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Sustaining Arctic Observing Networks' (SAON) Roadmap for Arctic Observing and Data Systems (ROADS)

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ABSTRACT. Arctic observing and data systems have been widely recognized as critical infrastructures to support decision making and understanding across sectors in the Arctic and globally. Yet due to broad and persistent issues related to coordination, deployment infrastructure and technology gaps, the Arctic remains among the most poorly observed regions on the planet from the standpoint of conventional observing systems. Sustaining Arctic Observing Networks (SAON) was initiated in 2011 to address the persistent shortcomings in the coordination of Arctic observations that are maintained by its many national and organizational partners. SAON set forth a bold vision in its 2018–28 strategic plan to develop a roadmap for Arctic observing and data systems (ROADS) to specifically address a key gap in coordination efforts—the current lack of a systematic planning mechanism to develop and link observing and data system requirements and implementation strategies in the Arctic region. This coordination gap has hampered partnership development and investments toward improved observing and data systems. ROADS seeks to address this shortcoming through generating a systems-level view of observing requirements and implementation strategies across SAON's many partners through its roadmap. A critical success factor for ROADS is equitable participation of Arctic Indigenous Peoples in the design and development process, starting at the process design stage to build needed equity. ROADS is both a comprehensive concept, building from a societal benefit assessment approach, and one that can proceed step-wise so that the most imperative Arctic observations—here described as shared Arctic variables (SAVs)—can be rapidly improved. SAVs will be identified through rigorous assessment at the beginning of the ROADS process, with an emphasis in that assessment on increasing shared benefit of proposed system improvements across a range of partnerships from local to global scales. The success of the ROADS process will ultimately be measured by the realization of concrete investments in and well-structured partnerships for the improved sustainment of Arctic observing and data systems in support of societal benefit.

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Key words: framework; roadmap; observing; data; Indigenous knowledge; societal benefit; essential variable; shared Arctic variable

RÉSUMÉ. Les systèmes de données et d'observation de l'Arctique sont grandement considérés comme des infrastructures critiques en matière de prise de décisions et de compréhension dans les divers secteurs de l'Arctique et d'ailleurs dans le monde. Pourtant, en raison de problèmes importants et persistants en matière de coordination, d'infrastructure de déploiement et de retards technologiques, l'Arctique figure toujours parmi les régions les moins bien observées de la planète pour ce qui est des systèmes d'observation conventionnels. Les réseaux Sustaining Arctic Observing Networks (SAON) ont été mis en œuvre en 2011 afin de combler les écarts persistants en matière de coordination des observations dans l'Arctique, observations effectuées par ses nombreux partenaires nationaux et organisationnels. Dans son plan stratégique de 2018 à 2028, SAON a dressé une vision audacieuse en vue de l'élaboration d'un plan pour les systèmes de données et d'observation de l'Arctique (ROADS) afin de combler un écart important en matière d'efforts de coordination, soit l'absence actuelle d'un mécanisme de planification systématique pour développer et interconnecter les exigences et les stratégies de mise en œuvre des systèmes d'observation et de données dans la région de l'Arctique. Ce manque de coordination a nui à la conclusion de partenariats et d'investissements donnant lieu à des systèmes de données et d'observation améliorés. ROADS a comme objectif de combler cet écart grâce à la détermination des exigences d'observation et à des stratégies de mise en œuvre au niveau des systèmes pour tous les partenaires de SAON grâce au plan établi. Un facteur de réussite critique pour ROADS consiste en la participation équitable des peuples autochtones de l'Arctique au processus de conception et de développement, en commençant par le stade de la conception afin d'obtenir la participation nécessaire. ROADS est à la fois un concept exhaustif qui s'appuie sur une démarche d'évaluation des avantages pour la société et un concept progressif permettant l'amélioration rapide des observations les plus impératives de l'Arctique, ici décrites comme les variables partagées de l'Arctique (SAV). Les SAV seront déterminées au moyen d'une évaluation rigoureuse au début du processus ROADS, l'accent de cette évaluation étant mis sur l'augmentation des avantages partagés découlant des améliorations proposées aux systèmes dans le cadre de divers partenariats, tant à l'échelle locale que mondiale. Au bout du compte, le succès remporté par le processus ROADS se mesurera en fonction d'investissements concrets dans des partenariats bien structurés en vue du soutien amélioré des systèmes de données et d'observation de l'Arctique pour favoriser les avantages qu'en tirera la société.

Mots clés : cadre de référence; plan; observation; données; connaissances autochtones; avantages pour la société; variable essentielle; variable partagée de l'Arctique

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BACKGROUND

The initiation of the international Sustaining Arctic Observing Networks (SAON) was motivated by the collective challenges associated with coordinating, improving, integrating and sustaining pan-Arctic observations in the face of rapid environmental and social change. SAON is a joint initiative of the Arctic Council and the International Arctic Science Committee (IASC), both of which recognized that the complex organizational dimensions of Arctic observing activities (i.e., multidisciplinary, transboundary, cross-sectoral, overlapping mandates) called for a body like SAON to serve as a regional facilitator toward shared goals (AC, 2011). SAON has been recognized as a critical infrastructure in the region to support sustainable development and decision making (Berkman, 2015). Its intent as an open initiative is to engage Arctic and non-Arctic countries, Indigenous Peoples, academia, the private sector, and other key partners in support of a comprehensive, integrated observing network supported by interoperable data systems. Since its formal inception in 2011, SAON has grown into a vibrant and progressive collection of activities in support of data interoperability and network synthesis. Recently, SAON has been called upon to engage more directly in developing planning approaches for the needed observing networks and data systems (AOS, 2016; ASM2, 2018; ASM3, 2021). Such an ambitious undertaking requires a clear outline of the specific challenges and objectives that such planning entails, which begins within the context of widespread changes witnessed in the Arctic.

In recent decades, scientific, Indigenous, and local observations of the Arctic system (Murray et al., 2010) have revealed a pace, magnitude, and extent of change that is unprecedented by many measures. These changes include rapid melting and thawing of the cryosphere (AMAP, 2017a; IPCC, 2019), and shifts in ecological communities that threaten biodiversity (ICC-AK, 2015; CAFF, 2017; Lento et al., 2019) and undermine food security and resilience across northern communities (ICC-AK, 2015; AC, 2016). These changes result in adverse impacts to natural and built Arctic environments including increased coastal and riverine erosion, storm surges, more numerous and severe wildfires, damage to infrastructure, and risks to fresh water supplies (Ivanov et al., 2020, Lappalainen et al., in press). Observed impacts from Arctic change are not confined to the region. Melting Arctic land ice impacts global sea level and ocean circulation (IPCC, 2019). Moreover, regional alterations to sea ice, ocean surface waters, and the overlying atmosphere may influence the severity of weather in midlatitudes

(Overland et al., 2016). Migratory wildlife constitutes a living connection between the Arctic and the rest of the world. Sustained observations of the region, along with model projections, provide critical insights to develop urgently needed adaptation strategies (e.g., Knapp and Trainor, 2013; AMAP, 2017a, b, c, 2018; Cuyler et al., 2020; Petäjä et al., 2020), yet Arctic observations are currently too limited both spatially and temporally and insufficiently coordinated to adequately inform them (e.g., Lee et al., 2019).

There are several intersecting challenges to collecting, coordinating, and disseminating Arctic observations. The physical challenges of polar conditions (e.g., polar night, extreme cold, lack of conventional infrastructure, access, and communications systems [Jeddi et al., 2020]) increase conventional observing system costs, constrain coverage, and limit real-time data dissemination. Coordination challenges arise from the vastness, interdisciplinary scope, and multilevel governance of the Arctic. Observing activities involve diverse knowledge systems (Tengö et al., 2014, 2021) and scientific disciplines and span national boundaries and Indigenous homelands. Presently, a heterogenous range of independently sponsored activities collect and disseminate Arctic observations. Most activities lack the Indigenous leadership or representation that has been called for in northern research strategies and critiques (e.g., ITK, 2018; Saami Council, 2019; Kawerak Inc., 2020; Stone, 2020), even as locally embedded observing strategies that include Indigenous observers have been identified as resilient, safe, equitable (Petrov et al., 2020), and low-carbon (e.g., IASC Action Group on Carbon Footprint) ways to increase Arctic observations. Remarkably, there is no comprehensive planning mechanism for linking and coordinating across current observing and data management activities or identified needs. This important gap leads to further challenges. For example, fragmented research and observing activities put a strain on Indigenous communities and are unlikely to address the needs they have determined to support decision making. Fragmentation also impedes investment decisions within funding agencies, which are required to justify their resource allocations in the face of these complexities.

SAON's national partners have already invested a considerable amount into Arctic in situ and satellite observing and related data infrastructure in support of operational needs and academic research; these investments have been demonstrated to deliver economic benefits exceeding their costs (Dobricic et al., 2018). Governments at all levels, Indigenous Peoples, and local communities sustain their own networks as well (Danielsen et al., 2021). An important portion of these activities is independently initiated through grassroots efforts, supported by proposal writing and revolving grant awards. SAON's vision is to bring these parties into a connected, collaborative, and comprehensive long-term pan-Arctic observing and data system of systems that serves societal needs.

Collectively, sponsors and partners have turned to SAON to guide Arctic observing and data system development, yet it is important to recognize that SAON's ability to influence partner actions through collaborative governance is non-hierarchical and therefore contingent upon cooperation. Ostrom (2010) would describe the SAON governance model as polycentric, which describes governance systems through which multiple centers of authority are working toward a common goal. Morrison et al. (2019) noted that "polycentric actors" like SAON might exert three types of power: by design, pragmatic, and framing. Of these, framing power is most applicable to SAON, where it can lead on problem framing, setting norms, and influencing discourse.

Reflective of its role as a polycentric actor, SAON's strategic plan (SAON, 2018) outlined important guiding principles to achieve its vision. Those principles include a recognition that SAON values both research and operational needs for Arctic observations and that the needed observations will be implemented and sustained through cooperative partnerships under a common SAON umbrella. Because these partnerships are found across a variety of organizational settings from governmental to academic, SAON recognizes that the design and operation of Arctic observing and data systems will be guided by a balance between grassroots and top-down needs, priorities, and perspectives.

SAON's partnerships with Arctic Indigenous Peoples' organizations entail specific guiding principles for ethical and equitable engagement in linking diverse knowledge systems, including scientific, Indigenous, and local systems, each of which holds unique perspectives on the Arctic system. Indigenous knowledge is a systematic way of thinking and knowing that is elaborated and applied to phenomena across biological, physical, cultural, and linguistic systems. Indigenous knowledge is owned by the holders of that knowledge, often collectively, and is uniquely expressed and transmitted through Indigenous languages. It is a body of knowledge generated through cultural practices, lived experiences including extensive and sometimes multigenerational observations, lessons, and skills. It is still developing in a living process, including knowledge acquired today and in the future (IPS, 2020). Local knowledge refers to skills and understandings developed by groups of individuals in a specific local setting, often informing decision making in day-to-day life. In contrast with Indigenous knowledge, local knowledge does not presuppose a broader, shared worldview, although it often is associated with a shared local understanding of context. Most local and Indigenous knowledge systems are empirically tested, applied, contested, and validated through different means in different contexts (Hill et al., 2020; Eicken et al., 2021). These specific guiding principles in SAON's strategic plan aim to support equity in addition to rigor, as fragmented science efforts that do not engage these principles can lead to false conclusions (e.g., Ward-Fear et al., 2019; Raymond et al., 2020).

Through following these principles in its strategic plan, SAON aims to mobilize the support for sustained observations on time-scales from years to decades and also from local to regional to global scales. Such aims require robust planning approaches.

A ROADMAP APPROACH:RECOMMENDATIONS OF SAON'S ROADMAP TASK FORCE

As part of its strategic plan, SAON identified the need for a Roadmap for Arctic Observing and Data Systems (ROADS) to set a course towards systematically defining the needed observing and data systems and to specify how the various partners and players are going to collectively work towards achieving that system. SAON's goal for its roadmap was presented to and supported by the second and third Arctic Science Ministerial processes (ASM2, 2018; ASM3, 2021). The joint statement from the Third Ministerial called for a strengthening of SAON's work, recommending to "Encourage finalizing the Roadmap for Arctic Observing and Data Systems (ROADS) through the coordination and cooperation between national and international programs, small and large projects, and infrastructures, and prioritize implementation" (ASM3, 2021:5). ROADS is a critical tool to identify and integrate requirements for observing and data systems along with implementation strategies that support data interoperability. To initiate ROADS, the SAON Board empaneled a Task Force to set forth guidelines for the community of contributors to its roadmap. The Task Force identified the following principles to guide the ROADS process:

- Indigenous Peoples' equitable partnership and funding for their active participation is critical to ROADS;
- All aspects of the ROADS process should support broadly shared benefit from the observing and data systems;
- The ROADS process should complement and integrate, without duplication, the current planning approaches used by existing networks (regional to global), activities, and projects;
- ROADS should support stepwise development through a flexible and evolving structure that allows grassroots identification of themes, infrastructures, and regional foci.

The purpose of ROADS is to stimulate new multinational investments around specific plans with clear societal value propositions, to serve as a tool for linking observations collected in support of different objectives and knowledge systems, and to ensure maximal benefits are delivered from Arctic observing and data systems to their intended users. The ROADS process is targeted towards policy makers at all levels, Arctic Indigenous communities and organizations, Arctic and non-Arctic states, academia, civil society, and the private sector, as well as other multilateral/international groups and organizations. To succeed at this ambitious challenge, SAON must engage with new partners and revitalize the terms of its engagement with existing partners.

The Arctic Observing Summit (AOS) convenes many of these partners in its biennial gathering (Murray et al., 2018). The virtual AOS 2020 sessions involved 350 participants from 29 countries and provided a critical opportunity for SAON to engage a broad and diverse cross section of its intended audience in deliberations about how the ROADS process should proceed. The following descriptions of the ROADS process reflect these combined perspectives.

A Network that Serves Societal Needs

The ROADS process is first and foremost oriented towards generating societal benefit within the Arctic region, with an emphasis on the inclusion of Indigenous worldviews in assessing that benefit. Critiques of science planning and conduct in the Arctic have shown that when locally defined societal benefit is not considered, conventional observing systems fail to address community priorities in the Arctic region, and the realized benefits are confined to the objectives of the research enterprise itself (e.g., ITK, 2018; Carlo, 2020). Further, the underlying worldview of Indigenous knowledge is holistic, whereas hypothesis-driven science methodologies favor deduction and reductionism, which constrains efforts to make use of their conclusions in a more holistic decision-making context (e.g., ICC-AK, 2020). For these reasons, Indigenous self-determination in research and co-production of knowledge approaches are emerging as necessary practices (CTKW, 2014; ITK, 2018; Behe et al., 2019) in Arctic research planning, with an emphasis on building equity.

Equity has emerged as an important goal within planning processes, particularly those related to sustainable development, exemplified by the Aichi targets of the Convention on Biological Diversity (McDermott et al., 2013; CBD, 2020). Definitions of equity in relation to sustainable development highlight three interrelated dimensions that are also applicable to the development of the ROADS process: distribution, procedure, and recognition (McDermott et al., 2013). Distribution is concerned with who realizes benefits or incurs costs (Walker, 2012); procedure refers to how decisions are made and by whom; recognition is about the status afforded to different social and cultural values or identities and to the social groups who hold them (De Jonge, 2011). These considerations inform the type of assessment methods the ROADS process should use to establish a communal and inclusive view of societal benefit across the intended user base of Arctic observations.

One starting point for societal benefit assessment is the *International Arctic Observations Assessment Framework* (AOF) (IDA STPI and SAON, 2017), an assessment framework jointly created by SAON partners to support multicriteria decision making for observing system investments. The AOF identified 12 interdependent, Arctic-specific Societal Benefit Areas (SBAs) including Food Security, Disaster Preparedness, Weather and Climate, Human Health, and Fundamental Understanding of Arctic

Systems. Critically, the AOF provides a mechanism to identify intersections between common needs in the observing system across spatial scales from local to global and time-scales from days to decades. For example, global networks and national hydrometeorological institutes fund investments to support AOF objectives under its Weather and Climate SBA to capture a comprehensive, real-time global picture of conditions. These same products, if adequately specified, could also inform AOF objectives identified under the SBAs of Disaster Preparedness, Food Security, and Fundamental Understanding in the region. The AOF has already been applied to the EU's *Impact Assessment on Long-Term Investment on Arctic Observations* project to demonstrate how the economic value of Arctic observations compounds across application areas like ship routing and fisheries management (Dobricic et al., 2018). AOF results were also applied to a value tree for physical atmosphere and ocean observations in the Arctic (Strahlendorff et al., 2019) to improve weather and climate forecasts. Further work on the AOF is being conducted in the U.S. to support improved forecasts and climate assessments (Starkweather et al., 2020).

An important input from the AOS 2020 dialog was the recognition that the AOF should not be the sole tool used for assessing impacts of observing system improvements, even as it should be further developed and adapted with broader community input, including more extensive input from Indigenous Peoples. The Indigenous Food Security Working Group, one of the AOS 2020 working groups, found the descriptions within the AOF, particularly under the Food Security area, siloed and limited. They have since undertaken an effort to establish an improved set of linked objectives within the theme of food security (FSWG, 2020), building upon previous work by the Inuit Circumpolar Council-Alaska's food security framework (ICC-AK, 2015). Given these considerations, and in support of its guiding principle for the equitable inclusion of Indigenous Peoples, the ROADS process must approach assessment as an adaptive process, with the AOF and comparable frameworks viewed as having equal value.

Assessment methods can take many forms. The AOF, for example, lends itself well to value-tree style assessments (IDA STPI and SAON, 2017), which link observations to value-added products and services. Within the ROADS process, systematic assessment of observing networks should assure that the developed requirements are consistent with a network that broadly serves societal needs and provide the rationale for sustained investments and engagement in Arctic observing. ROADS will ultimately translate relevant societal benefit objectives into requirements for the observing and data system and estimate the resources that will be needed to implement them.

Organizing Around Essential Variables

Given the complex breadth of the Arctic system, the ROADS process requires an organizational strategy for requirements and implementation strategies that supports planning by parts, but does not generate planning silos, which is considered one of the persistent failings of Arctic research planning (Carlo, 2020). SAON's Task Force reviewed network-building approaches employed by a variety of global and regional observing networks, including the Global Ocean Observing System (GOOS) Framework for Ocean Observing (FOO, 2012), Global Climate Observing System (GCOS), Circumpolar Biodiversity Monitoring Programme (CBMP), Arctic Monitoring and Assessment Programme (AMAP), Group on Earth Observations (GEO) flagships (including Global Water Sustainability, GEO Biodiversity Observing Network, and GEO Global Agricultural Monitoring), and the World Meteorological Organization's (WMO) Integrated Global Observing System. The Task Force also reviewed planning guidelines and frameworks provided by Indigenous organizations (ITK, 2018; Saami Council, 2019).

The essential variable strategy, which goes by many names, emerged as a good practice for supporting network design and development. An essential variable strategy is used to parse a system into conceptually broad observable phenomena (e.g., sea ice or precipitation) that are critical for characterizing a system and its changes. Ideally, the scope of each essential variable should strike a balance between breadth and specificity to achieve the desired outcome of integrating the observational expertise and harmonizing the methods of related communities of practitioners, without proliferating organizational complexity. The ROADS process supports a view that taking the Arctic system as a whole is vital in supporting robust adaptation strategies, decision making, and scientific understanding, but parsing it into smaller planning units is a necessary organizational step. As the highly connected Arctic system cannot solely be understood from the standpoint of the magnitude of different state variables, it may help to further characterize the system through a related set of essential processes. In the context of ROADS, an essential variable or process approach can support the guiding principle of building on existing planning efforts as many SAON partners already use some version of essential variables; it also supports the guiding principle of proceeding step-wise. Ultimately, even a partial collection of essential variables or processes would support a broad view of observing and data infrastructure needs. With these considerations in mind, the Task Force concluded that an essential variable or process approach is robust, provided there are strong, overarching mechanisms in place to avoid siloed approaches.

A fully defined essential variable, including requirements and strategies for data sharing, should be codeveloped by all of those who would share the benefit of the information. The AOS Indigenous Food Security Working Group recommends taking a co-production of knowledge approach (CTKW, 2014; Behe and Daniel, 2018; Norström, 2020) in defining variables to ensure the equitable inclusion of Indigenous Peoples and knowledge systems from the beginning. Support for coproduction of knowledge entails financial support for sustained inclusion of Indigenous Peoples, who too often are not funded for their participation in research. AOS 2020 deliberations emphasized this important gap, as well as the broad need for Indigenous Peoples to have access to capacity-building opportunities (as they have identified) within Indigenous communities and organizations to support equitable partnership in ROADS (Wheeler et al., 2020).

The ROADS guiding principle for shared benefit was underscored and enhanced through deliberations at the AOS 2020, in particular to emphasize the need for cross-disciplinary and cross-sector integration of observations that ideally tie into global observing frameworks. AOS 2020 participants recommended adopting the term "shared Arctic variables" (SAVs) (Bradley et al., 2021) for the essential variables or processes developed under ROADS and underscored that a key criterion for SAVs would be cross-sectoral use. Specifically, observations and data systems that warrant the level of effort associated with the ROADS process should serve multiple sectors and data user groups and ideally address priorities at the intersection of Arctic community-identified needs, regionally identified cross-sectoral needs and those of the global observing programs (Fig. 1). For example, a SAV might address information needs expressed by Arctic coastal communities from a coastal hazards perspective, serve Arctic research interests focused on long-term trends and variability in the state of the coastal seas, and preferably also tie back to one or more essential climate variables in the context of the GCOS. The Arctic Monitoring and Assessment Programme is already reviewing the fitness of GCOS essential climate variable requirements for Arctic applications. In contrast, observations of an essential variable that has been prioritized by a global observing program and is tracked by a narrow group of constituents is not contingent on high-level, cross-sector, international coordination. While the language "variable" is being adopted, SAVs might also center on processes.

The Task Force recommends that ROADS should focus on a select list of highly impactful variables that would be broadly beneficial and are not currently well-specified by the regional or global networks, rather than seeking to identify every possible phenomenon in the Arctic system. A noteworthy caution is that GOOS and GCOS, with 31 and 54 essential variables respectively, have struggled to develop requirements and implementation strategies for each.

In keeping with the ROADS principle of complementing current efforts in a non-duplicative approach, relevant global linkages should be identified from existing catalogs of essential variables associated with global networks (e.g., essential ocean variables, essential climate variables, essential biodiversity variables), regional programs (e.g., AMAP and CBMP), and with reference to gaps analyses like the European Space Agency's Polaris assessment (Polar View Earth Observation Limited, 2016). A global variable should only be directly adopted by ROADS as a SAV if it is found to be critical across sectors, and the global definition is inadequately serving Arctic needs. In these cases, the ROADS process should extend the requirements (e.g., adding requirements for land-fast ice observations to global variables for sea ice) and implementation strategies of the global networks where necessary to account for Arctic conditions (e.g., ice-covered ocean) and opportunities (e.g., community observers [Johnson et al., 2016; Danielsen et al., 2021]). While some global variables might not reach the level of a SAV, the ROADS process could still serve as a mechanism for improving the requirements and implementation of Arctic-relevant variables. Each SAV under ROADS should fully specify the observing and data system requirements from acquisition through high-impact information dissemination; these specifications should support consistency and interoperability across the network. The vehicle for identifying, defining, and implementing SAVs is the subject of the following section.

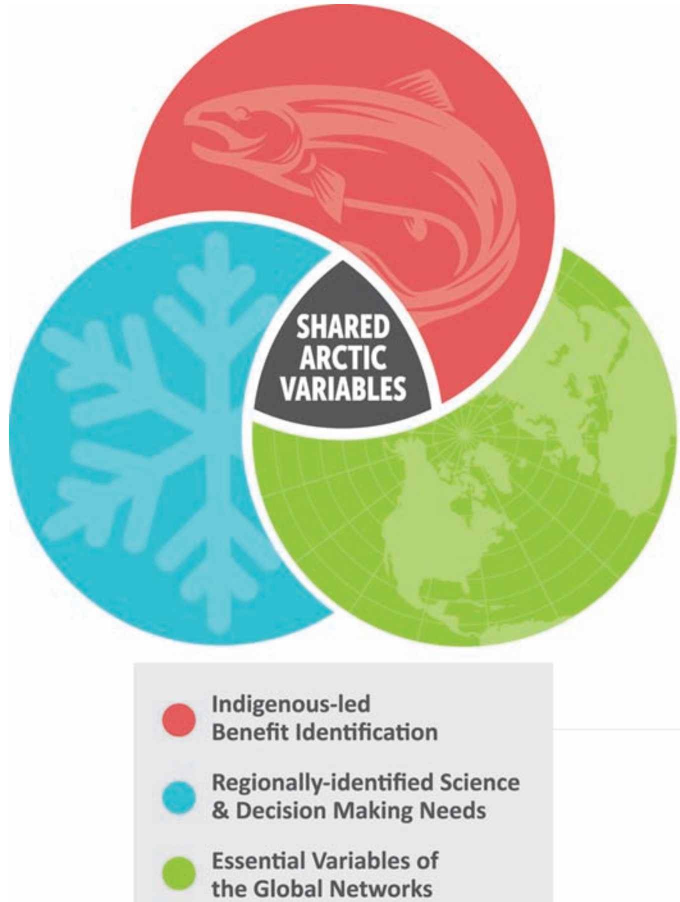

FIG. 1. Following rigorous assessment of societal benefit, Shared Arctic Variables (SAV), which characterize a fundamental aspect of the Arctic System, are identified at the intersection of benefit realization from at least two broad constituencies of use. An ideal SAV would realize community-identified benefits in Indigenous communities (light red), support fundamental understanding of Arctic systems and regional decision-making needs (blue), and inform science and decision-making needs at the global scale and integrate with operational global networks (green). Observing and data system implementation strategies for SAVs would then find support from these broad constituencies as well. For example, community-embedded observing strategies that are organized within the context of Indigenous data sovereignty would be best suited to support community identified requirements within an SAV.

Collaborative Governance

SAON sits at the intersection of a complex of research governance entities that are active across scales from the community to the global level, with science and policy foci from broad (e.g., global weather and climate) to specific (e.g., ocean noise), making polycentric governance approaches a good model for SAON and ROADS. In consideration of the progress made under the Framework for Ocean Observing (FOO, 2012) and the Circumpolar Biodiversity Monitoring Programme's ecosystem assessment studies, both of which share polycentric governance challenges, the Task Force recommended adopting a similar governance approach, using a single Advisory Panel working across a collection of regional or thematic Expert Panels. While SAON itself will appoint the Advisory Panel, it is envisioned that Expert Panels will initiate from SAON's network of partners, developing one or several SAVs within their purview. Participation in the panels must be as inclusive and relevant as the scope of the panels' proposed efforts, drawing subject matter experts from academia, Indigenous organizations, northern communities, operational agencies, partner organizations, the private sector, and government. Comprehensive subject matter expertise should include experts on value delivery such as data managers and information end users. It is critical to underline that ROADS Expert Panels are envisioned to have a scope that is consistent with a funded (or in-kind) effort, and SAON will encourage adequate support for panels to assure timely progress and equitable outcomes.

The intersecting model for SAVs suggests that Expert Panels could originate from any one of the three conceptual constituencies represented in Figure 1, while the advisory process would assure that all constituencies are fully engaged. For example, the World Meteorological Organization has initiated a series of regional projects to improve monitoring of freshwater systems (HYCOS), and the Arctic HYCOS group would make an excellent candidate to initiate a SAON Expert Panel on freshwater. In this case, the advisory process would extend invitations to Indigenous and regional organizations with shared interests and expertise. In another scenario, Arctic Council expert groups could initiate Expert Panels to augment and extend their efforts through formalizing relevant monitoring strategies under ROADS. For example, the Arctic Council's AMAP working group regularly empanels experts to address critical issues, like Arctic cryospheric change or litter and microplastics. In addition to these global and regional examples, initiating an Expert Panel is also open to Indigenous networks and working groups (e.g., Indigenous Knowledge Social Network, and the AOS Indigenous Food Security Working Group), infrastructures (e.g., Svalbard Integrated Observing System [SIOS] and International Network for Terrestrial Research and Monitoring in the Arctic [INTERACT]), research consortia (e.g., Canada's ArcticNet), and regional activities (e.g., Alaska Ocean Observing System [AOOS]).

Using an Expert Panel approach entails that the success of the ROADS process relies upon partnership, so ROADS must add critical value to current planning approaches to succeed. While many Arctic observing networks and SAON partner institutions (e.g., WMO) have their own processes for identifying observing system priorities, there is currently no meta-structure to tie these efforts together into a systematic, pan-Arctic view. The grassroots Arctic Observing Summit (AOS, 2016; Murray et al., 2018) and the Arctic Science Ministerial processes (ASM2, 2018; ASM3, 2021) have both upheld the need for such a structure, as well as SAON's role in shepherding it forward. Partnership with SAON continues to be a critical success factor for grant proposals. It was a requirement for the EU Horizon2020 award to the Arctic PASSION (Pan-Arctic Observation System of Systems) project and was voluntarily pursued by the recently awarded U.S. proposal: Research Networking Activities in Support of Sustained Coordinated Observations of Arctic Change (RNA CoObs; NSF-OPP 1936805). Both projects have aligned to provide direct or indirect support to the ROADS process, including funding support for engagement by Indigenous Peoples.

The ROADS Advisory Panel is intended to provide a neutral and collaborative standing body to assure that each SAV is identified, defined, and follows an implementation strategy that is consistent with ROADS principles. In addition to assuring an inclusive process, the Advisory Panel will have the mandate to foster integration across panels, mobilize international participation and collaboration with global networks, and work to cultivate consensus approaches across panels. The ROADS Advisory Panel should also work with relevant funding agencies and organizations, as well as the Arctic Funders Forum (AFF, 2020), to advance support for Expert Panel efforts, including their implementation strategies. These panels will interact following a multiphase process described next.

A Facilitated Process from SAVs to Implementation

The Task Force outlined a multiphase process for the initiation and progression of Expert Panel work under ROADS (Fig. 2) and the interactive facilitation of the ROADS Advisory Panel, which will review each step of the process. The steps of the ROADS process are:

- Initiate – Each proposing Expert Panel is invited to write a brief proposal to the ROADS Advisory Panel outlining a scope of assessment and relevant participants, highlighting the anticipated impacts on decision making and new knowledge. The Advisory Panel will have the opportunity to assure alignment with ROADS principles, like the equitable inclusion of Indigenous experts. It will also identify linkages with existing Expert Panels. While it is not necessary for each panel to have funding, SAON will encourage and support panels in seeking resources for community meetings (virtual or in-person), coordination of documentation, and any necessary cyberinfrastructure.

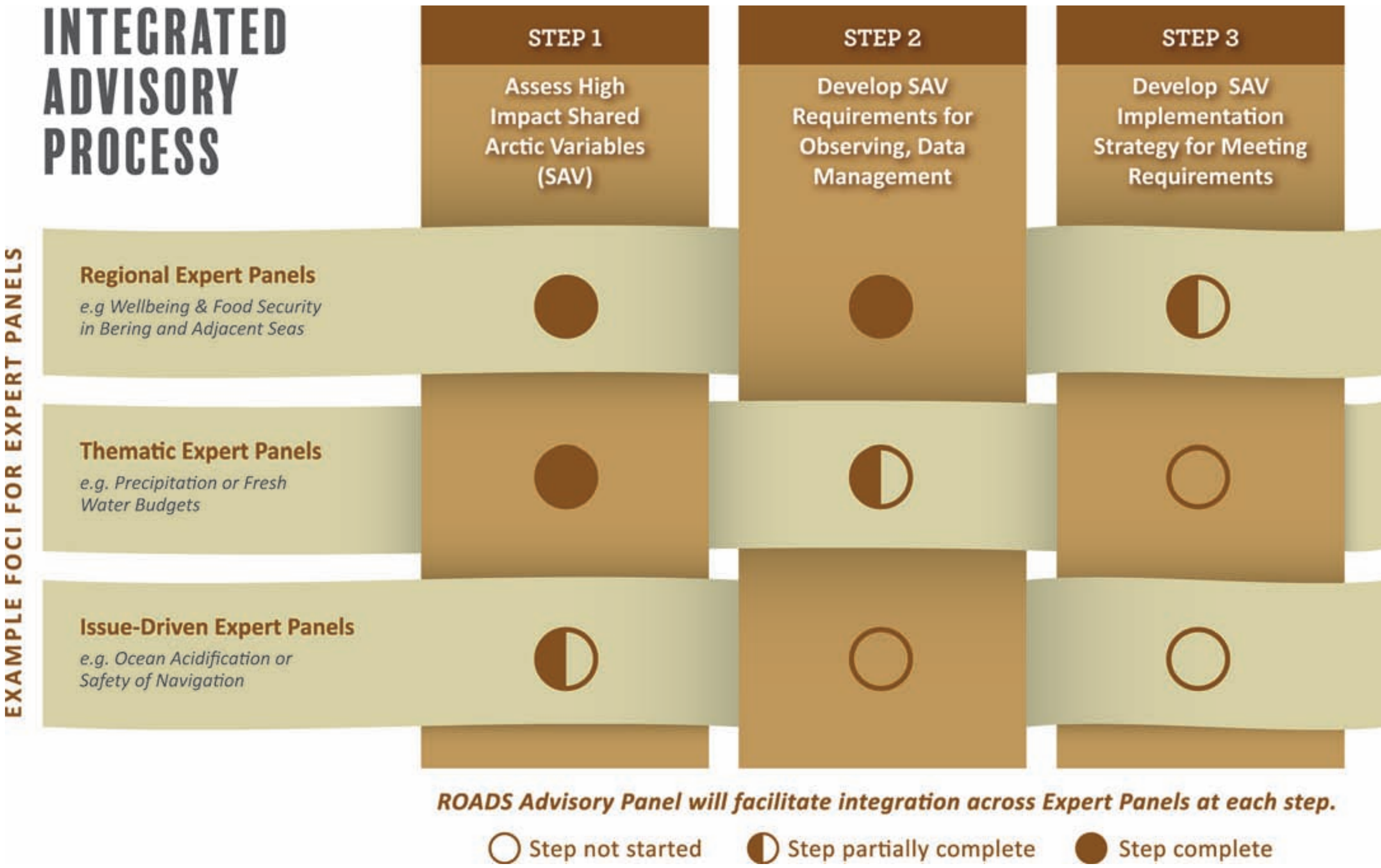

FIG. 2. In this future-looking vision, we demonstrate that the ROADS process will proceed at the intersection of subject-driven Expert Panels (as illustrated by the light horizontal bands) and the ROADS Advisory Panel, which will advise each step (as illustrated by the darker vertical bands). Three examples of different types of Expert Panels are shown as it is expected that Expert Panels will self-organize in diverse ways, for example around regions, topics or issues that are broad enough to address at least one SAV. Each Expert Panel will move through the steps of the ROADS process; symbols in the figure illustrate that Expert Panels will proceed asynchronously from each other, with some completing tasks before others. The Advisory Panel will in turn weave together the related aspects of the individual Expert Panels at each advising step to prevent siloing of outcomes.

- STEP 1 – Convene relevant participants (as identified at the Initiating step) in sufficient community meetings to identify critical SAVs for the panel's scope of interest. Criticality of SAVs should be systematically assessed as described above. Case studies for tracking the impact of anticipated SAV benefits should be identified. Results should be reported back to the Advisory Panel at this stage for review and approval to proceed to the next phase. It could occur that more than one panel is working on different aspects of the same SAVs for different outcomes. The Advisory Panel will facilitate cooperation in these instances.
- STEP 2 – Convene relevant participants in sufficient community meetings to specify the requirements and harmonization needs for each relevant SAV for the scope. These descriptions should be comprehensive of data collection, data management (in keeping with the *Statement of Principles and Practices for Arctic Data Management* [IASC, 2013], FAIR in Wilkinson et al., 2016 and CARE [Research Data Alliance International Indigenous Data Sovereignty Interest Group, 2019] principles), analysis, system management, and dissemination. Systematic approaches to design development, such as observing system experiments, are highly encouraged where viable. The relationship between requirements and anticipated outcomes should be clearly outlined along with metrics for their tracking. Results should be reported back to the Advisory Panel for review and agreement to proceed to the next phase.
- STEP 3 – Convene relevant participants, in collaboration with relevant funding agencies and partner organizations, to outline strategies for implementation and engage commitments for their sustainment, including technical, organizational, financial, and of human capacity. This process should describe which infrastructures (physical and virtual) and organizational and human professional resources are essential for current implementation. Implementation strategies should address the optimized joint use of satellite earth observation programs; community-embedded, -driven, and -led observations; terrestrial stations; vessels; aircraft; and various autonomous platforms providing observing systems. Implementation should also describe how these infrastructures will be integrated into value-added services and products and the strategy for their dissemination. This phase of work should also identify

technology development needs in order to improve readiness of future generations of the observing system and strategies to advance them.

The assessments, requirements, and strategies collated throughout the multiphase ROADS process should be accessible, transparent, and aligned across partner organizations to avoid conflicting or wastefully duplicative results. The WMO's Rolling Review of Requirements provides a model for good practices and is suggestive of the type of cyberinfrastructure that the ROADS process will ultimately require. SAON and the Advisory Panel's ongoing role will be to knit together the results of the ROADS process into a coherent whole so that actions of broadest societal benefit can be prioritized. Mechanisms for evaluating the beneficial impact of plans should be developed in each phase of the process in close partnership with those who will use observations in decision-making contexts. The ROADS process must proceed in a spirit of continuous improvement, such that SAVs and the process as whole are the subject of evaluation and review on a regular basis.

Evaluation

Given the multicomponent and progressive nature of the proposed ROADS process, it will be critical to regularly evaluate its elements and effectiveness. The Task Force recommends a full-process evaluation following the first two years of pilot efforts, potentially in collaboration with AOS 2024 and its working groups. The U.S. RNA CoObs award includes funding for evaluation of its success within the ROADS process. The experiences and the outcomes of the Arctic PASSION project will prove extremely valuable to refining ROADS for ongoing success. Evaluation of the degree to which equity and other desired objectives are achieved in the process from an Indigenous point of view will be critical.

To evaluate the elements of ROADS, the Task Force recommends that the collection of approved SAVs and their underlying descriptions be evaluated every five to seven years as the requirements and strategies for observing will be subject to change. The pace of Arctic change suggests as much, but there is also recognition that our scientific and societal needs of an observing system will change over time and that the observing system will need to be flexible to meet these needs.

Evaluating the impact of ROADS on its overall objective to support societal benefit is critical, but it is anticipated that evidence of this impact will take longer to emerge. The multiphase process to develop SAVs thus includes explicit actions to identify means to demonstrate the impact of SAVs on decision making. This type of evaluation should be considered an important deliverable to the Arctic Science Ministerial process.

WHERE WILL ROADS TAKE US?

ROADS is both a comprehensive approach, building from the systematic approach of SAON's societal benefit framework, and one that can proceed step-wise so that the most imperative Arctic observing system elements can be rapidly improved under a model of benefit sharing that crosses scales. For each SAV identified, ROADS will produce well-specified requirements for observing and a strategy for their implementation and timely data dissemination. ROADS is envisioned to be an inclusive and transparent process that is proceeding in collaboration with funding agencies and observing organizations, as represented by the membership of the SAON Board. The use of Expert Panels will generate strong grassroots ownership of plans across a range of partners. Active advising from SAON will provide overarching insights to weave the system of SAVs together. If successful, ROADS will unify the communities of Arctic observing, data management, and decision making across scales through its structured requirements and implementation strategies. Funding agencies and governments will recognize the merits of an integrated and systematic process with coordinated international engagement, while global networks will recognize the value of regional facilitation through SAVs that extend the definitions and utility of their own efforts.

Here, it should be underscored that Arctic Indigenous Peoples need to be recognized as rights holders and knowledge holders in the Arctic, and research in their homeland needs to be conducted in partnership with them. Governance of and progress under ROADS shall be shaped by and benefit greatly from this critical consideration. ROADS shall proceed in accordance with guidelines on ethical research (e.g., IARPC, 2018; ITK, 2018) provided by Arctic Indigenous Peoples in the various locations. It is important to acknowledge that many of the long-standing issues that have resulted in tensions between knowledge systems or diverging principles toward data access (e.g., sovereignty versus open access) have roots in colonial histories that persist as systemic barriers for Indigenous people to this day (Wong, 2020; *M'sit No'kmaq* et al., 2021). In its current form, ROADS does not provide an immediate remedy to these issues, but it does seek to build partnerships and conceptual tools that will support the urgent need to decolonize research practices, including planning processes.

The SAON Strategy covers a 10-year timeline from 2018 to 2028 (SAON, 2018), but progress on ROADS is expected to advance more swiftly. Activity under the ROADS process will be one measure of its success, but the extent to which ROADS realizes societal benefit and improved decision making in the Arctic through enhanced observations and data systems is the most powerful measure of success. The former is more readily measured than the latter and both should be tracked. Activity under ROADS can be measured by the number of societal benefit areas that have been translated through SAVs into a coherent system of observing requirements and resource-estimated implementation plans. Collaboration with AOS working groups and funded proposals working on ROADS will provide critical vehicles for this progress. Each AOS will provide an opportunity to measure this progress. For example, it is proposed that two to four SAVs will be fully developed by AOS 2024.

ROADS development will support each of the three goals outlined in SAON's strategy. It will directly result in the roadmap called for under Goal 1; it will support ethical access to Arctic data called for under Goal 2 through well-defined data management strategies, co-developed with Indigenous partners tied to each SAV; and it will ensure the sustainability of the Arctic Observing System called for under Goal 3 through an integrated system of community-endorsed observing targets and strategies that are justified based on their broad societal and economic value.

SAON has matured since its inception into an organization with a clear mandate, compelling vision, and robust partnerships. With the recent attention of the Arctic Science Ministerial process, the convening power of the AOS, and the increasing effectiveness of its Board and committees, SAON is poised to deliver a roadmap that will mobilize substantial sustained investments in well-defined and coordinated Arctic observing. If successful, ROADS will yield more than a strategic investment strategy for observing and data system funders and organizations, it will build an inclusive, polycentric community of practice prepared to move forward together, equitably, in support of shared benefit. We call upon SAON's partners in networks, infrastructures, and observing activities to take up this call to join the ROADS process.

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