**Collaborative Research: Research Networking Activities in Support of Sustained Coordinated Observations of Arctic Change**

**Proposal to NSF-AON, Final Version, submitted 31 May 2019**

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*Project Summary*

Recent scientific studies and the work of the Sustaining Arctic Observing Networks (SAON) initiative of the International Arctic Science Committee (IASC) and the Arctic Council, the Arctic Science Ministe­rials (ASM), and the Arctic Observing Summits (AOS) have established and quantified the shared bene­fits that sustained observations of a changing Arctic provide to Arctic and non-Arctic countries. The collec­tive convening capacity of SAON and AOS has assembled scientific leadership from scores of nations and thousands of participants since the first AOS in 2013. Collaborative approaches to sustained obser­va­tions require a capacity to support the convergence of different types of observing activities into a common framework. SAON has emerged as the governance body to provide an inclusive environment within which to establish such a framework, with a vision for a connected, collaborative, and comprehen­sive long-term pan-Arctic Observing System that serves societal needs. SAON has identified develop­ment of a Roadmap for Arctic Observing (RAO) as a key starting point for implementing its strategy: to detail where observing and data management efforts need to go and how SAON partners will jointly get there. However, as recognized at AOS 2018 and ASM2, specific (inter)national activities in response to the SAON strategy are lacking. We propose to fulfill the international community’s and speci­fi­cally SAON’s vision by developing content through support actions and Research Networking Activi­ties, structured into four areas promoting sustained observations: coordination, requirements capture, design development, and information infrastructure. We will help network international teams under the SAON umbrella – with a restructured AOS serving as an anchor, entraining other local to global programs to jointly address key objectives. Drawing on the Global Ocean Observing System’s Frame­work for Ocean Observations and other guiding documents, we plan to link societal benefits to specific essential variables and observing system technical design and reporting requirements. The project will then develop or adapt information infrastructure around these activities to demonstrate how an internationally coordinated roadmap for Arctic observing can be designed and developed, in service to operators, the research community and decision-makers. These objectives will be achieved through a combination of facilitated meetings, formal and informal collaborations, and – critically – by developing a major case study into a broader resource and model for pan-Arctic observing coordination and integration. The case study will focus on food security in coastal and marine environments in the Pacific Arctic sector, and will assemble an international team comprising Indigenous experts, coastal community representatives, agency personnel, research scientists (both observationalists and modelers). The food security observing roadmap emerging from this collaborative team effort will guide observing activities in the region and inform the broader RAO effort under SAON at the pan-Arctic scale.

***Intellectual Merit:*** Creating a research network to establish critical capacity in guiding and sustaining observations on society relevant problems is a research challenge unto itself. We will develop a range of new techniques, drawing on principles of co-production of knowledge, observing system simulation experi­ments, and systems engineering to determine shared benefits and quantitatively assess the impacts of optimized observations relevant in a food security and marine ecosystems context. Data and tools emerging from this work will inform a food security information product to be shared through the Group on Earth Observations observing system of systems framework.

***Broader Impacts:*** We will generate an observing roadmap for the Pacific Arctic sector, contributing to and aligning with the broader SAON RAO and international initiatives such as the Pacific Arctic Group and the Distributed Biological Observatory. Our efforts will result in observations and information infrastructure that more effectively serve the research community, Indige­nous and community-based observing initiatives, agencies, and others with a stake in Arctic observing. The AOS will be transformed into a sustained process, building capacity through establishment of task teams and an Indigenous Food Security Working Group. We will partner with the Association of Polar Early Career Scientists to entrain new perspectives and foster continuity. By growing a community of practice in support of the SAON roadmap process, the project will help plant the seeds for an integrated observing system.

**Project Description**

*1. Motivation and key objectives*

There is an urgent need for an Arctic observing system that tracks sub-seasonal to multidecadal change, advances understanding of Arctic social-environmental systems, and informs predictions of and responses to rapid Arctic change across a range of scales and sectors. Both need and urgency have been articulated by a range of studies, assessments, and bodies; most recently the Arctic Observing Summits (AOS) [1-3], the Second Arctic Science Ministerial (ASM2), and in particular the Sustaining Arctic Observing Net­works (SAON) initiative of the Arctic Council (AC) and the International Arctic Science Committee (IASC). In the U.S. and internationally, individual research collaborations [4-8], bottom-up, community-driven programs such as the Study of Environmental Arctic Change (SEARCH) [9-11], and high-level assess­ments [12] have articulated the need for such an integrated observing system. Recently, through the work of SAON, other international bodies, and the AOS, the societal and socio-economic benefits of sustained Arctic observations have been evaluated [13-15].

Progress on such calls for integrated observing is often impeded not by technical challenges, but by organizational and institutional barriers that require human capacity, planning tools, and sustained gover­nance models [16]. Surveys of sustained observations in marine and coastal environments reveal a dispa­rity among different types of observations collected by many entities without much prior coordi­nation or integration into a uniform framework. Such disparity presents a major hurdle towards integration of observing efforts [17,18]. SAON, represented at the national level by the U.S. Arctic Observing Network (USAON) office, with further guidance from an Interagency Arctic Research Policy Committee (IARPC) Collaboration Team (CT) on Arctic observing, has developed a strategy that lays out a collabo­ra­tive pathway to overcome these challenges [19]. Specifically, it defines a roadmap that identifies and puts into context observations, products, and services following a value-based approach. Such an approach goes beyond inventorying observations to fully elucidating how specific observations support one or more societal benefit areas (SBAs) comprising the socio-economic and environmental domains in which observing services, operations, and research provide societal benefits [13]. This approach lays the groundwork for transparent, quantitative, and collectively-endorsed observing strategies that build from existing capacities towards an optimized and adaptable observing system serving a range of end users.

Importantly, SAON has emerged as the governance body to provide an inclusive environment within which to establish such an observing framework, with a vision for a connected, collaborative, and com­pre­hensive long-term pan-Arctic Observing System that serves societal needs. SAON is governed by a board of 18 national and 13 multi-national and organization representatives including permanent participants of the Arctic Council, the World Meteorological Organization (WMO), the Group on Earth Observations (GEO), and the GOOS Regional Alliance. Its governance model recognizes the need to recon­cile interests and priorities of Arctic nations as well as those of the broader global community of nations with strong scientific interests in Arctic change. However, SAON has suffered from a lack of resources and capacity to fully engage with the broader research and stakeholder community, and to advance more comprehen­sive observing implementation efforts [20,21] (Fig. 1). An assessment by the SAON Board established that capabilities tied to developing the observing roadmap were urgent at the national level. SAON is now working on a clear definition of what a roadmap for integrated Arctic observing would encompass (Roadmap Task Force, RMTF, Definition Phase). However, existing SAON bodies (Board; Committee on Observations and Networks, CON; Arctic Data Committee, ADC) lack capacity and resources to develop the roadmap itself, let alone using it to guide observing system design and implementation. This shortcoming also impacts attainment of SAON strategy goals: Create a roadmap to a well-integrated Arctic Obser­ving System (G1); Promote free and ethical open access to Arctic observational data (G2); Ensure sustai­na­bility of Arctic observing (G3), as summarized in Fig. 1.

The Research Networking Activities (RNA) proposed here aim to advance actions at the national level that address the first two SAON goals and improve linkages among the research community, different Arctic observing data users, Arctic communities, and key international bodies and partners in order to meet these objectives. Specifically, the activities detailed below are a response to the SAON strategy,

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|  | *Fig. 1: SAON partners have vary­ing degrees of capa­city for imple­men­ting the Strategy repre­sen­ted by this matrix, compiled by the SAON Secretariat from national respon­ses to date: Red-no capacity, Yellow-limited capacity, green- extensive capacity. Even for areas of extensive national capacity, the SAON Secretariat has low capacity to coordi­nate across its members.* |

vital international coordination identified at ASM2, and the AOS 2018 call to action, and will result in

(i) an assessment of current capabilities, associated benefits, and major gaps (“knowledge map”),

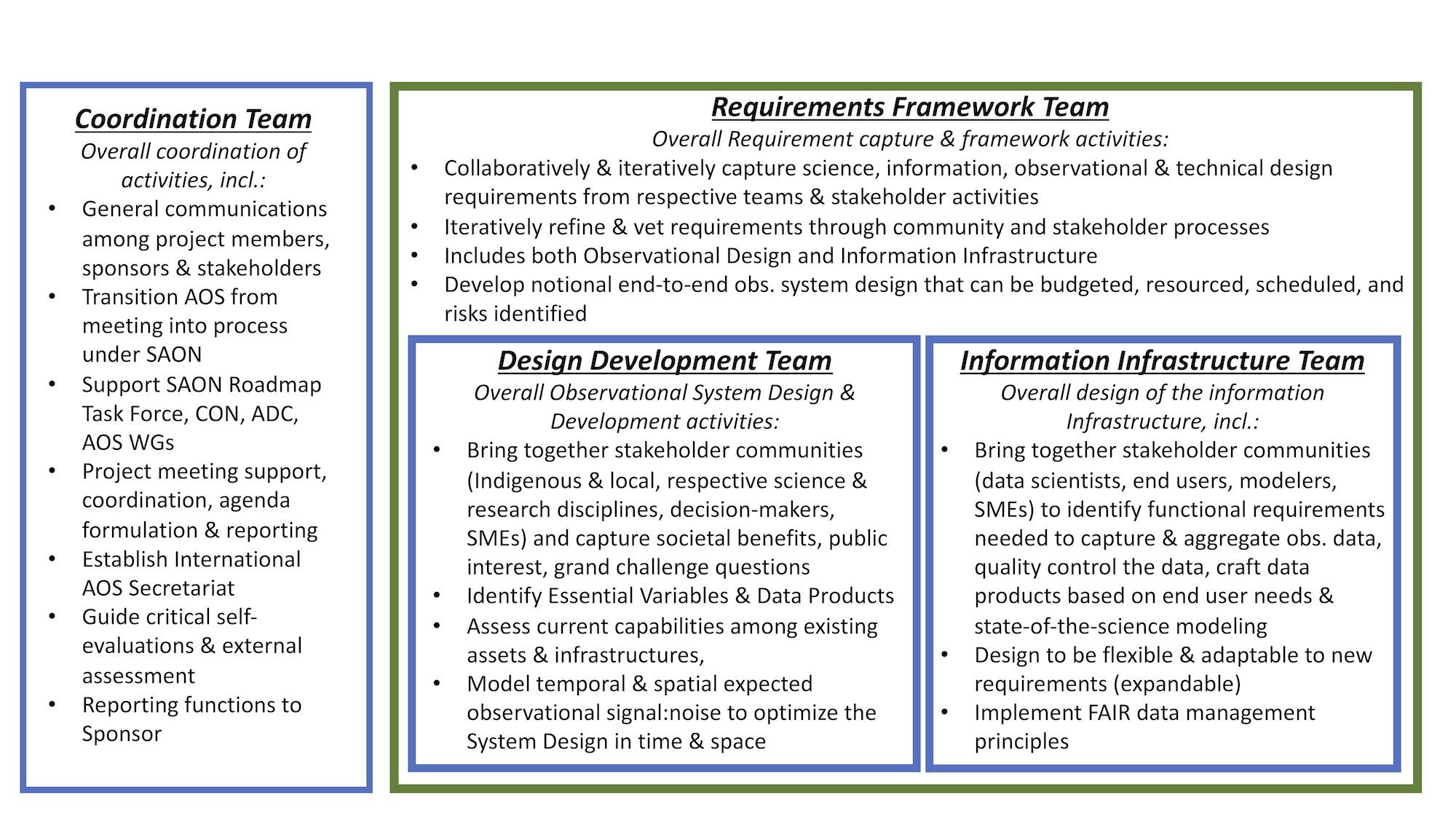
(ii) development of a roadmap that clearly lays out a path towards an integrated Arctic observing system or system of systems, tying into local, national and global frameworks and networks, and

(iii) initiation of specific steps and implementation action that builds on (i) and (ii).

The networking activities we envision address these tasks with a focus on shared, cross-sector benefits (extending from research to policy and planning to strategy and tactics in responding to Arctic change, [10,20]), and the recognition that such an integrated Arctic observing system has to be designed around and through pre-existing observing activities, from research projects, agency-led programs at the national and international level, to community-based monitoring efforts. The National Science Foundation’s (NSF) RNA support is an ideal support mechanism for such work. RNA encompass “collaboration by groups of investigators to advance our knowledge by aggregating research results across disciplinary, organizational, or international boundaries” through “synthesis of research results, inter-comparison of existing data or models, developing networks of connections among existing research projects [...] and efforts to establish best practices for data collection, observations, models, or data management” (NSF Program Solicitation 16-595). RNA supports efforts are “more complicated and larger in scope than are appropriate for a Research Coordination Network”. The work is further motivated by NSF Director Cordova’s remarks at ASM2, captured in the Joint Ministers’ Statement asking to take “stock of progress made in the analysis of societal benefits of Arctic observations, continue and expand the cooperation in this area by progressively moving from the design to the deployment phase of an integrated Arctic observing system which also supports and includes community-based observatories, in cooperation with [...] SAON[...], and other major operational observing networks, such as the […] Distributed Biological Observatory (DBO)” [20]. We are planning to advance SAON’s observing roadmap along these very lines, focusing on a food security theme.

*2. Approach*

Network objectives and activities fall into four different categories: (i) coordination, (ii) design develop­ment, (iii) requirements capture, and (iv) information infrastructure, each supporting roadmap develop­ment. We outline an approach that brings together researchers, scientific bodies, data users, agency managers, Arctic community representatives, and others to collaborate on roadmapping activities starting

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*Fig. 2: Structure and responsibilities of task teams assembled under the RNA effort. For specific roles and membership see Section 3 and Fig. 5.*

with coordination of observations, moving on to observing system design development. This work leads into and helps define, establish and adapt existing information infrastructure in support of researchers and decision-makers who draw on Arctic observations and information products in support of SBA’s. The diverse, international group of experts associated with this work will assemble into four teams, associated with each of the four core activities (Fig. 2).

These internationally networked roadmapping activities are meant to help transform dispersed, uncoor­dinated observations into an integrated observing system. We envision what is outlined here as a U.S. contribution to the broader SAON Roadmap for Arctic Observing, contributing to, but not subsuming, a formal long-term observing system implementation plan. By focusing on the theme of food security in the coastal and marine Pacific Arctic sector, the proposed effort seeks to serve as a nucleus for a broader-scale observing system implementa­tion. Such a U.S. contribution to SAON would serve as a model for a more comprehensive, pan-Arctic Roadmap to be adopted and expanded upon through other national funding opportunities, as outlined in SAON G3 (Fig. 1). To meet these broader objectives we propose to assemble professionally facilitated and coordinated task teams operating through SAON and its two extant committees, CON and ADC (Fig. 2). An essential comple­mentary function will come through transforming the AOS from a biennial meeting into a sustained process that provides convening oppor­tunities across scales and disciplines (on-going working groups, white paper teams, community-wide planning, detailed in [1,22,23]) and structured support (professional coor­di­na­tors, structured facilitation models, meeting planning and follow-up) for such a complex consensus-building process. These different groups would support SAON by (a) helping complete the CON’s capabilities assessment (“knowledge map”) that identifies critical gaps, (b) producing an observing road­map towards an integrated observing system, (c) facilitating design development of specific observing activities in high priority areas identified under (a) and (b) with a focus on food security in the Pacific Arctic sector, and (d) building information infrastructure that supports the user community, in particular decision-makers and researchers.

Here, we will bring together key stakeholders with disparate expertise, elicit knowledge and challenges, define problem-solving paths, and collaboratively design key elements of an Arctic Observing System, with a single system design that focuses on food security and related marine processes. Our aim is to achieve this through various engagement activities, and to integrate existing capabilities and augment the design with new attributes. In particular, we aim to use the AOS as a process to conduct focused activities involving key stakeholders, data users and providers, modelers and observationalists. Such activities would bring together the NSF-supported Arctic Data Center (NSF-ADC) to facilitate access to relevant data sets and guide data curation, Indigenous and community experts familiar with the require­ments of food security observations, observing system design experts (both systems engineers and experts in observing system simulation experiments and quantitative network design), data scientists and observing system operators. Drawing on the successful model of NSF-ADC synthesis working group support we propose to develop a community of practice around observations informing food security concerns.

If the task at hand were to craft a new Arctic Observing System from the ground up, stakeholders would be brought together, societal impact and grand challenges crafted, and requirements captured. In our case, much of this information has been derived through SAON, the AOS, and different (inter)national efforts [13-15,24]. Hence, observing system studies, planning documents and position papers reflecting the diverse interests of local communities, research activities and disciplines, Arctic organizations and many others are already in place [25]. For each theme, we will synthesize legacy information into a baseline that will be used as the starting point for the proposed system design activities including capturing requirements and critical observing system attributes (Fig. 3). As part of the proposed activities, we will apply system engineering approaches to distill grand challenge questions, hypotheses, and societal benefit into tiered requirements, accounting for inherent complexity at the inception of the develop­ment process (Fig. 3, [26-28]). Systematic capture of requirements relates directly to both scientific and societal needs, and provides a foundation for an explicit observing system design. Require­ments capture is not a static process, but iterative with reviews and vetting to assure the needs of the broadest possible range of stakeholders are met. It encompasses the tools by which budget, risk, schedule, can be assessed in trade-off analyses that result in an optimized design solution. Requirements flow from high-level, aspirational Grand Challenges, to more detailed science and design requirements; all of which must also meet societal benefit and public interest [25].

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| *Fig. 3. System engineering approach to distill research questions and decision support into tiered requirements with flow of information addressing research and operational needs.* |

Secondary benefits of a requirement-based approach are: (i) serving as a way to find common ground among different stakeholders, users and obser­vation and data provider groups, (ii) cost savings by apply­ing a focused approach *a priori*, and not continually changing scope, (iii) precise communication of observing system design and process among all stakeholders, sponsors, and the public, and (iv) providing mechanisms to accom­modate future changes in design or scope. This approach has been used successfully for other large-scale science infrastructures (e.g., ocean research vessels, telescopes, etc.), but is still nascent in the environmental and social sciences.

To help link extant and newly implemented obser­ving efforts into a coordinated, collaborative frame­work that provides shared societal benefits to diffe­rent data providers and users, we propose to draw on the Essential Variables (EV) concept (Fig. 4). Many global programs (e.g., GOOS, Global Climate Observing System – GCOS) and regional efforts (e.g., Circumpolar Biodiversity Monitoring Program), have recognized the value of EVs in helping focus and consolidate observing efforts. Identification of EVs associated with different societal benefit areas and operational applications can help provide observing requirements, with explicit attention to time and spatial scales as well as data latency requirements [29]. These requirements in turn guide how observa­tions are carried out (sensor type, location, sampling rate, etc.) and provide a link to existing or needed observing platforms and sensor systems. In moving from coordination of observations to design develop­ment to information infrastructure (Fig. 4), the EV concept is a powerful focal mechanism that can help bridge different knowledge systems, applications, or observing approaches. Here, we suggest that deve­lop­ment of a suite of EVs along with specific requirements and guidance on observing tactics for the theme of food security in coastal and marine environments can help illustrate how to overcome broader challenges. Such work would directly support SAON’s Roadmap process, which will likely need to (i) identify the most relevant EV's from existing global frameworks such as those referenced above, (ii) seek to expand their definitions and observing strategies to meet regional Arctic considerations, and (iii) denote EV's that have not yet been defined but are critical in Arctic settings.

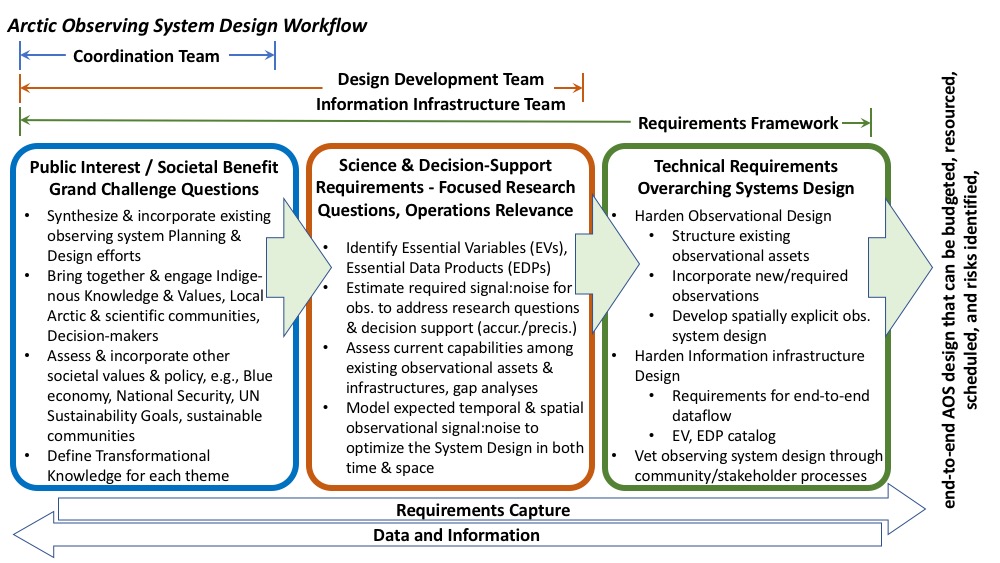
*2.1. Coordination - Leveraging a New Role for the AOS through SAON*

The AOS has emerged as the central coordination forum for the broader Arctic observing community. It promises to be one of the critical mechanisms through which SAON goals and objectives can be achie­ved. The development of a SAON Roadmap for Arctic Observing (RAO) to optimize international invest­ments around the most crucial observing foci would draw particular benefit from the AOS. However, as recognized at AOS 2018 and follow-on workshops [20,21], capacity needs to be built internationally to attain such goals through the AOS and provide a mechanism for the international observing and data user community to co-design and co-manage the nascent observing system. This aim requires the transforma­tion of the AOS from a meeting into a sustained engagement process under SAON that draws on teams, such as those outlined here (Fig. 2, 4), to execute specific tasks.

The AOS was established in 2012 as a SAON Task that fed into the SAON implementation process. AOS is a joint effort of the International Study of Arctic Change (ISAC), IASC, the AC’s Arctic Monito­ring and Assessment Programme (AMAP), and an international scientific advisory committee that inclu­des Indigenous expertise. AOS’ purpose is to provide community-driven, science-based gui­dance for the design, implementation, coordination, and operation of a long-term international network of Arctic observing systems. The AOS is an international, biennial forum of hundreds of people from among all sectors invested in Arctic observing that occurs in conjunction with Arctic Science Summit Week. It aims to optimize resource allocation and minimize gaps and duplication, through coordination and exchange among researchers, government agencies, Indigenous and northern peoples, non-governmental organiza­tions, the private sector and others associated with long-term observing activities. Key summit outcomes are summarized in synthesis reports [1,23] and collected white paper contributions (e.g., [2]). SAON and AOS are now well-established, with governance and operating procedures clearly documented [23,31]. With the SAON strategy laying out a path for greater coordination of observing activities, now is the time to fully harness the broad convening capacity of the AOS to help implement SAON’s strategy.

The International Arctic Research Center (IARC) at the University of Alaska Fairbanks (UAF) and the Arctic Institute of North America (AINA, Calgary, Canada) have informally supported AOS coordination with staff, resources and expertise. Toge­ther, IARC and AINA are well-positioned to create a joint, inter­na­tio­nal secretariat that can ensure continued AOS success, allow it to evolve into an on-going process, and support SAON objectives and the RAO. As non-Arctic nations seek to contribute to the activities and objectives of the Arctic Council, they could do so through contribution to AOS Secretariat staffing. Such an approach would reduce costs and reinforce the international collaborations required to advance an integrated Arctic observing system. As part of this RNA proposal, we are also partnering with Indigenous Peoples’ organizations, such as Inuit Circumpolar Council (ICC) in Alaska and Canada, to help build capacity for them to actively participate in this process, including development of resources to help commu­nities and policymakers navigate AOS products and assessment results.

Early career researchers (ECRs, incl. students) will be targeted through the Association of Polar Early Career Scientists (APECS), informing both how to most effectively integrate ECRs into the AOS structure and how to package assessment results into educational materials.

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*Figure 4: Workflow and activities for key elements of the observing design development process.*

An AOS process will also build capacity to follow through on key calls to action from the summits, which have been reviewed and refined at the two ASMs held to date. Major successes such as the reports on societal and economic benefits of sustained observations [13-15] and observing case studies demon­stra­ting positive return on investment [22] are outcomes of AOS calls to action taken up by the ASM.

However, many other actions, in particular those requiring collaboration with the research commu­nity and Indigenous Peoples organizations have langui­shed due to lack of resources. To address such shortfalls, we request support for AOS working groups to link with SAON CON and ADC (Fig. 2, 5).

Beyond the AOS, the proposed coordination efforts will support the SAON roadmap process and the RMTF. Their first task (Definition Phase) is to define Roadmap scope from the standpoint of national funding agencies, elaborating how societal benefits and alignment with global and regional networks should be considered. The RAO serves as a metastructure under which specific observing system frame­works can be integrated and supported. CON and ADC plan to take up this definition to develop its design and align existing cyberinfrastructures to support its execution. These tasks will require conside­rable collaboration with the broader research community through existing and newly defined networks as well as more frequent convening opportunities - a need that this proposal seeks to address (Fig. 5). The food security theme, outlined below, will serve as nucleus and case study to help achieve these outcomes.

*2.2. Design Development - Food Security in the Pacific Arctic Sector*

The Requirements Framework (Fig. 4) provides context and links activities described below to obser­ving system design development. We will test its utility and advance its broader implementation by focu­sing on the theme of food security. To do so, this project will bring together - for the first time - the observing systems design and engineering perspective, quantitative observing system design approaches [20], and Arctic Indigenous Peoples’ and coastal communities’ perspective on food security and marine eco­systems, to help guide the co-design and co-management of observing system resources. The work will focus on the Pacific Arctic sector - specifically the U.S. coastal Arctic where converging research inte­rests [32-34], decision-maker information needs [35,36], and observing activities from a range of nations (such as the Pacific Arctic Group, PAG, and the DBO; [4,37]) converge. The aim is to bring toge­ther experts from these different groups under the umbrella of observing design development. Two key elements of this work - Indigenous expertise on food security and quantitative observing system design and optimization approaches - are explored in more depth to illustrate how EVs will be identified in a decision-making and research context, thereby informing technical requirements and system design.

Indigenous Perspectives on Food Security. Arctic Indigenous peoples have a holistic view of the envi­ron­ment that recognizes people as entwined with the system. Distinct worldviews with complex know­ledge systems passed on from generation to generation have evolved and are still developing today. Indi­genous Peoples’ knowledge systems interlink both cultural and ecological systems and have their own methodologies, evaluation and analysis processes (e.g., [38,39]). The concept of food security for Arctic Indigenous Peoples goes beyond just counting calories, or food availability, it encompasses many inter­con­nected components such as biological systems, cultural practices, physical systems, and language impor­tant to Indigenous Peoples worldviews [38,40-42]. Traditional foods are essential not just for provi­ding nutritional sustenance and ensuring physical health, but also for psychological well-being. Conse­quently, Indigenous food security presents different challenges from western-based societies that might look at isolated attributes for monitoring single species.

The Alaska Inuit food security lens was documented through an Inuit systematic way of knowing [38] that characterizes it through environmental health with six interconnecting dimensions: 1) availability, 2) Inuit culture, 3) decision-making power and management, 4) health and wellness, 5) stability and 6) accessibility. For Inuit to be food secure all these aspects need to be considered simultaneously, requiring a focus on relationships. In the case of monitoring and observing, simultaneous observations from multiple variables across these interconnections are essential in a food-security observing framework.

A similar effort at capturing the challenges of food security in the midst of a rapidly changing environ­ments involved Indigenous groups from Interior Alaska comprising members of the Tanana Chiefs Con­fe­rence (TCC) and the Council of Athabascan Tribal Governments (CATG) consortia, who identified 47 interconnected drivers of food security and insecurity. Traditional knowledge practices and cooperation were identified as the drivers with the highest impacts on food security, whereas climate change, restrictive regulations, and high costs of fuel, energy and equipment contribute most to food insecurity. There are important drivers that link the highest impactful drivers of food security and insecurity. These include increased Indigenous sovereignty in resource management, increased recognition of Indigenous knowledge and worldview which positively affect food security, whereas loss of Elders and their knowledge, reduced food availability and increased individualism threaten food security [42].

Climate change and its environmental impacts are adversely affecting food security in the Arctic. Changes such as increased warming are altering traditional food gathering grounds, making sub­sis­tence resources less accessible and in some instances, scarce. Such changes also alter habitats for sub­sis­tence resources and introduce new pollutants [43,44]. One of the most substantial ecosystem changes has been observed in Arctic marine benthos, with far-reaching implications for the entire Arctic landscape [44,46].

Considering the rate of change, there is an urgency to gain a more complete understanding of the inter­connecting systems important for food security from an Indigenous perspective. Arctic Indigenous Obser­va­tions may be rooted in science, Indigenous Peoples’ knowledge systems, or both, through a co-produc­tion of knowledge approach that equitably brings together multiple knowledge systems in creating new knowledge (e.g., [47,48]). Scientific observations alone may be limited in time and space. Observations from a food security perspective establish relationships and allow for connected observations across multiple variables. Both scientific and Indigenous knowledge systems should equitably inform an obser­ving system [49]. The role of community-based monitoring (CBM) projects is important in advancing a complete observing system [50,51]. Scaling up from CBM to regional and international observing systems will require strong cross-cultural and interdisciplinary partnerships and cross-scale collaboration. Existing multi-level monitoring programs may provide required information, but rely on further linkages across monitoring or development of new monitoring programs.

We propose to establish an Indigenous Food Security Working Group (WG). The design of the WG aligns with collaborative Indigenous approaches of coming together to solve challenges. It includes recommendations for action from ICC-Alaska [38], such as developing partner­ships between Inuit experts and external entities, generating monitoring systems by engaging both Indige­nous Knowledge and science, and drawing on management experiences by Inuit in identifying best strate­gies to address monitoring needs. The WG will be important in establishing process, identifying key issues that need monitoring, identifying gaps in current observing systems and providing recommenda­tions for future observing systems that align with an Indigenous food security perspective. The roughly 10-member WG will be similar in composition to the AOS 2016 WG, representing Indigenous organiza­tions and knowledge holders [52]. The proposal includes paid time for WG members to engage through­out the project - an important consideration in working towards knowledge co-production. The WG will be established by the PIs and collaborators, with a coordinator and tribal liaison at IARC to work with the WG members and other Indigenous organizations, helping build capacity for Indigenous co-management.

Process is important in ensuring equitable consideration of Indigenous Peoples’ knowledge systems and science in the design of observing systems. Best practices from an Indigenous perspective will be identi­fied from existing CBM and other research projects. These will be important in informing future, connec­ted observing systems. This will be accomplished through a workshop hosted by the WG proposed for fall 2020 (Fig. 5). The workshop will bring in expert knowledge holders in addition to WG members to iden­tify best practices. Processes will intersect with the ICC-Alaska [38] six dimensions of food security and the 47 drivers of food (in)security identified by TCC and CATG affiliated Indigenous groups [42].

Quantitative Observing System Design and Optimization. The team’s main task is to link research questions and decision support to specific information needs and associated observing system require­ments (Fig. 3). Necessary steps for this task are to identify strengths, gaps, and redundancies in current obser­ving networks and to define metrics for optimization of new networks. Optimal observing system design serves as a quantitative tool to guide such implemen­tation and assessment. To tackle an optimiza­tion problem with multi-system constraints, e.g., food security and marine ecosystems constraints, one can draw on Bayesian inverse methods and classical economic theory, among other fields [53,54]. Bayesian inverse methods offer a range of algorithms to assess the degree to which feasible observations may constrain unobserved quantities of interest (i.e., oceanographic, climate, or socio-economic metrics [55]). These algorithms take advantage of known dynamics, prior knowledge and measurement uncertain­ty to assess information content as well as redundancy in hypothe­tical observing networks [56-60].

Classic economic theory and integrated assessment models take into account multi-system quantities of interest, including societal, biological, economical, and environmental factors [61]. The optimization prob­lems typically addressed in such models aim to balance a cost-benefit tradeoff [62]. For the food secu­rity problem, a potentially productive approach is to attempt to describe "food security" in terms of observable, quantifiable variables. A useful example is the coupling of a simplified climate model with an aggregated economic model to quantify the balance between economic growth and climate change related impacts [63]. In this example, qualitative constraints, such as “societal welfare”, were translated into quantitative elements (a monetized welfare function) and used to identify time scales and dominant factors in the conceptual climate-economy cost-benefit tradeoff. Here, guidance from the Indigenous Food Security WG and from resource managers and other decision-makers convened through the activities outlined in Fig. 5 will help identify relevant constraints.

In this quantitative modeling framework, which combines approaches and theory from diverse fields, the functional forms and mathematical relations of the optimization problem account for the system-wide dynamic interactions, both in static and in time-evolving states. Of course, these models cannot consider all factors, and thus a very important task for the team is to achieve, through discussion with the Indige­nous Food Security WG and the Requirement Framework and Design Development Teams, an understan­ding and identification of quantifiable metrics for the optimization problem. Beyond the application outcome of such an approach, the very approach itself is an important emerging research topic.

A key aspect of food security in the Pacific Arctic sector is the role of sea ice as a major constraint and means of access to subsistence foods [64,65]. Changing ice conditions also drive mari­time traffic patterns and intensity which in turn impacts food security. Effective guidance about sea ice conditions in this context relies on acquiring the relevant EVs at certain locations and times. Advanced data assimilation methods combine models and observations to improve the accuracy of observations and fill-in data gaps. Observing System Simulation Experiments (OSSEs) are a means to test the relative importance of observations for estimating sea ice, ocean and atmosphere conditions. Past work on a pan-Arctic scale has emphasized the value of sea ice thickness and the proportion of sea ice that is multi-year versus first year [66], with an indication of the long-lasting value of thickness measurements for just a fraction of the year (e.g., [67,68]). Applying such techniques for coastal sea ice conditions holds promise to identify where observations may provide the greatest benefit for the local scale. Our effort focuses on increasing the resolution and including new physics, both presently under development to treat local characteristics, such as sea ice grounding on ocean sediments and landfast ice.

*2.3. Requirements Capture*

Bringing together the vast body of knowledge, prior and future planning, and the societal imperatives to design this Arctic observing system use case is an inherently complex problem. Hence, we will use proven system engineering approaches to account for project complexity [69-71] in both design and operations, involving rigorous requirements identification that enables us todefine and manage project scope. This in turn allows for robust cost estimation, well defined roles and responsibilities, and efficient project, budget, schedule, risk, and people management [69-71]. Accounting for such project complexity is not uncommon for large-scale scientific endeavors, such as NASA satellites or NSF telescopes. This approach is, however, novel to the environmental and social sciences, with the National Ecological Observatory Network (NEON) leading this effort globally [25,26]. The lack of well-defined project scope and management is the current primary cause for cost over-runs and failure of environmental research infrastructures within the European Union [72-74]. Using system engineering approaches to capture and manage project scope requirements is now advocated as ‘Best Community Practice’ by the G7 Group of Senior Officials on Global Research Infrastructures [75].

The requirement framework is hierarchical, with technical and observational design (Fig. 3) drawing from the aspirational (Societal Benefit, Grand Challenge Questions) to achieve specific scientific under­standing (scientific requirements). Through a community-oriented process (workshops, WG meetings, regular communications), the Requirements Team will capture these requirements, develop the hierarchi­cal flow of one requirement to the next for a complete end-to-end observing system scope that is mature enough to budget, determine the level-of-effort and roles and responsibilities, identify and manage risk. Towards this end, the Requirements Team will (i) capture mention of draft requirements, (ii) define draft requirements in more detail (e.g., signal/noise ratios) for operational decision-making and scientific research, (iii) capture decision points informing design elements (cost/benefit trade-offs), (iv) develop a requirements database to manage scope, (v) vet requirements with the user communities, and glean approval for the requirements framework, and (vi) map the spatial design, roles and responsibilities of contributors and design the dataflow. The Requirements Framework provides other value-added benefits. It fosters efficiencies by identifying design redundancies and interdependencies among project teams and contributors, and thereby can inform and optimize an organizational structure for observing system implementation. The framework also serves as a basis to manage scope and function of the system, incorporate future improvements, and thereby reduce overall risk.

*2.4. Information Infrastructure*

Data and information systems are an integral element of obser­ving systems. Without data systems that make well documented data information accessible and usable, many kinds of observations are of limited value. This project will ensure that the overarching observing framework emphasizes data integrity spanning collection and management over time to different data uses, including science, community manage­ment activities, policy development, and decision-making at all scales.

In recent years, the Polar Data Community has made significant progress in realizing systems that adhere to FAIR data principles (Findable, Accessible, Interoperable, Reusable). Building on the International Polar Year 2007-09, the SAON ADC has adhered to the community-developed guidelines for practice [76] that follow the FAIR principles. Following a series of workshops, an international, interconnected Arctic data system, that leverages existing resources and cyberinfrastructure and integrates with the broader global data system, was designed and includes people and organizations working to share Indigenous knowledge and other information.

The established community structures (e.g. ADC, AOS, ASM deliverables) provide a mature frame­work for the information infrastructure component of this project. The Information Infrastructure Task Team will function as a SAON ADC WG, adopting the structure and responsibilities outlined in Fig. 2, and timelines and interconnections depicted in Fig. 5. The existing SAON ADC framework includes formal connections to U.S. AON, IARPC and its Arctic Data and Arctic Observing Systems Sub-Teams, and others. These bodies bring together agencies including NSF (i.e. NSF-ADC and the Arctic Observing Viewer web mapping team), NASA Distributed Active Archive Centers, NOAA, and many others. Through SAON ADC international partner­ships will be leveraged, e.g., with Global Cryosphere Watch, GEO Cold Regions Initiative, major regional projects such as INTAROS, as well as national initiatives such as the Canadian Consor­tium for Arctic Data Interopera­bi­lity, the National Institute for Polar Research (NIPR, Japan) and many others. Local engagement is achieved through Indigenous organizations, and projects such as the Exchange for Local Observa­tions and Knowledge of the Arctic and others. Leveraging this mature community coordi­na­tion structure will facilitate success in the proposed systems engineering and requirements development process.

Engagement of data and information users will be modeled on synthesis workshops hosted by the National Center for Ecological Assessment and Synthesis (NCEAS) and NSF-ADC. NSF-ADC has a wealth of data relevant to the food secu­ri­ty theme, and the proposed workshops will leverage these resources along with relevant data held else­where to determine accessibility and usability of data aligned with the food security priority EVs. Data will be collected, homogenized, managed and sustained under the direction of the project leads in collaboration with the Projects Data Specialist. Data will be evaluated for adherence to FAIR principles through objective, quantitative measures, and workshop participants will develop recommendations and best practices for metadata and data enhancement. Dataset provenance will be tracked to ensure appropriate attribution of source data and to enable reproducibility. Data, metadata and provenance information will be published to the NSF-ADC who will engage in workshop activities as facilitators and curators to support data discovery, access, assessment and interoperability.

We will also address a fundamental challenge for assessment, planning, integration, and synthesis: how to target SBAs by discovering and integrating suitable datasets that transcend observing platforms. Des­pite recent advances, it is impossible to execute such searches as most inventories and portals are limited in scope, and almost none share information in a way that can be aggregated for a comprehensive assess­ment. Specifically, we will explore how regionalized and focused efforts such as the food security case study can be integrated into information systems that span other interests and larger spatial scales. To aid this effort and promote broader community involvement, we envision establishing an ad-hoc Obser­ving Network Interoperability WG (e.g., under CON, ADC, and/or AOS) with the goals of (i) refining and promoting community-based standards for network-, project-, and site-level metadata; (ii) developing controlled vocabularies for SBAs, EVs, and other metadata elements; (iii) establishing compatible web service endpoints. The NSF-funded Arctic Observing Viewer (AOV) team will lead this effort. An ECR with AOV will assist as a metadata liaison – visiting network offices, remotely assisting with harvesting and compiling observing-related metadata catalogs from multiple agencies, networks, and programs, and enabling these for sharing in a manner that can serve as a model for other such integration efforts.

With NSF-ADC and AOV focusing on discoverability and usability, UAF’s Scenarios Networking for Alaska and Arctic Planning (SNAP) team will concentrate on adapting tools for Indigenous and coastal communities, managers and decision-makers. SNAP proposes to use their MapVentures technology to build a collaborative tool focused on EV’s linked to food security. MapVentures enables rapid map development and a framework that facilitates publishing of interactive maps and geospatial data. This technology utilizes two open-source tools. GeoServer is a geospatial publishing platform and Postgres is a database server with a geospatial extension to support large-scale geospatial data warehousing and publishing with GeoServer. The MapVentures approach offers a “Tour” of every map, “On-ramps” that target diverse audiences and connect the user with possible uses of the data, and “Off-ramps” that link to source data and additional information. These tools will support co-production and co-design efforts by the Indigenous Food Security WG and the other teams outlined in Fig. 4 and 5.

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*Fig. 5: Project timeline, major meetings and linkages. Project team leads for different efforts identified by initials (see Section 3.1), for key partners at (inter)national level see also letters of collaboration.*

*3. Management Plan*

*3.1. Network Leadership Roles and Responsibilities, National and International Partnerships*

Specific roles and responsibilities of the network leadership, key entities and (inter)national partners, as well as others supporting the effort are specified in Table 1 and Fig. 5. Because of the complexity of the RNA effort, an Executive Steering Committee (members identified in Table 1 by asterisk), will hold teleconferences every 1-3 months to synchronize and review core activities, with a broader project communications plan supported through the AOS Secretariat and the Project Coordinator.

(i) The AOS Secretariat provides the personnel and supporting resources to build up and maintain the AOS process and activities laid in Fig. 5. Initially led out of IARC (Project Coordinator Yarmey) and out of AINA by a staff member, with further support from key international partners. The Secretariat also translates guidance from the SAON Board and Committees into specific action.

(ii) A project coordinator (Lynn Yarmey) (co)leads the AOS Secretariat; supports the transition of AOS into the SAON governance model and processes; aligns priorities, timelines, and requirements across the two bodies; coordinates the communication and collaboration processes among the Task Teams (Fig. 2) and in particular, facilitates the activities under these Task Teams to maintain connections from SBAs through EVs to specific observing activities and into resulting data products (Fig. 4).

(iii) SAON helps guide work of the Task Teams, with ADC, CON and a to-be-established AOS Steering Group serving in an oversight role. The SAON Secretariat at AMAP, currently resource-limited, interfa­ces with AOS Secretariat for effective sharing of responsibilities. The SAON RMTF informs the coordi­na­tion-design development-information infrastructure cycle and associated program elements (Fig. 5).

(iv) A major element of building capacity in support of SAON and U.S. AON goals is the entrainment of a range of different partners at the (inter)national level. For U.S. partners, in addition to established research groups and other entities, the goal is to involve ECRs (incl. students), scientists/researchers from outside of the Arctic community, and non-experts in the Arctic community (i.e., communities and people in policy-advising roles). While each of these groups has their own needs for this observing network, the framework of AOS WGs, Task Teams and SAON Committees provides different entry points for diffe­rent levels of interest and engagement. The food security theme will help ensure relevance and utility of the activities to these different participants and constituents.

Beyond these engagement efforts, close collaboration with organizations and groups active in the U.S. Arctic observing community will be critical. Key partners, where appropriate identified in the letters of collaboration for this proposal, include the IARPC Observing and Environmental Intelligence Collaboration Teams (and other CTs as appropriate), the SEARCH program’s Arctic Observing WG, ICC, NCEAS as a host of the information infrastructure element, the Arctic Observing Viewer (AOV) team and Alaska Ocean Observing System (AOOS) for tracking, visualization, and planning of observing assets and asset planning, the Alaska Climate Adaptation Science Center (CASC) as a way to link into tribal and federal agency information needs and data holdings.

Importantly, large observing projects or initiatives with a footprint in the Pacific Arctic sector and links to marine and coastal food security, such as the Distributed Biological Observatory (DBO) or the Beau­fort Gyre Observing System, would be involved through membership in one of the AOS WGs or task team member­ship and other mechanisms. Partnering with DBO and PAG, in particular, will tie into efforts to advance DBO data discoverability and relevance to coastal communities, enhanced by DBO membership in the relevant task teams and WGs and participation by task team members in DBO data workshops (Fig. 5). The observing system scoping and requirements process (Section 2.3, Fig. 2) would serve the broader community of agency-led (e.g., NOAA efforts, incl. AOOS) and NSF-supported observing programs, such as NSF-AON, by providing links to specific SBAs and EVs, along with system requirements and design guidance from OSSEs and system optimization contri­bu­ted by the respective task teams. We also envision a link to NSF’s Navigating the New Arctic (NNA) projects, specifically those with a food security or observing component, drawing on the annual NNA project meeting and the AOS as means to interface.

*Table 1. Project team membership - Roles and links*

|  |  |  |
| --- | --- | --- |
| ***Name*** | ***Role & activities*** | ***Affiliations & links*** |
| Hajo Eicken\* | Oversees entire effort, supervisor of Project Coordinator & Indigenous liaison | AOS ExComm & WG; AOS Secretariat |
| Lynn Yarmey\* | Project Coordinator, (co-)leads AOS Secretariat; coordinates collaborations among task teams and working groups | AOS Secretariat |
| Sandra Starkweather\* | NOAA Collaborator, maintains formal links to SAON as Board Vice-Chair and to USAON as Executive Director | SAON: Board, RTMF; USAON; IARPC |
| Alice C. Bradley | Leads ECR engagement & capacity development | AOS ExComm & WG |
| Henry Loescher\* | Leads Requirements Capture Team, responsible for associated deliverables | NEON |
| Raychelle Aluaq Daniel\* | Leads Indigenous Food Security WG and oversees associated activities | Pew Trust; AOS WG |
| Josephine-M. Sam | Postdoc; supports Indigenous Food Security WG | AOS WG |
| Malinda Chase | Collaborator, Tribal Liaison at CASC-IARC; mentors Indigenous project liaison; represents Alaska Native Non-Profit Corp. | APIA, CASC |
| An Nguyen, Pat-rick Heimbach | Optimization & OSSE Leads in Design Development Task Team; Estimating Circulation & Climate of the Ocean (ECCO2) links | ECCO2 |
| Cecilia Bitz | Sea ice OSSE Lead; Sea Ice Prediction Network (SIPN) co-lead | SIPN |
| William Ambrose | Brings together different perspectives of food security case study, incl. bridging ICC perspectives & scientific programs (e.g., DBO) | IARPC |
| Olivia Lee | Helps guide & support the AOS WG process | AOS WGs |
| Peter Pulsifer | Collaborator, maintains links to SAON ADC & data community | SAON ADC |
| Matthew Jones | Oversees ADC data synthesis workshops; manages liaison between data users/providers & NCEAS projects data coordinator | NSF-ADC |
| Amber Budden\* | Coordinates & facilitates data synthesis workshops, supporting assessment of data discovery & usability | NSF-ADC |
| Craig Tweedie | Facilitates AOV contributions, participation in Information Infrastructure Team & data and information gathering by ECR | AOV Dev Team |
| Scott Rupp | Leads information infrastructure tool development & AK data leveraging of Alaska data sets | CASC, SNAP |
| Maribeth Murray\* | AINA Director; oversees AINA component of AOS Secretariat, supports essential services for AOS management and coordination | AOS Secretariat |

(v) Key international partners include AOS Secretariat contributors, specifically AINA in Canada in the near-term and others from Asia and Europe in the long-term. Beyond that, partnerships with national research institutes with a strong Arctic observing component, such as Alfred Wegener Institute in Germany, NIPR in Japan, and others will help in the transition from coordination to design development and information infrastructure. Indigenous Peoples organizations and local/regional Arctic governments are part of the food security thematic activities. International observing initiatives play a key role in the SAON Road Map process and the AOS. Two efforts, one currently underway, the European Union supported INTAROS project and an effort anticipated to ramp up in 2020, i.e., an Arctic node of the Global Earth Observing System of Systems (ArcticGEOSS) are of particular relevance, as are more broadly GEO and GCOS under WMO. For the food security theme, DBO and PAG will facilitate coordination of observations and data sets and take an active role in some of the workshops.

*3.2. Assessment of Activities and Networking*

Given the complexity and scope of the organizational structure described here, an assessment of the efficacy of the activities and networking is important to help guide the overall process as well as steer specific action on the food security theme. An external evaluator will provide such an assessment at the mid-way point of the project in order to achieve the greatest impact on deliverables and outcomes.

*4. Outcomes*

Major expected outcomes of the proposed RNA include:

(i) SAON strategy and roadmap are advanced through specific support action, coordinating sustained observations and planting the seeds for an integrated observing system of systems.

(ii) Implementation of an internationally coordinated suite of observations in the Pacific Arctic sector, centered around a set of EVs, and the resulting information products meet key priorities and information needs of communities, Indigenous Peoples organizations, agencies, and the research community.

(iii) A pan-Arctic food-security oriented observing system information product emerges from the effort as a signature contribution to the global and Arctic GEOSS product portfolio.

(iv) Sustained observing activities supported by NSF (NSF-AON) and agencies (U.S. AON) benefit from adapting parts of their observing activities to align with the framework developed here by a) being able to draw on complementary observations by other entities that are fully aligned with the suite of EVs of interest; b) obtaining guidance from OSSEs and the Indigenous Food Security WG on how to maximize scientific and societal benefits.

(v) A community of practice is established that brings different knowledge systems and bodies of expertise (systems engineering, environmental science, inverse modeling and optimization, Indigenous Knowledge, and others) to bear on the problem of observing system co-design and co-management.

(vi) Capacity is built with key Indigenous Peoples’ organizations through the establishment of a resourced Indigenous Food Security Working Group, with involvement of a tribal liaison and training of Indigenous students/staff at UAF and partner institutions.

(vii) Tools and information products for decision-makers, researchers and Indigenous and coastal communities help advance shared societal benefits and implement FAIR principles.

(viii) The AOS is restructured and anchored within SAON to better engage and entrain the joint contributions of the research community, Indigenous and community-based observing initiatives, agencies, the private sector and others into a well-governed collaborative planning process.

(ix) The AOS draws on the principles of knowledge co-production as well as observing system co-design and co-management to advance internationally coordinated observing of a changing Arctic with a focus on shared societal benefits.

(x) In total, these products and outcomes prepare the ground for a (SAON-led) decadal scale implementation plan for an Arctic observing system of systems.

*5. Intellectual Merit*

As an RNA activity, a major focus of the work is to derive synergies and benefits from improved collaboration and coordination. This will lead to research activities under a more rigorously co-designed observing system with intellectual merit in terms of understanding key mechanisms of Arctic environmental change and informing responses to such change across disciplines and sectors. The proposed work also has substantial intellectual merit in its own right. In particular, the combination of Indigenous and local knowledge with conceptual and quantitative approaches within a single framework for observing system design and optimization is novel and likely to yield new insights into state variables and indicators that can serve as EVs and describe the evolution of the Arctic system.

*6. Broader Impacts*

The proposed work directly contributes to the attainment of broader societal impacts by relying on a societal benefits area framework to help guide observing design development, information infrastructure, and optimization or implementation of specific observations. This is achieved by involving stake­hol­­ders at all levels of the proposed activities (Fig. 3). Specifically, we are following a co-production approach [48] and are explicitly directing significant resources into engagement of Indi­ge­nous and coastal commu­nity experts and information users, as well as helping build capacity through a tribal liaison model. Early career engagement in the AOS process prepares future experts. By developing a community of practice and building international capacity in support of SAON and AOS, we are seeking to sustain broader impacts beyond the lifetime of this project. The task teams and WGs will conduct activities that advance the vision of shared societal benefits through coordinated Arctic Observing.

*7. Results from Prior NSF Support*

**Eicken,** Lovecraft, Mahoney, Johnson, Heinrichs, Petrich:ARC-0856867; *Collaborative Research on the State of the Arctic Sea Ice Cover: Sustaining the Integrated Seasonal Ice Zone Observing Network (SIZONET)*. 01/2010-12/2016; $1,388K*.* Intellectual merit: Key findings include: i) major changes in the mass budget and seasonal stability of coastal ice [64,67,77]; ii) remarkable consistency in the onset of key melt stages in relation to albedo evolution [78]; iii) presence of systematic errors in modeled ice thicknesses in AOMIP models [79]; iv) impact of decreased stability of landfast ice and changes in ice retreat on subsistence activities [80]; v) relevance of sea ice changes for ice use and management of maritime activities [35,81]. Broader impacts: SIZONet data products have been utilized by government agencies, academia, private industry, and Arctic residents, and have been used in >25 peer-reviewed pub­li­cations spanning physical, biological and social sciences, and applications such as ice forecasting and satellite validation. SIZONet has supported 3 PhD and 2 MS students and 2 early-career researchers.

Wanamaker, **Ambrose,** Retelle; #1417766, $810,000 08/01/2014-07/31/2019, *Collaborative research: Exploring the role of oceanic and atmospheric forcing on Arctic marine climate from newly developed annual shell based records in coastal Norway*. Intellectual Merit: This project’s goal is to reconstruct annual hydrographic variability during key climate intervals within the last millennium from far northern Norway. We are using annual shell-based records (i.e., master shell chronology, isotopes) to reconstruct regional hydrographic variability along the northernmost coast of Norway during intervals of the Medieval Climate Anomaly, the Little Ice Age, and for Modern Climate. Broader Impacts: The project has supported one female Ph.D. student, 6 graduate student research assistants, 3 undergraduates, 2 technicians, and a K-12 teacher. Results have been published in 3 peer-reviewed articles (another in review) and presented by PIs and students at 8 conferences. The project also ran a paleoclimate workshop for Maine high school teachers from diverse backgrounds and educational environments to teach practical examples of basic STEM activities focused on climate change for use in the classroom.

**Loescher**, GEO-132159, ‘SAVI: *Building an international cooperative framework between the EU and the USA to harmonize data products relevant to global research infrastructures in the environmental field’*, awarded $1,418,731, 05/13/2013-08/31/2019 Intellectual Merit:Advanced a large international community that continues to advance e-infrastructures globally and have contributed to the G7 GSO activities. Research infrastructures include UNAVCO, EARTHSCOPE, NEON (NSF); ICOS, Lifewatch, Globis-B, EMSO, EPOS, eLTER, TERENO (EU); CERN (China); TERN (AUS). Broader impacts: (3) Workshops for early career scientists (>100), >15 peer-reviewed papers, 1 book (32 contributing chapters), webpages, newsletter, and broad inclusion.

**Nguyen, Heimbach**; OPP-1603903, *Collaborative Research: Understanding Arctic System Change through Synthesis of Hydrographic and Sea Ice Observations from the Early 21st Century*, 07/15/2016-06/30/2020, $512,630.00. Intellectual Merit: This project brings together hydrographic data from ship, aircraft and autonomous instruments; sea ice data from in situ buoys, satellites and manned vessels; and boundary-layer meteorology within the adjoint-based Arctic Subpolar Gyre State Estimate to develop a dynamical description of the Arctic Ocean during the early 21st century. Broader Impacts: In collaboration with UT Austin’s Visual Arts Center and the Texas Advanced Computing Center, we assembled an exhibit, “Exploring the Arctic Ocean" in the fall semester of 2018. Diverse multimedia projects depicted changes due to ongoing major shifts in the Arctic Ocean. The exhibit was accompanied by a series of events, including lectures and panel discussions. Publications: [82-91].

**Bitz**, Frierson, Battisti - *The Hydroclimate of Antarctica PLR-1341497*: $421,132, Jan 2014 – Jan 2017. Intellectual Merit:This project focused on improving understanding of the Antarctic atmo­spheric water cycle and the coupled interactions of its components with the Southern Ocean and Antarctic land and sea-ice cover. We investigated the influence of the water cycle on attributing changes in the Southern Ocean and its sea-ice cover. Eleven peer-reviewed publications and an article in the CLIVAR newsletter resulted from this research. Broader Impacts:This grant supported graduate student Emily Newsom and partially supported three more female graduate students. The research team made an outreach video about the Coriolis effect (on YouTube UWAtmosOutreach) and created a teaching module for high school girls to learn about running energy balance climate models using Python.

**Jones**, **Budden**: OPP-1546024, *Scientia Arctica: A knowledge archive for discovery and reproducible science in the Arctic*, 2016-2021, $3,643,567. Intellectual Merit: The Arctic Data Center curates, preserves, and disseminates over 5000 Arctic data sets following FAIR principles, and provides data management services to the Arctic researcher community. Broader Impacts: The Arctic Data Center provides intensive data science trainings to the Arctic research community, runs a data science fellowship and internship program to support skill building and data literacy and delivers user-friendly interfaces for metadata creation, data upload, metadata quality checks and data usage metrics.

Oberbauer, **Tweedie**,Hollister,Welker: AON1504345. *Arctic Observing Networks: Collaborative Research: ITEX AON - understanding the relationships between vegetation change, plant phenology, and ecosystem function in a warming Arctic*. Intellectual merit: Continued US participation in the Internatio­nal Tundra Experiment (ITEX); sustained monitoring of vegetation change in response to warming and Arctic change; improved automation and spatial coverage of measurements; synthesized results across the ITEX network. 35 peer reviewed articles were published/submitted. Findings include demonstration of how new low cost sensors and alternate analytical approaches can advance knowledge of vegetation change; advanced understanding of patterns and drivers of arctic vegetation change. Broader Impacts: >150 datasets, 30,000 data files, and 2.2TB of data have been archived at NSF-ADC and UNAVCO. At UTEP, 1 postdoc, 6 graduate students, and 5 undergraduate students were trained – all Hispanic and more than half female.

Brinkman, **Rupp**,Chapin, Little, CNH-L-1518563; $1,525,274; 8/2015-8/2019, *Adaptive Coupling of Human Environment Linkages in Response to Globally Driven Changes in Subsistence in Rural Alaska*. This project investigates climate-change impacts to rural communities and facilitates adaptive responses. Intellectual merit: Through community-based and led research, this project: documents impacts of climate change and energy costs on traditional harvest systems; identifies community characteristics that influ­ence vulnerability of these systems to impacts; creates intensive research partnerships with communities to address local priorities and scientific inquiries; catalogs/evaluates effectiveness of adaptive responses to impacts; assesses and facilitates the spread of adaptive responses across communities; evaluates the transferability of findings to other regions. Broader Impacts: Work with 8 communities in coproduction, involving students and ECRs. Research products: To date, 433 people from 33 rural communities have completed a traditional harvest survey; intensive research partnerships initiated with 4 communities; one stakeholder workshop completed; multiple manuscripts, book chapters, and reports submitted/published.

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