RE-THINKING THE ARCTIC OBSERVING SYSTEM FOR IMPROVED DATA INTEGRATION AND INFORMATION SHARING

Authors
Dr. L. Alessa; President's Professor, University of Idaho; Big Data Advanced Analytics. alessa@uidaho.edu
Dr. William Ambrose; Department of Biology, Bates College. wambrose@bates.edu
Dr. Andrew Kliskey; Director, the Center for Resilient Communities, University of Idaho akliskey@uidaho.edu.

Abstract
In order to support a business case for an Arctic Observing Network it is first important to understand: a) critical threats to Arctic security; b) capability gaps in current observing networks, and; c) the means to address these through innovative data analysis and fusion. This white paper presents: a) preliminary results from several community workshops; b) a tangible community-driven effort to address capability gaps, and; c) recommendations for operationalizing a more integrated arctic observing network for decision-support to a range of stakeholders.

Arctic Observing Networks for All Domain Awareness
All domain awareness (ADA) is the integration and application of knowledge from cyber, land, maritime, and space observing networks and systems. Achieving ADA in the Arctic is emerging as a critical task that encompass a range of security needs: from protecting the livelihoods and security of Arctic residents to ensuring the Arctic is not exploited as a seam by threat actors. Changes in environmental, geopolitical, and economic dynamics have led to an asymmetric environment. Currently we lack both a framework that we can use to accurately characterize the consequences of such changes and the means to fuse data-streams from any Arctic Observing Network (AON) for multiple scales of situational awareness. ADA must be achieved based on a more evolved, progressive, and diversified observing system that enables forward and central data fusion[1] so rapid and precise situational context can be achieved. This is critical for operations ranging from search and rescue to subsistence hunting to law enforcement to commercial ship traffic. A more diversified and integrated observing system will allow the establishment of the *context* of information developed, so as to enhance *preparedness, coordination, and deployment* of operations across Federal, State, Local, Tribal and Territorial partners (FSLTTP). This white paper presents the results of several community workshops regarding the current diversity of data and sensors for the Arctic and introduces an initiative, Neural Analytics for Understanding Threats and Change Assessment (NAUTICA, see below) to establish a proof of concept demonstrating the feasibility of enterprise-level integration across existing AON sensors.

Problem Statement
While much discussion has occurred regarding the development of a diverse AON there remain significant gaps in: a) a community-wide understanding of the range of applications of data, b) a systematic assessment of sensor and data feeds, and c) innovation in data fusion for decision-support across FSLTT partners. Recent advances in a range of technologies that support ADA through observing systems have enhanced

[1] Forward fusion is the integration of *in situ* data in the locale of an incident or a suspected emergence. Data-streams must, by nature of the operational environment, be finished data that is bandwidth frugal. Central Fusion refers to data integration and intelligence that can accommodate a broad range of ingests including imagery and analytic models that can take advantage of larger bandwidth.

the available data to help inform operational decision-making. Despite the increase in data-streams their diversity remains fairly low and they frequently fail to provide contextual information that makes the raw data useful. As a result, advances in acquiring improved situational context, particularly at fine local scales, remain poorly developed. In other words, operators are starving for ***operationally relevant context*** and we consistently fail to forecast the evolution of change, particularly on timescales of hours to days which is the period in which most incident-response (such as during an oil-spill or search and rescue) occurs.

Current Observing Systems

Arctic observing assets are currently deployed from the sea-floor to space, ranging from fixed and mobile sensors dedicated to classified data-streams to open-source platforms (Figure 1). However, the spatiotemporal coverage of these sensors remains poor, they are disproportionally focused in tight proximity to population centers, they have wide border spaces with extremely sparse information, and funding and infrastructure will remain problematic. At the widest scale, space-based systems provide broad views of activities, but current capabilities have limited durations and low frequency. Supporting space-based platforms are aerial sensors, including random patrols and targeted flights necessitated by risk or threat indicators. At an even finer scale, local sensors provide dedicated data-streams, though they are also challenged by range and number. In the Arctic, there have traditionally been few satellites in polar orbit, flights face significant obstacles of distance and weather, and local sensors are primarily concentrated around populated areas – none provide context.

For the Arctic, an overall low diversity, fidelity, and infrequent revisit rates of sensors results in consistently poor local and situational context (Figure 2). This creates a vulnerability that renders all Arctic nations relatively uncoordinated across their collective Arctic endeavors. Without a re-configured AON and an enterprise-level data fusion framework we lack the means to achieve environmental intelligence in a way that supports forecasting trajectories for a range of operations.

Figure 1: *Nested observing framework for Arctic observing.*

Data Fusion from Current Observing Systems

Agile decision-support requires information fusion that extends and expands the existing work of several agencies who have created common operating pictures and/or data fusion capabilities. Increased capacity for information fusion creates an opportunity for improved information sharing, aiding cost effectiveness, and capability transition as opposed to creating distinctly new and ‘siloed’ systems. Arctic information fusion spans a wide range of topics that includes information systems in use today, methods for data fusion, machine intelligence, and information visualization techniques. Information fusion can support decisions in everything from hunting routes by subsistence hunters to cruise ship passages to security missions by developing a suite of capabilities, supporting agile decision-support, leveraging data from the tactical edge, enabling use-case oriented course of action development, and informing decision management. More specifically, in addressing security concerns in Arctic spaces, decision-makers need intelligently fused and visualized data to support Arctic ADA for operators in both the field and in command centers. Accordingly, extracting key features from heterogeneous data sources and media types (e.g. machine sensors, human sensors, historical records, multispectral imagery, etc.) and presenting a fused, context-rich decision aid remains a significant challenge. As such, information fusion supports a platform upon which data of all types can be disseminated, processed, delivered, and visualized for others that may need high fidelity contextual information related to the Arctic domain.

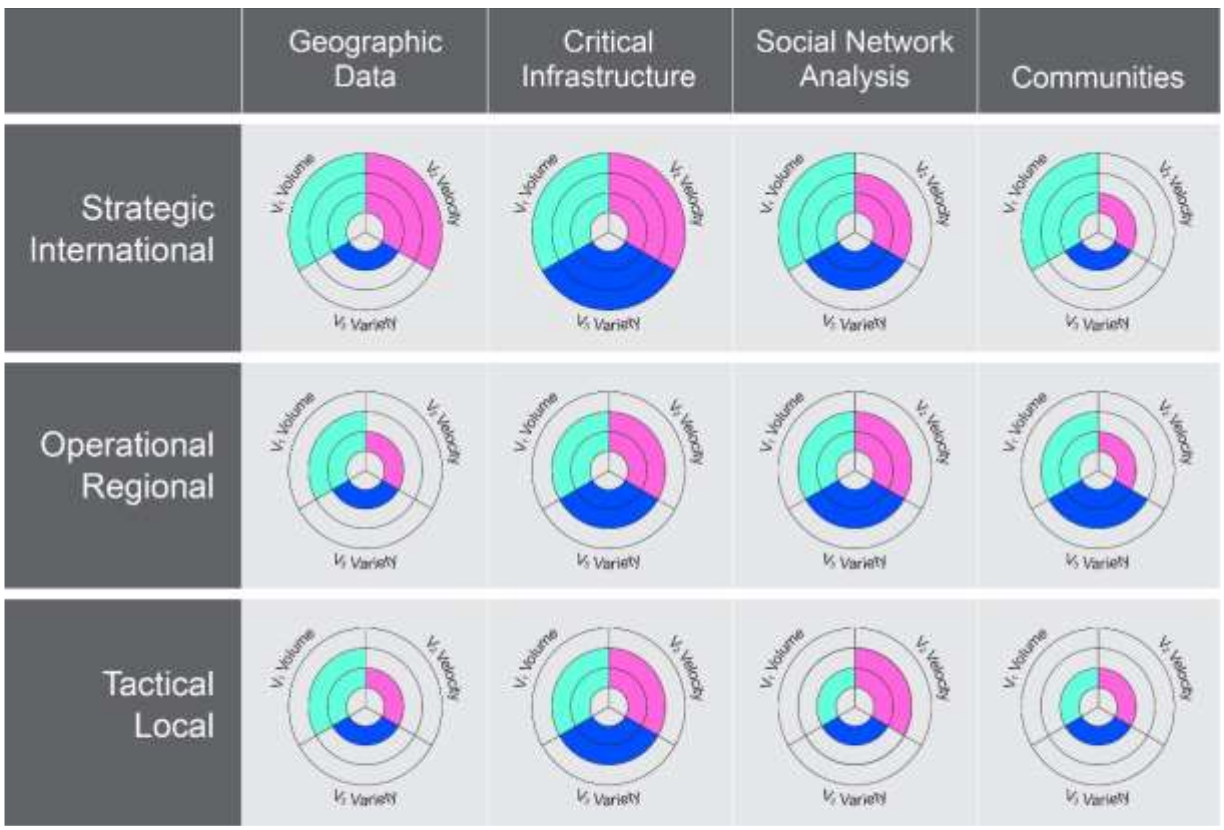

Figure 2: *Data types and diversity as derived from 148 Data Experts during, and following an EyesNorth (CAPRRI) QED Workshop, November 2017. There is an over-emphasis on satellite systems which do not convey context.*

To address these issues, the EyesNorth, a National Science Foundation supported Research Coordinating Network (RCN) held a quadrant-enabled Delphi workshop in February 2018 focused on Data Interoperability and Information Sharing. The workshop participants identified the ten most important challenges in data interoperability and information sharing (Table 1). Three top themes were identified: 1) lack of local, situational context for understanding data and/or analytical products by field operators; 2) lack of standardized workflows across the enterprise; and 3) lack of personnel capable of working within enterprise scale data for decision-support across FSLTT operations.

Table 1: *Top ten capability gaps/challenges in data interoperability and information sharing across combined sensors.*

Issue/Topic	Domain
1. Policy / Legal / Organizational Reticence to Share	Information Sharing
2. How Data/Info are fused: Too much manual vs. automated	Data Fusion
3. Wrong People/Position Performing Analysis	Data Analysis
4. Analysts subjectively holding data; Data available in cloud but not accessible	Data Discovery
5. Analysis Without a Clear Goal (or Question)	Data Analysis
6. Local Data Storage/Limited Access (Agency/Subnetworks): data stored within components versus enterprise-wide	Data Production
7. Co-production/Collaborative Production designed for CTOC as Opposed to Sharing Products	Data Production
8. Manual Extraction from Text/Data-Streams	Data Production
9. Lack of Understanding of Other Data Ecosystems	Data Analysis
10. Data Discoverability	Information Sharing

Initial Solutions Identified:

1. Bring situational context to data for field operations: diversify data feeds by incorporating systematic and standardized inputs from field.
2. Establish an Arctic Security Office with integrated/joint personnel trained in data production, discovery and fusion processes to advise bottom-up and top-down information sharing agreements and protocols.
3. Utilize genetic algorithm-class artificial intelligence to acquire knowledge of data ecosystem.
4. Minimize data pool silos by leveraging AI capabilities to create enterprise level data access.
5. For bulk data: enhance information sharing by creating a systematic set of protocols to protect data and PII.

EyesNorth Use-Case: Neural Analytics for Understanding Threat Indicators and Change Assessment (NAUTICA) in the Arctic Maritime Environment

Toward operationalizing the solutions outlined by the attendees of the Data Interoperability and Information Sharing workshop, we are conducting a best practice use-case to operationalize the solutions identified by the conference participants. This use-case proves the feasibility, and accessibility, of accomplishing central fusion (from a command center vantage, e.g., National Weather Service, United States Coast Guard and other public service agencies) and forward fusion for on-scene responders and local communities. This effort, NAUTICA, is currently underway through a FSLTT partnership that includes academia, federal agencies such as the National Atmospheric and Oceanographic Administration, the National Maritime Intelligence-Integration Office, State, tribal and industry partners. NAUTICA has completed a phase 1 set of composite genetic algorithms to work with a range of Arctic data sources without physically moving the data themselves. In other words, this is a revolutionary way to create a data ecosystem from data pools that can remain in their own niches. NAUTICA ground-truth historic trends of key variables in North Pacific and Arctic Ocean resources and patterns so as to project future trajectories. This enables patterns that are currently invisible using conventional data analytic approaches to be revealed and establishes authoritative retrospective and anticipatory trends for key oceanic variables that affect ocean resources, impact ecosystem stability, and have implications for resource security and maritime operations. NAUTICA serves the following Objectives, as identified by the EyesNorth community:

Objective 1: Establish best practices for applying AI to create an enterprise level data ecosystem for Arctic Observing Networks.
Objective 2: Assess the gaps in the data ecosystem food web with an emphasis on providing local situational context through community based observing networks.
Objective 3: Use forensic analytics on big data sets to inform abductive, anticipatory, and alternative futures analytics to model plausible scenarios that enable decision-support across a range of critical societal and operational challenges, specifically food security (as a consequence of marine ecosystem stability) and maritime operations related to economic and security resilience.

Conclusion and Recommendations:

The EyesNorth RCN has, to date, focused on the task of bringing a diverse community of Arctic scientists, practitioners and policy makers to re-examine our current AON systems such that they are capable of detecting environmental and security changes for the purpose of rapid and effective data fusion and information sharing.

We offer three core recommendations representing the inputs of several hundred attendees from across our EyesNorth FSLTT partners:

1. Develop more progressive mechanisms to foster information sharing among the Arctic nations to expand regional ADA into that which covers the circumpolar North. This ADA must be focused not only on the production of academic knowledge but also in support of operators and policy makers. A re-structured and more integrated AON will require that the human capital involved is properly trained to understand not only the production of data but also the way it is integrated, fused, and made available for decision-support at both central and forward fusion levels.

2. Utilize enterprise level data fusion capabilities that enable machine learning to work from a data ecosystem instead of 'siloed' data pools. This will allow us to not only ***anticipate and prepare*** for emerging threats (rather than merely respond to incidents as they occur) but also coordinate for better, and more successful, responses on the ground.

3. Everyone, from the federal government to local communities, needs to begin viewing data as a national asset. *Data must be made available to the entire enterprise without compromising security and personal identifier protocols.*

Scotland's Marine Monitoring Actions and their contribution to international efforts for a sustained Arctic Observing System

Berx, B.[1]*, Cottier, F.[2,5], Cunningham, S.[2], Gallego, A.[1], Holliday, N. P.[3], Hopkins, J.[4], Inall, M.[2], McDonagh, E.[3], Miller, R. G.[2], Moffat, C.F.[1], Turrell, W.R.[1]

* Corresponding author: b.berx@marlab.ac.uk

[1] Marine Scotland Science, Marine Laboratory, Aberdeen, AB11 9DB, UK

[2] Scottish Association for Marine Science, Scottish Marine Institute, Oban, PA37 1QA, UK

[3] National Oceanography Centre Southampton, European Way, Southampton, SO14 3ZH, UK

[4] National Oceanography Centre Liverpool, Joseph Proudman Building, Liverpool, L3 5DA, UK

[5] UiT, The Arctic University of Norway, Department for Arctic and Marine Biology, Tromsø, NORWAY

To better understand and predict changing conditions in the Arctic, it is essential to monitor the properties (temperature, salinity, nutrients) and strength of currents flowing between the North East Atlantic and the Arctic. The currents around Scotland have been monitored for decades; and the Scottish oceanographic community is committed to sustaining these observations into the future, and continuing their methodological modernisation with emerging robotic technologies. In addition, the Scottish science community hosts a wealth of expertise in Arctic glacial and marine systems. This statement outlines Scotland's current commitments to a sustained Arctic Observing System, as well as ambitions for future contributions.

The balance of heat in the Arctic Ocean is a primary driver of change in the region. Extremes in weather and shifts in the climate of Europe are strongly coupled to changes in the Arctic. The North Atlantic Current (NAC) flows northward through the Iceland Basin and Rockall Trough (Figure 1). It is the principal part of the upper ocean branch of the Atlantic Meridional Overturning Circulation (AMOC), is the source of waters entering the Nordic Seas and Arctic Ocean, and is a strong influence on UK weather and conditions of shelf-sea waters (both the western shelf and in the North Sea). Surface ocean currents around Scotland transport warm and saline Atlantic-origin water masses northwards, and these pathways contribute significantly to the Atlantic water entering the Arctic Ocean. At depth, the return flow from the Arctic basin into the North Atlantic forms the lower limb of the AMOC.

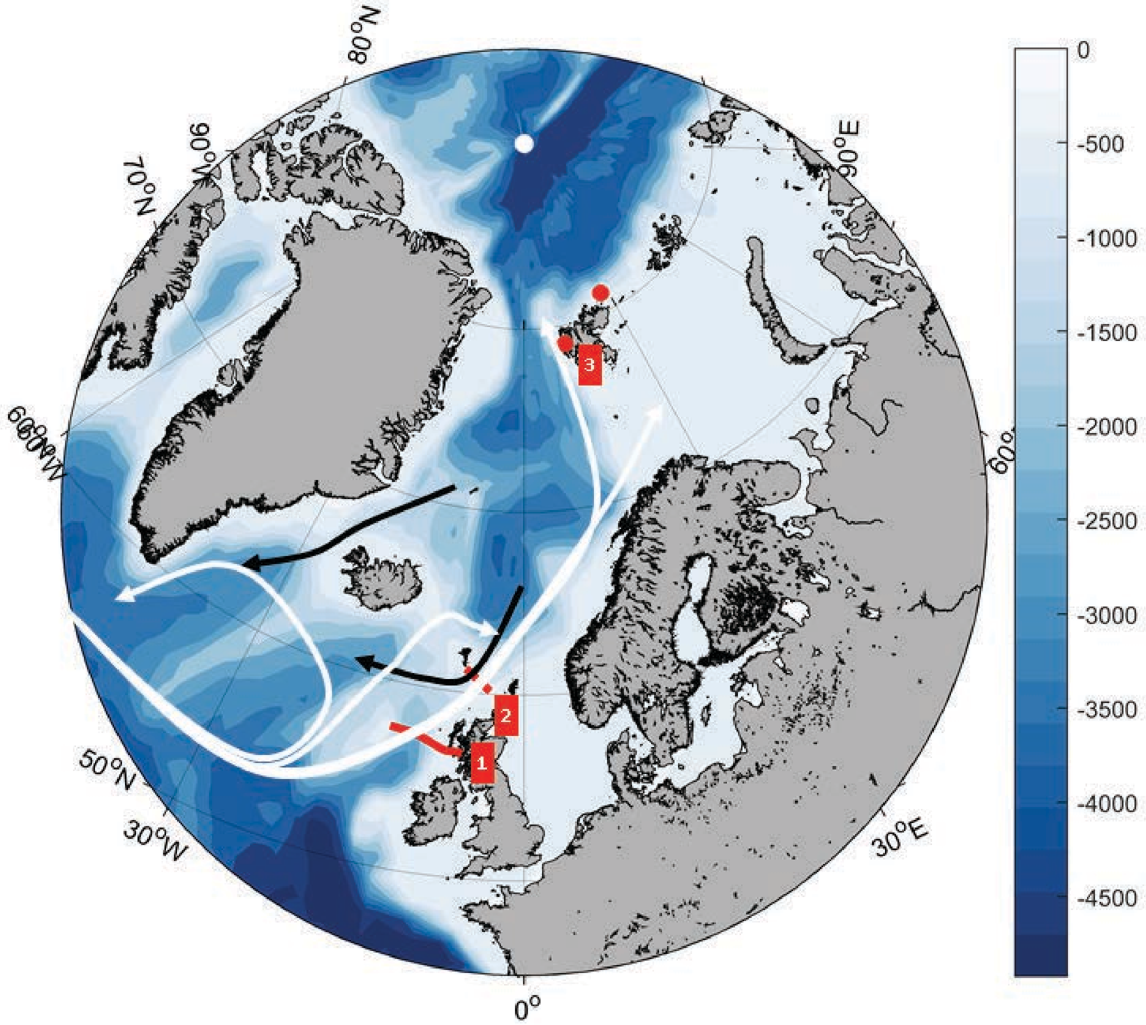

Figure 1. Scotland's Monitoring Actions and their relation to key circulation pathways: 1) the Ellett Array; 2) the Faroe-Shetland Channel; and 3) polar monitoring around Svalbard. White arrows highlight Atlantic Water pathways, black arrows the deep Arctic-origin overflows. Shaded colour shows bathymetry in metres, land has been shaded grey.

In addition to observing the variability of temperature, salinity, nutrients and ocean currents, there is a strong interest from the Scottish community in a wide range of other areas related to Arctic observing including:

- *Invasive non-native species (INNS)*: The possibility of trans-Arctic shipping routes being open throughout the year and therefore becoming a significant transport route to/from the Pacific increases the risk of the introduction of INNS to the Arctic and waters south of the Arctic.
- *Marine litter* (plastics, macro-litter, micro-litter and nanoparticles): an increasing problem due to the resistance of plastic to degradation and their mechanical break up into micro-particles which can be ingested by marine organisms. Marine litter impacts on marine flora

and fauna and is carried by the currents such that areas remote from the source are affected.

- *Contaminants*, especially persistent organic pollutants (POPs) such as halogenated hydrocarbons in top predators: POPs have population consequences for top predators (cetaceans, seabirds), while industrial POP emissions and discharges can be transported in the atmosphere to the Arctic, impacting the Arctic ecosystem. Understanding the impact in the Arctic builds an evidence base to support the decisions of Governments and inter-Governmental organisations.
- *Ocean acidification*: Ocean acidification is more likely to be detected in Northern waters, which can provide potential early warning signals for more southerly waters. However, more critical is that global observation is fundamental in providing the required evidence to support regulation that reduces the emissions of carbon dioxide.
- *General marine observations* with the objective of contributing to the World Ocean Assessment 2: The continual flow and movement of water around our globe dictates that we must continue to make marine observations worldwide, to understand what the global changes that are taking place and their drivers. Cooperative observing systems, with common reporting can provide sound evidence and recommendations, and are key to such delivery.
- Development of *marine indicators* covering both pressure and state: this is particularly relevant given the fact that the UK is a Contracting Party to OSPAR and the OSPAR North-East Atlantic Environment Strategy. The status of the OSPAR Maritime Area, which includes Arctic Waters (OSPAR Region I) will be assessed using common indicators in the Quality Status Report 2023 (OSPAR, 2017).

The Ellett Array – Sustained Observations In The Sub-Polar North Atlantic

The Ellett Array (Figure 1) is a new observing programme that builds on the scientific knowledge generated through observations on the Ellett line since 1950, the Extended Ellett Line (EEL) since 1996 (UK NERC National Capability programmes, operated by SAMS and NOC jointly) and the Overturning in the Subpolar North Atlantic Program (OSNAP) since 2014 (Holliday and Cunningham, 2013). The Ellett Array (UK NERC funding) will utilise moored instruments and ocean gliders across the Rockall Trough at a latitude of 57° N to continuously observe the strength and structure of the North Atlantic Current (NAC) and European Slope Current. The purposefully designed Ellett Array reduces hydrographic survey time from ships, for sustained climate monitoring, by using moorings and ocean gliders. We continuously observe mass, heat and freshwater transports of the NAC through the continuous measurement of velocity, temperature and salinity from instruments on moorings. These data will be augmented by mid-summer and mid-winter high-resolution ocean glider sections, observing the warm throughflow of the shallow Hatton-Rockall Basin. Taking advantage of the new technology development work, we aim to enhance the mooring sensor array to include key biogeochemical parameters, and technological advances in full ocean depth (6,000 m) gliders will be trialled from 2019.

Ship-based hydrography is the primary method for obtaining high quality physical and chemical samples with high spatial and vertical resolution measurements over the full water column (especially for the deep ocean below 2,000 m, e.g. 52% of the global ocean volume cannot currently be sampled by profiling floats). The Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP) provides climate-quality observations that are the basis of our understanding of the decadal heat, salt and carbon variability in the ocean. As part of the UK's GO-SHIP contribution a hydrographic section, with biogeochemistry observations will be repeated (first occupied in 2014 also by the UK) across the North Atlantic basin at 57° N (A25/AR07) in 2021/22.

The Faroe-Shetland Channel – gateway to the Arctic

Atlantic-origin water passes from the NE Atlantic through the Faroe-Shetland Channel (FSC) on its pathway to the Nordic Seas, and beyond to the Arctic (Figure 1). At depth a return flow of cold and fresh Arctic water flows back to the Atlantic. Hydrographic data have been collected from two standard hydrographic sections in the FSC on a regular basis since 1893 by researchers from many nations, although the most consistent effort has been by Scottish and Faroese scientists.

In the mid-1990s, regular monitoring of the Atlantic inflow and deep-water overflow by direct measurement using moored current meters was initiated in the FSC (Berx et al., 2013) and Faroe Bank Channel (Hansen et al., 2016). Since then, research has demonstrated the integration of satellite-based measurements of sea surface height (altimetry) to estimate transport of Atlantic water via the FSC (Berx et al., 2013) optimises the *in situ* monitoring effort.

Through funding from EU projects, such as AtlantOS and Blue-Action, and the commitments of the Scottish and Faroese governments to monitor the marine environment, the FSC monitoring programme will continue its measurements of the transport and properties of the exchange between the North Atlantic and Arctic basins. Ambitions to enhance the observational potential of the transport mooring array and associated monitoring programmes are currently being explored as part of the AtlantOS project.

Monitoring Programmes within the Arctic

The passage of Atlantic Water northwards ultimately brings it to the Fram Strait. Here, the balance of Atlantic versus Polar Waters makes it a region of considerable oceanographic importance, and it is often cited as a location where we will see the impact of warming ocean conditions on the Arctic marine system. Indeed, over the last decades there has been a recognition of the steady "Atlantification" occurring in this sector of the Arctic (Polyakov et al., 2017). In an effort to observe the impact of increased Atlantic inflow on oceanographic conditions in Svalbard, the Scottish Association for Marine Science (SAMS) has maintained a fixed mooring in Kongsfjorden, NW Spitsbergen since 2002. To accomplish this, the mooring operations and provision of instrumentation have been a collaborative activity been SAMS and key Norwegian institutes, such as the University Centre in Svalbard, UiT The Arctic University of Norway, and the Norwegian Polar Institute.

The 15-year time series includes measurements of physical, biological and geochemical parameters. During this period, we have observed years with varying Atlantic dominance which is mirrored in observations as diverse as pelagic zooplankton populations, bloom dynamics and glacial melt rates. One of the key oceanographic changes has been the persistent lack of sea ice formation in the west Spitsbergen fjords, and a gradual increase in the winter water temperatures. In addition to long time series analyses, the moorings have permitted insight into Arctic processes such as zooplankton migrations (Wallace et al., 2010) and glacial calving events (Luckman et al., 2015). These observations are further supplemented by a second mooring with identical instrumentation being placed in the far north east of Svalbard in a Polar Water dominated fjord (in place since 2006). This pair of sustained observatories has enabled us to make direct comparisons of the role that Atlantic water plays in modifying an Arctic marine system. These monitoring platforms are an important element in the Svalbard Integrated Observing System, an international program that aims to support long-term measurements of key environmental properties on and around the Svalbard archipelago to address questions of Earth System Science.

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Building an Arctic GEOSS
SAON Strategy: 2018-2028

Jan René Larsen, Sustaining Arctic Observing Networks (SAON), jan.rene.larsen@amap.no
Mikko Strahlendorf, Finnish Meteorological Institute (FMI)
Douglas Cripe, Group on Earth Observations (GEO) Secretariat

Introduction

The Sustaining Arctic Observing Networks (SAON) is a joint initiative of the Arctic Council and the International Arctic Science Committee that aims to strengthen multinational engagement in pan-Arctic observing. The SAON process was established in 2011 at the Seventh Ministerial Meeting of the Arctic Council (AC) via the Nuuk Declaration. This declaration recognizes the “importance of the Sustaining Arctic Observing Networks (SAON) process as a major legacy of the International Polar Year for enhancing scientific observations and data-sharing.” The declaration also defines the SAON governance structure and Terms of Reference, which were formally approved in 2012[1].

In 2014, the SAON Board finalized its first implementation plan, which established two committees: The Arctic Data Committee (ADC) and the Committee on Observations and Networks (CON). The ADC aims to promote and facilitate international collaboration to establish free, ethically open, sustained, and timely access to Arctic data through easily accessible and interoperable systems. The CON aims to promote and facilitate international collaboration towards a pan-Arctic Observing System.

The following SAON Strategy document provides a 10-year strategy for addressing current and future Arctic observing needs. The document, approved by the SAON Board in January 2018, sets priorities for how SAON will fulfil its mission. It describes SAON’s vision, mission, guiding principle and goals, and outlines the manner in which the goals will be achieved, through the establishement of a Global Earth Observations System of Systems (GEOSS) for the Arctic.

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[1] https://www.arcticobserving.org/images/pdf/Terms_of_Reference/saon-terms-of-reference.pdf

Vision

SAON's vision is a connected, collaborative, and comprehensive long-term pan-Arctic Observing System that serves societal needs.

Mission

SAON facilitates, coordinates, and advocates for coordinated international pan-Arctic observations and mobilizes the support needed to sustain them.

Guiding Principles

The following guiding principles reflect the overarching philosophies that drive the SAON process.

- SAON values both research and operational needs for Arctic observations;
- The Observing System is implemented and sustained through open cooperation among with all those committed to Arctic observations under a common SAON umbrella;
- The design and operation of the Observing System will be guided by a balance between bottom-up and top-down needs and priorities;
- SAON will promote contributions of all types of observations including but not limited to *in situ*, remotely sensed, and community-based observations, and the infrastructure supporting them;
- The Observing System will utilize Indigenous and local knowledge guided by ethical use and honouring the proprietary rights of data contributors;
- SAON will promote ethically free and open access to ethically-collected data;
- SAON will work with counterparts in the Antarctic, global, and national observation communities, where appropriate.

Following these principles, SAON aims to promote Arctic observing and to mobilize the support needed to achieve full implementation and sustain operations on time scales of decades and beyond.

SAON itself will not undertake research, science planning, policymaking, observations, data archiving, or funding of these efforts. SAON will however encourage and promote collaboration among ongoing networks/sites/systems and data centers, the organizations that support them, or appropriate decision-makers within these areas.

Goals

In keeping with the above vision and mission, SAON has adopted the following three goals and SAON's guiding principles support its work across these:

1. Create a roadmap to a well-integrated Arctic GEOSS;
2. Promote free and ethically open access to all Arctic observational data; and
3. Ensure sustainability of Arctic observing.

Addressing these goals will require the expertise and cooperation of a wide range of stakeholders and knowledge systems. While the Arctic Council is well-positioned to coordinate state level priorities and actions, effective implementation of the SAON Strategy will require partnerships. These partnerships include but are not limited to collaborations with policy-makers at all levels, Arctic Indigenous Peoples organizations, non-Arctic states, academia, civil society and the private sector, as well as engagement from other multilateral/international groups. SAON believes that effective implementation will require the participation of Indigenous Peoples and local communities and gender-balanced approaches.

Goal 1: Create a roadmap to a well-integrated Arctic GEOSS

The rapid on-going changes in the Arctic present an urgent need to better observe, characterize and quantify processes and properties of the Arctic system.

SAON will engage and facilitate connections among the producers and end-users of Arctic observations in order to create and sustain a well-integrated Arctic GEOSS. In order to achieve this goal, SAON believes that it is essential for participating parties to adopt a community-endorsed framework. The International Arctic Observations Assessment Framework[2], developed in partnership with SAON, provides such a starting point. SAON's role in further developing and implementing this framework will be to help to identify critical observations, products, and services that are relevant to the Arctic Observations *value tree*[3]. A holistic benefit analysis can then be used to assess the responsiveness of current Observing System and identify potential expansions. The results of this analysis will be central to the creation of a roadmap to well-integrated Arctic observing that is responsive to Societal Benefit Areas. This roadmap will also be used to identify funding sources to support

[2] https://www.arcticobserving.org/images/pdf/misc/STPI-SAON-International-Arctic-Observations-Framework-Report-2017.pdf
[3] At the top level of the *value tree* are the Societal Benefit Areas (SBAs) that define the environmental, economic, and social domains in which services, operations, and research provide societal benefit. For more information about the *value tree* concept, see the source under footnote 2)

infrastructure required for sustaining or adding new observational capabilities as well as technological innovations to improve observation capacity.

SAON will collaborate closely with its partners and other prominent Arctic and international organisations as well as with the Arctic Council Permanent Participants to find synergies and joint activities to avoid overlapping efforts to achieve Goal 1[4].

Goal 1 has five objectives:

1) Conduct an inventory of national observational capacities.
2) Complete an assessment of Arctic observational capacity.
3) Provide recommendations for a roadmap for future Arctic observational capacities.
4) Create opportunities to develop and implement observations in support of Arctic Societal Benefit Areas (SBAs).
5) Develop a long-term repository for relevant project deliverables.

Goal 2: Promote free and ethically open access to Arctic observational data

One of SAON's guiding principles is to promote ethically free and open access[5] to ethically-collected data. The approximately sixty international participants at the 2016 Polar Connections Interoperability Workshop and Assessment Process agreed that the key current challenges impeding the development of a globally connected, interoperable system are social and organizational rather than technical: supporting human networks, promoting standards, and aligning policy with implementation.

A review of relevant Arctic data management efforts and results have guided the SAON vision for an open, interconnected, international system for sharing data across disciplines, domains, and cultures. Requirements and characteristics of such a system include but are not limited to:

- A distributed design that connects different data repositories and other resources. This implies and requires interoperability that supports sharing data among various information systems in a useful and meaningful manner;
- Many linked catalogues fostering 'single window' search;
- High quality, ethically open data sustainably preserved over time;
- Data as a responsive, "live" service rather than simple download approach;
- Inclusive of Indigenous and local perspectives and information;

[4] SAON partners: https://www.arcticobserving.org/partners
[5] The source of this concept is *International Arctic Science Committee, 2013. Statement of Principles and Practices for Arctic Data Management*: https://www.iasc.info/data-observations/iasc-data-statement

- Access to “big data” and powerful analytical tools (e.g. cloud platforms); and
- Cost effective, maximizing the investments made to develop and maintain the system.

In recognizing the elements of the envisioned system and the key challenges identified by the community, SAON will first focus on improving connections, and cooperation between actors. This will be achieved by working with the global Arctic data community, including data providers, data scientists, funders, users and beneficiaries within society. This effort will provide the necessary collaborative foundation needed to achieve the desired system.

Goal 2 has three objectives:
1) Create a road map outlining the steps towards achieving a system that will facilitate access to Arctic observational data.
2) Advance a system to facilitate access to Arctic observational data.
3) Establish a persistent consortium of organizations to oversee the development of a sustainable, world-wide system for access to all Arctic data.

Goal 3: Ensure sustainability of Arctic observing

Goals 1 and 2 can only be successful if the need for improved coordinated Arctic observation and sharing of data and resources are supported by all relevant stakeholders over the long term.

Goal 3 has three objectives:
1) Develop a strategy for long-term financial commitment in Arctic observations;
2) Apply the strategy developed in 3.1 to lobby funding agencies and states to ensure sustainability of Arctic observing; and
3) Secure funding for international SAON secretariat and operational costs.

Implementation

This Strategy will be implemented by the SAON Board and the SAON Committees as described in the *SAON Implementation*[6] document for establishing an Arctic GEOSS. This document provides detailed information about how SAON will achieve its objectives, including description of timelines, cooperation with external organisation, and resource/funding requirements. The *SAON Implementation* is a living document that the SAON Board, Committees, and partners will update on a continuous basis.

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[6] https://www.arcticobserving.org/strategy

AOS 2018 Short Statement
Sub-theme 3. Operating Observing Systems and Networks

Arctic Heat Transfer Mechanisms between Ocean and Atmosphere during Autumn and Winter

Anja Rösel, anja.rosel@npolar.no, Norwegian Polar Institute, Norway (contact)
Lana Cohen, lana.cohen@npolar.no, Norwegian Polar Institute, Norway
Glen E. Liston, glen.liston@colostate.edu, Colorado State University, CO, USA
Stephen Hudson, stephen.hudson@npolar.no, Norwegian Polar Institute, Norway
Polona Itkin, polona.itkin@npolar.no, Norwegian Polar Institute, Norway
Sebastian Gerland, sebastian.gerland@npolar.no, Norwegian Polar Institute, Norway

The changing Arctic shows us two key realities. First, Arctic air temperatures are increasing faster and are more extreme than in almost all other areas of the world (e.g. Hansen et al., 2010; Cohen et al., 2014; AMAP 2017). Second, current Earth System Models (ESMs) as well as operational forecasting and regional models are unable to reproduce recent observed Arctic sea ice and air temperature trends (e.g. Stroeve et al., 2007, updated; Stroeve and Notz, 2015). The enhanced Arctic warming is primarily an autumn and winter phenomenon (e.g. Serreze and Barry, 2011), thus a focus on Arctic processes in these seasons is of particular importance.

Based on N-ICE2015 expedition results, which took place from January through June 2015 in the Arctic north of Svalbard (Granskog et al., 2016), we have identified autumn- and winter-related Heat Transfer Mechanisms (HTMs) that have not been adequately observed and are therefore not ideally represented in current modeling systems. We conclude that creating more accurate Arctic and global predictive models requires, at least in part, improved representations of the most important factors controlling heat fluxes between the Arctic Ocean and atmosphere, which in turn requires better observations of these fluxes. We therefore propose that the following HTMs should be a focus of near-future observational and modeling research.

Atmosphere:
The atmosphere has a large impact on heat and moisture transfer to and within the Arctic (e.g. Graversen et al., 2008; Overland and Wang, 2010, 2016), and atmospheric processes that drive heat and moisture transport are important on a wide range of temporal and spatial scales (Serreze and Barry, 2011). There is also evidence of strong regional variability within the Arctic (e.g. Francis et al., 2005; Park et al., 2015), making it vital to demonstrate which processes exhibit Arctic-wide controls and which are more regionally important. The following atmospheric processes have the greatest impacts on Arctic heat and moisture budgets and require additional and improved observation and modeling efforts.

- Clouds and cloud properties are highly variable in time and space, and with today's observations and models it is challenging to quantify and parameterize these properties. Macro- and micro-physical properties greatly affect the surface energy budget and precipitation processes.

- Precipitation is also highly variable in time and space, and its distribution is not well known over Arctic sea ice. Precipitation amounts are notoriously difficult to measure in cold regions, so even a realistic Arctic climatology does not exist. Evaluating precipitation amounts in models is therefore challenging. Yet the amount and phase of the precipitation, as well as the timing of ice formation in autumn and winter, ultimately determines the thickness, mass, and mobility of the snow deposited on sea ice. This precipitation-related snow accumulation imposes critical controls on heat transfers and is often the key to accurate interpretation of remote sensing data.

- Near-surface air temperature, humidity, wind, and mixing are strongly affected by the extreme stratification common in the winter Arctic atmospheric boundary layer. Unfortunately, most of today's ESMs do not adequately represent atmospheric processes and fluxes in stable boundary layers. Among other problems, this often leads to substantial overestimation of surface temperatures during clear, calm periods.

- Observations of the impacts of synoptic events, especially storms, on sea ice and snow processes are also needed.

ESMs represent the atmospheric synoptic variability quite accurately, and thus future focus on observations and modeling of the processes and system-wide impacts is necessary to ensure these are also well represented in ESMs.

Snow and ice thermodynamics:
Snow on sea ice strongly regulates the thermodynamic processes of sea ice growth. Due to the low thermal conductivity of the snowpack, snow largely controls heat fluxes between the atmosphere and ocean (Sturm et al., 2002a, 2002b) and thus directly impacts ice growth and melt. Since Arctic snow depths are largely controlled by unknown precipitation inputs, it is hard to quantify the actual snow thickness and its spatial variability on sea ice using just models; some kind of additional observation is required. In addition to its relevance for the energy fluxes, knowledge about snow thickness is also crucial for sea ice thickness calculations from altimetry such as CryoSat-2 (e.g. Laxon et al., 2013), or the coming ICESat-2 (Markus et al., 2017).

- Heat fluxes between the atmosphere and sea ice are generally regulated by the presence of a snow layer. At the floe scale, heat fluxes are strongly modified by spatial variability of the snow thickness at scales of tens of cm to tens of m. Modeling studies indicate this spatial patchiness may play a crucial role in ice growth and heat fluxes to the atmosphere, and that the associated processes may lead to significantly enhanced heat fluxes during the early-winter when the snow and ice are relatively thin. In ESMs, and even in regional models, snow is represented as a homogeneous layer and small scale variability is generally not accounted for. Observational and modelling efforts are needed to assess the importance of this variability and to determine how its effects can be incorporated into ESMs.

- The spatial variability in snow depth covers large areas of the Arctic Basin and persists throughout the winter. The integrated effect of locally thin snow-covered areas over long periods of time, particularly during the early snow-formation phase, as well as during the onset of ice formation plays an important role in Arctic ocean-to-atmosphere heat fluxes and needs to be better observed and addressed in ESMs.

- A thick snow layer on relatively thin ice causes negative freeboard and can allow relatively warm ocean water to flood the sea ice surface, causing snow-ice formation if temperatures are low enough. The thinning of Arctic sea ice makes this process more likely in the present and future Arctic than it was in the past. These mechanisms strongly modify conductive and latent heat fluxes in the system and thus impact the ice mass balance. Flooding and snow ice formation are included in some ESMs, but these processes are not well studied in the Arctic and further observations of their extent and impacts are needed. Knowledge and identification of flooded areas are also expected to be useful for remote sensing applications.

Sea ice dynamics:
Recent observations suggest that the increasing mobility of sea ice has led to an increase in sea ice deformation (Rampal et al, 2009; Itkin et al, 2017). More observational and remote sensing studies are necessary to confirm this finding Arctic-wide. Combining observational data and numerical models is especially challenging due to the spatial and temporal dependencies of deformation. Direct observations of ocean and atmosphere heat fluxes through resulting leads remain a challenge because the sea ice pack is highly dynamic and the fluxes are localized.

- Leads in sea ice enhance heat and moisture exchange to the atmosphere. In addition, sea ice leads drive new sea ice growth. It is important to improve observations of heat fluxes through leads to ensure these processes are adequately represented in ESMs.

- Where sea ice is compressed into pressure ridges, the roughness of the top and bottom ice surfaces enhances the momentum transfer between the atmosphere and ocean. Mixing of the oceanic surface layer in areas where relatively warm ocean water lies at shallow depths, such as in the area of Atlantic Water inflow, can then lead to stronger ocean heat fluxes, which then melt the sea ice and enhance heat transport into the atmosphere. The impact of sea ice roughness on ocean mixing is highly variable in space and time, and it is not well observed over all regions and spatial scales. ESMs typically use constant values for sea ice form drag.

- Rough sea ice surfaces and leads are sinks for snow. Large fractions of snow can be redistributed into drifts adjacent to ridges or lost in the open water of leads. The redistribution of snow in drifts and loss to leads has yet to be quantified by observations and are not represented in the ESMs.

Conclusions:

These winter HTMs and their controls on fluxes between the Arctic Ocean and the atmosphere are critical areas for improvements in our understanding and ability to model Earth's climate system. In addition, these mechanisms are generally thought to be high-resolution, sub-grid processes that require parameterization within the next (or current) generation of ESMs. They are Arctic system features that often evolve quickly in time; vary from region to region and seasonally; have important consequences for ecosystem, light, and ocean heat fluxes; and are expected to drive important teleconnections.

In addition, there is a need to implement observing programs that focus on processes represented by these HTMs, and to use those observations to develop sub-grid-process parameterizations for implementation within ESMs.

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Integrating permafrost monitoring into a pan-Arctic observing system

Sarah M. Strand[1], Dmitry Streletskiy[2], and Boris Biskaborn[3]

[1]The University Centre in Svalbard, Longyearbyen, Norway

[2]The George Washington University, Washington D.C., USA

[3]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

Correspondence to contact@ipa-permafrost.org

Permafrost is a critical aspect of the Arctic environment and cryosphere in general, and thus is a natural component of a comprehensive pan-Arctic observing system. The development of such a system should link with the datasets and other scientific products already available through the International Permafrost Association (IPA) and the Global Terrestrial Network for Permafrost (GTN-P). The IPA and GTN-P already operate in collaboration with IASC and SAON, and welcome collaborations with other related networks.

The International Permafrost Association (IPA, permafrost.org) fosters dissemination of knowledge concerning permafrost and promotes cooperation among people and organizations engaged in scientific investigation and engineering work on permafrost. The Global Terrestrial Network for Permafrost (GTN-P, gtnp.org) was established in 1999 by the IPA as part of the Global Terrestrial Observing System (GCOS) branch of the Global Climate Observing System (GCOS). Permafrost temperature and active layer thickness are recognized as essential climate variables for land by GCOS, and these variables are the focus of GTN-P. The GTN-P monitoring network, which has grown out of coordination by the IPA, currently includes approximately 1360 boreholes and 250 active layer monitoring sites. The GTN-P database houses these open-access ground temperature and active layer thickness data. The majority of the sites are located in the Arctic, but data also comes from other permafrost regions including the Alps, high-elevation parts of Asia, and Antarctica.

The IPA is currently supporting new permafrost map development through its Mapping Action Group. New map products will incorporate the model-based maps being developed by the ESA initiative GlobPermafrost and will be validated by GTN-P data, preexisting permafrost maps, and the local knowledge of permafrost scientists and engineers in their respective field areas. These future permafrost map products would also positively contribute to a pan-Arctic observing system.

Both the IPA and GTN-P strive to provide permafrost information to the scientific community, policy makers, and to the public in general. The IPA and GTN-P advocate for permafrost as a primary component of a pan-Arctic observing system and are willing collaborators in Arctic observation.

PolarWatch - A NOAA initiative to increase access to ocean remote sensing data products for the Arctic and Southern Oceans

Cara Wilson[1], Sinead L. Farrell[2], Dale Robinson[3], Jennifer Sevadjian[3], Veronica Lance[2]

1. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC), Environmental Research Division (ERD), 99 Pacific Street, Suite 255A, Monterey, CA, 93940, USA. ***Email***: cara.wilson@noaa.gov
2. NOAA, National Environmental Satellite Data and Information Service (NESDIS), Center for Satellite Applications and Research (STAR), Satellite Oceanography and Climatology Division (SOCD), College Park, MD, USA
3. NOAA/NMFS/SWFSC, Santa Cruz, CA, USA

Executive Summary: PolarWatch is a new initiative of the United States (US) National Oceanic and Atmospheric Administration (NOAA) to deliver multi-sensor physical and biological ocean remote sensing data to diverse end-users, and across disciplines, in support of broad applications in the Arctic and Southern Oceans. The primary goals of PolarWatch are to enable data discovery and broader use of publicly-available high-latitude ocean remote sensing datasets. The Arctic is currently undergoing rapid environmental change, including accelerated ice loss from the Greenland Ice Sheet and Arctic glaciers, rising permafrost and sea surface temperatures, and long-term losses in the extent and thickness of the sea ice cover (*Richter-Menge et al*., 2017). These environmental changes influence resource management protocols and regional commerce, and directly impact Arctic residents. NOAA's Arctic vision and strategy (*NOAA*, 2014) includes strengthening foundational science to understand and detect Arctic climate and ecosystem changes, and improving stewardship and management of ocean and coastal resources in the Arctic. PolarWatch advances the priorities outlined in NOAA's Arctic Action Plan by providing a systematic method to monitor Arctic change, and easily access relevant data sets. NOAA PolarWatch is relevant to the Arctic Observing Summit 2018 as an example of a new initiative, that demonstrates the use of data and information derived from satellite remote sensing systems in support of sustained, pan-Arctic observing. PolarWatch is particularly relevant to *Sub-Theme 3 "Operating Observing Systems and Networks" (Working Group 5)* as an emerging example of the value derived from the generation and distribution of public-domain satellite data products to address societal needs.

A joint initiative between the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) / Center for Satellite Applications and Research (STAR) and the NOAA National Marine Fisheries Service (NMFS) / Southwest Fisheries Science Center (SWFSC), PolarWatch builds upon and leverages the NOAA CoastWatch/OceanWatch program (coastwatch.noaa.gov). PolarWatch was created as a "node" of CoastWatch that serves both the Arctic and Antarctic regions, leveraging existing CoastWatch data services and data management capabilities. PolarWatch data products are available in a variety of file formats, accessible via a common protocol, and fully documented following established metadata standards. PolarWatch distributes data using an "ERDDAP" data server (*Simons*, 2017) that provides a simple, consistent way to download subsets of gridded, scientific datasets, in standardized machine-readable formats (e.g. netCDF, MATLAB, geoJSON, XML) and includes metadata that follows the standards for COARDS, Climate Forecast (CF), and Attribute Conventions for Data Discovery (ACDD). Download formats also include images (geoTIF, PNG, KML, PDF) and various text formats.

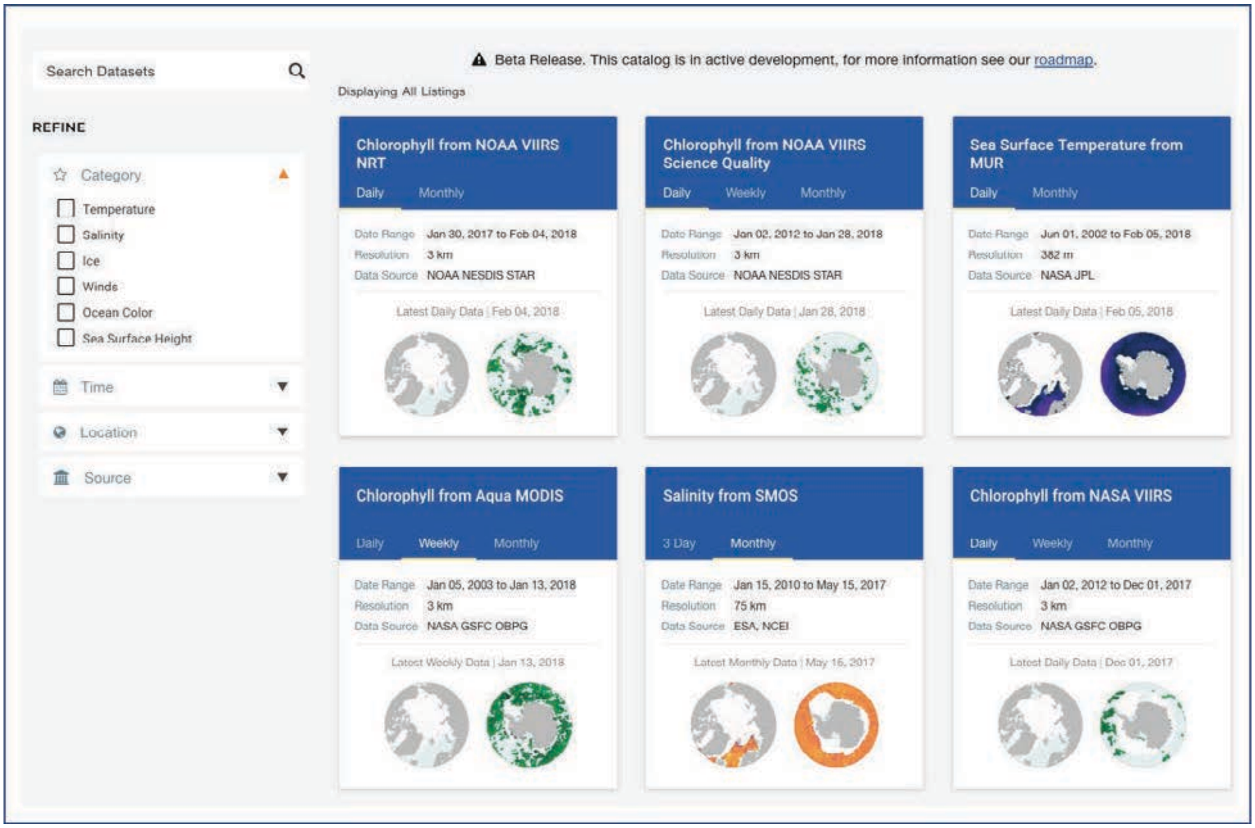

Figure 1. Interface of the NOAA PolarWatch catalogue (beta version) used to search and filter satellite ocean remote sensing datasets. The portal highlights data availability in a polarstereographic projection, for both the Arctic and Southern Oceans. Additional data products are available online at polarwatch.noaa.gov.

A primary feature of PolarWatch is an online catalogue that delivers a suite of satellite data products from a variety of sensors and data providers (Figure 1). The catalogue provides data preview and access pages, including details and background information about each data product. Previews are provided for both the Arctic and Southern Oceans in polarstereographic projection. Data downloads may be customized by area, date, parameter, and file format. The Polarwatch portal delivers both near-real-time data products, as well as science quality data products, spanning the full temporal range of the dataset. Initial datasets include sea ice concentration, sea surface height, salinity, sea surface temperature, ocean surface winds, and ocean color. During the pilot effort, we are engaging with users at the following NOAA centers: the Alaska Fisheries Science Center, the Antarctic Ecosystem Research Division, the Environmental Modeling Center, the Earth System Research Laboratory, the NOAA Climate Program Office, the Center for Satellite Applications and Research, as well as the National Ice Center.

PolarWatch also aims to provide new satellite data products to existing and emerging Arctic and Antarctic data portals. We plan to leverage existing collaborations with NOAA's National Centers for Environmental Information (NCEI) Arctic Team and the U.S. National Snow and Ice Data Center (NSIDC) to ensure PolarWatch is a complimentary service to existing national polar data services and portals. We also look forward to working with others engaged in polar data distribution to help ensure PolarWatch provides needed datasets that are interoperable with existing systems. A long-term objective of PolarWatch is to engage a diversity of stakeholders including local, state, and federal agencies, and international partners, to maximize the value of high-latitude, satellite data products.

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