

White paper for Arctic Observing Summit, Vancouver, BC, Canada, April 30 – May 2, 2013; Revised version, 25 April 2013

Dual-purpose Arctic observing networks: Lessons from SEARCH on frameworks for prioritization and coordination

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Summary

The majority of arctic observation networks are thematically focused or used for specific operations and services, resulting in a relatively narrow scope of observations – only three countries have “broad” observing networks. Across all networks there is a need to better coordinate government priority setting in order to (1) be most efficient with the available government funding, and to (2) present a stable, cross-referenceable set of goals and priorities to facilitate international cooperation. In addition, there is a general mismatch between identified science needs and desired outcomes by society. To help reduce this mismatch and optimize observing networks, we suggest to establish a hierarchy of interconnected activities that drive the observing network design and implementation. The hierarchy would specifically include levels of *Problem definition, Strategy, Tactics, and Deployment scale*, and across the hierarchy we must define a set of “actionable” science questions that drive network design, with priorities set by the number of societal applications or needs that a science question can inform. Engaging with the private sector in observing networks will likely require a more concerted effort including direct collaboration and targeted meetings with overarching organizations. Both government agencies and their funded, coordinating entities such as SEARCH and ACCESS can help streamline coordination and funnel efforts within and among observational networks in the Arctic.

1. Introduction

System-level understanding of and effective responses to a rapidly transforming Arctic require long-term observations of the extent, origins and impacts of Arctic environmental and socio-economic changes. The importance of such observations has been recognized in a range of different scientific contexts, such as global climate change (e.g., Calder et al. 2010; Serreze and Barry 2011), ecosystem services (Chapin et al. 2005), and human activities (Krupnik and Jolly 2002; Hovelsrud et al. 2011). At the same time, the urgency

of adaptation and mitigation at the local and regional level and increasing industrial activity (Brigham 2011, Lovecraft and Eicken 2011) have highlighted the need for data and information products that serve the needs of different stakeholder groups. The recent agreements by the Arctic Council on search and rescue and oil spill response are examples of such information needs, as both require the availability of a range of environmental data for planning and response (Emergency Prevention, Preparedness and Response Working Group 2011).

Against this backdrop of a rapidly changing and in many respects uncharted Arctic, the scientific community faces a number of challenges and opportunities. Three stand out in the context of the Arctic Observing Summit (AOS) and are discussed further in this white paper.

- (1) Recognizing the need for Arctic observing systems to serve a dual role with respect to the demands of science and societal response outlined above, how can we strike a balance between scientific research needs (e.g., long-term observations to track and understand change on seasonal to multi-decadal timescales or process studies aimed at critical drivers and modulators of Arctic change) and the information needs of key stakeholders who are living with, working in, or responding to a rapidly changing Arctic?
- (2) Entities tracking elements of Arctic change reflect the disproportionate importance of academic research programs, community-based observations, and international partnerships. How can these activities best partner with and link to emerging agency and private sector observing programs?
- (3) Considering the realities of limited resources and the challenges of conducting research programs in Arctic environments, how can we best prioritize, focus and coordinate long-term observations that meet the criteria established in response to challenge #1 above?

The importance of these questions, in particular as seen through the lens of challenge #3, is highlighted by the fact that AOS white paper contributions are by and large focused on one particular sector, discipline, or topic, with very few exploring overarching issues that are of relevance in the discussion of coordination of networks or observing systems.

By focusing on activities launched in recent years by the U.S. interagency Study of Environmental Arctic Change (SEARCH), in particular the U.S. Arctic Observing Network (AON) Design and Implementation (ADI) Task Force, this white paper explores potential approaches to address these three challenges in an international setting. Our contribution relies on and is informed by partner programs in other countries, in particular DAMOCLES, ACCESS, and ArcticNet (<http://www.damocles-eu.org/>; <http://www.access-eu.org/>; <http://www.arcticnet.ulaval.ca/>), as subsumed under the International Study of Arctic Change (ISAC), an activity initiated by the International Arctic Science Committee (IASC). First, we will briefly review key drivers of observation programs and information needs, followed by a short survey of the current landscape of observing network activities. Drawing on SEARCH activities as an example, we will explore different approaches to focus, prioritize and coordinate

observing activities at the national level, concluding with some recommendations that may be applicable at the international level and within the context of the AOS.

2. Drivers of Arctic observing systems: Scientific and stakeholder information

Arctic environmental and socio-economic change has been a subject of discussion going back to the 19th and early 20th century (e.g., Brooks 1938). As early as the mid-19th century Rochefort Maguire was reporting on observations by Alaska Iñupiat elders about a warming climate (Bockstoce 1988). Recent, changes of a transformative nature were starting to be reported by Arctic residents and indigenous experts as well as the scientific community beginning in the 1980s (see discussion in Hinzman et al. 2005, Krupnik and Jolly 2002). Initial synthesis of individual research findings and results from programs focusing on specific aspects of such change led to the articulation of overarching science questions that needed to be addressed in order to improve understanding and responses to Arctic environmental change (e.g., Overpeck et al. 2005; Dickson 1999; Callaghan et al. 2011b). In the U.S., a SEARCH open science meeting galvanized the research community (SEARCH 2005a) and led to a SEARCH workshop that articulated science questions and associated research priorities in the context of *observing, understanding and responding* to Arctic environmental change (SEARCH 2005b). Other research programs such as Canada's ArcticNet, the European DAMOCLES program (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) or ScanNet set out on a similar path. Convergence of these activities resulted in the development of the international program ISAC to track, understand and inform responses to Arctic change. The ISAC Science Plan (Murray et al. 2010) distilled overarching scientific interests and priorities into the following nine guiding questions:

- (1) How is the Arctic linked with/to Global Change?
- (2) How persistent is the presently observed Arctic Change and is it unique?
- (3) How large is the anthropogenic component of observed Arctic Change compared to natural variability?
- (4) Why are many aspects of Arctic Change amplified with respect to global conditions?
- (5) How well can Arctic Change be projected and what is needed to improve projections?
- (6) What are the adaptive capacity and resilience of Arctic ecological systems?
- (7) To what extent are ecological systems able to adapt to the effects of Arctic Change?
- (8) How does environmental change in the Arctic affect the resilience, adaptive capacity and, ultimately, viability of human communities?
- (9) How can new insight into Arctic Change and its impacts be translated into solutions for increased adaptation, management and mitigation?

These questions already reflect some degree of prioritization beyond national programs, such as the recognition that the Arctic is in fact in the midst of a major transition - possibly into a new state - and that scientific research would play a role in informing mitigation and adaptation strategies. Moreover, the questions also build on the strong arguments made by Arctic residents (reflected by a range of white papers prepared for the AOS 2013) and a host of activities during the International Polar Year 2007-08 (IPY) to include a strong component focusing on people and social-environmental systems

(Krupnik et al., 2011). While only the last two guiding questions address human concerns directly, questions 5 to 7 (and to some extent 3) are intertwined with societal interests and concerns by Arctic decision-makers.

Stakeholders interests in long-term observing activities are typically mediated through their specific concerns and aims, which can be framed in the context of desired outcomes. As detailed by Murray et al. (2012) in the final report for an international workshop on Responding to Arctic Change, these desired outcomes are typically separated by a large gap from the types of questions listed above that drive improvements in the understanding of the Arctic system and its key components. The services delivered by the Arctic system (analogous to ecosystem services discussed, e.g., in the Millennium Ecosystem Assessment, see Chapin et al. 2005) provide a link between the priorities and information needs of Arctic stakeholders and those of the scientific community.

This mismatch between observing activities and desired outcomes results in the need to translate or recast the state variables or target quantities that observing systems track in an Arctic system science context, into parameters that can be directly linked to Arctic system services and ultimately stakeholder desired outcomes. Such exercises are not trivial and the AOS may help initiate or synthesize successful efforts along these lines. In this context, national or international agencies charged with the management or oversight of Arctic issues may serve as important allies, since they typically require the condensation of desired outcomes into specific management directives or institutional regimes. One approach to parse and prioritize observing system activities is through the analysis of the spatial and temporal distribution and density of such rule sets that govern a range of activities in the Arctic. This approach is outlined in more detail by Lovcraft et al. (2013) in an example focusing on management of sea ice system services in the Alaskan Arctic. Other examples of such synthesis of different stakeholder interests and information needs include the development of representative indicator variables. The European Environmental Agency (EEA, <http://www.eea.europa.eu>), for example, has developed a series of indicators that address European environmental priorities and concerns and are being tracked at an international level. However, only very few EEA indicators directly target the Arctic (such as sea ice and permafrost extent); the European Arctic Climate Change, Economy and Society (ACCESS) program has now been charged with developing a new set of indicators focusing on sustainable development in the Arctic (Gascard and Karcher, personal communication, 2013). Such efforts may be of significant value in a broader setting and warrant discussion at the AOS. In this context, Arctic Council Working Groups and other international consortia, such as working groups within the International Maritime Organization or other bodies, may also be able to help identify priorities for stakeholder information needs and societal relevance.

3. Landscape of existing observing programs and networks

International efforts to create observing networks in the Arctic have increased amid growing interests and identified information needs. The Sustaining Arctic Observation Networks initiative of the Arctic Council (SAON; <http://www.arcticobserving.org>)

compiled an inventory of existing networks in 2010, the results of which are used to further describe the landscape of international Arctic observing activities below. Results from a similar effort for the U.S. Arctic sector were recently compiled by Eicken and Lee (unpublished). The inventory of networks was reclassified into the following general categories: (1) *Broad networks* such as the U.S. AON and ArcticNet in Canada that include a broad range of interdisciplinary observations and projects, (2) *Focused networks* that are confined to specific themes or disciplines, such as marine ecological monitoring, (3) *Commercial networks* that provide observational data for profit, (4) *Operations or service-oriented networks* such as the Global Atmosphere Watch (GAW) feeding data to weather service and forecasting entities, and (5) *Resource-extraction networks* that conduct monitoring or baseline observations specifically for planned or ongoing resource extraction activities. The number of observation networks in each country by type is provided in Table 1.

Table 1. Number of observing networks by category and country

Category	USA	Canada	Finland	Iceland	Denmark	Russia	Norway
Broad	2	3					1
Commercial				1	1		
Focused	12	7	2	1	16	11	11
Operations	21	4	2	12	14	6	9
Resource Extraction	2			2	1		
<i>Sum</i>	<i>37</i>	<i>14</i>	<i>4</i>	<i>16</i>	<i>32</i>	<i>17</i>	<i>21</i>

*Project information obtained for each country from: <http://www.arcticobserving.org/national-reports>

The majority of observation networks were either thematically focused or used for specific operations and services, resulting in a relatively narrow scope of observations. The U.S. has the highest number of networks that are related to operations, and many of these observation networks are linked to Federal and State agencies. Coordination and data exchange among agencies can already be a complex process, but the problem of coordinating efforts for long-term observations is even more complex when academic and international government cooperation is involved. Here, efforts such as the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT) have been exploring viable approaches of how to deal with such challenges. Broad networks were identified in only three countries: U.S., Canada, and Norway which may reflect current and future challenges in coordinating observational networks and has important implications for the development of overarching observing frameworks. Almost all the broad networks included components for observing the coast, ocean, cryosphere and atmosphere (Table 2). In contrast, the majority of focused and operations networks emphasized marine ecosystem and atmosphere observations. Most observational networks do not focus on the terrestrial, human/social, and cryosphere themes.

The data availability also differed by category and by country. For all network types, less than half of the networks offered full, free access to data (Table 3). However, focused and operations networks provide the greatest access to data and partial data sets. Fully

accessible data was most common for the Atmosphere, Marine and Marine Ecosystem themes. Partial data access was typically offered for the majority of broad networks and resource extraction networks, and typically included the availability of metadata and published reports only. The countries with the greatest proportion of networks with freely accessible data were Finland and Norway, with 75% and 85% of their networks providing freely accessible data, respectively.

Table 2. Percentage of networks in each category that include specific thematic observations.*

	Broad	Commercial	Focused	Operations	Resource Extraction
Terrestrial	17%	50%	31%	7%	20%
Terrestrial ecosystem	67%		28%	24%	
Atmosphere	83%		41%	35%	60%
Marine ecosystem	67%		54%	32%	
Coastal	100%		23%	24%	40%
Oceans	100%		28%	24%	40%
Human	50%		26%	12%	
Freshwater	67%		31%	29%	
Cryosphere	100%	50%	28%	9%	

* Note that some networks include observations on multiple themes counted separately such that the sum of different themes in each network category may exceed 100%. Data from May 2011 SAON network descriptions list. An updated list of observing networks is accessible from: <http://pusnes.grida.no/amap/amappd/?org=4>

Table 3. Data availability by network category

	Broad	Commercial	Focused	Operations	Resource Extraction
All data freely available	17%		47%	46%	20%
Data partially available	50%		23%	22%	60%
Data on request			12%	18%	
No data available		50%	3%		
Data available for a fee		50%		1%	
Unknown	33%		15%	13%	20%

* Data from May 2011 SAON network descriptions list.

3.1 Distribution of observing assets

Limited coordination of efforts and specific areas of interest can result in a patchy distribution of observing assets (Figure 1). We used data on specific observing assets from the Alaska Ocean Observing System (AOOS) for sensors active in 2011 to 2012 to describe the distribution of U. S. ocean observing assets. It is important to note that we used relatively short-term project-based asset distribution for illustrative purposes here. Although important, we did not conduct an explicit analysis of observing asset distributions for longer time scales needed for dedicated long-term monitoring. Such an analysis of the distribution of long-term monitoring efforts may show some temporal and spatial variation in asset distribution, but this is beyond the scope of this white paper. However, discussion at the Arctic Observing Summit may benefit from an analysis of observing activities that qualify as true monitoring (i.e., extending over timescales of several decades). In the U.S., one such effort is the National Park Service's Vital Signs project that identifies a list of core variables that are monitored over a time scale of at least thirty years (Lawler et al. 2009).

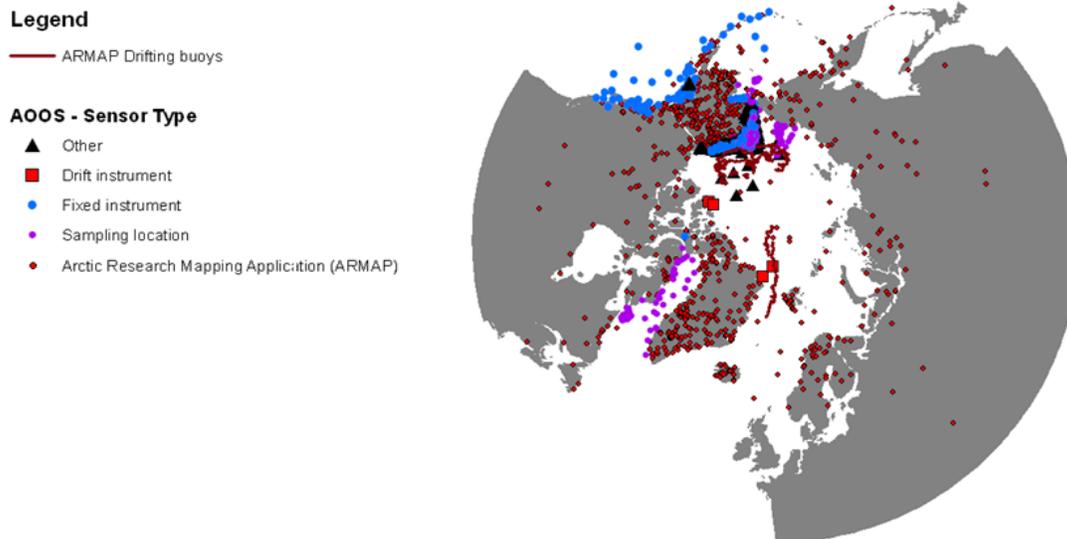
A more general view of SAON projects can also be viewed by theme and country (<http://portal.inter-map.com/#mapID=49&groupID=&z=1.0&up=214.4&left=2001105.4>). Although the data were not easily ascribed to specific networks we were able to quantify 2011 – 2012 observing efforts in three regions from the coast to approximately 500 km offshore: (1) South-Western Chukchi sea, (2) North-Eastern Chukchi Sea, and (3) Beaufort Sea. Observation asset density in the North-Eastern Chukchi Sea (0.0037 assets km⁻²) was almost three times the density of assets in the Beaufort Sea (0.0014 assets km⁻²), with the smallest densities found in the South-Western Chukchi Sea (0.0008 assets km⁻²). Our brief analysis reveals that there is significant effort needed to quantify the spatial scales of observing asset distribution to ensure circumpolar coverage, and identify relevant spatial scales for different observation types. Efforts to quantify the spatial distribution of assets would benefit from coordinating with current efforts such as AOOS or the Arctic Research Mapping Application and Arctic Observing Viewer (see Manley et al. 2013) that currently provide visualization tools for Arctic projects and assets.

4. Developing a framework to foster prioritization and coordination of observing system efforts: A brief summary of relevant SEARCH activities in the U.S.

Since SEARCH played a key role in several activities related to the building and coordination of the AON at the U.S. national level, it is instructive to briefly review the key elements and approaches aimed at prioritization and improved coordination of AON activities. As a program that has been aiming at both improved scientific understanding of Arctic change and generation of data and tools that can inform effective responses to change, SEARCH initially focused on the driving science questions (Morrison et al. 2001, SEARCH 2003, SEARCH 2005). This led to the build-out of a core AON drawing on key pre-existing elements, such as the North Pole Environmental Observatory (NPEO; Morrison et al. 2002), during the IPY. In parallel, the SEARCH Observing Change Panel helped facilitate PI-level coordination through annual AON PI meetings that started in

2007. The first AON PI meeting provided a means to establish communication among AON investigators and help establish guidelines on the implementation of CADIS (Cooperative Arctic Data and Information System) as the data portal for data dissemination and archiving. Most important, these activities were framed by the SEARCH data policy (http://www.arcus.org/files/page/documents/19286/search_datapolicy_051207.pdf) which stipulates rapid, free and open access to all AON data to maximize scientific benefits, promote collaboration, and enhance information transfer to stakeholders.

The 2008 AON PI meeting was jointly organized with the DAMOCLES Program, and focused on building international partnerships and fostering broader network integration. Subsequent meetings have continued to promote the coordination of AON internationally, with the 2009 State of the AON report (AON 2010) an important guiding document. In 2009 the AON Design and Implementation (ADI) Task Force was established with guidance from the National Science Foundation (NSF). ADI was meant to explore the range of viable observing system design and optimization options while at the same time providing guidance on prioritization. The ADI final report was released in 2012 (ADI Task Force 2012) following a series of meetings and a 2010 workshop that provided information on different observing efforts. The ADI report includes recommendations to achieve an effective and robust U.S. Arctic observing effort that integrates with international efforts as outlined in section 3 above.



*Figure 1. Distribution of U.S. observing assets in the Arctic. AOOOS sensor shows only active marine observing assets for 2011 to 2012. *Data for drifting buoys and ARMAP locations from Arctic Research Mapping Application and Arctic Observing Viewer; data for sensor types from Alaska Ocean Observing System*

Table 4. Hierarchy of AON design and implementation elements

AON design elements	Activity	Implementation
<i>Problem definition</i>	<ul style="list-style-type: none"> • Scenarios • Institutional analysis • Feedback/impact assessment 	<ul style="list-style-type: none"> • SEARCH SSC/panels • Agency teams (e.g., North Slope Science Initiative) • Assessments
<i>Strategy</i>	<ul style="list-style-type: none"> • Scenario consistency analysis • Institutional analysis • Model-based assessments • Process studies 	<ul style="list-style-type: none"> • Working groups • Funded projects • Ad-hoc meetings
<i>Tactics</i>	<ul style="list-style-type: none"> • Target quantity definition and measurement options • Model-based assessments 	<ul style="list-style-type: none"> • Synthesis forums (e.g., Flagship site teams, Sea Ice Outlook), funded program (e.g., Landscape Conservation Cooperatives) and ad-hoc meetings
<i>Deployment scale</i>	<ul style="list-style-type: none"> • Sampling array design 	<ul style="list-style-type: none"> • Site teams • Observing System (Simulation) Experiments

While some of the ADI findings will be discussed further in Section 5, a key conclusion centers on the need to establish a hierarchy of interconnected activities that drive the observing network design and implementation. Thus, while there is a tendency to focus on very specific, “blueprint”-type design and optimization activities that employ observing system simulation experiments (OSSEs) and other approaches to determine sensor placement and measurement approaches, such efforts are premature without a clear problem definition and associated strategies and tactics (Table 4). Similarly, established problem definitions and strategies that utilize older datasets and hindcasts are important for monitoring efforts to successfully transition towards a predictive capacity (see Callaghan et al. 2011a for example monitoring applications). For broad networks such as those outlined in the previous section, coordination of activities that complement each other within all four levels of this hierarchy is important to achieve scientific focus and maintain the balance between science and stakeholder/policy drivers of the observations. Within the context of the AOS, mapping and reconciling the range of activities at these different levels throughout the Arctic may lead to more robust networks.

In the context of SEARCH, the top level within the hierarchy was addressed through a 1-year process that involved the scientific community in collaboration with the SEARCH agency partners to arrive at a set of 5-year, near-term goals and corresponding focal areas. These 5-year goals as described below are not meant to detract from the importance of long-term observations for the AON, but rather provide a means to focus SEARCH activities, and provide the flexibility for prioritizing sustained observations.

Since they reflect some degree of consensus within the U.S. Arctic research community they may also provide helpful in framing discussion at the Arctic Observing Summit. The SEARCH five-year science goals are:

- 1. Improve Understanding, Advance Prediction, and Explore Consequences of Changing Arctic Sea Ice** (details at: <http://www.arcus.org/search/sea-ice>)
- 2. Document and Understand How Degradation of Near-Surface Permafrost Will Affect Arctic and Global Systems** (details at: <http://www.arcus.org/search/permafrost>)
- 3. Improve Predictions of Future Land-ice Loss and Impacts on Sea Level** (details at: <http://www.arcus.org/search/land-ice>)
- 4. Analyze Societal and Policy Implications of Arctic Environmental Change** (details at: <http://www.arcus.org/search/society>)

These goals address areas of scientific and societal urgency and were developed with significant input from the broader scientific community. These goals also overlap and complement existing agency priorities and national research plans, such as the National Ocean Policy (<http://www.whitehouse.gov/administration/eop/oceans/policy>), the National Oceanic and Atmospheric Administration's (NOAA) Arctic Strategy (http://www.arctic.noaa.gov/docs/NOAAArctic_V_S_2011.pdf), or the Interagency Arctic Research Policy Committee's implementation strategy (IARPC 2012) and the U.S. Arctic Research Commission's Goals and Objectives for Arctic Research (2013). Even though the overlap of goals and priorities are currently similar among these U.S. agencies, it will be increasingly important to coordinate the goal-setting and prioritization process in the future in order to (1) be most efficient with the available government funding, and to (2) present a stable, cross-referenceable set of goals and priorities to better facilitate international cooperation.

These four SEARCH science goals complement each other and will be brought together towards the end of the five-year period through development of scenarios to emerge from a proposed *Arctic Futures 2050* synthesis meeting series. At the same time, they address the upper tiers of the hierarchy and each subsume activities which are led by a goal-specific Action Team that delve down into the strategy, tactics, and deployment scale.

While further details on these activities and their role in the evolving AON can be found at the SEARCH website (<http://www.arcus.org/search/aon>), a brief illustration of how prioritization and coordination activities may intertwine can be given for the goal related to the impacts of a diminishing Arctic Ocean ice cover. The specific objectives for this theme are (1) assessing the predictability of summer arctic sea ice extent, thickness, and properties on seasonal to decadal timescales and improving ice forecasts, and (2) exploring consequences of the changing ice cover on arctic ecosystems, the global climate system, and people.

SEARCH organized a U.S. Arctic Observing Coordination Workshop in Anchorage, Alaska in 2012 that was structured around the five-year goals (Perovich et al. 2012). The meeting brought together scientists, data managers, stakeholders, decision-makers and local, state and federal representatives to facilitate coordination of efforts and goals for the AON. The meeting led to the identification of a number of "showcase" projects that

would address urgent questions and build on partnerships among agencies, stakeholders and the research community. Several of these showcase projects are represented at the AOS. In the way of committed funding resources and coordination with other relevant activities the showcase project for a “Distributed Environmental Observatory for Terrestrial Change Detection” (Lead: P. Martin; cf. Payne et al. 2013) is of particular interest for the AOS where links to other terrestrial networks can be strengthened.

The meeting highlighted the fact that decision-makers by necessity often focus on the local and regional scale, such as the changing ice cover in Alaska offshore oil and gas lease areas from the perspective of impacts on operations, environmental security, and ecosystems and people. In the context of an observing system that can help anticipate and track major changes and drivers at the pan-Arctic scale necessary to inform responses at the local level, finding approaches to reconcile or balance activities at different scales presents a major challenge.

To address this challenge, SEARCH has worked towards the establishment of “communities of practice” that can help overcome institutional barriers, improve communication, and develop an observing program that flows naturally through the four levels of hierarchy outlined in Table 4. Examples of such groups include the Sea Ice Outlook (<http://www.arcus.org/search/seaiceoutlook/index.php>) and the Sea Ice for Walrus Outlook (<http://www.arcus.org/search/siwo>). Both of these serve as forums for the international or national ice prediction and observation community to jointly review and synthesize forecasts at different scales. By involving stakeholders and local experts at the Arctic village level, prediction and observation efforts can be revised and calibrated against both the driving scientific research priorities and the key questions and outcomes desired by the end-users of the information. Seeding and nurturing such communities of practice is a major challenge, in particular at the international level. Here, an AOS can serve an important function by bringing in operational agencies (such as those subsumed under the World Meteorological’s programs) and offering a platform to establish and share best practices.

5. Towards internationally integrated approaches in observing system design, optimization, and implementation

Drawing on the activities and findings discussed in the previous sections, we can identify a number of different approaches that can form the basis for discussions at the AOS to help address the three questions posed in section 1 above, i.e., how to best balance scientific and stakeholder information needs; build partnerships between academia, stakeholders including Arctic residents, and the private sector; and prioritize, focus and coordinate key long-term observations.

A review of a range of both narrow- and broad-focus observing programs as part of ADI suggests that networks with a distinct focus rather than broader, less clearly articulated objectives are more successful, in particular if coupled with continuous feedback from stakeholders and data users on the evolution of network requirements. Achieving balance

between the different constituents of an observing network is greatly aided by first defining a set of actionable science questions that drive network design. Here, “actionable” implies the following: (1) An overarching science question, such as those developed by ISAC at the international level, is translated such that it links directly to specific quantities that need to be determined in the context of an observing system; (2) Data and information derived from addressing this actionable question allow stakeholders or governing bodies to develop policies or inform specific decisions and actions in response to Arctic change. For such actionable questions, guidance on prioritization can be derived from the breadth of applications that can be linked to a specific question, with higher priority assigned to those approaches that can help address multiple questions.

Methodologies and implementation strategies for network design and optimization vary widely between disciplines, both in approach and maturity. Hence, no single blueprint or common design exists for the components of a pan-Arctic observing network or system of systems. Rather, observing system design and optimization need to be considered in a hierarchy of relevant approaches (Table 4). Hence, the diversity of science questions that an observing network must address requires an extensive strategic analysis of (1) their prioritization, (2) the variety of observational methodologies that must be implemented, and (3) the different levels of readiness in each field. An important aspect of network design is the ability of the network to remain agile and able to adapt to a rapidly changing Arctic, coupled with an evolving set of actionable scientific questions. Designing such an agile network is complicated by the requirement that scientific observations maintain “consistency” in method or approach, and they must be sufficiently “long-term” to damp out random variation and identify robust patterns or trends. One approach to this complication may be through better coordination of different network efforts in order to partition resources to cover both the needs for long-term observations and the capability to rapidly respond to new data needs for models or management decisions.

In the context of the AOS, it may be fruitful to review and discuss how the existing landscape of observing programs and networks, as archived by SAON (and analyzed in Section 3 above) and discussed by the AOS white papers and other contributions to the summit, matches up with the hierarchy of design approaches outlined in Table 4. This in turn may then serve as the basis for the identification of a few sets of activities deemed of high priority at a high level of readiness that can serve as showcase projects and help advance and illustrate the type of international coordination and focusing that the 2013 summit is aiming to foster. For example, the set of key research questions defined by ISAC may be reviewed and prioritized in collaboration with agencies and stakeholders at the summit or in designated follow-up activities. Here, drawing on the help of SAON to query Arctic Council (AC) Working Groups and other AC programs such as the Circumpolar Biodiversity Monitoring Program (CBMP) or projects focused on community-based observations may prove fruitful, as may be the engagement of the private sector. The latter is not straightforward and may require a more concerted effort and direct collaboration with overarching organizations. For example, the World Ocean Council’s (WOC) Sustainable Oceans Summit (http://www.oceancouncil.org/site/summit_2013/) immediately preceding the AOS will likely generate desired outcomes that are of direct relevance to the Arctic. Developing a

partnership with WOC to address such topics jointly at a follow-up meeting may result in specific actions that can be reviewed and implemented through a process growing out of the AOS.

Along the same lines, partnerships with international programs that are focusing on actionable science, such as some of the WMO and World Climate Research Program (WRCP) activities could be of great value. This applies both to well-established programs such as the Global Atmosphere Watch, as well as emerging projects such as the Global Cryosphere Watch (Key et al. 2013). A discussion of how Arctic observing activities would tie in with the Global Earth Observation System of Systems (<http://www.earthobservations.org/geoss.shtml>) may prove fruitful as well.

References

- AON, 2010, Arctic Observing Network (AON) Program Status Report – 2009. Results from the Third AON Principal Investigators (PI) Meeting, 30 November – 2 December, 2009, Boulder, CO.
- AON Design and Implementation Task Force., 2012, Designing, Optimizing, and Implementing an Arctic Observing Network (AON): A Report by the AON Design and Implementation (ADI) Task Force. Study of Environmental Arctic Change (SEARCH), Fairbanks, Alaska. 64 pp.
- Bockstoce, J. (ed.), 1988, *The journal of Rochfort Maguire 1852-1854: Two years at Point Barrow, Alaska, aboard H.M.S. Plover in the search for Sir John Franklin*. London: The Hakluyt Society, 2 vols.
- Brooks, C. E. P. 1938, The warming Arctic, *The Meteorological Magazine*, 73, 29-32
- Brigham, L. W., 2011, Globalization and challenges for the maritime Arctic. In: Davor Vidas and Peter Johan Schei (eds), *The World Ocean in Globalisation*, Leiden/Boston: Martinus Nijhoff Publishers/Brill, p. 305–320.
- Calder, J. and eleven co-Authors, 2010, An Integrated International Approach to Arctic Ocean Observations for Society (A Legacy of the International Polar Year); *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2)*, Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, doi:10.5270/OceanObs09.cwp.14
- Callaghan, T. V., C. E. Tweedie, P. J. Webber., 2011a, Multi-decadal changes in tundra environments and ecosystems: The International Polar Year-Back to the Future Project, *Ambio*, 40(6). 555-557
- Callaghan, T. V., M. Johansson, J. Key, T. Prowse, M. Ananicheva, A. Klepikov., 2011b, Feedbacks and interactions: from the Arctic cryosphere to the climate system. *Ambio* 40: 75-86.
- Chapin III, F.S., Berman, M., Callaghan, T.V., Convey, P., Crepin, A.-S., Danell, K., Ducklow, H., Forbes, B., Kofinas, G., McGuire, A.D., Nuttall, M., Virginia, R., Young, O., and Zimov, S.A., 2005, Polar systems, in Assessment, M.E., ed., *Ecosystems and human well-being: Current state and trends. Findings of the Conditions and Trends Working Group Millennium Ecosystem Assessment Series*: Washington, Island Press, p. 717-743.
- Dickson, B., 1999, All change in the Arctic: *Nature*, v. 397, p. 389-391.
- Emergency Prevention, Preparedness and Response (EPPR) working group, 2011, Behaviour of oil and other hazardous and noxious substances (HNS) spilled in Arctic waters (BoHaSA). 127 pp. Available from: <http://eppr.arctic-council.org/>
- Hinzman, L. D., Bettez, N. D., Bolton, W. R., Chapin, F. S., Dyurgerov, M. B., Fastie, C. L., ... & Yoshikawa, K., 2005, Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change*, 72(3), 251-298.
- Hovelsrud, G.K., B. Poppel, B. van Oort, J.D. Reist, J.L. White, H. Dannevig, S. Rybråten, D. Armitage, et al., 2011, Arctic societies, cultures, and peoples in a changing cryosphere. In *Arctic cryosphere—Changes and impacts*, ed. T.V. Callaghan, M. Johansson, and T.D. Prowse. *Ambio*, 40(S1). doi:10.1007/s13280-011-0219-4
- IARPC., 2012, Interagency Arctic Research Policy Committee Arctic Research Plan: FY2013-2017. Available from: http://www.nsf.gov/od/opp/arctic/iarpc/iarpc_5yr_plan/arc_res_5yr_plan_septdraft.pdf. 100 p.

- Key, J., B. Goodison, W. Schoener, M. Ondras, Ø. Godøy (2013) A Global Cryosphere Watch. Community White Paper for Arctic Observing Summit 2013.
- Krupnik, I., I. Allison, R. Bell, P. Cutler, D. Hik, J. Lopez-Martinez, V. Rachold, E. Sarukhanian, C. Summerhayes (eds.), 2011, Understanding Earth's polar challenges: International Polar Year 2007-2008. World Meteorological Organization. 724 pp.
- Krupnik, I., and Jolly, D., 2002, The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change: Fairbanks, Alaska, Arctic Research Consortium of the United States, 384 pp.
- Lawler, J. P., S. D. Miller, D. M. Sanzone, J. Ver Hoef, and S. B. Young, 2009, Arctic Network vital signs monitoring plan. Natural Resource Report NPS/ARC/NRR—2009/088. National Park Service, Fort Collins, Colorado.
- Lovecraft, A.L., Meek, C.L., and Eicken, H., 2013, Connecting scientific observations to stakeholder needs in sea ice social-environmental systems: The institutional geography of northern Alaska: *Polar Geogr.*, v. 36, p. 105-125.
- Lovecraft, A. L., H. Eicken (eds.), 2011, North by 2020: Perspectives on Alaska's Changing Social-Ecological Systems. University of Alaska Press, Fairbanks, AK, 736 p.
- Manley, W. F., A. G. Gaylord, A. Kassin, D. H. Lin, R. Cody, M. Dover, R. Score, C. E. Tweedie, 2013, The new U.S. Arctic Observing Viewer: A tool for strategic assessment, Arctic Observing Summit submitted white paper, Vancouver, B. C. April 29 – May 2, 2013.
- Morison, J., V. Alexander, L. Codispoti, T. Delworth, B. Dickson, H. Eicken, J. Grebmeier, J. Kruse, J. Overland, J. Overpeck, P. Schlosser, M. Serreze, J. Walsh. 2001. SEARCH: Study of Environmental Arctic Change, Science Plan, 2001, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, 89 p.
- Morison, J.H., Aagaard, K., Falkner, K.K., Hatakeyama, K., Moritz, R., Overland, J.E., Perovich, D., Shimada, K., Steele, M., Takizawa, T., and Woodgate, R., 2002, North Pole Environmental Observatory delivers early results: *Eos, Transact. Am. Geophys. Un.*, v. 83, p. 357, 360, 361.
- Murray, M.S., L. Anderson, G. Cherkashov, C. Cuyler, B. Forbes, J.C. Gascard, C. Haas, P. Schlosser, G. Shaver, K. Shimada, M. Tjernström, J. Walsh and J. Wandell, Z. Zhao., 2010, International Study of Arctic Change: Science Plan. ISAC International Program Office, Stockholm.
- Murray, M.S., H. Eicken, S. Starkweather, S.C. Gerlach, B. Evengaad, S. Gearheard, P. Schollosser, M. P. Karcher, D. McLeannan, H. Epstein, N. Bock, C. Juillet, S. Graben, B. Grimwood, D. Labonte, K. Pletnikof, N. Scott, M. Sommerkorn, M. Vardy, V. Vitale, I. Wagner, Wagner., 2012, Responding to Arctic Environmental change: Translating our growing understanding into a research agenda for action. International Study of Arctic Change, Stockholm/ Fairbanks. 35 pp.
- Overpeck, J., and 20 co-authors, 2005, Arctic system on trajectory to new, seasonally ice-free state: *Eos, Trans. Am. Geophys. Un.*, v. 86, p. 309, 312-313.
- Payne, J., D. Perovich, R. Shnorro, and H. Wiggins, eds., 2013, U.S. Arctic Observing Network Coordination Workshop Report. Study of Environmental Arctic Change (SEARCH), Fairbanks, Alaska, 52 pp.
- Perovich, D., J. Payne, H. Eicken, 2012, Improving coordination and integration of observations of Arctic change. *Eos, Transact. Am. Geophys. Un.*, 93(43), 428.
- SEARCH., 2003, SEARCH: Study of Environmental Arctic Change, Implementation Strategy, Revision 1.0. Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, Washington, U.S.A. 370 pp.
- SEARCH, 2005a. Proceedings of the SEARCH Open Science Meeting, 27–30 October 2003, Seattle, Washington. Fairbanks, Alaska: Arctic Research Consortium of the U.S. (ARCUS). 370 pp
- SEARCH., 2005b, Study of Environmental Arctic Change: Plans for Implementation During the International Polar Year and Beyond. Fairbanks, Alaska: Arctic Research Consortium of the United States (ARCUS). 104 pp
- Serreze, M.C. and R.G. Barry, 2011, Processes and impacts of Arctic amplification: A research synthesis. *Glob. Planet. Change*, 77, 85-96.
- U.S. Arctic Research Commission, 2013, Report on the goals and objectives for Arctic research 2013-2014 for the US Arctic Research Program Plan. http://www.arctic.gov/publications/2013-14_usarc_goals.html