AOS Summary Report - WG 1: Design, Implementation, and Optimization of Arctic observing systems

1. Working Group goals

The Design, Implementation, and Optimization working group contributes to the development of the SAON Roadmap for Arctic Observing and Data Systems (ROADS) process through discussion and sourcing contributions in the form of white papers and short statements.

Initially, the stated goals of the working group were:

a) Review of relevant initiatives and tools aimed at cataloging and assessing various existing observing system components (in situ, satellite, and associated model and prediction systems). Relevant observatories include big national/international programs, single-institution long-term monitoring projects, community-based monitoring as well as individual/small team observing campaigns.

b) Drawing on findings from goal a) to identify the value and role of the various observing activities in the context of an overarching observing system, and to chart paths towards integration of such system components.

c) Identifying criteria for observing system optimization.

As the ROADS process developed, the working group was further tasked with generating recommendations for how to define and select Essential Arctic Variables (EAV) and for the ROADS process as a whole.

2. AOS 2020 WG 1 session summaries and outcomes

Working group 1 met during the 2020 AOS during 7 breakout sessions for a total of 17 hours. These sessions were scheduled to repeat content in different time zones, and the recommendations from similar sessions were combined.

Day 1: Recommendations for a structured observing coordination model

Existing global observing systems provide frameworks for coordinated observations, including, e.g., domain-specific infrastructure for international coordination and observing system development. Such global-scale coordination frameworks are particularly well developed in the physical sciences (e.g., Global Ocean Observing System, GOOS, Global Cryosphere Watch, GCW, and others), in contrast with, e.g., social or community-based observations. At present, in the Arctic there is a need for (i) improved coordination of observations that could link to existing global frameworks, (ii) ramp-up of coordination for activities that lack frameworks entirely, and (iii) coordination across observations of different system components, disciplines or sectors.

A Coordinated Arctic Observing System (CArObS) should therefore leverage the strengths of the global networks and operate in coordination with these initiatives wherever possible. However, it needs to be more than the sum of the existing systems. In order to meet the needs of the Arctic research, resident, and private sector communities additional frameworks are required to coordinate observing in this more complex space, as tentatively identified in the early ROADS planning process. Barriers to implementing ROADS include technological considerations (with regard to difficulty of operation in the Arctic, accessibility, and economies of scale), appropriate data access approaches, and the need for operationalization (rather than project-funded mechanisms) of core components of the observing system.

Ultimately, advancing ROADS will require a combination of bottom-up and top-down approaches to link societal benefit areas to achievable observations. Widely representative expert panels and well-advertised rounds of community input are seen as the path forward: Arctic Indigenous community support is critical for success. At the same time, meaningful engagement of global networks including GOOS, GCW, and others is necessary for an interoperable system.

Invited presentations:

Several invited presentations provided perspectives on the issues identified above.

- Tonghua Wu, Chinese Academy of Sciences - State Key Laboratory on Cryospheric Sciences - Frameworks for observations of cryospheric change in China & application for Arctic settings
- Jun Inoue, National Institute of Polar Research, Japan - Observations for Asian extreme weather prediction and Arctic maritime transport
- Jari Haapala, Finnish Meteorological Institute - Global Ocean Observing System framework and coordinated Arctic observations
- Tom Christensen, Circumpolar Biodiversity Monitoring Program (CBMP) - Lessons from CBMP for more broadly coordinated observations of Arctic change
- Olivia Lee, University of Alaska Fairbanks & Finn Danielsen, Nordeco - Community-based monitoring for living resource management

Day 2: Recommendations for Essential Arctic Variables

The draft ROADS process proposed using Essential Arctic Variables as a frame around which to organize a broader observing system. WG1 discussions in Day 2 sessions focused on how to define or scope Essential Arctic Variables in order to maximize their benefits to the community.

These discussions highlighted several competing approaches for proposed EAVs:

- There is an opportunity to leverage existing global variables (Global Climate Variables, GOOS Essential Variables, etc.) but also a hesitancy to reinvent the wheel by replicating work done by these global organizations.
- The great success of many global programs is in the absolute standardization of measurement practices, but we recognize that the Arctic has a great diversity of sectors, sub-systems and disciplinary foci, and individual observers may or may not have access to particular technologies and equipment.
- There is a great need for observations in the Arctic, but limited resources with which to gather them.

Additional discussion in the WG3-organized cross-cutting session provided context from the Indigenous community for these variables. Ultimately, several key ideas for EAVs emerged:

- Essential Arctic Variables are Shared Arctic Variables: The observables for which this level of effort in coordination is warranted are those for which there is demand across multiple sectors. If only one group has a use for a particular type of information, it does not need a high level of international and cross-sector organization.
- Measurement standards should be defined, but such that there are multiple data quality thresholds that allow for different levels of rigor to contribute to the observing system. Some participating observers will have more resources than others, and a successful observing system will be accessible to everyone who is able to contribute.
- These measurement standards should include recommended paired observations, in order to best leverage observing activities being organized within the context of particular scientific disciplines for other purposes. This may also contribute towards the Indigenous food security lens (WG3) emphasis on contextualizing information. Research supersites are an example of this in practice, but the approach should be taken at smaller scales as well.
- Global Essential Variables are defined in addition to Shared/Essential Arctic Variables: An Arctic system should contribute to the global observing systems in addition to meeting Arctic-specific needs.
- Potential utility in supporting forecasting models, i.e., data that inform improved process modeling or contribute to model initialization, and/or the relevance to decision making were highlighted as key criteria for selecting EAV.
- Candidate Essential Arctic Variables should be considered from a broader pool than only geophysical parameters: ecosystems, contaminants, and social systems are integral parts of the Arctic and require mechanisms for sharing observations.

Day 2/3: Furthering the ROADS process and additional recommendations

Further discussions focused on the ROADS process and specific steps to begin its implementation. Expert panels were identified as the key instrument to define and select EAVs, though additional rounds of community comment are required throughout the process to achieve broad buy-in to the concept. Expert panels should draw from diverse sectors, with observers and those who use the observations wellrepresented. It is critically important that Indigenous knowledge holders be part of each panel, and that the process for assembling the groups be transparent. Language and differences in background are certainly going to be challenges in developing the standards, and as such we as a community must commit to taking the time to communicate respectfully and thoroughly.

Discussions identified a need for an intermediate step in the development of the ROADS process through which ideas and approaches could be applied at a regional scale. With fewer actors and a more focused goal, a regional observing system would be a testbed for the full Arctic Observing System. The Bering Sea region (and the broader Pacific Arctic sector extending into the Chukchi Sea) was proposed as the initial test region, as there is already active engagement with a number of individuals and groups operating in the region and the local Indigenous community. An additional site may be spun up in the Barents Sea.

In light of the COVID-19 pandemic, the working group recognizes that Arctic Indigenous Peoples' are in both a position of heightened risk and have a unique position to contribute to observing activities in the coming year(s). Indigenous community observing frameworks should be supported through technical and financial support from research institutions and agencies. This would both help sustain key existing long-term observations and develop additional capacity in the region.

3. White paper contributions

The existing Arctic Observing system is a mix of components, networks, and organizations each operating within their own topical, national, methodological, or circumstantial scopes. The Design, Implementation, and Optimization working group (WG1) works to conceptualize a unified, Coordinated Arctic Observing System (CArObS) in which these efforts operate in concert. To do so requires first an understanding of existing initiatives and networks and observing activities across the Arctic. Several white papers and short statements submitted to AOS 2020 responded to this call. Below, a synthesis of white papers pertaining to WG1 identifies ways forward in implementing ROADS through development of assessment criteria and evaluation of potential observing system components.s

3.1 Existing initiatives and networks

Development of a comprehensive CArObS builds on initiatives and tools aimed at cataloging and assessing potential in situ and satellite observing system components, and associated model and prediction systems. Global initiatives have identified challenges standing in the way of an IAOS. National/international programs, single-institution long-term monitoring projects, community-based monitoring as well as individual/small team observing campaigns have developed strategies for organizing and prioritizing observing efforts. The white papers and short statements discussed below provide key insights into processes and values that should be reflected in the future CArObS.

3.1.1 Global initiatives and Arctic interests

Global efforts help illustrate how to coordinate across stakeholders with varied interests. Several global observing initiatives already include Arctic components that need to be considered in developing a CArObS.

Partnership for Observation of the Global Ocean members recognize an interest in Arctic observing, noting especially geopolitical and climatic drivers, the unique logistical and geopolitical challenges, and have accordingly agreed to prioritize international coordination for Arctic Ocean observing (Seeyave and Owens, 2019). They consider ongoing AOS efforts key to further development in this area, and emphasize the development of a Arctic Regional Component of the Global Ocean Observing System in collaboration with regional and global initiatives. Such an ARC-GOOS will better integrate the region into the global observation system, and leverage the system infrastructure for delivering these observations in areas of societal interest (Starkweather et al., 2019a).

Cripe and Jarvis (2019) note that the Arctic community could adopt an approach similar to the Global Agricultural Monitoring (GEOGLAM) Flagship activity, part of the Group on Earth Observations observing and information product portfolio. An Arctic flagship activity emulating GEOGLAM might consist of a federated Arctic observing system capable of tackling challenges such as food security for the region, drawing on a flexible and efficient governance structure. A key recommendation that draws on the experience with GEO is attaining "a political mandate for supporting food security in the Arctic …[as] another key component for success. As has been shown by the GEOGLAM experience, having the endorsement of the G-20 Ministers is essential for giving the initiative the necessary gravitas, authority and credibility to rally international cooperation in a non-binding, best efforts context."

3.1.2 Regional initiatives in Arctic observing

Joseph et al. (2019) summarize the SAON survey that identified the state of readiness of different SAON member nations in addressing the three main SAON goals and associated sub-tasks. In doing so, they add weight to Cripe and Jarvis' suggestions in terms of the need to further consolidate the mandate at the national and international level, using existing SAON and Arctic Science Ministerial (ASM) channels. The survey results are highly encouraging in terms of seeing progress on major goals, developing and supporting the SAON Roadmap, and they furthermore provide specific guidance on where more work is needed, in particular with respect to creating funding and support mechanisms to sustain coordinated observations in the Arctic. These latter findings should enter into the crafting of the AOS input into the ASM-3.

Components of a larger Arctic Ocean observing systems are underway around the world, though without the international governance to efficiently coordinate the national infrastructures. As these programs develop further, the complex landscape of systems makes for a system that inefficiently addresses societal needs. A roadmap for coordinating the greater observing system is therefore urgently needed, addressing collaboration and governance, best practices and standards, and data management (Sagen et al., 2019).

International efforts such as the Year of Polar Prediction and the MOSAiC field campaign may provide insights into the most impactful observational strategies and a path forward for observing system design (Starkweather, 2019) and governance.

Similarly, regional initiatives like that described by Druckenmiller et al. (2019) which aims to enhance the coordination, design, and development of transboundary landscape-scale coordinated monitoring networks in the Northwest Boreal region of Alaska, Yukon, Northwest Territories, and British Columbia, provide an example of linking societal needs to observing priorities at the local to regional scale.

Barry et al. (2019) provided a brief overview of the Circumpolar Biodiversity Monitoring Plan that aims to monitor Arctic living resources in coastal, marine, freshwater and terrestrial ecosystems. Focal Ecosystem Components (key indicator species) that are jointly developed by scientists and traditional knowledge holders demonstrate how the collaboration can work in the context of Indigneous food security.

3.1.3 National-scale observing networks

Gilmour (2019) describes existing and planned observing activities and infrastructure in the Canadian Arctic used primarily for surveillance of the Canadian Arctic. These include satellite assets, air ships, passive acoustic hydrophone arrays, unmanned aerial vehicles, and patrol ships. The focus on Arctic observations for surveillance purposes is important to acknowledge, but the issue of accessibility of these observations is typically beyond the scope of discussion among scientists and civilian decision-makers.

Lappalainen et al. (2019) illustrate the Pan-Eurasian Experiment (PEEX) Program, an international, multidisciplinary, multiscale initiative that integrates measurements of the hierarchical PEEX network (including flagship stations as well as flux stations and stations with different standards) to increase the knowledge of land, atmosphere, and ocean interaction processes. In particular, the focus of the network is to increase our understanding of how anthropogenic activities impact ecosystems and urban environments, to address global grand challenges such as climate change, urban air pollution, ocean acidification, food security. PEEX objectives and multiscale approach are shared with the international initiative “air Pollution in the Arctic: Climate Environment and Societies” (PACES) described by Law et al. (2019).

Hübner et al. (2019) describe the Svalbard Integrated Arctic Earth Observing System (SIOS), a multidomain distributed system comprising infrastructure established by 25 institutions from 10 countries. SIOS focuses on processes and the interactions between biosphere, geosphere, atmosphere, cryosphere, and hydrosphere. Coordination of such a distributed observing system occurs through an adaptive monitoring mechanism that enables prioritization decisions in a concerted and transparent manner.

Hogg (2019) presents the Canadian High Arctic Research Station (CHARS) campus in Cambridge Bay (Iqaluktutiak), Nunavut (Canada) as a potential long-term location for a nodal measurement site that will enhance understanding of biological response to environmental change. Following the model given by the ANTOS (Antarctic Nearshore and Terrestrial Observation System) initiative, the site could become a reference site of a tiered observation network that requires varying levels of resourcing, logistic and scientific capabilities. The long-term sustainability is assured by the support of Polar Knowledge Canada.

Straneo et al. (2019) describe the Greenland Ice sheet-Ocean Observing System (GrIOOS), consisting of a set of ocean, glacier, and atmosphere essential variables to be collected at diverse sites around Greenland for a minimum of two decades. The scope of the system is to address the needs of society in relation to a changing Greenland Ice Sheet (sea level, ocean circulation, sea ice, biogeochemistry, and marine ecosystems around Greenland). The Arctic research community in Greenland and Denmark (Christensen et al., 2019) proposes the parallel establishment of a collaborative platform across all sciences to document and understand Greenland's ongoing changes and predict impacts. This Greenland Integrated Observing System (GIOS) would build on existing infrastructure and research initiatives, providing sustained observations of key climate, ecosystem and societal variables at key sites around Greenland.

3.2 Observing activities and networks

3.2.1 Citizen science and Community-based monitoring

The Indigenous Sentinel Network (ISN) conceived and refined over close to two decades by the community of St. Paul, Alaska, has established an observing framework for marine mammal observations and related subsistence harvest information. A mobile phone app and a set of rigorous community-guided protocols support the observing efforts. Strong ties with government agencies and scientists to link community observations to marine resource management are key program strengths. ISN is currently expanding, partnering with communities in other parts of the North American Arctic (Divine and Robson, 2019).

The INTAROS project and Association of Arctic Expedition Cruise Operators see Arctic expedition cruises as an opportunity for increasing in situ observations in remote Arctic waters. Citizen science programs are adapted for passengers on cruises, who appreciate the opportunity to contribute. Additional opportunities exist for cruise vessels to collect samples to send back to scientists or to carry monitoring instrumentation (Poulsen et al., 2019). Polar Citizen Science Collective promotes ship-based citizen science projects in the Arctic as well (Taylor et al., 2019). More structured guidelines on observing standards would help cruise operators better meet scientific needs.

3.2.2 In situ platforms

Developments in in situ observation technology highlight the need for a coordinated observing system. Köhler et al. (2019) highlight the need for more seismic and cryoseismic monitoring infrastructure.

Planck (2019) illustrates how improvements in sea-ice buoy functionality and reliability help the instrumentation engineering community better address observational needs, assuming that community-generated requirements, especially with regard to data availability and format, guide next steps in development. Coordination with proposed telecommunication cables across the Arctic could create opportunities for coastal stations (Sagen et al., 2019). Petäjä (2019) encourages circumpolar collaboration in interest of maintaining interdisciplinary observing stations and further filling in gaps.

3.2.3 Space-based platforms

Satellite-based instruments provide extensive and frequent coverage of the Arctic environment that cannot be matched by other types of platforms. The breadth and variety of information gathered through satellite observations is a massive component of the Arctic observing system. Services that provide higher level products derived from satellite observations bring this information to the people who need it. The Finnish Environment Institute (Koponen et al., 2019) has developed environmental monitoring services using Copernicus products including water quality, snow cover extent, and lake ice extent. These products are available for the public, stakeholders, and decision makers to use for their own purposes, including risk mitigation and climate adaptation.

3.2.4 Use cases

Several short statements emphasize specific improvements to the Arctic observing system that are important to understand specific research needs, both in terrestrial and marine environments.

Duncan and Ott (2019) emphasize that existing satellite observing networks are inadequate to address improved process-understanding of the carbon and hydrological cycles in the Arctic Boreal Zone, and a step-wise approach to improve satellite observations and data standards is recommended. Konoreva et al. (2019) suggest improvements for monitoring lichen distribution, diversity, and chemical structure in the Arctic. Sudakov (2019) describes an approach to use machine learning to integrate satellite and field observations into models of permafrost disturbance and microbial community change in Siberia. Kaplin (2019) shares concerns of large-scale Siberian forest fires, and the role that better observations could play in understanding carbon release from such fires and improvements to enforce logging company compliance. Streletskiy et al. (2019) describe the success of the Global Terrestrial Network for Permafrost (GTN-P), but emphasize the need for a more stable funding structure to enable sustainable coordination and long-term collaboration for this network that is already providing products used by many stakeholders. Yurganov (2019) describes current shortcomings in monitoring methane emissions over the Arctic ocean, and provides recommendations for improvements in satellite observations and modeling efforts that are needed to further understanding this component of Arctic change.

3.3 Criteria for observing system optimization

The GOOS framework described bySeeyave and Owens (2019) is structured around policy drivers and the scientific and operational needs they create. This process requires the identification of Societal Benefit Areas to guide the requirements for the observations and motivates investments in the observing system as a whole.

Jones et al. (2019) describe the concept of Focal Ecosystem Components (FECs) which were jointly identified by scientists and traditional knowledge holders to develop a shared understanding of how to monitor coastal biodiversity change. For each of these FECs further work was done to identify general categories for monitoring (attributes) and specific measurements (parameters) that apply across seven identified Arctic 'coastscapes'. There are parallels between the SBA framework and the FEC framework used in the development of the Arctic Coastal Monitoring Plan, and the lessons learned from this effort would be helpful to inform further development of the ROADS process.

The new NSF project presented by Druckenmiller et al. (2019) will build strategies for coordinated monitoring networks results to be more effectively applied to important decision-making processes around community resilience, maintaining cultural heritage, land and resource management, climate adaptation and land use planning, sustainable economic development, engineering strategies, and hazard mitigation.

Abdel-Fattah et al. (2019) suggest a new multi-stakeholder, multi-criteria approach based on decision and risk analysis to understand the effects of a changing Arctic and more broadly the cryosphere. They apply this approach in the mitigation of glacial lake outburst floods, which pose potential hazardous impacts in a number of downstream communities worldwide. An optimal mitigation strategy will be identified based off this research, with the intention that it can be shared with the Arctic local communities for their review and assessment.

INTAROS (Tjernstrom et al., 2019) carried out a significant assessment of Arctic observing systems, covering aspects including system sustainability, funding status, technical maturity, and data handling. They recommend that Arctic observing efforts coordinate with international and regional programs that have existing procedures rather than reinvent Arctic-specific processes, suggesting that the best value in new scientific instrumentation investment would be at existing research sites, in order to allow for interdisciplinary studies and leverage existing infrastructure. Additional ship-based research expeditions are required, and these can be addressed through a combination of increased funding, using ships of opportunity, and implementing a standard set of core observations across all scientific vessels in the Arctic. INTAROS recognizes that because of the limited in situ observations in the Arctic, coupled reanalysis products constitute an important part of the 'observing' network and as such require additional investment.

UArctic is establishing a *Thematic Network on Collaborative Natural Resource Management and Community-Based Observing* in response to increased calls for collaborative management and monitoring. The process for developing an IAOS should consider what capacity needs are required to meet observing goals and communicate these to systems in educational roles (Danielsen et al., 2019).

3.4 Input into the ROADS process

Existing systems of observations have valuable experience to inform the ROADS process. Prior discussions - many through the Implementation, Design, and Optimization working group at the 2018 AOS - have contributed to SAON's ROADS strategy. There is a definite need for consolidated recommendations for funding agencies, and in doing so a set of priorities must be developed (Starkweather et al., 2019b). The GOOS model of structuring observing efforts around Essential Ocean Variables has been identified as a path forward in the Arctic (Starkweather et al., 2019a).

Cripe and Jarvis (2019) highlight the importance of a flexible governance structure that proved to be essential in implementing GEOGLAM, where it consisted of an executive committee, a secretariat, and ad-hoc working groups along with regional network coordination. They see the definition of essential variables – supported through a dedicated working group – as a key step towards success. Such a working group in the case of the Arctic would likely emerge out of AOS activities and entrain expertise through SAON and other international bodies. Cripe and Jarvis emphasize the need for a focus, e.g., on food security including fisheries and aquaculture. A draft set of EVs for the Arctic could then be jointly reviewed with GEO entities such as the Committee on Earth Observing Satellites (CEOS) and the GEO Marine Biodiversity Observation Network (MBON) to help address observing gaps.

Governance and implementation remain a challenge in the ROADS process, but there are examples to draw from. Joseph et al. (2019) point out that while the majority of SAON member countries are able to engage in the ROADS process, there are still gaps in filling in the details of ROADS and sustaining observing system activities. The structures created to coordinate SIOS are built to facilitate and stimulate the involvement of the entire decentralized research community in the adaptive evolution of the observation system. They are based on bottom-up commitment and a top-down prioritization mechanism (Hübner et al., 2019). A similar approach may be appropriate in further development of ROADS. Lappalainen et al. (2019) describe the hierarchical network concept applied in PEEX as an example of integration of existing measuring platforms to observe interdisciplinary processes across different spatial and temporal scales. The idea of a 'tiered observation network' is supported also by Polar Knowledge Canada (Hogg 2019). The Arctic GEOSS (Global Earth Observation System of Systems) initiative, a collaboration between SAON and GEO, has overarching goals similar to ROADS (Joseph et al., 2019).

Several efforts to assess observing capacity have conducted inventories (SAON Committee on Observations and Networks, EU-PolarNet, INTAROS, Arctic Observing Viewer, Alaska Ocean Observing System, and others) that are limited in scope and do not share information between them (Manley et al., 2019). An "Observing Network Interoperability Working Group" with representation from these observing networks could define community-generated standards for metadata on the network-level in addition to project and site levels. This working group could also be responsible for refining definitions related to SBAs, EAVs, and other shared terminology, and for establishing compatible web services. This would allow new assessments to work more efficiently, using the systems developed previously to build out a more comprehensive assessment of Arctic observing systems.

Andersen et al. (2019) provide a very helpful overview of key aspects of the Copernicus program portfolio that are in need of data/information or other types of linkages to Arctic observing programs. The Copernicus In Situ Coordination activity led by the European Environment Agency in particular is an effort that is potentially of substantial value in informing key elements of ROADS, specifically those related to capturing observing system requirements for specific applications or missions. The report from this activity furthermore illustrates some of the challenges and provides further justification to the goals of SAON and the ROADS process.

4. Overall conclusions & specific recommendations

Through the white paper process and the discussion sessions at AOS 2020, WG1 has concrete recommendations for SAON with regards to the ROADs process and the development of the Essential Arctic Variable concept. Recognizing that the herculean effort of organizing observations is most valuable when there is a specific need for sharing information across sectors without other means of collaboration, we propose that Shared Arctic Variables be the standard around which the coordinated system is organized. This system must provide standards applicable across sectors in order for observations to meet established needs for societal benefit, but also have sufficient flexibility to be inclusive of the groups that have resources (including time, access, and ideas) to contribute.

Overall, the ROADS process has been recognized as an important and timely next step towards an organized and collaborative Arctic Observing System. The working group recommends SAON convene broadly inclusive expert panels in order to begin development of a set of Shared Arctic Variables in geophysical, biological, and social science fields.

In parallel, regional efforts to implement these ideas will offer test scenarios for an organized Integrated Arctic Observing System, in which disparate sector and national interests can gather around shared information needs and pool resources towards better observations of the current state of the Arctic. The Bering and Barents Sea regions along with other regions have been identified as suitable candidates for the regional pilot programs. For the Bering Sea and adjacent Pacific Arctic sector, WG 1 presentations and deliberations have identified the Global Ocean Observing System - with its Arctic regional team of experts, the Circumpolar Biodiversity Monitoring Program, several regional, community-driven observing initiatives including the Indigenous Sentinel Network, and others as partners in organizing a regional workshop and follow-up activities.

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