CAPARDUS - Capacity-building in Arctic standardization development

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Executive Summary

Standards can act as common language and practices among actors when aiming to share and use observing systems, data, ensure safety, and many other activities in the Arctic. Equipment manufacturers, observing programs, data producers, citizens, and governments all benefit from the creation of open standards. It is vital that the standards development process ensures that all interested parties work together in the context of openness and transparency. In particular, as data becomes the world's most valuable resource, it becomes ever more important that the digital ecosystem for data be designed and managed in a way that ensures sufficient user access, transparency, accountability, and quality assurance.

This report presents a review of a subset of Arctic domains that could benefit from some level of standardization. Standards are typically technical documents, while standardization is a human process that takes place in an ecosystem of interrelated and interdependent human actors, institutions, norms, and practices (including standards), technologies, information objects, and relationships. To enhance standards adoption, it is equally important to understand the ecosystem and its subsystems (general kinds of things, linkages and flows in the system) and the details of its interacting parts (e.g. the specific organizations, technologies, people and their needs). To manage this complex task, the report introduces a relatively simple framework, supported by emerging advanced information structures (linked open data represented using the Resource Description Framework, ontologies) that help to document and understand the ecosystem to support standards development, maintenance, and implementation.

Section 2 establishes that standardization is a challenging and complex process. The term standard can be vague: some may see a standard as a formal set of documents and compliance process, while others see a set of rules or agreements established by a "community" that are based on norms and ethical behaviors. In this broad gradation, there is overlap between more formal top-down standards and bottom-up community developed "conventions" or "best practices". To add to the complexity in the Arctic context, standards do not exist in a single research or social domain. Research includes many disciplines, the peoples of the Arctic and focusing on many economic, social, and research opportunities. Governments have a mandate to cover all aspects of the Arctic at the same time as the world experiences dramatic environmental, social and geopolitical change.

Section 3 documents the methods used to start the process of developing an arctic standards framework. The initial scope (modified due to COVID-19) included extensive in-person community engagement. The primary method used was a systematic literature review focused on four key domains relevant to standardization: cross-cutting themes, observing, safety and data. Literature reviewed was stored in an online bibliographic database and will be made available for community use through the CAPARDUS website.

Section 4 presents the results of the work package analysis. Cross-cutting themes such as governance and Indigenous knowledge comprise many entities relevant to enhancing standardization. In the case of governance, the lack of a centralized arctic governance regime makes standardization challenging. Similarly, increasing recognition of Indigenous Knowledge and related topics such as Indigenous data sovereignty and ethical use of representation of Indigenous Knowledge, highlights the critical importance of including Indigenous peoples and their representative organizations in the standardization dialogue. Analysis of the observing system revealed similar patterns. Observing networks and other programs and projects that are relevant to and could act as hubs and provide a foundation for standardization already exist and need to be harnessed. The situation is similar in the domain of arctic data. Relevant organizations within and outside of the arctic community already exist, however, areas such as governance need to be enhanced to move to the next stage of meaningful standardization. Standardization in the areas of operations, hazard response, shipping, and tourism would greatly enhance safety. There are many challenges in achieving safety-related standardization including adequate education and training, funding and recognition of the significant risks posed by failure to establish standards (e.g. sub-optimal to totally inadequate hazard response).

Section 4 identifies many concepts important to standardization, and many individual projects, programs and initiatives that are relevant to standardization. These concepts (e.g. governance) and individuals (e.g. the Arctic Data Committee) have existing relationships, or require that relationships be established. These concepts, individuals and relationships are documented and discussed, including references to related resources. A key result of this section is the revelation of the breadth and complexity of the human and technical systems implicated in standards and standardization.

Section 5 proposes a method for documenting and understanding an arctic standards framework that represents the various relevant systems of organizations, individuals, technologies etc. Due to the breadth, depth and complexity of the systems involved, a simple report documentation method is not adequate nor able to capture the dynamic nature of standardization through updates. A graph database model that uses the established and standard Resource Description Framework is presented. This prototype-database captures the key concepts (classes), individuals and relationships in the systems as documented in Section 4. This knowledge graph (database) can be a dynamic framework to enhance standardization.

Section 6 presents several key results that are critically important in establishing a framework for arctics standardization, among others:

- Implementing standards requires a deep understanding of the domain of interest (e.g. observing, safety, a research discipline) to select the appropriate type of standard and standardization process required. What works for one community of practice may not work for another.
- The Arctic is comprises many domains including communities with Indigenous and non-Indigenous residents, multiple governance models, operational environments, research with many individual disciplines and sub-disciplines, civil society actors, and many social, economic, and environmental dimensions. This complexity prevents development of a simple standards framework for the Arctic.
- A standards framework requires a practical model that can document and analyse this complex system to identify the nodes or entities (standards, people, organizations) that can play a role in enhancing standardization. This must be a “living” model that engages the community in its construction and is regularly updated to reflect the situation at any given time.
- There are many existing frameworks, programs, projects, and activities that can be leveraged to enhance standardization. In the domains surveyed, there would be little need to establish new organizations or standards bodies to move forward.
- A graph database using the RDF Model is a practical method for documenting and analysing the arctic standards ecosystem. The prototype-database created in CAPARDUS will be made public through the project website, with supporting tools in GitHub. A working group will be proposed under the Arctic Data Committee to continue the development of the CAPARDUS framework in line with recommendations of the Third Arctic Science Ministerial.

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Abbreviations

ADC	Arctic Data Committee
AECO	Association of Arctic Expedition Cruise Operators
AMAP	Arctic Monitoring and Assessment Programme
API	Application Programming Interface
APS	Arctic Practices System
ARCGOOS	Arctic Region Component of the Global Ocean Observing System
ARCMAP	Marine data in the Arctic: From mapping to knowledge
ASM	Arctic Science Ministerial
CAFF	Conservation of Arctic Flora and Fauna (Arctic Council working group)
CARE	Collective benefit, Authority to control, Responsibility, Ethics
CBM	Community-Based Monitoring
CSA	Coordination and Support Action
DAP	Data Access Protocol
DCAT	Data Catalog Vocabulary
DIF	Directory Interchange Format
EAV	Essential Arctic Variables
EC	European Commission
ECV	Essential Climate Variables
EMB	European Marine Board
EOV	Essential Ocean Variables
EOOS	European Ocean Observing System
EPOS	European Plate Observing System
EPPR	Emergency Prevention, Preparedness and Response (Arctic Council working group)
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAIR	Findability, Accessibility, Interoperability, and Reusability
FOO	Framework for Ocean Observing
GAIA-CLIM	Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring
GCW	Global Cryosphere Watch
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEO-CRI	GEO Cold Regions Initiative
IARPC	Interagency Arctic Research Policy Committee
ICOS	Integrated Carbon Observation System
ICT	Information and communication technologies
IMO	International Maritime Organization
INTAROS	Integrated Arctic Observation System
ISO	International Organization for Standardization
ITK	Inuit Tapiriit Kanatami
LOD	Linked Open Data
NetCDF	network Common Data Form
NISR	National Inuit Strategy on Research
NSF	National Science Foundation
OAI-PMH	Open Archives Initiative Protocol for Metadata Harvesting
OBPS	Ocean Best Practice System
OGC	Open Geospatial Consortium
PAME	Protection of the Arctic Marine Environment (Arctic Council working group)
POLDER	Polar Data Discovery Enhancement Research
RDA	Research Data Alliance
RDF	Resource Description Framework
ROADS	SAON Roadmap
SAON	Sustaining Arctic Observing Networks
SAV	Shared Arctic Variables
SBA	Societal Benefit Area
SDG	Sustainable Development Goal
STS	Science and technology studies
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
U.S. AON	U.S. Arctic Observing Network
W3C	World Wide Web Consortium
WCS	Web Coverage Service
WMO	World Meteorological Organization

1. Introduction

1.1. Arctic Standards

Standards offer a common language among actors when dealing with observing, technology, data, safety, and the transition of technology into commercial products and services. Equipment manufacturers, data producers, citizens, and governments all benefit from the creation of open standards. In the transition of a technology stemming from scientific research to commercial application, standards enable more rapid implementation at a lower cost while helping to ensure safety, reliability, and acceptance. In the merging of scientific research and experience, standards codify the precise, optimum requirements for the effective deployment of some aspect of technology. It is vital that the standards development process ensures that actors work together in the context of openness and transparency.

1.2. The CAPARDUS approach

CAPARDUS is a Coordination and Support Action (CSA) project with focus on capacity-building to develop guidelines, standards and best practices related to exploitation of new technologies and utilization of data to support sustainable development in the Arctic. The capacity-building involves scientists, students, technology providers, economic actors, local communities, regulators, and their organisations, who will participate in a series of workshops and research schools from 2020 to 2023. These events will be used as part of case studies in local communities in different regions, as input to the development of a reference framework for Arctic standards (described in this report), and to define requirements for an Arctic Practice System (APS).

This report presents a review of a subset of Arctic domains that could benefit from some level of standardization, ranging from sharing practices to adopting international de jure standards to adhering to international treaties and conventions. The review materials inform a reference framework proposed as an approach to enhancing standards, standards development processes, and adoption of standards. Central to this approach is conceptualizing the Arctic community and standards-related entities as an ecosystem "of interrelated and interdependent human actors, institutions, norms, and practices (including standards), technologies, information objects, relationships, and the broader socio-technical environment in which it exists" (Pulsifer et al., 2020, p. 270). To enhance standards adoption where appropriate, it is equally important to understand the ecosystem and its subsystems (general kinds of things, linkages and flows in the system) and the details of its interacting parts (e.g., the specific organizations, technologies, people and their needs). To manage this complex task, we propose a relatively simple framework, supported by advanced information technology that help to document and understand the system to support standards development, maintenance, and implementation.

1.3. Framework development in WP1

CAPARDUS Work Package 1, Establishing a Comprehensive Framework for Arctic Standards, has the following objectives:

1. Develop a framework that through a systematic review process, identifies existing Arctic standards of importance for Arctic operators and communities.
2. Create a model that identifies and describes key relationships and creates links between and among different standards and links with other relevant entities (e.g. legislation, academic bodies of knowledge).
3. Engage with arctic communities of practice and relevant organisations to co-develop the Comprehensive Framework.

The framework presented in this report was created from analysis of the documents and the experience of the authors. There is a particular focus on data and observation standards, but the framework includes other standards. The framework includes a prototype relationship model and associated documentation (report) that describes and analyses key relationships and links between and among different parts of the ecosystem, related standards, and Arctic applications. To organize and disseminate the content of a framework we propose a Linked Open Data (LOD) database and related ontology (concepts and categories and their properties and the relations between them). Using this approach allows for the results of WP1 to be analysed, shared, and, importantly, maintained over time. Moreover, some parts of the framework (themes, keywords, documents) can be directly incorporated into the APS.

2. Towards a Theoretical and Practical Framework for Implementing Standards and Best Practices

2.1. Definition of a Framework

In the context of this report a framework is a real or conceptual scheme or structure intended to serve as a support or guide for the building of something that expands the structure into something useful. We aim to establish a framework for Arctic standards that focuses on identifying appropriate standards (broadly defined – see below) for a particular context and creating a roadmap for effective adoption of these standards. This process is guided by primary and secondary themes as detailed in Section 3.

To expand, other definitions of "Framework" are relevant here, including:

- a basic **structure** underlying a system, concept, or text
- **a system of rules, ideas, or beliefs that is used to plan or decide something**
- the ideas, information, and principles that form the **structure** of an organization or plan
- a supporting structure around which **something can be built**

When defining Framework, we often use the term structure. Structure can be defined as the arrangement of and relations between the parts or elements of something complex. As we will elaborate later, this definition of structure aligns with the definition of a knowledge graph and related ontology that we create as part of the project (Section 5). This forms the basis of our analysis and its parts. Our job is to identify the structure (parts, relationships, arrangement) of the Arctic standards domain and then provide the European Commission with support, and advice in planning and decision. Together, this forms our framework. To build our framework, we started our analysis by posing basic questions when analysing domain documents (see Methods section for details). These questions were:

- What are the key concepts relevant to Arctic standards for different, previously established themes and sub-themes (e.g. Arctic observing standards, Arctic safety standards)? A key concept might be an existing standards document and its sub-concepts (e.g. a data standard and sub-concepts of data structure, byte encoding, data vocabularies); or, it could be an indirect concept such as the lack of funding required to train qualified personnel to implement standards as documented in a research paper.
- What are the key relationships between and among Arctic standards concepts? This might be a set of causal relationships that highlight that standardization requires the development of a community that agrees on the standard, followed by establishment of a body to oversee standard compliance, resulting in enhanced efficiency and reliability. The concepts on their own are important, however, understanding the causal chain is critical to developing a Framework.
- What are examples of "instances' of Arctic standards entities in the domain? This could be a community that has developed a high level of standardization; or a specific, important standard in a sub-domain such as tourism or data; or a standard organization relevant to standards development. Identifying specific instances is an important part of the Framework as identifying these entities will allow for the leveraging of existing resources (standards, technology, humans, institutions etc.)

Building on these questions, we iterated through the review and analysis process to present an essential framework to guide Arctic standardization. The original workplan for CAPARDUS included significant levels of community engagement that were not fully realized due to the COVID-19 pandemic. Some entities and relationships could not be identified strictly from literature review. However, the resulting framework is extensible, and can be brought forward in new initiatives and projects.

2.2. Defining Standards

Recalling the CAPARDUS proposal, the term "standard" can be vague, depending on the context. To some, a standard is a set of technical directives developed by international standards organizations and confirmed and monitored for compliance by governance bodies. Others may consider standards to be a set of rules or agreements established by a "community" that are based on norms and ethical behaviors. In this broad gradation, there is overlap between more formal top-down standards and bottom-up community developed "conventions" or "best practices". Figure 2.1 presents our original continuum model that situates different kinds of “standards” ranging from culturally socially negotiated ethics and norms, to formally negotiated laws. A factor in this continuum model is the gradations of time scales for implementation, with the more formal standards taking longer to formulate and be accepted.

Our focus in CAPARDUS is on the range from “convention” (as opposed to Formal Convention) to International Standard, while understanding and drawing from Ethics, Norms and Informal agreements and considering the process of moving into more formal constructs such as Policy and various forms of law. Figure 2.1 was used in planning document analysis and other activities to ensure a joint understanding of the current level or lack of standardization, the appropriateness and ethics of aiming to establish a particular level of standardization, and the process and cost-benefits for moving from less formal to more formal standardization as appropriate. This will be very important in relation to local communities and Indigenous Peoples, whose “standards” may be quite different than that of a scientific discipline or engineering community. This may be the result of differences in many things including language, epistemology, culture, customary law, level of community ownership and many others.

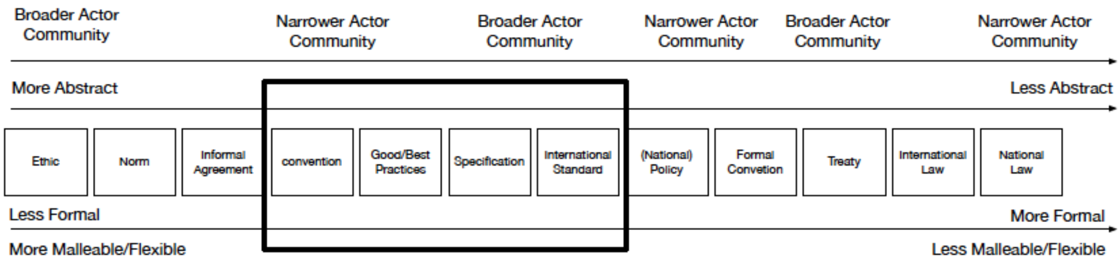


Figure 2.1. This standardization continuum presented in the CAPARDUS proposal is being refined through discussion and expert analysis and synthesis process.

The initial standardization continuum model has been further developed by the CAPARDUS team. Table 2.1 presents these terms as a set of document types with definitions as of November 2020. These document types are a key facet being used for identifying and selecting standards for analysis. Pearlman et al. (2022) expand the types of standards to include attributes such as the driver of origin of the standard, who creates it, and potential impacts (Figure 2.2). This provides a more detailed conceptualization of standards and their development and implementation.

These definitions of standards are important to the aim of establishing a framework. In simplest terms, we could focus a framework strictly on de jure standards such as those developed by the International Organization for Standardization (ISO). This would provide options for many types of standards ranging from safety to data, however, we recognize that all domains in the Arctic are making use of de jure standards, particularly researchers and communities who historically have not had drivers for adoption of such standards. The framework presented here provides the option of including all kinds of standards. In particular, the Arctic Practices System that is being further developed through CAPARDUS has focused on the practical benefits afforded by practices.

To develop a framework ethically and responsibly, we must go beyond simply defining types of standards and recognize the complex nature of standards and standardization. Ensuring transparency and full access for the documents in the standardization goes beyond simply creating an open, documented process. There is an increasingly large body of work in fields such as science and technology studies (STS), critical data studies, decolonial theory, and Indigenous data sovereignty that highlights the importance of understanding the context and process of developing and applying theory, methods, and standards (broadly defined). This body of work confirms the importance of using methods, standards and processes with dialogues that are equitable and inclusive, consider power imbalances, and are mindful of historical and current injustices and misuse of research, observations and data (Bowker & Star 2000, Carroll et al. 2020, Kanatami 2018, Kukutai & Taylor 2016, Lampland & Star 2009, Reid & Sieber 2020). Failure to recognize and engage in these dialogues will limit the ability to establish the full transparency and trust needed to effectively share observations and knowledge through shared standards.

Table 2.1. CAPARDUS document types based on the standards continuum. Research papers, reports, concepts and frameworks relevant to CAPARDUS have no formal definitions.

CAPARDUS Standards Types based on a standardization continuum	
Type	Provisional Definition
Method	a way of doing anything, esp. according to a defined and regular plan; a mode of procedure in any activity, business, etc.)
Ethic	a system or set of moral principles; (in weaker sense) a set of social or personal values
Norm	a standard or pattern of social behaviour that is accepted in or expected of a group
Informal Agreement	an arrangement made between two or more parties and agreed by mutual consent
Convention	a rule or practice based upon general consent, or accepted and upheld by society at large
Guideline	a general rule, principle, or piece of advice
Standard Operating Procedure	a Standard Operating Procedure is a document which describes the regularly recurring operations to ensure that the operations are carried out correctly (quality) and always in the same manner (consistency)
Common Practice	something that is done frequently within a community of practice and is considered normal
Good Practice	a good practice is a successful experience that has been tested and replicated in different contexts and can therefore be recommended as a model.
Best Practice	commercial or professional procedures that are accepted or prescribed as being correct or most effective
Specification / technical standard	an established norm or requirement for a repeatable technical task. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes, and practice
International Standard	an internationally recognized exemplar of correctness, perfection, or some definite degree of any quality
(National) Policy	a principle or course of action adopted or proposed as desirable, advantageous, or expedient; esp. one formally advocated by a government, political party, etc.)
Formal Convention	an agreement between countries that is legally binding to the contracting States
Treaty	a contract between two or more states, relating to peace, truce, alliance, commerce, or other international relation
International Law	(legal instrument) (the body or branch of law concerned with dealings between nations; a law of this kind)
National Law	a binding rule or body of rules prescribed by the government of a sovereign state that holds force throughout the regions and territories within the government's dominion

Type	Origin	Process	Authorship	What is the form?	How is conformance determined, enforced?	Who is affected?	What is the impact on those affected?
Norm/ethic/tradition	need for functional society	informal	members of a society	interpretation	parental, societal pressure	members of a society	Allows for cohesion and interpretation
Practice	practical experience	informal	practitioners	practice	voluntary	self-selected	Provides norms for processes; encourages interoperability and allows for fluid evolution
De Facto Specification	need for compatibility	formal, informal	practitioners	as built	non-binding	practitioners	Widely adopted process, may be a best practice
Standard Profile/Extension	need for more specificity	formal, informal	standards adopters	Software	conformance clauses	specific community	Consistency of implementation, easier to assess conformance
De jure standard	compatibility, interoperability, reliability,	managed development	affected stakeholders	Device, procedure	conformance clauses	narrow/broad stakeholder community	Provides formalized, stable process descriptions for production and interfaces
Code	need for safety, reliability	deliberations	responsible officials	practice	law enforcement	local jurisdiction	Defines requirements for process implementation for safety and conformity
Policy/Law	public interest	lawmaking	lawmakers	practice	law enforcement	jurisdiction	Legal requirements for societal safety and economic growth
Treaty	international relations	negotiations	government officials	practice	economic, military	nations	Establishes relations between different governing bodies for security and commerce.

Figure 2.2. Multidimensional view of different types of standards (Pearlman et. al 2022)

3. Methodology

3.1. Systematic Literature Review and Content Analysis: Collection and Broad Categorization of Corpus

3.1.1. General Methods

In this project we used multi-method and mixed methods approaches to carrying out research in support of establishing a "standards" framework. This included expert review, analysis and synthesis by members of the CAPARDUS team of standards-related documents (the primary method used as the basis for this report). A two-tier approach was taken. The first is based on the systematic literature review method. A systematic review provides a thorough summary of current literature relevant to a research domain and specific questions. In this case, Arctic standards. This type of review uses a rigorous and transparent approach for research synthesis, with the aim of assessing and minimizing bias and making results openly available. The second, complementary approach, was the use of thematic analysis using qualitative analysis software (NVivo). This builds on the traditions of the more quantitative aspects of content analysis (Krippendorff 2018) and the qualitative aspect of thematic analysis, broadly defined. Through both processes we aimed to identify and examine key concepts (themes) and relationships between and among concepts relating to establishing an Arctic standards framework. We aimed to establish patterns of meaning within the documents (data) analyzed and documenting these elements through tagging, coding, analysis, discussion, synthesis, development of a model framework, and provision of recommendations where appropriate.

The project team proposed to use the NVivo qualitative data analysis software to analyze documents. The software was not used extensively for practical reasons. The project team members were geographically distant. Collaborating with NVivo requires a special version of the software that is expensive and involves institutional commitment etc. This was not practical. Where document tagging was required, an alternative tagging approach using the Zotero bibliographic software was used as described in the next section. Following the analytical phase, part of the framework development involved transferring the bibliographic data collected and made available through this study to an open bibliographic database that can be use by others in the project (e.g. CAPARDUS WP 6, the Arctic Practices System) or the community as a whole. Additionally, the knowledge graph and ontology developed in WP1 will be shared with the APS for potential inclusion in their search and retrieval sub-systems.

The general pattern used in reporting the review (Section 4) is as follows: A summary table documenting one or more “representative documents” that are discussed in the review. For example:

References	(Lee et al., 2019) https://doi.org/10.3389/fmars.2019.00451
CAPARDUS Themes	Cross-cutting
CAPARDUS Document Type	Convention, Best Practice, Policy Document
CAPARDUS Subthemes	Governance; Observing frameworks; Data system; Data management; Data delivery chains.

Each table is followed by a Summary discussion that relates to the representative document(s). This is then followed by additional links under two headings:

References to other relevant standards documents for [TOPIC]:

References to other documents that evaluate or provide additional context for [TOPIC]:

3.1.2. Online Zotero Bibliography

Reports can have limited value because many of the resources referenced may be “hidden” within the body of the report and not readily available to the community as a stand alone resource. The resources identified in WP1 are being made available as an open resource using the Zotero bibliographic platform (https://www.zotero.org/). This provides a valuable resource to the community by making the resources available and reusable. To some extent, we aimed to make the bibliographic resources as FAIR as possible (see Section 4 for further discussion of the FAIR principles).

To add value, the Zotero tagging feature was used to categorize resources. The tags were used to assist with the analysis but also have potential future use for addition to the APS and the framework model proposed (Section 5). As previously explained, for practical reasons, the NVivo qualitative research software was not extensively used for document coding as originally planned. The Zotero tagging function provided a useful alternative for linking concepts to documents. Full tagging of documents has not been completed, however, the project team is exploring continuation of this through an open, participatory project, possibly as a task under the Arctic Data Committee.

The resulting Zotero library from the project can be found through the CAPARDUS website: https://capardus.nersc.no/backgrounddocs

3.1.3. Relationship to Arctic Practices System (WP6)

A foundational component of CAPARDUS is the Arctic Practices System being utilized and refined through WP6. Arctic Practices (including standards) will have broader adoption when available online through knowledge representation technology (i.e. ontologies and vocabularies). This technology is used to tag digital resources such as protocols, procedures, manuals and other documents, in order to link related resources and support significantly improved (semantic) search. Use of these methods in the Arctic Practices System will advance standardization by making information searchable and accessible for a wide range of users. The scope of WP6 will include the co-design of a repository for documents and other material describing common Arctic practices, based on results from WP1-WP5 and will be aligned with the FAIR and CARE principles. These inputs will form the concept for a fit for purpose Arctic Practices System. The outcome of the co-design process will be documented in a roadmap. Additionally, the APS' basic functions are being piloted through contributions of Arctic practices to the Ocean Best Practice System (OBPS), which has been initiated in the AtlantOS project (https://www.atlantos-h2020.eu/). As part of the framework development, a model was created that identifies and describes key relationships and creates links between and among different standards and links with other relevant entries (e.g. legislation, academic bodies of knowledge). This model can then be used with identified documents addressing common practices from WP1-WP5.

3.2. Framework Themes and Sub-Themes Analyzed

The framework themes and sub-themes analyzed are documented below. There were others that fall within the domain of arctic standards (e.g. research technology standards, legal standards), however they were deemed out of scope. The framework produced is not comprehensive, however it is extensible and additional themes could be added in the future as desired and resources allow.

- Cross-cutting themes
- Observing System-> Essential Variables
- Observing System-> Scales and Timeliness
- Observing System-> Observing Technology
- Observing System-> Readiness Levels
- Observing System-> Citizen Science
- Observing System-> Community-Based Monitoring
- Arctic Safety->Hazard Response
- Arctic Safety->Operational
- Arctic Safety->Shipping[1]
- Arctic Safety->Tourism
- Sustainable Development Resource Management->Natural Resource Management
- Sustainable Development Resource Management->Research Community Collaboration
- Arctic Data-> Ecosystem
- Arctic Data-> Human Dimensions
- Arctic Data->Technical Dimensions

[1] Covered in the report under Safety->Operational

4. Review and Analysis Results

This section presents the review and a synthesis of the analysis conducted for the selected themes: (1) Cross Cutting (section 4.1), Observing Systems (section 4.2), Data Systems (section 4.3).

4.1. Cross Cutting Themes

Documents under cross cutting themes address a broad range of topics related to observing systems and/or data systems. The main topics addressed are illustrated in Figure 4.1, with sub-themes and documents reviewed listed in Table 4.1.

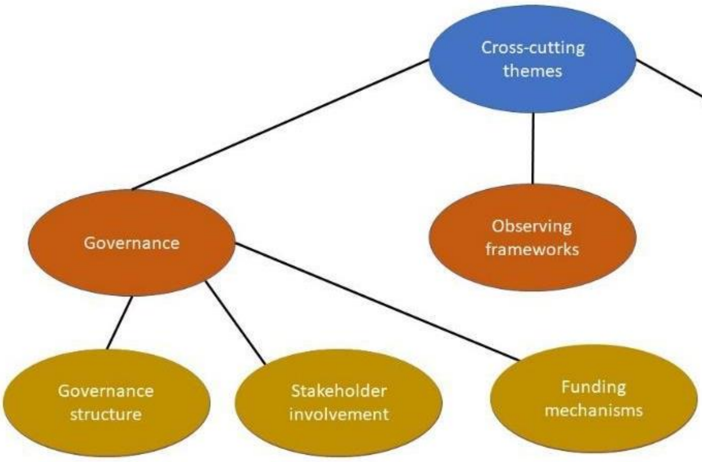


Figure 4.1. Cross-cutting themes and sub-themes.

Table 4.1. Cross-cutting theme, with sub-themes and documents reviewed.

Theme	Sub-theme	Documents
Cross-cutting	Governance (including governance structure, stakeholder and rights holder involvement, funding mechanisms)	Lee et al., 2019 (ARCGOOS) Sandven et al., 2022a (INTAROS) Starkweather et al., 2022 (SAON) IARPC, 2022 (U.S. AON) EuroGOOS and EMB, 2023 (EOOS)
	Observing frameworks	Lindstrom et al., 2012 (FOO)
	Indigenous Research	Kanatami, I. T., 2018 (ITK)

4.1.1. Arctic Observing, Data, Science and Standards Organizations and Programs

Arctic Region Component of the Global Ocean Observing System (ARCGOOS)

PRIMARY THEME: CROSS-CUTTING TOPICS

Reference	(Lee et al., 2019) https://doi.org/10.3389/fmars.2019.00451
CAPARDUS Themes	Cross-cutting
CAPARDUS Document Type	Convention, Best Practice, Policy Document
CAPARDUS Subthemes	Governance; Observing frameworks; Data system; Data management; Data delivery chains.

Summary. Lee et al. (2019) provides a roadmap for establishing an Arctic Region Component of the Global Ocean Observing System (ARCGOOS). Authors state that ARCGOOS establishment must be driven by: (1) a framework that expedites coordinated development of observing system components and their integration in the overall system, (2) a governance structure endorsed by major international and national actors in Arctic observing, monitoring and management, (3) a robust and reliable data delivery chain, (4) secured long-term storage ensuring access to observations and derived data, and (5) active involvement and influence of Arctic Indigenous Peoples and residents. Each of these aspects necessitate broad international collaboration and coordination.

The framework should be based on widely accepted observing frameworks, such as the FOO, EAV and the International Arctic Observations Assessment Framework. This will ensure that ARCGOOS generates high-relevance data for users and actors across the targeted sectors. A trustworthy international body or consortium of bodies must lead the development of ARCGOOS, for making both the framework and governance structure a success. An efficient data delivery chain combining remote sensing and in situ data must serve the needs of the defined Arctic SBAs. Technology development and innovation for increasing in-situ observations under the ice is called for, as is strengthening important aspects of data systems such as standardisation of metadata, data licensing, crediting (e.g., by DOIs), and interoperability between different data systems.

Challenges and gaps. The harsh environment, remoteness and difficult accessibility make logistics particularly challenging in the Arctic. Coordination of activities and logistics between actors in different countries and international organisations require careful planning and cooperation. Logistics as well as technological challenges limit which variables can be measured and where observing platforms can be operated. Deployment and observations from vessels and aircraft are restricted by sea ice and weather conditions. Increased use of autonomous approaches can extend the area and time range covered, but the current technology is a limiting factor for both number and type of parameters. For instance, there is a clear need for technology development for biological, biogeochemical and atmospheric sensors. Societal benefit is key to ARCGOOS development but the translation from general SBAs to observing frameworks such as FOO, EOV and EAV is challenging. Observing frameworks and essential variables are further discussed in sections 4.1.2 and 4.2.1, respectively.

References to other relevant or complementary standards documents for ARCGOOS:

Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO 2012, IOC/INF-1284, doi: 10.5270/OceanObs09-FOO

IDA-STPI and SAON. 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.

References to other documents that evaluate or provide additional context for ARCGOOS:

Dobricic, S., Monforti, F., Pozzoli, L., Wilson, J., Gambardella, A., and Tilche, A. (2018). Impact Assessment Study on Societal Benefits of Arctic Observing Systems IMOBAR. Luxembourg: European Union, doi: 10.2760/713084

Sandven, S., Sagen, H., Buch, E., Pirazzini, R., Gustavson, D., Beszczynska-Möller, A., et al. (2018). The in situ component of Arctic observing systems opportunities and challenges in implementation of platforms and sensors. in Proceedings of the AOS 2018 Statement paper, (Calgary, AB: Arctic Observing Summit).

Starkweather, S., Larsen, J. R., Kruemmel, E., Eicken, H., Arthurs, D., Bradley, A. C., Carlo, N., et al. (2021). Sustaining arctic observing networks'(SAON) roadmap for arctic observing and data systems (ROADS).

European Ocean Observing System (EOOS)

PRIMARY THEME: CROSS-CUTTING TOPICS

Reference	(EuroGOOS and EMB, 2023) https://www.eoos-ocean.eu/publications/eoos-strategy-2023-2027/
CAPARDUS Themes	Cross-cutting
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Governance

Summary. EOOS overall objective is to establish a sustained European Ocean Observing System by coordinating existing national efforts to operate, support and maintain ocean observing infrastructures. The EOOS strategy 2023-2027 defines three high-level objectives. First, to unite the European ocean observing community through the EOOS Framework, collaboratively designing and developing a sustained EOOS meeting specific users' needs. Secondly, to improve collaboration across the whole marine knowledge value chain by engaging European providers of services and products derived from ocean observations. Finally, to provide advice for governance, funding, and policy making to implement recommendations for reaching a sustained EOOS. The EOOS strategy is followed up in a Roadmap for Implementation with specific activities to realise the three major objectives.

References to other documents that evaluate or provide additional context for EOOS:

EOOS concept note on Benefits of Ocean Observation. https://www.eoos-ocean.eu/publications/eoos-concept-note-on-benefits-of-ocean-observation/

EuroGOOS, 2023 EOOS Roadmap for Implementation 2023-2027. https://www.eoos-ocean.eu/wp-content/uploads/2023/02/EOOS-Roadmap-for-implementation-2023-2027.pdf

Integrated Arctic Observation System (INTAROS)

PRIMARY THEME: CROSS-CUTTING TOPICS

Reference	(Sandven et al., 2022a) https://doi.org/10.5281/zenodo.7033845
CAPARDUS Themes	Cross-cutting topics
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Governance; Observing requirements; Observing system design; Data systems; Data management; Data delivery chain.

Summary. The INTAROS Roadmap describes a pathway for improving and sustaining the observing capacity in the Arctic. The roadmap addresses the full data delivery chain from observations are collected to data products are published in long-term repositories. The INTAROS Roadmap focuses on in situ observations and describes key factors determining how well an observing system can function in the Arctic, including technological advances, infrastructure, and data networks. Data systems are recognised as being critical for implementing the FAIR principles. However, there are many barriers and challenges in having a common understanding of how the data flow can be optimised and sustained between data collectors, data managers, and those using data for services and research. In addition, the roadmap highlights the importance of cross disciplinary collaboration, stakeholder and rights holder engagement as part of the data delivery chain.

Challenges and gaps. The INTAROS Roadmap identifies several challenges that must be resolved to establish a sustained Arctic Ocean Observing System.

- Lack of in situ observations. Sustained in situ observations must be acknowledged as the backbone for building knowledge about climate and environmental change in the Arctic. This must be promoted to the same level as satellite observations and modelling systems.
- Fragmented funding. Stronger and more coordinated funding mechanisms for in situ observing systems are needed, pulling together resources between national and international programmes, projects and institutions involved in Arctic observation, including local communities.
- Lack of resources for data sharing. The commitment of The Joint Statement of Ministers (ASM, 2021), stating that the need for strengthening cooperation on implementing Arctic observing and data sharing must be followed up. This implies that resources must be allocated for including in situ measurements in Arctic observing systems and for making these observations available.
- Technology development. The need for more robust and reliable in situ observing systems in the Arctic necessitates development of innovative technologies. Major industry actors can play a role

here by investing in autonomous platforms and sensors capable of operating for longer periods without human intervention.

- Operationalised data delivery chains. Data delivery from discipline-oriented in situ observing systems must be operationalised to facilitate data sharing. INTAROS defined a generic model for a data delivery chain for in situ, remote sensing and model products (Figure 4.2). While such delivery chains are generally better developed for remote sensing and model products, processing, quality control and formatting of in situ products are often less developed.

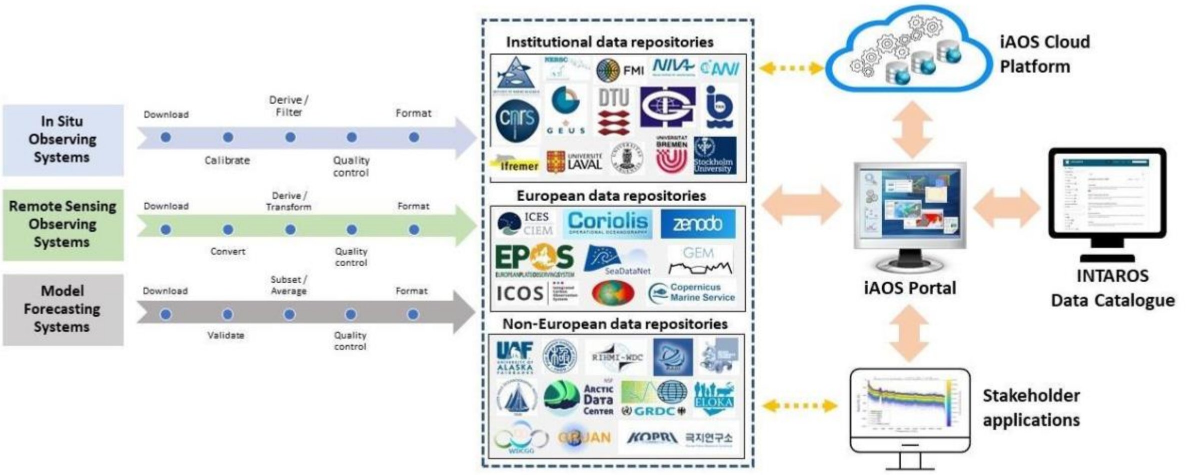


Figure 4.2. Data delivery chains for integrating INTAROS data into the various iAOS subsystems (Hamre et al., 2021).

The INTAROS Roadmap further highlights that data systems depend entirely on obtaining data from many national and international research programs and infrastructures with different data policies, and often legacy non-standard search and access interfaces. The diversity of existing data systems means more effort is needed towards harmonisation and standardisation of formats, as well as interfaces for searching and accessing metadata and data in distributed data catalogues and portals. An assessment of the maturity and capacity of previous and ongoing in situ observing systems in the Arctic will be useful for both scientists planning field activities as well as for funding agencies planning new research programs and/or observing systems.

INTAROS developed a methodology for assessment of the maturity of observing systems. This was implemented as a web application called ARCMAP (http://arcmap.nersc.no), which allows for registering and provides dynamic updates of statistics. The application is maintained by NERSC. Examples of information from ARCMAP are shown in Figure 4.3. The assessment in INTAROS showed the large temporal and spatial gaps in Arctic in situ observing systems, in particular for the ice-covered ocean. This is due to several challenges, such as deficiencies in observing technology and data management, or lack of sustained funding mechanisms (Tjernstrøm et al. 2019). In INTAROS the characteristics of the systems (e.g., documentation, data management, uncertainty handling, sustainability) was assessed using a maturity score from 1 to 6. It was found that the systems with highest maturity were those with sustainable funding for the whole data production and data management chain. Sustained funding is provided from national sources to monitoring programs for resource management, climate monitoring, seismological stations, and weather services. Long-term funding of research infrastructures are also provided through the ESFRI program, e.g., EuroArgo ERIC, EPOS ERIC, ICOS ERIC. However, the European infrastructures have poor coverage in the Arctic, and often there is a lack of adequate platforms and sensors for use in the Arctic.

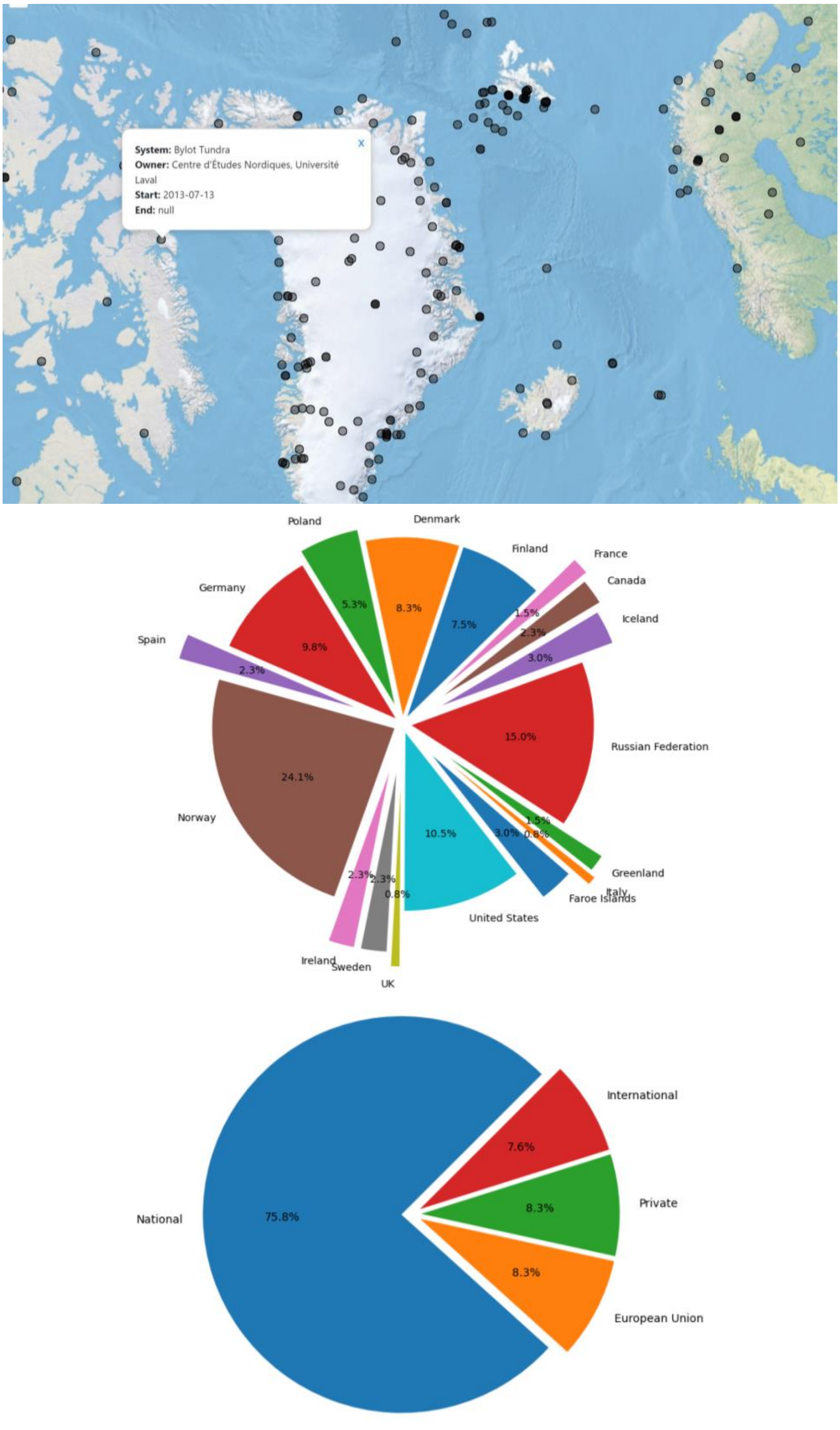


Figure 4.3. (a) Location of some of the individual stations, ocean moorings and other point-based in situ observing systems in ARCMAP (https://arcmap.nersc.no/) (b) Percentage of assessed systems sorted by countries. (c) Distribution of funding sources for the observing systems.

References to other documents that evaluate or provide additional context for INTAROS:

Arctic Science Ministerial 2021: Joint Statement of Ministers. https://ams3.org

Hamre, Torill, Monsen, Frode, Olaussen, Tor I., Geyer, Florian, Lygre, Kjetil, Pirazzini, Roberta and Hanne Sagen, 2021. ARCMAP: A database for Arctic Observing Systems. Final report. NERSC Special Report.

Ludwigsen, Carsten Ankjær, Pirazzini, Roberta, Sagen, Hanne, Hamre, Torill, Sandven, Stein, Stette, Morten, Babiker, Mohamed, Schewe, Ingo, Soltwedel, Thomas, Behrendt, Axel, Andersen, Ole B., Beszczynska-Möller, Agnieszka, Walczowski, Waldemar, Ottersen, Geir, Renner, Angelica, Morvik, Arnfinn, Sejr, Mikael K., King, Andrew, Gustafsson, David, … Aarnes, Øivin. (2018). Deliverable 2.1 Report on present observing capacities and gaps: ocean and sea ice observing system. Zenodo. https://doi.org/10.5281/zenodo.7014496

Lygre K, Hamre T, Monsen F, Olaussen T, Sagen H. Analysis of passive acoustic in situ observing systems in the Arctic Ocean using ARCMAP. Proceedings of Meetings on Acoustics (POMA). 2021;44(070018).

Sandven, Stein, Sagen, Hanne, Pirazzini, Roberta, Beszczynska-Möller, Agnieszka, Danielsen, Finn, Gonçalves, Pedro, Ottersen, Geir, Zona, Donatella, Buch, Erik, Gustavson, David, Voss, Peter, Iversen, Lisbeth, Hamre, Torill, Sejr, Mikael, & Higgins, Ruth. (2022). Deliverable 1.11 Final synthesis report. Zenodo. https://doi.org/10.5281/zenodo.7033824

Tjernstrøm, Michael; Pirazzini, Roberta; Sandven, Stein; Sagen, Hanne; Hamre, Torill; Ludwigsen, Carsten; Beszczynska-Möller, Agnieszka; Gustafsson, David; Heygster, Georg; Sejr, Mikael K; Ahlstrøm, Andreas; Navarro, Francisco; Goeckede, Mathias; Zona, Donatella; Buch, Erik; Johannessen, Truls; Sørensen, Mathilde B.; Soltwedel, Thomas; Danielsen, Finn. (2019). Deliverable 2.10. Synthesis of gap analysis and exploitation of the existing Arctic observing systems. Zenodo. https://doi.org/10.5281/zenodo.7050807

Sustaining Arctic Observing Networks (SAON)

PRIMARY THEME: CROSS-CUTTING TOPICS

References	(Starkweather et al., 2022) https://journalhosting.ucalgary.ca/index.php/arctic/article/view/74330
CAPARDUS Themes	Cross-cutting topics
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Governance; Observing requirements; Data systems; Data management; Critical infrastructures.

Summary. The SAON Roadmap (ROADS) addresses the current lack of a systematic planning mechanism to develop and link observing and data system requirements and implementation strategies in the Arctic region. This coordination gap has hampered partnership development and investments toward improved observing and data systems. ROADS seeks to address this shortcoming through generating a systems-level view of observing requirements and implementation strategies. A critical success factor for ROADS is equitable participation of Arctic Indigenous Peoples in the design and development process, starting at the process design stage to build needed equity. ROADS is developed using a societal benefit assessment approach that can proceed stepwise so the most important variables, named shared Arctic variables (SAVs) (Figure 4.4), can be rapidly improved.

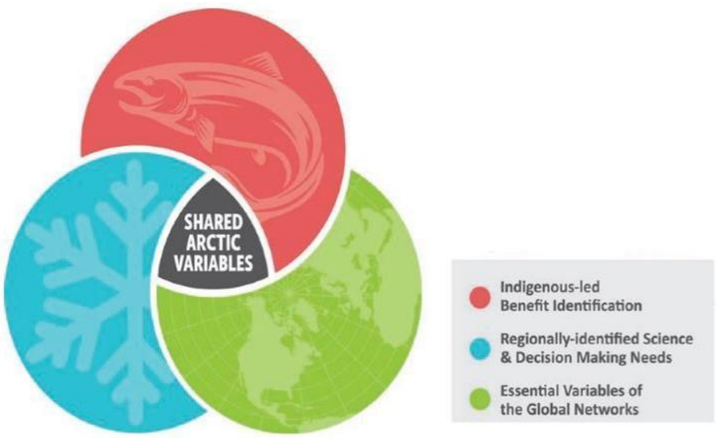


Figure 4.4. The Shared Arctic Variables (SAV) framework combines two or more broad sectors, such as community-identified benefits in Indigenous communities (light red), fundamental understanding of Arctic systems and regional decision-making needs (blue), and informing science and decision-making needs at the global scale (green). (source: Starkweather et al., 2022).

References to other relevant or complementary standards documents:

Carroll, S.R., Garba, I., Figueroa-Rodríguez, O.L., Holbrook, J., Lovett, R., Materechera, S., Parsons, M., Raseroka, K., Rodriguez-Lonebear, D., Rowe, R., Sara, R., Walker, J.D., Anderson, J. and Hudson, M., 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal, 19(1), p.43.DOI: https://doi.org/10.5334/dsj-2020-043

Lee, C.M., Starkweather, S., Eicken, H., Timmermans, M.-L., Wilkinson, J., Sandven, S., Dukhovskoy, D., et al. 2019. A framework for the development, design and implementation of a sustained Arctic Ocean observing system. Frontiers in Marine Science, Volume 6 - 2019 | https://doi.org/10.3389/fmars.2019.00451

References to other documents that evaluate or provide additional context for SAON:

ASM3 (Arctic Science Ministerial 3). 2021. Joint statement of ministers on the occasion of the Third Arctic Science Ministerial, 9 May 2021, Tokyo, Japan. https://asm3.org/library/Files/ASM3_Joint_Statement.pdf

U.S Arctic Observing Network (U.S. AON)

PRIMARY THEME: CROSS-CUTTING TOPICS

References	(IARPC, 2022) https://www.iarpccollaborations.org/uploads/cms/documents/usaon-report-20221215.pdf
CAPARDUS Themes	Cross-cutting topics
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Governance; Observing requirements; Observing system design; Data systems; Data management; Capacity building; Critical infrastructures.

Summary. U.S. AON (IARPC, 2022) describes the need for improving and extending Arctic observing systems and networks to advance the understanding of climate change in the region and how this impacts people, the environment and business in the Arctic as well as in lower latitudes. It points to some of the critical infrastructure needed to realise the U.S. AON, among others, satellites, aircrafts, in situ platforms in the ocean, on ice, on land and atmosphere, vessels, and community-based monitoring systems. The document further calls for an Implementation Plan to drive the development of U.S. AON forward in a coordinated manner involving all relevant actors.

The overall recommendations of the document are to: “1. Support coordinated sustained critical observations and infrastructure. 2. Develop a shared data management system across observing networks that enables cross agency data synthesis and rapid dissemination of data in formats required by decision makers. 3. Prioritise human and technological capacity building. 4. Close observational gaps in marine, cryospheric, terrestrial, atmospheric, and social systems observations using the best available human and autonomous observations. 5. Ensure engagement and inclusion of stakeholders and rights holders, including Indigenous Arctic residents, to extend the benefits beyond scientists and government agencies to those living in the Arctic”.

References to other documents that evaluate or provide additional context for U.S. AON:

Interagency Arctic Research Policy Committee (IARPC). (2021). Arctic Research Plan 2022-2026. https://www.iarpccollaborations.org/uploads/cms/documents/final-arp-2022-202620211214.pdf

Inuit Tapiriit Kanatami. (2018). National Inuit Strategy on Research. https://www.itk.ca/wpcontent/uploads/2020/10/ITK-National-Inuit-Strategy-on-Research.pdf

Lee, C.M., Starkweather, S., Eicken, H., Timmermans, M.-L., Wilkinson, J., Sandven, S., Dukhovskoy, D., et al. 2019. A framework for the development, design and implementation of a sustained Arctic Ocean observing system. Frontiers in Marine Science, Volume 6 - 2019 | https://doi.org/10.3389/fmars.2019.00451

The White House. (2022, October). National Strategy for the Arctic Region. https://www.whitehouse.gov/wp-content/uploads/2022/10/National-Strategy-for-the-ArcticRegion.pdf

United Nations (UN). (2021). Ocean Decade — Arctic Action Plan. https://www.oceandecade.dk/decade-actions/arctic-action-plan

4.1.2. Observing Frameworks

An observing framework is a set of conventions for defining (essential) variables that are measured, derived or aggregated to characterize the state of the environment in an unambiguous manner that can be applied to different regions, possibly with customizations. The variables in an observing framework are often linked to societal benefit areas and will support the requirements of one of more (broad) user communities.

A Framework for Ocean Observing (FOO)

PRIMARY THEME: CROSS-CUTTING TOPICS

References	(Lindstrom et al., 2012) doi: 10.5270/OceanObs09-FOO
CAPARDUS Themes	Cross-cutting topics
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Observing requirements.

Summary. OceanObs'09 resulted in a key recommendation on the need for increased international integration and coordination of interdisciplinary ocean observations. This document is written by an international team of ocean observing experts in response to this. It defines a framework for ocean observing (FOO) that includes a governance model to optimize collaboration and integration across the many observing system elements and communities. Governance includes: (1) a Steering Group promoting alignment of existing structures and oversee creation of any new entities required to support new elements of the observing system, (2) three Ocean Observing Panels (Physics, Biogeochemistry, Biology) in charge of formulating requirements for EOVs, documentation and sharing of best practices, assessment of readiness levels, development of implementation strategies and coordination of activities across local, national, regional and international communities, and (3) a set of Ocean Observing System Implementation Teams driving the development by supporting activities defined by the Panels, and ensuring community commitment and contributions to the Framework.

References to other relevant or complementary standards documents:

UNESCO-IOC (2014). Report of the First Workshop of Technical Experts for the Global Ocean Observing System (GOOS) Biology and Ecosystems Panel: Identifying ecosystem essential ocean variables (EOVs). Paris, France: UNESCO-IOC.

4.1.3. Indigenous Research

Inuit Tapiriit Kanatami (National Inuit Strategy on Research)

PRIMARY THEME: CROSS-CUTTING TOPICS

References	(Kanatami, I. T., 20180) https://www.itk.ca/wp-content/uploads/2020/10/ITK-National-Inuit-Strategy-on-Research.pdf
CAPARDUS Themes	Cross-cutting topics
CAPARDUS Document Type	Policy Document
CAPARDUS Subthemes	Ethical research, Indigenous Peoples, governance, consent, community rights, self-determination, data ownership, data sharing.

Summary. Inuit Tapiriit Kanatami (ITK) is the national representational organization for the 65,000 Inuit in Canada. The document discusses the need for strong public policies and Inuit self-determination in research governance to address the impacts of colonial approaches to research in Canada. It emphasizes that Inuit should have the ability to make decisions about research activities in their homeland, including setting the research agenda, monitoring compliance with ethical guidelines, and determining how data is collected, stored, used, and shared. The document highlights the focus on biological-physical science research in Inuit Nunangat, the Inuit homeland, and the exclusion of Inuit representational organizations from research funding eligibility. The authors propose the National Inuit Strategy on Research (NISR) as a framework to advance Inuit governance, ethical conduct of research, funding alignment, data ownership, and capacity building in Inuit Nunangat research, in partnership with other, non-Inuit stakeholders such as governments and research institutions.

References to other documents that evaluate or provide additional context for ITK:

Inuit Tapiriit Kanatami. National Inuit Strategy on Research: Implementation Plan. Ottawa: Inuit Tapiriit Kanatami, 2018.

4.1.4. Synthesis of cross-cutting documents

This section presents the review of a selection of high-level cross-cutting documents on Arctic Ocean observation systems. The review focused on main characteristics, challenges and gaps identified for each observation system.

Governance

We define "governance" as "the way that observing systems are managed, and the procedures for doing this" (adapted from: https://dictionary.cambridge.org/dictionary/english/governance). In line with this definition, the governance of an observation system for the Arctic Ocean is comprised of several aspects.

Governance structure

The governance structure must incorporate the major actors in Arctic Ocean Observing to pull together the needed resources (financial, logistical, and human) to realise a sustained observing system. This will include high-level bodies at national and international level with clear policy mandates for monitoring, sustaining, and securing the Arctic marine environment and its resources. The governance structure should establish links to GEO through its relevant initiatives (e.g., the Cold Regions Initiative (GEO-CRI)), and to European level users of ocean in situ observations such as the Copernicus Marine Service. Furthermore, the governance structure must foster broad international cooperation to be able to establish and maintain a pan-Arctic system collecting and managing observations in a wide range of disciplines, spatial and temporal time scales.

The roles and responsibilities of each actor must be clearly defined through legally binding agreements, along with the procedures for decision-making. This is needed to ensure a transparent governance structure that is recognised by and thereby can work effectively with the national agencies in charge of the different regions of the Arctic Ocean. Finally, the governance structure must be based on widely accepted high-policy drivers for societal benefits, and on meeting the scientific and operational objectives originating from these drivers. A joint understanding of common goals (e.g., UN SDGs) is needed to trigger coordinated funding from national and international agencies to develop a sustainable observation system for the Arctic Ocean.

Stakeholder and Rights Holder involvement

The key to succeeding in developing a sustained pan-Arctic Ocean Observing System is active and regular involvement of a wide range of experts in science, technology, business, authorities, local communities, and Indigenous Peoples (rights holders). Each sector will bring unique expertise needed to co-develop an observing system meeting the combined needs of the society as a whole, thereby increasing the likelihood of establishing a long-term system. A broad range of users, stakeholders and rights holders must be involved at local, national, regional, and international scales. This is needed to ensure that the observing system is anchored and prioritised in all relevant communities and communities of practice, enabling individuals and organisations to state their requirements for observations and products, and allow for participation in system co-design and data collection.

Funding mechanisms

Funding mechanisms for sustaining in situ ocean observing systems must be strengthened and better coordinated between national and international funding bodies, as recommended by the Joint Statement of Ministers (ASM 2021). The same applies to funding for corresponding data systems securing long-term storage and access to the collected observations and to derived products. Linking the funding mechanisms for observing systems and data systems together will ensure that the effect of financial support is maximised. Such linkage will promote collaboration between scientists, technology providers, data managers and e-infrastructure operators, leading to increased standardisation of the data delivery chains and thereby the available datasets and products.

Challenges and gaps

Data collection in the Arctic is expensive, requires extensive planning and complex logistics. This is especially the case for ocean observing, which in many cases necessitates the use of icebreakers to deploy or recover observing platforms. As a result, in situ data collection is sparse and scattered across the region. The majority in situ observing systems are operated as part of short-term research projects. The INTAROS Roadmap (Sandven et al., 2022a) points out that more involvement of Arctic residents, including women and young people, in collecting and interpreting environmental data can be beneficial. This will both increase the amount of data and locations covered without inflicting impact from visiting scientists on the fragile environment. Further, it will anchor the observing systems in the local communities by giving them influence and ownership of the observations.

Other challenges identified by INTAROS include lack of free data exchange, competence building, sustainability of in situ observing systems and robust technology. Allocating resources to improve and where feasible automating data delivery chains will contribute to more data being shared. The use and common understanding of data licences and the IPR of data collectors and rights owners are also important aspects of data sharing. Competence building in practical data collection methods and procedures, data sharing principles and tools, as well as capabilities of new observing technologies is important for advancing research driven in situ observing systems into sustainable research infrastructures. With increased involvement of local communities in Arctic observing, protocols for ethical sharing of traditional and local knowledge should be developed separately as appropriate for each knowledge type (EU Polarnet, 2017). Documentation of procedures and best practices should be shared through open channels such as Zenodo and Ocean Best Practices System (Sandven et al., 2022a).

High-level observing requirements

In this section, the term “observing requirements" is used to denote the high-level requirements for an ocean observing system for the Arctic. We consider the following categories of observing requirements: for what purpose is the observing system created and operated, for whom is it made, and what parameters are measured or derived). We further discuss some gaps and challenges identified in the reviewed documents, and identify some of the protocols and standards related to observing requirements.

Purpose of observing

All observing systems are designed and implemented with a specific objective in mind. Lee et al. (2019) defines three broad categories of information needs for different user, stakeholder and rights holder groups: (1) long-range planning and policy making, (2) strategic decision-making, and (3) tactical support. Observing systems for long-range planning and policy making uses scientific observations and methods to keep authorities informed about state and changes in the natural and man-made environment on a decadal timescale. These systems focus on supporting long-term sustainable development of communities, for managing resources and protecting the environment. Observing systems for supporting strategic planning and decision-making are designed to provide seasonal to decadal data for authorities, private sector, science, and local communities. Observing systems for tactical support focus on providing data supporting daily operations including operational forecasting. Lee et al focuses on observing systems for “Planning/Policy" and “Strategy,” and emphasises the challenges of sustaining an observing system over large geographic areas (regional to pan-Arctic) and for periods up to decades.

While a long-term observing system ideally should cover all areas and time ranges of interest, the high cost and logistical complexity of collecting in situ data on a regular basis prohibits this. Sandven et al. (2022a) instead concludes that “in situ data should be collected in key locations which are important for processes or can be representative for a larger region”. Furthermore, the INTAROS Roadmap notes that requirements for an observing system for the whole Arctic and global monitoring will differ significantly from one that is designed to support need on a national and local scale. As with any system, the requirements will change over time. The organisation(s) operating the observing system must therefore maintain a running dialogue with the targeted user groups, stakeholders and rights holder to capture new requirements arising from new societal needs and advances in observing technologies (Sandven et al., 2002b).

Target groups

Observations and derived products for the Arctic are made to support a series of users, stakeholders and rights holders. Target groups include, among others, the scientific community, Arctic residents, decision-makers in public and private sectors, industry and small businesses operating in the region, local communities, Indigenous Peoples and organisations, and the wider society. Each target group has its own requirements, which will change over time due to new requests or regulations from society and authorities. The various observing systems must thus be updated to the revised requirements and priorities, incorporating advances in observing technologies that can yield improved or new observations of requested parameters.

Parameters

The reviewed documents address the needs for parameters at two levels. First, as observation frameworks for higher-level parameters such as Essential Climate Variables (ECVs), Essential Biodiversity Variables (EBVs), Essential Arctic Variables (EAVs), SAON’s Shared Arctic Variables (SAVs), and for supporting general frameworks such as the UN Sustainable Development Goals (SDGs) and the GEOSS Societal Benefit Areas (SBAs). Secondly, thematic disciplines, groups or individual parameters that can be measured directly or derived by means of an empirical model. These parameters are identified as the most important for observing climate change, natural resources, and impact of human activity and natural hazards. For instance, the U.S. AON design document defines in situ temperature and salinity profiles to a depth of at least 500 m, estimate upper ocean heat content, stratification and several sea ice parameters (e.g., concentration, thickness, roughness, snow cover), optical and biogeochemical properties of the ice pack, as key parameters that should be measured stringently. U.S. AON further identifies atmosphere-ocean (-ice, and -land) radiative and turbulent fluxes as key parameters that should be measured for reliable estimates of the surface energy balance.

Challenges and gaps

In situ observation programs in the Arctic have large gaps, especially in the Central Arctic. For instance, the global Argo program cannot operate their floats properly under sea ice. The floats cannot send data while under ice, nor get a position to geo-locate their data. For vessel-based observations most observations are during the summer season, with little or no data the rest of the year. Geographically, the in-situ observations are scattered throughout the Arctic, and particularly limited in Russian waters due to the current geopolitical situation. Biogeochemical and biological observations are extremely scarce in the Arctic Ocean as a whole.

Technological development is needed to implement more robust sensors with low energy consumption that can operate for longer periods without recovery and refurbishing or redeployment. Innovative communication mechanisms for data transmission from moorings or bottom observatories to the surface without recovery of instruments to vessels, need to be developed as well. Such developments will both contribute to establishing a sustained ocean observing system for the Arctic. Moreover, a better funding mechanism (long-term, coordinated across countries) is needed to facilitate the development of new technologies and logistical support for field operations.

Transforming an observing system driven by short-term research projects into a sustained research infrastructure is a further challenge. Meeting this challenge entails broad international collaboration and cooperation by the scientific community, national agencies and authorities, large Arctic programs and corresponding funding bodies (nationally and internationally).

Ensuring the observing system continues to serve its purpose, a close dialog with users, stakeholders and rights holders must be maintained to incorporate new requirements during the lifetime of the system. For some observing systems this may entail development of location-specific strategies for adapting to climate and societal change (U.S. AON, 2022). For observing systems with scientists and service developers as the primary target group, integration of new observing and communication technologies will be an important part of evolving the system.

Standards and protocols

The following standards and protocols were identified in the reviewed documents:

Table 4.2 Standards and protocols identified in governance documents.

Standard or protocol	Description
UNFCCC Paris Agreement	A legally binding international treaty on climate change.
Sendai Framework for Disaster Reduction	A framework for preventing new and reducing existing disaster risks. Priorities: (1) understanding risks, (2) strengthening risk governance, (3) disaster reduction, and (4) enhancing disaster preparedness.
United Nations SDGs	17 goals for sustainable development of societies worldwide, aiming to improve health and education, reduce inequality, and stimulate economic growth.
Data Catalog Vocabulary (DCAT)	Ann RDF vocabulary to facilitate interoperability between data catalogues published on the Web.
Framework for Ocean Observing (FOO)	A system-level view of effective practices for defining requirements, coordinating observation networks, and delivering sustained information products.
GCOS Essential Climate Variable (ECV)	A physical, chemical or biological variable or a group of linked variables that is critical to characterise the Earth' s climate.
GEOBON Essential Biodiversity Variables (EBVs)	Derived measurements required to study, report, and manage biodiversity change, focusing on status and trends.
WMO Global Cryosphere Watch (GCW) observing specifications	Best practices for measuring cryosphere variables (e.g., snow; ice sheets and ice caps; sea/lake/river ice; permafrost; solid precipitation).
SAON Shared Arctic Variables (SAVs)	Essential variables or processes developed under ROADS.

4.2. Observing systems

In this section, an observing system is defined to be the data collection component. Observing systems provide observations on the state of the atmosphere, ocean, land and cryosphere from space-based to ocean bottom deployed instruments.

4.2.1. Essential Variables

The Essential Variable (EV) model was addressed under parameters in the previous section “Synthesis of cross-cutting documents”. This model has emerged as the core approach to channel limited observing resources into activities that address the most pressing needs through efficient collaborative approaches. These observing frameworks were developed for specific purposes other than an Arctic observing system of systems. The Shared Arctic Variable framework builds on the concept of essential variables, as defined in a number of different observing contexts (reviewed cross cutting documents), but adapts it to Arctic settings (see Requirements in Bradley et al. 2021). Other documents describing essential variables are listed in Table 4.3.

Table 4.3. Observing system theme, with sub-theme and documents for essential variables.

Theme	Sub-theme	Documents
Observing systems	Essential variables	Bradley et al., 2021 UNESCO, 2012 Tanhua et al., 2019 Buch et al., 2017 Lancheros et al., 2018 Miloslavich et al., 2018 Muller-Krager et al., 2018 Specification sheets on EVs (Global Ocean Observing System (goosocean.org), GCOS | WMO)

Shared Arctic Variable Framework Links Local to Global Observing System Priorities and Requirements

PRIMARY THEME: Observing systems

References	(Bradley et al., 2021) https://journalhosting.ucalgary.ca/index.php/arctic/article/view/76429
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	
CAPARDUS Subthemes	Essential variables, Shared Arctic Variables,

Summary: Requirements for the Arctic observing systems are more demanding because of a greater need for cross-disciplinary and cross-sectoral prioritization and refinement from the local to the pan-Arctic scale, in order to maximize the use of resources in challenging environmental settings. Consideration of Arctic Indigenous Peoples' observing priorities and needs has emerged as a core tenet of governance and coordination frameworks. The Shared Arctic Variables (SAVs) represent measurable phenomena or processes that are important enough to multiple communities/sectors to make it worth the work to coordinate their acquisition across the Arctic observing community. SAVs align with essential variables as defined, for example, by global observing frameworks, in that they guide coordinated observations across processes that are of interest to multiple sectors. SAVs are responsive to the information needs of Arctic Indigenous Peoples and draw on their capacity to co-design and co-manage observing efforts. SAVs are also tailored to accommodate the logistical challenges of Arctic operations and address unique aspects of the Arctic environment, such as the central role of the cryosphere.

More detailed requirements for the essential variables (i.e., SAVs, EOV, ECV etc.) can be considered as multiple sub-themes which will be further addressed in the following sections.

References to other relevant or complementary standards documents for essential variables:

Specification sheets on essential variables from GOOS and GCOS (Global Ocean Observing System (goosocean.org) *and* *GCOS | WMO)*

UNESCO-IOC (2014). Report of the First Workshop of Technical Experts for the Global Ocean Observing System (GOOS) Biology and Ecosystems Panel: Identifying ecosystem essential ocean variables (EOVs). Paris, France: UNESCO-IOC.

References to other documents that evaluate or provide additional context for essential variables:

Lindstrom, E., Gunn, J., Fischer, A., McCurdy, A., & Glover, L. K. (2012). A framework for ocean observing. By the task team for an Integrated Framework for Sustained Ocean Observing. Paris, France: UNESCO.

Muller-Karger FE, Miloslavich P, Bax NJ, Simmons S, Costello MJ, Sousa Pinto I, Canonico G, Turner W, Gill M, Montes E, Best BD, Pearlman J, Halpin P, Dunn D, Benson A, Martin CS, Weatherdon LV, Appeltans W, Provoost P, Klein E, Kelble CR, Miller RJ, Chavez FP, Iken K, Chiba S, Obura D, Navarro LM, Pereira HM, Allain V, Batten S, Benedetti-Checchi L, Duffy JE, Kudela RM, Rebelo L-M, Shin Y and Geller G (2018) Advancing Marine Biological Observations and Data Requirements of the Complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) Frameworks. Front. Mar. Sci. 5:211. doi: 10.3389/fmars.2018.00211

Lancheros E, Camps A, Park H, Sicard P, Mangin A, Matevosyan H, Lluch I. Gaps Analysis and Requirements Specification for the Evolution of Copernicus System for Polar Regions Monitoring: Addressing the Challenges in the Horizon 2020–2030. Remote Sensing. 2018; 10(7):1098. https://doi.org/10.3390/rs10071098

Patricia Miloslavich, Sophie Seeyave, Frank Muller-Karger, Nicholas Bax, Elham Ali, Claudia Delgado, Hayley Evers-King, Benjamin Loveday, Vivian Lutz, Jan Newton, Glenn Nolan, Ana C. Peralta Brichtova, Christine Traeger-Chatterjee & Edward Urban (2019) Challenges for global ocean observation: the need for increased human capacity, Journal of Operational Oceanography, 12:sup2, S137-S156, DOI: 10.1080/1755876X.2018.1526463

4.2.2. Scales and timeliness

To optimize an Arctic observing system, it is essential to determine the spatial and temporal scale requirements based on the specific application (e.g., operational forecasting, climate monitoring, or process understanding and model development) and the social benefit area it aims to address. Delivering observations of sufficient temporal and spatial scales in a timely manner are crucial for detecting and responding to rapid changes in the Arctic environment. This requires the development of standardized protocols for data collection and analysis, timely reporting and sharing of data to support informed decision-making and policy development. Table 4.4 lists the documents identified for this sub-theme.

Table 4.4. Observing system theme, with sub-theme and documents for scales and timeliness.

Theme	Sub-theme	Documents
Observing systems	Scales and timeliness	Lancheros et al., 2018 Sandven et al., 2022b Tjernström et al., 2018 (INTAROS D2.4) Zona et al., 2018 (INTAROS D2.7) Ludwigsen et al., 2018 (INTAROS D2.1) Tjernström et al., 2019 (INTAROS D2.10) Lee et al., 2022

Synthesis of gap analysis and exploitation of the existing Arctic observing systems

PRIMARY THEME: Observing systems

References	(Tjernström et al., 2019) https://doi.org/10.5281/zenodo.7050807
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	
CAPARDUS Subthemes	Spatiotemporal scales and timeliness, observing technology and design (platforms and instrumentation), terrestrial, atmosphere, ocean, in-situ, satellite products

Summary: This report presents a synthesis of the substantial assessment of Arctic in-situ observing systems in the atmosphere, ocean and terrestrial, data collections and satellite products across scientific disciplines within the INTAROS project. The assessment analyses sustainability, including funding, technical maturity and data handling for the entire chain from observation to users. Moreover, it provides a gap analysis of technical characteristics, such as spatial and temporal coverage and resolution or accuracy.

Challenges regarding standardisation of scales and timeliness

Technological and logistical deficiencies severely restrict the required temporal and spatial scales of observing efforts (Lee et al. 2022). Satellite observations provide the only possibility for a sufficient areal and temporal cover and resolution, due to the convergence of polar satellite orbital tracks on the poles (Tjernström et al. 2020). However, the extensive sea ice cover, the spatiotemporal scales provided by satellite remote sensing are not able to observe the Arctic Ocean.

Recommendations

Mapping of the potential technologies to improve or cover measurements with spatiotemporal and/or timeliness gaps (Lancheros et al. 2018). Focus on observing efforts at key locations (Sandven et al. 2022). Further develop the EBVs and documentation of associated requirements on spatiotemporal scales and timeliness of data delivery. Understanding and optimising the scales and scope of the observations needed to deliver the required information within specified uncertainties and representativeness should be focused on (Lee et al. 2019).

References to other relevant or complementary standards documents for INTAROS gap analysis:

Thorne, Peter, Schulz, Joerg, Tan, David, Ingleby, Bruce, Madonna, Fabio, Pappalardo, Gelsomina,Oakley, Tim. (2015). Deliverable 1.3.

Thorne, P. W., Madonna, F., Schulz, J., Oakley, T., Ingleby, B., Rosoldi, M., Tramutola, E., Arola, A., Buschmann, M., Mikalsen, A. C., Davy, R., Voces, C., Kreher, K., De Maziere, M., and Pappalardo, G.: Making better sense of the mosaic of environmental measurement networks: a system-of-systems approach and quantitative assessment, Geosci. Instrum. Method. Data Syst., 6, 453–472, https://doi.org/10.5194/gi-6-453-2017, 2017.

References to other documents that evaluate or provide additional context for INTAROS gap analysis:

Ludwigsen, Carsten Ankjær, Pirazzini, Roberta, Sagen, Hanne, Hamre, Torill, Sandven, Stein, Stette, Morten, Babiker, Mohamed, Schewe, Ingo, Soltwedel, Thomas, Behrendt, Axel, Andersen, Ole B., Beszczynska-Möller, Agnieszka, Walczowski, Waldemar, Ottersen, Geir, Renner, Angelica, Morvik, Arnfinn, Sejr, Mikael K., King, Andrew, Gustafsson, David, … Aarnes, Øivin. (2018). Deliverable 2.1 Report on present observing capacities and gaps: ocean and sea ice observing system. Zenodo. https://doi.org/10.5281/zenodo.7014496

Michael Tjernström, Eija Asmi, Roberta Pirazzini, Tuomas Naakka, Ewan O'Connor, Joseph Sedlar, Abhay Devasthale, Harald Sodemann, Andreas Peter Ahlstrøm, Robert Schjøtt Fausto, Katrin Kohnert, Andrei Serafimovich, Torsten Sachs, Peter Thorne, Mathias Goeckede, Martijn Pallandt, Hanna K Lappalainen, Alexander Mahura, Anna Kontu, Tomasz Wawrzyniak, Piotr Glowacki, Mikael Kristian Sejr, Andrew King, Geir Ottersen. (2018). Deliverable 2.4. Report on present observing capabilities and gaps: Atmosphere. Zenodo. https://doi.org/10.5281/zenodo.7031275

Zona, Donatella; Ahlstrøm, Andreas Peter; Pirazzini, Roberta; Goeckede, Mathias; Navarro, Francisco; Kohnert, Katrin; Kontu, Anna; Lemmetyinen, Juha; Fausto, Robert Schjøtt; Voss, Peter; Solgaard, Anne M.; Gustafsson, David; Corcuera, Maria I.; Oechel, Walter; Serafimovich, Andrei; Sachs, Torsten; Pallandt, Martijn; Knudsen, Per; Wawrzyniak, Tomasz; Glowacki, Piotr; Mahura, Alexander; Lappalainen, Hanna K; Grabiec, Mariusz; Błaszczyk, Małgorzata; Sørensen, Mathilde B.; Atakan, Kuvvet; Citterio, Michele; Khan, S. Abbas; Isberg, Kristina; Otero, Jaime; Larsen, Tine B.; Dahl-Jensen, Trine; Storvold, Rune; Quegan, Shaun. (2018). Deliverable 2.7. Report on present observing capacities and gaps: Land and cryosphere. Zenodo. https://doi.org/10.5281/zenodo.7032084

Beszczynska-Möller, Agnieszka, Ahlstrøm, Andreas Peter; Pirazzini, Roberta; Navarro, Francisco; Cheng, Bin; Babin, Marcel; Marec, Claudie; Sejr, Mikael K.; Houssais, Marie-Noëlle; Herbaut, Christophe; Nilsen, Frank; Johannessen, Truls; Roden, Nicholas; Rogge, Andreas; Allen, Ian; Renner, Angelica; Ottersen, Geir; Soltwedel, Thomas; Gattuso, Jean-Pierre; King, Andrew; Forget, Marie-Helene; Testor, Pierre; Walczowski, Waldemar; Mathias, Delphine; Sagen, Hanne; Worcester, Peter; Dzieciuch, Matthew; Howe, Bruce; Sørensen, Mathilde; Voss, Peter; Goeckede, Mathias; Sachs, Torsten; Oechel, Walter; Zona, Donatella; Domine, Florent; Tjernström, Michael. (2022). Deliverable 3.16. Synthesis and technical recommendations. Zenodo. https://doi.org/10.5281/zenodo.7093053

4.2.3. Observing Technology

The observing technology theme includes hardware such as instrumentation and platforms used in an observing system. The sensors and instruments are tools used to measure various physical, biological, and chemical parameters. The observational platforms refer to the physical platforms, such as ships, buoys, drones, and satellites, that are used to observe the Arctic. The documents identified for sub-theme Observing Technology are listed in Table 4.5.

Table 4.5. Observing system theme, with sub-theme and documents for observing technology.

Theme	Sub-theme	Documents
Observing systems	Observing technology	Sastri et al., 2019

		Lancheros et al., 2018 Buch et al., 2017 Lee al., 2022 Krishfield et al., 2006 Arctic Council Secretariat, 2017 WMO, 2017 Spec sheets on platforms (Global Ocean Observing System (goosocean.org)

Emerging technologies and approaches for in situ, autonomous observing in the Arctic
PRIMARY THEME: Observing systems

References	(Lee al., 2022) https://doi.org/10.5670/oceanog.2022.127
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	Guideline
CAPARDUS Subthemes	Observing technology and design (platforms and sensors), spatiotemporal scales and timeliness

Summary: Reviewed frameworks and roadmaps for establishing an observing system includes a stepwise guideline resulting in a set of suitable platform designs and sensors. This may include for example choosing a stationary or mobile platform, or the level of accuracy and resolution of a sensor sufficient for its purpose. The selection heavily depends on the high-level requirements of application and goal of the observing system.

The more in-depth review of specific documents and standards on observing platforms provides guidance on e.g., the design, operation procedures, and maintenance. Whereas related standards on instrumentation provide guidance on e.g., the calibration, accuracy, and reliability of these sensors and instruments. For example, good practices describe regular calibration and maintenance of sensors and observing platforms, which is crucial to ensure accurate and reliable measurements. This includes performing routine checks of instrument drift, and ensuring that sensors are free from e.g., ice build-up, biofouling, and corrosion, or other damage that could impact their performance. It is recommended to establish a regular schedule for calibration and maintenance, and ensure that personnel are properly trained to perform these tasks. However, this is challenging in the remote areas of the Arctic. Thus, robust hardware and methods to decrease the need for maintenance are essential (e.g., anti-biofouling techniques). Other essential elements of an observing system include power supply, data storage, and telecommunication systems. The more in-depth technical specifications on hardware components will have to be evaluated by skilled technicians and engineers. Development of this should be in collaboration with researchers.

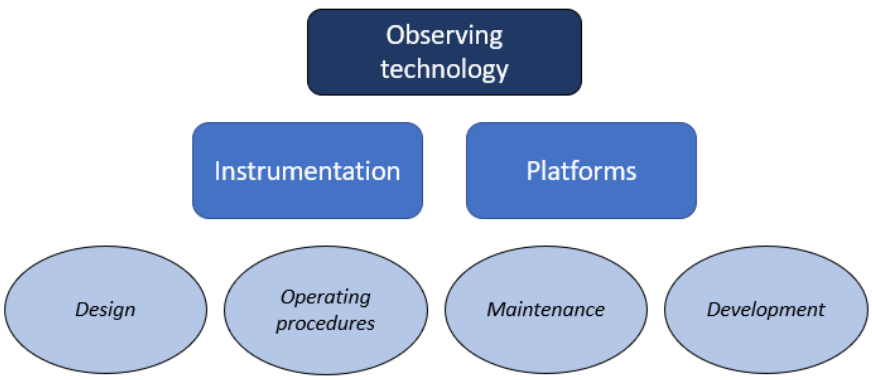


Figure 4.5. Sub-themes of Observing Technology.

Challenges regarding standardization of observing technology: One of the main challenges for the standardization development of observing technology is the limited available data on platform performance and effectiveness. Thus, identifying areas for improvement and to develop more effective standards and guidelines can be difficult. Moreover, the constantly evolving technologies and methods makes it demanding to keep the standards up-to-date and utilizing the most effective and efficient technologies and methods possible.

Moreover, technological development of biogeochemical and biological observations still lags behind the physical observations (Muller-Krager et al. 2018, Bailey et al. 2019). Today, there exist numerous methods to observe various biogeochemical and biological parameters, however they are often costly and time consuming. In some cases, there are no suitable sensors to measure the parameters required or these sensors are too expensive, especially for biogeochemical variables. Although, as the technology continues to evolve it is possible that these sensors may become more accessible due to reduced costs (Bailey et al. 2019).

Recommendations: The recommendations for the development of new observing technology considers specific characteristics of observing sensors and platforms. The call for technological development includes low-cost, long-endurance and autonomous platforms that offer promising new approaches for large-scale, sustained observing. Miniature and lightweight platforms will benefit massive deployments and easier logistics and handling in the field. Development of small, low-power sensors suitable for deployment on these platforms requires further support and attention by both the engineering and research community. Development and implementation of systems for geo-positioning and telemetry is needed to make underwater autonomous observing systems fully operational and ensure more timely data (Lee et al. 2022, Arctic Council Secretariat 2017). Further develop instrumentation for observing essential biological and biogeochemistry variables, which is currently complex and expensive (Muller-Karger et al. 2018, Bailey et al. 2019). Best practice of implementing new observing technology includes a community-wide evaluation and assessment (i.e., mature) before deployment (Lindstrom et al. 2012). This will secure the stability and continuity of the observing system important for long-term climate studies. Developing and implementing new mature technology while keeping the continuity and stability of the observing system.

Reference to other documents that evaluate or provide additional context for observing technology:

Sastri AR, Christian JR, Achterberg EP, Atamanchuk D, Buck JJH, Bresnahan P, Duke PJ, Evans W, Gonski SF, Johnson B, Juniper SK, Mihaly S, Miller LA, Morley M, Murphy D, Nakaoka S-i, Ono T, Parker G, Simpson K and Tsunoda T (2019) Perspectives on in situ Sensors for Ocean Acidification Research. Front. Mar. Sci. 6:653. doi: 10.3389/fmars.2019.00653

Arctic Council Task Force on Telecommunications Infrastructure in the Arctic, 2017, Telecommunications infrastructure in the Arctic: a circumpolar assessment. Arctic Council Task Force on Telecommunications Infrastructure in the Arctic (TFTIA). 90 pp.

4.2.4. Readiness Levels

Evaluating and monitoring an observing system is a crucial component of its development and improvement. To achieve this, it is essential to assess the readiness of all components of the system and report on its performance and progress over time towards meeting necessary requirements and capability of delivering the required data and information to end-users. One common method for doing so is using the system maturity matrix developed under the Horizon 2020 GAIA-CLIM project, which enables a systematic assessment of the readiness level of the observing system components. By using this matrix, the system's maturity level can be monitored and gaps and areas for improvement can be identified.

Table 4.6. Observing system theme, with sub-theme and documents for readiness levels.

Theme	Sub-theme	Documents
Observing systems	Readiness levels	Sandven et al., 2022a Zakharova et al., 2019 Thorne et al., 2015

		EUMETSAT, 2014 Lindstrom et al., 2012

Report on system of systems approach adopted and rationale

PRIMARY THEME: Observing systems

References	(Thorne et al., 2015) http://www.gaia-clim.eu/system/files/workpkg_files/640276_Report%20on%20system%20of%20systems%20approach%20adopted%20and%20rationale.pdf
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	Method, guideline
CAPARDUS Subthemes	Readiness level, metadata, documentation, observational capabilities

Summary: The system maturity matrix is a tool developed within the EU Horizon 2020 funded GAIA-CLIM project, to assess the readiness level of an observing system. The system maturity matrix categorizes the observing system components in a hierarchical structure as either a “reference”, “baseline”, or “comprehensive” system based on its readiness level (Thorne et al. 2015, Lindstrom et al. 2012). The assessment has many potential scientific and societal benefits, relating to the appropriate use of the data collected for many applications. The categorization is achieved through applying a set of semi-quantitative assessment criteria against the following seven thematic areas, which may reasonably differentiate the observational capability maturity:

1. Metadata
2. Documentation
3. Uncertainty characterisation
4. Public access, feedback, and update
5. Usage
6. Sustainability
7. Software (optional)

Thorne et al. 2015 provides a section on how to perform the assessment. However, this guidance provides no in-depth information. They kept the guidance “relatively open”/non-specific” such that it would not be outdated due to e.g., technological or best practice developments.

The Framework for Ocean Observing describes the readiness levels and associated attributes which provides additional context to the method, as well as its relations to other key framework elements (e.g., EVs, observing technology, sustainability). Additionally, Zakharova et al. (2019) assessed multiple observing systems in the Arctic, showing its use which can be a helpful example of implementation.

Challenges implementing the GAIA-CLIM method:

- The challenges of implementing the system maturity matrix tool for a robust assessment of the readiness level have to be addressed. Potential uncertainties can arise due to: inadequacies in the guidance; incomplete knowledge of the observing system assessors; and ambiguity in performance of the observing systems, amongst others (Zakharova et al. 2019).
- No specific step-by-step guidance on how to execute the assessment in detail. They leave this up to an expert guiding the team assessing the observing systems, thus there is a need for this resource.
- The flexibility of choosing what elements are more or less important, i.e., should be weighted in the assessment, may however, be difficult to agree upon and can cause a subjective evaluation.

Additional challenges:

- Funding mechanisms – lack of funding throughout the whole value chain, thus affecting the data management, i.e., inadequate metadata and documentation resulting in low maturity scores of the observing systems (Zakharova et al. 2019)

References to other relevant or complementary standards documents for GAIA-CLIM methodology:

Elena Zakharova, Peter Thorne, Roberta Pirazzini, Torill Hamre, Hanne Sagen, Stein Sandven. (2019). Deliverable 2.11. Report on the maturity of existing observing systems in the Arctic. Zenodo. https://doi.org/10.5281/zenodo.7051020

Thorne, Peter, Schulz, Joerg, Tan, David, Ingleby, Bruce, Madonna, Fabio, Pappalardo, Gelsomina,Oakley, Tim. (2015). Deliverable 1.3. Report on system of systems approach adopted and rationale. www.gaia-clim.eu/page/deliverables

Thorne, P. W., Madonna, F., Schulz, J., Oakley, T., Ingleby, B., Rosoldi, M., Tramutola, E., Arola, A., Buschmann, M., Mikalsen, A. C., Davy, R., Voces, C., Kreher, K., De Maziere, M., and Pappalardo, G.: Making better sense of the mosaic of environmental measurement networks: a system-of-systems approach and quantitative assessment, Geosci. Instrum. Method. Data Syst., 6, 453–472, https://doi.org/10.5194/gi-6-453-2017, 2017.

Reference to other documents that evaluate or provide additional context for GAIA-CLIM methodology:

Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO 2012, IOC/INF-1284, doi: 10.5270/OceanObs09-FOO

4.2.5. Citizen Science

Citizen science refers to the involvement of the general public in scientific research activities. The Arctic is a vast and remote area, making it difficult for scientists to collect data and monitor changes in the environment. Citizen science provides an opportunity for non-scientists to contribute to scientific research and data collection. Citizen science projects in the Arctic focus on a range of topics, including climate change, biodiversity, and cultural heritage. Participants can help collect data on animal populations, water quality, and weather patterns. Such initiatives bring benefits to both the scientific field and society. It increased the amount of data available, which can improve the understanding of the Arctic ecosystem and inform policy- and decision-making. Citizen science projects also promote public engagement and awareness, which can promote scientific literacy and promote environmental stewardship.

Table 4.7. Observing system theme, with sub-theme and documents for citizen science.

Theme	Sub-theme	Documents
Observing Systems	Citizen science	De Rijck et al, 2020 Schwoerer et al., 2021 Dunmall and Reist, 2018 de la Barre et al., 2016 Taylor et al., 2020 French et al., 2017 Balázs et al., 2021

Best Practices in Citizen Science for Environmental Monitoring: Commission Staff Working Document

PRIMARY THEME: Observing systems

References	(De Rijck et al, 2020) http://dx.doi.org/10.25607/OBP-1779
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	Best practice, guideline
CAPARDUS Subthemes	Citizen science, observing capacity, co-creation and contributory projects, awareness and knowledge-transfer, lessons learned, spatiotemporal scales, knowledge-based decision- and policy-making, natural resource management

Summary: This document was prepared based on a 2018 study, “Citizen science for environmental policy: development of an EU-wide inventory and analysis of selected practices”. The study assesses the impact and policy applications of citizen science in environmental monitoring by providing an inventory of 503 environmental citizen science initiatives of EU policy relevance and in-depth analysis of 45 selected initiatives. Moreover, the guide provides a set of best practices for designing, implementing, and evaluating citizen science projects. Covering topics such as project planning and management, data quality and validation, participant recruitment and engagement, and communication and outreach strategies. It is clear and well-organized, intended to serve as a resource for practitioners and observers interested in citizen science as a tool for environmental monitoring and conservation. Additionally, it provides gap analysis including recommendations and possible actions described in short and in detail.

The document is not directly focusing on the Arctic, thus not covering the specific challenges for the Arctic region. The citizen science projects in the Arctic are generally more towards the contributory side of the spectrum, whereas co-created projects (community-based monitoring) are on the other side (Schwoerer et al. 2021). Thus, facing challenges such as time-limited contribution and engagement of non-local citizens (e.g., tourists), limited populated areas and possible experience of contributory fatigue in populated areas. However, Schwoerer et al. (2021) emphasises the need for both project models (contributory and co-created) to run alongside in the Arctic observing system at a range of spatial and temporal scales.

Challenges regarding standardization of citizen science

- Need of resources for capacity-building, including training and knowledge-transfer, which can help minimizing biases in data.
- Data collected from citizen science projects are underused and are rarely incorporated into standard data repositories. Clear need to facilitate the discovery and wider availability of curated, well-documented citizen science data (De Rijck et al. 2020). Thus, should the incorporation of citizen science data into the Arctic observing system through data repositories be enhanced.
- The authors acknowledge that despite best practices and guidelines for citizen science projects, there are multiple factors determining the outcome of such projects. Strategies for engagement, communication, and outreach following a “cook book” may not result in a successful project, due to for example lack of public engagement in project topics.

Recommendation:

- Close collaboration with the tourist industry (e.g., polar expedition operators), shipping industry (IMOS Ships of Opportunity), and other actors in the Arctic.
- Communication plan and outreach for engaging and raising awareness. To achieve increased awareness, however, participants need to understand the value of their contributions. If participants have a sense of ownership in data collection, the resulting management actions and policies have higher public acceptance than would otherwise be the case.

References to other relevant or complementary standards documents for citizen science:

Schwoerer, Tobias & Spellman, Katie & Davis, Tammy & Lee, Olivia & Martin, Aaron & Mulder, Christa & Swenson, Nicole & Taylor, Audrey & Winter, Genelle. (2021). Harnessing the Power of Community Science to Address Data Gaps in Arctic Observing: Invasive Species in Alaska as Case Examples. Arctic. 72. 1-14. 10.14430/arctic73773.

Reference to other documents that evaluate or provide additional context for citizen science :

de la Barre S., Maher P., Dawson J., Hillmer-Pegram K., Huijbens E., Lamers M., Liggett D., Müller D., Pashkevich A., & Stewart E. (2016). Tourism and Arctic Observation Systems: exploring the relationships. Polar Research, 35. https://doi.org/10.3402/polar.v35.24980

Fraisl, D., Hager, G., Bedessem, B. et al. Citizen science in environmental and ecological sciences. Nat Rev Methods Primers 2, 64 (2022). https://doi.org/10.1038/s43586-022-00144-4

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J. and Waller, D. M. (2011). Assessing citizen science data quality: An invasive species case study. Conservation Letters, 4(6). 433–42. DOI:10.1111/j.1755-263X.2011.00196.x

Kosmala, M., Wiggins, A., Swanson, A. and Simmons, B. (2016). Assessing data quality in citizen science. Frontiers in Ecology and the Environment, 14(10). 551–60. DOI:10.1002/fee.1436

4.2.6. Community-Based Observing

Community-based monitoring (CBM) is an approach to environmental monitoring that involves collaboration between scientists and local communities to collect data on environmental change. Arctic residents conduct or are involved in ongoing observing and monitoring activities. Arctic Indigenous peoples have been observing the environment for millennia, and CBM often incorporates traditional knowledge, which may be used independently from or in partnership with conventional scientific monitoring methods. CBM engages Arctic residents in the monitoring process and empowers them to participate in decision-making about the management and protection of their local environment. The data collected through CBM is a valuable tool for informing policies and practices that promote sustainable resource management and community resilience in the Arctic.

Table 4.8. Observing system theme, with sub-theme and documents for community-based observing.

Theme	Sub-theme	Documents
Observing Systems	Community-based observing	Johnson et al., 2015 CAFF, 2015 Gofman, 2010 Nielsen et al., 2022 Kettle et al., 2022 Danielsen et al., 2022 Inuit Circumpolar Council, 2022 UNESCO, 2021 ECSA, 2015 Gold, 2020

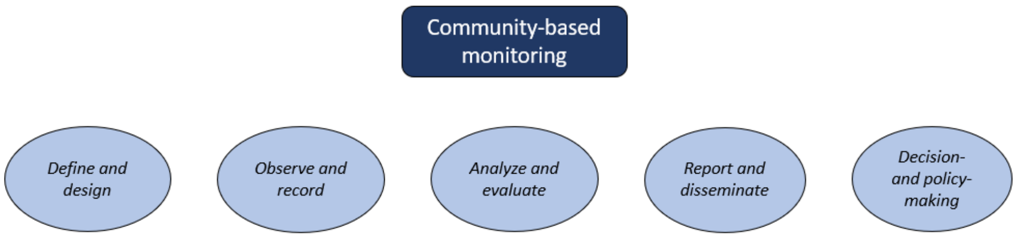


Figure 4.6. Further attributes (of practices) within community-based monitoring.

Community based monitoring programmes in the Arctic: Capabilities, good practice and challenges

PRIMARY THEME: Observing systems

References	(Danielsen et al., 2022) https://doi.org/10.5281/zenodo.7112842
CAPARDUS Themes	Observing systems
CAPARDUS Document Type	Good practice, guideline
CAPARDUS Subthemes	Community-based monitoring, observing capacity, co-creation, awareness and knowledge-transfer, lessons learned, spatiotemporal scales, knowledge-based decision- and policy-making, natural resource management

Summary: This document provides an overview of the state of CBM programmes in the Arctic with its capabilities and challenges. 45 CBM programmes were selected for a more in depth analysis to reflect the widest possible set of situations and issues. Thirty out of the 45 CBM programmes targeted completed their survey. It also provides several "good practice" activities, which refers to activities that CBM programme facilitators or community members engaged in CBM programmes have highlighted as being important and effective when undertaking CBM programmes or activities that have been identified as useful in the scientific peer reviewed literature.

These good practices provide several inputs to the elements in Figure 4.6 and some are listed in the following:

- Careful planning in defining and designing the programme. The co-production of knowledge requires creative and culturally appropriate methodologies and technologies that use both Traditional Knowledge and science applied across all processes of knowledge creation. One should recognize the need to bridge these knowledge systems, including leveraging existing Indigenous Knowledge networks, institutions, and organizations, as well as developing education strategies to broaden mutual understanding (Arctic Council Permanent Participants 2015). Partnering with communities is highlighted, where co-designing and co-developing projects are essential. Community-led initiatives and local needs must be of priority and could empower the community in natural resource management (Buch et al. 2017). Trust-building and ethical and equitable collaboration.
- Observing and recording. Selection of tools and methods (from both the natural and social sciences are often used) should be done by locals, and ideally be incorporated in everyday life activities. Training and guidance of appropriate tools and methods are important and should be provided.
- Analyse and evaluate. An effective two-way communication throughout all steps of the process. Engaging Indigenous peoples as knowledge holders, Indigenous peoples and governments should be taking a lead role in all aspects of monitoring including analysis and interpretation (Wilson et al. 2018).
- Obtaining impact through CBM. Greater impacts may be obtained by further developing protocols and procedures to enable management agencies to incorporate CBM-derived information into decision making, and by bringing communities together, sharing information, and promoting advocacy on the importance of using information from CBM programmes. Greater impacts may also be achieved by further developing national policies in support of CBM programmes, and requirements to incorporate information from CBM into the decision-making process.

Challenges regarding standardization of Community-Based Monitoring

CB initiatives remain little documented and are often unconnected to wider networks, however significant progress has been made in recent years with respect to identifying CBM programs and linking them to other networks. For example, and there are projects taking place that are making significant contributions including the Atlas of Community-Based Monitoring in a Changing Arctic (www.articcbm.org). This product is part of the Sustaining Arctic Observing Networks program that has the potential to play a significant role in the creation of networks and establishment of standards. These projects reveal that CBM projects and programs are implemented within legal and governance frameworks that vary significantly both within and among different national contexts. This results in many practitioners working to develop a better sense of the field and how best to support its growth and development. In addition, the diversity of knowledge-systems, culture, worldview, languages, regional differences, make it difficult for standards to be applicable in different regions. Indigenous communities are unique and CBM often embodies a significant contribution from traditional epistemologies. Developing standards and best practices that are inclusive of all these communities and their perspectives can be challenging (Gofman 2010). Moreover, communication formats and tools should be through mediums that are comprehensible for community members. Oral knowledge transfer is usually more suitable than written formats within many Indigenous communities. This way of gathering and documenting knowledge is however more time and resource consuming (e.g., interviews, transcription etc.). National funding is often designed to support governance and research institutions. Thus, community-led CBM initiatives that lack direct connections to these institutions face a relative disadvantage (Johnson et al. 2015).

Recommendations:

Proposed advancement of standardization of CBM is to create a set of standards based on the initial requirements (project target and user-needs) and a suitable standard will then be identified in the initial phase (Johnson et al. 2015). Also, further documentation of differences and similarities among Arctic communities in relation to observing needs, capacities, interests, and institutional, legal and governance frameworks will help assess how CBM can contribute to Arctic observing networks. Additionally, further developing national policies in support of CBM programmes, and requirements to incorporate information from CBM into the decision-making process to achieve greater impacts are strongly recommended.

Reference to other documents that evaluate or provide additional context for community-based observing:

Johnson, N., Alessa, L., Behe, C., Danielsen, F., Gearheard, S., Gofman-Wallingford, V., Kliskey, A., Krümmel, E.-M., Lynch, A., Mustonen, T., Pulsifer, P., & Svoboda, M. (2015). The Contributions of Community-Based Monitoring and Traditional Knowledge to Arctic Observing Networks: Reflections on the State of the Field. Arctic, 68, 28–40. http://www.jstor.org/stable/43871384

Victoria Gofman. Community-based monitoring handbook: lessons from the Arctic, CAFF CBMP Report No.21, August 2010, CAFF International Secretariat, Akureyri, Iceland. ISBN 978-9979-9778-4-1.

Nicole J. Wilson, Edda Mutter, Jody Inkster, Terre Satterfield. Community-Based Monitoring as the practice of Indigenous governance: A case study of Indigenous-led water quality monitoring in the Yukon River Basin, Journal of Environmental Management. (2018). Volume 210, Pages 290-298, https://doi.org/10.1016/j.jenvman.2018.01.020

Arctic Council Permanent Participants. (2015). Fundamental Principles for the Use of Traditional Knowledge in Strengthening the Work of the Arctic Council.

4.3. Arctic Safety

The Arctic Safety theme in CAPARDUS is focused on safety of operations across different sectors. This has become a critical theme in recent years due to the strong increase in human activity in this region.

4.3.1. Operational

The increasing number of people travelling to the Arctic as a result of shipping, industrial activities, various expeditions, and other tourist traffic represent significant risks for accidents (Sandven et al., 2020). In most areas there is a lack of infrastructure for emergency preparedness, search and rescue operations, medical services, and transport systems. This implies that even small accidents, which can be handled easily in populated communities, become challenging in remote Arctic areas. Building up safety of operations, both on land, sea, and air, is therefore of high priority in Arctic areas. The Polar Code, which entered into force in 2017, is an example of regulations established by the International Maritime Organization (IMO) to ensure that there are minimum requirements for ships operating in Polar regions. Several documents relating to operational aspects of Arctic safety have been reviewed in the CAPARDUS (Table 4.9), and a summary of the most important findings is included below.

Table 4.9. Arctic safety theme, with sub-theme and documents for operational activities.

Theme	Sub-theme	Documents
Arctic safety	Operational	PAME, 2014 Indreiten et al., 2018 Adumene and Ikue-John, 2022 Washington et al., 2018 INTERACT Fieldwork Planning Handbook. Eds.: Rasch, M. et al. 2019 IMO, 2017 INTERACT Practical Field Guide. Eds.: Rasch, M. et al. 2019 INTERACT Fieldwork Communication and Navigation. Eds.: Schneider, A. et al., 2021 Doble et al. 2009

Arctic Offshore Oil and Gas Guidelines: Systems Safety Management and Safety Culture
PRIMARY THEME: Arctic Safety – Operational

References	(PAME, 2014) http://hdl.handle.net/11374/418
CAPARDUS Themes	Arctic Safety – operational
CAPARDUS Document Type	Guideline
CAPARDUS Subthemes	Operating procedures, safety management, risk assessment, hazard identification, capacity-building, communication, quality assurance, gaps and challenges

Summary: PAME (2014) is primarily intended as a guidance tool for those more directly responsible for regulating, influencing and overseeing the safety of a broad range of activities associated with oil and gas exploration and production offshore in the Arctic. The scope of this document is based upon a review identifying elements from safety system regulations in Norway, Canada, Greenland, and the United States. The areas for recommended guidance in the report were refined and focused to the following nine categories:

1. Continuous Improvement
2. Risk and Hazard Analysis
3. Management of Change
4. Training and Competence for the Arctic
5. Accountability and Responsibility
6. Operating Procedures
7. Quality Assurance and Mechanical Integrity[2]
8. Documentation and Reporting
9. Communications

The guideline includes possible challenges in each of the categories and provides recommendations for actions and approaches to improve and overcome these challenges. In addition, this document provides comprehensive information and appendices containing further details and additional reference documents to support guidance and recommendations for international standards and practices, among others.

Challenges regarding standardization of operational safety: There is a lack of data and documentation of operations due to absence of significant history of operations (and no major accidents) in the offshore Arctic. Various and complex operations in dynamic conditions in different Arctic areas may hinder the application of specific technical standards across the Arctic offshore (PAME 2014). Additionally, systems failures are complex and rarely involve the exact same causes, making it difficult to prescribe specific solutions to cover future accidents. Interventions for improvements in many of the safety systems such as risk management, quality assurance, maintenance tracking, and adjusting operating procedures, all require monitoring using quality, reliable documentation and reporting. Continuous improvement in virtually all aspects of safety management systems and safety culture requires the collection and analysis of data from reviews, audits, inspections, surveys and reports. Without these solid records documented, it is often difficult to expose deficiencies or track any evidence of deterioration in safety vigilance.

Recommendations: Continuous improvement of methods and tools for risk and safety analyses. Lessons learned should not all be from major accidents or worst-case scenarios. But should include trend analysis of performance using a combination of near-misses, deviations from safety protocols, and incidents, using results of audits, worker questionnaires and surveys, records of safety meetings, and other documents. Collective learning from sharing incident and near-miss data and analyses

[2] Mechanical integrity involves ensuring that equipment and systems are designed, installed, operated, and maintained in accordance with established standards and procedures (e.g., Polar Code). This includes regular inspections and maintenance to identify and address any defects or potential issues before they lead to equipment failure or safety incidents.

between operators and regulators is necessary to ensure that lessons learned are applied before an accident happens. This can be done by identifying hazards and trends in safety performance. It is also important to make near-miss and incident analyses public to foster transparency and help improve industry and regulator accountability.

References to other relevant or complementary standards documents for operational safety (including shipping):

EPPR, 2017, Final Report: Standardization as a Tool for Prevention of Oil Spills in the Arctic. 129 pp. http://hdl.handle.net/11374/1951

AMAP, 2010. Assessment 2007: Oil and Gas Activities in the Arctic - Effects and Potential Effects. Volume 1.

Det norske Veritas, 2013. Recommended Practices for Arctic Oil Spill Prevention. Emergency Prevention, Preparedness and Response (EPPR).

IMO, 2015. INTERNATIONAL CODE FOR SHIPS OPERATING IN POLAR WATERS (POLAR CODE).

IMO. 2016. Guidance on Methodologies for Assessing Operational Capabilities and Limitations in Ice; MSC.1/Circ.1519; International Maritime Organization (IMO): London, UK.

Reference to other documents that evaluate or provide additional context for operational safety (including shipping):

Browne, T., et al., 2020. A Framework for Integrating Life-Safety and Environmental Consequences into Conventional Arctic Shipping Risk Models. DOI 10.3390/app10082937.

Lamson, C., 1987. Arctic shipping, marine safety and environmental protection. DOI 10.1016/0308-597X(87)90035-2.

Ryan, C., Giles, T., Stagonas, D., 2020. Arctic Shipping Trends 2050. DOI 10.13140/RG.2.2.34680.67840.

Salokannel, J., Ruoslahti, H., Knuuttila. J., 2018. Arctic Maritime Safety: The Human Element Seen from the Captain's Table. In Sustainable Shipping in a Changing Arctic, edited by Hildebrand, L. P., Brigham, L. W., Johansson, T. M., 2018. Springer International Publishing. ISBN 978-3-319-78424-3.

4.3.2. Hazard Response

This sub-theme addresses standards and best practices for responding to natural or man-made hazards. A set of relevant documents have been identified (Table 4.10) and a summary provided below.

Table 4.10. Arctic safety theme, with sub-theme and documents for hazard response.

Theme	Sub-theme	Documents
Arctic safety	Hazard response	Arctic Council EPPR, 2021 Arctic Council EPPR, 2017 Arctic Council EPPR, 2015 Arctic Council EPPR, 2011 Kruke and Auestad, 2021 Browne et al., 2021 Indreiten et al,. 2018 Benoit, 2017

Emergency preparedness and rescue in Arctic waters

PRIMARY THEME: Arctic Safety – Hazard Response

References	(Kruke and Auestad, 2021) https://www.sciencedirect.com/science/article/pii/S0925753521000060
CAPARDUS Themes	Arctic Safety – Hazard Response
CAPARDUS Document Type	
CAPARDUS Subthemes	Capacity-building (theory and practice), Communication, Preparedness (coordinating, logistical), Emergency management, Safety and risk assessment

Summary: This document addresses maritime safety in the context of special challenges of operating in the Arctic. The paper defines a general model consisting of three phases for emergency handling. The key phases are defined in Figure 4.7.

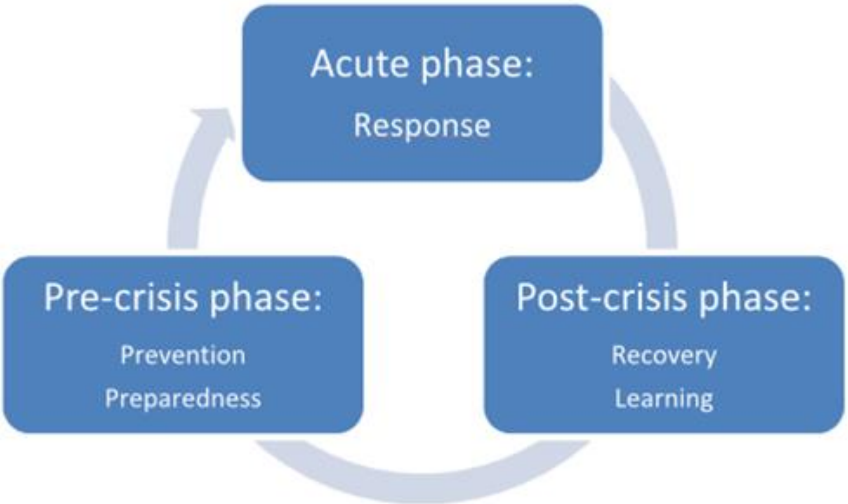


Figure 4.7. The three crisis phases and key elements during each phase (Kruke and Auestad 2021).

Pre-crisis phase: Prevention & preparedness. There is a clear link between preparations, training and exercises in the pre-crisis phase and the quality of the response in the acute phase (Kruke and Auestad 2021). Establishment of a clear emergency response protocol to facilitate an effective cooperative incident response. Continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action is essential to ensure effective coordination during incident response.

Acute phase: The response is divided into three sub-phases or parts. The main response in the first part of the acute phase, is conducted by the people or the organization experiencing the crisis. The quality of this response heavily depends on the preparations in the pre-crisis phase carried out by this group and also on their ability to take responsibility for the initial response. The second part of the acute phase is the response of spontaneous volunteers who offer assistance following a disaster and who are not previously affiliated with recognized volunteer agencies and may or may not have relevant training, skills, or experience. Then, in the third part, we have the availability of various organised response actors and their mobilization and deployment time. Response actors are often thought of as professional response organizations. According to emergency management theory, one of the principle requirements for an effective response to any emergency is a clear understanding by all responders of who will take charge of the rescue and co-ordinate the response (Benoit 2017).

Post-crisis: Recovery & learning. This phase should include a thorough review in order to identify and evaluate areas for improvement and to make necessary changes. The emergency preparedness process is a continuous and iterative process, and the end of the post-crisis phase is the beginning of the pre-crisis phase.

Challenges regarding standardization of hazard response:

- Insufficient data/documentation (for monitoring, assessment, and development): Scientific knowledge for spill response often lags behind the rapid application of new petroleum extraction technologies. A lack of accident data for Arctic regions prevents the use of conventional statistical approaches to assessing life-safety risk (EPPR 2015, IMO 2018). The accident data that does exist often has insufficient detail on the circumstances surrounding the accidents, and historical data may not be relevant for new technologies (Browne et al. 2021).
- Complexity of regional, national, and international laws and jurisdictions (EPPR 2011).
- Lack of awareness and/or understanding among the various responders of each other's obligations, mandates, and protocols (Benoit 2017). Including lack of clearly defined roles and responsibilities,

which could have implications for important aspects of emergency response such as notification, communication, and reaction (EPPR 2011).
- Complex communication schemes dependent on and thus a result of the two previous points.
- Logistical and infrastructure deficits, including equipment (e.g., The SARex2 2017 exercise revealed deficiencies in thermal survival clothing (Kruke and Auestad 2021)).

Recommendations: *Awareness-rising of and capacity-building* in implementing current standards, protocols, and requirements is strongly recommended. However, even with the implementation of the Polar Code, recent maritime accidents in Arctic and Antarctic waters, and the SARex exercises, indicate that neither equipment nor ship crew competence are at the required level for own rescue for the maximum expected time of rescue of five days or more. Findings from the SARex2 in 2017 actually reveal that most "survivors" in the life raft would not have been able to stay alive for a period of up to 5 days, as specified in the Polar Code. *Thus, there is a need to revise the ability to prepare for, and handle, a major maritime accident in Arctic waters* (Kruke and Auestad 2021). Furthermore, it is needed to *continue development of both regional and comprehensive international cooperative agreements and conventions* through implementation and identification of current gaps and areas of improvement (EPPR 2011).

References to other relevant or complementary standards documents for hazard response:

Arctic Council EPPR, 2011. "Arctic Emergencies: Current and Future Risks, Mitigation, and Response Cooperation". Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group. Tromsø, Norway.

Arctic Council EPPR, 2017. "Final Report: Standardization as a tool for prevention of oil spills in the Arctic". Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group. Tromsø, Norway.

Arctic Council EPPR, 2021. "Report: Arctic oil pollution research and development workshop". Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group. Tromsø, Norway.

International Maritime Organization, MSC.1/Circ.892/Rev.1 Guidance on Alerting of Search and Rescue Authorities, 28 November 2022.

International Maritime Organization, MSC.1/Circ.1248 Minimizing delays in search and rescue response to distress alerts, 16 October 2007.

International Maritime Organization, MSC-MEPC.2/Circ.12/Rev.2 Revised guidelines for formal safety assessment (FSA) for use in the IMO rule-making process, 9 April 2018.

Reference to other documents that evaluate or provide additional context for hazard response:

Arctic Council EPPR, 2015. "Arctic Environmental Hazards and National Mitigation Programs.". Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group. Tromsø, Norway.

Browne, T., Veitch, B., Taylor, R., Smith, J., Smith, D., Khan, F., 2021. Consequence modelling for Arctic ship evacuations using expert knowledge, Marine Policy, Volume 130, https://doi.org/10.1016/j.marpol.2021.104582.

Indreiten, M., Albrechtsen, E., Cohen, S.M., 2018. Field operations in the high arctic—experienced feedback and tacit knowledge as key tools for safety management. In Safety and Reliability – Safe Societies in a Changing World, 1st Edition, CRC Press. ISBN ISBN9781351174664.

Benoit, L., 2017. Perspectives on Emergency Response in the Canadian Arctic – Part C. Munk-Gordon Arctic Security Program.

4.3.3. Shipping

This sub-theme is addressed under "operational safety" (section 4.3.1).

4.3.4. Tourism

Tourism is an evolving and important industry in many Arctic regions involving different generations and genders (Sandven et al., 2020). This industry provides several opportunities for individuals and communities, but it also introduces several challenges across the topics addressed in CAPARDUS. Conflicts between local communities and tourism can easily occur e.g., the resource management and cruise ships. It is therefore imperative to find solutions on how tourism can develop side by side with the traditional activities for a sustainable development of the Arctic communities. In particular, the increased tourism increases the need for safety and preparedness. It is essential that planning and decision-making concerning development of new businesses such as tourism is based on the best available data both to avoid too restrictive regulations hampering sustaining communities in the Arctic region. CBM will be an important tool for collecting data and tourism can play an important role through citizen science. Table 4.11 lists some relevant documents for Arctic tourism. Information in these documents have been used to develop the knowledge graph described in section 5.

Table 4.11. Arctic safety theme, with sub-theme and documents for tourism.

Theme	Sub-theme	Documents
Arctic safety	Tourism	Maher et al., 2014 AECO 2020 guidelines (Guidelines - AECO) Palma et al., 2019 PAME, 2015 Vaarala, 2006 Hagen et al., 2012

FINAL REPORT: Sustainable Model of Arctic Regional Tourism (SMART)
PRIMARY THEME: Arctic Safety – Tourism

References	(Vaarala, 2006) https://oaarchive.arctic-council.org/handle/11374/33
CAPARDUS Themes	Arctic Safety – Tourism
CAPARDUS Document Type	
CAPARDUS Subthemes	Sustainable development, local communities, environmental impact, capacity-building, safety and risk assessment

Summary: Arctic safety regarding tourism is in many ways considered under the section "safety of operation". However, an additional aspect of safety in standards concerning Arctic tourism, is the safety of the local communities and fragile environment. Recent tourism trends in the North show that current practices and future tourism development have to take into account the environmental, social, cultural and economic aspects in a balanced approach to ensure that tourism will benefit the local people and the environment in the long term. Unplanned or poorly planned tourism activity can eventually degrade the natural environment and create conflicts with local people, decreasing the quality of life in the local community and undermining the basis of tourism. Tourism planning and development should be done in harmony with the local inhabitants, improving the quality and safety standards of the products are important aspects of how operators can minimize cultural and natural risks.

References to other relevant or complementary standards documents for tourism:
AECO. Developing Site Specific Guidelines (2020).
AECO. Arctic Cultural Remains Guidelines (2019).

Reference to other documents that evaluate or provide additional context for hazard response:
Hagen D., Vistad O. I., Eide N. E., Flyen A. C., & Fangel K. (2012). Perspective: Managing visitor sites in Svalbard: from a precautionary approach towards knowledge-based management. Polar Research, 31. https://doi.org/10.3402/polar.v31i0.18432
David Palma, Alix Varnajot, Kari Dalen, Ilker K. Basaran, Charles Brunette, Marta Bystrowska, Anastasia D. Korablina, Robynne C. Nowicki & Thomas A. Ronge (2019) Cruising the marginal ice zone: climate change and Arctic tourism, Polar Geography, 42:4, 215-235, DOI: 10.1080/1088937X.2019.1648585

4.4. Arctic Data

There are many different human dimensions of the Arctic data ecosystem. There are many that could be discussed including the process of enhancing the ecosystem and network building, development and retention of qualified human resources (an increasingly serious problem), linkages to societal benefits of data and standardization, and critical examinations of data and standardization to explore the risks and potential harm of standardization (Lampland & Star, 2009). We touch on a number of these areas without going into detail considering the intended scope of the document. However, we focus here on the three interrelated human frames that are most relevant to standards and standardization: the data ecosystem; data governance; and data policy.

4.4.1. Arctic Data System Overview

Over several decades, and since the International Polar Year 2007-09 in particular, the polar community has established a vision for a highly accessible, interoperable and usable Arctic data system. In summarizing several key workshops and reports (AOS 2020, Pulsifer et al. 2013, Pundsack et al. 2013 we see some key desired objectives for such a system: i) the system must provide common, open access to data; ii) high quality, ethically open data preserved over time (sustainable); iii) "single window" discovery of and access to data using easy to use tools; iv) easy access to data through "data as a service" (live, online); v) interoperability to support sharing and integration of data among various information systems in a useful and meaningful manner; vi) inclusive of Indigenous and local perspectives and data; vii) access to "big data" and powerful analytical tools (e.g. cloud platforms); viii) it must be cost effective! Appropriate levels of standards adoption, ranging from norms and practices to formal standards and international agreement will contribute to meeting all of these objectives.

The opportunity and challenge for the EC is to establish the ways in which they can engage in contributing to achieving, or even going beyond, this collective vision. Examining the elements of the aforementioned vision reveals a complex, multifaceted system that will require development of standards in the form policy and norms (e.g. open data), understanding the concept of ethically open data - particularly with respect to documented Indigenous knowledge, establishment of standards-based distributed systems (such as search), implementation of service infrastructures, creation of models for interoperability (incl. standards, technologies, architecture, governance etc.), meaningful engagement with Indigenous organizations and communities, efficient and effective adoption of new technologies, and development of innovative business models. This is not strictly an engagement in technical activities, but will require that the *socio-techn*ical nature of the system be recognized by the EC (Figure 4.8).

This section provides a review of Arctic data as a complex system of interrelated information resources, technology, funding, humans and machines and other components that can be seen as an "ecosystem" (Parsons et al. 2011, Pulsifer et al. 2020). Adopting any type of standard will require an understanding of, and engagement in the ecosystem. Before addressing the technical aspects of a framework for Arctic data (that includes but is not limited to standards) an overview of the human dimensions of the system is provided (Sections 4.4.2).

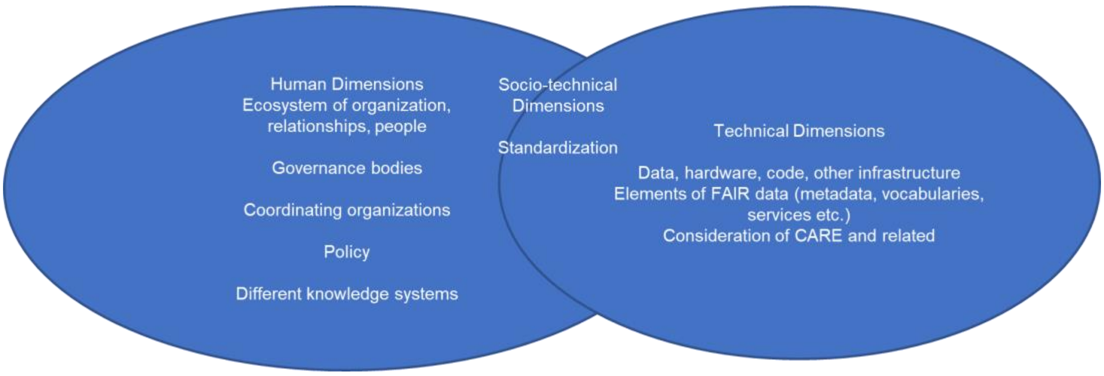


Figure 4.8. Standards and standardization sit at the intersection of human and technical dimensions of the arctic data ecosystem.

4.4.2. Human Dimensions of the Arctic Data Ecosystem

The following section reports on selected human dimensions of the arctic data ecosystem. As discussed in the analysis, entire disciplines and bodies of literature examine these topics in detail. The overview provided here examines the key dimensions related to standardization.

The Polar Data Ecosystem

PRIMARY THEME: Arctic Data

Reference	Pulsifer et al. 2020
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Research
CAPARDUS Subthemes	Arctic Data - Data Ecosystem

Summary: Governance involves processes of interaction, dialogue, negotiation and decision making among many actors involved in the development of social norms and institutions, including the establishment of standards (practices, specification, de jure standards etc.). The Arctic region is complex, comprising a diverse set of actors, requiring "polycentric governance", a system in which many diverse centres of partial authority collectively cover the full range of governance tasks (Starkweather et al., 2022). Polycentric governance can benefit from conceptualizing that Arctic data systems as an information ecosystem, defined as "a system of interrelated and interdependent human actors, institutions, norms and practices (including standards), technologies, information objects, relationships and the broader socio-technical environment in which it exists" (Pulsifer et al., 2020, p. 270).

As established in Section 2 of this report, adoption of existing or development of new standards will require cooperation, collaboration, governance, implementation, and management over time. All of this will benefit from, even require, an understanding of the data, and broader observing and Arctic standards ecosystem. Emerging tools such as linked open data, knowledge graphs, and formal ontologies that capture the semantics of the ecosystem and/or data and information (definition of concepts, hierarchies, relationships etc.) can greatly facilitate our ability to document and understand the Arctic data ecosystem (Pulsifer et al., 2020, p. 283). This understanding is critically important to designing, implementing or facilitating the emergence of standards. Particularly important are the identification of "keystone species" that are central to any effort to move towards standardization: polar data coordination groups; international initiatives with an Arctic focus; international initiatives; national and regional initiatives; and Indigenous Knowledge and Community Based Monitoring Initiatives.

Data Coordination Groups

The roles of these organizations are to: i) Advise their communities on matters related to data management and data sharing; ii) Contribute to the understanding of the nature and structure of the polar data system in the context of the global data system; iii) Promote and enable: - Ethically open access to data - Norms of fair attribution and use of data - Long term preservation of data; iv) Facilitate the adoption, implementation and development (where necessary) of standards that will enable free, open and timely access to data; v) Facilitate interoperability of data and systems as needed to support the needs of researchers, Arctic residents, decision makers and others; vi) Establish expert groups to examine specific questions or coordinate the implementation of data management and sharing solutions. Partnerships with existing or proposed initiatives driven by members of the polar science and data community and Northern communities will be encouraged (Polar Data Community 2017)

There are several arctic data coordination groups that are active in the Arctic data ecosystem. The Arctic Data Committee (ADC) was established by the International Arctic Science Committee and Sustaining Arctic Observing Networks program in 2014 based on community recommendations and research (IASC 2013, Pulsifer et al. 2014). Since then the ADC has been actively facilitating broad collaboration between and among community members, including co-establishing working groups focused on standardization (see POLDER activities in Section 4.5.3). The work of ADC has been recognized by higher level Arctic governance-related bodies such as the Arctic Science Ministerial meeting (ASM 2021) and the Arctic Observing Summit (AOS 2020). ADC works in close collaboration with the Standing Committee on Antarctic Data Management, Southern Ocean Observing System, Polar Data Forum (as a lead and co-organizer), the WMO Global Cryosphere Watch, Federation of Earth

Science information Professionals, the Group on Earth Observation and others (see https://arcticdc.org). In June of 2020, the ADC initiated the Polar to Global Online Interoperability and Data Sharing Workshop/Hackathon (https://p2g-data.org/). This bi-monthly event has become a critically important platform for collaboration and production of community products, including standard-oriented products outlined in subsequent sections.

International Initiatives with an Arctic Focus

International initiatives with an Arctic focus play an important role in the ecosystem and are critically important i f we aim to establish globally adopted standards. The aforementioned data coordination groups are working closely with these initiatives, and this should continue to be enhanced. Some organizations, such as the World Meteorological Organization are actively engaged in collecting and disseminating data and information through programs such as the Global Cryosphere Watch and the related Arctic Data Center. Others, such as the International Science Council sponsor initiatives like the World Data System that aims to establish standards, protocols, and infrastructure at an international level, with a recognition of specific needs for regions such as the Arctic. The Group on Earth Observations (GEO) is taking a similar approach through its Cold Regions Initiative. Other organizations such as the Research Data Alliance (RDA) focus on developing governance models, technical methods, standards, protocols, and general convening of the community. A polar interest group is under development under the RDA. Lastly, organizations like the United Nations (UN) are in some cases developing declarations or other framework entities that have an impact on how we collect and manage Arctic information. For example, the UN Declaration on the Rights of Indigenous Peoples. While these international initiatives may not be of central concern for national entities like the EC, they should be considered as part of establishing priorities and activities as the global initiatives are generating a range of different relevant outputs ranging from policy to databases.

International Arctic Initiatives

There is an increasingly large number of general international initiatives (not data specific) focused on the Arctic. Some, such as the International Arctic Science Committee, Arctic Council Working Groups, the Inuit Circumpolar Council and other Permanent Participant of the Arctic Council, and Arctic Observing Summit are well established and visible. While the mandates of these organizations go well beyond data and information, they play important roles in many aspects of the domain. Others, such as the Arctic Science Ministerial Process are becoming more prominent and active. Some initiatives, such as the Alaska Ocean Observing System have their roots in a national program and funding but are starting to serve international activities. Thus, the Arctic international sub-system is highly relevant to the EC standardization interests and should be considered as part of the planning process.

Regional and National Arctic Initiatives

Regional and national arctic initiatives (projects, programs etc.) are critically keystone species in the ecosystem as they hold much of the funding and resources (human and technical) to achieve the previously outlined goals of the community, including appropriate standardization. These include EC-funded entities such as INTAROS, EU-PolarNet, Arctic PASSION and many other regional programs. Most European nations have national programs that include world-leading institutions (e.g. Alfred Wegener Institute, Met Norway, NERSC and many others). Similarly, we see organizations in North America such as the Canadian Consortium of Arctic Data Interoperability, Polar Knowledge Canada, the NSF Arctic Data Center, the U.S. Interagency Arctic Research Policy Committee, NOAA National Center for Environmental Information and many others. The National Polar Research Institute of Japan, the Polar Research Institute of China and many others have been playing a leadership role in the development of Asian data ecosystem components. Engagement with these initiatives, through the coordination groups discussed will be critically important

Indigenous Knowledge and Community Based Monitoring Initiatives

Major developments and progress has been made in the area of managing data and information resulting from Indigenous Knowledge and Community Based Monitoring Initiatives. A number of community-driven and controlled information dissemination projects have been published or are under development. Projects such as the ICC-led and POLAR-funded Atlas of Community-Based Monitoring

(CBM) (http://arcticcbm.org) and related reports (http://www.inuitcircumpolar.com/community-based-monitoring.html) provide some insight into the breadth and nature of CBM activities. All of these efforts have a strong information component and reveal many great opportunities as well as challenges related to how to appropriately and ethically share resulting information, appropriate technologies, intellectual property rights and others. There is a strong community of Indigenous organizations, communities and other practitioners who are engaged in addressing these issues.

Standardization is a social process as much as it is a technical one (Goldstein & Nost, 2022; Lampland & Star, 2009). Simply developing a standard or set of standards will not result in adoption and the desired level of standardization. Developing standards and facilitating adoption requires knowledge and understanding of the data ecosystem as previously defined. Current efforts such as the Mapping the Polar Data Ecosystem initiative established by the Arctic Data Committee and now being carried out in partnership with POLDER and the EU-Funded Arctic PASSION project are contributing to this needed documentation and understanding. Section 5 of this report provides more details on understanding the standards ecosystem, and Section 5 the foundational role that understanding the standards ecosystem plays in developing a framework.

References to other relevant or complementary standards documents for data ecosystem:

W3C 2014. The Resource Description Framework. https://www.w3.org/RDF/
W3C 2004. OWL Web Ontology Language Semantics and Abstract Syntax. https://www.w3.org/TR/owl-semantics/
Schema.org 2023. Welcome to Schema.org. https://schema.org/

Reference to other documents that evaluate or provide additional context for data ecosystem:

Version 1 of Mapping Arctic Data Ecosystem product reported in Pulsifer et al. 2020 http://staging.arctic-data-ecosystem.apps.nsidc.org/
Version 2 of what is now called Mapping the Polar Data Ecosystem https://mpde.gcrc.carleton.ca/index.html
Mapping Open Science Resources from Around the World by Discipline https://scholarlykitchen.sspnet.org/2023/04/19/guest-post-mapping-open-science-resources-from-around-the-world-by-discipline/

PRIMARY THEME: Arctic Data

Reference	Third Arctic Science Ministerial Joint Statement https://asm3.org/library/Files/ASM3_Joint_Statement.pdf
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Statement
CAPARDUS Subthemes	Data Governance

Summary: Data governance is the exercise of authority, control and shared decision making (planning, monitoring and enforcement) over the management of data assets. It refers to the overall management of the availability, usability, integrity, and security of the data employed in a community. A sound data governance program includes a governing body or council, a defined set of procedures, and a plan to execute those procedures (Reference - https://codata.org/rdm-terminology/data-governance/). Defining a flexible and adaptable governance structure is key to moving beyond a project-specific approach to collaboration and coordination. It is a community-scale process requiring established and agreed upon principles and core values while recognizing the diversity within, and the complex, multi-actor nature of, the community. Engagement with governance and planning requires resources; some individuals or organizations are more easily engaged than others. Thus, to avoid uneven representation, it is imperative to use a process that offers ample opportunity for diverse input through mechanisms such as community review and consensus building.

As previously stated, the Arctic region is essentially governed through a polycentric governance system. Consequently, there is no single arctic data governance body or council. The Arctic Data Committee and related bodies are effectively coordinating, but do not have a governance mandate. Such a mandate is difficult to establish, and funding and jurisdiction typically lies at the national and sub-national level. However, there are governance bodies that can use some mandates and their convening power to support data initiatives, including standardization. For example, there is an effort to develop an Arctic Council

Data Policy, that would include statements on standardization and be informed by a policy alignment document developed by the previously mentioned Polar to Global Hackathon process (Tronstad et al., 2021, ASSW 2022).

Ultimately, the Community must make inroads with decision makers to ensure the necessary long-term support that is needed to manage polar data to best meet the needs of the broad user community. The recent Joint Statement of Ministers on the Occasion of the 3rd Arctic Science Ministerial specifically prioritizes knowledge for a sustainable Arctic and the first sub-theme of "Observe: implementing observing networks; data-sharing". More specifically, the ministers state:

> *Support ongoing efforts from the IASC/SAON-led Arctic Data Committee and others to harmonize data collection and sharing, particularly those working to make Arctic data and metadata more consistent, discoverable, interoperable, ethically open and accessible, and respect the rights of Indigenous Peoples, as applicable, especially with data pertaining to Indigenous Peoples*. (Page 5.)

Realizing these objectives (i.e. consistent) implies and requires standardization of all kinds. Thus, there is a governance and policy mandate for data sharing that can be leveraged to support standardization efforts.

References to other relevant or complementary standards documents for data governance:
https://www.arctic.gov/uploads/assets/supporting_arctic_science.pdf
https://www.arcticscienceministerial.org/arctic/shareddocs/downloads/asm2_joint_statement.pdf?__blob=publicationFile&v=2
Arctic Council 2022. Generating Data and Knowledge. https://arctic-council.org/explore/work/arctic-knowledge/

Reference to other documents that evaluate or provide additional context for data governance:
Mayernik, M.S., 2023. Toward stronger coupling between technical infrastructures and institutional processes in data-intensive science, in: Ma, X., Mookerjee, M., Hsu, L., Hills, D. (Eds.), Recent Advancement in Geoinformatics and Data Science. Geological Society of America, p. 0. https://doi.org/10.1130/2022.2558(04)

PRIMARY THEME: Arctic Data

Reference	(Tronstad et al., 2021) https://zenodo.org/record/5734900#.ZF6BTnbMKwU
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Review Paper
CAPARDUS Subthemes	Data Governance - Policy

Summary: Data policy is a fundamental component of data governance and typically outlines general and specific aspects of data standardization. The Fourth International Polar Year (2007-09) highlighted the need for community-wide data policy. The International Polar Year data policy was confirmed on May 22nd 2006 as the result of a series of international meetings and consultations. The policy aimed to provide a framework for IPY data to "ensure that these data to be handled in a consistent manner, and to strike a balance between the rights of investigators, the rights of Indigenous peoples, and the need for widespread access through the free and unrestricted sharing and exchange of both data and metadata" The IPY data policy includes a number of key elements that are identified in many of the data policy documents reviewed. Notable elements that all require standardization include:

- *Full, free, and open access to and sharing of metadata and data*
- *The need for the complete documentation of data using structured, standards-compliant metadata*
- *Recognition of Indigenous (traditional) Knowledge and related cultural heritage and resulting data as an entity requiring specific attention*
- *The fundamental importance of long-term preservation (security) of data*
- *The importance of attribution (acknowledgement) through formal data citation*
- *The need to clearly define the data resources that fall within the scope of a data policy.*

- *The recognition of the need for special policy and access considerations for data that have legitimate restrictions (i.e. traditional knowledge, human subjects data, IP issues, where open data release may cause harm)*
- *The need to harmonize data policy with other relevant policies (e.g. ICSU, WMO)*

Although this can now be considered a historical document, it was and is relevant to many actors operating or living in the Arctic. The policy was used as a reference for the IASC Statement of Principles and Practices for Arctic Data Management (IASC 2013), which in turn has been used by data centres and government agencies to develop specific policies that guide the day to day collection, management and use of Arctic data (e.g. https://arcticnet.ulaval.ca/data-management/). The last point noted was the need to harmonize data policy. To that end, under the Polar to Global hackathon process, Tronstad et al. (2021) provide a thorough review of data policies relevant to the broader Arctic community. A detailed review of the document is not provided here, however, the principles that it sets out through review of many principles provide a standard policy framework where one does not already exist.

References to other relevant or complementary standards documents for data policy:

IASC (International Arctic Science Committee). (2013). Statement of Principles and Practices for Arctic Data Management. Retrieved from http://www.iasc.info/images/pdf/IASC_data_statement.pdf

Arctic Council Agreement on Enhancing International Arctic Scientific Cooperation https://oaarchive.arctic-council.org/handle/11374/1916

SCAR 2011. SCAR Report 39 - 2011 June - SCAR Data Policy. https://www.scar.org/scar-library/reports-and-bulletins/scar-reports/2717-scar-report-39/

ATS 2023. The Antarctic Treaty. https://www.ats.aq/e/antarctictreaty.html

SIOS 2018. SIOS Data Policy. https://sios-svalbard.org/sites/sios-svalbard.org/files/common/SIOS_Data_Policy.pdf

INTERACT 2019. INTERACT Data Policy. https://eu-interact.org/app/uploads/2019/02/D4.4.pdf

Reference to other documents that evaluate or provide additional context for data policy:

Carroll, S.R., Garba, I., Figueroa-Rodríguez, O.L., Holbrook, J., Lovett, R., Materechera, S., Parsons, M., Raseroka, K., Rodriguez-Lonebear, D., Rowe, R., Sara, R., Walker, J.D., Anderson, J., Hudson, M., 2020. The CARE Principles for Indigenous Data Governance. Data Science Journal 19, 43. https://doi.org/10.5334/dsj-2020-043

Parsons, M., Barry, R., 2006. International Polar Year Data Management Workshop [WWW Document]. URL https://nsidc.org/sites/default/files/documents/other/glaciological_data_33.pdf (accessed 5.14.23).

Parsons, M.A., Godøy, Ø., LeDrew, E., de Bruin, T.F., Danis, B., Tomlinson, S., Carlson, D., 2011. A conceptual framework for managing very diverse data for complex, interdisciplinary science. Journal of Information Science 37, 555–569. https://doi.org/10.1177/0165551511412705

PL, P., Yarmey, L., Godøy, Ø., Friddell, J., Parsons, M., WF, V., de Bruin, T., Manley, W., Gaylord, A., Hayes, A., 2014. Towards an international polar data coordination network. Data Science Journal IFPDA-16.

CODATA 2023. International Data Policy Committee. https://codata.org/initiatives/data-policy/international-data-policy-committee/

MEOPAR 2017. MEOPAR Data Policy. https://meopar.ca/wp-content/uploads/2021/01/Data_Management_Policy_-_September_2017.pdf

4.4.3. Technical Elements of the Arctic Data Ecosystem

The data ecosystem has many human nodes and relations, however, data, technology and other technical elements are central to the data system. A full discussion of all technical dimensions is beyond the scope of this report, however, the now well-known FAIR principles (Wilkinson et al., 2016)(Wilkinson et al., 2016) provide a useful set of topics used here to organize a discussion of core technical aspects of the data system. An emerging trend towards data platforms is also discussed as an increasingly important infrastructure element.

Findable

PRIMARY THEME: Arctic Data

Reference	https://zenodo.org/record/7787161#.ZF9zjXbMKMo
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Best Practice
CAPARDUS Subthemes	Data Management - Discovery

Summary: Data discovery is the foundation as it allows users to find data and evaluate its fitness for use. The FAIR principles dictate that data discovery, the foundation of data sharing and reuse, is supported by creation of rich metadata that is assigned a globally unique and persistent identifier and registered and indexed in a searchable resource. We now see many well-established institutional catalogues that are implementing these principles INTAROS in Europe, the Polar Data Catalogue in Canada, NSF Arctic Data Center in USA, and many others. However, this results in many catalogues and increases the level of effort required by users to find the best data available. The goal of "single-window" data discovery has been identified as a polar user community need for decades (Parsons and Barry, 2006). In that same report, Pulsifer and others propose a Union Catalogue that would share standardized metadata between data catalogues. There are many different standards available for metadata, with adoption typically related to the type or data and/or the research domain. ISO 19115 for geospatial data which touches on many research disciplines and community-based applications. More general standards such as the widely used Dublin Core, and W3C's DCAT. Although not a formal standard, a specification driven initially by industry is now being widely adopted in the research community.Schema.org is a lightweight specification that is meant to be easy to implement, with less complex structures (and rigorous development process) than more formal standards such as ISO.

The representative paper for this section (https://zenodo.org/record/7787161#.ZF9zjXbMKMo) *POLDER best practice guide to implementing schema.org for data discovery* provides community practices (standards) that were developed through community activities including the Polar Data Planning Summit, the Third Polar Data Forum and the Polar to Global Hackathon. This is an excellent example of the standards process (as practice) in action.

References to other relevant or complementary standards documents for data discovery:

ISO 2019. ISO 19115-1:2014. https://www.iso.org/standard/53798.html
Schema.org 2023. Welcome to Schema.org. https://schema.org/

Reference to other documents that evaluate or provide additional context for data discovery:

Contaxis, N., Clark, J., Dellureficio, A., Gonzales, S., Mannheimer, S., Oxley, P.R., Ratajeski, M.A., Surkis, A., Yarnell, A.M., Yee, M. and Holmes, K., 2022. Ten simple rules for improving research data discovery. PLoS computational biology, 18(2), p.e1009768.

Accessible

PRIMARY THEME: Arctic Data

Reference	(Godøy & Saadatnejad, 2017) (Pulsifer et al., 2018)
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Research
CAPARDUS Subthemes	Data Management - Access

Summary: The FAIR principles related to data access are relatively simple: (Meta)data retrievable by their identifier using a standardised communications protocol; a protocol that is open, free, and universally implementable; a protocol that allows for an authentication and authorisation procedure, where necessary; metadata that are accessible, even when the data are no longer available. Data access adds several dimensions of complexity that includes considerations for standardization. Non-standard data formats or proprietary/custom formats can make data access and integration very time consuming or impossible. This situation is often observed at portals that feature a more FTP-like data access rather than a Web service with a rich query interface. Using an open, interoperable standard with support for temporal dimensions (e.g., NetCDF, OGC WCS) avoids custom development tasks related to the integration of these data.

Godoy and Saadatnejad (2017) report a number of key considerations for FAIR date access. They recognize the continued move away from centralized systems to distributed systems and the related need for standards-based data services or Application Programming Interfaces. In this case, they adopt the use of the Data Access Protocol (DAP) and a standard format (NetCDF), along with standards-based metadata (DIF) and interface (OAI-PMH). This demonstrates that systems that demonstrate FAIR data access have been in place for some years. Standards are at the core of this system.

Interoperable

PRIMARY THEME: Arctic Data

References	(OceanInfoHub 2020), (Pulsifer et al. 2018)
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Research
CAPARDUS Subthemes	Data Management - Interoperability

Summary: Interoperability can be defined as properties of data and information systems that allow them to work and share with other information products or systems, present or future, without unintended restrictions. Moving towards interoperable polar information systems that are connected to the global information system is important and urgent considering the rate of environmental and social change being observed in the polar regions. Data and information systems are evolving rapidly and there are many existing, maturing and new projects, models and paradigms (e.g. Cloud Computing, Big Data, Semantic Web). Understanding and harnessing the most appropriate projects, models and paradigms is a high priority for the polar data community and decisions made now may have implications for decades to come. The FAIR principles set out several requirements for ensuring interoperable data: (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation ; (Meta)data use vocabularies that follow FAIR principles (see Cox et al. 2021); (Meta)data include qualified references to other (meta)data. As with other FAIR principles, metadata is at the core of interoperability. Additionally, standardized, shared vocabularies are central to (semantic) interoperability.

Semantic interoperability has been elusive for the data community as a whole and the Arctic data community in particular and there is little reported in the literature. However, systems are emerging. The highlight links in this section link to the Ocean InfoHub project that is producing a semantically interoperable hub for connecting many distributed system (see https://oceaninfohub.org/). Similarly, Pulsifer et al. (2018)(https://ccadi.ca) are deploying semantically interoperable web services that link Canadian data resources. All of these systems require documentation of shared vocabularies in standardized form, an important component of a standards framework.

References to other relevant or complementary standards documents for data interoperability:
ISO 2023. Standards by ISO/TC 211 Geographic information/Geomatics. https://www.iso.org/committee/54904/x/catalogue/
OGC 2023. OGC Standards. https://www.ogc.org/standards/

Reference to other documents that evaluate or provide additional context for data interoperability:
Zhao, Z., Hellström, M., 2020. Towards Interoperable Research Infrastructures for Environmental and Earth Sciences: A Reference Model Guided Approach for Common Challenges. Springer Nature.

Reusable

PRIMARY THEME: Arctic Data

Reference	(Nelson 2009), (McLean et al. 2020)
CAPARDUS Themes	Arctic Data
CAPARDUS Document Type	Research
CAPARDUS Subthemes	Data Management - Reuse

Summary: Data reuse builds on the other FAIR principles and include additional usage requirements: (Meta)data are richly described with a plurality of accurate and relevant attributes; (Meta)data are released with a clear and accessible data usage license; (Meta)data are associated with detailed provenance (e.g. processing history); (Meta)data meet domain-relevant community standards. The last principle is central to the focus of this report. Community standards are required to make data fully FAIR.

Re-use cannot be achieved if the data are not available over time. Therefore, data, representation of Indigenous Knowledge (especially of Elders), and all the necessary descriptive information, must be preserved. Too often, preservation is forgotten and data managers must pursue “data rescue” activities. Even current data are at risk of loss. Strategic data rescue programs must be developed, and preservation must be prioritized as a long-term investment and cost saving measure. The highlighted articles for this section focus on the archiving and preservation aspects of reusable. If preservation is not achieved, then the other elements of the FAIR reusable principle are irrelevant.

References to other relevant or complementary standards documents for data reusability:

OAI . Open Archives Initiative. https://www.openarchives.org/
W3C 2013. PROV-O: The PROV Ontology. https://www.w3.org/TR/prov-o/

Reference to other documents that evaluate or provide additional context for data reusability:

Borgman, C.L., 2017. Big data, little data, no data: Scholarship in the networked world. MIT press.

4.4.4. Data Platforms

The development of polar data infrastructure is occurring within a context of rapid growth in the provision of polar data and change in user expectations about access to and use of such data. The data available on the state of the planet is growing in precision, volume, velocity, variety, and value, increasing the complexity of scenarios for data exploitation, as well as the resources required by the communities using the data. A number of groups are developing innovative approaches to the creation of polar data platforms. These approaches share some common characteristics: Individual parameters by themselves are not nearly as valuable as integrated data sets. Therefore, the trend is to provide data platform users with access to a wide range of data types that they can be exploited together; With the explosion of the data that are available, data discovery and analysis is becoming increasingly challenging. As a result, the trend is to include sophisticated data visualization tools to enable data platform users to easily see and understand both the data they can utilize and the results of their analysis of that data.; The quantity of data available, especially EO data, means that it is often not practical for each user to download the data they need to their local environment. Rather, the trend is to bring the algorithms to the data and only download the results of their calculations; Working with such large data sets is often computationally intensive. This means that modern data platforms need to provide users with highly capable ICT infrastructure for data processing, storage, and networking; Research is increasingly collaborative. Therefore, the trend is to combine data and computation capabilities with the tools required for such collaboration and the ensuing dissemination of research results; The increasing diversity of data sources and the need for scientific and operational communities to access data unfamiliar to them makes it essential that useable data quality information is available for all products.

DATA SYSTEM RECOMMENDATIONS

Standardization

- Before creating strategies to enhance standardization, invest in understanding the standardization ecosystem. Establish an ongoing program that documents the entities in the system (standards, standards bodies, coordinating bodies) and the relationships between these entities. This understanding can support development of efficient and effective strategy.
- Understand the different kinds of standards involved in particular aspects of the data domain. For example, metadata standards are central to Findability in FAIR. Data standards are more aligned with Access, vocabulary standards with Interoperability etc. Standardization in this domain involves many related standards, not a single standard.
- Wherever possible, work with existing organizations to enhance standardization. Ecosystem mapping activities reported in this section clearly establish that there are many coordinating bodies and standards organizations working in this space. Leveraging these bodies will increase efficiency and accelerate progress.
- Recognize that standardization comprises more than identifying a standard. The human process of standardization includes governance, coordination and collaboration, an understanding of the ecosystem, technical considerations, resources, and qualified people, and others.

Governance

- Standardization in the area of data (and as a proxy for other themes) requires governance, collaboration, shared commitment, resources, technical platforms, skills and knowledge through education and training.
- Specifically, this should include the recognition of the right of Indigenous Peoples and nations to govern collection, ownership, and application of their own data, and the broad adherence of emerging principles and protocols such as the CARE (Collective benefit; Authority to Control; Responsibility; and Ethics) principles.

Coordination and collaboration:

- Maximizing the benefit of these advancements requires that the Arctic data community work closely with the global community and the Arctic observing community to address focused, real-world problems that are important to Arctic residents, and Indigenous peoples of the Arctic in particular.
- To continue functioning well as a community, we will enhance, extend, and formalize the SAON Arctic Data Committee and its pivotal role in driving collaboration (AOS) 2020
- Ensure representation from Indigenous Peoples and their representative organizations, the operational communities including the corporate sector, academic research community, national governments, international organizations, and funders.

Ecosystem:

- Building on existing efforts we will focus on establishing a distributed, co-owned, sustainable and coherent registry of digital resources which all partners can co-develop, access, and leverage for their needs.

Technical:

- We need to continue to work towards a broadly networked, collaborative, interoperable Arctic digital system based on a co-production model that includes much-needed mutual education and training.
- Facilitating the adoption, implementation and development (where necessary) of standards.
- Develop common metadata elements for use in a “single window” search.
- Developing an infrastructure that goes beyond a portal that provides data discovery and access functionality to a platform that also provides software and computing resources to analyze Big Data and produce information products making use of Cloud computing. With the massive volumes of data (particularly imagery) that are becoming available, processes need to be shipped to and executed as closely as possible to the actual data.

Funding:

- The Arctic observing community, including data managers, must continue to work together with Indigenous Peoples, funders, legislators, and other stakeholders to provide international funding opportunities.

Skills and Knowledge Development

- We recognize the need for the necessary resources to adequately support all actors participating in the co-production model. Achieving this vision will improve access to, and reuse of, invaluable Arctic data for the benefit of all users.
- Develop the capacity of data suppliers to collect and provide data in formats compatible with the polar data system.
- Develop mechanisms to support and build knowledge and skills among Indigenous communities and organizations so that they may fully participate in data initiatives.
- Develop courses to prepare researchers and community members with the skills needed to solve data-driven problems in research.

5. A framework for implementing standards and best practices

5.1. Framework Development Methodology

Section 2 defines a framework as a real or conceptual scheme or structure intended to serve as a support or guide for the building of something that expands the structure into something useful. In the case of CAPARDUS, we are aiming to establish a framework for Arctic standards that is focused on identifying the standards (broadly defined – see below) for a particular context and creating a road map for effective adoption of these standards. To scope this process, CAPARDUS is guided by primary and secondary themes as detailed in Section 3 with analysis reported in Section 4. As stated in Section 3, the framework is limited to review of literature. In the future, the community consultation originally proposed would allow for establishment of a validated, more detailed framework that can be used for decision support.

The analysis reported in Section 4 reveals a very complex set of ecosystems in all domains (cross-cutting, observing, safety, data, and many others). A standard is often a document (de jure standard, specification, law etc.). This standard is, however, produced through a social process of knowledge and requirements collection, implementation of structures, negotiation, promotion, distribution and other activities. Therefore, these ecosystems comprise people, organizations, governance models, standards, technology, and many other entities that in some way relate to the standardization process. To effectively facilitate standardization requires knowledge and understanding of these complex ecosystems. To move towards achieving this, the framework presented here is a combination of the analysis presented in Section 4 and a structured model represented as a graph-based model as outlined in this Section 2. A graph model describes the structure of a graph database, and is comprised of two core components—nodes and edges. An edge connects two nodes together by describing their relationship to one another. With many nodes connected by many edges, a spider-web of interconnected points emerges and is referred to as a graph. As a summary of Section 2, the primary elements of our graph are:

- The key concepts (classes) relevant to Arctic standards for the themes analysed? A key concept might be an existing standards document and its sub-concepts, or a standards body.
- The key relationships between and among Arctic standards concepts. This might be a set of causal relationships that highlight that standardization requires *the development of a community of practice* that agrees on the standard.
- Key "instances' of Arctic standards entities in the domain. This could be a community that has developed a high level of standardization; or a specific, important standard in a sub-domain such as tourism or data. Identifying specific instances is an important part of the framework as identifying these entities will allow for the leveraging of existing resources (standards, technology, humans, institutions etc.)

Building on these questions, we iterated through the review and analysis process to present an essential framework to guide Arctic standardization.

The following sections present a set of classes, relationships and individuals that are part of the framework at the time of writing. The process of developing the graph will continue beyond the duration of the project as a community activity. The graph database and related literature database will be made available through the CAPARDUS website at https://capardus.nersc.no/backgrounddocs. The Arctic standards ecosystem is constantly evolving and thus the framework and related models must be a living document.

5.2. Classes

Table 5.1 provides an example of a class hierarchy developed for the framework model. Establishing the class model for the proposed framework was challenging as it was based strictly on analysis of documents. Creation of a class model typically begins with analysis of documents or other related artefacts and is followed by community consultation and engagement (out of scope for this study). However, this example indicates how the concepts related to standardization can be structured from literature review. The class model provides structure for the nodes within our knowledge graph which provides context and the ability to analyse, aggregate and otherwise query the data in meaningful ways.

Classes are the core concepts of the framework. They represent the kinds of things that exist in our knowledge of standards and what must be considered when aiming to enhance our understanding to make informed decisions.

Table 5.1. A simplified class model by theme with example instances. Note that classes have been simplified here for representation. A more rigorous model would decompose the classes for simplicity (e.g. Class Standard with a "type" attribute value of 'Data').

Theme	Class	Subclass	Sub-subclass	Individuals
Data	DataEnabler	DataStandardsBody	De jure	World Meteorological Organization (WMO)
			De jure	International Organization of Standardization – Technical Committee 211 (ISO TC211)
			Profile	Open Geospatial Consortium
			De jure	World Wide Web Consortium
			De jure	Institute of Electrical and Electronics Engineers
			De facto	Open Archives Initiative
			De facto	Data Documentation Initiative
		DataStandard	Meteorological	Climate and Forecasting Convention
			Geographic	Geography Markup Language
			Metadata	ISO 19115
				…
		DataPrinciple	Interoperability	Findable, Accessible, Interoperable, Reusable (FAIR)
			Indigenous	Collective benefit, Authority to control, Responsibility, Ethics (CARE)
				…
		DataFunder	Regional	European Commission
			National	National Science Foundation
			Foundation	Melon Foundation
				…
Observing	ObservingSystem	ObservingStandard	EssentialVariable	
			SharedArcticVariable	
			ClimateObservingConventions	
			CBMStandard	
…				

For example, being aware of the kinds of existing data standards relevant to a research discipline (e.g., atmospheric, geospatial etc.) provides an understanding of the domain. Knowledge is further enhanced by providing real world instances or individual members of a class (see Table 5.1 and Section 5.4). Including classes (concepts) and individuals (instances) in the framework supports concrete understanding and decision support. For example, when aiming to move forward with a data standardization process for a particular discipline or domain, it is useful to know what kinds of things exist in the knowledge system (Data Standards, Data Standards Bodies, Data Principles). Concrete decisions on how to move forward can be made through understanding of specific standards, related principles and the bodies that created them: potential partners in the standardization process.

Fully understanding the ecosystem requires knowledge of relationships between classes and other classes and individuals. For example, know that the ISO 19115 metadata standard is published by the ISO Technical Committee 211.

5.3. Relationships

Relationships (properties, edges) allow us to go beyond simply identifying the entities that exist in the framework and provide a mechanism to understand not only the connections between entities but the specific nature of those connections. Relationships in the framework provide the ability to carry out advanced queries for understanding the ecosystem represented by the framework. For example, select all of data projects that use a specific data standard *and* the data standards body that publishes the standard.

Table 5.2. Relationships connect entities. Each relationship can be defined by one or more associated domains (the class to which the subject of a relation belongs) and a range (the class of its object value).

Relationship	Domain (example)	Range (example)
funds	DataFunder	Object: Individuals (e.g. institutions) receiving project funds
publishes	DataStandardsBody	Object: Individual of type DataStandard
isPublishedBy	DataStandard	Object: Individual of type DataStandardsBody
isMemberOf	DataCoordinationBody	Object: Individual of type DataActor
uses	DataStandard	Object: Individual of type DataCentre
…		

5.4. Individuals

Classes and relationships allow us to model our general knowledge that exists in the framework (that standards bodies publish standards and that data projects use standards). As introduced in Section 5.1, to document specific, real-world examples of these kinds of things, we include individuals in the framework. The documents analyzed and reported in Section 4, reveal classes and relationships, but also many, many individual entities that are part of the overall arctic standards ecosystem. We are often interested in these *individuals* (i.e. individual organizations, communities, programs, projects, , standards) as they are the core of the standardization process. For example, to establish a strategy for enhancing standardization in a particular domain (e.g., arctic observing) it is useful to know which observing projects are currently using a standard, the publisher of that standard, the specific standard being used, and a coordination group associated with the project. People from the project and coordination group could then be approached to consider building on the current level of standardization.

Table 5.3 provides a sample of examples of specific individuals that are relevant to a standards process. The table is not intended to be authoritative or comprehensive, however, it provides a framework for including individuals in the graph database. The specific individuals included in each class (e.g., Observing Framework, Observing Program etc.) will require additional research and, more importantly, community engagement, to populate the list of appropriate specific individuals. As pointed out by the EC reviewers, governance structures are often complex, requiring involvement of entities at different levels, both nationally and internationally. For example, when considering Indigenous governance organizations, including a national organization (e.g., ITK in Canada) is necessary but not sufficient. Going forward, the graph database would require inclusion of other international (e.g., Inuit Circumpolar Council and other Permanent Participants under the Arctic Council), national (First Nations Information Governance Centre), regional (e.g., Inuit regional land claim organizations/regional governments), and local (e.g., hunter and trapper organizations).

As part of the broader standards community, all organizations and other individuals would need to work together to identify the relevant voices and governance bodies needed to develop broadly inclusive and useful standards. Again, using Indigenous governance as an example, governance structures for Arctic Indigenous Peoples exist and consulting their international representative organizations (such as the respective Permanent Participant organizations of Arctic Council) to inquire about the proper approach for each is critical.

Similarly, to strategically reach all Arctic countries, Arctic Indigenous Peoples, and several pertinent organizations active in the Arctic, it would be most effective to include and approach Arctic Council at the higher political levels (Arctic Council Ministerial and/or Senior Arctic Officials) and work down to working groups and experts groups to achieve integration of all Arctic Council parts and associated bodies (including AMAP, CAFF, EPPR, SAON, as well as work up to ministerial levels of the eight Arctic countries, include the six Indigenous Permanent Participant organizations, and also observers of the Arctic Council). If done well, this would engage Arctic Indigenous Peoples, governments, research- and economic organizations active in the Arctic all at the same time and would be much more effective compared to individually approaching/including separate bodies and countries associated with the Arctic Council, while leaving out others. This approach would provide a mechanism to populate the proposed framework and graph database.

Table 5.3. Individuals are the specific entities (i.e., the proper nouns) in the framework. An individual is an instance of a class (see Table 5.1). This table provides examples of individuals by class drawn from Section 4.

Individual Name	Label	Country	Document Reference
Observing Framework (Class)			
FOO	Framework for Ocean Observing	International	4.1.2
EOV	Essential Ocean Variables	International	4.2.1
SBA	Societal Benefit Areas	International	4.1.1, 4.1.4
SAV	Shared Arctic Variable	International	4.1.1
…			
Observing Program (Class)			
US AON	U.S. Arctic Observing Network	U.S.A	4.1.1
SAON	Sustaining Arctic Observing Networks	International	4.4.2, 4.1.1
AMAP	Arctic Monitoring and Assessment Program	International	
IASC	International Arctic Science Committee	International	4.4.2
WMO	World Meteorological Organization	International	4.4.2
IPCC	International Panel on Climate Change	International	
INTERACT		International	4.4.2
…			

Organization (Class)			
ITK	Inuit Tapiriit Kanatami	Canada	4.1.3
IARPC	Interagency Arctic Research Policy Committee	U.S.A.	4.1.1
CAFF		International	4.2.6
GOOS	Global Ocean Observing System	International	4.1.1
NOAA	National Oceanographic Atmospheric Administration	U.S.A.	4.4.2
NSF	National Science Foundation	U.S.A.	4.4.2
USGS	U.S. Geological Survey	U.S.A.	
NSIDC	National Snow and Ice Data Center	U.S.A.	4.4.2
…			

5.5. A Knowledge Graph and Ontology Representing an Arctic Standards Framework

A framework of classes, relationships and instances can be documented and presented as a set of tables as we have done in Sections 5.2 – 5.4. This approach presents elements of the framework, however, a simple tabular representation is impractical and does not scale well. As stated, the ecosystem(s) involved in arctic standards is large and complex. Documenting the framework as a series of multi-page tables is difficult to interpret and maintain. Additionally, in many cases classes are associated with many different relationships and individuals can link to many other individuals in many ways. Tabular representations of these relationships, while possible, are difficult to interpret. Moreover, representation of the framework in tables in a report does not allow us to query the large volume of data to extract specific knowledge. To manage the volume and complexity, we propose the use of a graph data model to represent the elements of the framework. A prototype graph database has been created as part of the deliverables for WP1. This model and database is a prototype. A production-level model would require additional development and, importantly, consultation with the domain communities of practice (e.g. observing, tourism) to refine and validate the model and data. However, we recommend this approach as a fundamental part of building a framework for standardization. The following sections provide selected views of the prototype database developed for WP1.

5.6. Framework Concepts (Classes, Nodes)

Section 5.2 explained the importance of classes in the graph model that represents the components of the arctic standards framework reported in Section 4. From that analysis a series of classes emerged and are represented in the framework graph model. For example, top level classes include the Polar Data Ecosystem (see Section 4.4.2) and a set of subclasses that comprise the ecosystem (e.g. data principle, data governance body, data standard). These subclasses can be further refined to include more specific classes (e.g. metadata standard, atmospheric data standard) (Figure 5.1). This class structure or hierarchy is represented as a graph model serialized or formatted using the increasingly well-established World Wide Web Consortium's (W3C) Resource Description Framework (RDF) model and associated vocabularies such as the Web Ontology Language (OWL) (see Figure 5.7).

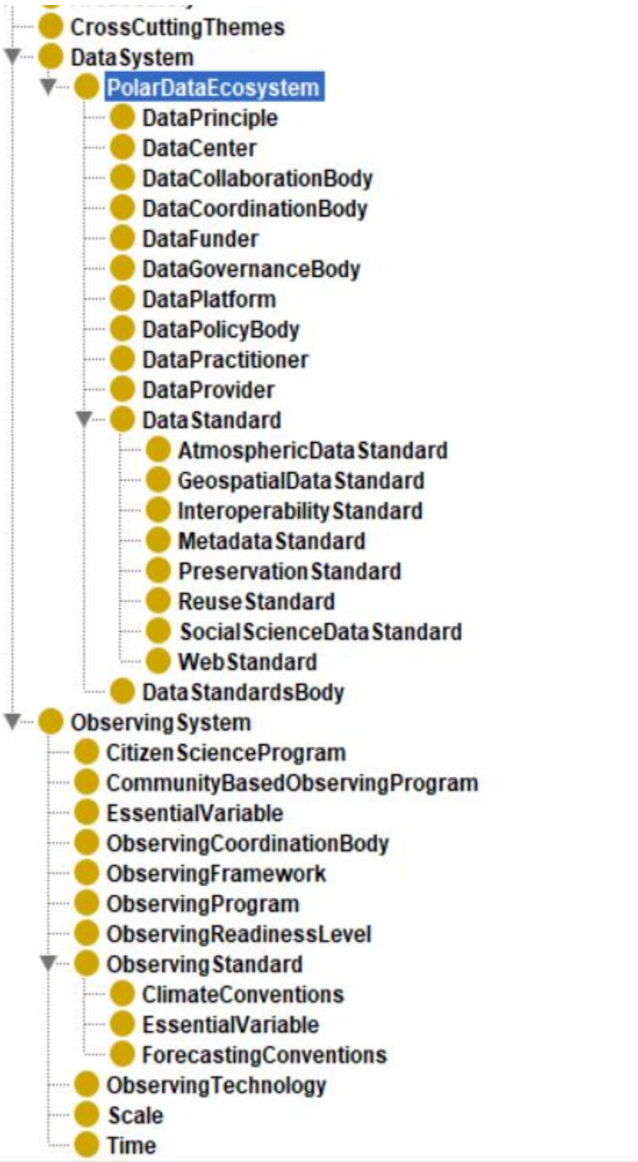


Figure 5.1. Partial representation of the framework concepts rendered in knowledge graph tool

5.7. Framework Relationships (Properties, Edges)

As previously explained, classes are one part of the framework and a graph model. Relationships are a fundamental part of a graph model and link classes to other classes or to individuals. For example, relationships can establish which funding agency *funds* which *data centre* or which *data standard is published by* which *data standards body*. Relationships are stored in the RDF graph model (Figure 5.2)

Figure 5.2. A subset of framework relationships used to connect instances of a class (e.g. NSF Arctic Data Center isFundedBy NSF).

5.8. Framework Instances (Individuals)

Linking classes to other classes using relationships can provide useful knowledge. For example, that a *Data Standard is published by* a *Data Standards Body*. To ground our knowledge, we typically also want to know the specific individual kinds of things and their relationships to one another. Building on the previous example, to inform decisions it is useful to know that the ISO 19115 Metadata Standard (a kind of Data Standard) is published by the ISO Technical Committee 211 (a Standards Body). The individuals included in the arctic standards framework were identified through the analysis presented in Section 4 and are modeled in the graph database using RDF as visualized in Figure 5.3.

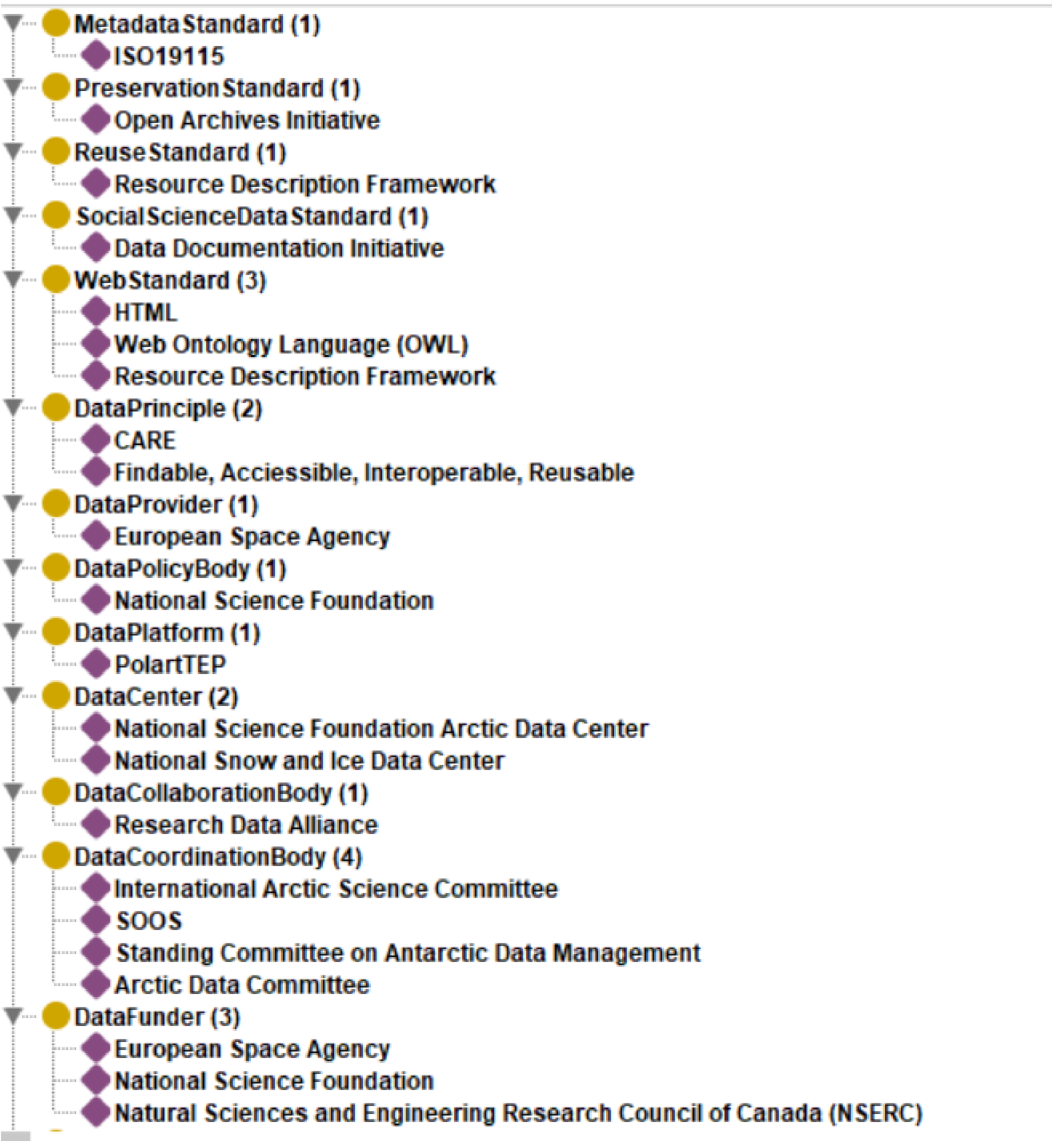


Figure 5.3. Selected individuals of different types. The graph database used to store the framework data can be queried to select by class or other logical expressions

5.9. Graph and Ontology Visualizations

The graph database is stored as code using the Resource Description Framework (RDF) and other vocabularies that very formally and precisely model the elements of the arctic standards framework (Figure 5.7) and this can be used by knowledge modeling experts and computer software to understand the framework. However, for non-experts, interpreting RDF code can be difficult if not impossible. Visualization is often used to make the graph database accessible to non-experts. Figure 5.4 presents an arctic standards graph database visualization of classes (circles) and relationships (lines). The visualization was generated using a powerful free and open source tool called WebVOWL (http://vowl.visualdataweb.org/webvowl.html). There are other tools available for visualizing and analyzing graphs including Kumu (https://kumu.io/, commercial) and the open source Protégé (https://protege.stanford.edu/, advanced functions). Instructions on how to visualize the arctic standards graph are provided on the CAPARDUS website at: https://capardus.nersc.no/backgrounddocs (see https://github.com/nansencenter/capardus/blob/main/README.md for specifics).

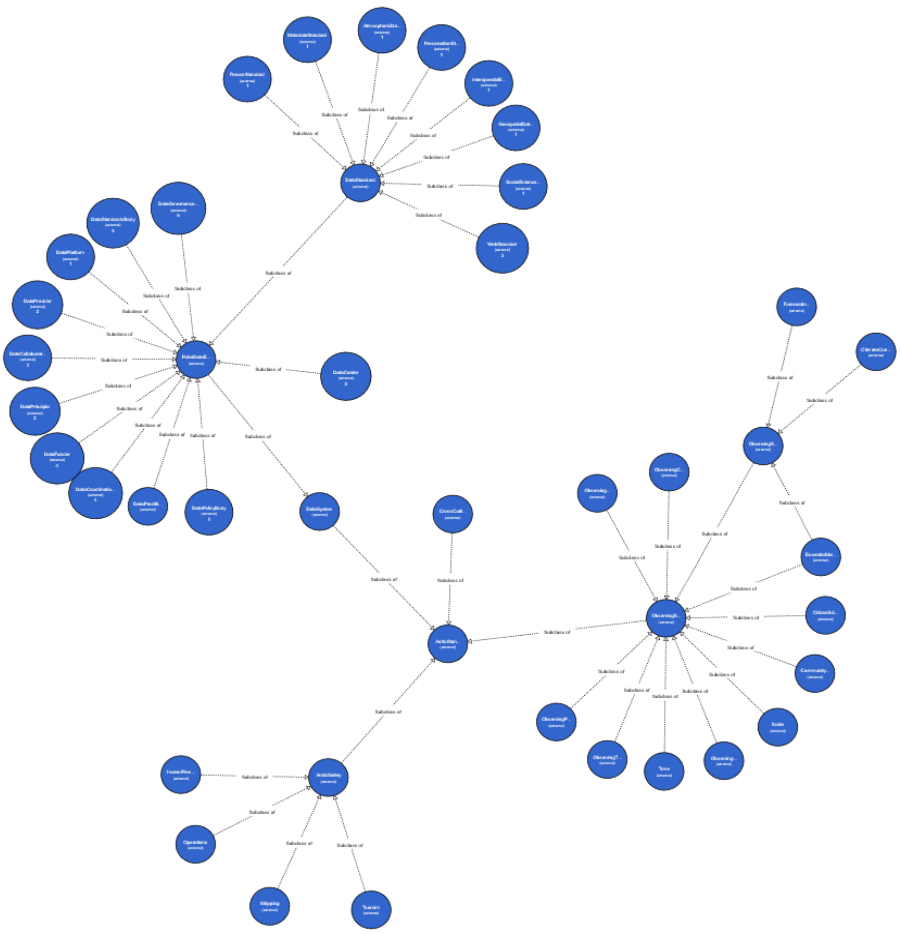


Figure 5.4. Visualization of complete framework class graph. See Figure 5.5 for detail.

Visualizing classes, relationships and individuals can provide a complete picture of the knowledge graph by including specific entities. Figure 5.6 was generated by the aforementioned Protégé tool and visualizes classes, relationships and individuals, differentiated using different symbols.

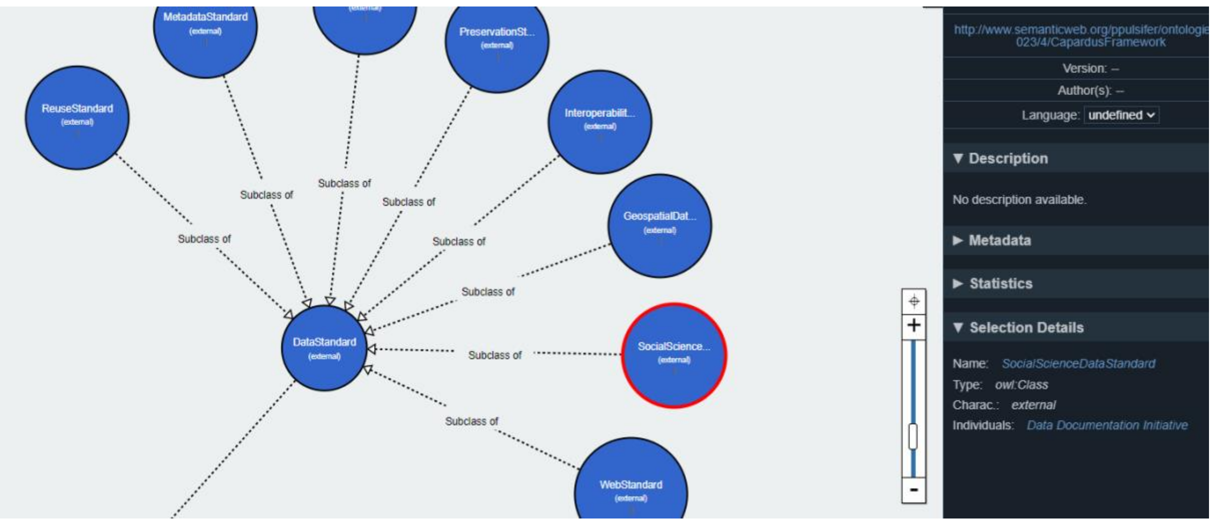
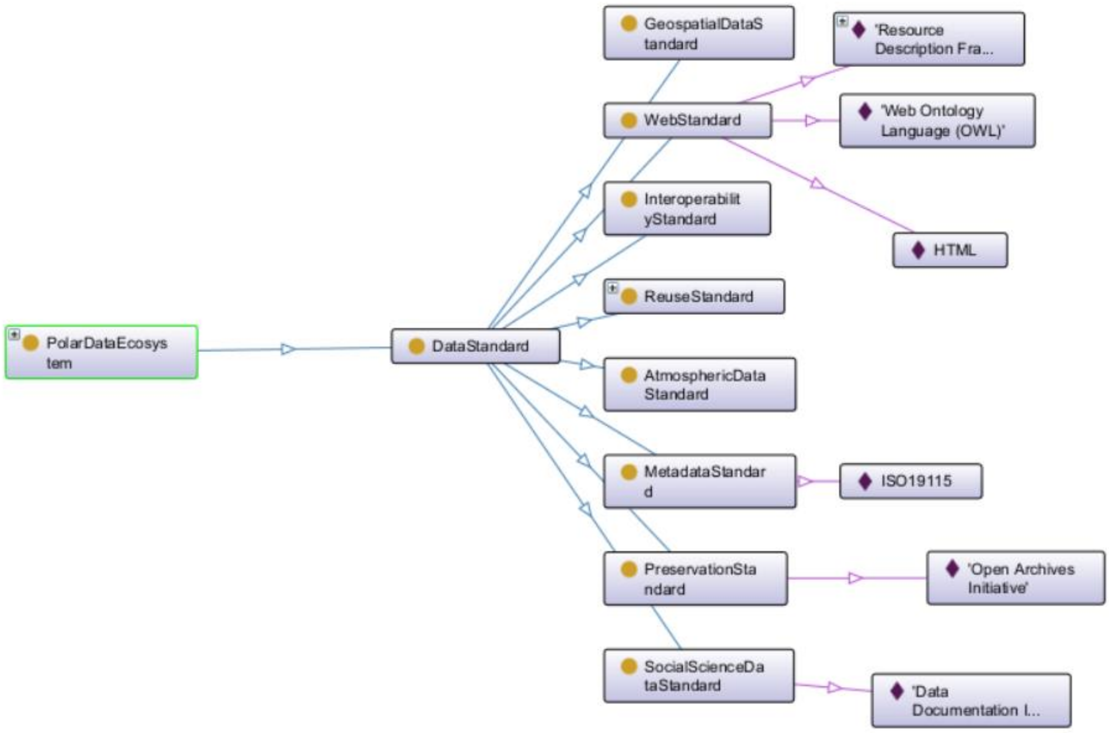


Figure 5.5. An enlarged view of the DataStandards subclasses. Note in the lower right corner of the image a list of instances (i.e. Data Documentation Initiative) can be viewed by selecting a subclass.



Class of entity (i.e. Data Standard) Real world instance of a class (i.e. ISO 19115)

Figure 5.6. A subset of the framework graph focused on different types of standards and real world examples. Specific standards of that type (silver box with purple diamond.

5.10. Graph and Ontology Code

The graph database produced using the results of the analysis presented in Section 4 can provide valuable insights and decision support simply through visualization and the enhanced understanding of the system that that provides. The true power of the graph database is realized through analysis of the underlying code using tools such as the SPARQL query language for RDF (https://www.w3.org/TR/rdf-sparql-query/). This allows a user to "ask questions" of the database: how many Data Standards exist in the ecosystem? Which Data Standards Organization publishes the Climate and Forecasting Conventions?

Expert users can use many tools to analyze the arctic standards framework graph database. Easy to use tools can be developed (outside of current scope) to allow non-experts to perform simple analyses. For example, the first version of the Mapping the Polar Data Ecosystem tool (Pulsifer et al. 2020) uses SPARQL queries to support simple filtering of that graph (http://staging.arctic-data-ecosystem.apps.nsidc.org/nationality). Users can simplify a very complex graph that includes hundreds of nodes and select a subset of only a few nodes (for example, visualize only the data organizations in Sweden).

An arctic standards framework is necessarily complex and large and includes many classes, subclasses, relationships, and individuals. Section 4 presents analysis of a sample of the arctic standards system focused on specific domains (cross-cutting themes, observing, safety, and data). This analysis reveals a dynamic, complex system of many entities (organizations, standards, technologies etc.), the understanding of which is required to frame and enhance standardization. The scale and complexity of the system and any framework designed to support standardization requires tools that go beyond a simple, static report document. A regularly updated database of entities and relationships is required to build on works like this to avoid the problem associated with many reports and assessments: they quickly become out of date and less useful. The highly connected, networked nature of the arctic standards system means that a graph database is ideal for representing the arctic standards framework.

This project has produced a prototype-database that can be enhanced and expanded through future community activities and projects.

```
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .

#    Classes
http://www.semanticweb.org/ontologies/2023/4/CapardusFramework#AtmosphericDataStandard
:AtmosphericDataStandard rdf:type owl:Class ;
                    rdfs:subClassOf :DataStandard .

http://www.semanticweb.org/ppulsifer/ontologies/2023/4/CapardusFramework#ClimateConventi
ons
:ClimateConventions rdf:type owl:Class ;
                rdfs:subClassOf :ObservingStandard .

…
#    Object Properties

  http://www.semanticweb.org/ontologies/2023/4/CapardusFramework#funds
:funds rdf:type owl:ObjectProperty ;
      owl:inverseOf :isFundedBy .

  http://www.semanticweb.org/ontologies/2023/4/CapardusFramework#isFundedBy
:isFundedBy rdf:type owl:ObjectProperty .

#    Individuals

http://www.semanticweb.org/ontologies/2023/4/CapardusFramework#ArcticDataCommittee
:ArcticDataCommittee rdf:type owl:NamedIndividual ,
                        :DataCoordinationBody ;
                :isMemberOf :IASC ;
                rdfs:label "Arctic Data Committee" ;
                rdfs:seeAlso "https://arcticdc.org" .

http://www.semanticweb.org/ontologies/2023/4/CapardusFramework#ArcticNet
:ArcticNet rdf:type owl:NamedIndividual ,
                :DataGovernanceBody .
```

Figure 5.7 The Arctic standards framework is stored as code in the Resource Description Framework model. The code can be analysed and visualized.

6. Conclusion

Standards can act as common language and practices among actors when aiming to share and use observing systems, data, ensure safety, and many other activities in the Arctic. It is vital that the standards development process ensures that all interested parties work together in the context of openness and transparency.

This report presented a review of a subset of Arctic domains that could benefit from some level of standardization. Standards are typically technical documents, while standardization is a human process that takes place in an ecosystem of interrelated and interdependent human actors, institutions, norms, and practices (including standards), technologies, information objects, and relationships. To enhance standards adoption, it is equally important to understand the ecosystem and its subsystems (general kinds of things, linkages and flows in the system) and the details of its interacting parts (e.g. the specific organizations, technologies, people and their needs). Standardization is a challenging and complex process and even defining the concept of standard can be difficult. As a geographically defined domain, the Arctic is highly complex and contains many knowledge systems, research disciplines, Indigenous peoples. settler residents, and operational activities to name a few. All of these elements need to be considered as part of any standardization effort. The analysis presented in Section 4 confirms this complexity, but also many opportunities to leverage existing nodes in the ecosystem to move the standardization process forward.

Section 5 proposed a method for documenting and understanding an arctic standards framework that represents the various relevant systems of organizations, individuals, technologies etc. Due to the breadth, depth and complexity of the systems involved, a simple report documentation method is not adequate nor able to capture the dynamic nature of standardization through updates. A graph database model that uses the standard Resource Description Framework is presented. This prototype-database captures the key concepts (classes), individuals and relationships in the systems as documented in Section 4. This knowledge graph (database) can be a dynamic framework to enhance standardization.

This Work Package presents several key results that are critically important in establishing a framework for arctics standardization.

- The concept of a "standard" is broad and complex, ranging from social norms to international technical standards to international treaties (and many others). Implementing standards requires a deep understanding of the domain of interest (e.g. observing, safety, a research discipline) to select the appropriate type of standard and standardization process required. What works for one community of practice may not work for another.
- The Arctic is a geographically defined community, and it comprises many domains including communities with Indigenous and non-Indigenous residents, multiple governance models, operational environments, research with many individual disciplines and sub-disciplines, civil society actors, and many social, economic, and environmental dimensions. This complexity prevents development of a simple standards framework for the Arctic.
- A standards framework requires a practical model that can document and analyse this complex system to identify the nodes or entities (standards, people, organizations) that can play a role in enhancing standardization. This must be a "living" model that engages the community in its construction and is regularly updated to reflect the situation at any given time.
- There are many existing frameworks, programs, projects, and activities that can be leveraged to enhance standardization. In the domains surveyed, there would be little need to establish new organizations or standards bodies to move forward.
- A graph database using the RDF Model is a practical method for documenting and analysing the arctic standards ecosystem. A prototype-database has been created through this Work Package and will be published through CAPARDUS website and supporting tools (i.e. GitHub) to allow for further development. To continue the work in line with recommendations of the Third Arctic Science Ministerial, a working group will be proposed under the Arctic Data Committee. This working group will leverage and contribute to the work of existing initiatives such as the Mapping the Polar Data Ecosystem project referenced in this report and the Arctic Data Committee Semantics and Vocabularies Working Group. The new working group will be proposed at the next Polar to Global Hackathon at the end of summer 2023.

Moreover, the results described above will provide valuable input to the development of a design and roadmap for an Arctic Practices System (APS). The APS is "a digital system to promote the sharing of methodological knowledge about living, working, researching, and sustainably managing the Arctic and its resources" (Buttigieg et al., 2023). Incorporating the domain knowledge, practices and standards documents, as well as the standards framework model and tools described in this report will support the establishment of an initial version of the APS. As the standards framework model evolves, additional resources will become available for extending APS content and functionality further.

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