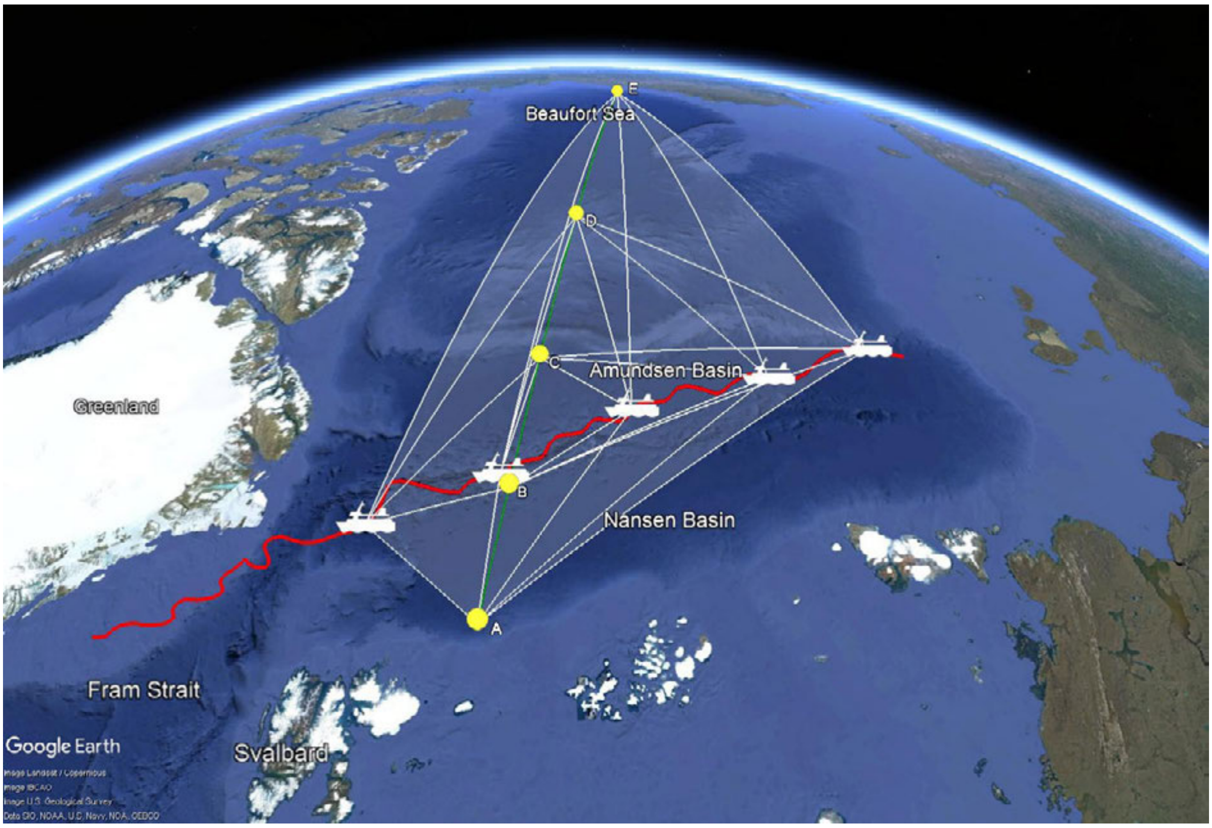

Figure 1. The CAATEX observational concept comprises: The anticipated drift of the MOSAIC platforms is shown by the red line. The planned acoustic moorings (A, B, C, D, E). D and E are provided by the US partners. (white lines) Examples of paths between the drifting source and moorings. The shadowed area illustrates the volume scanned by acoustic thermometry. The green line will coincide with experiments 20 years ago.

The in situ component of Arctic observing systems – opportunities and challenges in implementation of platforms and sensors

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Abstract

The INTAROS project funded by H2020 for the period 2016-2021 has been established to advance the development of an integrated Arctic Observation System. INTAROS has focus on the in situ component of the observing system, where collaboration across the Pan-Arctic regions is necessary in order to make progress on the four main challenges: (1) Organisation, (2) Technology, (3) Data collection and dissemination, and (4) Funding mechanisms. In Europe, the collaboration is built on established initiatives such as the EU Arctic Cluster projects, infrastructure projects and the Copernicus services. In the Pan-Arctic region, collaboration is developed under SAON (Sustaining *Arctic* Observing Networks) including the Arctic Data Committee, Committee on Observations and Networks, Global Cryosphere Watch, Year of Polar Prediction and other ongoing polar programmes.

Introduction

The possibilities to build up in situ observing systems in the Arctic are foreseen to increase in the coming years as a result of more human activities in the region. Many countries, in particular the Arctic countries, EU and several Asian countries, plan to increase their research efforts, participate in exploitation of resources, development of transport systems, and thus play a role in the economic development in the region (Arctic Research Commission, 2016). On this background, the opportunities to collect more environment and climate data in the Arctic are expected to increase. The main challenge is therefore to organise and enhance the data collection as a collaborative effort between researchers and stakeholders and to establish funding mechanisms to secure sustainability of the observing systems.

Requirements to a Pan-Arctic Observing System

In order to better observe, understand and predict the changes, it is important to build up a network of observing systems covering atmosphere, ocean and terrestrial sites across the pan-Arctic region. Observing systems are normally set up to serve specific applications, such as climate monitoring, natural hazard monitoring (storm surges, earthquakes), pollution monitoring or fisheries management. Common for all observing systems is the definition of requirements on what variables should be observed, where and how the data should be collected and be used in the specific applications. Observing systems for climate should operate over decades and secure global observations that are required for climate research and climate change impact assessment. The Global Climate Observing System (GCOS) has defined a number of Essential Climate Variables that are key for sustainable climate observations (GCOS, 2016). Weather and sea ice services have requirements for climate data as well as near real-time data for use in forecasting models. Other dedicated observing systems are under development for pollution monitoring and traffic control.

Ongoing efforts

Significant efforts have been initiated to build components of Arctic observing systems, addressing specific thematic areas or regions in order to serve relevant stakeholders. Most efforts to build and operate observing systems are based on time-limited research funding, which is usually not sustainable. The IPY (2007-2009) and the upcoming MOSAIC programme (2019-2020) are examples of intensified observing campaigns. These campaigns provide enhanced data collection, but they do not necessarily contribute to long-term observing system. A number of countries have invested in infrastructure and logistical services (research stations, ships and aircraft) supporting the observing systems, but they are very scattered in the Pan-Arctic areas. Svalbard, as an example, has many research stations and a large number of scientist involved in developing and maintaining various observing systems. However, most of the Arctic is not covered by any ground-based observing system.

Satellite Earth Observation is the major contributor to data collection in the Arctic. The Sentinel satellites under EU's Copernicus programme is the single largest data producer, providing vast amounts of data that are openly available to users. However, many essential variables cannot be observed from satellites and require in situ observations. For some basic variables (e.g. meterological observations) national weather services operate in situ observing systems in the Arctic as part of their monitoring and forecasting services. However, these are usually limited to national areas, which means that there are few observations in the large Arctic Ocean.

Building sustainable observing systems

How can research-generated observations be transferred to long-term monitoring programmes for selected key variables ? In order to succeed in building sustainable observing systems, the following four challenges need to be advanced: organisation, technology, data collection and dissemination, and the funding mechanisms.

(1) Organisation. It is necessary to develop better collaboration between the providers of data, including both researchers, operational agencies, industry and local communities. The goal is to optimize usage of the available resources and to find new resources to fill major gaps in the observing systems. There is collaboration for example among institutions working on research vessels and icebreakers as well as operators of research stations and other infrastructures. But in many cases, the collaboration regarding data collection can be improved among the scientific groups working in the Arctic as well as with local communities and industry. The organisation of

the in situ data collection is hampered by lack of an overarching body working on Pan-Arctic scale. The Satellite Earth Observation community is well organised through space agencies (e.g. ESA, Eumetsat, NASA, etc.), implying that the observing systems are well-functioning and evolves in a coordinated manner. The in situ component of the observing systems does not have this level of organisation, and is therefore mainly dependent on national, regional or discipline-oriented programmes. Some global programmes (e.g. through WMO, CGOS) support internationally coordinated observing systems, but these are mostly funded nationally and have poor data coverage in the Arctic.

(2) Technology. There is significant development of observing technologies that can contribute to the in situ component of the observing systems in the Arctic, such as ice buoys, underwater platforms, drones and other atmospheric-terrestrial systems. The main challenge is to install and operate robust and automated systems that can function throughout the year. Industry plays an important role to develop such systems, but this requires technology development programmes which are scarce in most countries. Industry investments in Arctic technology is dependent on expected future market development in shipping, oil and gas exploration, tourism, communication and other commercial activities. There are expectations for increased commercial activities in the coming years, which can play an important role in developing and operating observing systems in the Arctic.

(3) Data collection and dissemination. Thanks to the Copernicus programme and other satellite programmes, data collection and dissemination services develop rapidly for Earth Observation data. For the in situ component the data collection evolves much slower because deployment of observing platforms is hampered by technology, logistics, data communication and relative high cost of operating the platforms. Also data policy and accessibility to data are limiting factors.

(4) Funding mechanisms. For space data, the space agencies are funded by the governments/countries, usually with long-term budgeting that is necessary for planning and implementing space infrastructure, ground segments and data dissemination. The main funding for the in situ observations (from stations on land and ship observations at sea) comes from the nations who have responsibilities in national territories and coastal ocean areas. Observations in the central Arctic is usually funded by research programmes and is therefore challenging to sustain. EU is the largest contributor to Arctic research projects and it would be important for the sustainability if some of this funding can be allocated towards building and operating long-term observing systems.

References:

United States Arctic Research Commission and Arctic Executive Steering Committee, eds. 2016. Supporting Arctic Science: A Summary of the White House Arctic Science Ministerial Meeting, September 28, 2016, Washington, DC. United States Arctic Research Commission, Arlington, VA, 78 pp. (https://www.arctic.gov/publications.html)

GCOS (2016), The Global Observing System of Climate: Implementation Needs, WMO publ. no. GCOS-200 (https://library.wmo.int/opac/doc_num.php?explnum_id=3417)

The Case for a Framework - Optimizing Observing and Data Systems for Sea Ice Forecasting & Monitoring under the Arctic Observing Network

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Background

The case for a sustained, international, multi-disciplinary Arctic Observing Network (AON) has been upheld and advanced within national and international settings for more than a decade (NRC, 2006; IARPC, 2007; AOS, 2016). Recently, the U.S. has indicated its readiness to act by formally establishing a U.S. Arctic Observing Network (U.S. AON), which is also intended to support the strategy of the international Sustaining Arctic Observing Networks (SAON). The U.S. AON Office, under the guidance of a Federal U.S. AON Board, coordinates funders, subject matter experts, research networks, international partners, and stakeholders through advancing two distinct, but interrelated, approaches: an AON Framework and U.S. AON Tasks.

Structured Approaches to Observing Network Development

A value-based observing framework is an organizational tool that brings systematic coherence to a complex of observing objectives. The goal is to elucidate and build upon common denominators across these objectives, in order to maximize the user base and societal benefits of the observing system. Framework development should be undertaken by an authoritative body whose mandate fits the scope of the effort. SAON, whose mandate is suitable to the scope of an international AON, has recently made progress on a key input to an AON framework through the International Arctic Observing Assessment Framework (IAOAF, IDA, 2017), which identified Arctic-specific societal benefits and 120 "Key Objectives" that support those benefits.

Tasks provide an implementation structure through which an AON framework can be advanced at national or international levels. Tasks must also be supported by authoritative (and ideally, funded) bodies to legitimize and sustain their efforts. For example, U.S. AON Tasks are led by one or more U.S. agency in alignment with their mission; each has the potential to internationalize. SAON has already endorsed many international Tasks that represent large, thematic observing efforts. Tasks rely upon a strong base of grassroots support from voluntary subject matter experts.

Frameworks and Tasks progress in relation to one another. Tasks provide organizational starting points for Framework development and manageable units for Framework implementation. Frameworks enhance the collective benefits of the Tasks and generate coherence and linkages across the constituent parts. In network parlance, Tasks are the Nodes and the Framework demonstrates how the Nodes are Linked or related, thereby enhancing their value.

U.S. AON Task: Mobilizing Observations in Support of Sea Ice Forecasting

The recently initiated U.S. AON - Sea Ice Forecasting (U.S. AON - SIF) Task has drawn together subject matter experts in sea ice, satellite, airborne and in situ observing, data assimilation, coupled model development, operational model development, and data product and data service providers. The first purpose of U.S. AON - SIF is to drive greater integration across sea ice observing activities of relevance to ice forecasting services, with the aim of generating new and more accessible observational products. The extended purpose of U.S. AON - SIF is to take a holistic and strategic view (i.e. framework) towards the required sea ice observing systems of the future AON. In the near term U.S. AON - SIF is focused on mobilizing algorithm development for a multi-sensor, sea ice thickness (SIT) product in support of operational forecasts. It is anticipated that this effort will demonstrate the utility of a sea ice thickness product for improved forecasting and thereby provide the impetus for an operationalized daily product.

Facilitating the U.S. AON - SIF with the Framework for Ocean Observing

This AOS Conference Statement demonstrates how an existing observing framework, the Framework for Ocean Observing (FOO, UNESCO, 2012), provides a coherent structure that can be adopted, with modification, for the successful implementation and internationalization of Tasks such as the U.S. AON - SIF. Through the FOO, the Global Ocean Observing System (GOOS) mobilizes broad, sustained, international participation in ocean observing to serve a large research and operational user base. We here illustrate how a Framework for Arctic Observing would consolidate and extend the benefits of U.S. AON - SIF through the elements of the FOO, defined below.

1. Requirements Element: *Subject Matter Experts identify the system requirements based on their level of scientific and societal impact as well as on how feasible they are to observe.*

A number of U.S. federal agencies, including the National Ice Center (NIC), National Oceanic and Atmospheric Administration (NOAA) and the U.S. Navy, have defined mission requirements for accurate monitoring and timely charting of sea ice conditions. The U.S. AON - SIF team is working to assemble the federal mission observational requirements for sea ice into a consolidated national view.

The AON scope for SIF requirements includes key objectives under the IAOAF societal benefit areas: Weather and Climate, Infrastructure and Operations, Food Security, and Disaster Preparedness. This scope guides which subject matter experts need to be included in requirements setting. For example, the key objective - *Ensure domain awareness for disaster response* - under Disaster Preparedness suggests that operational responders must be included. Following the FOO requirement template, applying the IAOAF and involving international partners would generate a valuable input to AON for sea ice.

2. Essential Observing Variables Element: *A discrete set of technology-neutral observing targets that have been demonstrated to be highly impactful across the framework objectives with a mature 'readiness level'.*

Sea Ice is already an 'essential ocean variable' under the FOO (see link), with observing requirements that are heavily focused on the societal benefit of global climate projections. Applying the IAOAF societal benefits lens to this variable under the FOO would enhance AON for SIF. For example, SIT has been identified as high impact for Arctic SIF through ad hoc model experiments, but it's operational readiness in the Arctic is very low. A community level focus on this issue is needed to advance the operational readiness of SIT observations (see Element 4).

3. Observations Element: *Under observations, the framework clarifies specific bodies that undertake specific observations and their data accessibility.*

While U.S. AON - SIF provides a valuable national interface to improve readiness, sea ice monitoring and forecasting ultimately requires international collaboration and coordination. Many organizations work around this issue, but there has been limited success in providing a holistic, consistent, and sustainable approach towards polar ice monitoring. WMO's Snow Watch under Global Cryosphere Watch (GCW) has set out to improve international cooperation and can serve as a model for creation of an "Ice Watch". The main goals of Snow Watch are improvement of in situ snow reporting and measurements, evaluation of snow product accuracy and maturity, exchange of snow data and information, and identification of critical snow-related issues. It would be valuable to provide similar international cooperation between ice charting services, ice remote sensing data providers, in situ observers, ice modelers and data assimilators, and long-term ice monitoring agencies.

4. Improving Readiness Element: *Partnerships and tasks improve the readiness levels of requirements, observations elements and data systems.*

A focal point for this element is improving observational approaches for those sub-variables identified as high impact and low readiness under the essential variable process. For example, the U.S. AON SIF Task Team is focused on algorithm development for a multi-sensor, sea ice thickness product in support of operational forecasts. The team will utilize satellite sea ice freeboard and thickness observations from the European Space Agency (ESA) CryoSat-2 and the NASA ICESat-2 (due for launch in Sept. 2018) missions to develop high-resolution, along-track products, as well as weekly-, monthly- and seasonally-averaged grids, for data assimilation (DA) and forecasting experiments. The outcome of this effort will improve the readiness of this sub-variable under an AON for sea ice.

5. System Evaluation Element: *The observing system should be under constant evaluation to discern changes in readiness and identify risks to its sustainability.*

Several partners of the US AON - SIF Team (Naval Research Lab, NOAA's RASM-ESRL-SIFT, NOAA's Arctic Test Bed) already contribute towards system evaluation and welcome the opportunity to align approaches and share lessons. Additionally, the team includes efforts to independently verify the impact of specific parameters on forecasts through Observing System Simulation Experiments (OSSE's). It was through such an OSSE that high impact of SIT on forecast bias was identified. Needless to say, international alignment greatly accelerates the pace of evaluation efforts.

Conclusion

The purpose of this statement was to explore how relevant AON Tasks might benefit from applying an approach like FOO, with regionally specific considerations. The FOO approach provides a valuable, systematic means to organize U.S. AON - SIF, and ultimately provides a gateway to well coordinated international partnership. A valuable outcome of the AOS would be the systematic mobilization of such an approach towards a Framework for Arctic Observing. We encourage SAON and its members to advance its efforts towards a framework in order provide the vital linkages between the nodes of the Arctic Observing Network.

References

AOS, 2016. Conference Statement.

IARPC, 2007. Arctic Observing Network (AON): Toward a US Contribution to Pan-Arctic Observing. Arctic Research of the United States.

IDA [Science and Technology Policy Institute and Sustaining Arctic Observing Networks]. 2017. International Arctic Observations Assessment Framework. IDA Science and Technology Policy Institute, Washington, DC, U.S.A., and Sustaining Arctic Observing Networks, Oslo, Norway, 73 pp.

NRC, 2006. Towards an Integrated Arctic Observing Network.

UNESCO, 2012. A Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing. IOC/INF-1284 rev., doi: 10.5270/OceanObs09-FOO

AUTONOMOUS OBSERVATION OF THE ARCTIC OCEAN BELOW SEA ICE

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ABSTRACT

The Ice-Tethered Profiler program at the Woods Hole Oceanographic Institution was initiated in late summer, 2004 with the deployment of the first prototype system in the Arctic's Canada Basin. Over the subsequent 13 years, with contributions from European, Asian, and fellow North American investigators, 97 ITP systems have been fielded in the Arctic that have collectively returned nearly 100,000 data files containing information about the Arctic Ocean's thermohaline stratification and a variety of other parameters. The design and performance of these ITP systems are reviewed, recent enhancements and capabilities summarized, and challenges to the future of the program are discussed.

INTRODUCTION AND SYSTEM DESCRIPTION

The Ice-Tethered Profiler system (ITP) was designed to sample the upper ocean below drifting sea ice and return data in near real time. Krishfield et al. (2008) and Toole et al. (2011) describe the technology and system performance (see also www.whoi.edu/itp). In short, the expendable ITP consists of a surface buoy (housing telemetry and GPS electronics) that supports a weighted wire-rope tether extending through the ice and down to (at most) 800 m, Fig 1a. The heart of the ITP system is a cylindrical vehicle fitted with sensors (similar in size and shape to an Argo float) that employs a traction wheel to travel up and down the tether at a nominal speed of 25 cm/s. Sensors are operated continuously (at native sample rate) during profiling; data are uploaded to the surface buoy after each profile using inductive modem technology and then telemetered to shore via Iridium Rudics. Data may be stored in the underwater vehicle and/or surface buoy should satellite telemetry be interrupted. Discrete sensors may be additionally affixed to the tether above and/or below the profiling interval, with data telemetry managed similarly. ITP sampling is governed by a user-defined schedule that may be modified in near real time after deployment. Sampling options include the timing of observations and pressure interval to profile, as well as ability to make observations for a specified period at a constant depth. Deployments may be done from ice camps (supported by fixed wing aircraft or helicopters) or ships. The majority of deployments have been through holes augured through ice floes but a handful of systems have been installed in open water (the buoy has sufficient buoyancy to support the system); most of those have survived fall freeze-up.

The basic ITP system was designed for an operational lifetime of more than 2 years assuming approximately 1500 m of profiling per day (e.g., 2 one-way profiles of 750-m span). Actual lifetimes of the full ITP system are often less than this, Fig 1b. There are two major failure modes of ITPs: crushing of the surface buoy and/or breaking of the tether in ice ridging events and dragging of the tether in shallow water (causing the vehicle to be ripped off the wire or the tether to break). Attempts to restrict deep profiling as ITP systems approach shallow water have had mixed success. As is evident in Fig 1b, ITP surface buoys frequently transmit position data for extended time after communication with the underwater units is lost (returning ice drift information). A small number of ITP systems that were rafted over by ice later reemerged and sent backlogs of observations obtained while the system was buried. In these cases, ice drift estimates from neighboring buoys and satellite products are used to estimate where those observations were made.

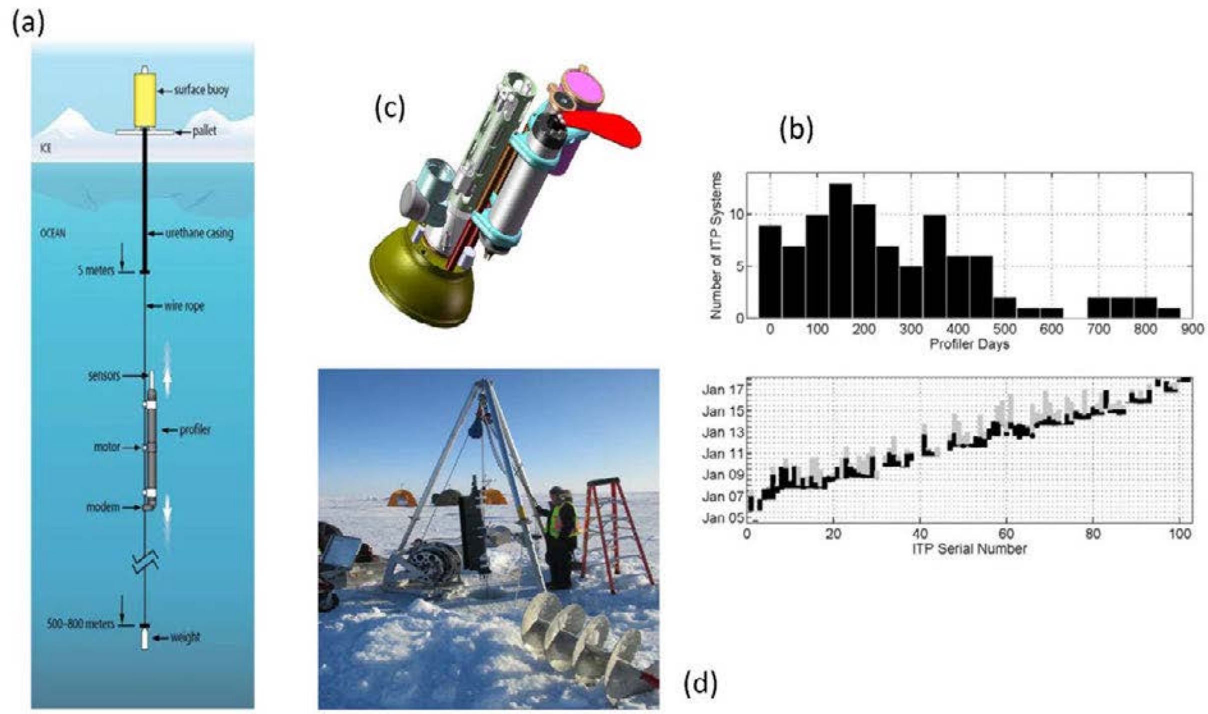

Figure 1. (a) Schematic drawing of the WHOI Ice-Tethered Profiler system; (b) Histogram of ITP underwater vehicle lifetimes (top) and (bottom) the periods (shown as black vertical bars) over which telemetry was received from each ITP underwater unit and from each corresponding surface buoy (black plus gray bars). The history of ITP systems deployed in the Southern Ocean and in lakes are excluded from this plot. (c) Schematic drawing of the bio-optical ITP sensor suite with CTD/O2, chlorophyll fluorescence, CDOM, optical backscatter and PAR (the latter suite housed under a retractable shutter), and (d) installation photograph of an Ice-Tethered Profiler with Velocity (ITP-V).

SENSORS AND RECENT ENHANCEMENTS

The first ITP systems were equipped with Sea-Bird Electronics, Inc. Conductivity-Temperature-Depth (CTD) sensors for observing the ocean's thermohaline stratification. Subsequent systems have incorporated a variety of additional sensors on the profiling vehicle including dissolved oxygen (Timmermans et al., 2010), bio-optical sensors (Laney et al., 2013), and current meters (Thwaites et al., 2011; Cole et al., 2015). In addition, temperature-conductivity, SAMI pCO_2, dissolved O_2 and pH sensors have been deployed on ITP tethers just below the ice-ocean interface (Islam et al., 2016).

ITPs record and telemeter full-resolution, full-sample-rate data, allowing accurate sensor response correction (e.g. Johnson et al., 2007) and study of small-scale ocean structures such as double diffusive staircase stratifications (Timmermans et al., 2008; Shibley et al., 2016). To reduce telemetry energy, time and cost, data compression was implemented in the ITP system, possible because of a new controller installed in the surface buoy (O'Brien et al., 2015; 2016). Work is underway presently to adapt this controller to the ITP underwater vehicle, allowing compression to occur prior to inductive telemetry to the surface buoy (saving energy in the underwater vehicle). The more capable controller will also support more complex sampling schemes, such as selectively powering sensors subsets on specified profiles. In addition, design for a new, lower-cost measurement system (allowing more widespread deployment) that focuses on the upper 1-200 m of the water column is under development.

SCIENTIFIC ANALYSES

ITP data have been and continue to be used to support a range of scientific investigations and student projects. The basin-wide and year-round coverage facilitates studies of seasonal to interannual physical and biogeochemical processes (e.g. Rabe et al., 2010; McPhee, 2013; Laney et al., 2013, 2017; Islam et al., 2017) and basin-scale phenomena (e.g. Timmermans et al., 2014), as well as supports the initialization/validation of and/or data assimilation into numerical models (W. Maslowsky, J. Carton, A. Nguyen, personal communications). Smaller scale processes may also be investigated with ITP data, including meso- and sub-mesoscale variability (e.g. Zhao et al., 2014; 2016; Timmermans et al., 2011), near-inertial internal waves (Dosser et al., 2014; Cole et al., 2014) and double diffusion (e.g. Shibley et al., 2017). Notably, the range of sensors able to be supported on ITPs and their sampling flexibility provide a wide-ranging view of the evolving Arctic Ocean system.

CHALLENGES FOR THE FUTURE

It is widely known that sea ice in the Arctic is shrinking in areal coverage, thinning, and becoming more mobile. All present complications to an ice-based observing system. Although diminished, the sea ice will remain critically important to earth's climate- and eco-systems as well as transportation and tourism, making ice-following observing platforms necessary into the future. The WHOI ITP is able to float and has demonstrated resilience during fall freeze-up. But thinner, more mobile ice can be more prone to ridging that can damage ice based buoys. It has not proven feasible to maintain the array of 20 ITP systems in the Arctic that was envisioned at program initiation. Nevertheless, ITPs have and are continuing to return valuable ocean data from the Arctic. Buoy clusters sampling various elements of the atmosphere, sea ice and upper ocean have proven particularly valuable. Beyond the cost of the ITP system (significantly greater than an Argo float), deployment logistics have constrained where and when ITP systems are deployed. It is hoped that international collaborations will continue in future to facilitate deployment of polar ocean instruments. Similar wishes extend to open, rapid data sharing of observations from all autonomous instruments deployed in the polar oceans.

REFERENCES

Cole, S.T., M.-L. Timmermans, J.M. Toole, R.A. Krishfield and F.T. Thwaites, 2014. Ekman veering, internal waves, and turbulence observed under Arctic sea-ice. *Journal of Physical Oceanography*, doi: http://dx.doi.org/10.1175/JPO-D-12-0191.1

Cole, S.T., F.T. Thwaites, R.A. Krishfield, and J.M. Toole, 2015. Processing of Velocity Observations from Ice-Tethered Profilers. Proceedings Oceans 2015 MTS/IEEE, Washington, D.C. Oct 19-22, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7401887&refinements%3D4224619700%26filter%3DAND%28p_IS_Number%3A7401802%29

Dosser, H.V., L. Rainville and J. M. Toole, 2014. Near-inertial internal wave field in the Canada Basin from Ice-Tethered Profilers. *Journal of Physical Oceanography*, **44**, 413-426, DOI: 10.1175/JPO-D-13-0117.1

Islam, F., M. DeGrandpre, C. Beatty, M.-L. Timmermans, R. Krishfield, J. Toole and S. Laney, 2017. Sea surface pCO_2 and O_2 dynamics in the partially ice-covered Arctic Ocean. *Journal of Geophysical Research*, doi:10.1002/2016JC012162.

Johnson, G. C., J. M. Toole, and N. G. Larson, 2007. Sensor corrections for Sea-Bird SBE-41CP and SBE-41 CTDs. *Journal of Atmospheric and Oceanic Technology*, **24**, 1117-1130.

Krishfield, R., J. Toole, A. Proshutinsky, and M.-L. Timmermans, 2008. Automated Ice-Tethered Profilers for seawater observations under pack ice in all seasons. *Journal of Atmospheric and Oceanic Technology*, **25**, Issue 11, 2091-2105.

Laney, S.R., R. A. Krishfield, J. M. Toole, T. R. Hammar, and C. J. Ashjian, 2013. Assessing Phytoplankton Biomass and Bio-optical Distributions in Perennially Ice-Covered Polar Ocean Ecosystems. *Polar Science*, 10.1016/j.polar.2013.12.003

Laney, S.R., R.A. Krishfield and J.M. Toole, 2017. The euphotic zone under Arctic Ocean sea ice: vertical extents and seasonal trends. *Limnology and Oceanography,* **62**, 1910–1934*,* doi:10.1002/lno.10543.McPhee, M., 2013. Intensification of geostrophic currents in the Canada Basin, Arctic Ocean. J. Climate, 26,3130-3138, DOI:10.1175/JCLI-D-12-00289.1,

O'Brien, J., K. von der Heyt, R. Krishfield, J. Toole and S. Lerner, 2015. A Linux-based Surface controller for the Ice-Tethered Profiler and Other Applications. Presentation at the Polar Technology conference, Denver CO, March, 24-26, 2015. http://polarpower.org/PTC/2015_pdf/PTC2015_OBrien.pdf

O'Brien, J., J. Toole, R. Krishfield, K. von der Heydt, R. Pickart, M.-L. Timmermans, E. Shroyer and C. Clayson, 2016. Other Applications for the Ice-Tethered Profiler Linux-based Surface Controller. Presentation at the 11th MTS Buoy Workshop, Woods Hole MA, April 18-21, 2016.

Rabe, B., M. Karcher, U. Schauer, J. M. Toole, R. A. Krishfield, S. Pisarev, F. Kaukera, R. Gerdes and T. Kikuchi, 2010. An assessment of pan-Arctic Ocean freshwater content changes from the 1990s to the IPY period. *Deep-Sea Research-I,* **58**, 173–185, ISSN 0967-0637, DOI: 10.1016/j.dsr.2010.12.002

Shibley, N., M.-L. Timmermans, J.R. Carpenter and J. Toole, 2016. Spatial variability of the Arctic Ocean's double-diffusive staircase. *Journal of Geophysical Research*, accepted.

Timmermans, M.-L., J. Toole, R. Krishfield, and P. Winsor, 2008. Ice-Tethered Profiler observations of the double-diffusive staircase in the Canada Basin thermocline, *J. Geophys. Res.*, **113**, C00A02, doi:10.1029/2008JC004829.

Timmermans, M.L., R. Krishfield, S. Laney, and J. Toole, 2010. Ice-Tethered Profiler measurements of dissolved oxygen under permanent ice cover in the Arctic Ocean. *Journal of Atmospheric and Oceanic Technology*, 10.1175/2010JTECHO772.1.

Timmermans, M.-L., S. T. Cole, and J. M. Toole, 2011. Horizontal density structure and restratification of the Arctic ocean surface layer, *Journal of Physical Oceanography,* **42**, 659-668, doi: 10.1175/JPO-D-11-0125.1

Timmermans, M.-L., A. Proshutinsky, E. Golubeva, J. M. Jackson, R. Krishfield, M. McCall, G. Platov, J. Toole, W. Williams, T. Kikuchi, and S. Nishino, 2014. Mechanisms of Pacific Summer Water variability in the Arctic's Central Canada Basin, *Journal of Geophysical Research*, **119**, 7523–7548, doi:10.1002/2014JC010273.

Toole, J.M., R.A. Krishfield, M.-L. Timmermans and A. Proshutinsky. 2011. The Ice-Tethered Profiler: Argo of the Arctic. *Oceanography*, **24**(3):126–135, http://dx.doi.org/10.5670/oceanog.2011.64.

Thwaites, F. T., R. Krishfield, M-L. Timmermans, J. M. Toole, and A. J. Williams 3rd, 2011. Flux Measurements from an Ice-Tethered Profiler: First Look, Proceedings Oceans 2011 IEEE-Santander, Spain, 6-9 June 2011, IEEE/OES, 6 pages.

Zhao, M., M.-L. Timmermans, S. Cole, R. Krishfield, A. Proshutinsky, and J. Toole, 2014. Characterizing the eddy field in the Arctic Ocean halocline, *Journal of Geophysical Research*, **119**, doi:10.1002/2014JC010488.

Zhao, M., M.-L. Timmermans, S. Cole, R. Krishfield and J. Toole, 2016. Evolution of the Eddy Field in the Arctic Ocean's Canada Basin, 2005 - 2015. *Geophysical Research Letters,* **43***,* 8106–8114*, doi:10.1002/2016FL069671.*