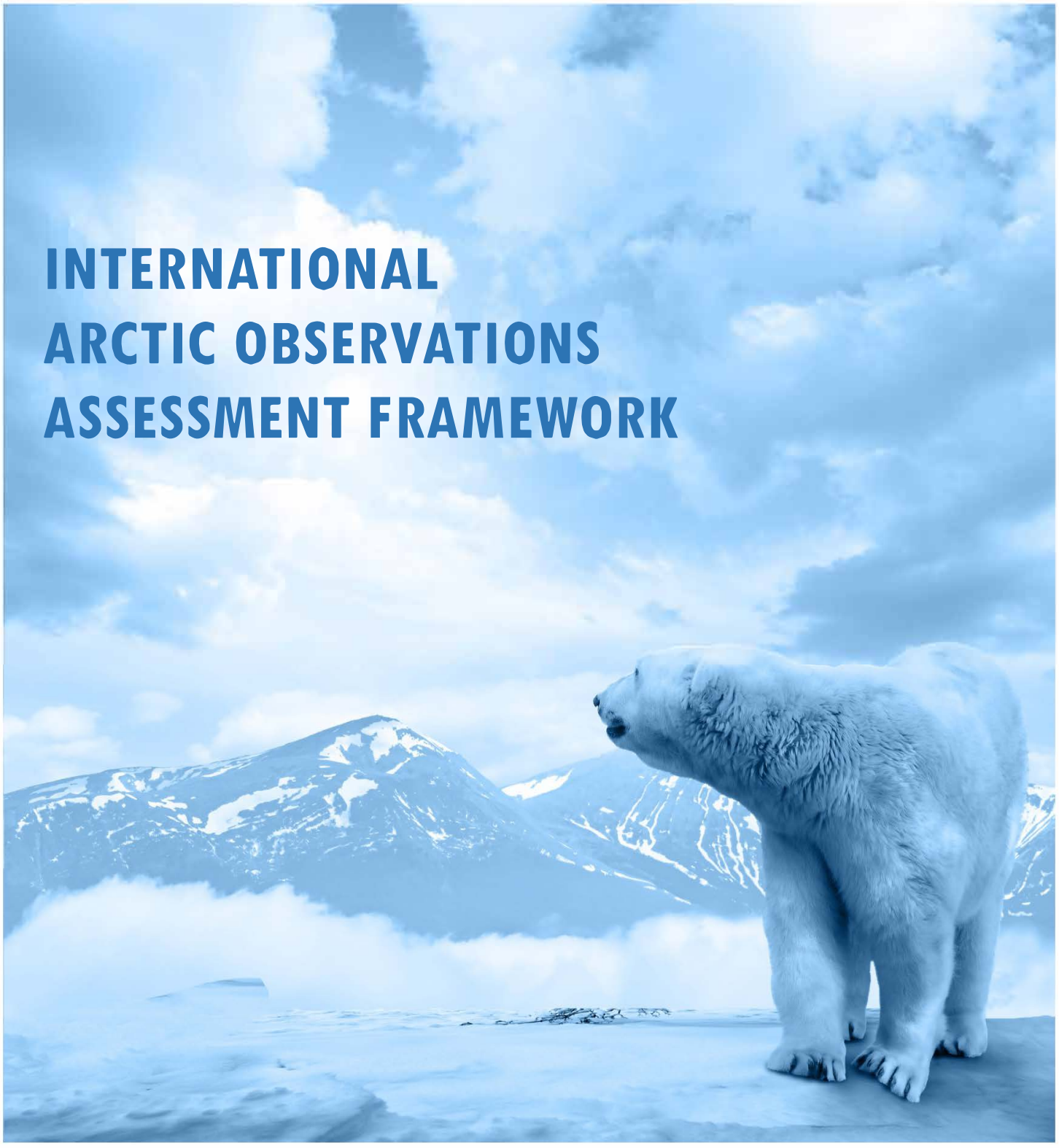
INTERNATIONAL ARCTIC OBSERVATIONS ASSESSMENT FRAMEWORK



SAON
SUSTAINING ARCTIC OBSERVING NETWORKS

IDA SCIENCE AND TECHNOLOGY POLICY INSTITUTE

Recommended Citation:

IDA Science and Technology Policy Institute and Sustaining Arctic Observing Networks. 2017. *International Arctic Observations Assessment Framework*. IDA Science and Technology Policy Institute, Washington, DC, U.S.A., and Sustaining Arctic Observing Networks, Oslo, Norway, 73 pp.

Executive Summary

On January 12 and 13, 2017, the IDA Science and Technology Policy Institute (STPI) and the Sustaining Arctic Observing Networks (SAON) co-hosted a workshop to develop an international Arctic Observations Assessment Framework. The workshop convened experts from international, state, and local governments; industry; academia; and non-governmental organizations to review and revise a framework for assessing the societal benefits derived from Arctic observations. The goal of the workshop was to achieve international consensus on a comprehensive set of key objectives that rely on these observations.

Prior to the workshop, a notional assessment framework was drafted using a value tree analysis methodology. The methodology involved a review of international Arctic strategies for common objectives that rely on Earth observations. These key objectives were then grouped into 12 high-level societal benefit areas (SBAs) and sub-areas under each to compose a hierarchical value tree framework. Workshop participants refined the draft value tree framework by revising the scope of the draft SBAs, defining the SBA sub-areas, and reviewing and revising the draft objectives. The resulting international Arctic Observations Assessment Framework will provide the foundation for future international efforts to assess the value of Arctic observations and to structure a pan-Arctic observing system.

Keynote speakers on the first day of the workshop highlighted the opportunities for using and improving Earth observations in the Arctic and the ultimate benefit of developing an Arctic Observations Assessment Framework. The Arctic serves as a particularly important location to understand and conduct observations, not only because observation activities across the Arctic can prove challenging given the region's great size and remoteness, but also because events and processes in the Arctic influence those in other parts of the world. Open and readily accessible data can improve research, operations, and community activities in the Arctic, which can also have value for non-Arctic countries and peoples. Federal agencies in the United States and international groups such as the Group on Earth Observations (GEO) have established their own value tree analyses, which are used to track how individual observations contribute to organizational missions, to identify the organization's most critical observations, and to determine interdependencies across systems.

The panel that followed the first day's keynote speech consisted of four panelists who described the types of observations used by their respective organizations to support their missions, the critical and time-consuming process of gathering social data, and the importance of making the data available for public use. Predictions from universities and scientists vary not only in terms of climate projections, but also in terms of expected

community responses to these potential changes. Local observation systems can provide valuable feedback on the effects of decision making on communities, which decision makers can then use to inform future decisions. Panelists highlighted the need for decisions and actions to be based on measures of sociological value in addition to economic value.

The afternoon of the first day and the most of the second day consisted of break-out groups for discussing SBAs associated with four focus areas (Economy, Environment, People, and Climate). The discussion groups commented on the preliminary SBA descriptions, adjusted the proposed sub-areas, and developed key objectives and associated descriptions for the 12 SBAs.

1. Disaster Preparedness
2. Environmental Quality
3. Food Security
4. Fundamental Understanding of Arctic Systems
5. Human Health
6. Infrastructure and Operations
7. Marine and Coastal Ecosystems and Processes
8. Natural Resources
9. Resilient Communities
10. Sociocultural Services
11. Terrestrial and Freshwater Ecosystems and Processes
12. Weather and Climate

The final Arctic Observations Assessment Framework from the workshop consists of these 12 SBAs, 41 SBA sub-areas, and 163 key objectives. The next two phases of the work to quantify the societal benefits derived from Earth observations of the Arctic region are (1) completing the value tree by identifying the key products, services, and research outcomes of Earth observations that contribute to the achievement of international objectives in the Arctic and (2) proceeding with an assessment of Arctic observations. These two phases can be initiated and implemented by a single organization, or be a coordinated effort by multiple organizations using a common data collection process and repository. The output from each phase will be immediately useful for identifying the information products and Earth-observing system inputs that are heavily relied on for the delivery of societal benefit across the Arctic Observations Assessment Framework.

Contents

A. Introduction

Earth observations in the Arctic contribute to key national and international objectives across a range of important domains, including food, energy, and water security; transportation; and natural resource development. The international Arctic scientific community recognizes the critical need for a sustained and integrated portfolio of pan-Arctic observing systems to deliver services that support operational and research objectives in the Arctic. Coordinating such a portfolio requires an evaluation of the way in which Arctic observations contribute to a common set of international objectives for the delivery of societal benefit to the region. To begin, a consensus assessment framework is needed to connect the Arctic observations to the key objectives they serve.

To meet this need, the IDA Science and Technology Policy Institute (STPI) facilitated an international effort to identify common objectives that rely on Earth-observing system data to deliver societal benefit in the Arctic. Previous international efforts have laid the groundwork for developing an Arctic Observations Assessment Framework. For example, the first Arctic Science Ministerial was held in Washington, D.C., on September 28, 2016. The ministerial brought together participants from Arctic and non-Arctic nations interested in a cooperative approach to understanding the Arctic and its effect on the rest of the world. Developing an international consensus on an Arctic observations assessment framework contributes to one of the ministerial themes, Strengthening and Integrating Arctic Observations and Data Sharing.

STPI invited the Sustaining Arctic Observing Networks (SAON) to collaborate on the planning and organization of a workshop to facilitate an international consensus on an Arctic Observations Assessment Framework. A participating organization in the Group on Earth Observations, SAON is a joint effort of the Arctic Council and the International Arctic Science Committee with expertise in Arctic observations and data sharing. The STPI team and SAON's Executive Committee together identified international subject matter experts (SMEs) to serve on the Workshop Organizing Committee (WOC). The STPI team and the WOC then developed a notional assessment framework in the form of a value tree in advance of the workshop. The notional value tree consisted of thematic domain areas or societal benefit areas (SBAs), sub-areas under each SBA, and domain-specific objectives that rely on Earth observations to deliver societal benefit.

The workshop was held at the National Science Foundation in Arlington, Virginia, on January 12 and 13, 2017. The goal of the workshop was to review and revise the notional framework to develop a consensus framework that identified thematic application areas and key objectives that rely on the use of Earth observations in the Arctic. The framework is designed to serve as a foundation for future national or international efforts to assess the contribution of Earth observations to the delivery of societal benefit in the Arctic. The workshop output can improve understanding of how Earth observation data are used to

support key international objectives in the Arctic. The consensus framework is an international benchmark that could be used or adapted by interested organizations or nations to assess their own reliance on Earth-observing systems to achieve key objectives in the Arctic. This report highlights some of the potential applications of the Arctic value tree framework and outlines activities associated with accomplishing an assessment of Arctic observations.

B. Methodology

In September 2016, the STPI team and the WOC began to develop the concept and supporting materials for an international workshop to develop the Arctic Observations Assessment Framework. STPI researchers met weekly via teleconference with WOC members to design the workshop agenda, create a list of invitees, and develop a notional Arctic Observations Assessment Framework in advance of the workshop.

1. Value Tree Analysis

The notional framework was based on a Value Tree Analysis (VTA) approach that relies on expert domain knowledge to develop a logical and interdependent framework for decision support. A VTA is useful for defining thematic concepts, identifying objectives, and creating a hierarchy of those objectives. VTAs were used for Earth observation applications in both the 2012 and 2016 United States National Civil Earth Observation Assessments as well as for a needs assessments conducted by the National Oceanic and Atmospheric Administration and the United States Geological Survey.

The value tree used for the Arctic Observations Assessment Framework is a multi-level SBA value tree that establishes the connection between societal benefits and the set of Earth observation inputs that contribute to delivering those benefits (Figure 1). At the top level of the value tree are the SBAs that define the environmental, economic, and social domains in which services, operations, and research provide societal benefit. Sub-areas represent natural thematic divisions of each SBA. Each sub-area is composed of key objectives (KOs). KOs are service, operational, or research activities that are clearly supported by and can be linked to Earth-observing systems and their data and information products. From the SBA down through the sub-area KOs is referred to as the "top of the tree," which provides the framework for an observation assessment.

A complete value tree framework would consist of a complementary "bottom of the tree" where products, services, and research outcomes that contribute to the achievement of international objectives in the Arctic are identified. Through structured interviews with key product, service, and outcome (KPSO) SMEs, the Earth-observing system inputs that are relied on to produce the KPSOs at the bottom of the tree to achieve the KOs at the top of the tree can be identified. By evaluating the connection between Earth-observing system inputs and areas of societal benefit, the assessment framework can provide a snapshot of

the inputs most critical for a sustained portfolio of Arctic-observing systems as defined by the value tree.

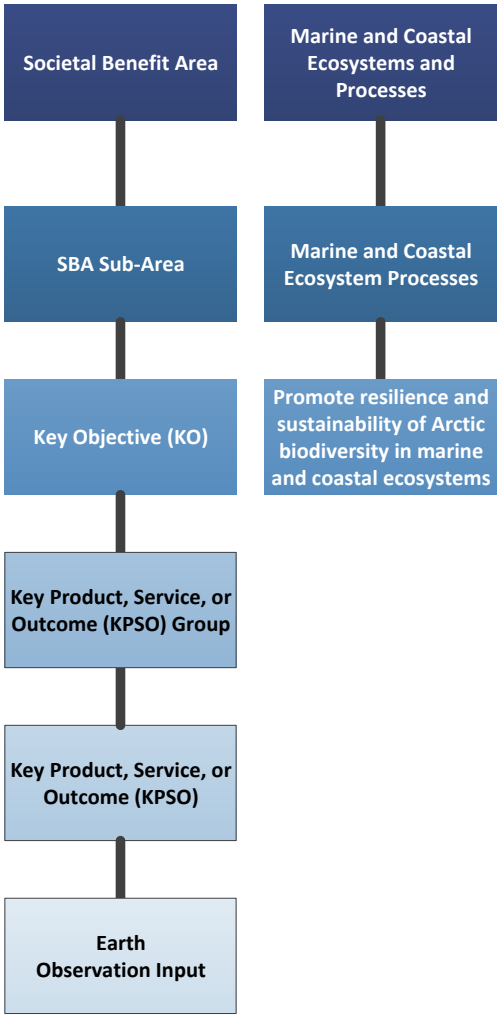


Figure 1. Full Value Tree Framework (left) and Top-of-the-Tree Example (right) for the Marine and Coastal Ecosystem SBA

2. Arctic Observations Assessment Framework

The STPI team developed an initial set of KOs for a value tree based on themes, goals, objectives, and priorities identified in a review of 25 international Arctic strategy documents (see Appendix A). The team grouped these KOs into a set of thematic SBAs and sub-areas. Mapping the Arctic framework SBAs to the SBAs adopted by the Group on Earth Observations (GEO) indicates the degree of alignment the SBAs have with other international observation efforts (Table 1). The WOC refined the resulting framework to create a value tree to serve as the primary input for workshop attendees.

Table 1. Mapping of Societal Benefit Areas (SBAs)

Notional Arctic Framework SBAs	Group on Earth Observations SBAs
Disaster Preparedness	Disaster Resilience
Environmental Quality	*No direct SBA match*
Food Security	Food Security and Sustainable Agriculture
Fundamental Understanding of Arctic Systems	*No direct SBA match*
Human Health	Public Health Surveillance
Infrastructure and Operations	Infrastructure and Transport Management
Marine and Coastal Ecosystems and Processes	Biodiversity and Ecosystem Sustainability
Natural Resources	Energy and Mineral Resources Management
Resilient Communities	*No direct SBA match*
Sociocultural Services	*No direct SBA match*
Terrestrial and Freshwater Ecosystems and Processes	Biodiversity and Ecosystem Sustainability
Weather and Climate	*No direct SBA match*
No direct SBA match	Sustainable Urban Development
No direct SBA match	Water Resources Management

3. Facilitated Revision of the Notional Value Tree

At the January workshop, participants engaged in Arctic observation activities contributed to facilitated discussion of the value tree. The goal was to reach a consensus on the SBAs, sub-areas, and KOs at the top of the tree.

The workshop participants represented national, state, and local governments; academia; international research organizations; and indigenous peoples' groups. (See Appendix B for a list of workshop participants.) These SMEs identified their areas of expertise prior to the workshop and were assigned at the workshop to the most relevant of the four discussion groups: Economy, Environment, Human, and Climate. It is important to note, though, that SMEs were not restricted to their assigned groups and could contribute to other discussions over the course of the workshop. (See Appendix C for the workshop agenda.)

Using a modified Delphi method,[1] STPI facilitators guided group discussions in 12 SBA-specific working groups over the remainder of the two-day workshop. SMEs were asked to provide input on the sub-areas and KOs within the SBAs and to revise and reorganize the value tree until a consensus was reached within the group.

[1] The Delphi method is a structured communication technique, developed as a systematic, interactive forecasting method that relies on a panel of experts. The experts answer questionnaires in two or more rounds.

C. Workshop Summary

1. Introductory Remarks and Keynote Speeches

The four introductory speakers highlighted opportunities for using and improving Earth observations in the Arctic and discussed the benefit to be derived from developing an Arctic observations framework. The following subsections summarize introductory remarks and keynote speakers.

a. Welcome: Will Ambrose, Arctic Observing Network Program Director, National Science Foundation

The first Arctic Science Ministerial in September 2016 had identified both Arctic observations and data sharing and management as national and international priorities. The development of an integrated observing network and assessment framework is pivotal to supporting these priorities. A consensus framework will enable users to understand Earth observations through their applications to societal benefit.

For the purposes of the Arctic Observations Assessment Framework, "Earth observations" are defined as the data and products derived from Earth-observing systems and surveys. The term "observing systems" refers to sensing elements that directly or indirectly collect observations of the Earth, measure environmental variables, or survey biological or other Earth resources (land surface, biosphere, solid Earth, atmosphere, and oceans). Sensing elements may be deployed as individual sensors or in constellations or networks and may include instrumentation or human elements. Observing-system platforms can be mobile or fixed and are space-based, airborne, terrestrial, freshwater or marine-based, or community-based.

The Arctic serves as a particularly important location to understand and conduct observations, not only because measuring across the Arctic can prove challenging given its great size and remoteness, but also because events and processes in the Arctic influence those in other parts of the world. For example, the melting of the Arctic glaciers and ice caps and the Greenland Ice Sheet is contributing significantly to global sea level rise, and there is growing evidence that the diminishing summer sea ice cover is having a greater influence on the weather in lower latitude regions.

b. Opening Remarks: Christine Daae Olseng, Sustaining Arctic Observation Networks (SAON) Chair

Open and readily accessible data can improve research, adaptation, operations, and community activities in the Arctic, and can also provide value for non-Arctic countries and peoples. Well-defined observing networks that enable users to have access to free, open, and high-quality data will ensure pan-Arctic and global value-added services are available to provide societal benefits. Coordination, integration, sharing, and synthesis of data and

related information can help reach this international goal. As a partner in the workshop, SAON plans to use the Arctic Observations Assessment Framework as part of its effort to coordinate the implementation of a pan-Arctic observing system and develop a broad, globally connected Arctic data and information system of systems.

c. Keynote: "Managing an Observations Portfolio for Societal Benefit," Joseph A. Pica, Director, Office of Observations, National Weather Service

The National Oceanic and Atmospheric Administration (NOAA) has established an internal, quantitative Earth observations assessment for its portfolio management. NOAA considers the following information in order to develop an efficient and effective mission architecture: observing requirements, observing systems and capabilities, and data source effects on mission service. NOAA employs a VTA to evaluate the use of Earth observations to meet mission requirements, develop and deliver products and public services, and determine how data are used across programs. This analysis aids in programmatic decision making by helping NOAA answer the question, "How does an observation contribute to an end goal?" The analysis can also be used to determine whether a decrease in a single program's funding levels will affect other programs. The VTA can therefore support cost-benefit analyses that may inform decision makers.

NOAA can also use its observations assessment to determine what its most critical data sources are for sustaining specific missions, and what products support each mission. The VTA can also inform NOAA as to the organization's needs by overlaying agency requirements and observation systems to determine gaps. Furthermore, and particularly critical for the Arctic given the international interest in observations, a VTA can identify interdependencies across the system and determine how partners, such as local and state governments, and national and international bodies, contribute to specific missions and overall societal benefit. In the future, NOAA intends to develop the capability to weight different missions, systems, and needs to aid in decision making.

d. Keynote: "International Perspective on Societal Benefit," William Sonntag, Group on Earth Observations (GEO) Representative

GEO's goal is "to realize a future wherein decisions and actions, for the benefit of humankind, are informed by coordinated, comprehensive, and sustained Earth observations and information."[2] Societal benefit areas are the organizing framework for GEO. GEO works to promote full and open exchange of data and is involved in international coordination among hundreds of participating organizations and public data providers. The Cold Regions Initiative is one of GEO's Arctic-related efforts. While GEO's purview is global, it supports region-specific analyses to highlight specific concerns and activities. For

[2] Group on Earth Observations, "Our Mandate," https://www.earthobservations.org/vision.php.

example, the Arctic Observations Assessment Framework addresses Arctic-specific environmental and social challenges, such as the impacts of fossil fuel drilling in the Arctic and impacts on indigenous Arctic cultures, which would not otherwise be addressed in global or other regional assessments.

2. Summary of Panel Presentations and Discussion

Each of four panelists was invited to present a 5-minute briefing on his or her organization, the types of observations used by the organization, and how the organization uses the observations to support or achieve its objectives.

a. Marcus Carson from the Stockholm Environment Institute (SEI)

The process of gathering social data in the Arctic is important, but time-consuming because it is sparsely populated. Livelihood and well-being are connected to the environment, with household income being used as a proxy for well-being. Many communities in the Arctic rely on non-market activities such as informal trading networks. However, non-market economies are not included in most indicators, and additional information is needed beyond typical market-oriented data. Research on local community interactions can improve understanding of Arctic peoples' ways of life and improve data gathering activities to aid Arctic peoples in using natural resources.

b. Martina Löbl, Alfred Wegener Institute (AWI)

Data sharing is essential to successful efforts in the Arctic. AWI has invested 25 million Euros to achieve its goal of making Arctic data available as quickly as possible. The objective is for the AWI portal to almost immediately publish remote sensing, biogeochemical, climatological, and weather data as they are collected and to model outputs as they are generated. AWI also invests in data education and provides explanations to help users understand data at differing levels of complexity, such as simple temperature data; ice drift data, which is more complex; and sea floor oxygen flux data, which is difficult to understand in its raw form. AWI intends to publish its diverse data for public use, but public outreach is also key for people to understand the data in a way that tells a compelling story that people can see for themselves.

c. Molly McCammon from the Alaska Ocean Observing System (AOOS)

AOOS uses a process that first identifies social benefit, then identifies stakeholders and the products and tools that will support their specific needs, and finally identifies the observing systems that will provide the necessary information. AOOS focuses on integrating useful data into decision support tools. AOOS has a history of using alternative observations to meet stakeholder needs. For example, rather than using scientific-research-quality water observations, which are expensive, AOOS uses cheaper tools that may be

less precise, but still meet their stakeholders' needs. Making data and information products available and useful often involves synthesizing data into a GIS layer to create maps for communities.

d. Denise Michels from Kawerak, Inc., and former mayor of Nome, Alaska

Kawerak collects and combines traditional tribal knowledge with scientific knowledge. For example, to help with oil spill responses, Kawerak has published traditional knowledge of ocean currents. Kawerak has also developed subsistence maps that reflect hunters' understanding of the locations of walruses and seals, ship route maps, and data and products that inform regulatory decisions. Tribal governments have a government-to-government relationship with the United States government, allowing regulatory negotiations to take place. Kawerak coordinates with the University of Alaska Fairbanks to develop climate projections that consider how temperature increases and permafrost warming could affect infrastructure such as houses and roads.

As a result of potential expansion of vessel traffic in the Northwest Passage, increases in Arctic shipping will strain current infrastructure. For example, Nome's harbor is not deep enough for large shipping vessels to come to port. Predictions from universities and scientists vary not only in terms of climate projections, but also in how changes will influence marine trade. Without knowledge of how shipping will increase, communities struggle to plan for adaptation and economic expansion. The ocean now does not freeze until January, so harbors must staff additional people at the ports. Cable companies can now lay cable through November because of the late onset of freezing. Communities rely on the most extreme prediction (such as shipping increasing by 1,000%) in the hopes of receiving funding to handle the worst-case scenario, but this preparation may be based on inaccurate predictions.

e. Panel Discussion Summary

- It cannot be assumed that stakeholders are prepared to use observational data to make decisions without context and training.
- Greater research into the pedagogical reasons for why and how people make decisions and use information tools can inform efforts to improve the utility of observations.
  - For example, AWI has developed software that finds the most efficient route through Arctic ice and used it on the research vessel *Polarstern*. This ultimately led to time and fuel savings, which was instrumental in convincing the ship's captain to trust the software.
- Time and resources to investigate data processes and data gaps are needed to ensure all data collected contribute to societal benefit.

- Decisions and actions cannot exclusively rely on estimations of economic value because they do not accurately measure human well-being and may not highlight some beneficial activities.
  - Subsistence communities may not place economic value on their ways of life due to the holistic approach to nature and its positive influence on well-being and society.
  - Resources may have different values depending on perspectives; a commercial fisherman and a subsistence fisherman may perceive the value of salmon differently.
  - Understanding these perspectives may help more accurately reflect all of the equities at stake in political decisions that affect resources of value to indigenous peoples and Arctic communities.
- Access to open data on the Arctic has the potential to spur economic development and growth in the Arctic and elsewhere.
  - Data inform decisions.
  - Data are often available, but discovery and access is challenging.
  - Data accessibility in the Arctic may be inhibited by a lack of broadband access to download large data files and conduct complex analyses, forcing communities to use synthetic data or data products from tools available despite Internet constraints.

D. Workshop Output

The material presented in this section represents the consensus Arctic Observing Assessment Framework developed collaboratively by the STPI team, the WOC, and the workshop participants. The material is presented in terms of the 12 Arctic SBAs with accompanying descriptions of components at the top of the value tree (i.e., SBA, sub-area, and key objective). The information sets the boundaries for an assessment of the Earth-observing system inputs that are currently relied on to deliver societal benefit in the Arctic through the key objectives (KOs) identified.

1. Disaster Preparedness

In the Disaster Preparedness SBA, societal benefit accrues from those activities designed to prepare for, prevent, mitigate, respond to, and recover from both natural and human-made emergencies and disasters. Preparedness, response, recovery, and mitigation refer to a cycle divided by pre- and post-event developments, in which preparedness occurs pre-event, response is initiated directly after the event to bring stability to the situation, recovery is long-term care required to return to a baseline, and mitigation is a post-event

process that becomes a pre-event activity before the next disaster. This SBA incorporates both emergencies and disasters taking place in the Arctic, and emergencies and disasters affecting other regions of the world caused by events in the Arctic (Table 2).

Table 2. SBA Sub-areas and Key Objectives for Disaster Preparedness

Sub-area	Key Objectives
Disaster Mitigation	• Apply common indices and indicators to inform disaster mitigation activities • Develop education, training, and compliance procedures for disaster mitigation • Ensure access to disaster-relevant environmental intelligence • Inform infrastructure design standards for disaster mitigation
Disaster Protection and Prevention	• Apply common indices and indicators to assess state of disaster preparedness • Conduct risk assessments to inform disaster preparedness activities • Deploy emergency responder personnel and equipment in an optimal manner prior to a disaster • Develop and execute plans and procedures for disaster prevention • Improve emergency preparedness for human-made hazards • Improve emergency preparedness for natural hazards
Disaster Recovery	• Conduct damage assessments to inform disaster recovery • Improve future disaster preparedness activities • Inform social, economic, and cultural post-disaster recovery • Support disaster aid planning and deployment
Disaster Response	• Conduct disaster response operations in a timely and cost-effective manner • Conduct search and rescue operations in a safe and effective manner • Deploy emergency responder personnel and equipment in an optimal manner during and after a disaster • Ensure domain awareness for disaster response
Hazard Identification and Disaster Prediction	• Develop and maintain analytical capabilities for hazard identification and disaster prediction • Ensure domain awareness for identification and prediction of all hazards • Improve understanding of Earth systems to inform hazard identification and disaster prediction

a. Disaster Mitigation

This sub-area includes international treaties regarding emergency responses, data-sharing activities or resolutions between countries for disaster mitigation purposes, infrastructure planning, and other forms of disaster mitigation.

1) **Apply common indices and indicators to inform disaster mitigation activities**

Activities to meet this objective help communities map their risks and assess their mitigation resources and abilities through development and application of common indices and indicators, such as those from Integrated Research on Disease Risk (IRDR) and World Meteorological Organization (WMO).

2) **Develop education, training, and compliance procedures for disaster mitigation**

This objective includes the development of materials and processes to mitigate the impact of natural disasters by improving disaster-related education and training for planners, first-responders, and indigenous communities.

3) **Ensure access to disaster-relevant environmental intelligence**

Activities to meet this objective improve disaster responses and mitigation efforts through enhanced collaboration and sharing among individuals, organizations, and countries of relevant environmental intelligence.

4) **Inform infrastructure design standards for disaster mitigation**

Activities to meet this objective reduce the impacts of various disasters through development of infrastructure design standards, such as building codes that help structures resist seismic forces during earthquakes. All relevant hazards are within the scope of this objective.

b. Disaster Protection and Prevention

This sub-area addresses the need to prepare for disasters once they have been predicted. Disaster protection and prevention involves deploying capabilities and plans for disaster mitigation and response.

1) **Apply common indices and indicators to assess state of disaster preparedness**

This objective addresses the use of consistent metrics and assessments to determine levels of disaster preparedness throughout the Arctic.

2) **Conduct risk assessments to inform disaster preparedness activities**

This objective is met through activities to understand and prepare for potential disasters before they occur by identifying potential hazards and estimating their likely impacts.

3) Deploy emergency responder personnel and equipment in an optimal manner prior to a disaster

This objective is achieved thorough optimizing the deployment of emergency responder personnel and equipment in preparation for anticipated or potential disasters through the use of disaster impact forecasts and information.

4) Develop and execute plans and procedures for disaster prevention

This objective includes the development of plans for evacuation, education and training, egress, and proper infrastructure and building codes in the context of the most relevant hazards.

5) Improve emergency preparedness for human-made hazards

This objective is met through the development of plans related to emergency situations, protocols for action, and educational materials about emergency response procedures in response to human-made hazards.

6) Improve emergency preparedness for natural hazards

This objective is met through the development of plans related to identification of emergency situations, protocols for action, and education about emergency response procedures in during natural hazards.

c. Disaster Recovery

This sub-area addresses post-response activities that revitalize an affected area, including both damage assessments of the affected area and economic analyses of the impact of the disaster.

1) Conduct damage assessments to inform disaster recovery

Activities to meet this objective inform recovery efforts through surveys and assessments of affected areas after an event to determine the extent of damage.

2) Improve future disaster preparedness activities

This objective includes activities that help communities address and prepare for future disasters through retrospective analyses of the successes and failures of past disaster responses, such as analyses of lessons learned and after-incident reports.

3) Inform social, economic, and cultural post-disaster recovery

This objective includes activities to revitalize the local economy and culture, as well as inputs for analyses of the impacts of the disaster on the local society, including its economy and culture.

4) Support disaster aid planning and deployment

This objective is met through use of information about the extent and damage of a disaster to determine the location, amount, and type of resources that should be distributed to aid in post-event recovery.

d. Disaster Response

This sub-area covers aspects of disaster evaluation and assessment as well as response options for responders and decision makers. Adequate disaster response relies on real-time or near-real-time data to inform decisions and actions in the affected areas.

1) Conduct disaster response operations in a timely and cost-effective manner

This objective is achieved through more efficient disaster response operations, including rescue and clean-up activities.

2) Conduct search and rescue operations in a safe and effective manner

This objective involves protecting and saving lives and property after disasters, while ensuring appropriate safety standards for emergency responders.

3) Deploy emergency responder personnel and equipment in an optimal manner during and after a disaster

Activities to meet this objective ensure the safety, timeliness, and cost-effectiveness of deploying emergency responder personnel and equipment while protecting affected people and areas during disaster response operations. This objective includes rescue and recovery efforts.

4) Ensure domain awareness for disaster response

This objective is achieved through the collection and analysis of real-time or near-real-time data to help maintain domain awareness for emergency responders and decision makers during disaster response.

e. Hazard Identification and Disaster Prediction

This sub-area involves using historical data to improve the fundamental understanding of disaster-relevant Earth systems, including anticipating disasters and analyzing risks to prevent loss of human life or damage to infrastructure and the economy.

1) Develop and maintain analytical capabilities for hazard identification and disaster prediction

The objective includes developing high-quality disaster models and anticipating the analytical capabilities to improve hazard and disaster predictions.

2) Ensure domain awareness for identification and prediction of all hazards

This objective is achieved through the identification and prediction of human and environmental hazards. This objective is applicable to both natural and human-made hazards.

3) Improve understanding of Earth systems to inform hazard identification and disaster prediction

Activities to meet this objective improve observation networks, modeling efforts, and other research activities associated with hazard and disaster prediction and identification through the use of historical data and recent or real-time measurements.

2. Environmental Quality

In the Environmental Quality SBA, societal benefit accrues from protecting, preserving, and adapting to the natural environment. This SBA includes monitoring and measuring the effects of transboundary pollutants in the Arctic, maintaining healthy ecosystems, sustaining ecosystems that support people and biodiversity, handling waste, and managing and developing the Arctic in an environmentally responsible manner (Table 3). This may improve the identification of environmental observation requirements needed to inform decision making.

Table 3. SBA Sub-areas and Key Objectives for Environmental Quality

Sub-area	Key Objectives
Drivers of Environmental Impacts	• Improve ability to identify environmental impact thresholds and predict their consequences • Improve understanding of climate as a driver of changing environmental quality • Manage regional and local human activities in the Arctic to mitigate environmental impact • Reduce the sources of transboundary and local pollutants in the Arctic
Environmental Impacts	• Adapt to and mitigate the impacts of climate change on ecosystems and human health • Improve understanding of the impacts of climate change on ecosystems and human health • Manage the environmental impacts of increased human activities in the Arctic • Mitigate the impacts of pollutants on ecosystems and human health • Understand the impact of pollutants on the energy balance and the effects on the cryosphere
Quality of Ecosystem Functions	• Ensure the availability of freshwater suitable for human use and ecosystem function • Improve understanding and function of habitats in the Arctic • Improve understanding of the value proposition of ecosystem services in the Arctic • Maintain ecosystem quality, diversity, and extent to ensure the delivery of ecosystem functions and services

a. Drivers of Environmental Impacts

This sub-area includes efforts to improve understanding of the three main categories that drive environmental impacts in the Arctic (climate change, pollutants, and human activities) and, where possible, to manage them at local, national, and regional scales.

1) Improve ability to identify environmental impact thresholds and predict their consequences

This objective is achieved through research to identify tipping points and changes in fundamental properties (e.g., pH and temperature) that cause cascading effects across the entire Arctic ecosystem and characterize related impacts. Impacts may include insect infestations, changes in fire regimes or hydrological processes, permafrost thaw, and extinctions.

2) Improve understanding of climate as a driver of changing environmental quality

This objective includes research to study major processes of climate variability and change in the Arctic and the mechanisms by which these processes impact environmental systems.

3) Manage regional and local human activities in the Arctic to mitigate environmental impact

This objective is achieved through the management of human activities, such as industrial exploration and exploitation, tourism, immigration, and uncontrolled development that have had detrimental effects on the Arctic environment. Effects include those that effect atmospheric composition and exchange processes and the Arctic's wildlife, ecosystems, and indigenous populations.

4) Reduce the sources of transboundary and local pollutants in the Arctic

This objective includes reducing the release of pollutants and contaminants from local human and industrial activities as well as reducing pollutants transported into the Arctic environment through rivers, oceans, and the atmosphere. This objective requires the ability to identify and screen for chemicals and other materials that endanger ecosystem and human health.

b. Environmental Impacts

This sub-area includes efforts to manage the impacts of the three main categories that drive environmental impacts in the Arctic (climate change, pollutants, and human activities) in ways that sustain people and biodiversity.

1) Adapt to and mitigate the impacts of climate change on ecosystems and human health

This objective is to determine how Arctic nations can deal with impacts on ecosystems and populations resulting from climate change. Impacts include shifts in vegetation zones and growing seasons, forest expansion, wildlife habitat expansion or destruction, changes in species diversity, and elevated ultraviolet radiation.

2) Improve understanding of the impacts of climate change on ecosystems and human health

This objective involves research to understand the effects of climate change on Arctic ecosystems and human populations. This includes research to understand shifts in vegetation zones and growing seasons, forest expansion, wildlife habitat expansion or destruction, changing species diversity, and elevated ultraviolet radiation.

3) Manage the environmental impacts of increased human activities in the Arctic

This objective is achieved through the management of human activities (e.g., industrial exploration and exploitation, tourism, and immigration) that have resulted in physical, chemical, biological, and social impacts on Arctic environments.

4) Mitigate the impacts of pollutants on ecosystems and human health

This objective involves efforts to regulate and reduce contamination levels in the Arctic environment, including levels of critical and transboundary pollutants, plastics, and radioactive contaminants.

5) Understand the impact of pollutants on the energy balance and the effects on the cryosphere

This objective includes research on processes in the Arctic that are affected by pollutants, such as feedback loops involving ocean currents, greenhouse gas releases, and sunlight reflections that accelerate warming in the Arctic.

c. Quality of Ecosystem Functions

This sub-area derives benefit from maintaining healthy ecosystems and includes efforts to understand key ecosystem functions, as well as ecosystem variability and change.

1) Ensure the availability of freshwater suitable for human use and ecosystem function

Activities to meet this objective ensure water security for Arctic communities and ecosystems and mitigate the impact of a changing climate on freshwater sources in the Arctic (e.g., glacial melting, permafrost degradation, and impacts on precipitation or evapotranspiration).

2) Improve understanding and function of habitats in the Arctic

This objective includes activities in the Arctic that improve the spatial resolution and comprehensiveness of Arctic habitat mapping and characterization. Examples include vegetation mapping and distribution and abundance of critical species.

3) Improve understanding of the value proposition of ecosystem services in the Arctic

This objective is achieved through research designed to describe and communicate benefits provided by Arctic ecosystem services to stakeholders within and beyond

the Arctic. This communication is crucial to incentivize the sustainable management of social-ecological systems in the Arctic.

4) Maintain ecosystem quality, diversity, and extent to ensure the delivery of ecosystem functions and services

This objective addresses the habitats, ecological communities, and species diversity of both terrestrial and aquatic ecosystems in the Arctic. The objective also includes efforts to prevent range extension of, and increases in, native and non-native invasive species.

3. Food Security

In the Food Security SBA, societal benefit accrues from the accessibility, availability, sustainability, safety, and exchange of food for Arctic peoples. Food accessibility and availability includes safe access to hunting and fishing grounds; abundant availability of animals, fish, and edible plants; resilience of food resources to climate change; and sustainable management of food resources (Table 4). Safe food addresses human consumption, storage, and nutritional value of food. The exchange of food refers to market forces and formal and informal networks for Arctic peoples and in regions where these foods are imported and exported.

Table 4. SBA Sub-areas and Key Objectives for the Food Security

Sub-area	Key Objectives
Accessible, Available, and Sustainable Food	• Enhance resilience to changes in Arctic climate and ecosystems that affect access to food • Ensure continued access to and viability of hunting, fishing, and gathering activities in the Arctic • Improve stewardship of fisheries and animal stocks in an environmentally sustainable manner • Improve understanding of land use on sustainable stewardship of food resources • Improve understanding of the energy demands associated with the Arctic food supply chain • Improve understanding of the impacts of climate change on hunting and fishing in the Arctic • Improve understanding of the impacts of climate change on the Arctic food supply chain • Understand and coordinate institutional arrangements affecting the availability, accessibility, and sustainability of food
Exchange of Food	• Ensure continued operation of transportation and shipping activities for food exchange • Improve understanding of formal and informal exchange networks to assess the use of food beyond its currency value • Understand and coordinate food exchange regulations and activities to mitigate resource scarcity and overabundance
Safe Food	• Ensure food supplies do not exceed minimum pollutant thresholds • Ensure the safety and storage of food supplies under changing environmental conditions • Improve the quality of and access to information about the availability and safety of food • Improve understanding of the nutritional quality of food in the Arctic • Improve understanding of the nutritional requirements of Arctic populations • Understand and coordinate institutional arrangements affecting food safety

a. Accessible, Available, and Sustainable Food

This sub-area involves short-term and long-term efforts to ensure the continued availability of food sources through the stewardship of Arctic resources.

1) Enhance resilience to changes in Arctic climates and ecosystems that affect access to food

This objective is met by improvements to access to food in the Arctic that is safe and affordable; application of climate and ecosystem monitoring to ensure access to food; and provision of forecasts, projections, and data to inform decision making at national, regional, local, and community levels.

2) **Ensure continued access to and viability of hunting, fishing, and gathering activities in the Arctic**

This objective is achieved by ensuring access to the grounds and resources necessary to hunt, fish, and gather through traditional and other means.

3) **Improve stewardship of fisheries and animal stocks in an environmentally sustainable manner**

Activities to meet this objective ensure long-term food supply availability through sustainable management of fisheries and animal stocks and understanding of how changes to Arctic systems may affect current and future stocks.

4) **Improve understanding of land use on sustainable stewardship of food resources**

This objective ensures the maintenance of terrestrial food sources, including livestock and hunted and gathered food, through an understanding of land use, land cover, and sustainable management practices.

5) **Improve understanding of the energy demands associated with the Arctic food supply chain**

This objective includes research to improve the sustainability of the food supply chain through an increased understanding of the amount of energy required to harvest and store food.

6) **Improve understanding of the impacts of climate change on hunting and fishing in the Arctic**

This objective is achieved by assessing how changes in climate can affect the accessibility, availability, and sustainability of food sources in the Arctic (including potential impacts on hunting and fishing practices) and by determining how to respond to and prepare for such changes.

7) **Improve understanding of the impacts of climate change on the Arctic food supply chain**

This objective is achieved by assessing how changes in climate can impact food availability and security in the Arctic. The scope includes activities that seek to address how changing environmental conditions will affect Arctic food supply chain logistics and transportation.

8) Understand and coordinate institutional arrangements affecting the availability, accessibility, and sustainability of food

Activities to meet this objective improve the availability, accessibility, and sustainability of food by understanding the consequences of institutional arrangements and regulations, such as whale hunting quotas that influence the availability of whale meat.

b. Exchange of Food

This sub-area includes objectives related to the commercial and non-commercial exchange of food, the role of regulations in food markets, and the delivery of food to and from markets.

1) Ensure continued operation of transportation and shipping activities for food exchange

This objective addresses consumer access to food. The logistics of food transportation is particularly complex for northern cities and may involve boats, trains, trucks, and airplanes.

2) Improve understanding of formal and informal exchange networks to assess the use of food beyond its currency value

This objective involves research that describes the socioeconomic value chain by understanding the exchange of food through formal and informal exchange networks. Formal exchange networks include exchanges of food for currency. Informal exchange networks include broad trading networks among family and friends.

3) Understand and coordinate food exchange regulations and activities to mitigate resource scarcity and overabundance

Activities to meet this objective improve the availability, accessibility, and sustainability of food by understanding the consequences of institutional arrangements and regulations, such as impacts on markets, trade networks, and food prices.

c. Safe Food

This sub-area encompasses objectives related to pollutants that impact food supplies, food safety knowledge, food storage, nutritional quality, and genetic variations of certain populations' nutritional needs. Ensuring that populations have safe food requires improved understanding of the impact of both imported and locally available food on different populations.

1) Ensure food supplies do not exceed minimum pollutant thresholds

Activities to meet this objective ensure that Arctic foods are safe for consumption by requiring that food fall below minimum pollutant thresholds, as determined by appropriate toxicological assessments.

2) Ensure the safety and storage of food supplies under changing environmental conditions

This objective is achieved through activities that address the impacts that warming temperatures, algal blooms, snowmelts, and other changing environmental conditions have on harvesting, consumption, and storage of food supplies.

3) Improve the quality of and access to information about the availability and safety of food

This objective is achieved through the dissemination of knowledge related to cooking, storing, and accessing food both from the Arctic and brought into the Arctic.

4) Improve understanding of the nutritional quality of food in the Arctic

This objective includes research to describe and assess the nutritional aspects of imported and exported foods, as well as food that is grown, hunted, fished, or otherwise gathered. The objective also addresses how the nutritional quality of traditional foods has changed over time.

5) Improve understanding of the nutritional requirements of Arctic populations

This objective is met through research that seeks to understand how populations in the Arctic have adjusted to certain diets based on genetic variations. This research includes how variation has contributed to different populations adopting different diets, as well as measurement of these genetic variations and their geographic distributions within different populations.

6) Understand and coordinate institutional arrangements affecting food safety

This objective is addressed through research that seeks to identify and describe the consequences of institutional arrangements and regulations on food storage, nutrition, and other factors that affect food safety.

4. Fundamental Understanding of Arctic Systems

In the Fundamental Understanding of Arctic Systems SBA, societal benefits accrue from continuous, high-quality, scientifically sound observations of variables that describe the state of Arctic social, economic, and environmental systems and the interrelationships of these systems with each other and with global systems. A systems-level understanding serves

society by identifying predictability limits for the Arctic system, by reducing uncertainty in projections of the evolution of the system as a whole, and by helping identify key drivers of Arctic system change and global-scale feedback (Table 5). Fundamental processes in the Arctic system are related to those elsewhere, such as weather and climate outside the Arctic.

Table 5. SBA Sub-areas and Key Objectives for Fundamental Understanding of Arctic Systems

Sub-area	Key Objectives
Linkages, Interactions, and Feedback among Arctic Subsystems	• Improve ability to scale projections, models, and information related to components of the Arctic system • Improve systems-level understanding by identifying predictability limits for the Arctic system • Improve understanding of processes, variables, and rates of change in components of the Arctic system, including the cryosphere
Linkages, Interactions, and Feedback between Arctic Subsystems and Global Systems	• Improve understanding of anthropogenic influences on Arctic change • Improve understanding of Arctic amplification of global warming • Improve understanding of the impacts of biologic drivers on the Arctic system • Improve understanding of the impacts of socioeconomic drivers on the Arctic system • Improve understanding of the relationship between Arctic and global atmospheric and oceanic processes

a. Linkages, Interactions, and Feedback among Arctic Subsystems

This sub-area involves Arctic intra-system research on biological, geophysical (e.g., marine, terrestrial, and atmospheric), and socioeconomic systems.

1) Improve ability to scale projections, models, and information related to components of the Arctic system

This objective includes activities to improve scaling spatial and temporal projections, models, and information to relevant ranges, such as downscaling climate projections to specific communities.

2) Improve systems-level understanding by identifying predictability limits for the Arctic system

This objective is met through research that identifies how abrupt or non-linear changes in components of the Arctic system will affect Arctic subsystems.

3) Improve understanding of processes, variables, and rates of change in components of the Arctic system, including the cryosphere

This objective includes research to understand Arctic conditions, rates of change, and feedback loops, and their impacts on the Arctic system.

b. Linkages, Interactions, and Feedback between Arctic Subsystems and Global Systems

This sub-area involves inter-system research on the relationships between Arctic subsystems and global systems, including biological, geophysical (e.g., marine, terrestrial, and atmospheric), and socioeconomic systems.

1) Improve understanding of anthropogenic influences on Arctic change

This objective is achieved through research on how greenhouse gas emissions, black carbon, and other short-lived forcing agents influence Arctic systems both from within the Arctic and outside of the Arctic on timescales ranging from hours to months.

2) Improve understanding of Arctic amplification of global warming

This objective involves research to describe the drivers and associated consequences of global warming in the Arctic, including amplifying feedback loops.

3) Improve understanding of the impacts of biologic drivers on the Arctic system

This objective seeks to improve understanding of the biologic drivers, from both within and outside the Arctic, that influence Arctic systems. Example drivers include changing species distributions and zoonotic diseases.

4) Improve understanding of the impacts of socioeconomic drivers on the Arctic system

This objective involves research into the socioeconomic drivers, including globalization and economic forces, which influence Arctic systems. These drivers may come from within or outside of the Arctic.

5) Improve understanding of the relationship between Arctic and global atmospheric and oceanic processes

This objective includes topics such as weather, sea level rise, ocean circulation and acidification, nutrient cycling, freshwater flow, thermohaline circulations, and components and processes involved in the energy and greenhouse gas budgets.

5. Human Health

In the Human Health SBA, societal benefit accrues from the ability to track, forecast, prevent, mitigate, and respond to threats to community public health in the Arctic. In this SBA, human health includes mental, nutritional, and physical health and health behaviors across communities, households, and individuals. In addition, this SBA promotes further scientific understanding of the linkages among animal populations, environmental and climatic conditions, and human health as they relate to safe drinking water and sanitation services, prevention of diseases, health education, mitigation of harmful impacts of pollutants, and prevention of suicide (Table 6).

Table 6. SBA Sub-areas and Key Objectives for Human Health

Sub-area	Key Objectives
Mental Health	• Improve understanding of mental health determinants of Arctic residents • Improve understanding of the risks and benefits of climatic and environmental changes on community, household, and individual mental health • Mitigate the impacts of climatic and environmental changes on community, household, and individual mental health • Promote community, household, and individual mental health through adaptation to climatic and environmental changes
Physical Health	• Improve understanding of physical health determinants of Arctic residents • Improve understanding of the risks and benefits of climatic and environmental changes on community, household, and individual physical health • Mitigate the impacts of climatic and environmental changes on community, household, and individual physical health • Promote community, household, and individual physical health through adaptation to climatic and environmental changes
Public Health	• Ensure access to health care and health promotion services • Improve access to clean water and sanitation infrastructure • Improve early warning systems for impending public health emergencies • Improve synthesis of health- and environmental health-related knowledge across Arctic cultures • Improve understanding of epidemiology and health behaviors in the Arctic to inform public health policies and strategies • Improve understanding of influences of climatic and environmental changes on emerging infectious diseases in the Arctic • Reduce presence of foodborne pathogens and contaminants in Arctic food supplies

a. Mental Health

This sub-area involves research and response efforts related to improving the mental health of Arctic residents, including through demographic and genetic research and research on the impacts of climatic and environmental changes on mental health.

1) Improve understanding of mental health determinants of Arctic residents

This objective involves research into how genetic variation and demography affect the mental health of Arctic residents.

2) Improve understanding of the risks and benefits of climatic and environmental changes on community, household, and individual mental health

This objective involves research into how various climatic and environmental changes influence the mental health of Arctic residents at the community, household, and individual levels.

3) Mitigate the impacts of climatic and environmental changes on community, household, and individual mental health

This objective is achieved through activities intended to decrease the negative impacts on mental health associated with climatic and environmental changes in the Arctic.

4) Promote community, household, and individual mental health through adaptation to climatic and environmental changes

This objective involves efforts to help Arctic communities persistently manage the impacts of climatic and environmental changes on mental health at the community, household, and individual levels.

b. Physical Health

This sub-area involves research and response efforts related to improving the physical health of Arctic residents, including through demographic and genetic research and research on the impacts of climate and environmental changes on physical health.

1) Improve understanding of physical health determinants of Arctic residents

This objective involves research into how genetic variation and demography affect the physical health of Arctic residents.

2) Improve understanding of the risks and benefits of climatic and environmental changes on community, household, and individual physical health

This objective addresses how various climate and environmental changes influence the physical health of Arctic residents at the community, household, and individual levels.

3) Mitigate the impacts of climatic and environmental changes on community, household, and individual physical health

Activities to meet this objective decrease the negative impacts on physical health associated with climate and environmental changes.

4) Promote community, household, and individual physical health through adaptation to climatic and environmental changes

This objective involves efforts to help Arctic communities persistently manage the impacts of climate and environmental changes on physical health at the community, household, and individual levels.

c. Public Health

This sub-area covers objectives associated with collective health decisions at the community level, including exercise and fitness programs, disease prevention, sanitation, infrastructure, health promotion, unhealthy behavior cessation, and nutritional health (including foodborne pathogens and pollutants).

1) Ensure access to health care and health promotion services

This objective is met through the adequate provision of health care and health promotion services in Arctic communities. This includes social and mental health services as well as medical care for zoonotic, infectious, and chronic diseases.

2) Improve access to clean water and sanitation infrastructure

The purpose of this objective is to ensure a clean water supply and sanitary waste water processing in Arctic communities. This is accomplished, in part, by improving understanding of the relationship between the physical environment and the water and sanitation infrastructure.

3) Improve early warning systems for impending public health emergencies

Activities to achieve this objective include the provision of public health emergency notifications and training Arctic communities to track and report health-related information.

4) Improve synthesis of health- and environmental health-related knowledge across Arctic cultures

Activities to meet this objective improve health outcomes in Arctic communities by enhancing the integration of indigenous Arctic and non-Arctic knowledge and science in order.

5) Improve understanding of epidemiology and health behaviors in the Arctic to inform public health policies and strategies

This objective involves Arctic epidemiology and health behavior research in order to better understand health and disease conditions among Arctic populations.

6) Improve understanding of influences of climatic and environmental changes on emerging infectious diseases in the Arctic

This objective involves research into the effect that climatic and environmental changes have on emerging zoonotic and other infectious diseases in the Arctic.

7) Reduce presence of foodborne pathogens and contaminants in Arctic food supplies

This objective addresses efforts to characterize, track, and mitigate pathogenic and contaminant risks to Arctic food supplies.

6. Infrastructure and Operations

In the Infrastructure and Operations SBA, societal benefit accrues from the safe and efficient operation of built and service infrastructure in the Artic. Built infrastructure includes energy, transportation, water and wastewater, information and communications, and building systems. Service infrastructure includes health and medical, food, government services, security, and maintenance systems. This SBA addresses the general life cycle of infrastructure systems from planning through development, operations, and decommissioning stages (Table 7).

Table 7. SBA Sub-areas and Key Objectives for Infrastructure and Operations

Sub-area	Key Objectives
Planning of Infrastructure	• Ensure safe and secure infrastructure design • Improve understanding of the impacts of infrastructure on the environment, human systems, and society • Support infrastructure design siting
Development of Infrastructure	• Ensure compliance with infrastructure codes and environmental regulations • Inform and support construction and quality assurance and control activities
Operations and Maintenance of Infrastructure	• Ensure safe and secure infrastructure operations • Improve understanding of environmental effects on infrastructure operations • Maintain awareness and provide predictive capabilities to support safe operation of infrastructure • Maintain operational awareness of infrastructure systems • Support economic optimization of operations
Decommissioning of Infrastructure	• Dispose of infrastructure materials or assets that cannot be re-utilized • Identify opportunities for re-utilization of infrastructure system assets • Improve understanding of long-term impacts of decommissioned infrastructure systems on Arctic communities and the environment • Inform decisions regarding re-utilization and disposition of infrastructure systems

a. Planning of Infrastructure

This sub-area includes predictive analysis, siting, safety and security planning, and infrastructure design optimization to ensure appropriate planning across the entire infrastructure life cycle.

1) Ensure safe and secure infrastructure design

This objective addresses infrastructure safety and security in the design process through the use of accurate geophysical measurements and consideration of forecasted weather and environmental conditions.

2) Improve understanding of the impacts of infrastructure on the environment, human systems, and society

This objective is met through research on the effects that infrastructure may have on the environment and society through the use of predictive analyses.

3) **Support infrastructure design and siting**

This objective is met through the use of detailed and quality-controlled Arctic environmental data to support decisions about the design and siting of Arctic infrastructure projects.

b. Development of Infrastructure

This sub-area involves verifying planning procedures and promoting quality assurance and control as infrastructure is built, including the code and environmental compliance of construction activities.

1) **Ensure compliance with infrastructure codes and environmental regulations**

This objective is met through the use of environmental impact inspections to ensure compliance with infrastructure codes and environmental regulations.

2) **Inform and support construction activities and quality assurance and control activities**

This objective involves ensuring that projects are developed safely and resources are deployed efficiently through the use of accurate weather forecasts, geophysical measurements, and environmental information to ensure quality assurance and control.

c. Operations and Maintenance of Infrastructure

This sub-area involves strategic and tactical awareness of infrastructure systems as well as safe operation and maintenance of these systems. Access to information is needed to understand and compare trade-offs between potential decisions that impact the operations and maintenance of infrastructure in the Arctic.

1) **Ensure safe and secure infrastructure operations**

This objective is met through the strategic and tactical uses of weather forecasting, geophysical measurements, and environmental data to respond to and prepare for natural and human-made threats to infrastructure operations and safety.

2) **Improve understanding of environmental effects on infrastructure operations**

This objective relies on research about the effects of the Arctic environment on infrastructure operations, including operations involving maritime, weather, environmental, geophysical, and species distribution data.

3) Maintain awareness and provide predictive capabilities to support safe operation of infrastructure

This objective addresses site-level safety issues, safety concerns such as the integrity of component materials, and strategic and tactical priority activities. The activities associated with this objective contribute to the safe, secure, and continuous operation of infrastructure systems.

4) Maintain operational awareness of infrastructure systems

To achieve this objective, infrastructure system owners and operators need accurate information, such as vehicle and ship tracking data and weather and environmental condition information, to help them ascertain how infrastructure systems are operating.

5) Support economic optimization of operations

To achieve this objective, infrastructure system owners and operators need accurate information on how infrastructure systems are operating as well as decision support tools to support economic optimization.

d. Decommissioning of Infrastructure

This sub-area addresses infrastructure decommissioning procedures and the long-term effects of decommissioning infrastructure on communities and the environment using near- and long-term predictive models.

1) Dispose of infrastructure materials or assets that cannot be re-utilized

This objective addresses the need for planning remediation operations, identifying hazardous materials that require special handling and containment, and minimizing environmental degradation and risks to human health and the economy.

2) Identify opportunities for re-utilization of infrastructure system assets

This objective is met through the identification of salvageable assets that may be reused or repurposed for infrastructural or other needs.

3) Improve understanding of long-term impacts of decommissioned infrastructure systems on Arctic communities and the environment

This objective relies on research that characterizes risks associated with decommissioned infrastructure systems to Arctic communities, such as economic losses and negative effects on human health, animal populations, and the environment.

4) Inform decisions regarding re-utilization and disposition of infrastructure systems

To achieve this objective, decision makers need real-time monitoring data and modeling and forecasting tools to be able to accurately predict the long-term effects of decommissioned or reutilized infrastructure.

7. Marine and Coastal Ecosystems and Processes

In the Marine Ecosystems and Processes SBA, societal benefit accrues from understanding, managing, monitoring, protecting, preserving, and sustainably using marine and coastal resources and ecosystems for food, energy, recreation, and transportation. This SBA includes efforts to understand terrestrial-ocean-atmosphere interactions across coastal and marine ecosystems and to ensure the continued and enhanced provision of benefits from ocean and coastal resources (Table 8). At the same time, it is important to ensure the provision of ecosystem services, to maintain biogeochemical processes such as biodiversity and geothermal fluxes, and to improve the ability to predict marine and coastal ecosystem responses to Arctic system changes.

Table 8. SBA Sub-areas and Key Objectives for Marine and Coastal Ecosystems and Processes

Sub-area	Key Objectives
Marine and Coastal Ecosystem Biodiversity	• Identify and preserve culturally important marine and coastal areas • Identify and preserve ecologically sensitive marine and coastal areas for biodiversity • Identify and understand the diversity of Arctic biota throughout their ranges • Manage and preserve Arctic biota throughout their ranges • Promote resilience and sustainability of Arctic biodiversity in marine and coastal ecosystems
Marine and Coastal Ecosystem Changes	• Improve understanding of impacts of environmental change on Arctic marine and coastal ecosystems • Improve understanding of ecological and evolutionary responses of marine and coastal organisms to changes in the Arctic • Inform human adaptation to ecosystem changes • Manage disturbances to marine and coastal ecosystems
Marine and Coastal Living Resources	• Characterize and assess the status and trends of Arctic and migratory living resources • Manage Arctic and migratory living resources in a sustainable manner • Sustain marine bioprospecting in the Arctic
Marine and Coastal Processes	• Assess the impact of changing hydrologic and cryospheric conditions on marine and coastal ecosystems • Improve decision making for responses to changes in marine and coastal conditions • Improve understanding of physical oceanography, ocean biogeochemistry, and their interactions

a. Marine and Coastal Ecosystem Biodiversity

This sub-area includes efforts to maintain culturally and ecologically important ecosystems and to understand and preserve biodiversity throughout the Arctic Ocean.

1) Identify and preserve culturally important marine and coastal areas

Activities to meet this objective preserve and protect geographic locales of cultural importance, including those inhabited or passed through by terrestrial and freshwater flora and fauna.

2) Identify and preserve ecologically sensitive marine and coastal areas for biodiversity

This objective is met through efforts to identify critical or ecologically significant areas, to manage hotspot and key ecological areas, and to ensure these areas; long-term viability.

3) Identify and understand the diversity of Arctic biota throughout their ranges

Activities to achieve this objective include research on Arctic marine and coastal species diversity, including migratory and cold-adapted species, to improve understanding of Arctic biota throughout their Arctic and non-Arctic environments. This objective incorporates research into where, how, and why species move as they shift further north due to environmental and climate changes.

4) Manage and preserve Arctic biota throughout their ranges

This objective addresses the need to protect and preserve marine and coastal species diversity, including migratory, cold-adapted, shifting, and managed species, throughout their Arctic and non-Arctic environments.

5) Promote resilience and sustainability of Arctic biodiversity in marine and coastal ecosystems

This objective encompasses efforts to support ecosystem resilience and sustainability across both the short-term and the long-term to promote biodiversity among Arctic ecosystems in the face of potentially rapid environmental change.

b. Marine and Coastal Ecosystem Changes

This sub-area includes responses by marine and coastal Arctic ecosystems to environmental change, including changes in species and community dynamics and physical processes.

1) Improve understanding of impacts of environmental change on Arctic marine and coastal ecosystems

Activities to achieve this objective include identification of and research into impacts on Arctic marine and coastal ecosystems, such as range extensions and shifts in the population dynamics of native and non-native invasive species, among other impacts, due to environmental changes.

2) Improve understanding of ecological and evolutionary responses of marine and coastal organisms to changes in the Arctic

This objective is met through research on the rate and timing of ecological and evolutionary responses to changes in the Arctic, including species range and abundance. These changes may impact human use of a particular natural resource.

3) Inform human adaptation to ecosystem changes

Activities to meet this objective ensure Arctic communities identify and appropriately adjust to ecosystem changes that may affect their cultural, economic, and subsistence activities through efforts to monitor changes and disseminate data and information.

4) Manage disturbances to marine and coastal ecosystems

This objective is met through management and stewardship of marine and coastal ecosystems to mitigate disturbances such as algal blooms, coastal erosion, and ocean acidification.

c. Marine and Coastal Living Resources

This sub-area includes research into living resources in the Arctic, including Arctic species (referring to native species) and migratory species (referring to species that move within or in and out of the Arctic).

1) Characterize and assess the status and trends of Arctic and migratory living resources

This objective addresses efforts to understand and monitor short- and long-term changes in the status and trends of biota due to environmental fluxes.

2) Manage Arctic and migratory living resources in a sustainable manner

This objective addresses the need for long-term human management of living resources for economic purposes, including through sustainable planning, characterization of biota needs, awareness of potential changes in Arctic systems, and other activities related to maintaining living resources.

3) Sustain marine bioprospecting in the Arctic

Activities to meet this objective ensure a sustainable level of harvesting of animals and plants for pharmaceutical research and development and other purposes, and they entail both bioprospecting and research into what constitutes a sustainable level of bioprospecting.

d. Marine and Coastal Processes

This sub-area includes non-biological processes in the Arctic oceans and cryosphere, including physical oceanography and biogeochemistry.

1) Assess the impact of changing hydrologic and cryospheric conditions on marine and coastal ecosystems

Activities to meet this objective improve understanding of the impact of changing sea-ice, permafrost, glaciers, oceans, ocean currents, water quality, stratification, and circulation on marine and coastal ecosystems and on humans and natural resources in these ecosystems.

2) Improve decision making for responses to changes in marine and coastal conditions

This objective addresses the need to acquire and provide accurate and timely information and forecasts to decision makers so that they ensure human safety and security and provide environmental stewardship in their responses to changes in environmental conditions, such as oil spills, harmful algal blooms that affect shellfish or fisheries, permafrost melt, coastal erosion, size of harvests for subsistence or industrial purposes, and catastrophic events.

3) Improve understanding of physical oceanography, ocean biogeochemistry, and their interactions

This objective is met through research into the underlying physical and biogeochemical processes of marine and coastal cryospheric and hydrospheric systems and their effect on species and ecosystems. These processes and systems include the ocean's heat capacity, salinity, density, and temperature; surface-energy balance; global nutrient cycles; uptake and release of greenhouse gases; and changes in ocean chemistry.

8. Natural Resources

In the Natural Resources SBA, societal benefit accrues from conducting activities surrounding the discovery, extraction, and processing of natural resources in a sustainable and responsible manner. This SBA focuses on economic uses of both renewable (e.g.,

forests and fisheries) and non-renewable (e.g., fossil fuels and minerals) natural resources and their impacts on the environment and society (Table 9).

Table 9. SBA Sub-areas and Key Objectives for Natural Resources

Sub-area	Key Objectives
Natural Resource Exploration and Assessment	• Assess and reduce the impact of natural resource exploration • Improve understanding of the connections and dynamics between resources and environment • Improve understanding of the distribution of Arctic natural resources • Manage inventories of existing natural resource stocks, including protected stocks, in a sustainable manner
Natural Resource Development and Exploitation	• Assess, manage, and reduce the impact of natural resource development and exploitation • Ensure regulatory compliance of natural resource development activities • Maintain the safe and secure operation of natural resource exploitation activities • Support natural resource development decisions • Understand and project conditions to inform facility management and support operator situational awareness
Natural Resource Decommissioning and Reclamation	• Assess long-term risks and hazards associated with reclaimed or decommissioned sites • Ensure effectiveness of reclamation measures in the Arctic • Ensure regulatory compliance of reclamation and decommissioning activities • Inform the development of long-term reclamation and decommissioning plans

a. Natural Resource Exploration and Assessment

This sub-area addresses the initial stages of natural resource use, which are finding and understanding resources before their extraction. Exploration refers to both resources that require discovery (e.g., fossil fuels or minerals) and those that require additional understanding and assessment (e.g., forests or fisheries).

1) Assess and reduce the impact of natural resource exploration

This objective is met through use of environmental, geophysical, and population data to characterize potential negative impacts of natural resource exploration practices and through support of mitigation efforts.

2) Improve understanding of the connections and dynamics between resources and environment

This objective involves research into how future exploitation may affect existing resource stores to improve decision-making capabilities and minimize negative environmental and social impacts as resources are extracted.

3) Improve understanding of the distribution of Arctic natural resources

Activities to meet this objective include charting and mapping natural resources across the Arctic to improve understanding of their locations and amounts.

4) Manage inventories of existing natural resource stocks, including protected stocks, in a sustainable manner

To achieve this objective, natural resource managers must understand the distribution of natural resource stocks, which change over time due to use and climatic and environmental conditions, and how continued use or exploitation affect the vitality and abundance of those stocks.

b. Natural Resource Development and Exploitation

This sub-area addresses activities associated with the preparation and removal of resources for economic gain. These include resource extraction planning, assessments, and operations.

1) Assess, manage, and reduce the impact of natural resource development and exploitation

This objective is met through the use of environmental, geophysical, and population data to develop and execute plans for natural resource exploitation, with a focus on reducing negative environmental and societal impacts.

2) Ensure regulatory compliance of natural resource development activities

Activities to achieve this objective include monitoring natural resource development sites to ensure compliance with regulations.

3) Maintain the safe and secure operation of natural resource exploitation activities

This objective relies on the use of environmental and geophysical data to ensure the safety and security of natural exploitation activities, given their remote locations and susceptibility to natural disasters and potential human-made threats.

4) Support natural resource development decisions

This objective is met through the use of environmental and geophysical data to support natural resource development, exploration, exploitation, and decommissioning decisions throughout natural resource development projects' life cycles.

5) Understand and project conditions to inform facility management and support operator situational awareness

This objective is supported through the use of environmental and geophysical data to predict and respond to changing climatic and environmental conditions.

c. Natural Resource Decommissioning and Reclamation

This sub-area involves decommissioning and reclamation conducted at the conclusion of exploitation activities, including subsequent monitoring to mitigate environmental or societal impacts at the site.

1) Assess long-term risks and hazards associated with reclaimed or decommissioned sites

This objective requires long-term monitoring of the environmental and health risks associated with changing climatic and environmental conditions at natural resource exploitation sites in the years following decommissioning or reclamation.

2) Ensure effectiveness of reclamation measures in the Arctic

This objective is met through testing and monitoring reclamation efforts successfully used at lower latitudes to determine if they can be successfully implemented in the Arctic.

3) Ensure regulatory compliance of reclamation and decommissioning activities

Activities to achieve this objective include routine monitoring of decommissioned or reclaimed natural resource sites to ensure regulatory compliance.

4) Inform the development of long-term reclamation and decommissioning plans

Activities that meet this objective inform decisions associated with the decommissioning of natural resource extraction sites. This includes efforts to mitigate impacts on water quality and ecosystems and enable better reclamation outcomes.

9. Resilient Communities

In the Resilient Communities SBA, societal benefit accrues by sustaining and preserving the vitality and security of Arctic communities in a changing region. This involves efforts to mitigate and adapt to changing climatic and environmental conditions in order to maintain, protect, and foster the vitality and livelihoods of communities. It also considers the potential impacts of climatic and environmental changes on food security and transportation (Table 10).

Table 10. SBA Sub-areas and Key Objectives for Resilient Communities

Sub-area	Key Objectives
Adaptation and Response of Communities	• Develop capacity to adapt and respond to Arctic system changes on communities • Improve community education on Arctic system changes and their impacts • Mitigate the impacts of Arctic system changes on communities
Baseline Conditions of Communities	• Assess community resources to adapt to Arctic system changes • Assess community understanding of the threats, impacts, and causes of Arctic system changes • Assess community vulnerability to Arctic system changes
Future Projections of Community Changes	• Characterize the magnitudes and rates of Arctic system changes and their impacts on communities • Improve the projections of impacts from Arctic system changes on communities

a. Adaptation and Response of Communities

This sub-area incorporates adaptation and mitigation efforts, including scenario development and planning, communication of the impacts on the Arctic, and creation and use of tools to build capacity for responding to future changes.

1) Develop capacity to adapt and respond to Arctic system changes on communities

This objective is met through the development of adaptive tools and sustainable technologies that respond to projected changes across Arctic systems.

2) Improve community education on Arctic system changes and their impacts

This objective addresses the need to educate communities about Arctic system changes and the best ways to respond to these changes. Activities include scenario development, education planning, and communication of the impacts of global change on the Arctic and of Arctic change on the globe.

3) Mitigate the impacts of Arctic system changes on communities

This objective involves efforts to reduce the negative impacts of Arctic system changes by using adaptive tools and building capacity to predict and respond to future changes. These efforts include greenhouse gas mitigation.

b. Baseline Conditions of Communities

This sub-area includes assessments of the threats to and vulnerabilities of Arctic communities and of the resources available to them.

1) Assess community resources to adapt to Arctic system changes

This objective covers cultural, human, and natural capital and other community resources that could be used to respond to Arctic system changes.

2) Assess community understanding of the threats, impacts, and causes of Arctic system changes

This objective is met through activities to determine what specific effects Arctic system changes, including climate and other environmental changes, have on community resources, safety, economy, society, and culture.

3) Assess community vulnerability to Arctic system changes

Activities to meet this objective determine the impacts of Arctic system changes on the supply and diversity of necessary resources and whether the community has the resilience to handle these changes.

c. Future Projections of Community Changes

This sub-area includes projections on potential ecosystem and livelihood changes and their impacts on Arctic communities. Ecosystem changes include sea level rise, sea ice loss, permafrost melt, coastal erosion, extreme weather events, and changes in the availability of natural resources. Livelihood changes include market and non-market impacts that affect Arctic community economies.

1) Characterize the magnitudes and rates of Arctic system changes and their impacts on communities

This objective involves efforts to research, monitor, and predict the impacts of Arctic system changes on communities.

2) Improve the projections of impacts from Arctic system changes on communities

Activities to meet this objective improve understanding of Arctic system changes in order to develop more accurate projections of Arctic systems and their impacts on social and economic systems and community services.

10. Sociocultural Services

In the Sociocultural Services SBA, societal benefit accrues from recognizing and maintaining the environment's role in sociocultural aspects of Arctic peoples, including across urban and rural Arctic cultures. For the purposes of this SBA, "society" reflects the combination of social, ecological, and technological components that compose a community. Societal benefit accrues from observations that inform activities to preserve natural and cultural resources for current and future generations in the Arctic. This SBA incorporates the role of socioeconomics into cultures, the interconnected and holistic view of the individual and the collective across the range of human activities, and the merging and sharing of ideas and information related to the Arctic (Table 11).

Table 11. SBA Sub-areas and Key Objectives for Sociocultural Services

Sub-area	Key Objectives
Cultural and Spiritual Experiences	• Ensure continued access to opportunities for recreation and human connection with nature • Maintain areas of cultural significance in the Arctic • Maintain the vitality of Arctic languages, cultures, and communities to preserve knowledge sources
Knowledge Development and Integration	• Ensure integration of indigenous languages, cultures, and communities for knowledge co-production • Improve understanding of Arctic processes and cultures to improve and enhance knowledge co-production • Support development, co-production, and dissemination of scientific knowledge across Arctic cultures
Socioeconomics	• Improve understanding of formal and informal exchange networks for Arctic resources • Improve understanding of socioeconomic systems that impact the Arctic • Improve understanding of the cryospheric and environmental processes in the Arctic on socioeconomic systems

a. Cultural and Spiritual Experiences

This sub-area emphasizes both knowledge of understanding the world and knowledge of understanding the self through culture, language, community, and nature.

1) **Ensure continued access to opportunities for recreation and human interface with nature**

Activities to achieve this objective include efforts to ensure continuation and availability of outdoor experiences through both economic (e.g., tourism and cruises) and non-economic (i.e., personally initiated) interactions with nature for cultural, spiritual, or recreational value.

2) **Maintain areas of cultural significance in the Arctic**

Activities to meet this objective protect, sustain, and preserve the physical locations where cultural life and society intersect.

3) **Maintain the vitality of Arctic languages, cultures, and communities to preserve knowledge sources**

This objective is met through knowledge dissemination to maintain cultural diversity in recognition that language and culture have value on their own.

b. Knowledge Development and Integration

This sub-area involves the expansion and integration of indigenous science and other types of scientific and cultural knowledge throughout the Arctic.

1) **Ensure integration of indigenous languages, cultures, and communities for knowledge co-production**

Activities to meet this objective integrate indigenous languages, cultures, and communities into concepts of Western science to improve understanding of the Arctic environment.

2) **Improve understanding of Arctic processes and cultures to improve and enhance knowledge co-production**

This objective is met through knowledge transfer and integration activities across all Arctic cultures to improve understanding of the Arctic environment.

3) **Support development, co-production, and dissemination of scientific knowledge across Arctic cultures**

This objective involves merging of indigenous science with Western science for mutual benefit.

c. Socioeconomics

This sub-area considers the impact of socioeconomic systems on the Arctic, of Arctic systems on socioeconomics, and of economic and non-economic exchange networks.

1) Improve understanding of formal and informal exchange networks for Arctic resources

Activities to meet this objective determine the economic and social value of Arctic resources and identify the formal and informal exchange networks for these resources to inform understanding of economic activity and growth in Arctic communities.

2) Improve understanding of socioeconomic systems that impact the Arctic

Activities to achieve this objective include identification of and research into the impacts of socioeconomic systems both in and outside of the Arctic on those systems within the Arctic. These systems include economically productive activities and resource extraction activities involving tourism, minerals, oil, timber, bioprospecting, fishing, whaling, herding, shipping, and aquaculture.

3) Improve understanding of the cryospheric and environmental processes in the Arctic on socioeconomic systems

This objective is met through efforts to monitor and understand the impact of cryosphere and environmental processes on human activities and culture in the Arctic.

11. Terrestrial and Freshwater Ecosystems and Processes

In the Terrestrial and Freshwater Ecosystems and Processes SBA, societal benefit accrues from understanding, managing, monitoring, protecting, preserving, and sustainably using terrestrial and freshwater resources and ecosystems for food, energy, recreation, and transportation. This SBA includes efforts to understand terrestrial-ocean-atmosphere interactions across terrestrial and freshwater ecosystems and to ensure the continued and enhanced provision of the myriad benefits of terrestrial and freshwater resources. These efforts are important to ensuring the provision of ecosystem services, maintaining biogeochemical processes, and improving the ability to predict terrestrial and freshwater ecosystem responses to Arctic system changes (Table 12).

Table 12. SBA Sub-areas and Key Objectives for Terrestrial and Freshwater Ecosystems and Processes

Sub-area	Key Objectives
Terrestrial and Freshwater Ecosystem Biodiversity	• Identify and preserve culturally important terrestrial and freshwater areas • Identify and preserve ecologically sensitive terrestrial and freshwater areas for biodiversity • Identify and understand the diversity of biota throughout their ranges • Manage and preserve biota throughout their ranges • Promote resilience and sustainability of biodiversity in terrestrial and freshwater ecosystems
Terrestrial and Freshwater Ecosystem Responses to Arctic Changes	• Improve understanding of changing environmental impacts on terrestrial and freshwater ecosystems • Improve understanding of ecological and evolutionary responses of terrestrial and freshwater organisms to changes in the Arctic • Inform human adaptation to ecosystem changes • Manage disturbances to terrestrial and freshwater ecosystems
Terrestrial and Freshwater Living Resources	• Assess and manage land cover and land use in a sustainable manner • Characterize and assess the status and trends of Arctic and migratory living resources • Manage and use water resources in a sustainable manner • Manage Arctic and migratory living resources in a sustainable manner • Manage natural resources that support the use of Arctic and migratory living resources in a sustainable manner • Understand and assess the role of the terrestrial cryosphere as a resource
Terrestrial and Freshwater Processes	• Assess the impact of changing hydrologic and cryospheric conditions on terrestrial and freshwater ecosystems • Improve decision making for responses to changes in terrestrial and freshwater conditions • Improve understanding of physical and biogeochemical processes in cryospheric and hydrospheric systems • Improve understanding of the impact of the hydrologic cycle on biota

a. Terrestrial and Freshwater Ecosystem Biodiversity

This sub-area includes efforts to maintain ecologically and culturally important ecosystems and to understand and preserve biodiversity throughout the Arctic.

1) Identify and preserve culturally important terrestrial and freshwater areas

Activities to meet this objective preserve and protect geographic locales of cultural importance, including those inhabited or passed through by terrestrial and freshwater flora and fauna.

2) Identify and preserve ecologically sensitive terrestrial and freshwater areas for biodiversity

This objective is met through efforts to identify and manage critical or ecologically significant areas, such as biodiversity and ecological hotspots, to ensure their long-term viability.

3) Identify and understand the diversity of Arctic biota throughout their ranges

Activities to achieve this objective include research on Arctic terrestrial and freshwater species diversity, including migratory and cold-adapted species, to improve understanding of Arctic biota throughout their Arctic and non-Arctic environments. This objective also incorporates research into where, how, and why species move as they shift further north due to climatic and environmental changes.

4) Manage and preserve Arctic biota throughout their ranges

This objective addresses the need to protect and preserve terrestrial and freshwater species diversity, including migratory, cold-adapted, shifting, and managed species, throughout their Arctic and non-Arctic environments.

5) Promote resilience and sustainability of Arctic biodiversity in terrestrial and freshwater ecosystems

This objective encompasses efforts to support ecosystem resilience and sustainability across both the short- and long-term to promote biodiversity among Arctic ecosystems in the face of potentially rapid environmental change.

b. Terrestrial and Freshwater Ecosystem Responses to Arctic Changes

This sub-area addresses responses of Arctic terrestrial and freshwater ecosystems to environmental change. These responses include changes in species and community dynamics, particularly those that are relied upon by Arctic human populations, as well as changes in physical processes in the environment.

1) Improve understanding of changing environmental impacts on Arctic terrestrial and freshwater ecosystems

Activities to achieve this objective include identification of and research into impacts on Arctic terrestrial and freshwater ecosystems, such as range extensions, shifts in the population dynamics of native and non-native invasive species, among other effects of environmental changes.

2) Improve understanding of ecological and evolutionary responses of terrestrial and freshwater organisms to changes in the Arctic

This objective is met through research on the rate and timing of ecological and evolutionary responses to changes in the Arctic, including species range and abundance. These changes may impact human use of a particular natural resource.

3) Inform human adaptation to ecosystem changes

Activities to meet this objective ensure Arctic communities identify and appropriately adjust to ecosystem changes that may affect their culture, economy, and subsistence through efforts to monitor changes and disseminate data and information.

4) Manage disturbances to terrestrial and freshwater ecosystems

This objective is met through management and stewardship of terrestrial and freshwater ecosystems to mitigate disturbances such as fires and floods.

c. Terrestrial and Freshwater Living Resources

This sub-area includes efforts to determine short- and long-term monitoring of changes in the status and trends of biota due to environmental fluxes, including water quality, use, and availability.

1) Assess and manage land cover and land use in a sustainable manner

This objective is met through activities that minimize segmentation and preserve land cover and use to the extent possible for future generations. Land cover refers to the urban built environment and to the different natural land classes irrespective of population, including agricultural, urban or paved, forested, grazed, or tundra land cover and use.

2) Characterize and assess the status and trends of Arctic and migratory living resources

This objective addresses efforts to understand and monitor short- and long-term changes in the status and trends of biota due to environmental fluxes.

3) Manage and use water resources in a sustainable manner

Activities to achieve this objective include research into stewardship of water resources, including water-reliant activities surrounding agriculture, sanitation, and consumption, as well as research into understanding and responding to changes in glacial volume, terrestrial ice, hydropower, and freshwater.

4) Manage Arctic and migratory living resources in a sustainable manner

This objective addresses the need for long-term human management of living resources, including for economic purposes, through sustainable planning, characterization of biota needs, and awareness of potential changes in Arctic systems, among other activities related to maintaining living resources.

5) Manage natural resources that support the use of Arctic and migratory living resources in a sustainable manner

This objective addresses the need for long-term human management of non-living resources, including for economic purposes, through sustainable planning, characterization of non-living resources such as soil and nutrient storage, and awareness of potential changes in Arctic systems, among other activities related to maintaining non-living natural resources.

6) Understand and assess the role of the terrestrial cryosphere as a resource

This objective is met through research into characterizing and understanding cryospheric resources, including glaciers, permafrost, and snowpack, and research into understanding the carbon-permafrost storage feedback cycle.

d. Terrestrial and Freshwater Processes

This sub-area includes non-biological processes in Arctic terrestrial and freshwater ecosystems.

1) Assess the impact of changing hydrologic and cryospheric conditions on terrestrial and freshwater ecosystems

Activities to meet this objective improve understanding of the impact of changing sea-ice, permafrost, glaciers, and oceans on terrestrial and freshwater ecosystems and on the humans and natural resources in these ecosystems.

2) Improve decision making for responses to changes in terrestrial and freshwater conditions

This objective addresses the need to acquire and provide accurate and timely information and forecasts to decision makers so that they ensure human safety and security and environmental stewardship in their responses to changes in environmental conditions, including oil spill responses, permafrost melt, coastal erosion, size of harvests for subsistence or industrial purposes, and catastrophic events.

3) Improve understanding of physical and biogeochemical processes in Arctic cryospheric and hydrospheric systems

This objective is met through research into the underlying physical and biogeochemical processes of terrestrial and freshwater cryospheric and hydrospheric systems, including the surface-energy balance, global nutrient cycles, uptake and release of greenhouse gases, and changes in ocean chemistry and their effect on species and ecosystems.

4) Improve understanding of the impact of the hydrologic cycle on Arctic biota

This objective addresses research into further understanding how Arctic flora and fauna respond to hydrologic and cryospheric changes.

12. Weather and Climate

In the Weather and Climate SBA, societal benefit accrues from improved weather and climate information; climate projections; enhanced weather forecasts; and more timely warnings that can save lives, provide socioeconomic benefits, and improve decision making for public and private services at community-relevant levels. The delivery of weather and climate information in an understandable and useable form is critical to inform users' decisions and accrue societal benefit. Improved timeliness and accuracy of predictions and projections support community efforts to prepare for and mitigate weather and climate events to reduce risk. Timely and accurate knowledge and forecasting of changes in temperature, precipitation, wind, and other weather variables directly and indirectly affect energy, transportation, construction, agriculture, tourism, and other critical sectors. Advances in weather research and measurements improve understanding of atmospheric and sea ice processes and initial conditions that drive weather models and improve prediction of mid-latitude weather conditions. Current observations support detection and attribution of past and future observations, including validating projections and identifying global, regional, and local climate- or weather-related changes (Table 13).

Table 13. SBA Sub-areas and Key Objectives for Weather and Climate

Sub-area	Key Objectives
Weather Effects on Economic Productivity	• Provide community-specific weather predictions for economic productivity • Provide sector-specific weather predictions for economic productivity
Weather Effects on Protection of Lives and Property	• Improve understanding, prediction, and detection of weather events in the Arctic and their effects on life and property • Reduce loss of life and injury and damage to property due to high-impact weather events • Reduce loss of life and injury and damage to property due to routine weather events
Weather Effects on Quality of Life	• Improve public understanding and use of weather products and services • Support ability to understand, plan for, and mitigate changing weather patterns in the Arctic • Support effective weather response, planning, mitigation, and resource allocation for communities
Weather Forecasting and Climate Projections	• Improve understanding of the relationship between the Arctic and global processes to improve weather predictions and climate projections • Improve linkages between weather and climate observations across timescales to reduce uncertainty in weather and climate modeling and prediction • Improve fundamental understanding of Arctic processes that impact weather in the mid-latitudes • Support effective response, planning, mitigation, and resource allocation based on changing climatic conditions

a. Weather Effects on Economic Productivity

This sub-area considers high-impact, extreme, and routine weather events and their community- and sector-specific effects.

1) Provide community-specific weather predictions for economic productivity

This objective is met through development of downscaled climate models and weather predictions to provide the guidance necessary for community-level economic activities, such as transportation and construction, in the Arctic.

2) Provide sector-specific weather predictions for economic productivity

This objective addresses the need to design climate models and weather predictions for individual, economically productive sectors to inform decision making in the Arctic.

b. Weather Effects on Protection of Lives and Property

This sub-area involves efforts to reduce the impacts of high-impact, extreme, and routine weather events to protect lives and property.

1) Improve understanding, prediction, and detection of weather events in the Arctic and their effects on life and property

Activities to achieve this objective include research into the numerical, statistical, and dynamical models that represent key polar processes and efforts to improve Arctic weather models and predictions via the transition from research to operations.

2) Reduce loss of life and injury and damage to property due to high-impact weather events

Activities to meet this objective reduce the risks associated with high-impact weather events, including extended periods of fog, gradually changing climates, and extreme weather events, by gathering, analyzing, and disseminating relevant information and research in the Arctic.

3) Reduce loss of life and injury and damage to property due to routine weather events

This objective involves efforts to minimize the risks associated with routine weather events, including effects on safety, well-being, and property, by gathering, analyzing, and disseminating relevant information and research in the Arctic.

c. Weather Effects on Quality of Life

This sub-area considers short- and long-term impacts on quality of life based on changing weather patterns and extreme and routine weather.

1) Improve public understanding and use of weather products and services

To achieve this objective, weather forecasts and products should be presented in an understandable format to communicate the application and use of the information to the community of users.

2) Support ability to understand, plan for, and mitigate changing weather patterns in the Arctic

Activities to meet this objective improve understanding of and appropriately prepare Arctic peoples for changing weather patterns through provision of timely, comprehensive, and salient decision support tools.

3) **Support effective weather response, planning, mitigation, and resource allocation for communities**

Activities to meet this objective ensure continuity of operations, maintenance of services, and adequate preparation and response efforts among communities affected by high-impact, extreme, and routine weather events.

d. Weather Forecasting and Climate Projections

This sub-area covers objectives related to both weather forecasting and climate projections. Climate-related objectives cover identifying future changes in climate under different greenhouse gas forcing scenarios, determining initial conditions, providing boundary problems, collecting data needed for model improvement, and participating in mitigation- and adaptation-related activities. Weather-related objectives in this sub-area are associated with the relationship between weather and climate and with the impact of processes in the Arctic on mid-latitude weather patterns.

1) **Improve understanding of the relationship between the Arctic and global processes to improve climate projections**

This objective is met through research into the impact of Arctic and global processes (including biological, geological, physical, and socioeconomic systems) on the climate and development of improved climate model projections.

2) **Improve linkages between weather and climate observations across timescales to reduce uncertainty in weather and climate modeling and prediction**

This objective addresses the need to improve understanding of the relationships between short-term weather processes and longer-term climate fluctuations to predict future weather phenomena and climate change. Many of the same processes (e.g., hydrologic processes) that operate on shorter weather timescales will also impact climate variations and change on longer time scales.

3) **Improve fundamental understanding of Arctic processes that impact weather in the mid-latitudes**

This objective is met through research into Arctic processes and their effects on mid-latitude weather conditions in order to improve the quality of mid-latitude weather predictions.

4) Support effective response, planning, mitigation, and resource allocation based on changing climatic conditions

This objective involves mitigation and adaptation efforts designed to respond to or mitigate current and projected climate scenarios through efforts to monitor changes, assess available resources, disseminate data and information, and guide decision making.

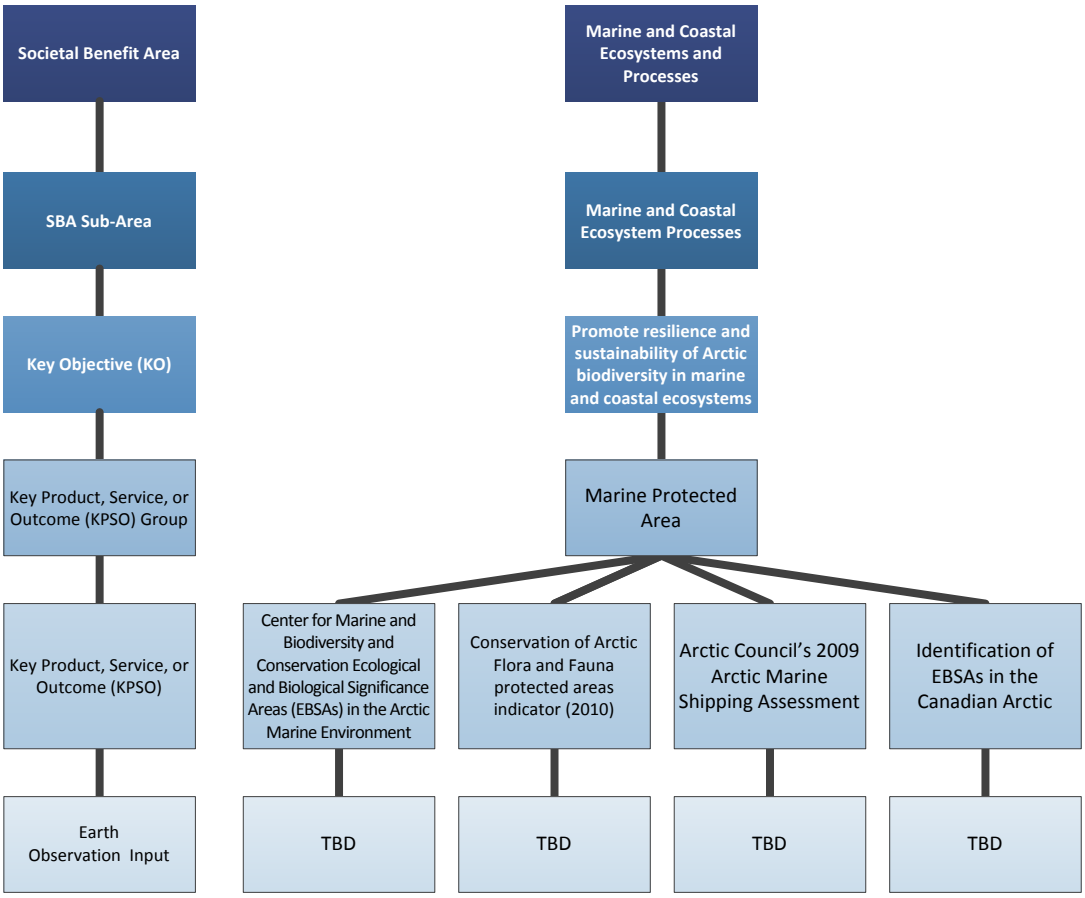
E. Potential Applications of the Framework

The consensus Arctic Observations Assessment Framework developed by workshop participants was the first phase of a multi-phase assessment process. The framework can serve as the foundation for future national or international efforts to assess current contributions of individual Earth observation systems, sensors, networks, surveys, and other data sources (including observations by people) to achieving societal benefit in the Arctic. Results from a complete assessment would help identify gaps and critical continuity issues associated with observations that support the KOs. An Arctic observations assessment that uses the value tree framework model will result in a database of Earth observations currently relied on to meet Arctic objectives. The database, in turn, could be used as input to inform investment in an integrated Arctic-observing network.

Phase 2 of the assessment process would be to identify representative groups of key products, services, or outcomes (KPSOs) that are used to achieve each objective described in the framework. For example, the KO *Promote resilience and sustainability of Arctic biodiversity in marine and coastal ecosystems* (from the Marine and Coastal Ecosystem Biodiversity sub-area of the Marine and Coastal Ecosystem Processes SBA) will rely on a range of KPSOs to achieve the objective. (Refer to Figure 1 in Section A). Phase 3 would use an expert elicitation process to identify and weight all of the sources of Arctic observation data necessary to develop individual KPSOs in each group.

1. Phase 2: Identify Key Product, Service, or Outcome (KPSO) Groups

In Phase 2, subject matter experts (SMEs) will identify products or groups of products that represent the full range of KPSOs for each KO. A notional example is presented in Figure 2.



Sources: Center for Marine and Biodiversity and Conservation Ecological and Biological Significance Areas (EBSAs) in the Arctic Marine Environment;[3] Conservation of Arctic Flora and Fauna protected areas indicator (2010);[4] Arctic Council's 2009 Arctic Marine Shipping Assessment;[5] and Identification of EBSAs in the Canadian Arctic.[6]

Figure 2. Full Value Tree Framework (left) and Notional Example (right) for the Marine and Coastal Ecosystem SBA

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3 Ecologic Institute and the Center for Marine Biodiversity and Conservation (CMBC) at the Scripps Institution of Oceanography, "EBSA (Ecological and Biological Significance Areas) in the Arctic Marine Environment," http://geo.abds.is/geonetwork/srv/eng/catalog.search#/metadata/06bcf22f-fcf5-4f56-b104-23888968f7e0.

4 Conservation of Arctic Flora and Fauna (CAFF), "Protected Areas," http://geo.abds.is/geonetwork/srv/eng/catalog.search#/metadata/346ddfc2-0a39-46df-879e-12b50a598a17.

5 Arctic Council, "Arctic Marine Shipping Assessment 2009 Report," (Tromsø, Norway: Arctic Council, 2009).

6 Ecologic Institute and the Center for Marine Biodiversity and Conservation (CMBC) at the Scripps Institution of Oceanography, "Identification of Ecologically and Biologically Significant Areas (EBSA) in the Canadian Arctic," http://geo.abds.is/geonetwork/srv/eng/catalog.search#/metadata/2aaa3fa0-f5e4-4125-b6c8-12609ad154ee.

In this notional example, five KPSO groups were identified. These groups represent categories of KPSOs that contribute to achieving the KO. In other words, they answer the question "What information products are representative of those that are essential to meet this KO?" The KPSO Group, *Marine Protected Areas*, consists of KPSOs that identify and assess the state of marine protected areas in the Arctic and that rely on a range of Earth observations to produce each product. This list can be representative rather than comprehensive at the product level, but should be comprehensive with respect to the range of Earth observation inputs that are used to produce information products in this group.

Phase 2 provides the initial mapping of information products to key objectives. This mapping can be used to identify information products that are heavily relied on and information gaps associated with the Arctic Observations Assessment Framework. The effort associated with Phase 2 data collection is limited to an SME survey or facilitated discussion to identify KPSO Groups and individual KPSOs. This could be carried out for all or part of the value tree (e.g., a single SBA, a combination of SBAs, or all 12 SBAs), and the SMEs could represent international, national, or organizational perspectives on information products. Regardless of the perspective, if the data are collected in the context of the consensus Arctic Observations Assessment Framework, the data can be shared and potentially compiled into a more comprehensive international database of KPSOs.

2. Phase 3: KPSO SME Elicitation

Phase 3 is the most resource-intensive portion of the value tree analysis process. For each KPSO identified, SMEs are asked to: (1) identify the Earth observation inputs they rely on to produce the KPSO; (2) quantify how well the KPSO is meeting its requirements or research goal; (3) quantify the criticality of individual data inputs; and (4) quantify their overall satisfaction with each data input (Figure 3). The criticality of each Earth observation input is determined using a technique called swing weighting.[7] Swing weighting information is used along with the data collected in step four to calculate the impact (or the relative reliance) of each input on each KPSO. The impact scores reflect the extent to which an input contributes to the KPSO's performance (or ability to meet requirements or goals). The SMEs are asked to review and verify that the impact scores represent their responses. This information can then be used to calculate relative reliance on individual Earth observation inputs at each level of the value tree.

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[7] This technique is described further in C. W. Kirkwood, *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets* (Belmont, CA: Duxbury Press, 1997); G. S. Parnell, P. J. Driscoll, and D. L. Henderson, eds., *Decision Making in Systems Engineering and Management*, Second ed., vol. 81 (Hoboken, NJ: John Wiley & Sons, 2011).

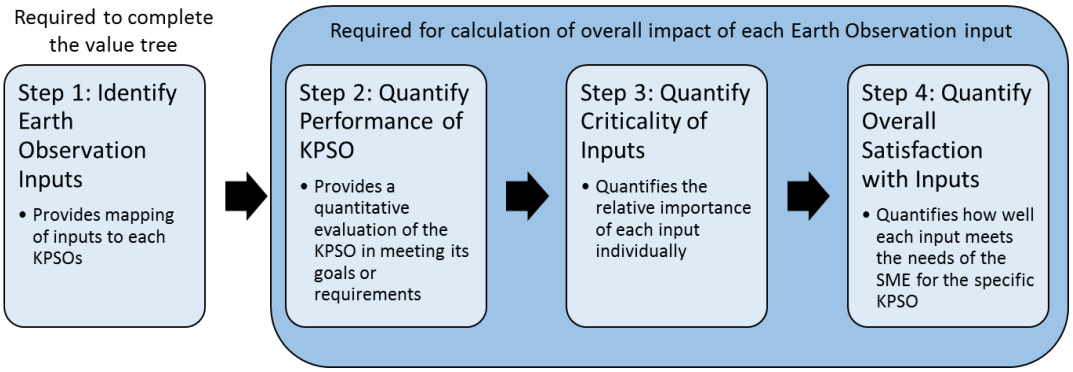

Figure 3. Four Steps Associated with Phase 3 of the Value Tree Assessment Process

There are several ways in which the data collected during Phase 3 can be used. Step 1 of the SME elicitation process completes the bottom of the value tree and provides the mapping from SBA down to the Earth observation inputs. Additional metrics that could be applied to the data collected during Step 1 would be capable of reporting on the number of times and locations in the framework an individual input is mentioned (e.g., MODIS satellite data is identified *X* times in the Marine and Coastal Ecosystems SBA and *Y* times across all SBAs). This type of information does not assess the performance or criticality of any individual input. However, this level of detail provides an unranked list of inputs required for a pan-Arctic observation network capable of delivering benefit through the KOs in the Arctic Observations Assessment Framework.

The data collected during Steps 2–4 are necessary to calculate the overall impact of each Earth observation input identified in the value tree. Impact scores for every input can be calculated and are most useful at the overall value tree, individual SBA, or sub-area levels. The calculation of overall impact is a computationally intensive process for the entire value tree and requires the use of proprietary analysis and decision support software. Steps 2–4 may be less important if the desired outcome is a framework that describes the Earth observation inputs relied on to deliver societal benefit in the Arctic rather than ranking those inputs to inform budgetary decisions.

F. Next Steps

As previously stated, the framework presented in this report can serve as the foundation for future national or international efforts to assess the current contribution of individual Earth observation systems. Embarking on Phases 2 and 3 of the assessment

would be an opportunity to implement portions of recommendations 2 and 6 of the 2016 Arctic Observing Summit:[8]

2. Propose to the highest levels of government, the business case for a comprehensive pan-Arctic observing system. This proposal should assess the costs and demonstrate the benefits for society at various levels, including an Implementation Plan that builds upon the present system and past planning, and that identifies needed resources including infrastructure, instrumentation, human capacity, the pathways to financing, and a strategy for sustained financing.

6. Prioritize, on an ongoing basis, observations that should be started and maintained over the long-term by operational and other relevant agencies. Collaborative, sustained observations need to be implemented through a combined research-operational system that extends across all scales relevant to those it serves, making use of both long-term national/institutional funding and of project based competitive funding.

The top of the value tree developed during the workshop and the resulting Arctic Observations Assessment Framework described in this report marks the completion of Phase 1 of a comprehensive assessment of Artic observations. The framework provides a common paradigm for international partners to begin to identify the type of information products and Earth observation inputs required to meet a common set of crosscutting objectives in the Arctic. The objectives initially derived from a wide range of international Arctic strategy documents were reviewed and further developed by international SMEs from key Arctic stakeholder groups. The framework is a useful benchmark for international discussion and is the starting point for Phase 2.

Phase 2 activities can be initiated and implemented by a single organization, or they can be coordinated by multiple organizations using a common data collection process and repository. The output from Phase 2 would be immediately useful to identify information products that are heavily relied on and information gaps in the Arctic Observations Assessment Framework. Phase 3 would be a multi-step process of which the first step could be the most useful and least resource-intensive. Step 1 will complete the bottom of the value tree and create a map of where observations contribute to the delivery of societal benefit across the Arctic Observations Assessment Framework. Phase 3 activities can be carried out using a similar model to that of Phase 2. Organizations such as SAON or the International Arctic Science Committee could be ideal candidates for carrying out Phases 2 and 3.

[8] Arctic Observing Summit 2016—Conference Statement, March 23, 2016, http://www.arcticobservingsummit.org/aos-2016-conference-statement-0.

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Appendix A.
International Strategies

Last Revised October 27, 2016

The draft key objectives were derived in part from the objectives and priorities listed in the following international Arctic strategy documents:

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France

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Italy

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Spain

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Sweden

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United States

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Appendix B.
Workshop Participants

Name	Organization
Alessa, Lil	University of Idaho
Ambrose, William	Office of Polar Programs, National Science Foundation (NSF)
Arthurs, David	Polar View
Ashik, Igor	Arctic and Antarctic Research Institute (AARI), Russian Federation
Bamzai, Anjuli	Office of Polar Programs, NSF
Baskin, Monique	Arctic Research Program, NOAA
Biebow, Nicole	EU-PolarNet, Alfred Wegener Institute (AWI), Germany
Brook, Mike	Alaska Native Tribal Health Consortium (ANTHC)
Carson, Marcus	Stockholm Environment Institute (SEI), Sweden
Clough, Lisa	Office of Polar Programs, National Science Foundation (NSF)
Cochran, Shawn	National Aeronautics and Space Administration (NASA)
Eicken, Hajo	University of Alaska Fairbanks
Flato, Gregory	Environment and Climate Change Canada
Gambardella, Attilio	European Commission
Gamble, Jim	Aleut International Association (AIA)
Hinzman, Larry	University of Alaska Fairbanks
Hoel, Alf Håkon	Institute of Marine Research, Royal Norwegian Embassy
Holm, Lene K	Greenland Climate Research Centre
Jeffries, Martin	White House Office of Science and Technology Policy (OSTP)
Kelly, Brendan	Study of Environmental Arctic Change (SEARCH)
Kennedy, David	National Ocean Service, NOAA
Lanckman, Jean-Pierre	Arctic Portal
Larsen, Jan Rene	Sustaining Arctic Observing Networks (SAON)
Lemay, Mickael	ArcticNet, Canada
Lev, Steven	Science and Technology Policy Institute (STPI)
Löbl, Martina	Alfred Wegener Institute (AWI), Germany
Mate, David	Polar Knowledge Canada (POLAR)
McCammon, Molly	Alaska Ocean Observing System (AOOS)

Name	Organization
Michels, Denise	Kawerak, Inc., Alaska
Miller, Charles “Chip”	Jet Propulsion Laboratory (JPL)
Moon, Sean	Office of Policy, U.S. Department of Homeland Security (DHS)
Nitu, Rodica	Global Cryosphere Watch, World Meteorological Organization (WMO)
Ohata, Tetsuo	National Institute of Polar Research (NIPR), Japan
Olseng, Christine Daae	Research Council of Norway
Pica, Joseph	National Weather Service (NWS), NOAA
Rack, Frank	Office of Polar Programs, National Science Foundation (NSF)
Reiersen, Lars-Otto	Arctic Monitoring and Assessment Programme (AMAP), Arctic Council
Ruck, Kate	Office of Polar Programs, National Science Foundation (NSF)
Schlosser, Peter	Columbia University
Smolyanitsky, Vasily	Arctic and Antarctic Research Institute (AARI), Russian Federation
Sonntag, William	U.S. Environmental Protection Agency, Group on Earth Observations (GEO)
Starkweather, Sandy	U.S. Arctic Observing Network (AON)
Stephenson, Simon	Office of Polar Programs, National Science Foundation (NSF)
Stow, Jason	Northern Contaminants Program (NCP), Indigenous and Northern Affairs Canada
Strahlendorff, Mikko	Finnish Meteorological Institute (FMI), Finland
Ukita, Jinro	Niigata University, Japan
Vitale, Vito	National Research Council of Italy (CNR)
Wolken, Gabriel	Alaska Division of Geological & Geophysical Surveys

Appendix C.
Workshop Agenda

International Arctic Observations Assessment Framework Workshop Agenda
Day 1—Thursday, January 12, 2017
National Science Foundation, Room 375

8:30 am	Welcome *Will Ambrose* *Arctic Observing Network Program Director* *National Science Foundation*
8:45 am	Opening Remarks *Christine Daae Olseng* *Chair, Sustaining Arctic Observation Networks (SAON)*
9:00 am	Workshop Charge *Steven Lev* *Science and Technology Policy Institute (STPI)*
9:30 am	Keynote: Use and Value of Earth Observation Assessments *Joseph A. Pica* *Director, Office of Observations* *National Weather Service* *National Oceanic and Atmospheric Administration (NOAA)*
	Break from 10:00 – 10:15 am
10:15 am	Keynote: International Perspective on Societal Benefit *William Sonntag* *Group on Earth Observations (GEO) Representative*
10:45 am	Panel: Key International- and Community-Level Objectives in the Arctic
11:30 am	Lunch Break
12:30 pm	Introduction to the Process
1:00 pm	Discussion Groups (breaks will be group-determined) • Focus Area 1 – Economy (*concurrent, room 375*): Disaster Preparedness • Focus Area 2 – Environment (*concurrent, room 375*): Environmental Quality • Focus Area 3 – Human (*concurrent, room 730*): Food Security

- Focus Area 4 – Climate (*concurrent, room 770*): Fundamental Understanding of Arctic Environmental Systems

Break from 3:30 – 3:45 pm

3:45 pm Summaries and Group Discussion

4:45 pm Workshop Day 1 Wrap-up

5:00 pm Close of Workshop Day 1

International Arctic Observations Assessment Framework Workshop Agenda
Day 2—Friday, January 13, 2017
National Science Foundation, Room 375

8:30 am Welcome back

8:45 am Discussion Groups (breaks will be group-determined)

- Focus Area 1 – Economy (*concurrent, room 375*): Infrastructure and Operations
- Focus Area 2 – Environment (*concurrent, room 320*): Marine and Coastal Ecosystems and Processes
- Focus Area 3 – Human (*concurrent, room 260*): Sociocultural Services
- Focus Area 4 – Climate (*concurrent, room 770*): Weather and Climate

Break from 11:00-11:15 am

11:15 am Summaries and Group Discussion

12:00 pm Lunch Break

1:00 pm Discussion Groups (breaks will be group-determined)

- Focus Area 1 – Economy (*concurrent, room 375*): Energy and Mineral Resources
- Focus Area 2 – Environment (*concurrent, room 320*): Terrestrial and Freshwater Ecosystems and Processes
- Focus Area 3 – Human (*concurrent, room 260*): Human Health and Well-being
- Focus Areas 1 & 3 (joint) – Economy & Human (*concurrent, room 770*): Resilient Communities

Break from 3:15-3:30 pm

3:30 pm Summaries and Group Discussion

4:15 pm Workshop Summary and Closing Remarks

5:00 pm Close of Workshop

Abbreviations

AOOS	Alaska Ocean Observing System
AWI	Alfred Wegener Institute
GEO	Group on Earth Observations
IARPC	Interagency Arctic Research Policy Committee
IDA	Institute for Defense Analyses
IRDR	Integrated Research on Disease Risk
KO	key objective
KPSO	key product, services, and outcome
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
SAON	Sustaining Arctic Observing Networks
SBA	societal benefit area
SEI	Stockholm Environment Institute
SME	subject matter expert
STPI	Science and Technology Policy Institute
VTA	Value Tree Analysis
WOC	Workshop Organizing Committee
WMO	World Meteorological Organization