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CANADIAN GEOSPATIAL DATA INFRASTRUCTURE
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ENVIRONMENTAL SCAN ON USER NEEDS ASSESSMENTS FOR THE ARCTIC SPATIAL DATA INFRASTRUCTURE

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ABDS	Arctic Biodiversity Data Service
ACAP	Arctic Contaminants Action Program
ADS	Arctic Data Archive System
AINA	Arctic Institute of North America (University of Calgary)
AIS	Automatic Identification System
AMAP	Arctic Monitoring and Assessment Programme
AOOS	Alaska Ocean Observing System
CaaS	Community as a Service
CAFF	Conservation of Arctic Flora and Fauna
CBM	Community-Based Monitoring
CEOS	Centre of Earth Observation Sciences (University of Manitoba)
CGDI	Canadian Geospatial Data Infrastructure
CI	Cyberinfrastructure
CSV	Comma-Separated Value
CSW	Catalogue Service for the Web
DaaS	Data as a Service
DEMs	Digital Elevation Models
DGGS	Discrete Global Grid System
DSM	Digital Surface Model
DWG	Data Working Group
EBSA	Ecological or Biological Sensitive Areas
EGNOS	European Geostationary Navigation Overlay Service
ELOKA	Exchange for Local Observations and Knowledge of the Arctic
EO	Earth Observation
EPSG	European Petroleum Survey Group
ERDAS	Earth Resources Data Analysis System
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
EU	European Union
FTP	File Transfer Protocol
GCMD	Global Change Master Directory
GCRC	Geomatics and Cartographic Research Centre (Carleton University)
GCW	Global Cryosphere Watch
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GEOTIFF	Geostationary Earth Orbit Tagged Image File Format

GGD	Global Geocryological Data
GML	Geography Markup Language
GNSS	Global Navigation Satellite Systems
HPC	High-Performance Computing
HTC	High-Throughput Computing
IBES	Institute at Brown for Environment and Society
ICC	Inuit Circumpolar Council
IHO	International Hydrographic Organization
IK	Indigenous Knowledge
IMO	International Maritime Organization
InaaS	Information as a Service
IRs	Implementing Rules
ITK	Inuit Tapiriit Kanatami
LTK	Local Traditional Knowledge
NetCDF	Network Common Data Format
NFS	Network File System
NGO	Non-Governmental Organization
NMAs	National Mapping Agencies
NORDECO	Nordic Agency for Development and Ecology
NPO	Non-Profit Organization
NSDI	National Spatial Data Infrastructure
NSIDC	National Snow and Ice Data Centre
OGC	Open Geospatial Consortium
OSCAR	Observing System Capability Analysis and Review
PacMARS	Pacific Marine Arctic Regional Synthesis
PAME	Protection of the Arctic Marine Environment
PDC	Polar Data Catalogue
PGC	Polar Geospatial Center
REST	Representational State Transfer
RFI	Request for Information
SaaS	Software as a Service
SBAS	Satellite-Based Augmentation System
SDI	Spatial Data Infrastructure
SLD	System Landscape Directory
SOS	Sensory Observation System
TEP	Thematic Exploitation Platform
UCD	User Centered Design
UI	User Interface

UNA	User Needs Assessment
VGI	Volunteered Geographic Information
WAAS	Wide Area Augmentation System
WCS	Web Coverage Service
WFS	Web Feature Service
WMO	World Meteorological Organization
WMS	Web Map Service
WMTS	Web Map Tile Service
WPS	Web Processing Service

EXECUTIVE SUMMARY

The purpose of this document is to report on findings related to the needs of the international Arctic community in terms of data and services (land and marine), standards, technologies (e.g. applications), operational policies, collaboration, leadership and governance. The research to identify needs was based primarily on an environmental scan of the available documentation and literature on Arctic user communities' needs, supplemented with selected consultations with developers and users of Arctic data. The report provides an assessment of user needs, illustrates the broad range and diversity of data providers, platforms and facilitators that exist in the Arctic and presents recommendations intended to help further the design and development of the Arctic Spatial Data Infrastructure.

User needs for data in the Arctic have been documented and analysed from a variety of perspectives. The range of data types is extensive given the large number of Indigenous activities, scientific disciplines and economic sectors involved in research and operations in the Arctic region. The major scientific user community segments and the types of activities driving data needs are multifaceted and there are complex interconnections between the different types of research being undertaken in the Arctic. In addition to science and research activities in the Arctic, the other key drivers of information requirements are operational processes in the region or elsewhere that affect or support the activities in the region. While there are relationships and overlaps between operational domains, there is a lower level of interconnection complexity.

User Needs

The study research suggests that Indigenous users have requirements for types of data that do not differ dramatically from other users' requirements. Data needs cover a broad spectrum with priority themes including, for example, traditional land use and environmental knowledge, administrative boundaries, sea ice, wildlife and remotely sensed imagery (i.e., base images). Particular requirements that typically differ from other users include data on cultural heritage (e.g. ceremonial and sacred sites, traditional use and harvesting areas). In addition, lay and traditional knowledge are of significant interest to these communities, and contribute to: climate change impacts, mitigation and adaptation; tackling food security; governance and resource rights; cultural identity; and conservation of biodiversity and habitats. Indigenous communities have unique concerns about data accessibility, ownership and control, which must be given consideration in SDI design and operation.

Non-Indigenous users in the Arctic require data covering the full gamut, from jurisdictional and administrative boundaries, to natural resources, protected areas and biodiversity, to environmental hazards, to sea, river and lake ice, permafrost and glaciers, to land use cover and change, and atmosphere, climate and weather. This data is required to support a wide range of scientific (e.g., climate change and adaptation, sea ice change, land use change, coastal zone change, species and ecosystem change, etc.) and operational (e.g., engineering design, environmental impact assessment, route planning, weather forecasting, search and rescue, etc.) activities. Users require access to both relatively static and dynamic kinds of data. For many scientific purposes and a few operational applications, there are requirements for archives of historical as well as more recent information, highlighting the importance of data curation and preservation. For the majority of operational uses, and particularly in the marine environment, access to near real-time information is critically important for safety of life and property purposes.

In addition to data access and discovery, users are increasingly interested in the ability to use cloud computing platforms to conduct data visualization, sophisticated data analyses, algorithm development and information product creation tasks and to share results with other users. Other considerations for the development and use of modern SDI platforms include such things as:

- Improved methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation and reflecting data quality limitations in metadata;
- Resolution of semantic issues in spatial data sharing and service interoperability;
- Common standards for and data integration between land and marine data sets;
- A common set of metadata elements relevant across polar sciences, to facilitate interoperability and sharing between polar data repositories and online portals;
- Development of strategic data rescue programs, and prioritization of preservation as a long-term investment and cost-saving measure; and
- Training of Indigenous communities and early career scientists and youth to ensure that they have the necessary data literacy to engage in intensive research while contributing to and benefitting from an open, interoperable system.

Data Providers, Platforms and Facilitators

An International Arctic SDI goes beyond data and services to include governance, establishment of standards and protocols, education, and engagement with user communities. Additional community building and deployment of Web services is required to fully realise an Arctic SDI. Thus, data facilitators, coordinators and other relevant organisations are included in this study. These organisations coordinate and drive collaboration as well as engage in research and education to bring about understanding, agreement and further the development of the Arctic data system.

The Arctic data system is large and complex, with hundreds of actors playing a variety of different roles. The summary of this ecosystem focuses on organisations that are acting as "hubs" in the network, either as a data aggregator or mediator, or a coordinator of activities related to the Arctic SDI. The discussion provides a method for situating various actors within the field to help Arctic SDI proponents to organize and prioritize engagement with initiatives. The overview is organised primarily by scale ranging from the international to more locally focused initiatives; however, "discipline" or subject matter can also be a useful organizational dimension. Appendix 5 of this report provides profiles of some 180 such organisations that developers of an International Arctic SDI should take into consideration.

The literature review identified numerous existing portals from which users can access data about the Arctic. A few of the major portals and the kinds of data and services that they provide include:

- *Arctic Spatial Data Infrastructure (Arctic SDI) Geoportal* – developed by the NMAs of the Arctic nations and providing pan-Arctic coverage, Arctic SDI layers (number) include: biota (8), boundaries (8), Climatology/meteorology/ atmosphere (30), economy (3), elevation (20), environment (27), farming (1), geoscience (10), health (3), imagery/base maps/earth cover (4), location (5), oceans (30), society (4), structure (2) and transportation (1)

- *Polar Thematic Exploitation Platform (Polar TEP)* – developed by Polar View Earth Observation, Polar TEP provides polar researchers with access to computing resources, earth observation (EO) and other data, and software tools in the cloud
- *GEOSS Portal* – operated by the Group on Earth Observations (GEO), the GEOSS Portal provides access to earth observation data in archives from 52 organisations worldwide
- *Observing Systems Capability Analysis and Review Tool (OSCAR)* – OSCAR contains quantitative user-defined requirements for observation of some 308 physical variables in application areas of WMO (i.e., related to weather, water and climate) and provides detailed information on all earth observation satellites and instruments and expert analyses of space-based capabilities.
- *Global Change Master Directory (GCMD)* – operated by the U. S. National Aeronautics and Space Administration (NASA), the GCMD is one of the largest public metadata inventories in the world, providing access to the following categories of data records (number of records): agriculture (1,838), atmosphere (&,848), biological classification (4,255), biosphere (7,046), climate indicators (700), cryosphere (3,109), human dimensions (3,870), hydrosphere (43), land surface (5,405), oceans (11,066), paleoclimate (1,621), solid earth (3,191), spectral/engineering (2,640), sun-earth interactions (439), terrestrial hydrosphere (3,294)
- *Polar Data Catalogue (PDC)* – a repository of metadata and data that describes and provides access to diverse datasets generated by Arctic and AntArctic researchers, the PDC is operated by the Canadian Cryospheric Information Network. The following datasets are accessible (number of datasets): Radarsat images of the Arctic (27,743), Radarsat images of the Ant Arctic (349), sea ice charts (3,972), other datasets of the Arctic (324)
- *Exchange for Local Observations and Knowledge of the Arctic (ELOKA)* – ELOKA fosters collaboration between resident Arctic experts and visiting researchers and hosts data management. An example, the Atlas of Community-Based Monitoring in a Changing Arctic, showcases the many community-based monitoring (CBM) and Indigenous Knowledge (IK) initiatives across the circumpolar region
- Atlas of Community-Based Monitoring in a Changing Arctic – designed to showcase the many community-based monitoring (CBM) and Indigenous Knowledge (IK) initiatives across the circumpolar region, this portal was developed with input from:
    - Inuit Circumpolar Council (ICC);
    - Institute at Brown for Environment and Society (IBES);
    - Exchange for Local Knowledge and Observations of the Arctic (ELOKA);
    - Inuit Qaujisarvingat: Inuit Knowledge Centre of Inuit Tapiriit Kanatami (ITK);
    - Carleton University's Geomatics and Cartographic Research Centre;
    - Nordic Agency for Development and Ecology (NORDECO);
    - Alaska Ocean Observing System (AOOS); and
    - Alaska Sea Grant.

Key Findings and Recommendations

This report clearly demonstrates the breadth of user requirements for data in the Arctic and highlights the existence of a diverse network of existing information providers and portals that are currently serving those needs. As a means of summarizing the key findings of the literature review, the report contains a table that adopts the following user needs assessment structure that is defined in the SDI Manual for the Arctic as follows:

- The **characteristics of users** (user profiles) that may impact use;
- The **key activities** or tasks performed by users;
- What reference and thematic **data** are the most useful for different types of users and at what geographic extent, spatial scale and time scale;
- What levels of **quality and usability of the data** (including licensing and use restrictions) are required in order to ensure that the data offerings can be fully exploited;
- What **data enhancements** are required;
- How existing **reference and thematic data** are **used** and **accessed**, and from where they can be accessed;
- What **distribution formats** are preferable for different types of users;
- What **Web services and tools** are the most useful for different types of users;
- What types of **data and service documentation** (e.g., metadata, user manuals) are required by different types of users in order for them to evaluate the fitness for use of the data and services;
- What data **products and services** might be **available** from providers or stakeholders;
- The scope of **general knowledge** about information management policies, geoportals, SDIs and their benefits;
- What legislation, strategic and operational policies, and **guidance** (standards, technology, procedures, etc.) are **required** or should be applied to enable the data providers, data distributors and data users to participate in the Arctic SDI;
- The level of **effort required** by data providers and staff of the participating NMAs **to incorporate** their **data** into the Arctic SDI; and
- What types of **future requirements** would be needed by users in order for them to better accomplish their work in the Arctic.

Based on the assessment of the study findings, the following steps in moving towards the establishment of a successful International Arctic SDI are proposed:

1. ***Develop an infrastructure that meets the growing demand for platform level services.*** This means going 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.

2. ***Ensure that data platforms are interoperable***. This means going beyond data interoperability to include sharing of code and processing of algorithms in chains across platforms. Making arbitrary applications available on cloud infrastructures or exploitation platforms in a standardised way is a key technology for Big Data in general and particularly true for Earth Observation satellite data processing.

3. ***Expand the scope of data that is accessible through the infrastructure to include social science data***. There is a need, particularly within Arctic Indigenous communities, for data and observations that can support decision-making in the context of socio-environmental change. The Atlas of Community-Based Monitoring in a Changing Arctic initiative is an example of initiatives being undertaken by Indigenous communities to help address this need.

4. ***In designing the infrastructure, ensure that the needs of "generalists" are given foremost consideration***. These Arctic data consumers (the vast majority of potential SDI users) typically have very limited education or training in the use of spatial information and lack the knowledge and experience to successfully engage with typical geoportals or SDIs. They require very simple user interfaces and tools to find and interpret the data they need.

5. ***Improve data discovery mechanisms, including annotation, vocabularies and linked data, crawling based approaches and service availability and reliability.*** Human- and machine-based annotation systems are required to identify data that has been used for specific purposes. Catalogues should provide their data in a way that search engines can fully harvest the catalogue content and other approaches such as direct harvesting of data services should be further investigated. Proper backlink mechanisms should be implemented that show data providers what the data has been used for.

6. ***Consider the distinctive needs of Indigenous communities in the development of infrastructure governance and policies.*** A number of studies have documented the sensitivities around sharing and use of Indigenous-specific and Indigenous-relevant indicators and data. Actions are underway to advance Indigenous community self-determination in collecting, verifying, analyzing, and disseminating Indigenous-specific data and information. Long-term capacity building must occur so that Indigenous people can be responsible for data design, collection, management, and application in research and decision making.

7. ***Build effective working relationships with established Arctic data management organisations and other data initiatives.*** To be successful in gaining traction with user communities and securing their interest in and use of an International Arctic SDI, the design and implementation must capitalise on the extensive work that has already been undertaken in these Arctic data communities (profiled in Appendix A5) and other data initiatives (e.g., Research Data Alliance) to make available data easy to access and use.

8. ***Support the further development of methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation.*** Users want access to the best quality data available and want the tools to assess their fitness for use. Provision of information on data quality and uncertainty is a critical part of metadata.

9. ***Provide functionality to handle the temporal dimension of data to meet the growing demand for analysis of the evolution of characteristics over time***. Using an open, interoperable standard with support for temporal dimensions (e.g., NetCDF, OGC WCS) will enable users to avoid custom development tasks related to the integration of these data. So-called "data cubes" are a data abstraction to evaluate aggregated data from a variety of viewpoints, including time series analyses.

10. ***Advocate for resolution of semantic issues in spatial data sharing and service interoperability***. In particular, semantic heterogeneity still causes several problems, including: discovery of data sets and services based on keywords; rigid metadata structures; missing semantics on technical terms; and missing matching capabilities for equivalent or related terms or symbols.

11. ***Ensure that the necessary resources are available to develop the capacity of data suppliers to collect data in a format compatible with SDI.*** Indigenous community members need appropriate training, equipment, and infrastructure and other support in order to carry out monitoring efforts that will facilitate data compatibility, and partnering scientists, funders and government workers need to develop new skills, capacities and knowledge areas.

1.0 INTRODUCTION

The Arctic Spatial Data Infrastructure (Arctic SDI) is the result of a voluntary and multilateral cooperation between the National Mapping Agencies (NMAs) of the Arctic countries (Canada, United States, Russia, Kingdom of Denmark, Iceland, Sweden, Norway and Finland). The goal of the Arctic SDI is to provide politicians, governments, policy makers, scientists, private enterprises and Northerners access to reliable and interoperable geospatial data, tools and services to facilitate monitoring and decision making in the Arctic. It is also offering tools for data distributors to ensure that geospatial data is easier for users to access, validate and combine with other data.

To be successful, the Arctic SDI must address and respond to user requirements, including interjurisdictional requirements and user-centered design issues, such as working in low bandwidth regions. The purpose of this document is to report on findings related to the needs of the international Arctic community in terms of data and services (land and marine), standards, technologies (e.g. applications), operational policies, collaboration, leadership and governance. The research to identify needs was based primarily on an environmental scan of the available documentation and literature on Arctic user communities' needs, supplemented with a few selected consultations with developers and users of Arctic data portals to learn more about design considerations.

Designing an infrastructure to meet the diverse range of user requirements for information in the Arctic is a daunting task. As illustrated in this report, not only is there a complex ecosystem of scientific and operational user communities with overlapping mandates and objectives, but there are also a plethora of data management initiatives and existing data portals that need to be taken into consideration.

The report is divided into six chapters. Following this introduction, the second chapter provides a brief description of the methodology employed for the study. Chapter 3 documents user needs for data in the Arctic identified from the review of previous relevant user needs assessments and available literature. The fourth chapter describes the key data providers, platforms and facilitators that currently exist to serve the needs of users in the Arctic. Chapter 5 highlights some of the important data access and use issues that impact how well user needs can be met in the Arctic. The sixth chapter discusses user-centered design considerations, including an independent review of the current Arctic SDI Geoportal user interface and a summary of the main trends revolving around user-centered design (UCD) of geospatial portals. Chapter 7 provides a summary of the key findings on user needs, in the format defined in the SDI Manual for the Arctic (Arctic SDI 2016), along with recommendations based on those findings. Chapter 8 provides a list of the references used. Appendices are provided that include more detailed information extracted from the documents examined, the types of organisations consulted from previous user needs assessments, and profiles of polar data initiatives and portals.

2.0 METHODOLOGY

The approach to identify user needs for international spatial data infrastructure comprised of two methods; document review and consultations. Beginning with a review of existing documentation and literature was an important first step given that much has already been written and studied about this subject area to date. This review resulted in a detailed summary of both user needs in the Indigenous community and other sectors as well as an overview of data providers. The review then identified data access and use issues as well as user-centered design considerations. Overall findings and summary conclusions were then developed in consultation and with expert guidance from Dr. Peter Pulsifer, current Chair, Arctic Data Committee of the International Arctic Science Committee and the Sustaining Arctic Observing Networks program and a leading expert in Arctic geospatial data.

Literature and Web Review

The literature review covered existing material concerning SDIs and user needs for spatial data. This included literature on international organisations that are concerned with spatial data in the Arctic, such as the *Arctic Spatial Data Infrastructure (Arctic SDI) Geoportal*, *Arctic Biodiversity Data Service (ABDS) Data Portal* and the *Polar Data Catalogue*, to name a few. Key documents dealing with Indigenous Community needs were reviewed, including the *Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis* study and the *Study on Arctic Lay and Traditional Knowledge*. The review also included an assessment of findings and conclusions from over 12 key international studies related to Arctic data including the *Polaris User Needs and High Level Requirements for Next Generation Observing Systems for the Polar Regions* and the *OGC Arctic Spatial Data Pilot – Phase 1 Report: Spatial Data Sharing for the Arctic*. As well, a web review of existing polar data portals and initiatives was undertaken. This work resulted in a comprehensive summary of existing user needs studies and a database of polar data portals/initiatives currently in existence (over 150), presented in Appendix A1 and A6 respectively.

Consultations

As noted above, the study team engaged with Dr. Peter Pulsifer as a key international expert in Arctic data management, and Dr. Pulsifer's insights on user needs and the organisations that are representing and responding to those needs are reflected in this report. While consultations with Arctic Council Permanent Participants were not conducted, some of these organisations have been engaged in a number of other user needs assessments in which Dr. David Arthurs and Dr. Pulsifer have been involved (e.g., the international Interoperability Workshop and Assessment Process held in Nov. 2016 and attended by ICC and Saami Council representatives). Through these interactions, a significant challenge has been identified - while these organisations have voiced strong interest in engaging in dialogue and requirements development around data issues, their capacity and expertise is limited. However, there are a number of related reports and documents that are relevant. For example, a 2016 White Paper[1] presented to the Arctic Observing Summit, which included participation by Inuit Circumpolar Council and Aleut International Association, outlines high level needs for how Indigenous people and organisations are engaged in the

[1] See (http://www.arcticobservingsummit.org/sites/arcticobservingsummit.org/files/Pulsifer-ELOKA--Extended_Sharing_Knowledge_statement.pdf)

consultation process. Similarly, the recently released National Inuit Strategy on Research[2], developed with ICC Canada, presents clear statements on access, ownership and control of data and information (pg. 30). Lastly, documents such as ICC's Alaskan Inuit Food Security Conceptual Framework report[3] provide details on information requirements (cf. pg 82). To adequately reflect needs from the perspective of Permanent Participants and other Indigenous organisations will require persistent dialogue and the development of ongoing relationships between these organisations and the Arctic SDI community. Partnership will be required to address the aforementioned capacity and expertise issues.

Additional consultations were undertaken with Indigenous communities in Northern Canada by Strata360 as part of the "Canadian Geospatial Data Infrastructure (CGDI) User Needs Assessments - Part B – Indigenous Communities and Spatial Data"[4] component of this study. Consultations also were attempted by RHEA Inc. to gather needs within the context of User-Centred Design. Unfortunately, due to time limitations, RHEA was not able to secure participation from the organisations they wished to consult in time for completion of the study.

[2] See https://itk.ca/national-strategy-on-research/

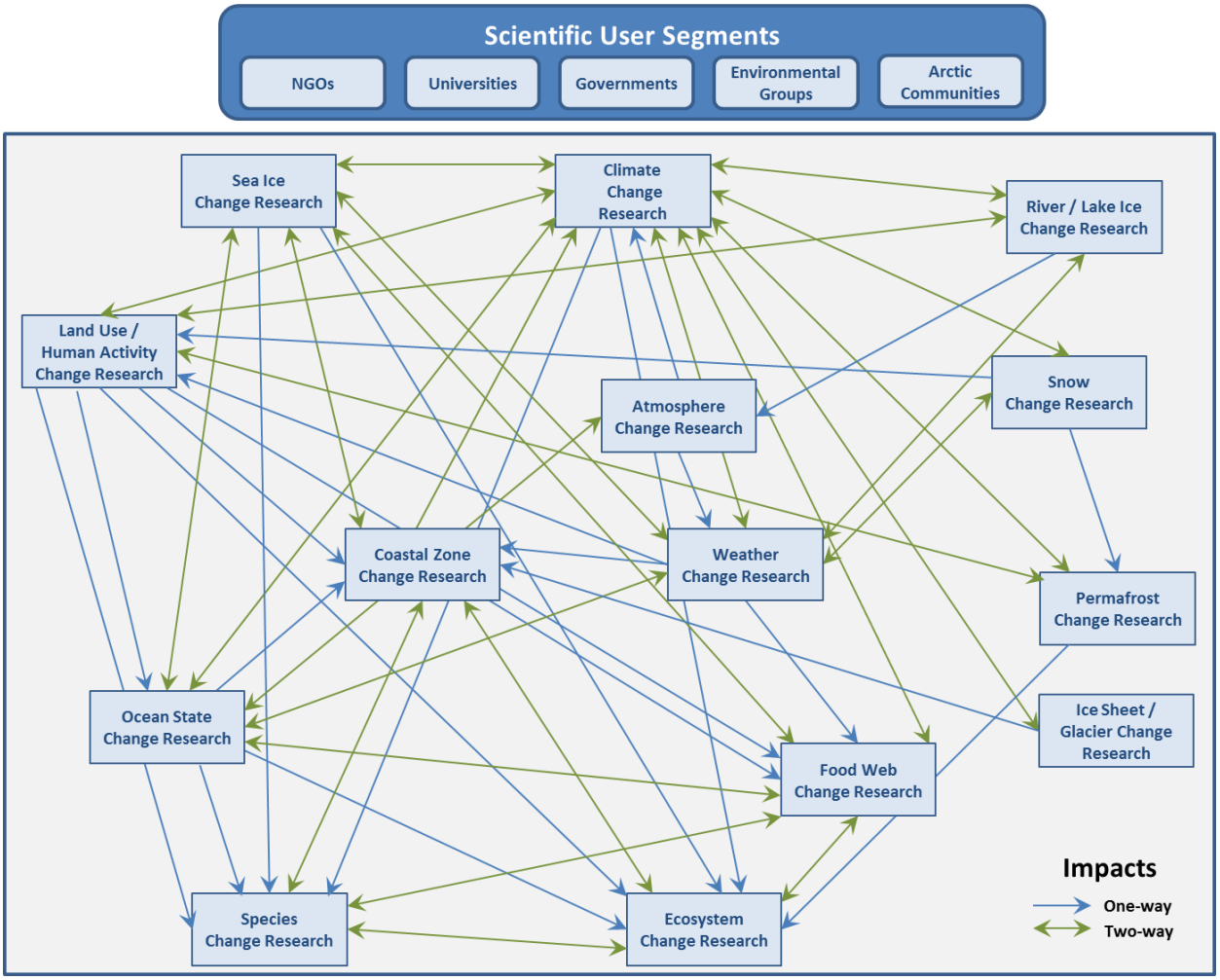
[3] See http://iccalaska.org/media-and-reports/

[4] See https://www.nrcan.gc.ca/earth-sciences/geomatics/canadas-spatial-data-infrastructure/8904

3.0 USER NEEDS FOR DATA IN THE ARCTIC

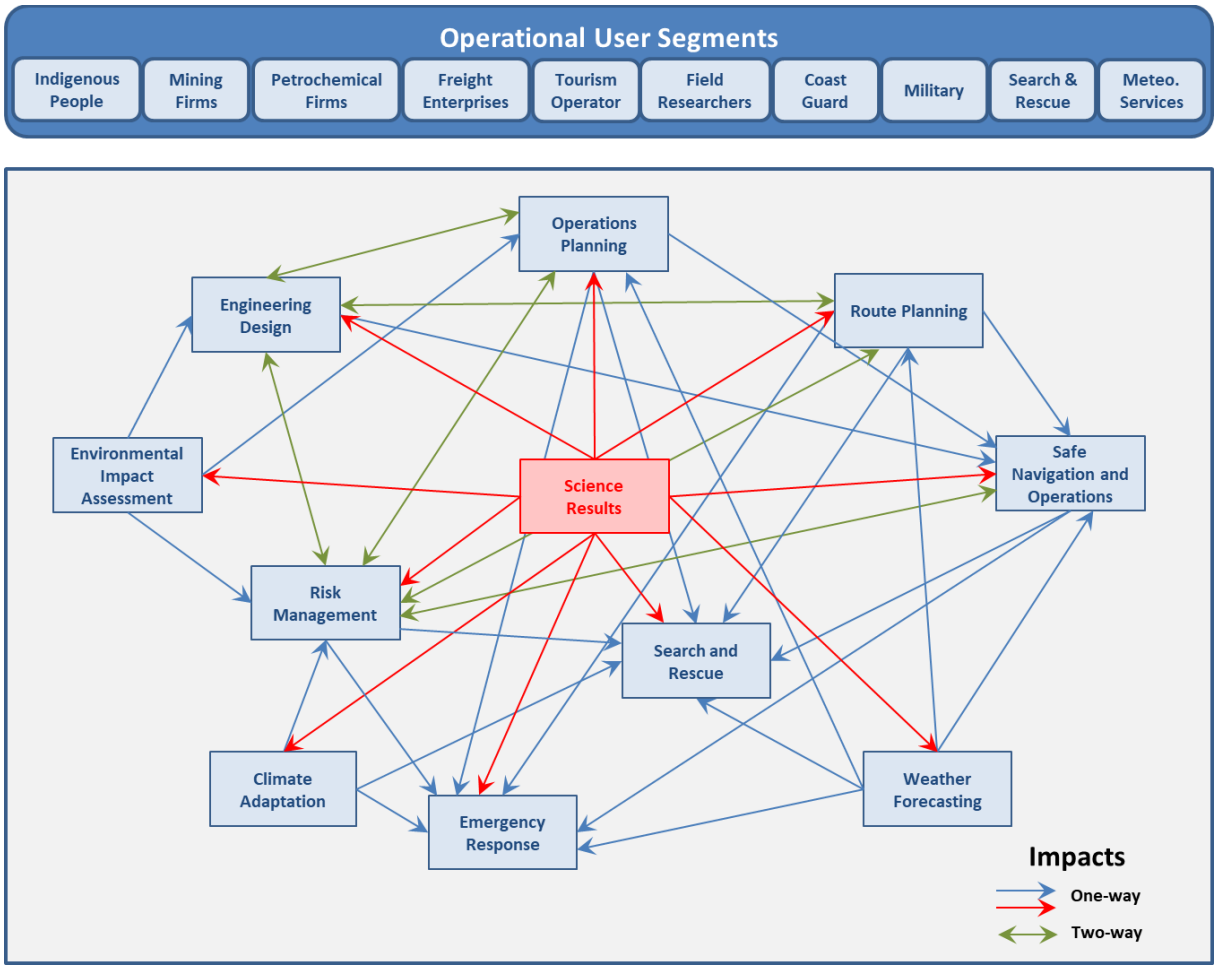
User needs for data in the Arctic have been documented and analysed from a variety of perspectives. The range of data types is extensive given the large number of scientific disciplines and economic sectors involved in research and operations in the Arctic region. The major scientific user community segments, and the types of activities driving data needs are identified in Figure 3.1, which illustrates the complexity of the research and science domain and identifies the connections between the different types of research being undertaken in the Arctic.

Figure 3.1 Arctic Science User Communities and Activities.



In addition to science and research in the Arctic, the other key drivers of information requirements are operational processes in the region or elsewhere that affect or support the activities in the region. While there are relationships and overlaps between operational domains, there is a lower level of complexity, as illustrated in Figure 3.2.

Figure 3.2 Operations User Communities and Activities.



The perspectives from which data needs in the Arctic have been assessed is impacted by the views of the diverse communities of users illustrated in Figures 3.1 and 3.2. This chapter provides a high level summary of the findings from the literature review of some of the key user needs assessments that have been conducted over the past ten years or so in two groupings – Indigenous Community and Other – which include:

Sources of Indigenous Community User Needs

- Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis, Executive Summary & Volume 2 Data Identification and Analysis (2008);
- Study on Arctic Lay and Traditional Knowledge (2014);
- Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic: A Review for the Sustaining Arctic Observing Networks (2016);
- Canadian Geospatial Data Infrastructure (CGDI) User Needs Assessments – Part B – Indigenous Communities and Spatial Data (2018); and
- National Inuit Strategy on Research (2018).

Sources of Other User Needs

- Strategic Roadmap for Canada's Arctic Spatial Data Infrastructure and Marine Cadastre;
- Polaris User Needs and High Level Requirements for Next Generation Observing Systems for the Polar Regions;
- EU-PolarNet Survey of existing use of space assets by European polar operators;
- Polar Thematic Exploitation Platform (P-TEP) Technical Note – Community Survey;
- Report on Workshop on Cyberinfrastructure for Polar Sciences;
- Summary – Arctic Council Joint Meeting – Outbreak Sessions on Geodata (September 2015);
- Response to the Open Geospatial Consortium Request for Information on Arctic Spatial Data by the Polar Data Community;
- OGC Arctic Spatial Data Pilot – Phase 1 Report: Spatial Data Sharing for the Arctic;
- OGC Arctic Spatial Data Pilot: Phase 2 Report;
- Interim Data Requirements for Arctic SDI;
- INSPIRE Data Specifications; and
- White Paper: The Hydrographic and Oceanographic Dimension to Marine Spatial Data Infrastructure Development: "Developing the Capability".
- Other Marine Spatial Data Infrastructure Initiatives

Further details of the literature review findings can be found in Appendix A1.

3.1 INDIGENOUS COMMUNITY USERS

3.1.1 Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis, Executive Summary (2008)

The purpose of this study was to develop a better understanding of geospatial data needs among Indigenous groups across Canada and issues surrounding how these data are being used. The objectives were (Makivik Corporation 2008a):

- to determine the key geospatial datasets required to support land and resource management by Indigenous communities; and
- to determine who the authoritative closest-to-source custodians are for the identified key geospatial datasets required to support land and resource management.

Data priorities and uses were identified by the study (see Appendix A1.1.2). Table 3.1 shows the dataset priorities identified by the communities that were consulted for the study.

Table 3.1 Dataset Priorities

Class	Sub-Class	PRIORITY	# Groups Identified as High Priority
Natural Heritage	Wildlife	HIGH	100%
Administrative/Development	Mining	HIGH	90%
Administrative/Development	Indigenous Territories	HIGH	80%
Administrative/Development	Forestry	HIGH	80%
Administrative/Development	Land Use / Land Management	HIGH	80%
Administrative/Development	Tourism and Recreation	HIGH	80%
Framework	Roads	HIGH	80%
Administrative/Development	Conservation/Protected Areas	HIGH	70%
Cultural Heritage	Use and Harvesting Areas	HIGH	70%
Natural Heritage	Ecology	HIGH	70%
Administrative/Development	Fishery	MEDIUM	60%
Framework	Infrastructure	MEDIUM	60%
Biophysical	Hydrology	MEDIUM	50%
Cultural Heritage	Travel and Trade Routes	MEDIUM	50%
Framework	Administrative Boundaries	MEDIUM	50%
Framework	Hydrography	MEDIUM	50%
Biophysical	Geology	MEDIUM	40%
Cultural Heritage	Archaeology	MEDIUM	40%
Cultural Heritage	Ceremonial and Sacred Sites	MEDIUM	40%

Aside from identifying how geospatial data were being used, other themes emerged as priorities for community practitioners, including:

- Issues of access to data;
- Lack of current use of web-based mapping;

- Problems associated with locating and downloading geospatial data;
- Lack of data standards and format issues;
- Issues of access to satellite imagery;
- Problems assembling and maintaining cultural data inventories;
- Difficulties establishing and retaining geomatics capacity;
- Concerns about data confidentiality and protocols;
- Understanding land use planning in context of broader issues; and
- The need to continue the dialogue.

Findings of the Aboriginal Community Land and Resource Management study that are of interest to this study were categorised as follows (See Appendix A1.1.1 for details):

- Data custodians / suppliers;
- Frequency of updates (data currency;
- Data formats;
- Data access;
- Data confidentiality;
- Datasets where cost is a factor in acquisition;
- Metadata; and
- Missing geospatial data and barriers to access and use.

3.1.2 Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis, Volume 2 Data Identification and Analysis (2008)

Volume 2 documents and summarizes the geospatial data used in ten Indigenous land use planning projects (Makivik Corporation 2008b). Table 3.2 provides a list of data categories, classes and sub-classes that are required to meet Indigenous Community Land and Resource Management needs[5].

[5] A comprehensive view of priority framework and thematic datasets as well as a list of the associated information (description, number of records, resolution, data providers, and dataset examples) can be found in Appendices B and C of the Makivik Corporation report, respectively.

Table 3.2 Data Required to Meet Indigenous Community Land and Resource Management Needs.

Category	Class	Sub-Class	Dataset
Thematic	Administrative / Development	**Indigenous Territories**	Boundary, Indian Reserve; Boundary, Indian Territory; Boundary, Treaty; Settlement Area Boundary
		Land Ownership	Boundary, Private Land; Cadastral; Right of Way
		Socio-Economic	Economic Data; Population/Census; Population Density
		Conservation / Protected Areas	Conservation/Protected Areas; National Parks; Park Proposals; Provincial Parks; Boundary, Parks; Protected Areas; Conservation Zone
		Agriculture	Agriculture
		Fishery	Fishery, Commercial
		Forestry	Forestry; Eligible Harvest Areas; Timber Harvesting; Proposed harvest units
		Land Use / Land Management	Land Use Zones; Land Management Zones; Land, Commercial; Land, Institutional; Land, Residential; Designated Areas; Human Impact; Landfill / Waste Sites; Special Management Zones
		Tourism and Recreation	Tourism; Hunting, Commercial; Hunting, Sport; Outfitting; Recreational Areas; Tourism Potential; Tourism Areas
		Energy Development	Energy Development; Wind; Hydro development
		Mining	Mining; Mineral Potential; Mineral Claim and Leases; Coal – Developed Prospect; Coal – Past Producer; Coal – Prospect; Coal – Showing
		Oil and Gas	Oil and Gas; Oil and Gas Rights; Proposed Pipeline
Thematic	Biophysical	**Weather and Climate**	Climatology; Precipitation; Temperature; Snowfall
		Geology	Geology
		Land Cover	Land Cover; Vegetation; Wetland Types; Wetlands; Built-up Areas
		Hydrology	Hydrology; Watershed Boundary; Watershed Units; Watersheds
		Coastal Zone	Tides; Currents; Water Levels
Thematic	Natural Heritage	**Fauna**	Animals; Birds; Fish
		Ecology	Habitat; Biogeography; Paleo-ecology
		Sensitive Areas	Environmentally Sensitive Area; Disturbed Area
Thematic	Cultural Heritage	**Archaeology**	Archaeology; Archaeological Finds; Archaeology Density
		Ceremonial and Sacred Sites	Sacred Areas and Burial Sites; Cultural Value Survey; Heritage Sites; Birth sites
		Use and Harvesting Areas	Traditional Land Use; Traditional Hunting; Fishing Sites; Medicinal Plants; Trapline Boundary; Traplines; Trapping; Traditional Use (Sites); Wildlife, Critical; Land Access
		Occupancy Areas	Cabins; Camps; Trading Posts
		Cultural Toponomy	Traditional Place Names
		Travel and Trade Routes	Traditional Place Names; Transportation Routes; Travel Routes; Canoe routes; Canoe Heritage Trail; Human Migration; Portage trails; Portages; Traditional trails

Table 3.2 (Cont'd.)

Category	Class	Sub-Class	Dataset
Framework	Framework	**Hydrography**	Waterbodies (Lakes/ Ponds); Waterways (Rivers/ Streams)
		Elevation	Contours; DEM; Hillshade
		Toponomy	Place Names (Toponomy)
		Bathymetry	Bathymetry
		Infrastructure	Infrastructure; Utilities; Utility Line; Water Supply; Powerlines; Transmission Lines; Transmission Tower; Airstrip; Anchorages; Bridges; Communication Lines
		Transportation	Railways; Shipping; Other
		Roads	Roads; All Weather Roads; Existing Roads; Unpaved (Public) Roads; Seasonal Road; Winter Roads
		Remote Sensing	Satellite Imagery; Aerial Photography; Lidar
		Administrative Boundaries	Boundary, Province; Boundary, Country; Towns and Communities
		National Topographic Datasets	Base Data – National Topographic; Data Base
		Provincial Topographic Datasets	British Columbia's Terrain Resource Information Management (TRIM)

3.1.3 Study on Arctic Lay and Traditional Knowledge (2014)

The purpose of this study was to identify and collect basic information on community-based monitoring and observing programmes in the European Arctic (European Commission 2014). Based on the analysis of community-based programmes, lay and traditional knowledge (LTK) was grouped into 5 main themes:

- Climate change impacts, mitigation and adaptation – LTK contributes to: setting baselines to guide scientific efforts; combining spatial and ethnographic data; identifying adaptation strategies developed by local communities; collecting evidence on human-ecological change and interaction; developing monitoring programmes; and feeding worldwide scientific networks.
- Tackling food security – LTK contributes to: combining LTK with scientific research; optimizing social networks; monitoring changes in subsistence-oriented behaviour and impact on community food distribution networks; and identifying factors affecting specific food resources.
- Governance and resource rights – LTK contributes to: enhancing dialogue among main Arctic actors and decision-making processes; building consensus and implementing actions; informing public policies and mitigation measures; designing adaptive management systems; achieving collaborations between communities and scientists; and identifying community-dependent needs.
- Cultural identity – LTK contributes to: monitoring sensitivity to changing conditions; fostering sustainable business development; quantifying traditional values; promoting knowledge transfer; and promoting LTK awareness to target audiences.

- Conservation of biodiversity and habitats – LTK contributes to: mapping and tracking endangered species; maximizing local skills; describing ice and sea-ice situations; improving public participation in wildlife conservation programmes; and coupling global and local problems and promoting broad alliances.

3.1.4 Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic: A Review for the Sustaining Arctic Observing Networks (2016)

This review sought to address the need for better information about community-based monitoring (CBM) in the Arctic (Johnson, Behe, et al. 2016). It drew on information about past and current CBM and Indigenous knowledge (IK) initiatives and programs in the circumpolar region that had been collected in the online Atlas of Community-Based Monitoring in a Changing Arctic. The kinds of information that these communities are collecting in their CBM programs include:

- Terrestrial animals
- Fish/Marine mammals
- Birds
- Plants, flora
- Human health
- Food security
- Lakes/rivers/streams
- Glaciers and/or snow
- Sea ice
- Weather
- Air quality
- Permafrost & terrestrial issues
- Resource extraction, industry & development
- Tourism
- Land/sea use
- Social/cultural/economic issues
- Governance & rights

3.1.5 Canadian Geospatial Data Infrastructure (CGDI) User Needs Assessments – Part B – Indigenous Communities and Spatial Data (2018)

The purpose of this study (conducted in parallel with this Arctic SDI environmental scan) was to assess Canadian geospatial data needs and requirements within the context the CGDI (Hatfield 2018). Building on Makivik (2008), which documented Indigenous use of geospatial data for land use planning, Part B focused on documenting a cross-section of Indigenous community needs for geospatial information across Canada. The research method included review of previous relevant studies and literature, an online survey of Indigenous communities, and direct interviews with individuals from selected organisations.

The research found that northern Indigenous organisations have spatial data needs that vary widely in both geographic scope and because of the nature of mandates, which differ because of differences in organization size and mandates. Northern Indigenous organisations include individual communities, regional land management organisations (e.g., Kivalliq Inuit Association), organisations with particular

administrative responsibilities (e.g., Nunavik Marine Region Wildlife Board), and regional co-management organisations (e.g., Yukon Land Use Planning Council). Each deals with barriers unique to their situations, but they often also share common needs, challenges, and goals for the future use of geospatial data.

The activities undertaken by these organisations vary widely. Traditional use and occupancy studies and natural resource management and planning were most commonly cited as important activities. Most respondents to the survey and interviewees from the study indicated use of geospatial data for climate change monitoring and adaptation, consultations with industry and government, and research projects.

Human capacity was found to be a barrier amongst Indigenous organisations. More than half of organisations surveyed reported training, skills, and capacity were challenges to acquiring and making use of geospatial information. Those without geomatics capacity perceived a need to establish it, and those with capacity perceived a need for more funding, time, personnel, and expertise. Many indicated that the uneven distribution of geomatics capacity in partner or constituent organisations is a barrier to being able to share data. Lack of funding to hire specialists and develop staff geospatial capability was also frequently discussed as a barrier.

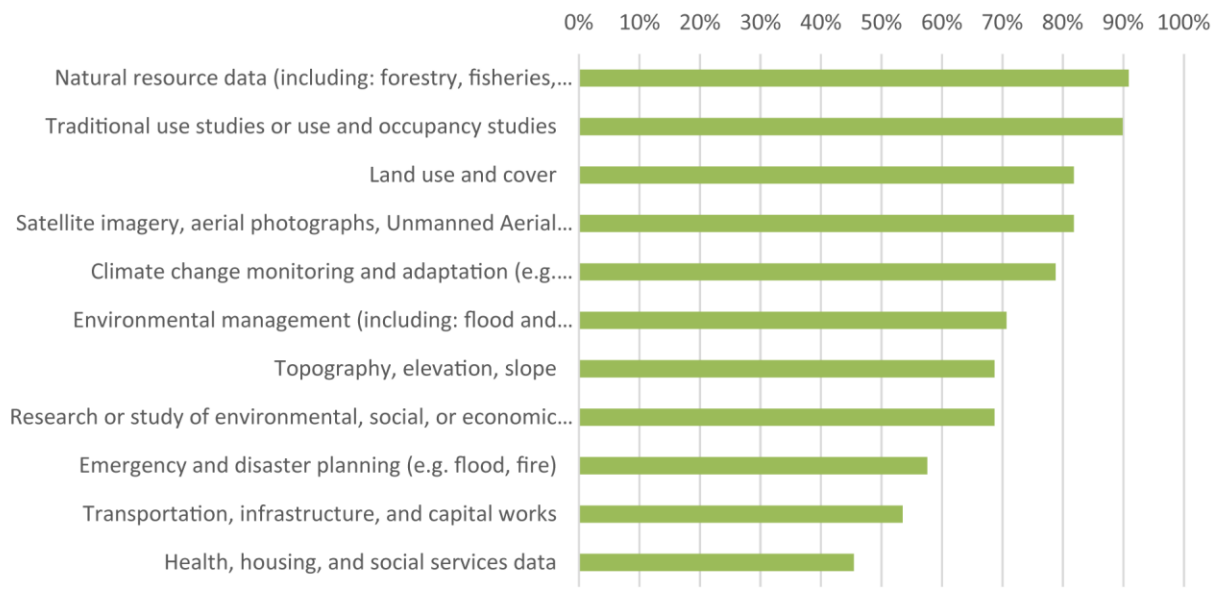
The research found that Indigenous communities often found geospatial data were not useful for decision making in raw format; they perceived raw datasets as large and complex, and refining them into useable information as requiring unavailable expertise in the subject matter and geoprocessing.

The research focused attention on geospatial information needs that Indigenous organisations perceived as not being satisfied. Shortcomings in ability to use desired information resulted from:

- the organization not being able to find it (either because information was unavailable or because of shortcomings in data discovery);
- data being available in raw formats that the organization did not have the capacity to process into a form useful for decision-making; and
- data being prohibitively expensive for the organization.

Figure 3.3 summarizes the percentage of Indigenous organisations who identified as important or very important, various types of geospatial data needs that would add value if the information was more readily available.

Figure 3.3 Types of geospatial information that would add value if more readily available, ranked by the percentage of Indigenous respondents.



Comparing these findings with the findings from the Makivik 2008 study, the following general observations can be made (although there are important differences in the data categories):

- Wildlife and forestry data continue to be high priority and fishery and hydrology/water resources data have apparently increased in importance.
- Traditional use data have apparently increased slightly in importance.
- New categories, satellite and airborne imagery and climate change, are highly valued.
- Apparently transportation (roads) decreased in importance while the importance of infrastructure remained approximately the same.
- Several categories of high importance to communities in 2008 (e.g. Indigenous territories and tourism and recreation data) were not included in the survey for the current study and important data categories in this study such as climate change and environmental management were not included in the 2008 study.

3.1.6 National Inuit Strategy on Research (2018)

The National Inuit Strategy on Research (NISR) was developed by Inuit Tapiriit Kanatami (ITK), the national representational organization for the Inuit in Canada (Inuit Tapiriit Kanatami 2018). The objectives and actions of the NISR fall within five priority areas: (1) Advance Inuit governance in research; (2) Enhance the ethical conduct of research; (3) Align funding with Inuit research priorities; (4) Ensure Inuit access, ownership, and control over data and information; and (5) Build capacity in Inuit Nunangat research.

Priority Area 4 is of particular relevance to this user needs study. To meet the objectives of the NISR, ITK plans to:

- Advocate for the consistent production and sharing of Inuit-specific and Inuit-relevant indicators and data, including the Inuit Health Survey;
- Invest in culturally-relevant, community-based technology to facilitate access to and management of data and information;
- Develop Inuit-specific guidelines on data accessibility, ownership, and control; and
- Create and invest in digital Inuit Nunangat data repositories that are inclusive of Inuit knowledge in ways that are respectful of its distinctive forms as well as the Inuit norms that govern its use and sharing.

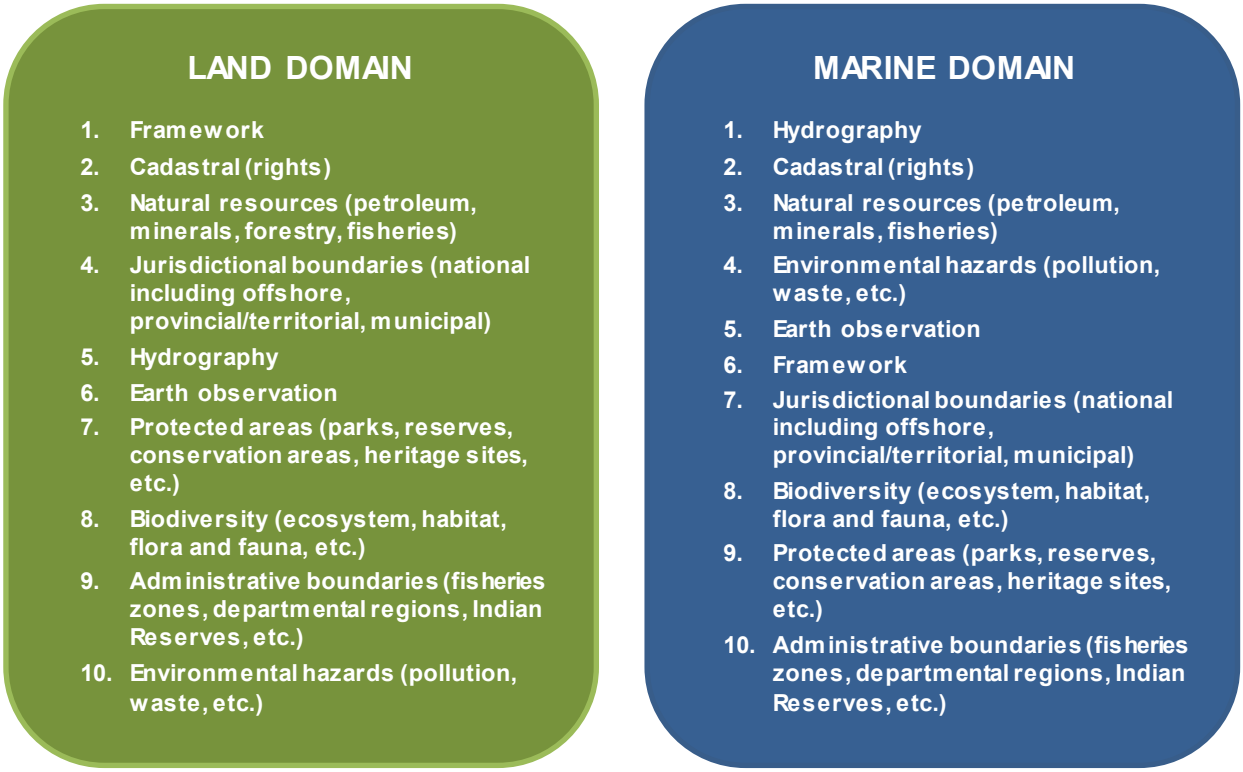
3.2 OTHER USERS

3.2.1 Strategic Roadmap for Canada's Arctic Spatial Data Infrastructure and Marine Cadastre

This project informed the development of a strategic plan and roadmap for Canada's Arctic SDI with a marine cadastre component. This strategic plan and roadmap was intended to assist in identifying priorities, needs, gaps and actions required to develop the CGDI to meet the needs of Arctic stakeholders (Fujitsu Consulting 2012a).

The results of the research and analysis of user needs for this project are presented in two reports. The *Environmental Scan Report* (Fujitsu Consulting, 2012a) documents the results of an environmental scan of relevant documentation, such as strategic policies, plans and priorities, legislative frameworks, technology demonstrations and other relevant federal, territorial, NGO, community, and international initiatives. The *Validation and Gap Analysis* report (Fujitsu Consulting 2012b) documents the results of the second phase of the project, which allowed the project team to: validate the findings of the environmental scan through consultations with stakeholders (see Appendix A2); determine geospatial data availability based on the requirements; and conduct a gap analysis between existing and required information. Based on the prevalence of data needs mentioned in (or implied from) the reviewed documents, the top ten assessed needs for data in order of priority are shown in Figure 3.4.

Figure 3.4 Land and Marine Data Needs in Order of Priority.



3.2.2 Polaris User Needs and High Level Requirements for Next Generation Observing Systems for the Polar Regions

The Polaris study was motivated by the rapidly increasing interest in the polar regions and the need to provide integrated information to support the research and operations of a wide range of user communities, including scientific, industry, governmental and non-governmental organisations and Arctic residents. The study results were intended to help develop new space mission concepts for the polar regions that address evolving scientific and operational information needs (Polar View 2016a).

The current information needs cover a broad spectrum of environmental parameters, with more than 250 different environmental parameters being of interest to the science and operations user communities working in the polar regions – a significant number of which are of common interest to the majority of users in both communities. The major scientific and operational user community segments and the types of activities for which data is needed are identified in Table 3.3 and Table 3.4, respectively.

Table 3.3 Arctic Science User Communities and Activities.

Scientific User Segments	Scientific Activities
Non-Governmental Organizations	Sea Ice Research
Universities	River / Lake Ice Research
Governments	Ice Sheet / Glacier Research
Environmental Groups	Snow Research

Scientific User Segments	Scientific Activities
Arctic Communities	Permafrost Research
	Climate Change Research
	Atmosphere Research
	Weather Research
	Land Use / Human Activity Research
	Ocean State Research
	Coastal Zone Research
	Ecosystem Research
	Species Research
	Food Web Research

Table 3.4 Operations User Communities and Activities.

Operations User Segments	Operational Activities
Shipping	Engineering Design
Mining	Operations Planning
Oil and Gas	Route Planning
Fishing	Environmental Impact Assessment
Tourism	Safe Navigation and Operations
Field Research	Risk Management
Coast Guards	Search and Rescue
Military	Emergency Response
Meteorological Services	Weather Forecasting
	Climate Adaptation

A brief summary of the key parameter requirements in the major information categories is shown in Table 3.5.

Table 3.5 Information Requirements in the Polar Regions.

Information Categories	Key Parameters
Sea Ice	Sea ice thickness, sea ice motion / drift, sea ice concentration, sea ice extent and sea ice pressure / ridges / deformation
River and Lake Ice	River / lake ice extent, river / lake ice thickness, river / lake ice concentration, river / lake ice freeze-up and break-up dates and snow depth on river/lake ice
Snow	Snow cover area / extent, snow water equivalent, snow thickness / depth, snow and ice albedo and snow pack condition / structure / stratigraphy
Atmosphere	Chemistry / greenhouse gases, surface air temperature, precipitation amount, surface wind direction and speed and precipitation rate
Ice Sheet	Ice sheet extent / margin, ice sheet basal melt magnitude, ice sheet mass change, ice sheet flow velocity and ice sheet snow accumulation
Permafrost	Permafrost extent / distribution, onset of seasonal permafrost freezing, permafrost active layer freezing depth, seasonal frost heave / thaw subsidence and permafrost thickness

Information Categories	Key Parameters
Land	Land use / cover and change, land surface temperature, soil moisture, above-ground biomass and biome / ecosystem identification and change
Glaciers and Ice Caps	Glacier / ice cap location and area, glacier mass balance, glacier topography, glacier ice thickness and glacier velocity / flow rate
Oceans	Marine ecosystem functioning, sea surface temperature, sea surface salinity, sea level and freshwater inputs / loads
Icebergs	Iceberg size / dimensions, iceberg detection / location, iceberg draft, iceberg motion / velocity and iceberg mass

Respondents also provided a range of perspectives on how their information requirements are expected to change in the future. Specific new or improved data variables or processes that were identified for future use included:

- More reliable sea ice thickness information
- More reliable high-resolution sea ice concentration information
- High-resolution monitoring of rapidly changing outlet glaciers and ice sheet margins
- A pan-Arctic dataset of in-situ snow measurements
- Improved methods for estimating snow water equivalent and snow depth and a Pan-European service for snow water equivalent and snow cover fraction
- Improved methods for estimating ice thickness from space, augmented by denser in-situ measurements of ice thickness
- Greater demand for higher resolution products for route planning and for navigation on ship bridges (e.g., locations of icebergs in pack ice, ice concentration, ice type, ice thickness)
- Reduction of uncertainties in modeling cryospheric processes (e.g., permafrost models under-represent ice content and the insulating effect of the organic layer; climate models do not resolve the steep topography of the Greenland Ice Sheet margins; models of snow-vegetation interactions need to be improved; and models that link meteorology to glacier mass balance need to incorporate downscaling techniques and satellite data)
- Information scaling, bridging the gap between discrete in-situ point measurements at the local level and large area coverage satellite data to a middle ground where catchment area sised datasets are needed, scaled up from the local level and scaled down from the broad satellite coverage
- Increased demand for cross-polarisation radar and multispectral images
- Integration of sea surface temperature and salinity data with ocean colour data

3.2.3 EU-PolarNet Survey of Existing Use of Space Assets by European Polar Operators

EU-PolarNet is a Horizon 2020 project being delivered by a large consortium of expertise and infrastructure for polar research to develop and deliver a strategic framework and mechanisms to prioritize science, optimize the use of polar infrastructure, and broker new partnerships that will lead to the co-design of polar

research projects that deliver tangible benefits for society. The D3.3 report (EU-PolarNet 2017) identifies uses of information derived from satellite remote sensing in the Arctic; the types of relevance to this study are illustrated in Table 3.6.

Table 3.6 Arctic Information Requirements.

Application Area	Information Types
Environmental impact assessment	▪ Physical and meteorological environment, ▪ Soil, soil productivity and vegetation ▪ Wetlands, water quality and quantity ▪ Fish, wildlife, and their habitat ▪ Species at risk or species of special status and related habitat ▪ Heritage resources ▪ Traditional land and resource use ▪ Human health, aesthetics and noise
Monitoring human impact	▪ Human presence and activities
Engineering design – siting buildings & offshore infrastructure	▪ Weather (cloud, temperature, prevailing wind direction and speed) ▪ Permafrost ▪ Surface topography ▪ Surface slope and aspect ▪ Sea ice ▪ Icebergs
Overland travel	▪ Crevassing ▪ Fractures in ice shelves ▪ Permafrost conditions ▪ State of winter roads over frozen lakes and rivers ▪ Historical and forecast weather conditions
Ship navigation and operations	▪ Ice charts ▪ Sea ice drift ▪ Sea ice conditions ▪ Iceberg conditions
Risk management	▪ Permafrost conditions ▪ Sea ice conditions ▪ Ice sheet conditions ▪ Iceberg density
Emergency response	▪ Weather conditions including wind speed and direction ▪ Sea state including wave height ▪ Presence of sea ice and icebergs ▪ Surface conditions and routes for responding assets ▪ Oil spill detection and movement

Table 3.6 (Cont'd.)

Application Area	Information Types
Weather forecasting	▪ Clouds ▪ Sea ice ▪ Ocean surface parameters and winds ▪ Atmospheric and ocean chemistry ▪ Melt ponds on sea ice
Climate change adaptation	▪ Aerosol ▪ Forest biomass ▪ Ocean colour ▪ Sea ice coverage. ▪ Albedo ▪ Cloud properties ▪ Elevation data ▪ Elevation models ▪ Earth radiation budget

3.2.4 Polar Thematic Exploitation Platform (P-TEP) Technical Note – Community Survey

The European Space Agency (ESA)'s TEP concept aims to provide a working environment where users can access algorithms and data remotely, supplying them with computing resources and tools that they might not otherwise have, and avoiding the need to download and store large volumes of data. This new way of working is intended to encourage wider exploitation of EO data. The TEP concept extends the SDI concept from a portal to a platform that not only provides easy and convenient access to data but also provides software and computing resources to analyze data and produce information products.

Polar View Earth Observation Limited (Polar View) has developed a Polar Thematic Exploitation Platform (Polar TEP) for ESA. Polar TEP provides polar researchers with access to computing resources, EO and other data, and software tools in the cloud. As part of the design of Polar TEP, Polar View engaged with stakeholders as one of the inputs to a high-level analysis of requirements and priorities of science and operational user communities (Polar View 2018). Based on this analysis, Table 3.7 summarizes the potential contribution of Polar TEP to science and policy priorities in key areas.

Table 3.7 Polar Science Priority Areas and Potential Polar TEP Contributions.

Thematic Area	Polar TEP Contribution
Logistics and data acquisition Ice sheets Snow Permafrost Sea ice Land processes and environment Atmosphere and ocean Safe economic development	Access to relevant satellite, airborne and in-situ data archives Access to relevant processing algorithms for data from new and emerging missions Access to relevant models or model output Provision of environment to develop, implement, test and run advanced data exploitation algorithms applicable for new and emerging EO missions Provision of environment to integrate observations from network of satellite, airborne and in-situ sensors Linkage of different stakeholder communities and promote exchange of ideas and experience through forums, communications and social networking Provision of environment to design, develop and deliver targeted training and capacity-building activities Provision of platform to coordinate use of logistics resources across different stakeholder communities Provision of platform for coordinated, multi-sensor image acquisition and distribution Provision of venue for training and capacity building Real-time access to observations from multiple (remote and in-situ) observation platforms Integration of modelling and monitoring (e.g., oil detection and fate modelling) Access to relevant databases of ice conditions Access to relevant processing algorithms for improved mapping of Arctic environments

3.2.5 Report on Workshop on Cyberinfrastructure for Polar Sciences

Sponsored by the U.S. National Science Foundation, the Workshop on Cyberinfrastructure (CI) for Polar Sciences was organised to engage polar and computer scientists and engineers to inform its Polar Cyberinfrastructure Program, to complement the EarthCube experience and to ensure that the CI needs for this community were understood, articulated, integrated, and aligned with the overall plans and design of a Polar Cyberinfrastructure Strategic Plan (Pundsack and al 2013). Similar in some respects to the TEP concept, Data as a Service (DaaS) was one of the most highly emphasised CI components during this workshop. Relevant DaaS recommendations from the workshop included:

Data Management

- Automate components supporting the workflow from data to information to knowledge
- Encourage interoperability (e.g., standards-based)
- Provision storage
- Develop methods for data quality assurance
- Provide for long-term data sustainability
- Reflect data quality limitations in metadata

Data Services

- Post all data center holdings via web services
- Leverage technologies for fostering near real-time data availability
- Build data processing services
- Share data services within and across communities

Data Archiving, Discovery and Access

- Access data through interfaces with existing catalogues
- Use ontology and semantics for searching
- Build lightweight processing (e.g., reprojection, integration, subsetting)
- Improve consumer searching of existing data repositories
- Build a one-stop portal for all available polar data

Data Analysis and Modeling

- Promote tools for sharing high-throughput computing or high-performance computing
- Promote the creation of an “NFSCloud” infrastructure
- Develop cloud-based analytical tools

3.2.6 Summary – Arctic Council Joint Meeting – Outbreak Sessions on Geodata (September 2015)

This document provides a summary of the responses to questions posed at Arctic Council Joint Meeting Outbreak Sessions on Geodata in September 2015, which was attended by representatives from AMAP, CAFF, ACAP, PAME, Arctic Council Secretariat and Arctic SDI. When asked about the biggest challenges to storing, accessing and updating geospatial data, participants provided the following responses of relevance to this study (Pouplier 2015):

Data

- No common standards to facilitate consolidation
- Availability of metadata
- Standardization protocols
- Compatible formats and scale
- Access to compatible geospatial data sources

Reference and Thematic Data

- Access to data: coastline, bathymetry and hydrography, ice cover, weather, ecologically or biologically significant areas (EBSAs)
- Agreed scales across themes

Data Access and Sharing in General

- Sharing data between user systems and nations
- Coordinating data collection, handling and sharing
- Collaborating across projects and with other organisations
- No central place to input and access all data for the Arctic Region
- How to handle ownership issues

Policy Guidelines / Guidelines / User Guides

- Common data sharing and standards framework
- Standardization protocols
- Level standards with the International Maritime Organization (IMO) / International Hydrographic Organization (IHO)
- Responsibilities of data providers / how to contract data
- Geodata users guide

- Best data storage and maintenance practice
- Best practice for workflow definition
- Common operational picture across bodies and authorities

3.2.7 Response to the Open Geospatial Consortium Request for Information on Arctic Spatial Data by the Polar Data Community

An ad hoc group of organisations representing the broad interests of the polar data community responded to the Request for Information (RFI) on Arctic spatial data interoperability and infrastructure issued by the OGC in early 2016. The OGC submission identified the following activities being undertaken by polar data management organisations in response to user needs (Polar Data Community 2016):

- **Interoperability**: Achieving interoperability will require adequate resources, a certain level of standardization, and a connected community.
- **Standards and Specifications**: The overarching purpose of the polar data management community is to facilitate the adoption, implementation and development (where necessary) of standards that will enable free, open and timely access to data.
- **Metadata**: The objective of this activity is to develop recommendations on a common set of metadata elements relevant across polar sciences, to facilitate interoperability and sharing between polar data repositories and online portals.
- **Data Publication**: The objective of this activity is to provide a report and guide on data publication and citation for polar researchers.
- **Including Arctic Indigenous Perspectives, Knowledge and Information**: The perspectives of Indigenous people and other northern residents must be heard directly, which will enhance understanding of how Indigenous and local knowledge and observations can be used appropriately.
- **Community Building**: Through the established bodies, improved communication, outreach, and coordination within the polar community is required, as well as engagement with broader global initiatives including OGC and GEO.
- **Data Preservation and Rescue**: Increasing our current understanding requires continual re-use and re-purposing of past observations. Strategic data rescue programs must be developed, and preservation must be prioritised as a long-term investment and cost-saving measure.
- **Adequate Resources**: More focus is needed on the training of early career scientists and youth to ensure that they have the necessary data literacy to engage in intensive research while contributing to and benefitting from an open, interoperable system.

3.2.8 OGC Arctic Spatial Data Pilot – Phase 1 Report: Spatial Data Sharing for the Arctic

This report presents the results of a concept development study on SDI for the Arctic, sponsored by US Geological Survey and Natural Resources Canada and executed by the OGC (Open Geospatial Consortium 2016). The report discusses the needs and requirements of the various types of stakeholders of an SDI for the Arctic on aspects such as data sharing, standards and interoperability, funding and investment, integration with existing systems, architecture and platform as well as security, privacy and safety.

The report includes a table (see Appendix A4) that identifies examples of the possible extensive range of applications that can be supported by an Arctic SDI. It also references the importance of including Indigenous knowledge and the underlying observations of Arctic peoples in Arctic SDIs and of including Indigenous and First Nations communities in the planning, design and development of Arctic SDIs and in their management and ongoing governance.

3.2.9 OGC Arctic Spatial Data Pilot: Phase 2 Report

This OGC report summarizes experiences during the Arctic Spatial Data Pilot implementation phase, provides guidelines for future service setup and data handling, and identifies future work items and potential approaches (Open Geospatial Consortium 2017a). In order to better address user requirements on both the data provider and consumer side, the report authors recommend that future initiatives should focus on the following aspects:

Data Discovery

- **Annotation, vocabularies, and linked data**: Human- and machine-based annotation systems are required to identify data that has been used for specific purposes.
- **Crawling based approaches**: Catalogues should provide their data in a way that search engines could fully harvest the catalogue content and other approaches such as direct harvesting of data services should be further investigated.
- **Service availability and reliability**: Proper backlink mechanisms should be implemented that show data providers what the data has been used for

Data Access

- Data owners should make their data available at **standardised interfaces**, ideally such as OGC WFS or WCS that support access to the underlying data.

Open Data, Usage Policies and Citations

- The community should increase the number of **openly available data sets** and employ new mechanisms to deal with usage policies and citations.

SDI Sustainability

- A key element is implementation of a **communication model** in combination with reliable links to resources, available at standardised interfaces that implement open access policies.

3.2.10 Interim Data Requirements for Arctic SDI

This document (Unknown 2017) was prepared for the purpose of communicating requirements to data providers until the new Arctic SDI Data Sub-Group is established and operational. The requirements identified include:

Data Requirements

- Pan-Arctic extent with active datasets whose services are updated dynamically
- Data currency preferences: current data, data that can be used in a time series animation, data that can be used for change detection algorithms and near real-time or real-time data feeds
- Thematic data sets: ground/cloud albedo, sea-surface temperature, ice thickness, 30-year averages of snow/temperature, ice extent and thickness, glaciers, permafrost, coastline and near shore, flora or fauna and/or their habitat, paleoclimatology, black carbon, greenhouse gases, ozone

Hosting Considerations

- Cloud environment
- Ready for incorporation into future OGC Testbeds and Pilots

Standards

- Supported standards in Arctic SDI Geoportal: WMS 1.3, WMS-T, WMTS, WFS 2.0, ESRI REST services, CSW and ISO 19115, 19139, etc.
- Support for the following projections: EPSG 3571 - 3576, Web Mercator
- Future standards: WCS 2.0, WPS and/or DGGS, SOS, OGC Marine DWG, IHO, SLD

3.2.11 INSPIRE Data Specifications

The INSPIRE Implementing Rules on interoperability of spatial data sets and services (IRs) and Technical Guidelines (Data Specifications) specify common data models, code lists, map layers and additional metadata on the interoperability to be used when exchanging spatial datasets (European Commission 2018b). Datasets in scope of INSPIRE, which have been determined to meet the needs of users for environmental information in the European Union (including Arctic users), are ones which come under one or more of the following 34 spatial data themes:

- Addresses
- Administrative units
- Agricultural and aquaculture facilities
- Area management / restriction / regulation zones and reporting units
- Atmospheric conditions
- Bio-geographical regions
- Buildings
- Cadastral parcels
- Coordinate reference systems
- Elevation.
- Energy resources
- Environmental monitoring facilities
- Geographical grid systems
- Geographical names
- Geology
- Habitats and biotopes
- Human health and safety
- Hydrography
- Land cover
- Land use
- Meteorological geographical features
- Mineral resources
- Natural risk zones
- Oceanographic geographical features
- Orthoimagery
- Population distribution – demography
- Production and industrial facilities
- Protected sites
- Sea regions
- Soil
- Species distribution
- Statistical units
- Transport networks
- Utility and governmental services

3.2.12 White Paper: The Hydrographic and Oceanographic Dimension to Marine Spatial Data Infrastructure Development: "Developing the capability"

This paper provides an approach to introduce and inform how Marine Spatial Data Infrastructure (MSDI) inter-reacts as a component framework within a National Spatial Data Infrastructure (NSDI) (International Hydrographic Organization 2010). The paper provides the following list of common types of information required by coastal states of MSDI:

- Bathymetric Elevation
- Climate
- Flood Hazards
- Gazetteer
- Land ownership
- Marine Transportation
- Maritime Baseline
- Maritime Boundaries
- Obstructions
- Offshore Cadastre
- Offshore Minerals
- Physical Oceanographic features
- Seabed Character and Bedform
- Shoreline or Coastline

3.2.13 Other Marine Spatial Data Infrastructure Initiatives

At least two initiatives are currently underway to move the development of MSDI forward. The Norwegian Mapping Authority has received funds to investigate how to gain better access to geographic information for the Arctic marine and ocean areas (Norwegian Mapping Authority 2017). The project resulted in a guide and a plan for better access to geospatial data with the Arctic SDI as a common platform for data sharing. Project participants worked closely with the Arctic Regional Marine SDI Working Group, established by the Artic Regional Hydrographic Commission (ARHC under the International Hydrographic Organization) and developed ties between the Arctic SDI, the ARHC working group and the Arctic Council working groups. The project includes a user survey and stakeholder workshops, and current relevant data sources were mapped and services tested and integrated within current user-applications. Final report available at: https://arctic-sdi.org/index.php/documents/strategic-documents/

A second initiative, undertaken by the OGC Marine Domain Working Group, is a Marine SDI Concept Development Study (OGC 2017).
Final report available at: http://www.opengeospatial.org/projects/initiatives/msdi-cds-2018

3.3 SUMMARY

This review of literature on user needs has demonstrated that the scientific and operational users of environmental information in the Arctic require not only data but sustainable infrastructure and other support mechanisms that will facilitate their easy access to and use of the data to make decisions and support their day-to-day activities. While spatial data is a fundamental requirement for many applications, the range of other types of data being used in the Arctic is substantial. Not all types of data have a geographic attribute, but the majority of information applications of importance in the Arctic are within a spatial context and could benefit from a properly designed and maintained infrastructure that provides easy access to and use of spatial data.

Users require access to both relatively static and dynamic kinds of data. For many scientific purposes and a few operational applications, there are requirements for archives of historical as well as more recent information, highlighting the importance of data curation and preservation. Archives of EO data, weather data, sea ice data, land use and settlement data, etc., support a range of research activities and the design and construction of new structures and facilities in the Arctic. For the majority of operational uses, and particularly in the marine environment, access to near real-time information is critical for safety of life and property purposes. For navigation through and operation of structures like oil drilling platforms within ice-covered waters, operational users need daily updates of sea ice conditions and iceberg movements, requiring rapid development and delivery of information products based primarily on EO data. This is driving the demand for data at a higher spatial resolution and based on sensor collection at an increased frequency (i.e., higher temporal resolution).

As illustrated in Figures 3.1 and 3.2, the user communities and information application uses in the Arctic are extremely diverse, which makes the development of an Arctic SDI to serve all of these communities very challenging. The available evidence suggests that user needs have evolved beyond the requirement for portals that focus on providing interoperable access to data in distributed networks, to a requirement for platforms that add: the ability to extract meaningful information from all available data and to deploy user-created or acquired algorithms/applications; provision of computing resources, storage and networking

capabilities, and collaborative tools for user communities to publish, share and discuss their results, information, data and software/code on the platform. This suggests that a paradigm shift will be required in the future development of an Arctic SDI if the needs of this large, growing and diverse user community are to be met.

To support the use of data platforms, users require a variety of support and facilitation mechanisms. These include, for example:

- Methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation;
- Provision of useable data quality information for all products;
- Provision of storage in a way that improves capacity and reduces latency (i.e., period of time between data acquisition and availability of products);
- Easier search functionality using ontology and semantics;
- Tools for sharing high-throughput computing (HTC) or high-performance computing (HPC) resources;
- Environments to design, develop and deliver targeted training and capacity-building activities; and
- Sophisticated data visualization tools for users to easily see and understand both the data they can utilize and the results of their analysis of that data.

4.0 DATA PROVIDERS, PLATFORMS AND FACILITATORS IN THE ARCTIC

This chapter provides a summary overview of key data coordinators, providers and platforms hosting data for the Arctic region. A more comprehensive description of this research is provided in Appendix A5 and an extensive inventory of organisations is included as Appendix A6. This Chapter and the related Appendices used results from the Arctic Data Committee's Mapping the Arctic Data Ecosystem initiative[6] as a starting point with significant additional contextual and analytical information added. Discussions with project leads indicate that this tool is under active development and a queryable database-driven version of the map will be available in Q2 of 2018. This can act as a useful tool as the ASDI moves forward. For the purposes of this report, selected static visualizations have been provided along with the textual and tabular information.

An International Arctic SDI goes beyond data and services to include governance, establishment of standards and protocols, education, and engagement with user communities. Moreover, we know from prior studies that not all data resources are readily available through Web Services. Additional community building and deployment of services is required to fully realize an Arctic SDI. Thus, data facilitators, coordinators and other relevant organisations are included in this discussion. These organisations coordinate and drive collaboration as well as engage in research and education to bring about understanding, agreement and further the development of the Arctic data system.

The current Arctic data system is large and complex, with hundreds of actors playing a variety of different roles. This summary focuses on organisations that are acting as "hubs" in the network, either as a data aggregator or mediator, or a coordinator of activities related to the Arctic SDI. The discussion provides a method for situating various actors within the field to help Arctic SDI proponents to organize and prioritize engagement with initiatives. The overview is organised primarily by scale ranging from the international to more locally focused initiatives; however, "discipline" or subject matter can also be a useful organizational dimension. Ultimately, all initiatives are related to the international level given the goal of establishing a pan-Arctic SDI that links to the larger global SDI. Many important data resources are collected at the local level, whether these are obtained using in-situ sensors, community-based monitoring or other techniques (e.g., various field collection methods). As indicated above, the reader can refer to Appendix A5 and Appendix A6 for more detail on many of the referenced initiatives.

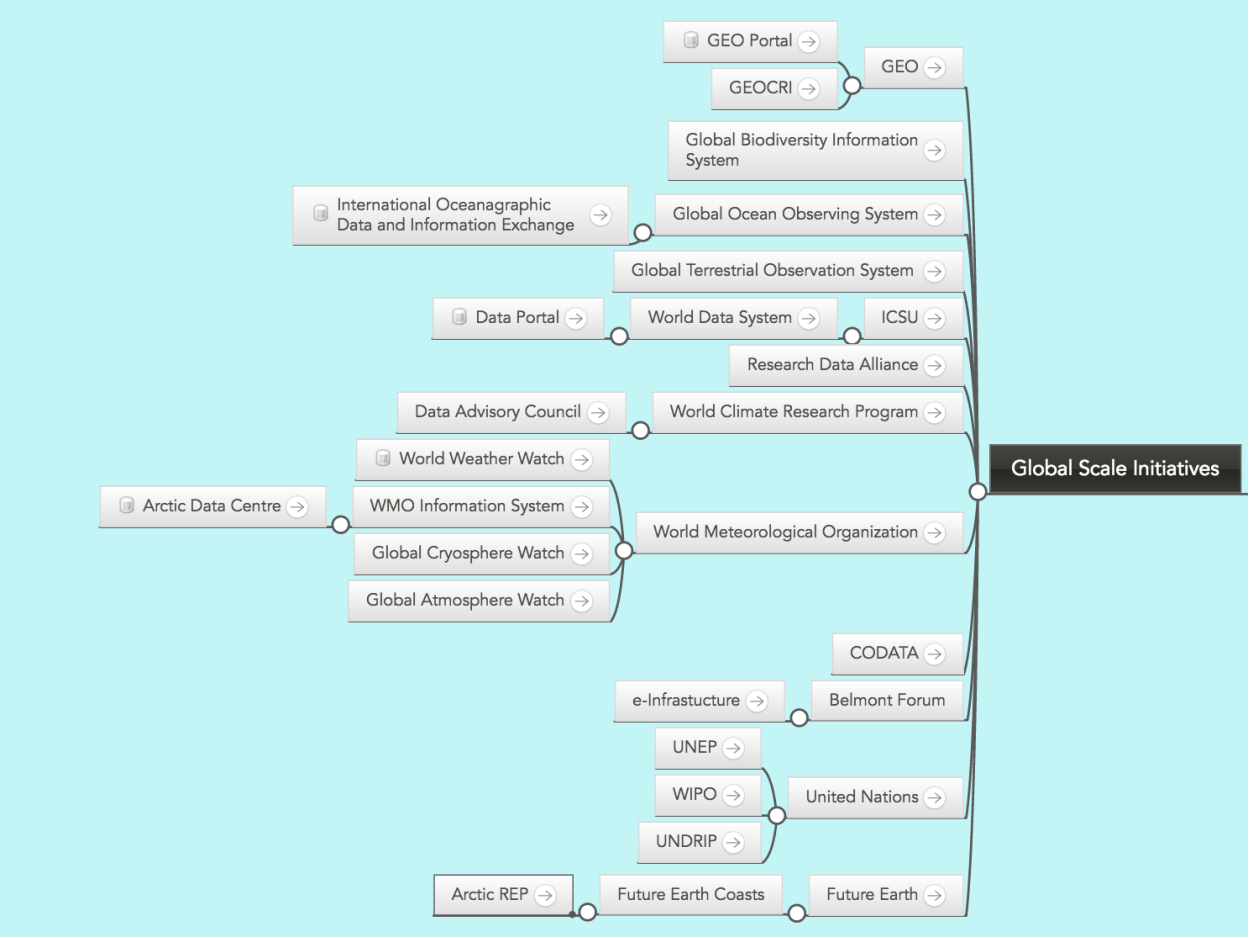
4.1 GLOBAL SCALE INITIATIVES WITH AN ARCTIC COMPONENT

There are many global scale initiatives with an Arctic component that are or may be relevant to Arctic SDI (see Figure 4.1). Global initiatives such as the Group on Earth Observation (GEO) and its Global Earth Observation System of Systems (GEOSS) are working to develop a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. These efforts include promotion of sound data practices as well as information system development with a particular focus on brokering and data aggregation. While the goals of GEO have yet to be fully achieved, the organization has recently entered its second 10-year mandate and significant investments are being made, particularly by the European Commission (https://ec.europa.eu/research/environment/index.cfm?pg=earth). GEO includes the GEO

[6] See https://arcticdc.org/products/data-ecosystem-map

Cold Regions Initiative and discussions are underway to develop an Arctic GEOSS regional node. It is recommended that Arctic SDI proponents monitor Arctic-oriented GEO developments and engage as appropriate.

Figure 4.1 Global programs and projects with an Arctic component (dynamic online version at https://Arcticdc.org/products/data-ecosystem-map).



Similar to GEO, the World Meteorological Organization (WMO) is an active organization with respect to Arctic data. Increasingly, they are focusing on making data available using a Data as a Service approach based on OPeNDAP and thus their projects can provide important scientific data nodes to the Arctic SDI. WMO is focused on meteorological data; however, they also connect sea ice and other kinds of data through programs such as the Year of Polar Prediction.

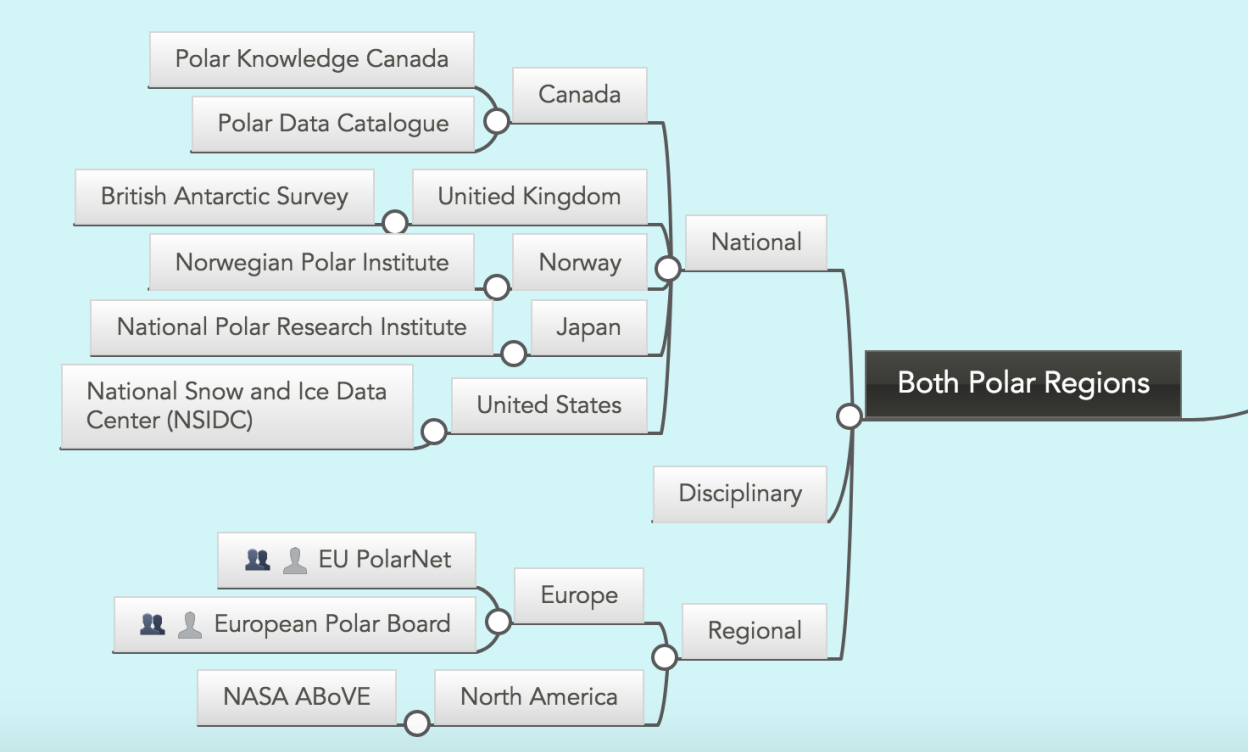
There are other domain-specific international data distribution networks that make Arctic data available. In the oceans domain, the International Oceanographic Data and Information Exchange (IODE) brings together oceanographic data from National Oceanographic Data Centers and other sources. In the domain of ocean life, aggregation programs such as the Global Biodiversity Information Facility (GBIF) and the Ocean Biogeographic Information Service make metadata and data available. While these programs are organised at a global level, they provide a conduit to location-specific Arctic data. These information resources are vast; however, additional research would be required to establish the specifics of using available data in an interoperable SDI environment.

In addition to global scale data providers, there are a number of important international bodies focused on the enhancement of data management methodologies, establishment of technical standards and driving discussions around data policy and other topics. These groups include the Research Data Alliance, the International Council of Scientific Union's Committee on Data (CODATA), and Belmont Forum e-Infrastructures and Data Management Collaborative Research Action. The activities taking place under these initiatives are vast and thus fully connecting Arctic SDI development to these bodies may not be necessary or practical. Or, there may already be connections through individuals, or, for example, OGC to RDA relationships. An appropriate level of engagement should be considered to ensure that developments from these groups can be leveraged for the benefit of the Arctic SDI, and to avoid duplication of effort.

4.2 POLAR INITIATIVES

Many countries establish organisations with a polar mandate (see Figure 4.2) rather than establishing a strictly Arctic portfolio of responsibilities and activities (e.g., Japan, Norway, China, etc.). As a result, there are a number of projects and data resources that relate to both the Arctic and AntArctic regions. For example, although initially focused on the AntArctic, the British AntArctic Survey now manages the Arctic research and data program for the U.K. Similarly, the National Snow and Ice Data Center (NSIDC) in the U.S., manages data for the Arctic, AntArctic and high mountain regions. Coordination bodies such as the European Polar Board and EU-PolarNet address both regions. Monitoring the activities of these polar organisations can be productive for the Arctic SDI. For example, organisations that may appear to be focused on the AntArctic (i.e., British AntArctic Survey) may also hold important Arctic data resources.

Figure 4.2 Selected polar data initiatives.



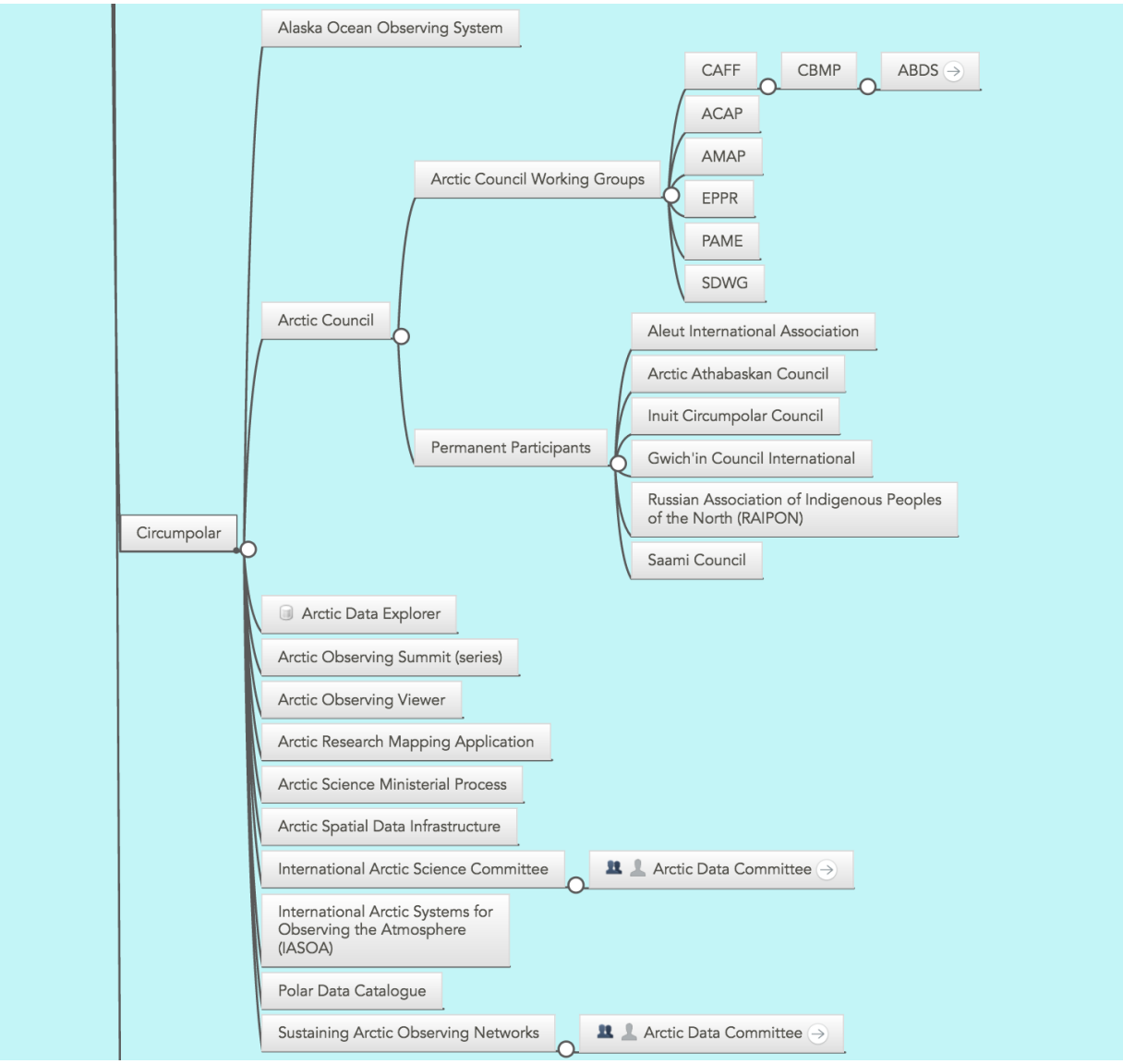
4.3 INTERNATIONAL ARCTIC INITIATIVES

The Arctic SDI is a major international Arctic initiative; however, there are a number of other international Arctic initiatives that are relevant in terms of data resources, facilitation of community building and development or adoption of standards and protocols (see Figure 4.3).

The Arctic SDI is endorsed by the Arctic Council along with a number of other data organizing and producing bodies. For example, the Conservation of Arctic Flora and Fauna's Circumpolar Biodiversity Monitoring Program produces the Arctic Biodiversity Data Service. Analyzing Arctic Council projects over decades reveals many data resources. A study is currently being carried out to identify Arctic Council reports and link them back to source and published data and this will be published later in 2018 (Personal Communication with P. Pulsifer).

Arctic Council endorsed bodies such as the Sustaining Arctic Observing Networks program are increasingly working to bring together Arctic observing and data actors to ensure overall interoperability across the community and strong linkage to the design of the international Arctic observing system. Specifically, the Arctic Data Committee and many partners have been convening events and generating products to achieve their objectives (see https://Arcticdc.org/about-us/adc-purpose). Arctic SDI has been engaging in these processes and there may be value in continuing to do so. Arctic SDI proponents are quite familiar with the Arctic Council system, so no additional information is provided here. It is important to continue strong connections with the Arctic Council system to ensure that these key data resources are part of the Arctic SDI.

Figure 4.3 International Arctic Activities.



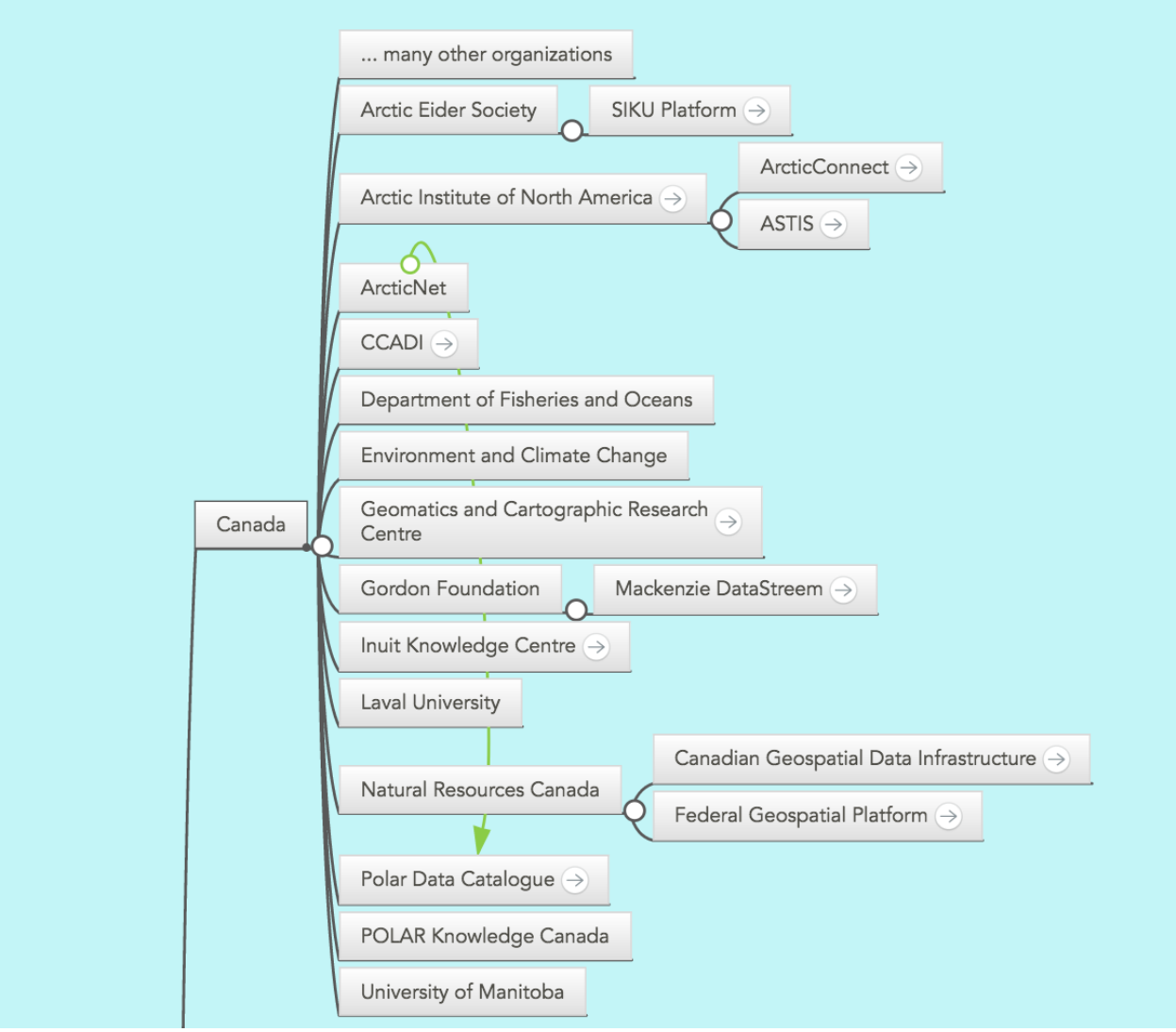
There are many other Arctic-wide projects and programs. Of particular note is the recent funding of a circumpolar observing and research project by the European Commission's Horizon 2020 program being organised under the EU Arctic Cluster (see A5). While funded by a particular region, these projects and programs are aiming to be circumpolar in scope and many have significant data components.

4.4 NATIONAL ARCTIC INITIATIVES

Whether Arctic nations or situated beyond, many countries have national Arctic programs and sub-national projects and programs in place (see Figure 4.4). This report and other documents and projects are documenting those initiatives. While national programs are not always comprehensive in terms of representing or being aware of all Arctic data activities in their jurisdiction (e.g., university-based data may not be readily visible or available through national programs), they are critical nodes in the Arctic data system. In some cases strong connections are being made among all national nodes. Such is the case for

the Interagency Arctic Research Policy Committee (IARPC) in the U.S., the National Institute for Polar Research in Japan and an emerging network in Canada called the Canadian Consortium for Arctic Data Interoperability (CCADI) that is making stronger links between government and academia.

Figure 4.4 Limited selection of Canadian Arctic data initiatives.



Appendix A5 and A6 provide a broad overview of many national Arctic initiatives. Appendix A5 selects and discusses national bodies that are particularly relevant to the Arctic SDI. It is noted that while the Arctic SDI has very strong, foundational connections to national mapping agencies in Arctic countries, the program may benefit from connecting to other national government departments and agencies both within and beyond Arctic nations.

4.5 UNIVERSITY INITIATIVES

Universities play a major role in collecting, managing, using and preserving Arctic data. For decades, university-based researchers have been collecting data on the Arctic physical and social environment. For example, the Arctic Institute of North America has a long history of managing Arctic data and metadata.

Two decades ago we saw the development of the Canadian Cryospheric Information Network at the University of Waterloo, followed by the establishment of the Polar Data Catalogue during the International Polar Year 2007-09. Other Canadian universities are engaged in Arctic data management, with many already publishing or planning to publish data using service-oriented, SDI-compatible approaches. The CCADI previously mentioned is linking a number of these initiatives. At the international level, we see other examples such as the NSIDC at the University of Colorado, the Polar Geospatial Center at the University of Minnesota, and the NSF Arctic Data Center at the University of California Santa Barbara.

The cases indicated in the previous paragraph are examples of well-developed or emerging data centres. However, significant volumes of data produced by the university sector still fall into what is known as the "long tail of data" – a very large number of small data collections that may not be easily discoverable or professionally managed in a repository or stable cyberinfrastructure. There is a significant opportunity for Arctic SDI to play an important role in addressing the problems presented by the "long tail" data collections (e.g., lack of discoverability or usability, data loss, etc.). Arctic SDI protocols, training materials and infrastructure can help to find or create a stable, managed location for some of these data. This can be done by connecting with individual researchers, laboratories or universities, or assisting established data centers in taking a service-oriented, SDI-compatible approach where this is not already the case.

4.6 INITIATIVES FOCUSED ON LOCAL AND INDIGENOUS KNOWLEDGE

Indigenous and local observations and knowledge and derived data and information are increasingly being recognised as valuable by researchers, governments and society. Community based monitoring programs as depicted on tools such as the Atlas of Community Based Monitoring (http://www.Arcticcbm.org) are producing data and, where appropriate, making them available. This can be an important part of the Arctic SDI. Working in this space can be challenging due to different ontology and epistemology, a wide variety of local contexts, variable funding models and technical challenges (http://www.inuitcircumpolar.com/community-based-monitoring.html; Johnson et al. 2015). Significant investments are being made though, and we can expect data sharing capacity to increase in coming years (cf. https://www.aadnc-aandc.gc.ca/eng/1509728370447/1509728402247).

A number of organisations and programs focused on this type of data sharing already exist in Canada and beyond, including the Inuit Knowledge Centre at ITK and regional organization partners, the Geomatics and Cartographic Research Centre at Carleton University, the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) program at University of Colorado, the EU INTAROS project and many others.

4.7 NOT-FOR-PROFIT INITIATIVES

The not-for-profit or civil society sector is one that should be monitored closely by Arctic SDI proponents. As indicated in Appendix A5 and Appendix A6, significant investments are being made by this sector, and major cyberinfrastructure and data platforms are being developed. Collectively, members of coordinating bodies such as the Arctic Funders Forum are investing millions of dollars in data producing and management projects, particularly in the area of community-driven or oriented monitoring and data management projects. Other not-for-profit organisations, such as Polar View Earth Observation, are bringing together different data-oriented organisations to develop data infrastructure such as the ESA-funded Polar Thematic Exploration Platform. Polar View is also engaged in a number of community

coordination projects. This sector is increasing in size and stands to play an important role in the broader Arctic data ecosystem.

In summary, the current Arctic data system is large and complex, with hundreds of actors playing a variety of different roles. Engaging with all of these actors directly is not practical for the Arctic SDI. There are a number of existing "hubs" that can facilitate access to data that are relevant to the Arctic SDI. Moreover, these hubs can allow for efficient connections between Arctic SDI and others in the areas of policy, development or adoption of standards and protocols and general planning for interoperability.

5.0 DATA ACCESS AND USE ISSUES

While the requirements for data in the Arctic are extensive and serve a broad range of scientific and operational applications, as demonstrated in Chapter 2, access to and use of the required data is impeded by a number of data issues. The following sections provide a brief overview of these issues, which impact the implementation of spatial data infrastructure such as an International Arctic SDI (Open Geospatial Consortium, 2017).

Missing Metadata for OGC Web Services Content

Although the use of OGC Web services is well-adopted by the geospatial community, served data often lacks proper metadata, which makes it difficult to interpret the services' offerings. For instance, many WMS layers use default or empty titles, abstract, keywords, etc., making it difficult for catalogues to help clients with their data search. Also, often only the service provider is mentioned in the metadata and the original data provider is missing, which causes problems for proper citations.

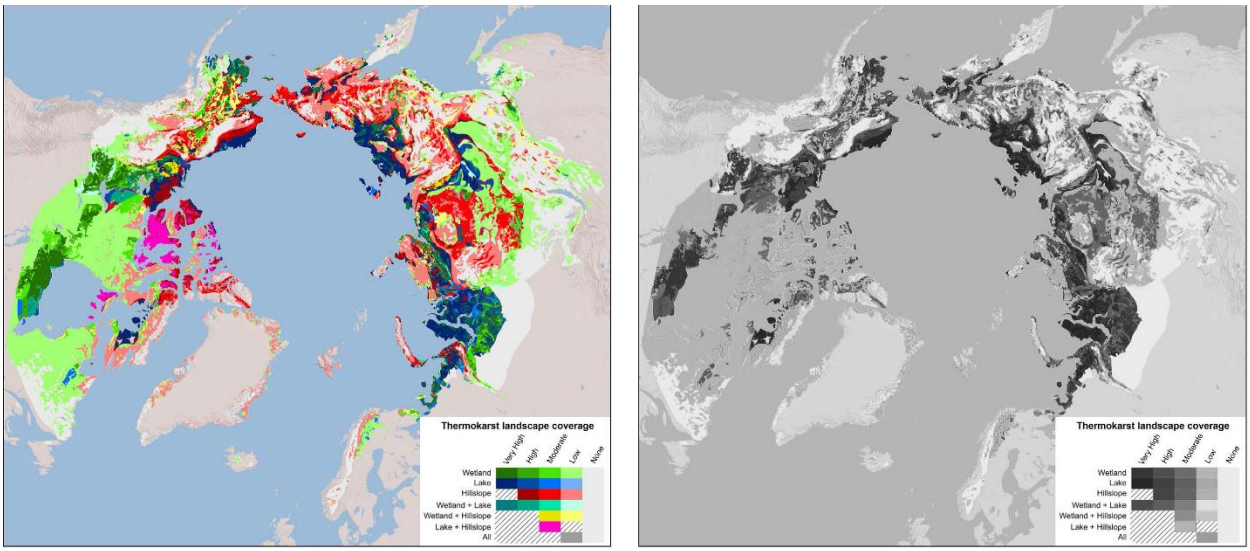
Data Formats

Proprietary/custom formats can make data integration very time consuming. This situation is often observed at portals that feature a more FTP-like data access rather than a Web service with rich query interface. As an example, the NSIDC Website offers sea ice age data for the Arctic region, covering the time span of 1984 until now. This data set is stored using a simple custom binary format and additional development time is required to integrate this data into applications. Additionally, the temporal dimension is not modeled in the data itself; instead, the file name is used to indicate the time instant (year and week). Though this is in principle a mechanism that is easily understood by humans, it prevents automated processing and requires humans to manually control the data integration process. 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.

Styling of Vector Data

Vector data is often made accessible using a format that doesn't contain any styling information (e.g., CSV file or ESRI Shapefile). While an application can read such a file relatively easily, having a meaningful style greatly helps to interpret the data. An example is the Thermokarst data served by Oak Ridge National Laboratory illustrated in Figure 5.1. A visualization of the data only makes sense with proper styling instructions, such as shown in the map on the left. The same map in black and white becomes pretty much useless, in particular as a two-dimensional color coding pattern has been applied (different colors and different levels of color saturation).

Figure 5.1 Dominant or co-dominant thermokarst landscapes within the northern boreal and tundra circumpolar permafrost region.



Source: https://daac.ornl.gov/SOILS/guides/Thermokarst_Circumpolar_Map.html

The OGC Symbology Encoding standard, a stand-alone styling definition language, is one example standard that can solve this problem. It is ideally suited for sharing of vector data with data consumers, possibly through a registry/discovery service such as an OGC CSW.

Temporal Characteristics

To analyze the evolution of some characteristics requires the use of the temporal dimension, which represents snapshots of the data at different points in time. Management of time in data has some impacts, the major one being the size of the dataset. Beyond the acquisition and storage challenge, the distribution of spatio-temporal datasets is not always easy. Some standard data formats like NetCDF and Grib are suited for multidimensional data. Raster data is usually organised following a specific directory or filename structure to represent the temporal dimension since often multiple acquisitions are not merged to be stored in a single file container. As far as distribution of temporal data is concerned, OGC standards completely fulfill the requirements for all of its Web services (e.g., WMS, WMTS, WFS, WCS).

Vendor Specific Solutions

Many data sets provide RESTful service interfaces that are based on open standards but are not OGC standards. Since it is generally simple for the data provider to also provide standardised OGC Web service interface support (e.g., WMS or WFS), failure to enable OGC service interfaces represents a lost opportunity for the data provider to increase exchange of their information.

Open Data and Data Access

The trend of open data should be encouraged because it maximizes usability. The increased availability makes it easier for scientists and decision makers to quickly correlate multiple data sets. If the data is sensitive, open access to a limited or out-of-date subset could be considered, which would allow potential users to quickly visualize or otherwise analyze the dataset to determine fitness for use or purpose. This

could then lead to negotiation of terms of use based on information provided in a full and complete metadata record following international standard models, as terms or usage are defined there.

The provision of open data needs to be combined with direct access to the data. Accessing data in an OGC service or client typically takes seconds / minutes, compared to data found in reports or in data files that need to be downloaded and further processed. In addition, it is very difficult to find pan-Arctic data. Pan-Arctic efforts such as the Arctic SDI Geoportal that are built for browsing, visualizing, analyzing, and sharing distributed geographic information for the full Arctic region play an important role. Key is that these efforts adhere to Open Data principles leveraging distributed spatial data infrastructures and making extensive use of services based on OGC standards and, ideally, international metadata standards.

Particular challenges can arise with access to community based monitoring (CBM) and traditional knowledge (TK) data. For example, its community-centered nature means that sharing CBM and TK data and information across scales at the regional or national levels can be more challenging (Johnson, Alessa, et al. 2015). CBM methods, including documentation of TK through qualitative methods such as interviews, can be difficult to translate into data formats that can be aggregated or shared in ways that are relevant for non-local use. In addition, sensitivities related to data ownership and sharing of TK may also prevent data sharing.

Shared Semantics and Quality Information

It is easier to reuse spatial data when information about their quality and fitness-for-use is available, and when technical and legal barriers for integrating these into the user systems are removed. The first condition, quality, requires that rich and meaningful metadata be used, while fitness for use requires the involvement of technical arrangements that ensure interoperability. Semantic issues in spatial data sharing and service interoperability have been recognised in the literature for a long time. Bishr summarised interoperability issues under the terms semantic heterogeneity, schematic heterogeneity, and syntactic heterogeneity (Bishr 1998). Though the latter two have generally been addressed successfully with GML and OGC Web service interface standards, semantic heterogeneity still causes several problems, including:

- discovery of data sets and services based on keywords;
- rigid metadata structures;
- missing semantics on technical terms; and
- missing matching capabilities for equivalent or related terms or symbols.

A key concept of the Semantic Web is the usage of URI as identifiers for objects, predicates, and subjects. If URIs would be used for keywords, discovery and usage of data for the Arctic would already be largely improved.

Aggregation and Data Fusion

Collaboration between organisations (e.g., NMAs) should be encouraged to build aggregated data sets. Tremendous value is created when the best data sources are unified in a single data set that can benefit from all authoritative updates and be the go-to source for a given data type, making it easy to find the best quality data. Data fusion steps help to efficiently integrate a large amount of small files. For example, a data

fusion step to combine 2800+ ERDAS Imagine elevation files for Alaska in one logical dataset followed by the use of an OGC Web Service helped to ease the integration of the data in applications. In this example, WCS and WMS were used to respectively access the raw elevation data and a rendered version of the elevation data. A data fusion step was also used to combine 1441 ArcticDEM GeoTIFF files in one logical data set and a corresponding Web service helped to ease the integration of the data in applications, avoiding the inefficient loading of 1441 files separately.

Resources and Capacity

When Indigenous community members want to share their data and results, they often lack the resources and capacity to disseminate them (Johnson et al. 2015). It is therefore important for program designers to consider both the data sharing goals of communities and the requirements of potential data users so that data are collected in a format compatible with data-sharing infrastructures. Although monitoring programs require long-term plans and sustained work to succeed, it is rare for CBM initiatives to find or secure long-term funding. Community members need appropriate training, equipment, and infrastructure and other support in order to carry out monitoring efforts, and partnering scientists, funders and government workers also need to develop new skills, capacities and knowledge areas. In addition, individual community programs may not have the capacity to summarize and synthesize data to share with decision makers beyond the community level, which suggests an important role for networks and regional CBM initiatives in linking community observing needs to larger information-sharing and funding platforms.

6.0 USER CENTRED DESIGN CONSIDERATIONS

Development of systems such as SDI typically focus on the business goals, features, and the technological capabilities of hardware or software tools, but must also include an important part of the process – the end user. User-Centered Design (UCD) is the process of designing a system focused from the perspective of the human user and how such a system will be understood and used[7]. The result of including a UCD process to the design process is to enable a more efficient, satisfying, and user-friendly experience for the end user.

This section summarizes analysis of geoportals user design elements, namely the independent analysis of the Arctic SDI geoportal user interface (UI) and the description of design trends as they related to UCD elements.

6.1 UCD CONSIDERATIONS – ARCTIC SDI GEOPORTAL

6.1.1 Introduction and Context

The Arctic SDI, launched in 2014 by the National Mapping Agencies of Canada, Kingdom of Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States and endorsed by the Arctic Council, provides a methodology, geospatial data and tools to achieve data sharing at all levels: local, national, regional and global. It documents and applies information management best practices, based on open international standards, to build communities of practice to share data. The purpose of the Arctic SDI is to support the Arctic Council and other stakeholders in their goals and objectives by providing easily accessible, reliable, harmonised and interoperable basic geospatial data of the Arctic. Recognizing the need to share and harmonize geospatial data for the Arctic regions worldwide, the Arctic SDI set out to define and achieve 6 strategic objectives (A-SDI, 2015):

- Objective 1: User and Stakeholder Needs and Requirements
- Objective 2: Reference Datasets
- Objective 3: Thematic Datasets
- Objective 4: Data and Technical Interoperability
- Objective 5: Spatial Operational Policies
- Objective 6: Communications

Strategic objective 1 (User Needs and Requirements) is focused on understanding of the needs and role in the Arctic SDI of relevant stakeholders and on the evaluation and prioritization of available, relevant datasets and services for inclusion into the Arctic SDI. (A-SDI, 2015b). For that purpose, the UNA follows a process of (1) developing questions to be used to document user needs, (2) capturing these needs from various stakeholders (including, but not limited to, Arctic Council Working Groups), and (3) analyzing and prioritization of the user requirements. This process is ongoing, iteratively, and will likely be an ongoing

[7] http://www.usabilityfirst.com/about-usability/introduction-to-user-centered-design/

process for the foreseeable future, in order to continue adding or improving new features as needs, technologies, and priorities evolve in time.

One of the key outcomes of the Arctic SDI initiative is the Arctic SDI Geoportal (https://geoportal.Arctic-sdi.org/) which is a powerful mapping tool for searching, visualizing, analyzing, and sharing distributed geographic information about the Arctic region (A-SDI 2017). The build-up of the Arctic SDI Geoportal is ongoing in parallel with the UNA process outlined above. The development of the core infrastructure of the platform is based on existing open source tools (Oskari open source software), on which map layers are added. The data underlying the map visualizations is provided by each of the NMAs involved in the Arctic SDI initiatives.

For this report, the project team did not obtain detailed information on the UCD process applied to the Arctic SDI Geoportal. However, a review of the geoportal's user interface was made, with a view to highlight strengths and opportunities for improvement, from a UCD point of view. A summary is provided below.

6.1.2 Summary of Arctic SDI Portal User Interface Review and Recommendations

Overall Impression

The Arctic SDI Geoportal landing page is clear and elegant, and as a result loads quickly. The landing page layout design is logical and self-explanatory, and the welcome tour provides a good overview of the geoportal system. The User Guide is comprehensive, though some pages covering the more complex functions could benefit from an update. The Landing page offers most functionality immediately to the user without the need to register/login. Registration is quick and simple, and future enhancements could include user credential handling. Other enhancements could also include updating tool icon design and tooltip information.

> First impressions are good – the Portal's primary functionality has been identified and well implemented. User Portals like this are often overly ambitious from the outset, and therefore complex to design and implement – leading to performance and usability problems. This does not appear to be the case here.

Functionality

> Future portal review work could include addressing layer display issues. Also, future development could focus on system/user requirements for initial selections of map layers and rationale for their selection; whether it be user or data availability driven approaches, or a combination of both.

The core functionality of the portal is to display multiple map layers containing specific thematic data on top of a geographical map, which the portal performs well. Future development could focus on system/user requirements for initial selections of map layers by the user.

In some cases layers did not display, a suggested future direction of investigative work. Selecting/unselecting map layers was generally rapid and stable. Some map legends became unstable under low or varying bandwidth.

Manipulation and analysis tools to provide added value for the user are provided. These tools work well and are stable. The complex/less self-evident tools can be initially tricky to master. Most would benefit from updated *Help*.

The potential for providing updated or new tools for data manipulation and analysis should be investigated via user consultation.

Data and metadata models should be reviewed in detail in order to troubleshoot issues with metadata unavailability and stability. Metadata is critical to the function and usability of a user portal, and data providers should view it as an asset rather than a burden.

Map layer details and metadata are informative and useful within the portal. Future work could include gap analysis of metadata for portal datasets.

Compatibilities

Operating system and browser compatibility were found to be good. Future work could include further development of the *Search* function. The default portal view can be difficult to use on a small screen, and future work could include addressing mobile usability and printing capability requirements, and social media integration and linkages.

Overall recommendation: It is a sound practice to regularly review user and system requirements to establish whether issues identified are related to issues of specification, design, or implementation, and to agree on a resolution.

6.2 GEOPORTAL DESIGN TRENDS

SDIs are typically driven by governmental organisations, and thus follow top-down approaches. While this provides for a concerted and harmonised framework for SDI implementations, the drawback is that it can make SDIs less able to evolve at the same speed as new technological trends.

In order to support their target communities and fulfil their initial requirements, SDI must follow UCD-related requirements, which can be broadly classified into two categories:

- User's expectations of the SDI's functional capabilities; and
- User's expectations of non-functional aspects relating mainly to the SDI's usability, such as performance, security and reliability, i.e., the Quality of Service.

The following sections address some of the main design trends for geoportals, driven by common UCD requirements falling into one or both categories.

New Data Access Paradigms: Big Data, Open Data Cube, and Analysis Ready Data (ARD)

EO instruments are increasingly complex and capable of collecting new types of data in ever-growing volumes. EO data supply is likely to dramatically increase in the coming years, due to publicly funded programs such as Copernicus in Europe or Radar Constellation Mission (RCM) in Canada, but also due to commercial initiatives: several constellations exist or are planned which offer higher resolutions, higher

revisit rates and lower costs compared to previous generations of EO satellites. Examples include Sentinels 1, 2 & 3 (2 spacecraft each), Planet, DigitalGlobe, Airbus-DS EO constellation, NorStar, and many others. In addition, numerous government funded networks for in-situ data collection and many initiatives collecting regional & local data using aircraft or UAVs, also contribute to the massive increase in geospatial data.

UCD designs for current and future geoportals that aim to leverage these massive data sets must consider user concerns for data access, data preparation (pre-processing), and data analytics in support of end-user applications. Common concerns that users of geoportals have include:

- As much as possible, and to the extent that it satisfies user requirements, access to free and open EO data and to processing algorithms;
- Consistent architectures that allow sharing of data, code, tools and algorithms;
- Access to specialised knowledge required to access and prepare satellite data;
- Efficient time series analytics to support land change applications;
- Combination of multiple datasets, which itself calls for data interoperability and complementarity; and
- Solutions that reduce dependency on commercial suppliers ("vendor lock-in" situation).

For example, one of the solutions that aims to address these UCD requirements is the Open Data Cube (ODC) initiative, which seeks to provide a data architecture solution that has value to its global users and increases the impact of EO satellite data. It is promoted currently by the Committee on Earth Observation Satellites (CEOS). The Open Data Cube architecture framework is free, open and available to everyone. A data cube refers to a four-dimensional (space and time) range of values that are generally used to explain the time sequence of an image's data. It is a data abstraction to evaluate aggregated data from a variety of viewpoints. It allows the storage of any dataset in a database, derived product and time series analysis output. One of the advantages of a data cube is the standardised data infrastructure, which removes the need for difficult and time-consuming pre-processing of the data for individual applications.

The ODC initiative is one possible implementation of a data cube. It provides a data architecture solution that lowers the technical barriers for users to exploit EO data and addresses issues of data accessibility and usage.

As part of the ODC initiative, there is a strong push for the generation and standardization of Analysis Ready Data (ARD). CEOS defines ARD as "satellite data that have been processed to a minimum set of requirements and organised into a form that allows immediate analysis without additional user effort". ARD products typically come with the following requirements: (1) metadata description; (2) radiometric calibration; (3) geometric calibration; (4a) solar and atmospheric calibrations (for optical sensors) or (4b) speckle filtering (for radar sensors). ARD data lower the barrier to data access, facilitate data preparation, and offer analytics in support of the implementation of user applications. Systematic and regular provision of ARD will significantly reduce the burden on EO data users.

The use of Open Data Cube initiative, in conjunction with ARD data and Big data analysis platforms in future SDIs will increase visibility and usability of future portals and will provide users with a much-needed

tool and extract value from the existent datasets. ODCs can scale with increases in data supplies and can offer in parallel the needed tools and technologies to mine and preserve these massive data sets. Consequently, the need to capture metadata is also becoming essential. Growing groups are focusing on making machine-readable metadata, so that search engines can utilize machine learning systems.

Cloud Computing

Historically, data providers and value-added service providers have relied on proprietary data storage and compute solutions, which have led to an inefficient and costly use of computing resources. Indeed, this is still the case for many geoportals in operations today. With the increasing availability of affordable cloud-based ICT resources offered as a commodity, more and more data providers and value-added service providers are now migrating to cloud architectures to serve their clients. The past, inefficient way of moving large amounts of data to processing infrastructures and to the user, is now replaced by an inverse trend in which users access and process data in the cloud. This trend responds to a UCD requirement to allow wider access to adequate IT infrastructure at affordable price.

Cloud computing is used when applications, services and datasets are no longer located on individuals' computers, but distributed over remote facilities operated by third party providers (e.g., AWS, Azure, Google). In cloud environments, users can allocate computational resources without requiring human interaction with a resource provider (on-demand self-service). Examples of such resources include storage, processing, memory, network bandwidth, and virtual machines. As discussed in Section 3.2.4, the European Space Agency is pioneering the development of Exploitation Platforms, which extends the SDI model from a "portal" to a "platform" that not only provides easy and convenient access to data but also provides software and computing resources to analyze data and produce information products in the cloud. In addition, OGC Testbed 14 includes an exploitation platform initiative in recognition of the challenges of rapidly growing data volumes. As stated in the OGC January 2, 2018 announcement, "Making arbitrary applications available on cloud infrastructures or exploitation platforms in a standardised way, is a key technology for Big Data in general and particularly true for Earth Observation satellite data processing. When the transport of large amounts of data is not feasible, or simply not cost efficient, processes need to be shipped and executed as closely as possible to the actual data."[8]

These resources and their capabilities are available over the network via standard mechanisms and simple web service interfaces. The providers of resources (physical and virtual resources) have to cope with multiple users and their dynamically changing demands. From the user's perspective, the availability of resources in the Cloud often appears to be unlimited.

For SDIs, the adoption of cloud computing allows organisations and governments to better plan their SDI infrastructures; for example, a project can start small with 1 or 2 servers and with a limited storage capacity and grow on demand, provided the overall architecture of the SDI allows this scalability. Cloud resources can also grow on demand more dynamically, e.g., to keep good performance during IT resources demand peak times.

Cloud computing helps mitigate usual issues with SDI users related to performance, availability, or reliability, since everything can be fully backed up and automatically deployed. The main benefits of cloud

[8] http://www.opengeospatial.org/pressroom/pressreleases/2716

computing are simplified deployment and maintenance of SDI services, and reduced costs of providing content and applications with a high quality of service.

UCD Impacts of Open Data

The policies around open data in Europe, US and Canada mean that users are expecting the access to data via the traditional data download and access to data via web map services (WMS, WMTS, WCS). In Canada, USA, Australia and elsewhere, government organisations are in various stages of implementing geospatial platforms, with a general trend towards open access. SDIs are expected to deliver and comply with standards around open data. The OGC is the foremost provider of open geospatial standards. It has a wide membership and has defined many standards. However, some of the OGC standards (e.g., for catalogues) are not regarded as being good enough, are too ambiguous and, as with many standardization bodies, the standardization process is rather slow. Therefore, other standards (de facto or de jure) might have to be used and it is unclear which standards will emerge as the main ones in use. This is not likely to be clear for a number of years. Whatever technical solutions are developing for SDIs, constant monitoring on how standardization evolves is necessary, in order to keep providing relevant tools to the geo-industry.

6.2.1 Conclusion: SDIs will Benefit from Existing IT Trends

SDIs are an integral part of the overall information infrastructure, driven by experts and stakeholders from the geospatial domain. The potential adoption of IT trends will happen rapidly, to the extent that they do not affect existing SDI-specific standards or agreements that have a wide acceptance in the community. The use of Cloud computing, for example, does not require any changes to SDI policies or institutional arrangements, and is already being increasingly adopted. However, taking advantage of Cloud infrastructure to migrate from spatial data portals to more robust platforms will require a shift in thinking on the purpose and role of SDI by those involved in their design and development.

The same is true of the publishing of public sector information (open data) in SDIs, based on standardised open data licenses, which will immediately result in better accessibility of spatial data for many purposes.

7.0 KEY FINDINGS AND RECOMMENDATIONS

7.1 SUMMARY OF FINDINGS

This report clearly demonstrates the breadth of user requirements for data in the Arctic and highlights the existence of a diverse network of existing information providers and portals that are currently serving those needs. As a means of summarizing the key findings of the literature review, Table 7.1 adopts the following user needs assessment structure that is defined in the SDI Manual for the Arctic (Arctic SDI 2016) as follows:

- The **characteristics of users** (user profiles) that may impact use;
- The **key activities** or tasks performed by users;
- What reference and thematic **data** are the most useful for different types of users and at what geographic extent, spatial scale and time scale;
- What levels of **quality and usability of the data** (including licensing and use restrictions) are required in order to ensure that the data offerings can be fully exploited;
- What **data enhancements** are required;
- How existing **reference and thematic data** are **used** and **accessed**, and from where they can be accessed;
- What **distribution formats** are preferable for different types of users;
- What **Web services and tools** are the most useful for different types of users;
- What types of **data and service documentation** (e.g., metadata, user manuals) are required by different types of users in order for them to evaluate the fitness for use of the data and services;
- What data **products and services** might be **available** from providers or stakeholders;
- The scope of **general knowledge** about information management policies, geoportals, SDIs and their benefits;
- What legislation, strategic and operational policies, and **guidance** (standards, technology, procedures, etc.) are **required** or should be applied to enable the data providers, data distributors and data users to participate in the Arctic SDI;
- The level of **effort required** by data providers and staff of the participating NMAs **to incorporate** their **data** into the Arctic SDI; and
- What types of **future requirements** would be needed by users in order for them to better accomplish their work in the Arctic.

Table 7.1 User Needs Assessment Components.

Needs Component	Findings
User Characteristics	Users can be divided into several categories that have generally similar characteristics: ▪ *Scientists and researchers* – these users are typically professionals in various disciplines (see Figure 3.1) who require information to plan for and conduct experiments and pursue scientific and research objectives in either an office/laboratory environment or in-situ in the Arctic ▪ *Operations personnel* – these users are typically engineering or technical operational people (see Figure 3.2) who require information to support design, planning or implementation of operations in the Arctic ▪ *Indigenous people* – these users are typically planning personnel who need information for land administration or resource management or hunters/trappers who require information for safe travels in the Arctic ▪ *Government officials* – these users are typically professional or technical experts who require information for management of government programs, regulatory enforcement, policy making or support of decision making ▪ *Educators and students* – these users require information for instruction purposes or for completion of student assignments ▪ *NPO/NGO personnel* – these users are typically professional or technical experts who use information in support of organizational purposes ▪ *Citizens* – these users typically do not have any detailed understanding of the use of spatial information but access geoportals to examine information for a variety of interests (e.g., travel/tourism, protection of the environment, education)
Key Activities	Examples of key activities for each of the categories of users include: ▪ *Scientists and researchers* – research in the Arctic on changes in and impacts of: sea, river and lake ice; ice sheets and glaciers; snow; permafrost; land use and human activities; ocean state; species ecosystems and food webs; coastal zones; and atmosphere, climate and weather ▪ *Operations personnel* – engineering design; operations and route planning; safe navigation and operations; risk management; emergency response; search and rescue; environmental impact assessment; weather forecasting; and climate adaptation ▪ *Indigenous people* – community based monitoring; land use planning; property management; infrastructure planning and development; natural resource management; traditional knowledge collection and management; planning for traditional country food collection expeditions; and safe travel over ice ▪ *Government officials* – design and development of policies and programs for the Arctic related to: sovereignty, safety and security; resource management; economic development; environmental protection; regulation enforcement; and emergency management ▪ *Educators and students* – planning, development and delivery of course materials; research for and completion of assignments; and research for and completion of postgraduate theses ▪ *NPO/NGO personnel* – planning and development of member/stakeholder programs; communication and outreach campaigns; and development of proposals and recommendations to governments

Table 7.1 (Cont'd.)

Needs Component	Findings
Key Activities (Cont'd.)	▪ *Citizens* – planning a trip; participating in a public relations campaign or protest; learning more about the Arctic; contributing data (volunteered geographic information (VGI) or crowdsourcing)
Data Needs	Users require a very broad spectrum of data covering the entire geographic extent of the Arctic, at local, regional and pan-Arctic scales. Time scales cover the full gamut from near real-time (e.g., for navigation through ice and avoidance of icebergs) to historical (e.g., design of vessels and structures, climate change research) data sets. Examples of the key data types/parameters that were identified include: ***Framework (Base) Data*** ▪ *Cadastral* – boundaries of land and marine property ▪ *Topography* – contours, DEMs, slope and aspect ▪ *Jurisdictional boundaries* – national including offshore, provincial/territorial, municipal ▪ *Administrative boundaries* – fisheries zones, departmental regions, Indian Reserves, statistical units ▪ *Hydrography* – land waterbodies and waterways, river basins, marine bathymetry and obstructions ▪ *Transportation* – highways, roads and streets, railway lines, marine anchorages, airports and airstrips ▪ *Infrastructure* – major powerlines, pipelines and communication lines, dams ▪ *Buildings* – location ▪ *Imagery* – satellite, airborne, geo-rectified or ortho-rectified imagery ▪ *Addresses*: road/street name, house number, postal code ▪ *Toponomy* – place names ▪ *Coordinate reference system* – coordinates (x, y, z), latitude and longitude and height ***Thematic Data*** ▪ *Sea, river and lake ice* – thickness, extent, motion, structure/age, freeze-thaw, topography, snow depth, surface state/albedo, ice damning ▪ *Ice sheets and glaciers* – extent, thickness, motion, structure/age, topography, snow depth, mass change, iceberg calving, surface state/albedo ▪ *Snow* – extent, structure/age, depth, freeze-thaw, surface state/albedo, snow water equivalent ▪ *Icebergs* – extent, motion, calving, location, size ▪ *Permafrost* – extent, freeze-thaw, surface state/albedo, elevation change ▪ *Ocean* – salinity, wind, waves, biota, temperature, seabed character and bedform ▪ *Land – surface state/albedo, biota, vegetation/land cover, biomass, use, human impact, wetland types, flood hazards* ▪ *Atmosphere and weather* – historical conditions and forecasts of wind, temperature, precipitation, humidity, clouds, snowfall, chemistry/ particulates ▪ *Natural resources* – petroleum, minerals, forestry, fisheries, wildlife ▪ *Energy resources* – hydropower, bio-energy, solar, wind ▪ *Infrastructure* – water and sewer lines, powerlines, pipelines, transmission towers, bridges, communication lines, dams, civil protection sites, schools, hospitals

Table 7.1 (Cont'd.)

Needs Component	Findings
Data Needs (Cont'd.)	▪ *Protected areas* – parks, reserves, conservation areas, heritage sites, recreational areas, environmentally sensitive areas ▪ *Biodiversity* – ecosystem, habitat, flora and fauna ▪ *Soils* – type, productivity, depth, texture, structure and content of particles and organic material, stoniness, erosion ▪ *Wetlands* – water quantity and quality ▪ *Environment* – pollution, waste, air quality ▪ *Human health and safety* – geographical distribution of pathologies (allergies, cancers, respiratory diseases) ▪ *Natural risk zones* –areas vulnerable to floods, landslides and subsidence, avalanches, forest fires, earthquakes, volcanic eruptions ▪ *Socio-economic* – economic, population/census, population density, food security ▪ *Agriculture* – productivity, crop growth and health, irrigation systems, greenhouses, stables ▪ *Hydrology* – watersheds, watershed units, watershed boundaries ▪ *Geology* – bedrock, aquifers, geomorphology ▪ *Coastal zone* – shoreline, tides, currents, water levels, erosion ▪ *Cultural heritage* – archaeology sites, ceremonial and sacred sites, use and harvesting areas, occupancy areas
Data Quality and Usability	Users want access to the best quality data with limited restrictions on their use. Required improvements include: ▪ Further development of methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation ▪ More provision of information on data quality and uncertainty as part of the metadata ▪ Further removal of technical and legal barriers for integrating accessible data into user systems ▪ Unification of the best data sources in a single data set that can benefit from all authoritative updates and be the go-to source for a given data type, making it easy to find the best quality data
Data Enhancements	Several studies have identified gaps and problems with existing data sets, which primarily result from inadequate satellite images / sensors and data updating and maintenance weaknesses. The required data enhancements include: ▪ Higher spatial resolution ▪ Higher temporal resolution (i.e., shorter intervals between repeat satellite imaging or in-situ data collection) ▪ Improved latency (i.e., reduced times between original data collection and availability of derived information products) ▪ Improved quality (i.e., better information products derived from satellite missions specifically targeting the Arctic region or increased density of in-situ sensors)

Table 7.1 (Cont'd.)

Needs Component	Findings
Data Access	The literature review identified numerous existing portals from which users can access the data about the Arctic that they need. Some of the major portals and the kinds of data and services that they provide include: ▪ *Arctic Spatial Data Infrastructure (Arctic SDI) Geoportal* – developed by the NMAs of the Arctic nations and providing pan-Arctic coverage, Arctic SDI layers (number) include: biota (8), boundaries (8), Climatology/meteorology/ atmosphere (30), economy (3), elevation (20), environment (27), farming (1), geoscience (10), health (3), imagery/base maps/earth cover (4), location (5), oceans (30), society (4), structure (2) and transportation (1) ▪ *Arctic Biodiversity Data Service (ABDS) Data Portal* – the data management framework for the Conservation of Arctic Flora and Fauna (CAFF) Working Group of the Arctic Council, the ABDS provides access to the following information types: Species (mammals, fishes, birds, invertebrates, lichen, fungi, etc.); Ecosystems (terrestrial, marine, freshwater, boundaries); Stressors (shipping, oil and gas, harvesting, tourism, climate change); and Indices (Arctic species trends, land cover change, protected areas, languages) ▪ *GEOSS Portal* – operated by the Group on Earth Observations (GEO), the GEOSS Portal provides access to earth observation data in archives from 52 organisations worldwide ▪ *Global Cryosphere Watch (GCW) Data Portal* – operated by the Norwegian Meteorological Institute on behalf of the World Meteorological Organization (WMO), via linkages with some 10 other data centres the GCW Data Portal provides access to a wide range of cryospheric information in the following categories (number of variables): frozen ground (9), glaciers/ice sheets (11), sea ice (23) and snow/ice (24) ▪ *Observing Systems Capability Analysis and Review Tool (OSCAR)* – OSCAR contains quantitative user-defined requirements for observation of some 308 physical variables in application areas of WMO (i.e., related to weather, water and climate) and provides detailed information on all earth observation satellites and instruments and expert analyses of space-based capabilities. ▪ *Federal Geospatial Platform Open Maps* – Open Maps, part of the Canadian federal government's Open Data portal, provides access to the Government of Canada's geospatial information (approximately 750 datasets). ▪ *Arctic Portal* – The Arctic Portal is operated by a not-for-profit organization in Iceland as a comprehensive gateway to Arctic information and data on the internet. ▪ *Arctic Data Archive System (ADS)* – operated by the Japanese National Institute of Polar Research, the ADS provides access to datasets in the following categories (number of datasets): agriculture (1), atmosphere (38), biosphere (35), climate indicators (148), cryosphere (103), oceans (39) and spectral/engineering (3) ▪ *Norwegian Polar Data Centre* – operated by the Norwegian Polar Institute, the Centre provides access to a full range of official topographical basemap datasets for Norwegian polar land areas and a variety of dynamic thematic map services (e.g., marine mammals, seabirds and fish, geology, sea ice, glaciers, administrative boundaries)

Table 7.1 (Cont'd.)

Needs Component	Findings
Data Access (Cont'd.)	▪ *Global Change Master Directory (GCMD)* – operated by the U. S. National Aeronautics and Space Administration (NASA), the GCMD is one of the largest public metadata inventories in the world, providing access to the following categories of data records (number of records): agriculture (1,838), atmosphere (&,848), biological classification (4,255), biosphere (7,046), climate indicators (700), cryosphere (3,109), human dimensions (3,870), hydrosphere (43), land surface (5,405), oceans (11,066), paleoclimate (1,621), solid earth (3,191), spectral/engineering (2,640), sun-earth interactions (439), terrestrial hydrosphere (3,294) ▪ *Polar Data Catalogue (PDC)* – a repository of metadata and data that describes and provides access to diverse datasets generated by Arctic and AntArctic researchers, the PDC is operated by the Canadian Cryospheric Information Network. The following datasets are accessible (number of datasets): Radarsat images of the Arctic (27,743), Radarsat images of the AntArctic (349), sea ice charts (3,972), other datasets of the Arctic (324) ▪ *Arctic Data Explorer* – this portal is operated by the U.S. National Snow and Ice Data Centre (NSIDC) and provides access to the following datasets (number of datasets): sea ice (3,260), biology (3,006), permafrost (2,315), meteorology (3,849), economics (696), hydrography (265), oceanography (8,416), biodiversity (338), terrestrial ecology (541), chemistry (4,996), local and traditional knowledge (117) ▪ *Exchange for Local Observations and Knowledge of the Arctic (ELOKA)* – ELOKA fosters collaboration between resident Arctic experts and visiting researchers and hosts data management. An example, the Atlas of Community-Based Monitoring in a Changing Arctic, showcases the many community-based monitoring (CBM) and Indigenous Knowledge (IK) initiatives across the circumpolar region ▪ *Polar Thematic Exploitation Platform (Polar TEP)* – developed by Polar View Earth Observation, Polar TEP provides polar researchers with access to computing resources, earth observation (EO) and other data, and software tools in the cloud ▪ Atlas of Community-Based Monitoring in a Changing Arctic – designed to showcase the many community-based monitoring (CBM) and Indigenous Knowledge (IK) initiatives across the circumpolar region, this portal was developed with input from: o Inuit Circumpolar Council (ICC); o Institute at Brown for Environment and Society (IBES); o Exchange for Local Knowledge and Observations of the Arctic (ELOKA); o Inuit Qaujisarvingat: Inuit Knowledge Centre of Inuit Tapiriit Kanatami (ITK); o Carleton University's Geomatics and Cartographic Research Centre; o Nordic Agency for Development and Ecology (NORDECO); o Alaska Ocean Observing System (AOOS); and o Alaska Sea Grant.

Table 7.1 (Cont'd.)

Needs Component	Findings
Distribution Formats	Users have identified the following requirements in terms of data distribution formats: ▪ Most users prefer data formats and access that adhere to recognised standards ▪ Ice sheet data users prefer NetCDF as a standard format but also want to have access to other standard formats ▪ Arctic Council users prefer the use of compatible formats based on common standards to facilitate data consolidation ▪ The Arctic Spatial Data Pilot team prefers that data owners make their data available at standardised interfaces, with temporal dimensions support, ideally such as Open Geospatial Consortium (OGC) Web Feature Service (WFS) or Web Coverage Service (WCS) that support access to the underlying data ▪ The Arctic Spatial Data Pilot team also prefers the use of formats that contain styling information (e.g., the OGC Symbology Encoding standard)
Web Services and Tools	The user centered design review identified the following preferences for web services and tools: ▪ Unified interfaces or a one-stop portal to provide discovery and access to all available polar data across existing metadata catalogues
Data and Service Documents	For users to evaluate the fitness for use of data and services, the following types of documentation are required: ▪ A fundamental requirement is for good metadata that provides information on data quality and uncertainty ▪ Metadata generation based on interoperability (e.g., standards-based) protocols ▪ A common set of metadata elements relevant across polar sciences, to facilitate interoperability and sharing between polar data repositories and online portals
Data and Service Availability	See **Data Access** above
General Knowledge	The literature review confirmed that the level of general knowledge about information management policies, geoportals, SDIs and their benefits vary widely within the user community. The community can be generally divided into two types of users, with the following knowledge characteristics: ▪ Specialists – these users typically have some education or training in the use of spatial information and enough knowledge and experience to engage with geoportals or SDIs to discover and access the data they need for their applications (e.g., geomatics specialists, engineers, foresters, biologists, geologists). They can use metadata and other tools to assess data fitness-for-use and download to their application the appropriate data. ▪ Generalists – these users typically have very limited education or training in the use of spatial information and lack the knowledge and experience to successfully engage with typical geoportals or SDIs (e.g., policy analysts, senior decision-makers, ships captains, Indigenous hunters and fishers, citizens). They require very simple user interfaces and tools to find and interpret the data they need or the help of specialists to produce information products to meet their needs.

Table 7.1 (Cont'd.)

Needs Component	Findings
Guidance Requirements	Users have identified the following types of requirements for guidance documentation to facilitate use of an international Arctic SDI: ▪ Policies for the definition of authoritative sources for data; ▪ Policies to establish data sensitivity for aspects which are specific to the north, such as classification related to traditional knowledge data; ▪ Policies related to language support (Inuktitut, French, English); ▪ Policies and eventually legislation requiring that all rights off-shore be interoperable and available through a common window; ▪ Policies requiring that any geospatial data submitted to federal agencies (e.g., assessment work, permits, new constructions, etc.) be in digital format, shareable and standardised; ▪ A common projection system for the north (e.g., Lambert Conformal Conic) and thesaurus contents with a classification that addresses objects that are unique to the North; ▪ Implementation based on consideration of Canadian Geospatial Data Infrastructure (CGDI) standards and INSPIRE standards (for interoperability with EU countries in the circumpolar Arctic SDI); ▪ Consideration of NetCDF as a standard format for Arctic research data; ▪ Methods for data quality assurance, uncertainty characterization, propagation of errors and provenance articulation; ▪ Provision and communication of quantified information product uncertainties; and ▪ Provision of environment to design, develop and deliver targeted training and capacity-building activities.
Data Incorporation Effort	Consultations are necessary to determine the level of effort required by data providers and staff of the participating NMAs to incorporate their data into the Arctic SDI ▪ Metadata standardizations is the biggest concern as it is a pre-requisite to make data searchable and to integrate them into the Arctic SDI. ▪ The adoption of ISO standards for metadata would help in addressing a wide audience beyond the USA and Canada.
Future Requirements	The requirements that users have identified as not yet being fully met and of increasing future importance include: ▪ Platforms that add to data access the ability to extract meaningful information from all available data and to deploy user-created or acquired algorithms/applications; provision of computing resources, storage and networking capabilities, and collaborative tools for user communities to publish, share and discuss their results, information, data and software/code on the platform ▪ Improved data visualization tools for users to easily see and understand both the data they can utilize and the results of their analysis of that data ▪ The use of ontologies (i.e., explicit specification mechanisms to express concepts in a computer-readable language) and semantics (i.e., use of mathematics-based languages to control the relationships between symbols and meanings, which allows data to be shared and reused across applications, enterprises, and community boundaries) to facilitate easier search functionality

Table 7.1 (Cont'd.)

Needs Component	Findings
Future Requirements (Cont'd.)	▪ Archives of historical as well as more recent EO data, weather data, sea ice data, land use and settlement data, etc., to support a range of research activities and the design and construction of new structures and facilities in the Arctic ▪ Significant growth in the use of spatial information as the impacts of global climate change (i.e., melting sea ice, ice sheets and permafrost) facilitate increases in marine traffic and cause damage to structures and facilities in the Arctic ▪ More sophisticated levels of integration of data from multiple sources (e.g., satellite sensors, in-situ sensors, Indigenous knowledge ▪ Information scaling by bridging the gap between discrete in-situ point measurements at the local level and large area coverage satellite data to a middle ground where catchment area-sised datasets are needed, scaled up from the local level and scaled down from the broad satellite coverage ▪ Improved veracity of data products through provision of detailed, easy-to-understand descriptions of the applied methods for generation of higher-order products (e.g., retrieval of sea ice thickness) and their limitations ▪ Increased demand for professional value-added, integrated data services that assess all the different data sources and products, and provide information services that integrate the best data and provide it to users

7.2 RECOMMENDATIONS

This report has demonstrated that the user needs for information and an infrastructure to support its discovery, access and use in the Arctic region are wide ranging and very diverse. Based on our assessment of the study findings, we propose the following steps in moving towards the establishment of a successful International Arctic SDI.

1. ***Develop an infrastructure that meets the growing demand for platform level services.*** This means going 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.

2. ***Ensure that data platforms are interoperable***. This means going beyond data interoperability to include sharing of code and processing of algorithms in chains across platforms. Making arbitrary applications available on cloud infrastructures or exploitation platforms in a standardised way is a key technology for Big Data in general and particularly true for Earth Observation satellite data processing.

3. ***Expand the scope of data that is accessible through the infrastructure to include social science data***. There is a need, particularly within Arctic Indigenous communities, for data and observations that can support decision-making in the context of socio-environmental change. The Atlas of Community-Based Monitoring in a Changing Arctic initiative is an example of initiatives being undertaken by Indigenous communities to help address this need.

4. ***In designing the infrastructure, ensure that the needs of "generalists" are given foremost consideration***. These Arctic data consumers (the vast majority of potential SDI users) typically have very limited education or training in the use of spatial information and lack the knowledge and experience to successfully engage with typical geoportals or SDIs. They require very simple user interfaces and tools to find and interpret the data they need.

5. ***Improve data discovery mechanisms, including annotation, vocabularies and linked data, crawling based approaches and service availability and reliability.*** Human- and machine-based annotation systems are required to identify data that has been used for specific purposes. Catalogues should provide their data in a way that search engines can fully harvest the catalogue content and other approaches such as direct harvesting of data services should be further investigated. Proper backlink mechanisms should be implemented that show data providers what the data has been used for.

6. ***Consider the distinctive needs of Indigenous communities in the development of infrastructure governance and policies.*** A number of studies have documented the sensitivities around sharing and use of Indigenous-specific and Indigenous-relevant indicators and data. Actions are underway to advance Indigenous community self-determination in collecting, verifying, analyzing, and disseminating Indigenous-specific data and information. Long-term capacity building must occur so that Indigenous people can be responsible for data design, collection, management, and application in research and decision making.

7. ***Build effective working relationships with established Arctic data management organisations and other data initiatives.*** To be successful in gaining traction with user communities and securing their interest in and use of an International Arctic SDI, the design and implementation must capitalize on the extensive work that has already been undertaken in these Arctic data communities (profiled in Appendix A5) and other data initiatives (e.g., Research Data Alliance) to make available data easy to access and use.

8. ***Support the further development of methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation.*** Users want access to the best quality data available and want the tools to assess their fitness for use. Provision of information on data quality and uncertainty is a critical part of metadata.

9. ***Provide functionality to handle the temporal dimension of data to meet the growing demand for analysis of the evolution of characteristics over time***. Using an open, interoperable standard with support for temporal dimensions (e.g., NetCDF, OGC WCS) will enable users to avoid custom development tasks related to the integration of these data. So-called "data cubes" are a data abstraction to evaluate aggregated data from a variety of viewpoints, including time series analyses.

10. ***Advocate for resolution of semantic issues in spatial data sharing and service interoperability***. In particular, semantic heterogeneity still causes several problems, including: discovery of data sets and services based on keywords; rigid metadata structures; missing semantics on technical terms; and missing matching capabilities for equivalent or related terms or symbols.

11. ***Ensure that the necessary resources are available to develop the capacity of data suppliers to collect data in a format compatible with SDI.*** Indigenous community members need appropriate training, equipment, and infrastructure and other support in order to carry out monitoring efforts that will facilitate data compatibility, and partnering scientists, funders and government workers also need to develop new skills, capacities and knowledge areas.

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APPENDICES

Appendix A1

Literature Review of User Needs

A1.0 LITERATURE REVIEW OF USER NEEDS

A1.1 SOURCES OF INDIGENOUS COMMUNITY USER NEEDS

A1.1.1 Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis, Executive Summary

The purpose of this study was to develop a better understanding of geospatial data needs among Indigenous groups across Canada and issues surrounding how these data are being used (Makivik Corporation 2008). The objectives were:

- to determine the key geospatial datasets required to support land and resource management by Indigenous communities; and
- to determine who the authoritative closest-to-source custodians are for the identified key geospatial datasets required to support land and resource management.

Data priorities and uses were identified by the study (see Section A1.1.2). Table A1.1 shows the dataset priorities identified by the communities that were consulted for the study.

Table A1.1 Dataset Priorities

Class	Sub-Class	PRIORITY	# Groups Identified as High Priority
Natural Heritage	Wildlife	HIGH	100%
Administrative/Development	Mining	HIGH	90%
Administrative/Development	Indigenous Territories	HIGH	80%
Administrative/Development	Forestry	HIGH	80%
Administrative/Development	Land Use / Land Management	HIGH	80%
Administrative/Development	Tourism and Recreation	HIGH	80%
Administrative/Development	Conservation/Protected Areas	HIGH	70%
Cultural Heritage	Use and Harvesting Areas	HIGH	70%
Natural Heritage	Ecology	HIGH	70%
Administrative/Development	Fishery	MEDIUM	60%
Biophysical	Hydrology	MEDIUM	50%
Cultural Heritage	Travel and Trade Routes	MEDIUM	50%

Class	Sub-Class	PRIORITY	# Groups Identified as High Priority
Biophysical	Geology	MEDIUM	40%
Cultural Heritage	Archaeology	MEDIUM	40%
Cultural Heritage	Ceremonial and Sacred Sites	MEDIUM	40%

Aside from identifying how geospatial data were being used, other themes emerged as priorities for community practitioners, including:

- Issues of access to data;
- Lack of current use of web-based mapping;
- Problems associated with locating and downloading geospatial data;
- Lack of data standards and format issues;
- Issues of access to satellite imagery;
- Problems assembling and maintaining cultural data inventories;
- Difficulties establishing and retaining geomatics capacity;
- Concerns about data confidentiality and protocols;
- Understanding land use planning in context of broader issues; and
- The need to continue the dialogue.

Findings of the Aboriginal Community Land and Resource Management study that are of interest to this study included:

- Data Custodians / Suppliers – 95 percent of Framework data sources were governmental, and 46 percent of thematic data came from Indigenous groups
- Frequency of Updates (Data Currency) – most datasets used or needed require yearly updates or updates every few years
- Data Formats – Shapefile format was used most frequently for both thematic (82.7 percent) and framework (79.3 percent) data; Web services only accounted for 2.9 percent of thematic and 0.5 percent of framework data
- Data Access – Access through web services (WMS/WFS) made up only 3.5 percent of the total data used
- Data Confidentiality – 54.5 percent of thematic data was identified as low security, compared to 96.7 percent of framework data; community-owned data (Traditional Knowledge, use & occupancy data) accounted for 18 percent of all thematic data and were ranked of high security importance

- Datasets where cost is a factor in acquisition – 87.8 percent of thematic data were available without cost, compared to only 48.6 percent of framework data
- Metadata – available for 94.4 percent of framework data, but only 12 percent of thematic data
- Missing Geospatial Data and Barriers to Access and Use – 78 percent of participants noted that some data were unavailable or inaccessible for their planning process; main barrier for framework data was cost (81 percent), while the main barrier for thematic data was security (77 percent)

A1.1.2 Aboriginal Community Land and Resource Management: Geospatial Data Needs Assessment and Data Identification and Analysis, Volume 2 Data Identification and Analysis

Volume 2 documents and summarizes the geospatial data used in ten Indigenous land use planning projects. While many of these projects are south of 60°, several of them are in Northern Canada (e.g., the resolution of specific land use conflicts in Dehcho, and planning for land-claims implementation – Nunavut Planning Commission and Sahtu) and consequently this report is of interest to this study.

The project team analysed each plan's set of maps and summarised a list of data used for each map. This resulted in a preliminary list of data used for each plan, summarised in an Excel spreadsheet. 2 summarizes the information captured for each data layer in the summary spreadsheet and 3 provides a list of data categories, classes and sub-classes that are required to meet Indigenous Community Land and Resource Management needs[9].

Table A1.2 List of Parameters Recorded for Each Geospatial Data Layer.

Field	Description
Group	The selected Indigenous group
Dataset name	The name of the dataset
Format	The format of the dataset (e.g., Shapefile)
Resolution/Scale	The scale of the dataset (e.g., national, provincial/territorial, regional and local)
Category	The data category (e.g., thematic or framework data)
Class	Main classes for data identified (biophysical, admin/development, natural and cultural heritage)
Sub-Class	Further sub-divisions of classes, providing increased resolution to the classification of the data identified
Update Status	Status of the data, updated and current as of (date)

[9] A comprehensive view of priority framework and thematic datasets as well as a list of the associated information (description, number of records, resolution, data providers, and dataset examples) can be found in Appendices B and C of the Makivik Corporation report, respectively.

Table A1.2 (Cont'd.)

Field	Description
Structure	Structure of the data (vector or raster)
Source	The authoritative source of the dataset
Metadata	Does the data have accompanying metadata? (yes/no)
Security	Can the dataset be shared (high, medium and low)
Cost	Any cost associated with obtaining the data
Access	Data access mechanism (free download, web services, etc.)
Barriers to access	Any barriers to accessing the data
Data availability	The availability data
Currency	Time period and data release date
Notes or Comments	Any notes or comments about the dataset

Table A1.3 Data Required to Meet Indigenous Community Land and Resource Management Needs.

Category	Class	Sub-Class	Dataset
Thematic	Administrative / Development	**Indigenous Territories**	Boundary, Indian Reserve; Boundary, Indian Territory; Boundary, Treaty; Settlement Area Boundary
		Land Ownership	Boundary, Private Land; Cadastral; Right of Way
		Socio-Economic	Economic Data; Population/Census; Population Density
		Conservation / Protected Areas	Conservation/Protected Areas; National Parks; Park Proposals; Provincial Parks; Boundary, Parks; Protected Areas; Conservation Zone
		Agriculture	Agriculture
		Fishery	Fishery, Commercial
		Forestry	Forestry; Eligible Harvest Areas; Timber Harvesting; Proposed harvest units
		Land Use / Land Management	Land Use Zones; Land Management Zones; Land, Commercial; Land, Institutional; Land, Residential; Designated Areas; Human Impact; Landfill / Waste Sites; Special Management Zones
		Tourism and Recreation	Tourism; Hunting, Commercial; Hunting, Sport; Outfitting; Recreational Areas; Tourism Potential; Tourism Areas
		Energy Development	Energy Development; Wind; Hydro development
		Mining	Mining; Mineral Potential; Mineral Claim and Leases; Coal – Developed Prospect; Coal – Past Producer; Coal – Prospect; Coal – Showing
		Oil and Gas	Oil and Gas; Oil and Gas Rights; Proposed Pipeline

Table A1. (Cont'd.)

Category	Class	Sub-Class	Dataset
Thematic	Biophysical	**Weather and Climate**	Climatology; Precipitation; Temperature; Snow fall
		Geology	Geology
		Land Cover	Land Cover; Vegetation; Wetland Types; Wetlands; Built-up Areas
		Hydrology	Hydrology; Watershed Boundary; Watershed Units; Watersheds
		Coastal Zone	Tides; Currents; Water Levels
Thematic	Natural Heritage	**Fauna**	Animals; Birds; Fish
		Ecology	Habitat; Biogeography; Paleo-ecology
		Sensitive Areas	Environmentally Sensitive Area; Disturbed Area
Thematic	Cultural Heritage	**Archaeology**	Archaeology; Archaeological Finds; Archaeology Density
		Ceremonial and Sacred Sites	Sacred Areas and Burial Sites; Cultural Value Survey; Heritage Sites; Birth sites
		Use and Harvesting Areas	Traditional Land Use; Traditional Hunting; Fishing Sites; Medicinal Plants; Trapline Boundary; Traplines; Trapping; Traditional Use (Sites); Wildlife, Critical; Land Access
		Occupancy Areas	Cabins; Camps; Trading Posts
		Cultural Toponomy	Traditional Place Names
		Travel and Trade Routes	Traditional Place Names; Transportation Routes; Travel Routes; Canoe routes; Canoe Heritage Trail; Human Migration; Portage trails; Portages; Traditional trails
Framework	Framework	**Hydrography**	Waterbodies (Lakes/ Ponds); Waterways (Rivers/ Streams)
		Elevation	Contours; DEM; Hillshade
		Toponomy	Place Names (Toponomy)
		Bathymetry	Bathymetry
		Infrastructure	Infrastructure; Utilities; Utility Line; Water Supply; Powerlines; Transmission Lines; Transmission Tower; Airstrip; Anchorages; Bridges; Communication Lines
		Transportation	Railways; Shipping; Other
		Roads	Roads; All Weather Roads; Existing Roads; Unpaved (Public) Roads; Seasonal Road; Winter Roads
		Remote Sensing	Satellite Imagery; Aerial Photography; Lidar
		Administrative Boundaries	Boundary, Province; Boundary, Country; Towns and Communities
		National Topographic Datasets	Base Data – National Topographic; Data Base
		Provincial Topographic Datasets	TRIM

A1.1.3 Community-Based Monitoring and Indigenous Knowledge in a Changing Arctic: A Review for the Sustaining Arctic Observing Networks

This review sought to address the need for better information about community-based monitoring (CBM) in the Arctic (Johnson, et al. 2016). It drew on information about past and current CBM and Indigenous knowledge (IK) initiatives in the circumpolar region that had been collected in the online Atlas of Community-Based Monitoring in a Changing Arctic, which is intended to serve as an inventory of initiatives that will assist with network building and identification of best practices and challenges for the field. The Atlas and review were part of a larger initiative to ensure that CBM and IK are part of the broader Arctic observing "network of networks" that make up the Sustaining Arctic Observing Networks (SAON).

Many programs in the Atlas were initiated based on a perceived need for data and observations that could support decision-making in the context of socio-environmental change. Critical issues that programs in the Atlas were designed to monitor include:

- Monitoring the impacts of development and extractive industry – CBM can offer communities a way of tracking the impacts of development, and can guide land use decision-making to minimize impacts on fragile ecosystems, human health, and subsistence use
- Species monitoring and biodiversity – Many programs monitored particular species based on CBM or IK methods, including those that are important to subsistence such as seals, salmon, bowhead whale, walrus, moose, and caribou, and predators including brown bear and polar bear.
- Contaminants monitoring – CBM programs concerned about the impacts of contaminants on human health engage community harvesters in collection of samples, which are then sent away for lab-based contaminant analysis.

The kinds of information that these communities are collecting in their CBM programs include:

- Terrestrial animals
- Fish/Marine mammals
- Birds
- Plants, flora
- Human health
- Food security
- Lakes/rivers/streams
- Glaciers and/or snow
- Sea ice
- Weather

- Air quality
- Permafrost & terrestrial issues
- Resource extraction, industry & development
- Tourism
- Land/sea use
- Social/cultural/economic issues (specify under “other”)
- Governance & rights

A1.1.4 Study on Arctic Lay and Traditional Knowledge

The purpose of this study was to identify and collect basic information on community-based monitoring and observing programmes in the European Arctic ((European Commission, 2014). The study fed into the Atlas of Community-Based Monitoring in a Changing Arctic initiative. The study used the following definition of lay and traditional knowledge (LTK), “cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environment”. In total, 72 community-based monitoring and observing programmes were identified through questionnaires, workshops, and literature analysis.

Based on the analysis of community-based programmes, LTK was grouped into 5 main themes:

- Climate change impacts, mitigation and adaptation – LTK contributes to: setting baselines to guide scientific efforts; combining spatial and ethnographic data to document and understand changes; identifying adaptation strategies developed by local communities to measure levels of resilience; collecting evidence on human-ecological change and interaction throughout the last century; developing monitoring programmes which include locals as observers; and feeding worldwide scientific networks and communities of practitioners in climate change.
- Tackling food security – LTK contributes to: combining LTK with scientific research to ensure food availability; optimizing social networks (e.g., subsistence food sharing networks, cooperative hunting, etc.); monitoring changes in subsistence-oriented behaviour and impact on community food distribution networks; and identifying factors affecting specific food resources (e.g., freshwater fish).
- Governance and resource rights – LTK contributes to: enhancing dialogue and engagement among main Arctic actors and decision-making processes; building consensus and implementing actions; informing public policies and mitigation measures; designing adaptive management systems for natural resources; achieving symmetric collaborations between communities and scientists; and identifying local or community-dependent needs and conditions calling for attention by the authorities.
- Cultural identity – LTK contributes to: monitoring the sensitivity of traditional activities to potential disruption by changing conditions; fostering sustainable business development in cultural sectors;

quantifying traditional values (e.g., respectful and reciprocal relationships); promoting knowledge transfer through training and capacity building; and promoting LTK awareness to target audiences (e.g., policy-makers, scientist and the general public).

- Conservation of biodiversity and habitats – LTK contributes to: mapping and tracking habitat use of endangered species; maximizing local skills (e.g., tagging by native hunters); describing reference topics (e.g., the ice and sea-ice situations) in the Northernmost inhabited areas; improving public participation in wildlife conservation programmes; and coupling global and local problems and promoting broad alliances.

A1.1.5 National Inuit Strategy on Research

The purpose of the National Inuit Strategy on Research (NISR) is to address research challenges through coordinated actions that enhance the efficacy, impact, and usefulness of Inuit Nunangat research for Inuit (Inuit Tapiriit Kanatami, 2018). The strategy was developed by Inuit Tapiriit Kanatami (ITK), the national representational organization for the Inuit in Canada, the majority of whom live in Inuit Nunangat, specifically, the Inuvialuit Settlement Region (Northwest Territories), Nunavut, Nunavik (Northern Québec), and Nunatsiavut (Northern Labrador). The objectives and actions that ITK is committed to implementing in partnership with Inuit representational organisations, governments, and research institutions, fall within five priority areas: 1) Advance Inuit governance in research; 2) Enhance the ethical conduct of research; 3) Align funding with Inuit research priorities; 4) Ensure Inuit access, ownership, and control over data and information; and 5) Build capacity in Inuit Nunangat research.

Priority Area 4 is of particular relevance to this user needs study. An enduring challenge in this area is the aggregation of Inuit-specific data with that of other Indigenous peoples, making relevant information impossible to discern or utilize. Specific objectives of the NISR in this priority area are:

- Advance Inuit self-determination in collecting, verifying, analyzing, and disseminating Inuit-specific data and information;
- Invest in Inuit-led data and information technology and infrastructure;
- Ensure ownership of Inuit data by Inuit-appointed entities; and
- Utilize Inuktut (the Inuit language) in data platforms and information management.

To meet these objectives, ITK plans to:

- Advocate for the consistent production and sharing of Inuit-specific and Inuit-relevant indicators and data, including the Inuit Health Survey;
- Invest in culturally-relevant, community-based technology to facilitate access to and management of data and information;
- Develop Inuit-specific guidelines on data accessibility, ownership, and control; and
- Create and invest in digital Inuit Nunangat data repositories that are inclusive of Inuit knowledge in ways that are respectful of its distinctive forms as well as the Inuit norms that govern its use and sharing.

A1.1.6 Indigenous Peoples' Secretariat

The Indigenous Peoples' Secretariat (IPS) is an entity within the Arctic Council Secretariat with its own board, designated budget and work plan. The IPS performs the following functions (Indigenous Peoples' Secretariat 2018):

- Facilitates the participation of Indigenous Peoples' organisations in the work of the Arctic Council, assists and provides Secretariat support functions to the six Permanent Participants primarily in Arctic Council activities;
- Enhances the capacity of the Permanent Participants to pursue the objectives of the Arctic Council;
- Facilitates dialogue and communications among the Permanent Participants and among Permanent Participants and other Arctic Council and related bodies;
- Supports the Permanent Participants in carrying out actions to maintain and promote the sustainable development of Indigenous Peoples cultures in the Arctic;
- Gathers and disseminates information on and provides and lists sources of different forms of knowledge; and
- Contributes to raising public awareness of Arctic Council issues through a web site, newsletters and other publications.

The IPS has launched a story map series focusing on the Indigenous peoples, environment and politics of the Arctic. Based on a review and analysis of the map series media, the following user needs were identified (Indigenous Peoples' Secretariat 2017):

- Improved sea ice information to help prevent hunters from falling through thin ice.
- Information on transport of sulphur dioxide and nitrogen oxide, the causes of acid rain, to help reduce the threat that is posed to fish stocks and other Indigenous food supplies.
- Information on transport of persistent organic pollutants (POPs), which accumulate in the fatty tissues of marine mammals such as seals, walrus and polar bears that are important sources of food for Indigenous peoples, to help reduce the effects on the reproductive system and child developmental, among other health effects.
- The systematic use of Indigenous and local knowledge to influence the nature of communications, the development of frameworks for scientific analysis and the policy decisions being made by the Arctic Council and its Working Groups.
- Improved information about how Arctic climate change will impact the region and its peoples, to ensure that appropriate action is taken to slow down the change and implement effective adaptation measures.
- While not directly related to data and information, the need to build Indigenous capacity to participate more fully in the work of the Arctic Council (e.g. with the Àlgu fund).

A1.2 SOURCES OF OTHER USER NEEDS

A1.2.1 Strategic Roadmap for Canada's Arctic Spatial Data Infrastructure and Marine Cadastre

This project informed the development of a strategic plan and roadmap for Canada's Arctic spatial data infrastructure (SDI) with a marine cadastre component. This strategic plan and roadmap was intended to assist in identifying priorities, needs, gaps and actions required to develop the Canadian Geospatial Data Infrastructure (CGDI) to meet the needs of Arctic stakeholders. The project objectives were to (Fujitsu Consulting, 2012a):

- Establish a comprehensive account of initiatives that support Government of Canada priorities and that could leverage a Canadian Arctic SDI in order to provide further understanding and to guide analysis, strategic planning and action planning in the development of a Canadian Arctic SDI including the marine cadastre component.
- Establish a baseline indication of the status and quality of geospatial information required to support Arctic initiatives and identify gaps.
- Provide general recommendations on the key elements of a strategy and roadmap required to develop a Canadian Arctic SDI including the marine cadastre component.
- Provide specific recommendations on opportunities for pilot projects to advance development of a Canadian Arctic SDI including the marine cadastre component, and to support the justification of broader CGDI development strategies and investments.

The results of the research and analysis of user needs for this project are presented in two reports. The *Environmental Scan Report* (Fujitsu Consulting, 2012a) documents the results of an environmental scan of relevant documentation, such as strategic policies, plans and priorities, legislative frameworks, technology demonstrations and other relevant federal, territorial, NGO, community, and international initiatives. The *Validation and Gap Analysis* report (Fujitsu Consulting 2012b) documents the results of the second phase of the project, which allowed the project team to: validate the findings of the environmental scan through consultations with stakeholders (see Appendix A2); determine geospatial data availability based on the requirements; and conduct a gap analysis between existing and required information.

The first report includes a series of tables identifying some 75 key activities/SDI drivers, the initiatives contributing to each and the land and marine data needs associated with each activity. Based on the prevalence of data needs mentioned in (or implied from) the reviewed documents, the top ten needs in order of priority were assessed to be:

Land Domain:

1. Framework data
2. Cadastral (rights) data
3. Natural resources (petroleum, minerals, forestry, fisheries) data
4. Jurisdictional boundaries (national including offshore, provincial/territorial, municipal) data
5. Hydrography data
6. Earth observation data
7. Protected areas (parks, reserves, conservation areas, heritage sites, etc.) data
8. Biodiversity (ecosystem, habitat, flora and fauna, etc.) data
9. Administrative boundaries (fisheries zones, departmental regions, Indian Reserves, etc.) data
10. Environmental hazards (pollution, waste, etc.) data

Marine Domain:

1. Hydrography data
2. Cadastral (rights) data
3. Natural resources (petroleum, minerals, fisheries) data
4. Environmental hazards (pollution, waste, etc.) data
5. Earth observation data
6. Framework data
7. Jurisdictional boundaries (national including offshore, provincial/territorial, municipal) data
8. Biodiversity (ecosystem, habitat, flora and fauna, etc.) data
9. Protected areas (parks, reserves, conservation areas, heritage sites, etc.) data
10. Administrative boundaries (fisheries zones, departmental regions, Indian Reserves, etc.) data

The following sections provide a synopsis of the requirements in each case (Fujitsu Consulting, 2012a).

Framework Data

As is common in other geographical regions, framework or 'base mapping' data is almost universally required as a backdrop or foundation for the display and analysis of the wide range of thematic data of interest to public and private sector actors in the Arctic. The needs range from very large scale data for planning and development of major infrastructure (for relatively small geographic extent) to small scale data for environmental reporting applications (large geographic extent). Unlike more populated regions of Canada, where road networks are the most popular data layer, high quality, geometrically corrected satellite

imagery is likely to be of most benefit in the Arctic. Such data is of relatively higher importance in the land domain, but some basic framework data (e.g., geodetic network and geographical names) is also required in the marine domain).

Cadastral Data

Sometimes considered a layer of framework data, in the Canadian context cadastral data is sometimes viewed as a separate data type of high value to a broad cross section of users. In the Canadian Arctic, cadastral data is a priority for many applications, including resource discovery and development (in both land and marine domains), infrastructure development, community planning and construction, and environmental regulation enforcement (in both land and marine domains). The definition of property boundaries and administration of cadastral information is particularly challenging in the marine environment and the pressure for creation and effective management of a marine cadastre will build as offshore resource development expands with continued climate change in the Arctic.

Natural Resources Data

The primary economic driver in the Arctic is natural resource development in both the land and marine domains, and particularly oil and gas and minerals. The principal users of geological, geophysical, fisheries and forestry information are private sector entities, which use all the available data that they can access from any source (primarily government) for exploration, planning and development purposes, but are also producers of data in their own right. Such data is also critically important to the government organisations mandated to manage and control resource development.

Jurisdictional Boundaries Data

Locations of the boundaries of municipalities, provinces and territories and the nation (including the extent of Canada's exclusive economic zone in the marine domain, which is being established under UNCLOS) are important for the exercise of sovereignty, the administration of justice, the granting of rights to land and resources, and the provision of a range of public services, among other things. In the Arctic context, such boundary data is particularly important in connection with the achievement of the economic development policy objectives, but figures highly in the other thematic priority areas as well.

Hydrography Data

As noted above, shipping is expected to increase in the Arctic and high quality hydrographic charting data is an important requirement for safe marine navigation. Such data creates a complete picture of the ocean bottom that allows vessel navigators to avoid obstacles and hazards, but is also beneficial for such applications as exploration for minerals and oil and gas beneath the ocean floor. In addition, hydrography data has an application in fisheries, since classifications of the sea floor and contours, for example, can help fishers locate fish populations and track migrations.

Earth Observation Data

As mentioned previously, high quality optical imagery from earth observation (EO) satellites is commonly included as a layer of framework data. However, beyond providing a foundation for overlay and analysis of other types of data, EO imagery has many other applications in the Arctic, as well as a huge potential for real time analysis, a vital quality for Arctic activities, which is rarely found with conventional vector geospatial

data. For example, radar imagery is frequently used as the major input to the production of ice charts and identification and tracking of oil spills in the marine domain. In addition, EO is being used to better understand and monitor the atmosphere, oceans, cryosphere and biosphere systems and how these are related, to predict and measure the impacts of climate change. Other operational environmental applications of EO in the Arctic region include pollution detection and wetlands mapping in the land domain, and coastal change detection, and accurate weather and climate forecasting and modeling.

Protected Areas Data

One of the important environmental protection objectives in the Arctic is to increase the number and variety of protected areas in both the marine and land domains, such as national parks, marine conservation areas, heritage sites, etc. The geographical locations of the existing and planned protected areas is essential to government organisations for identifying and planning the creation of new reserved areas and their administration once created. This data is also of vital importance to commercial players in the Arctic, who need to ensure that such areas are avoided in industrial developments, or that conditions of development within the areas are adhered to.

Biodiversity Data

Another important environmental protection objective is to preserve biodiversity in both the Arctic land and marine domains. For example, Canada participates in the Circumpolar Biodiversity Monitoring Program, an initiative of the Arctic Council, the goal of which is to facilitate more rapid detection, communication and response to the significant biodiversity-related trends and pressures affecting the circumpolar region. New initiatives are allowing Indigenous and other Arctic peoples who wish to impart their environmental understanding to scientific discourse, and have inherent capacity in community-based monitoring, to play an active role. The collection, preservation and sharing of georeferenced biodiversity data among groups in the Canadian Arctic, and between the Arctic nations, is critical to these efforts.

Administrative Boundaries Data

Below or within the jurisdictional (or political) boundaries are boundaries of a broad range of other areas and regions that are important in the Arctic context, primarily in the land domain. Many of the federal and provincial/territorial government departments that play a role in the north administer their programs by region. For example, AANDC continues to administer programs to a limited number of Indian Reserves in northern Canada, so the locations of reserve boundaries are essential. In the marine domain, under the Fishing Zones of Canada (Zone 6) Order, DFO administers the Arctic fishing zone, and under the Northwest Atlantic Fisheries Organization (NAFO) Convention, fishing zone boundaries have also been established in the Arctic. This kind of data rapidly becomes a burden though, as management faces complexity due to a great number of boundaries, all with their proper rules, regulations, constraints and owners.

Environmental Hazards Data

Finally, location and tracking data on environmental hazards is a priority under both the safety and environmental protection thematic priorities. In the marine domain, under the Canada Shipping Act DFO has responsibility for administering the regulations prohibiting discharge of pollutants from ships. The application of the Arctic Waters Pollution Prevention Act has been recently extended from 100 to 200 nautical miles and new ballast water control regulations will reduce the risk of vessels releasing harmful

aquatic species and pathogens into Canadian waters. Regulations under the Act prohibit the deposit of waste in Arctic waters or in any place on land where such waste may enter Arctic waters, and requires reporting of such deposits. And the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) has a mandate to monitor and assess the status of the Arctic region with respect to pollution in both the land and marine domains.

The second report indicates that the stakeholder interviews confirmed most of the findings derived from the environmental scan. The consultations revealed that users would like to have access to the widest possible array of geospatial data, with minor shifts in the level of priority, as shown in Table A1..

Table A1.4 Data Requirements Identified in Stakeholder Consultations.

Priority Data Types	Other Data Types
Basemap and framework data	Environmental hazards
Hydrographic charts and bathymetry	Communities
High resolution airborne and satellite imagery	Land parcels
Surface and subsurface rights	Natural resources development projects
Ice cover and motion	Ocean properties
Geoscience	Weather/climate
Protected areas	Culture and traditional knowledge
Biodiversity	GPS precise point positioning
Jurisdictional, sovereign and administrative boundaries	Pipelines and power lines
	Aids to navigation
	Aeronautical charts
	Soils
	Health
	Housing
	Infrastructure
	Wharves and other coastal facilities
	Water level and flow
	Vessel traffic

A third report from this project, *Phase 3: Strategic Framework and Roadmap*, identified a number of guidance requirements for Canada's Arctic SDI (Fujitsu Consulting 2012c):

- Policies and eventually legislation requiring that all rights off-shore be interoperable and available through a common window;
- Policies requiring that any geospatial data submitted to federal agencies (e.g., assessment work, permits, new constructions, etc.) be in digital format, shareable and standardised;
- Policies for the definition of authoritative sources for data;

- Policies to establish data sensitivity for aspects which are specific to the north, such as classification related to traditional knowledge data;
- Policies related to language support (Inuktitut, French, English);
- Implementation based on consideration of CGDI standards and INSPIRE standards (for interoperability with EU countries in the circumpolar Arctic SDI); and
- A common projection system for the north (e.g., Lambert Conformal Conic) and thesaurus contents with a classification that addresses objects that are unique to the North.

A1.2.2 Polaris User Needs and High Level Requirements for Next Generation Observing Systems for the Polar Regions

The Polaris study was motivated by the rapidly increasing interest in the polar regions and the need to provide integrated information to support the research and operations of a wide range of user communities, including scientific, industry, governmental and non-governmental organisations and Arctic residents. The study results were intended to help develop new space mission concepts for the polar regions that address evolving scientific and operational information needs.

The study findings were based on four lines of enquiry: a literature review, a review of polar data web portals, stakeholder consultations, and a stakeholder workshop (Polar View, 2016a). The study team reviewed approximately 150 reference documents and web resources on user needs and drivers of environmental information requirements in the polar regions. Telephone interviews were conducted with representatives of over 50 polar organisations (see Appendix A3). The information collected from the literature review and consultations was consolidated and discussed during a workshop attended by 20 polar stakeholder representatives. At each step in the process, the project team's work was reviewed by a steering committee of expert advisors that were chosen to reflect the interests of different polar information communities.

The requirements for environmental information in the polar regions are being driven by a broad range of scientific, operational, and societal imperatives. Researchers are involved in a host of studies on changes taking place across many domains, including climate, oceans, atmosphere, and ecosystems (as illustrated in Table 3.2), which have significant impacts in the regions and, through complex earth system connections, worldwide. The drivers include both national and international science policies, strategies and programmes that contribute to an understanding of the changes taking place in the polar regions and shape policy responses. A few examples of the many polar science activities are contained in Table A1..

Table A1.5 Examples of Polar Scientific Activities that Drive Information Requirements.

Theme	Examples of Types of Activities
Atmosphere, Climate and Weather Change Research	▪ Research on how interactions between the atmosphere, ocean and ice control the rate of climate change ▪ Increasing knowledge of how lake ice cover affects energy and water budgets to improve ability to forecast northern weather ▪ Research on land-fast sea ice distribution as a sensitive indicator of climate variability and change, especially in AntArctica
Land Surface and Use Change Research	▪ Research on structural and functional characteristics of land use systems to sustainably manage food, water and energy supplies ▪ Research on the impacts of human activities on the land in the Arctic
Ocean State and Coastal Zone Change Research	▪ Study of the role of the ocean in the stability of the AntArctic and Greenland ice sheets and its contribution to sea-level rise ▪ Monitoring and understanding extremes such as coastal sea level surges and ocean waves ▪ Study of how the melting of land-fast sea ice and advancing permafrost thawing is causing increasing coastal erosion that is impacting coastal infrastructure and local populations
Ecosystem and Organism Change Research	▪ Understanding the impact on ecosystems of reduced sea ice thickness and extent ▪ Research on how the thawing of permafrost is affecting wetlands and food security ▪ Research on how the reduction of ice cover on rivers and lakes is affecting animal and plant communities and subsistence activities
Sea Ice Change Research	▪ Research on the nature of changes in sea ice distribution and mass balance in response to climate change and variability ▪ Improving understanding of the impacts of a changing sea ice regime on coastal stability and communities ▪ Improving understanding of how a thinner and weaker ice cover responds to wind and precipitation
River and Lake Ice Change Research	▪ Research on the influence of river and lake ice on atmospheric circulation and composition ▪ Understanding hydrological processes involved in ice-jam break-up and flooding
Snow Change Research	▪ Understanding the role snow cover plays in the climatological, hydrological, ecological, and socio-economic systems of the polar regions ▪ Establishing the variability of snow regimes, and the trends over space and time
Ice Sheet and Glacier Change Research	▪ Establishing the net mass loss or gain from ice sheets and glaciers, and their contribution to sea level rise ▪ Predicting the impact of glacier retreat on water supplies for drinking water, irrigation, hydropower and industrial uses
Permafrost Change Research	▪ Research on the impact of rising temperatures on the extent and depth of permafrost ▪ Understanding the impact of the loss of permafrost on infrastructure, ecosystems, climate, and people

Operations in the polar regions take place under some of the most difficult conditions on Earth. Those involved in these operations, such as shipping and fisheries companies, offshore oil and gas operators, research organisations, coast guards, and local communities (as illustrated in Table 3.3), require access to reliable and often near real-time information to plan and undertake their activities. Drivers of information requirements include a range of regulations, standards, and policies (such as the new Polar Code[10]) aimed at ensuring safety of life and mitigating negative environmental impacts. Examples of the wide range of polar operational activities are contained in Table A1..

Table A1.6 Examples of Polar Operational Activities that Drive Information Requirements.

Theme	Examples of Types of Activities
Environmental Impact Assessment	▪ Supporting the responsible development of major infrastructure or resource development projects ▪ Assessing and mitigating the operation of such projects
Engineering Design	▪ Design of buildings and structures for installation in changing permafrost conditions ▪ Design of offshore drilling and production platforms for safe and effective deployment in ice-covered waters
Safe Navigation and Operations	▪ Navigation of vessels through hazardous ice-covered waters ▪ Avoiding collisions with icebergs in operation of offshore oil and gas exploration and production platforms ▪ Navigation to and along the sea ice edge for traditional hunting and fishing
Risk Management	▪ Assessing the risks of subsidence around buildings, pipelines and structures in permafrost areas ▪ Assessing and mitigating the risks of flooding due to ice-jammed rivers
Emergency Response	▪ Developing and maintaining a common operating picture (COP) between response organisations ▪ Expeditious movement of responders and their equipment from bases of operation to emergency sites
Weather Forecasting	▪ Observing and modelling weather patterns to improve short-term weather predictions in support of operations in the polar regions
Climate Change Adaptation	▪ Establishing new regulations and standards, investing in new infrastructure, and enhancing operational capabilities in reaction to changes in the polar climate and its impact on southern latitudes

A1.2.2.1 Current Information Requirements

The current information needs cover a broad spectrum of environmental parameters, with more than 250 different environmental parameters being of interest to the science and operations user communities working in the polar regions – a significant number of which are of common interest to the majority of users

[10] To help address the risks of operating in the polar regions, the International Maritime Organization (IMO) Marine Environment Protection Committee approved the "Draft International Code for Ships Operating in Polar Waters" (known as the Polar Code) on 21 January, 2015. It took effect on 1 January, 2017.

in both communities. A brief summary of the key parameter requirements in the major information categories follows.

Sea Ice

Exhibiting the most widespread use across scientific and operational communities, sea ice parameters were identified in approximately 70 percent of the reference documents, with the top five parameters in order of the number of references being: sea ice thickness, sea ice motion / drift, sea ice concentration, sea ice extent and sea ice pressure / ridges / deformation.

River and Lake Ice

Some 55 percent of the reference documents mentioned the need for river and lake ice parameters, with the most important being: river / lake ice extent, river / lake ice thickness, river / lake ice concentration, river / lake ice freeze-up and break-up dates and snow depth on river/lake ice.

Snow

Some 55 percent of the reference documents mentioned the need for snow parameters, with the most important being: snow cover area / extent, snow water equivalent, snow thickness / depth, snow and ice albedo and snowpack condition / structure / stratigraphy.

Atmosphere

Atmospheric parameters were identified in approximately 55 percent of the reference documents, with the top five parameters being: chemistry / greenhouse gases, surface air temperature, precipitation amount, surface wind direction and speed and precipitation rate.

Ice Sheet

Ice sheet parameters were identified in approximately 40 percent of the reference documents, with the top five parameters being: Ice sheet extent / margin, ice sheet basal melt magnitude, ice sheet mass change, ice sheet flow velocity and ice sheet snow accumulation.

Permafrost

Permafrost parameters were identified in approximately 40 percent of the reference documents, with the top five parameters being: permafrost extent / distribution, onset of seasonal permafrost freezing, permafrost active layer freezing depth, seasonal frost heave / thaw subsidence and permafrost thickness.

Land

Some 40 percent of the reference documents mentioned the need for land parameters, with the most important being: land use / cover and change, land surface temperature, soil moisture, above-ground biomass and biome / ecosystem identification and change.

Glaciers and Ice Caps

Glacier and ice cap parameters were identified in approximately 35 percent of the reference documents, with the top five parameters being: glacier / ice cap location and area, glacier mass balance, glacier topography, glacier ice thickness and glacier velocity / flow rate.

Oceans

Some 35 percent of the reference documents mentioned the need for ocean parameters, with the most important being: marine ecosystem functioning, sea surface temperature, sea surface salinity, sea level and freshwater inputs / loads.

Icebergs

Of interest to a smaller group of users, primarily for operational purposes, iceberg parameters were identified in some 23 percent of the reference documents, with the most important being: iceberg size / dimensions, iceberg detection / location, iceberg draft, iceberg motion / velocity and iceberg mass.

A1.2.2.2 Future Information Requirements

Respondents provided a range of perspectives on how their information requirements are expected to change in the future. In most instances it was difficult for them to differentiate their expected requirements between the short, medium and long terms. Very few respondents reported that their needs for information will remain unchanged in the future.

Increased demand for environmental information in the polar regions is expected to arise from multiple sources. Growth in traffic by government vessels for ice breaking, fisheries surveillance and search and rescue operations will grow as shipping and tourism traffic increases and the operational season extends to eight months and beyond. The commercial fisheries are migrating further north, with extended seasons in ice-infested waters. As traffic continues to grow, there are also expectations that responses to emergency situations (e.g., grounded vessels, oil and chemical spills) will also increase in frequency.

A requirement that generally applies to most user communities is for data at a higher spatial resolution and based on sensor collection at an increased frequency (i.e., higher temporal resolution). For example, coastal zone research stakeholders have an increasing need for near-shore information at a much higher resolution, including SAR imagery, for examining ocean acidification, forecasted algae blooms, etc. on a more precise level. Another example is fisheries management, where a two-tiered approach to accessing information (e.g., using coarser resolution products to focus the acquisition of higher resolution data over a specific geographical area) will be employed.

Near real-time applications requiring higher frequencies of satellite imaging for production of ice and iceberg dynamics products and services are expected to increase (e.g., support of higher levels of shipping traffic, direction of fishing vessels to safe waters in the polar regions, fisheries resource management and real-time monitoring of illegal fishing activity and navigating cruise vessels through ice-infested waters). In addition, since fishing vessels will remain in waters that will freeze or become ice-infested as long as they can, high quality near real-time information will be increasingly important so that they can extend the fishing season as long as possible. Since satellite collection of ocean colour data is limited by cloud cover, a higher imaging frequency than once daily is required to increase the possibility of cloud-free imagery, so 10 or 20

times per day is desirable in the short-term. There is an increasing requirement in risk monitoring (e.g., oil spills, air pollution, wildlife) during Arctic operations for higher temporal frequency of data collection, either by satellite or in-situ. Demands for future reductions in the latency period for access to near real-time products (i.e., period of time between data acquisition and availability of products) are also common.

The demands for simultaneous collection of different types of data and for integration of data are expected to grow. In addition to the interest in integrating data collected by satellite, airborne and in-situ sensors, crowd-sourced data provided by citizens will increasingly be available for potential use in the future. Using better coupled systems (e.g., satellites running in tandem, such as a limb sounder looking at the boundary layer in the atmosphere at the same time as obtaining SAR and thermal IR images of the surface), or simultaneous collection of multi-frequency data (e.g., X, C, L Ku and S band) is expected to increase in importance. Answers to some of the most complex scientific questions in the polar regions require data integration, including integration of surface and satellite observations. In addition, since Indigenous peoples in the Arctic will be required to adapt to climate change to a greater extent than their southern neighbours, integration of traditional knowledge with the information being produced by scientists will be essential to make adaptive management practices work effectively.

Several references were made by respondents to the changes in information requirements that will be imposed by the Polar Code, which came into effect in 2017. Vessel officers need to comply by 2018 and obtain Polar Certificates to show that their vessels can be operated under certain ice conditions and temperature. Therefore, high resolution imagery (i.e., tens of meters, swath 100 km) and ice cover information, such as density, age and thickness that can be delivered to the master on the ship bridge will be in higher demand.

Specific new or improved data variables or processes that were identified for future use included:

- More reliable sea ice thickness information
- More reliable high resolution sea ice concentration information
- High-resolution monitoring of rapidly changing outlet glaciers and ice sheet margins
- A pan-Arctic dataset of in-situ snow measurements
- Improved methods for estimating snow water equivalent and snow depth and a Pan-European service for snow water equivalent and snow cover fraction
- Improved methods for estimating ice thickness from space, augmented by denser in-situ measurements of ice thickness
- Greater demand for higher resolution products for route planning and for navigation on ship bridges (e.g., locations of icebergs in pack ice, ice concentration, ice type, ice thickness)
- Reduction of uncertainties in modeling cryospheric processes (e.g., permafrost models under-represent ice content and the insulating effect of the organic layer; climate models do not resolve the steep topography of the Greenland Ice Sheet margins; models of snow-vegetation interactions need to be improved; and models that link meteorology to glacier mass balance need to incorporate downscaling techniques and satellite data)

- Information scaling, bridging the gap between discrete in-situ point measurements at the local level and large area coverage satellite data to a middle ground where catchment area sised datasets are needed, scaled up from the local level and scaled down from the broad satellite coverage
- Increased demand for cross-polarisation radar and multispectral images
- Integration of sea surface temperature and salinity data with ocean colour data

Collaborative efforts between the public and private sector to collect in-situ oceanographic data are expected to increase. For example, the Commission for the Conservation of Ant Arctic Marine Living Resources is exploring a partnership with the Coalition of Legal Toothfish Operators (COLTO) WG for Science Collaboration to have relatively inexpensive oceanographic sensors added to the fishing gear of COLTO members. Another example is the work of the Alaska Ocean Observing System group with ferries and fishing companies to collect ocean bottom temperatures, etc., and with Marine Exchange of Alaska to have vessels in Alaskan waters return sea ice conditions as part of their AIS signal package.

Concerns about the veracity of data products will place an increasing focus on improving the robustness of information retrieval from remote sensing data (e. g. error quantification, reduction of uncertainties) so researchers have improved knowledge of the information reliability and its limitations for achieving their specific research goals, which will heighten the need for in-situ observations. Users are calling for detailed, easy-to-understand descriptions of the applied methods for generation of higher-order products (e. g. retrieval of sea ice thickness) and their limitations.

Reference was made to new types of sensors that will be required to meet future needs. For example, a need for ocean colour sensors that are polar-orbiting, and have higher frequency measurements (e.g., like the one that was considered for the PCW project), was identified, as well as better sensors for detecting the amount of light and other properties underneath the sea ice and other physical sea ice properties, such as ice thickness and snow thickness. The requirement for new hyperspectral sensors enabling more accurate land cover classifications and change detection was also identified. C-Band and X-band radiometers with high resolution will be required (e.g., 3-5 km with very little atmospheric interference in that frequency range), in particular for sea ice concentration and sea surface temperature applications.

Finally, the demand for value-added, integrated data services is expected to grow in the future. Having professional services available that assess all the different data sources and products, and provide information services that integrate the best data and provide it to users, is a better option for some users than building up internal capability.

A1.2.2.3 Information Gaps

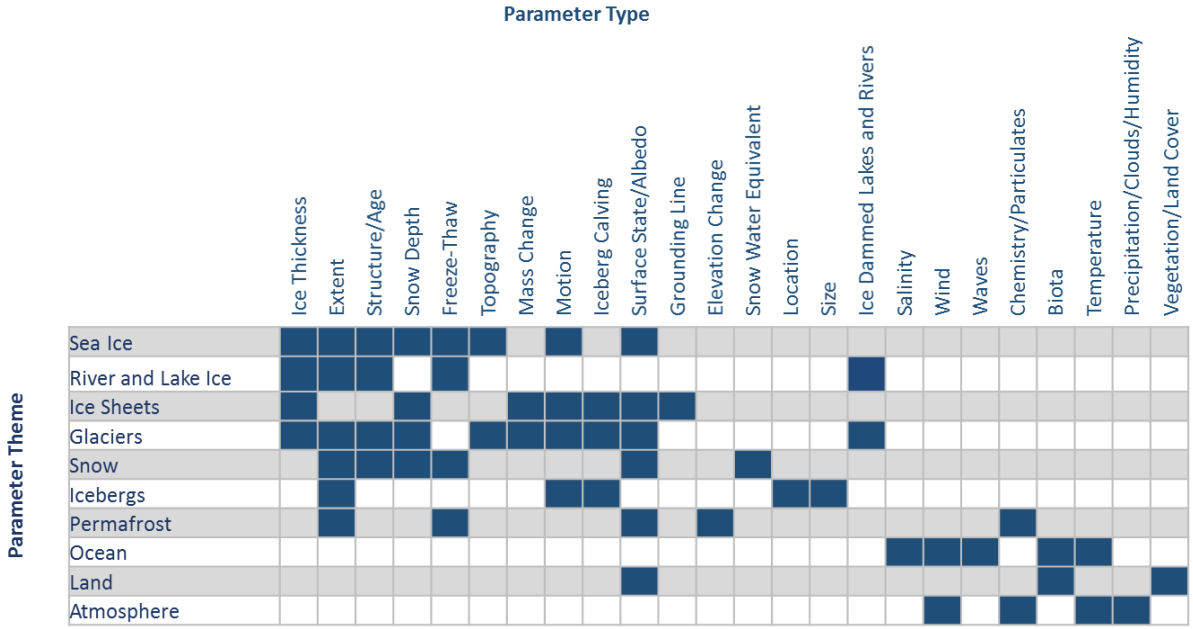
Where products and services are not available to meet user requirements, this can be attributed to two kinds of gaps: (1) gaps in data availability from current or planned EO missions and other space or non-space sources; and (2) gaps in the integrated information products and services derived from those data.

EO Information Gaps

While existing or planned EO missions are generally applicable to all the different information themes, consultations with users and EO experts identified a number of deficiencies resulting from inadequate

spatial resolution, temporal resolution and ability to combine data from different sensors (Polar View, 2016b). The gaps in existing information products and services derived from EO sensors to meet user requirements are identified in Table A1.. The gaps are broken down by parameter theme (along the left of the table) and parameter type (across the top of the table). Highlighted cells show where there is a shortcoming in the existing information (for example, in terms of spatial or temporal resolution), or where there are concerns about data continuity or coverage.

Table A1.7 Polar Information Gaps.



Environmental Information Gaps for Polar Sciences

Despite considerable progress in understanding the polar regions over the last decade, many gaps remain in observational capabilities and scientific knowledge. These gaps limit the present ability to understand and interpret on-going processes, prediction capabilities and forecasting in the polar regions, thereby hampering evidence-based decision-making. Sea ice and ice sheet mass balances were identified as key information gaps, both hampered by the difficulty in estimating varying snow cover and snow properties. Sea ice thickness influences the heat flux between the atmosphere and the ocean surface and ice sheet mass balance measurements are key to understanding and predicting sea level fluctuations. More precise measurements of phase changes from solid to liquid in sea ice and covering snow are important to climate studies and research on the physics of ice. The requirements for improving the knowledge of terrestrial snow (particularly snow water equivalent and snow depth), lake and river ice dynamics, and biodiversity were also highlighted.

Environmental Information Gaps for Polar Operations

The dominant information gaps are mainly driven by the need to have improved sea ice and iceberg information for tactical operations. This will require more detailed sea ice and iceberg classification products at a higher temporal resolution than is currently available. Sea ice thickness, stage of development,

structure, motion, extent, and topography were identified as parameters where significant gaps exist. In addition, having more accurate information about snow on sea ice will be required to reliably establish these information parameters. The ability to identify icebergs within sea ice and forecast iceberg motion are other capacities which are key to the communities carrying out polar operations, and linked to this is the issue of improved polar weather predictions (especially wind). Latency or timeliness of sea ice and iceberg product availability (i.e., the amount of delay between the data collection and its accessibility for subsequent use) and lack of satellite coverage of some areas and times of interest were also identified as significant weaknesses in information provision for operations.

Information System Gaps

Information deficiencies can be addressed in two ways: (1) by providing more capable earth observation technology (mission concepts), and/or (2) by improving how well the overall information acquisition and delivery systems work (system concepts). The following points examine steps that can be taken to improve gaps in the overall information system for polar data:

- **Data Integration** – Non-specialist users want customised information developed by professionals who have the expertise to integrate data in the way that best meets user needs. Data has more value if it can be easily integrated with other data from multiple sources and of multiple types – time series, other parameters, other regions, other sensors, etc. Data integration is facilitated by data formats and access that adhere to recognised standards.

- **Information Products** – Many end users are not in a position to work directly with earth observation data. Rather, they need information products and services that provide the processed data in the form they require.

- **Information Discovery** – Polar information is currently spread among a large number of sites and organisations. Better tools are needed to help in discovering this data, especially by non-specialists. Access to good metadata is an important component of the discovery process. Information on data quality and uncertainty needs to be part of the metadata.

- **Information Access** – Accessing information needs to be easy. Cost is a significant barrier to data access and use for many groups. The bandwidth limitations faced by most northern communities and vessels is an impediment to data access and use.

- **Training** – Users need to be educated in how to use data properly so that it is not misinterpreted or used inappropriately, and to identify which information is applicable to their needs.

- **Data Platforms** – The solution to many of the previous gaps could be achieved through good data platforms that would store polar information and provide tools for information integration, discovery, access, and training. These platforms should use open web services that can be used by value added partners in the development of applications and systems. They should provide processing capacity so that users do not need to download large volumes of EO data, but rather can manipulate the data “in the cloud”.

Other Space Capability Gaps

The use of global navigation satellite systems (GNSS) is ubiquitous in the polar regions, as it is elsewhere. Although the accuracy of positioning with GNSS and satellite-based augmentation systems (SBAS) in the higher latitudes at both poles is lower, it appears to be sufficient for applications involving integration of GNSS with EO. The most evident gap is in the coverage of the two primary SBAS (i.e., Wide Area Augmentation System [WAAS] and European Geostationary Navigation Overlay Service [EGNOS]) but no evidence has been found that this gap is of significant concern to the scientific and operational user communities.

Although there are a few S-AIS limitations (e.g., signal collisions and time latency), steps are being taken to reduce these limitations and they are being addressed in the design of new space missions covering the polar regions. A new ESA mission that involves such applications could leverage the value contained in third party AIS missions for enhanced data products.

Information from satellite telecommunications systems is not combined with earth observation information into integrated products and services per se, but these systems provide the essential infrastructure for the delivery of such products and services to users. Infrastructure gaps are a particularly important concern for operational users and communities, who often require near real-time delivery of information to ensure safety of life and efficient production. The proposed telecommunications systems appear to be designed to address future operational user requirements in the polar regions. However, it is clear that the systems in place today meet neither present nor future demands. To date, none of the new satellites has been launched and many are still under study or development. There is also the limitation from the lack of telecommunications ground infrastructure in the polar regions. There is a need for an intermediate solution and backup plan for higher bandwidth telecommunications for polar users.

Non-Space Information Gaps

The optimal system of sensors and sensor networks would be persistent, well-documented and with the resulting data being easily discoverable and broadly available and interoperable with EO systems. Unlike space-borne EO missions, which are typically designed by a single agency or at most a small number of well-connected agencies, in-situ sensors and networks are designed, coordinated, deployed and managed by a large number of (often nested) actors ranging from a single researcher to small Arctic communities, government agencies and international networks. All of these actors are contributing to the broader polar observing system, but they are not yet connected in an optimal way.

The integration of, and synergies between, space-based EO data and data collected with airborne and ground-based, or in-situ sensors and networks are well established. However, in-situ ground and airborne data collection is fragmented, sensor networks are not well distributed geographically, and there are large temporal gaps in coverage, primarily because many sensors are deployed for specific project-related, time-limited scientific or operational purposes. For example, the systematic measurement over large areas of snow depth and sea ice thickness would address an important gap in in-situ data that can be usefully integrated with space-based EO data to support operations in the polar regions.

A1.2.3 EU-PolarNet D 3.3 Survey of existing use of space assets by European polar operators

EU-PolarNet is a Horizon 2020 project being delivered by a large consortium of expertise and infrastructure for polar research to develop and deliver a strategic framework and mechanisms to prioritize science,

optimize the use of polar infrastructure, and broker new partnerships that will lead to the co-design of polar research projects that deliver tangible benefits for society. The D3.3 report is a component of EU-PolarNet work package 3, the objective of which is to consider joint programming of infrastructure to enable bigger and more complex science projects (EU-PolarNet 2017).

The report identifies uses of information derived from satellite remote sensing in the Arctic; the types of relevance to this study are illustrated in Table A1..

Table A1.8 Arctic Information Requirements.

Application Area	Information Types
Environmental impact assessment	▪ Physical and meteorological environment, ▪ Soil, soil productivity and vegetation ▪ Wetlands, water quality and quantity ▪ Fish, wildlife, and their habitat ▪ Species at risk or species of special status and related habitat ▪ Heritage resources ▪ Traditional land and resource use ▪ Human health, aesthetics and noise
Monitoring human impact	▪ Human presence and activities
Engineering design – siting buildings & offshore infrastructure	▪ Weather (cloud, temperature, prevailing wind direction and speed) ▪ Permafrost ▪ Surface topography ▪ Surface slope and aspect ▪ Sea ice ▪ Icebergs
Overland travel	▪ Crevassing ▪ Fractures in ice shelves ▪ Permafrost conditions ▪ State of winter roads over frozen lakes and rivers ▪ Historical and forecast weather conditions
Ship navigation and operations	▪ Ice charts ▪ Sea ice drift ▪ Sea ice conditions ▪ Iceberg conditions
Risk management	▪ Permafrost conditions ▪ Sea ice conditions ▪ Ice sheet conditions ▪ Iceberg density

Table A1. (Cont'd.)

Application Area	Information Types
Emergency response	▪ Weather conditions including wind speed and direction ▪ Sea state including wave height ▪ Presence of sea ice and icebergs ▪ Surface conditions and routes for responding assets ▪ Oil spill detection and movement
Weather forecasting	▪ Clouds ▪ Sea ice ▪ Ocean surface parameters and winds ▪ Atmospheric and ocean chemistry ▪ Melt ponds on sea ice
Climate change adaptation	▪ Aerosol ▪ Forest biomass ▪ Ocean colour ▪ Sea ice coverage. ▪ Albedo ▪ Cloud properties ▪ Elevation data ▪ Elevation models ▪ Earth radiation budget

A1.2.4 Polar Thematic Exploitation Platform (P-TEP) Technical Note – Community Survey

Polar View Earth Observation Limited (Polar View) has developed a Polar Thematic Exploitation Platform (Polar TEP) for the European Space Agency (ESA). Polar TEP provides polar researchers with access to computing resources, earth observation (EO) and other data, and software tools in the cloud.

In the traditional workflow for the analysis of earth observation (EO) data, users download the data to their local site and then process it using their available software and computing resources. With the increasing volume of data available from missions such as Sentinel, and the resulting need for powerful computing resources for processing, the existing methods of working are inefficient and restrict the use of EO data. This new approach removes the need to transfer large EO data sets around the world, while increasing the analytical power available to researchers and operational service providers.

ESA's Thematic Exploitation Platform (TEP) concept aims to provide a working environment where users can access algorithms and data remotely, supplying them with computing resources and tools that they might not otherwise have, and avoiding the need to download and store large volumes of data. This new way of working is intended to encourage wider exploitation of EO data. The TEP concept extends the SDI concept from a portal to a platform that not only provides easy and convenient access to data but also provides software and computing resources to analyze data and produce information products.

As part of the design of Polar TEP, Polar View engaged with stakeholders as one of the inputs to a high-level analysis of requirements and priorities of science and operational user communities (Polar View 2018).

Based on this analysis, Table A1. summarizes the potential contribution of Polar TEP to science and policy priorities in the following areas: Logistics and data acquisition; Ice sheets; Snow; Permafrost; Sea ice; Land processes and environment; Atmosphere and ocean; and Safe economic development.

Table A1.9 Polar Science Priorities and Potential Polar TEP Contributions.

Thematic Area	R&D Priorities to Close Knowledge Gaps	Polar TEP Contribution
Logistics and data acquisition	▪ Evaluate and supplement in-situ cryospheric reference network (CryoNet) ▪ Ensure that CryoNet is an acknowledged and supported component of the WMO Integrated Global Observing System. ▪ Develop a large network of autonomous robots, equipped to measure surface energy and mass flux ▪ Develop and implement a strategic investment plan to advance critical facilities and technologies ▪ Transfer knowledge and capabilities to empower a new generation of Arctic researchers from local communities ▪ Improve the coordination of logistic resources and partnerships across different disciplinary and jurisdictional boundaries	▪ Access to relevant satellite, airborne and in-situ data archives ▪ Access to relevant processing algorithms for data from new and emerging missions ▪ Access to relevant models or model output ▪ Provision of environment to develop, implement, test and run advanced data exploitation algorithms applicable for new and emerging EO missions ▪ Provision of environment to integrate observations from network of satellite, airborne and in-situ sensors ▪ Linkage of different stakeholder communities and promote exchange of ideas and experience through forums, communications and social networking ▪ Provision of environment to design, develop and deliver targeted training and capacity-building activities ▪ Provision of platform to coordinate use of logistics resources across different stakeholder communities ▪ Provision of platform for coordinated, multi-sensor image acquisition and distribution ▪ Provision of venue for training and capacity building ▪ Real-time access to observations from multiple (remote and in-situ) observation platforms ▪ Integration of modelling and monitoring (e.g., oil detection and fate modelling) ▪ Access to relevant databases of ice conditions
Ice sheets	▪ Special interest areas include fast moving glaciers around the margin of the Greenland ice sheet: glacier systems: Jakobshavn Ice Stream, Helheim Glacier, Petermann Glacier, Kangerlugssuaq, and Nuuk Fjord Glaciers ▪ Open access to data is critical ▪ High-level datasets are needed for researchers (e.g., modelers of climate, ice flow) with no special knowledge of satellite-based data ▪ NetCDF should be considered as standard format, other formats should be supported ▪ Obtain and maintain long and continuous observation records ▪ Mechanisms for AntArctic ice sheet mass loss ▪ Implement P-Band microwave concept for ice sheet sounding	
Snow	▪ Improve the user-interaction in all product phases from development to data dissemination ▪ Perform regular product inter-comparison, validation and product assessment exercises ▪ Communicate and provide quantified product uncertainties ▪ Timely transfer from R&D products and services into future sustainable initiatives	

Thematic Area	R&D Priorities to Close Knowledge Gaps	Polar TEP Contribution
	▪ Exploit the improved capabilities of new EO sensors ▪ Robust method for characterizing snow mass from satellite observations ▪ Concurrent use of multiple satellite and airborne sensors ▪ Improved integration of satellite observations of snow with physical and electromagnetic snow and soil models ▪ Coordinated field and EO observations to improve the representation of the snow microstructure and its evolution ▪ Comprehensive forcing and evaluation dataset to develop next-generation retrieval algorithms ▪ Operationalised satellite SWE and time-variable gravity measurements ▪ Seamless integration and distribution of cryospheric data products (e.g., mass balance of sea ice, land ice, snow cover)	▪ Access to relevant processing algorithms for improved mapping of Arctic environments
Permafrost	▪ Identify hot spots of permafrost surface change to guide the extension of relevant in-situ monitoring networks ▪ Support modelling of sub-surface conditions ▪ Provide measurements of a higher spatial and temporal resolution near long-term in-situ monitoring sites ▪ Place in-situ measurements into a wider spatial and temporal ▪ Implement P-Band microwave concept for potential permafrost applications	
Sea ice	▪ Near-simultaneous observation by multiple sensor types (SAR, optical TIR, PMW) to improve characterization n of sea ice processes ▪ Collaboration between operational ice services and research institutes dealing with floating ice ▪ Archives of satellite SAR data should be made fully accessible to research community ▪ Sustained international collaboration on collection of field data is required ▪ Closer coordination of data acquisition and distribution among satellite operators and data providers ▪ Seamless integration of data products	
Land processes and environment	▪ Quantitative knowledge and spatial distribution of carbon stocks and fluxes ▪ Estimation of vegetation stocks and productivity	

Thematic Area	R&D Priorities to Close Knowledge Gaps	Polar TEP Contribution
	▪ Upscaling of point observations of carbon fluxes to global scales ▪ Interaction of vegetation with water cycle variables ▪ Assimilation of land surface parameters into numerical weather prediction models ▪ Modelling of horizontal water transport ▪ Monitoring of habitat types, ecosystems, land use for biodiversity ▪ Monitoring of surface energy balance and water status of continental biosphere ▪ AntArctica's geological history and evolution ▪ Implement P-Band microwave concept for taiga biomass estimation ▪ Evolution and survival of AntArctic life ▪ Recognizing and mitigating anthropogenic influence on AntArctica	
Atmosphere and ocean	▪ Improve the understanding of the requirements for, and evaluate the benefits of, enhanced prediction information and services in polar regions ▪ Establish and apply verification methods appropriate for polar regions ▪ Provide guidance on optimizing polar observing systems, and coordinate additional observations to support modelling and verification ▪ Improve representation of key processes in models of the polar atmosphere, land, ocean and cryosphere ▪ Develop data assimilation systems that account for the unique characteristics of polar regions ▪ Develop and exploit ensemble prediction systems with appropriate representation of initial condition and model uncertainty for polar regions ▪ Determine predictability and identify key sources of forecast errors in polar regions ▪ Improve knowledge of two-way linkages between polar and lower latitudes, and their implications for global prediction ▪ Global impact of the AntArctic atmosphere and Southern Ocean ▪ Observations of space from AntArctica, incl. space weather ▪ Dynamic processes and feedbacks driving variability and change in the North Atlantic-Arctic climate system	

Thematic Area	R&D Priorities to Close Knowledge Gaps	Polar TEP Contribution
	▪ Impact of a changing Arctic cryosphere influence ocean-atmosphere-ice interactions ▪ Response of biogeochemical processes of shelf and open ocean waters of the North Atlantic and Arctic to climate change and human pressures ▪ Response of marine ecosystem structure and function to environmental change in climate, ocean physics, biogeochemistry, and human pressures ▪ Interactions between humans and a changing North Atlantic-Arctic marine system	
Safe economic development	▪ Environmental protection ▪ Ice management ▪ In-ice station keeping ▪ Ice loads and mechanics ▪ Environmental characterization ▪ Operations in harsh environmental conditions ▪ Site preparation techniques must be suitable for Arctic soil conditions ▪ Manage increased risk, lengthy lead times for development ▪ Mapping and characterizing Arctic environmental change ▪ Predictive modelling of ice and weather conditions ▪ Safety and environmental impacts related to Arctic shipping. ▪ Enhanced communication and cooperation between Arctic actors ▪ Characterize and assess risks related to disrupting change in the Arctic environment ▪ Assess current and predict future risks associated with ice hazards such as icebergs and ice islands	

A1.2.5 Report on Workshop on Cyberinfrastructure for Polar Sciences

Sponsored by the U.S. National Science Foundation, the Workshop on Cyberinfrastructure (CI) for Polar Sciences was organised to engage polar and computer scientists and engineers to inform its Polar Cyberinfrastructure Program, to complement the EarthCube experience and to ensure that the CI needs for this community were understood, articulated, integrated, and aligned with the overall plans and design of a Polar Cyberinfrastructure Strategic Plan (Pundsack & al, 2013). The workshop goal was to identify, characterize, and provide recommendations for the design, development and optimization of a comprehensive CI for polar sciences.

Similar in some respects to the TEP concept, Data as a Service (DaaS) was one of the most highly emphasised CI components during this workshop. Relevant DaaS recommendations from the workshop included:

Data Management

- Understand and automate, where possible, the components supporting the workflow from data to information to knowledge.
- Encourage interoperability (e.g., standards-based interface protocols) across all steps of the scientific workflow.
- Provision storage in a way that improves capacity and reduces latency in support of the DaaS goals.
- Develop methods for data quality assurance, uncertainty characterization and propagation of errors and provenance articulation.
- Provide for the sustainability of long-term data for polar regions.
- Ensure data curators are aware of limitations due to data quality and that these limitations are accurately reflected in metadata.
- Encourage interoperability (e.g., standards-based) protocols for data collection, metadata generation, data sharing, data services, data analytics, modeling and cross-domain integration.

Data Services

- Post all data center holdings, especially the polar gridded/raster data, via web services, such as OGC web services.
- Leverage technologies, such as cloud computing, that foster near real-time data availability to the community, and ensure that key technologies currently relied upon for near real-time data are adequately funded and maintained.
- Build a set of services for data processing.
- Ensure data services are sharable within and across communities.

Data Archiving, Discovery and Access

- Access all polar data through interfaces with existing catalogues.
- More easily search using ontology and semantics.
- Post all data center holdings, especially the polar gridded/ raster data, via web services such as OGC web services.
- Leverage technologies, such as cloud computing, that foster near real-time data availability to the community.

- Build popular and lightweight processing (e.g., reprojection, integration, subsetting).
- Improve consumer searching of existing data repositories.
- Unify interfaces or build a one-stop portal to provide discovery and access to all available polar data across existing metadata catalogues.

Data Analysis and Modeling

- Promote tools for sharing high-throughput computing (HTC) or high-performance computing (HPC) resources from different labs.
- Promote the creation of an "NFSCloud" infrastructure to facilitate broader access to big (i.e., efficient, cheap) data centers.
- Develop cloud-based analytical tools.

A1.2.6 Summary – Arctic Council Joint Meeting – Outbreak Sessions on Geodata (September 2015)

This document provides a summary of the responses to questions posed at Arctic Council Joint Meeting Outbreak Sessions on Geodata in September 2015, which was attended by representatives from AMAP, CAFF, ACAP, PAME, Arctic Council Secretariat and Arctic SDI. When asked about the biggest challenges to storing, accessing and updating geospatial data, participants provided the following responses of relevance to this study (Pouplier 2015):

Data

- Conforming data standards – no common standards to facilitate consolidation
- Availability of metadata
- Standardization protocols
- Compatible formats and scale
- Access to compatible geospatial data sources

Reference and Thematic Data

- Access to marine data – coastline, bathymetric and hydrographic data
- Access to thematic data – ice cover, weather, ecologically or biologically significant areas (EBSAs)
- Agreed scales across themes

Data Access and Sharing in General

- Sharing data between user systems
- Sharing data between Nations

- Sharing data between user systems (ECDIS/GIS)
- Coordinating data collection, handling and sharing among many different groups
- Collaborating across projects and with other organisations about data and securing data for public purposes
- No central place to input and access all data for the Arctic Region
- How to handle ownership issues

Policy Guidelines / Guidelines / User Guides

- Common framework for data sharing and standards
- Standardization protocols (storing, handling and distribution)
- Level standards with IMO / IHO
- Responsibilities of data providers / how to contract data
- Geodata users guide – where to go for which maps (authorised maps, commercial provided maps….), what services and tools, how to enhance data sharing and usability, etc.
- Best practice data storage and maintenance
- Draw the workflow from data collection by scientists all the way to the Geoportal (best practice)
- Common operational picture across bodies and authorities

A1.2.7 Response to the Open Geospatial Consortium Request for Information on Arctic Spatial Data by the Polar Data Community

An ad hoc group of organisations representing the broad interests of the polar data community responded to the Request for Information (RFI) on Arctic spatial data interoperability and infrastructure issued by the Open Geospatial Consortium (OGC) in early 2016. The polar data organisations and initiatives represented in this group included:

- Arctic Data Committee (ADC) of the International Arctic Science Committee (IASC), Sustaining Arctic Observing Networks (SAON) and the Arctic Portal;
- Standing Committee on AntArctic Data Management (SCADM) of the Scientific Committee on AntArctic Research (SCAR);
- Southern Ocean Observing System (SOOS);
- Climate and Cryosphere (CliC);
- International Ice Charting Working Group (IICWG);
- Polar View Earth Observation;

- National Snow and Ice Data Center (NSIDC);
- Interagency Arctic Research Policy Committee (IARPC) Arctic Data Coordination Team;
- Alaska Data Integration Working Group (ADIwg);
- NSF-funded AntArctic and Arctic Data Consortium (a2dc);
- Arctic Research Mapping Application;
- Arctic Observing Viewer;
- Barrow Area Information Database;
- Polar Knowledge Canada;
- Canadian Cryospheric Information Network (CCIN);
- Geomatics and Cartographic Research Centre at Carleton University;
- Canadian Consortium for Arctic Data Interoperability (CCADI);
- EU-PolarNet;
- European Space Agency (ESA); and
- Japan's National Institute of Polar Research (NIPR).

The group's submission noted that 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 data platforms. These approaches share the following common characteristics (Polar Data Community 2016):

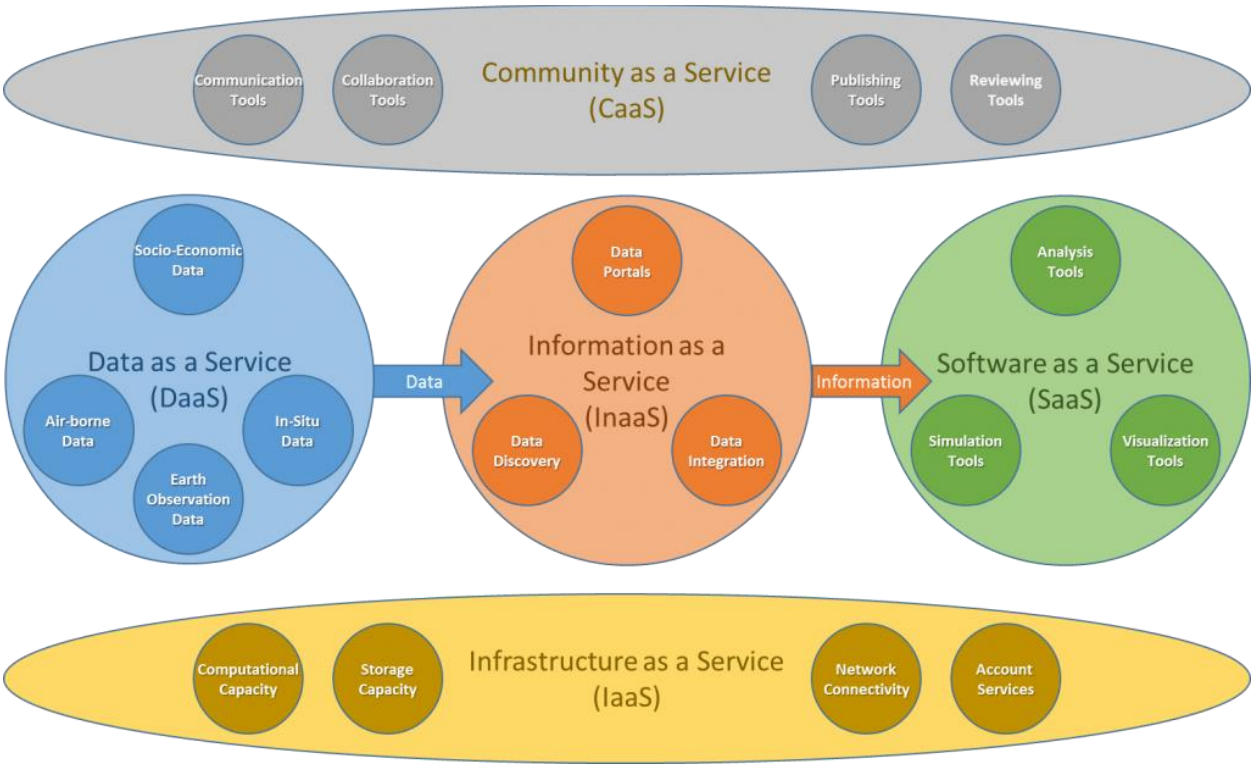
- Individual parameters by themselves are not nearly as valuable as integrated data sets. Therefore, the trend is to provide data platform users with access to a wide range of data types that they can be exploited together.
- With the explosion of the data that are available, data discovery and analysis 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.
- There is an aversion to lock-in with any one technology or supplier. Therefore, many data platforms use open source software where possible and are platform independent, often hosted in the cloud.

In summary, modern spatial data platforms are going far beyond traditional data portals by combining multiple functionalities and making them available in the cloud. The components of a modern data platform are shown in Figure A1.1, which represents an ideal architecture of an integrated Arctic information system for observing, research and community applications. As shown in the figure, platform components may include:

- Data as a Service (DaaS) – On-demand data sharing through discovery, access, and transportation. Data sets can cover earth observation, air-borne and in-situ sensors, as well as other socio-economic data. The emergence of service-oriented architecture has rendered the actual platform on which the data resides less relevant.
- Information as a Service (InaaS) – The ability to provide standardised and secure methods to create, manage, exchange, and extract meaningful information from all available data in the right format at the right time.
- Software as a Service (SaaS) – Delivery and management of applications and tools by the platform or its users that are used remotely on the platform. Provides users with the capability to deploy user-created or acquired applications.
- Infrastructure as a Service (IaaS) – The provision of computing resources, complemented by storage and networking capabilities, as shared resources, scalable on-demand, and enabling cost efficiencies.
- Community as a Service (CaaS) – Collaborative tools for users to publish, share and discuss their results, information, data and software/code on the platform. Social networking makes a new level of online collaboration among communities of practice possible.

Figure A1.1 The Components of a Modern Data Platform.



Source: Polar Data Community (2016)

The OGC submission identified the following activities being undertaken by polar data management organisations in response to user needs:

- **Interoperability**: Interoperability is one of the most important priorities identified by the polar data community. An interoperable system must enable data access that can support many different users. This may require visualization or other mediation such as translating vocabularies to make data usable by different communities. Achieving interoperability will require adequate resources, a certain level of standardization, and a connected community.
- **Standards and Specifications**: The overarching purpose of the polar data management community is to promote and facilitate international collaboration towards the goal of free, ethically open, sustained, and timely access to polar data through useful, usable and interoperable systems. This includes facilitating the adoption, implementation and development (where necessary) of standards that will enable free, open and timely access to data.
- **Metadata**: Building on the Polar Metadata Profile developed during the International Polar Year, the objective of this activity is to develop recommendations on a common set of metadata elements relevant across polar sciences, to facilitate interoperability and sharing between polar data repositories and online portals. To start, this effort will focus on identifying Arctic data centres or initiatives that have established a metadata template, schema, or profile. Initially, a limited set of disciplines or focus areas will be identified to make the scope manageable. Wherever possible and practical, the effort will build on and/or contribute to other related initiatives.

- **Data Publication**: The objective of this activity is to provide a report and guide on data publication and citation for polar researchers. This would provide the polar community with a resource to help them to understand developments in this area, including assignment of DOIs (Digital Object Identifiers) to published data sets.

- **Including Arctic Indigenous Perspectives, Knowledge and Information**: In this time of change, Indigenous knowledge and the underlying observations of Arctic peoples are more important than ever. Along with the knowledge of non-Indigenous local inhabitants, this knowledge is being increasingly documented and represented as digital data, but the nuances of these data are not well understood by the broader data management and science community. The perspectives of Indigenous people and other northern residents must be heard directly, which will enhance understanding of how Indigenous and local knowledge and observations can be used appropriately.

- **Community Building**: Improved polar data sharing that is part of a broader global system will require community building, collaboration, and coordination of efforts. Doing this requires a better understanding of the nature of the polar data community (e.g., who is doing the work, where, what systems, etc.) across many scales and what the community is collectively trying to achieve. Through the established bodies, improved communication, outreach, and coordination within the polar community is required, as well as engagement with broader global initiatives including OGC and GEO.

- **Data Preservation and Rescue**: Increasing our current understanding requires continual re-use and re-purposing of past observations. Therefore, data, 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 prioritised as a long-term investment and cost-saving measure.

- **Adequate Resources**: Making progress will require adequate financial, technical, and human resources. More focus is needed on the training of early career scientists and youth to ensure that they have the necessary data literacy to engage in intensive research while contributing to and benefitting from an open, interoperable system.

A1.2.8 OGC Arctic Spatial Data Pilot – Phase 1 Report: Spatial Data Sharing for the Arctic

This report presents the results of a concept development study on SDI for the Arctic, sponsored by US Geological Survey and Natural Resources Canada and executed by the Open Geospatial Consortium (OGC). The focus of this study was to understand: how to best support the development of an SDI for the Arctic; the view and specific requirements of Indigenous peoples in the North; and how to make existing implementations better known to stakeholders and better serve stakeholders' needs (Open Geospatial Consortium 2016).

The report discusses the needs and requirements of the various types of stakeholders of an SDI for the Arctic on aspects such as data sharing, standards and interoperability, funding and investment, integration with existing systems, architecture and platform as well as security, privacy and safety. The report further

discusses various architecture models with a focus on standards required to optimize discovery, usage and processing of data in a highly heterogeneous network of SDI data and service providers.

The business needs of stakeholders for Arctic SDIs that are identified in the report can be summarised as:

- Easy discovery, access, download and analysis of a wide range of data types that they can be exploited together on the data consumer side, and the ability to publish, integrate, aggregate and analyze geospatial data and related non-geospatial data on the data producer, provider and processor side
- Integrated systems, possibly in a system-of-systems or network-of-networks approach with the ability to harvest data from existing solutions in a secure, reliable manner
- Robust, but intuitive easy-to-use tools to access, visualize and contribute data and information in a manner that allows for ingestion into organisations to support policy development and decision making
- Systems that are operational and reliable with clear life cycle costs to providers and users, designed for no- or low-bandwidth areas where the Internet is not readily available and have the ability to cater to various levels of consumer capacities
- Architecture that supports integration of near real-time observations from both satellites and in-situ sensors, creation and exchange of research-oriented synthesised data sets (i.e., simulation model outputs), bridging a wide variety of technical solutions of differing ages and platforms and that minimizes the need for manually generated metadata
- Provision of highly capable information and communication technology (ICT) infrastructure for data processing, storage, and networking and the tools required for collaborative research and the ensuing dissemination of results
- Interoperability of SDI components across platforms, with data served at standardised Web interfaces using standardised encodings
- Availability of individual logins, firewall protection and a secure server connections capable of transferring and storing highly sensitive data
- SDIs for the Arctic that integrate with international, national and regional SDIs and data platforms operated by national space agencies

The report includes a table (see Appendix A4) that identifies examples of the possible extensive range of applications that can be supported by an Arctic SDI. It also references the importance of including Indigenous knowledge and the underlying observations of Arctic peoples in Arctic SDIs and of including Indigenous and First Nations communities in the planning, design and development of Arctic SDIs and in their management and ongoing governance.

A1.2.9 OGC Arctic Spatial Data Pilot: Phase 2 Report

This OGC report summarizes all experiences made during the Arctic Spatial Data Pilot implementation phase, provides guidelines for future service setup and data handling, and identifies future work items and

potential approaches (Open Geospatial Consortium, 2017). The report concludes that, although the Arctic SDI community has an impressive amount of data and services at their disposal, discovery and access issues prevent users from making efficient use of that data. In order to better address user requirements on both the data provider and consumer side, the report authors recommend that future initiatives should focus on the following aspects:

Data Discovery

- **Annotation, vocabularies, and linked data**: Human- and machine-based annotation systems are required to identify data that has been used for specific purposes. Both human and automated annotation should build on linked data principles, where publications link the underlying data sets, or users describing their work on (portal) web pages link the original data, styles, schemas, and other relevant aspects.

- **Crawling based approaches**: Users typically need to interact with a high number of catalogues, often through Web forms because the API endpoints are not directly exposed, which slows down the discovery process enormously. Catalogues should at least provide their data in a way that search engines could fully harvest the catalogue content. Other approaches such as direct harvesting of data services should be further investigated, ideally combined with automated data analysis mechanisms to get fine granular insights on the actual service offerings.

- **Service availability and reliability**: Many service URLs change without proper forwarding mechanisms put into action. Proper backlink mechanisms should be implemented that show data providers what the data has been used for (e.g., in publications, other website, research, leisure, exploitation planning, governmental planning, etc.). Currently, data providers often need to study the access logs of their Web servers to get insights into the user statistics, which does not go far enough. In addition, service operators should be enlightened on the importance of stable URLs and unique identifiers.

Data Access

- The integration time for data served at standardised interfaces using standardised data models is often a fraction of the time required to integrate data served in proprietary formats or embedded in Websites and reports provided as pdfs. Data owners should be urged to make their data available at standardised interfaces, ideally such as OGC WFS or WCS that support access to the underlying data (compared to, e.g., WMS, which only provides raster maps).

Open Data, Usage Policies and Citations

- It is a community responsibility to increase the number of openly available data sets and employ new mechanisms to deal with usage policies and citations. Citation mechanisms and backlinks play an important role in this discussion, as they can be used as arguments for continued support for data on the Web.

SDI Sustainability

- Sustainability is a key element for any successful Spatial Data Infrastructure. A key element will be the implementation of a communication model in combination with reliable links to resources, available at standardised interfaces that implement open access policies.

A1.2.10 Interim Data Requirements for Arctic SDI

This document (Arctic SDI, 2017) was prepared for the purpose of communicating requirements to data providers until the new Arctic SDI Data Sub-Group is established and operational. The requirements identified include:

Data Requirements

- Pan-Arctic extent with active datasets whose services are updated dynamically
- Data currency preferences: current data, data that can be used in a time series animation, data that can be used for change detection algorithms and near real-time or real-time data feeds
- Thematic data sets
    - Data used in climate change modelling (e.g., ground/cloud albedo, sea-surface temperature, ice thickness, 30-year averages of snow/temperature, ice extent and thickness, glaciers, permafrost, etc.)
    - Coastline and near shore data
    - Flora or fauna and/or their habitat
    - Paleoclimatology
    - Black carbon
    - Greenhouse gases (e.g., Methane)
    - Ozone

Hosting Considerations

- Cloud environment to help engage with the wider “non-geo” web development community
- Ready for incorporation into future OGC Testbeds and Pilots

Standards

- Supported standards in Arctic SDI Geoportal: WMS 1.3, WMS-T (temporal), WMTS (tile), WFS 2.0 (GML 3.2), ESRI REST services, CSW (if you can create one with NSIDC Arctic metadata) and ISO 19115, 19139, etc.
- Support for the following projections (amongst others): EPSG 3571 - 3576 (polar projections), Web Mercator

- Standards that Arctic SDI is working towards and need further support include: WCS 2.0, WPS and/or DGGS, SOS, Marine standards (e.g., OGC Marine DWG, IHO), APIs that respect standardization efforts and SLD and improving cartography

A1.2.11 INSPIRE Data Specifications

The Infrastructure for Spatial Information in Europe (INSPIRE) Directive aims to create a European Union (EU) spatial data infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment (European Commission 2018a). This infrastructure will enable the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policy-making across boundaries. INSPIRE is based on the infrastructures for spatial information established and operated by the EU Member States.

The INSPIRE Implementing Rules on interoperability of spatial data sets and services (IRs) and Technical Guidelines (Data Specifications) specify common data models, code lists, map layers and additional metadata on the interoperability to be used when exchanging spatial datasets (European Commission, 2018b). Datasets in scope of INSPIRE, which have been determined to meet the needs of users for environmental information in the European Union (including Arctic users), are ones which come under one or more of the 34 spatial data themes set out in the INSPIRE Directive, defined as follows:

- **Administrative units**: Units of administration, dividing areas where Member States have and/or exercise jurisdictional rights, for local, regional and national governance, separated by administrative boundaries.
- **Addresses**: Location of properties based on address identifiers, usually by road name, house number, postal code.
- **Buildings**: Geographical location of buildings.
- **Cadastral parcels**: Areas defined by cadastral registers or equivalent.
- **Geographical names**: Names of areas, regions, localities, cities, suburbs, towns or settlements, or any geographical or topographical feature of public or historical interest.
- **Hydrography**: Hydrographic elements, including marine areas and all other water bodies and items related to them, including river basins and sub-basins. Where appropriate, according to the definitions set out in Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (2) and in the form of networks.
- T**ransport networks**: Road, rail, air and water transport networks and related infrastructure. Includes links between different networks. Also includes the trans-European transport network as defined in Decision No 1692/96/EC of the European Parliament and of the Council of 23 July 1996 on Community Guidelines for the development of the trans-European transport network and future revisions of that Decision.
- **Geographical grid systems**: Harmonised multi-resolution grid with a common point of origin and standardised location and size of grid cells.

- **Coordinate reference systems**: Systems for uniquely referencing spatial information in space as a set of coordinates (x, y, z) and/or latitude and longitude and height, based on a geodetic horizontal and vertical datum.
- P**rotected sites**: Area designated or managed within a framework of international, Community and Member States' legislation to achieve specific conservation objectives.
- **Elevation**: Digital elevation models for land, ice and ocean surface. Includes terrestrial elevation, bathymetry and shoreline.
- **Land cover**: Physical and biological cover of the earth's surface including artificial surfaces, agricultural areas, forests, (semi-)natural areas, wetlands, water bodies.
- **Geology**: Geology characterised according to composition and structure. Includes bedrock, aquifers and geomorphology.
- **Orthoimagery**: Geo-referenced image data of the Earth's surface, from either satellite or airborne sensors.
- **Agricultural and aquaculture facilities**: Farming equipment and production facilities (including irrigation systems, greenhouses and stables).
- **Atmospheric conditions**: Physical conditions in the atmosphere. Includes spatial data based on measurements, on models or on a combination thereof and includes measurement locations.
- **Environmental monitoring facilities**: Location and operation of environmental monitoring facilities includes observation and measurement of emissions, of the state of environmental media and of other ecosystem parameters (biodiversity, ecological conditions of vegetation, etc.) by or on behalf of public authorities.
- **Human health and safety**: Geographical distribution of dominance of pathologies (allergies, cancers, respiratory diseases, etc.), information indicating the effect on health (biomarkers, decline of fertility, epidemics) or well-being of humans (fatigue, stress, etc.) linked directly (air pollution, chemicals, depletion of the ozone layer, noise, etc.) or indirectly (food, genetically modified organisms, etc.) to the quality of the environment.
- **Meteorological geographical features**: Weather conditions and their measurements; precipitation, temperature, evapotranspiration, wind speed and direction.
- **Natural risk zones**: Vulnerable areas characterised according to natural hazards (all atmospheric, hydrologic, seismic, volcanic and wildfire phenomena that, because of their location, severity, and frequency, have the potential to seriously affect society), e.g., floods, landslides and subsidence, avalanches, forest fires, earthquakes, volcanic eruptions.
- **Population distribution – demography**: Geographical distribution of people, including population characteristics and activity levels, aggregated by grid, region, administrative unit or other analytical unit.

- **Sea regions**: Physical conditions of seas and saline water bodies divided into regions and sub-regions with common characteristics.
- **Species distribution**: Geographical distribution of occurrence of animal and plant species aggregated by grid, region, administrative unit or other analytical unit.
- **Utility and governmental services**: Includes utility facilities such as sewage, waste management, energy supply and water supply, administrative and social governmental services such as public administrations, civil protection sites, schools and hospitals.
- **Area management/restriction/regulation zones and reporting units**: Areas managed, regulated or used for reporting at international, European, national, regional and local levels. Includes dumping sites, restricted areas around drinking water sources, nitrate-vulnerable zones, regulated fairways at sea or large inland waters, areas for the dumping of waste, noise restriction zones, prospecting and mining permit areas, river basin districts, relevant reporting units and coastal zone management areas.
- **Bio-geographical regions**: Areas of relatively homogeneous ecological conditions with common characteristics.
- **Energy resources**: Energy resources including hydrocarbons, hydropower, bio-energy, solar, wind, etc., where relevant including depth/height information on the extent of the resource.
- **Habitats and biotopes**: Geographical areas characterised by specific ecological conditions, processes, structure, and (life support) functions that physically support the organisms that live there. Includes terrestrial and aquatic areas distinguished by geographical, abiotic and biotic features, whether entirely natural or semi-natural.
- **Land use**: Territory characterised according to its current and future planned functional dimension or socio-economic purpose (e.g., residential, industrial, commercial, agricultural, forestry, recreational).
- **Mineral resources**: Mineral resources including metal ores, industrial minerals, etc., where relevant including depth/height information on the extent of the resource.
- **Oceanographic geographical features**: Physical conditions of oceans (currents, salinity, wave heights, etc.).
- **Production and industrial facilities**: Industrial production sites, including installations covered by Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (1) and water abstraction facilities, mining, storage sites.
- **Soil**: Soils and subsoil characterised according to depth, texture, structure and content of particles and organic material, stoniness, erosion, where appropriate mean slope and anticipated water storage capacity.
- **Statistical units**: Units for dissemination or use of statistical information.

A1.2.12 White Paper: The Hydrographic and Oceanographic Dimension to Marine Spatial Data Infrastructure Development: "Developing the capability"

This paper discusses the relevance of Marine Spatial Data Infrastructure (MSDI) to the development of a framework for coastal and marine spatial planning programs at the subnational, national and/or regional levels. It provides an approach to introduce and inform how MSDI inter-reacts as a component framework within a National Spatial Data Infrastructure (NSDI) (International Hydrographic Organization, 2010). As the marine component of an SDI, to be successful MSDI must encompasses all marine geographic and business information and be based on clear, broad-based goals that define the desired outcomes to be achieved. The paper provides the following list of common types of information required by coastal states of MSDI:

- **Maritime Baseline:** The line from which maritime zones and limits are measured and monitored internationally.
- **Offshore Cadastre:** The land management system extending from the baseline to the extent of national jurisdiction.
- **Climate:** The modeled and observed spatial and temporal data characteristics of the atmosphere, hydrosphere and land surface system.
- **Bathymetric Elevation:** The datum to which sea level is measured and maintained to support nautical charting, engineering and construction projects and to model the seabed.
- **Seabed Character and Bedform:** The complexion of the seabed in terms of its surface geology and sediment composition.
- **Land ownership:** Information and descriptions of property including title, estate or interest of the federal government (or other owner) in a parcel of real and mineral property.
- **Flood Hazards:** National flood insurance programs maintain flood hazard information around a nation.
- **Maritime Boundaries:** Sovereign sea beds defined by specific legislation and / or usage.
- **Offshore Minerals:** Minerals and hydrocarbons occurring on or under the seabed.
- **Shoreline or Coastline:** The mean position of the incidence of mean high water and land as observed and measured over many tidal cycles.
- **Marine Transportation:** Commercial, defense, and recreational in terms of surface navigation aids controlling where vessels might traverse.
- **Obstructions:** Those features that exist on the seabed (e.g., wrecks, well-heads).
- **Physical Oceanographic features:** Those temporal elements in the water column that describe the condition of the oceans (e.g., salinity, light attenuation, currents, waves).

- **Gazetteer:** A geographical dictionary or directory and reference for information about places and place names.

Appendix A2

Organizations Consulted for Strategic Roadmap Study

A2.0 ORGANIZATIONS CONSULTED FOR STRATEGIC ROADMAP STUDY

- Indigenous and Northern Affairs Canada (Contaminants, Informatics, Data Management, Lands, NOG, Minerals)
- Canadian Northern Economic Development Agency
- Natural Resources Canada (Energy, CSIB, GSC, SGB)
- Environment Canada (MSC, Geospatial, Science Policy, Environmental Emergencies, Emergency Response)
- Department of Fisheries and Oceans (CHS, CCG, Oceans, Oceans Policy and Planning)
- National Research Council Canada
- Department of National Defence
- Transport Canada
- RCMP National Operations Centre
- Public Safety Canada
- Canadian Polar Commission
- Northwest Territories Government (Geomatics Centre, Shared Services)
- Nunavut Government
- Ministère des Ressources naturelles et de la Faune du Québec
- Canadian Institute of Mining, Metallurgy and Petroleum
- Canadian Association of Petroleum Producers
- CanArctic Shipping
- Association of Canada Land Surveyors
- Nunavut Broadband Development Corporation
- Caris
- Nunavut Tunngavik
- Nunavut Research Institute
- University of Waterloo
- Carleton University
- Norwegian Mapping Authority
- United States Geological Survey
- Open Geospatial Consortium

Appendix A3

Organizations Consulted for Polaris Study

A3.0 ORGANIZATIONS CONSULTED FOR POLARIS STUDY

- Aker Arctic Technology Inc.
- Alfred Wegener Institute
- AntArctic and Southern Ocean Coalition
- Arctic and AntArctic Research Institute
- Arctic Monitoring and Assessment Programme
- Arctic Research Consortium of the United States
- Arctic Science Partnership
- ArcticNet
- Asiaq Greenland Survey
- Association of Arctic Expedition Cruise Operators
- Association of Polar Early Career Scientists
- Australian AntArctic Division
- British AntArctic Survey
- Canadian Coast Guard
- Canadian Cryospheric Information Network
- Canadian Shipping Company
- C-CORE
- Chevron Arctic Centre
- Circumpolar Conservation Union
- Coalition of Legal Toothfish Operators
- Commission for the Conservation of AntArctic Marine Living Resources
- Conservation of Arctic Flora and Fauna
- Danish Energy Agency
- Danish Meteorological Institute
- Danish Technical University
- European Fisheries Control Agency

- European Maritime Safety Agency
- Finnish Geospatial Research Institute
- Finnish Ministry of Defence
- International Association of AntArctica Tour Operators
- International Ice Charting Working Group
- International Network for Terrestrial Research and Monitoring in the Arctic
- Inuit Circumpolar Council-Alaska
- NASA Carbon Cycle and Ecosystems Office / SSAI
- National Snow and Ice Data Center, University of Colorado
- Norwegian Meteorological Institute
- Norwegian Polar Institute
- Polar Bears International
- Polar Geospatial Center
- Research Data Alliance
- Royal Belgian Institute for Natural Sciences
- Scientific Committee on AntArctic Research
- Shell Global
- Southern Ocean Observing System
- Stockholm University
- Sustaining Arctic Observing Networks
- The Nautical Institute
- UK Met Office
- WCRP Climate and Cryosphere Project
- ZAMG – Zentralanstalt für Meteorologie und Geodynamik

Appendix A4

Business Requirements Examples – ASD Pilot Phase 1 Report

A4.0 BUSINESS REQUIREMENTS EXAMPLES – ASD PILOT PHASE 1 REPORT

The following tables, which illustrate a few examples of the extensive range of applications that can be supported by an Arctic SDI, were copied from the report "OGC Arctic Spatial Data Pilot – Phase 1 Report: Spatial Data Sharing for the Arctic".

Data Type	Stakeholder	Application
Ice gouge data	Federal, state, and local government agencies	• Impact on navigation safety
	Oil and gas companies Mining companies Utility companies Port managers and harbor masters	• Infrastructure siting, planning, routing and protection • Impact on navigation safety
	Engineers	• Infrastructure siting, planning, routing and protection • Engineering design, construction, and maintenance • Impact on navigation safety
	Researchers	• Relationship of size and depth with age • Correlation to ice thickness mapping (sea ice)
	Geospatial community	• Survey methodologies • Technology manufacturing • Software development
Mid-resolution DEM	Federal, state, and local government agencies	• Aviation safety • Natural resource management • Infrastructure development • Change analysis • Public safety • Forestry • Emergency response
	Native corporations	• Land management
	Oil and gas companies Mining companies Utility companies	• Infrastructure siting and routing • Logistics planning
	Geospatial community	• Survey methodologies, technology manufacturing, software development

Data Type	Stakeholder	Application
Hydrographic mapping	Federal, state, local agencies	• Nautical charting for navigation safety • National defense • Emergency response • Infrastructure planning/development • Fisheries management • Legal boundary determinations • Flood planning • Baseline habitat mapping • Environmental baseline monitoring • Sovereignty
	Oil and gas companies	• Safe navigation • Engineering activities during exploration, development, and production • Environmental responsibilities related to sustainable development and protection of biodiversity
	Mining companies	• Safe navigation • Engineering activities during exploration, development, and production • Environmental responsibilities related to sustainable development and protection of biodiversity
	Utility companies	• Engineering activities during exploration, development, and production • Environmental responsibilities related to sustainable development and protection of biodiversity
	Shipping and cruise ship companies	• Safe navigation • Trip planning • Route planning
	Commercial fishing companies	• Safe navigation • Fishing sources geolocation
	Geospatial community	• Survey methodologies, technology manufacturing, software development
	General public	• Safe navigation, subsistence activities, recreational boating and recreational fishing
	Insurance companies	• Safe navigation • Route planning • Environmental baseline monitoring

Data Type	Stakeholder	Application
Coastal mapping	Federal, state, local agencies	• Maritime safety • Emergency response (natural disasters, etc.) • Offshore development regulation • Scientific research • Coastal monitoring (change analysis) • Coastal flooding modeling, analysis, mitigation • Earthquake/tsunami assessment, mitigation • Regional sediment management • Infrastructure development/maintenance • Fisheries management • Environmental baseline monitoring
	Engineers	• Infrastructure development/maintenance • Flood planning • Environmental baseline monitoring • Coastal monitoring (change analysis)
	Insurance companies, real estate companies, lenders	• Flood risk information • Tsunami inundation • Erosion studies
	General public	• Flood risk information • Erosion studies
	Geospatial community	• Survey methodologies, technology manufacturing, software development
Ice thickness mapping (sea ice)	Federal, state, local agencies	• Navigation safety during in-ice operations • Ice load information for infrastructure design/engineering • Establishment of shipping lanes
	Oil and gas companies	• Navigation safety during in-ice operations • Environmental protection during in-ice operations • Ice load information for infrastructure design/engineering
	Shipping companies Cruise ship companies	• Navigation safety during in-ice operations
	Insurance companies	• Risk assessment for vessel operations in Arctic waters
	Researchers	• Tracking icefields over time as a measure of climate change • Correlation to ice gouge mapping and monitoring
	Geospatial community	• Survey methodologies, technology manufacturing, software development

Appendix A5

Data Coordinators, Providers and Platforms in the Arctic

A5.0 DATA COORDINATORS, PROVIDERS AND PLATFORMS IN THE ARCTIC

A5.1 GLOBAL SCALE INITIATIVES WITH AN ARCTIC COMPONENT

A5.1.1 Group on Earth Observation (GEO)

GEO is a partnership of more than 100 national governments and in excess of 100 participating organisations that envisions a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations. Two key projects relevant to Arctic SDI include: GEOCRI (GEO Cold Regions Initiative), which aims to provide coordinated Earth observations and information services across a range of stakeholders to facilitate well-informed decisions and support the sustainable development of the cold regions globally; and the GEO Portal.

https://www.earthobservations.org/activity.php?id=114

GEO Portal

The GEO Portal provides interactive open access to EO data and maps across the globe.

http://www.geoportal.org/

GEO, GEOCRI and GEO Portal are important initiatives within the Arctic data domain and the Arctic SDI. Partnerships with Arctic organisations (i.e., SAON) provide a connection between the region and the global community. GEOCRI is engaged in a number of data related activities, including promoting standards and sound data management practices. The GEO Portal provides increasingly powerful discovery of Arctic data and, where possible, connections to a wide range of data services.

A5.1.2 World Meteorological Organization

The World Meteorological Organization is a very active organization with respect to Arctic data. Increasingly, they are focusing on making data available using a Data as a Service approach and thus their projects can provide important scientific data nodes to the Arctic SDI. WMO activities are carried out through a set of persistent and time limited activities and through partnership with other organisations (i.e., national meteorological organisations). Several of these programs are briefly described here.

Global Cryosphere Watch Data Portal

The World Meteorological Organization's Global Cryosphere Watch (GCW) is an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere.

WMO Polar Prediction Project (PPP)

The PPP is a long-term initiative by the World Meteorological Organization's (WMO) World Weather Research Programme (WWRP) together with the World Climate Research Programme (WCRP). The project was set up to understand and evaluate predictability and enhance prediction information and

services in the polar regions. The current focus of the program is the Year of Polar Prediction (YOPP) (2017-2019) which aims to enable significant improvements in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, verification, user-engagement and education activities. YOPP is developing improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, model error and the importance of coupled processes (e.g., atmosphere-sea ice interaction).

The YOPP Data Portal is the entry point for YOPP datasets. It offers a web interface that contains information about datasets (through discovery metadata). These metadata are harvested on a regular basis from data centres actually managing the data on behalf of the owners/providers of the data. The YOPP Data Portal utilizes standardised interoperability interfaces to metadata and data in order to provide a unified view on the datasets that are relevant for YOPP activities. It relies fully on the support from data centres contributing to YOPP as no data is handled within the portal itself, just metadata providing discovery information on the datasets and how to access them. In its simplest form, the YOPP data portal allows unified search across the contributing data centres. If the interoperability at the data level is sufficient, the portal may offer integration of datasets.

https://yopp.met.no/

Observing Systems Capability Analysis and Review Tool (OSCAR)

OSCAR is a resource developed by the WMO in support of Earth Observation applications, studies and global coordination. It contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e., related to weather, water and climate). OSCAR also provides detailed information on all earth observation satellites and instruments, and expert analyses of space-based capabilities.

https://www.wmo-sat.info/oscar/

As a whole, WMO Arctic projects are adopting standardised interoperability interfaces to metadata and data. As the services mature and as coordination and planning continues (see aforementioned OGC Arctic Spatial Data Pilot, Polar Data Planning Summit, etc.), they stand to act as important nodes in the Arctic SDI.

A5.1.3 International Oceanographic Data and Information Exchange (IODE)

IODE of the Intergovernmental Oceanographic Commission (IOC) of UNESCO was established in 1961. Its purpose is to enhance marine research, exploitation and development by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products.

The IODE, in conjunction with the International Ocean Observing System and other regional projects (e.g., SeaDataCloud – https://www.seadatanet.org/About-us/SeaDataCloud) is an increasingly mature standards-based data infrastructure. It acts as a gateway to oceanographic data and the related community. Considering the existing connection between Arctic SDI and IHO, connection to IODE can provide an opportunity to mobilize comprehensive data for the world's oceans and seabed information through the Arctic SDI.

https://www.iode.org/

A5.1.4 Svalbard Integrated Arctic Observing System (SIOS)

SIOS is a regional observing system for long-term measurements in and around Svalbard addressing Earth System Science questions. SIOS integrates the existing distributed observational infrastructure and generates added value for all partners beyond what their individual capacities can provide. The search interface was updated in November 2017 and is now harvesting and testing data from contributing repositories. The current version of the search interface connects to remote datasets using OPeNDAP where possible to determine the feature type (e.g., time series, grid, trajectory, etc.) while doing the search.

Although SIOS is a regional effort, due to the nature of research in this area, it is an international partnership. The standards based, service-oriented, distributed design makes it an ideal candidate node for connection to the Arctic SDI as well as a potential instructive case on developing effective international data partnerships and projects.

https://sios-svalbard.org/

A5.2 INTERNATIONAL ARCTIC INITIATIVES

A5.2.1 Arctic Council

The Arctic Council is the leading intergovernmental forum promoting cooperation, coordination and interaction among the Arctic States, Arctic Indigenous communities and other Arctic inhabitants on common Arctic issues, in particular on issues of sustainable development and environmental protection in the Arctic. There are a number of Arctic Council or Arctic Council-endorsed initiatives that are important for consideration as the development of the Arctic SDI moves forward.

A5.2.2 Arctic Spatial Data Infrastructure (Arctic SDI)

The Arctic SDI joint effort aims at creating a spatial data infrastructure for the Arctic region. It's a cooperation network of National mapping agencies in Norway, Kingdom of Denmark, Sweden, Finland, Iceland, Russia, Canada and USA. Its goal is to create an easy-to-use single point access for map and other geographic data of the Arctic region from various producers. The Arctic SDI is endorsed by the Arctic Council, and engaging with a number of other national and international organisations (e.g., Natural Resources Canada, U.S. Geological Survey, International Hydrographic Organization, etc.). The Arctic SDI has made great progress in establishing data infrastructure in the form of circumpolar map coverage served by a set of interoperable access tools (https://Arctic-sdi.org/index.php/map-gallery/). Additionally, the Arctic SDI group has published documents to guide the overall development of the Arctic SDI (https://Arctic-sdi.org/wp-content/uploads/2017/04/SDI-Manual-for-the-Arctic-EDITED2_PS.pdf)

The OGC Arctic Spatial Data Pilot was carried out within the Arctic SDI framework and produced a set of demonstration use cases and valuable reports that provide a foundation for the further development of the Arctic SDI. Thus, the Arctic SDI is critically important as a data provider and platform, education organization and major coordinating node in the Arctic data system.

https://Arctic-sdi.org/

A5.2.3 Arctic Council Sustaining Arctic Observing Networks (SAON)

SAON was established following the 2011 Arctic Council (AC) Nuuk Declaration. The declaration recognizes the "importance of the Sustaining Arctic Observing Networks (SAON) process as a major legacy of the International Polar Year for enhancing scientific observations and data-sharing." The declaration text also defines the SAON governance structure.

In 2014, the SAON Board finalised the first implementation plan for SAON, including a decision to establish two committees: the Arctic Data Committee (ADC) and the Committee on Observations and Networks (CON). In 2018, SAON will release its 5-year strategy and implementation plan that includes enabling free and ethically open access to Arctic observational data through system documentation and collaborative design and establishment of institutional coordination of Arctic observations and data. These activities are being carried out in partnership with many organisations, including Arctic SDI, GEO Cold Regions Initiative, the WMO, Permanent Participants of the Arctic Council and others. SAON is in the process of being established as the Arctic node of the GEO GEOSS (see GEO below).

https://www.Arcticobserving.org/

IASC-SAON Arctic Data Committee (ADC)

The overarching purpose of the ADC is to promote and facilitate international collaboration towards the goal of free, ethically open, sustained and timely access to Arctic data through useful, usable, and interoperable systems. The Arctic Data Committee (ADC) is a merger of the former Data Standing Committee of the International Arctic Science Committee (IASC) and the Committee on Data and Information Services (CDIS) of the Sustaining Arctic Observing Systems (SAON). Since its formation late in 2014, the group has coordinated a series of activities focused on Arctic data sharing and interoperability. The ADC is partnering with other polar data groups to host the Polar Data Planning Summit (https://Arcticdc.org/meetings/conferences/polar-data-planning-summit). The Arctic SDI group is co-organizing this event and it is expected to provide valuable connections to other Arctic data initiatives while collectively moving forward on technical design.

More recently, ADC has partnered with others to form working groups on federated search that are working towards common metadata schema elements and formulating recommendations on tools. Another working group is focused on semantics, with initial work on identifying organisations and projects working in this field and identifying core vocabularies and ontologies in use or emerging. The results of these efforts can act as foundational components of the Arctic SDI.

https://Arcticdc.org/

SAON Committee on Observations and Networks (CON)

The sister committee of the ADC, CON gives advice to the SAON Board on how to fund, coordinate and expand the scope of Arctic observational activities and address the questions of how to ensure sustainability of observational platforms in the Arctic and how easier access to them can be achieved. It is also ensuring the promotion of community-based monitoring within SAON and works on best practices for the utilization of traditional knowledge within Arctic observing activities. This committee is working closely with ADC on

system recommendations and thus it is relevant to the Arctic SDI. For example, CON is working towards a technology forum that could influence how manufacturers of sensors can support interoperability.

https://www.Arcticobserving.org/committees

A5.2.4 Arctic Council CAFF/CBMP

Conservation of Arctic Flora and Fauna (CAFF) is the biodiversity working group of the Arctic Council and consists of National Representatives assigned by each of the eight Arctic Council Member States, representatives of Indigenous Peoples' organisations that are Permanent Participants to the Council and Arctic Council observer countries and organisations. CAFF serves as a vehicle to cooperate on species and habitat management and utilization, to share information on management techniques and regulatory regimes and to facilitate more knowledgeable decision-making. It provides a mechanism to develop common responses on issues of importance for the Arctic ecosystem such as development and economic pressures, conservation opportunities and political commitments. The Circumpolar Biodiversity Monitoring Program (CBMP) is an international network of scientists, governments, Indigenous organisations and conservation groups working to harmonize and integrate efforts to monitor the Arctic's living resources working under CAFF. The CBMP goal is to facilitate more rapid detection, communication and response to the significant biodiversity-related trends and pressures affecting the circumpolar world.

The Arctic Biodiversity Data Service (ABDS) is the data management framework for CAFF and its programs and activities including the CBMP. It is an online, interoperable data management system that serves as a focal point and common platform for all CAFF programs and projects as well as a dynamic source for up-to-date circumpolar Arctic biodiversity information and emerging trends. The ABDS framework is built using the following open source solutions:

- GeoServer, a Java-based server that allows users to view and edit geospatial data;
- GeoNetwork, a catalogue application to manage spatially referenced resources; and
- PostgreSQL, an open source object-relational database system.

CBMP is consolidating the vast amount of disaggregated data across all Arctic sub-regions and biomes. This will improve access to biodiversity status and trends information and promote a deeper understanding of inter-relationships at the local, regional, circumpolar and global scales. The tools and standards used by the ABDS are directly compatible with the Arctic SDI design and it can be an important node in the Arctic SDI that will serve research, policy and local communities.

https://www.abds.is/

A5.2.5 Europe and European Commission

The European Commission is the executive body of the European Union (EU). It represents the interests of the EU as a whole and not the interests of individual Member States. The Horizon 2020 Research and Innovation Programme is the biggest EU research and innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020). Close to €100 M of these funds have been invested in Arctic research in recent years. This is resulting in transformative developments in the production and

management of Arctic data. A full review of relevant projects is not practical here; however, selected initiatives are highlighted including a newly formed coordination body (EU Arctic Cluster).

EU-PolarNet and EU Arctic Cluster

Currently funded Horizon 2020 Arctic projects together build the EU Arctic Cluster – a network that merges the most up-to-date findings on Arctic change and its global implications. Its objective is to provide guidance and policy-relevant information and to support the EU in advancing international cooperation, in responding to the impacts of climate change on the Arctic's fragile environment and on promoting and contributing to sustainable development. In doing so, the EU Arctic Cluster cooperates closely with policy makers, Indigenous peoples, local Arctic communities, business representatives and the European civil society. Many of the Cluster projects include a significant data component and most are working towards standards-based, distributed, interoperable data infrastructure and are thus relevant to the Arctic SDI. The following links provide details on the member projects.

- APPLICATE
- ARICE
- BLUE-ACTION
- EU-PolarNet (Research and Coordination)
- ICE-ARC
- INTAROS
- INTERACT
- NUNATARYUK

http://www.eu-polarnet.eu/eu-Arctic-cluster/

INTAROS

A foundational project with respect to data infrastructure is INTAROS. The overall objective of INTAROS is to develop an integrated Arctic Observation System (iAOS) by extending, improving and unifying existing systems in the different regions of the Arctic. INTAROS has a strong multidisciplinary focus, with tools for integration of data from atmosphere, ocean, cryosphere and terrestrial sciences, provided by institutions in Europe, North America and Asia. INTAROS is developing a platform, iAOS, to search for and access data from distributed databases. INTAROS includes development of community-based observing systems, where local knowledge is merged with scientific data.

INTERACT

INTERACT is an infrastructure project under the auspices of SCANNET, a circum-Arctic network of currently 79 terrestrial field bases in northern Europe, Russia, US, Canada, Greenland, Iceland, the Faroe Islands and Scotland as well as stations in northern alpine areas. INTERACT specifically seeks to build capacity for research and monitoring in the European Arctic and beyond and is offering access to numerous research stations through the Transnational Access program. INTERACT is multidisciplinary; together, the

stations in INTERACT host thousands of scientists from around the world who work on projects within the fields of glaciology, permafrost, climate, ecology, biodiversity and biogeochemical cycling. The INTERACT stations also host and facilitate many international single-discipline networks and aid training by hosting summer schools. Development of the INTERACT data system is in the early stages; however, they are partnering with groups such as WMO GCW, SIOS, the Norwegian Meteorological Institute (Met Norway) and others to design a standards-based, interoperable system. In the future, INTERACT can act as a significant node in the Arctic SDI.

INTERACT

A5.2.6 European Space Agency (ESA)

ESA is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. In 2015, ESA's Earth Observation budget was € 1.25 billion.

ESA is active in many areas of research, monitoring, and enforcement in a range of different domains. More details on ESA Arctic activities can be found at:

http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/Arctic

A5.3 NATIONAL ARCTIC INITIATIVES

A5.3.1 Canada

Natural Resources Canada (NRCan)

Many Government of Canada agencies and departments are engaged in Arctic data production, management and publication. In the interest of providing a concise review, the Federal Geospatial Platform (FGP) is being used as a proxy for access to these data. While not all data are currently available through the FGP, it is expected that resources will continue to increase significantly as has been the case since its inception.

Federal Geospatial Platform

The **Federal Geospatial Platform (FGP)** is an initiative of the **Federal Committee on Geomatics and Earth Observations (FCGEO)**, a committee of senior executives from 21 departments and agencies that are producers and/or consumers of geospatial data, or have an interest in activities, requirements and infrastructure related to geomatics. The FCGEO community recognised an opportunity for federal departments and agencies to manage geospatial information assets in a more efficient and coordinated way by using a common "platform" of technical infrastructure, policies, standards and governance.

The Federal Geospatial Platform has two faces: an internal site that can be found at gcgeo.gc.ca (internal government network), and a public site entitled Open Maps, on the Open Government Portal.

The FGP can act as a foundational contribution from Canada to the international Arctic SDI effort. The Open Maps component will be particularly important, while other data may be accessible through

organisations like NRCan. Through the close partnership between NRCan and the Arctic SDI, the FGP is highly compatible with the Arctic SDI infrastructure, policies, standards and governance.

Polar Knowledge Canada

Polar Knowledge Canada (POLAR) was established in 2015 and has a mandate to focus on Arctic issues and strengthen Canada's position internationally as a leader in polar science and technology. POLAR also promotes the development and distribution of knowledge of other circumpolar regions, including AntArctica. It will provide a world-class hub for science and technology research in Cambridge Bay, Nunavut called the Canadian High Arctic Research Station. As part of Canada's Northern Strategy, POLAR improves economic opportunities, environmental stewardship and quality of life for Northerners and other Canadians. The POLAR mandate also includes creation of technology and generation and management of data. As a relatively new organization, POLAR is actively building capacity and exploring and establishing its role in this area. POLAR stands to be a major organization in Canadian Arctic data and should be considered as Canada's contribution to the development of the Arctic SDI as it moves forward.

https://www.canada.ca/en/polar-knowledge.html

A5.3.2 Kingdom of Denmark

The Kingdom of Denmark operates under an Arctic strategy that includes research and knowledge management. As a member of the Arctic Council, the Kingdom of Denmark engages in Council activities and thus has a multidimensional role in the field of Arctic data and knowledge.

http://naalakkersuisut.gl/~/media/Nanoq/Images/Udenrigsdirektoratet/100295_Arktis_Rapport_UK_210x270_Final_Web.pdf

Two departments in particular are potentially relevant to the Arctic SDI.

Geological Survey of Denmark

The Geological Survey of Denmark and Greenland (GEUS) is a research and advisory institution in the Danish Ministry of Energy, Utilities and Climate. GEUS is a partner in Geocenter Denmark and is associated with EuroGeoSurveys. The work field of GEUS – geoscientific studies, research, consultancy and geological mapping – primarily covers the Kingdom of Denmark and Greenland. GEUS supports the Isaaffik Arctic Gateway, which is a website supporting Arctic research and collaboration.

http://www.geus.dk/UK/Pages/default.aspx

Danish Meteorological Institute (DMI)

Established in 1872, DMI is an institution under the Danish Ministry of Energy, Utilities and Climate. Its main objective is to provide meteorological services in the Kingdom of Denmark, the Faroe Islands, Greenland and the surrounding waters and airspace. To this end, part of its responsibilities is to monitor and produce maps of sea ice in and around Greenland.

http://ocean.dmi.dk/english/index.php

A5.3.3 Finland

In addition to the National Land Survey of Finland, the adhering body to the Arctic SDI, as documented in Appendix A6, there are a number of Finnish institutions relevant to Arctic SDI development. In this summary review, FMI is highlighted.

http://www.maanmittauslaitos.fi/en

Finnish Meteorological Institute (FMI)

FMI is a research and service agency under the Finnish Ministry of Transport and Communications. Its main objective is to provide the Finnish nation with the best possible information about the atmosphere above and around Finland, for ensuring public safety relating to atmospheric and airborne hazards and for satisfying requirements for specialised meteorological products.

At present, FMI is playing a major role in initiatives under the priorities of the Finnish chairmanship of the Arctic Council. FMI has organised and continues to organize workshops and other activities focused on Arctic observations and data. Through these activities and partnership with bodies such as the WMO, Polar View, ESA and others, FMI is increasing its capacity in data management and dissemination. They stand to be an important Arctic SDI partner.

http://en.ilmatieteenlaitos.fi/

A5.3.4 Iceland

Arctic Portal

The Arctic Portal, lead by a non profit organization, is a comprehensive gateway to Arctic information and data on the Internet, increasing information, sharing and co-operation among Arctic stakeholders and granting exposure to Arctic-related information and data. The Arctic Portal is managed from Akureyri, Iceland, under an international board of directors. It is operated in consultation and co-operation with members of the Arctic Council and its Working Groups, Arctic Council Permanent Participants, observers and other stakeholders.

Key focus areas of the Arctic Portal include: dissemination of Arctic News and Information, hosting of websites related to Arctic organizations and institutions, promotion of educational tools and mapping systems, and outreach and consultation. Specifically, the Portal has a combination of data discovery and access tools. Recent funding will be used to greatly enhance the system, including web services and other SDI relevant tools and interfaces.

https://Arcticportal.org/

Iceland Meteorological Office

The main purpose of the Iceland Meteorological Office is to contribute towards increased safety and efficiency in society by monitoring, analyzing, interpreting, informing, giving advice and counsel, providing warnings and forecasts and, where possible, predicting natural processes and natural hazards. The Office is a governmental institution under the Ministry of the Environment and Natural Resources.

As with other countries, the Office plays a significant role in the national and international data landscape. They also partner with WMO and are working towards the adoption of service-oriented systems under the GCW model.

http://en.vedur.is/

A5.3.5 Japan

Arctic Data Archive System (ADS)

Japan is making significant investments in Arctic science and implementation of Arctic data infrastructure. The ADS collects and disseminates observation data and modeling obtained via a broad range of Japanese research projects. By centrally managing a wide variety of Arctic observation data, this allows for the use of data across multiple disciplines. Researchers use these integrated databases to clarify the mechanisms of environmental change in the atmosphere, ocean, land-surface and cryosphere. At present, the system is not fully service enabled; however, representatives from Japan will participate in the aforementioned Polar Data Planning Summit to discuss how to better connect to global partners.

https://ads.nipr.ac.jp/portal/index.action

A5.3.6 Norway

Norway is very active in polar data management, in particular, through two organisations that are adopting service-oriented approaches to data discovery and access.

Norwegian Polar Institute (NPI)

NPI is Norway's central government institution for scientific research, mapping and environmental monitoring in the Arctic and the AntArctic. The Institute advises Norwegian authorities on matters concerning polar environmental management and is the official environmental management body for Norway's AntArctic territorial claims.

http://www.npolar.no/en/

Norwegian Polar Data Centre (NPDC)

NPI's NPDC manages and provides access to scientific data, environmental monitoring data and topographic and geological map data from the polar regions. The scientific datasets range from human field observations, through in-situ and moving sensor data, to remote sensing products. NPI's data holdings also include photographic images, audio and video records.

https://data.npolar.no/home/

Norwegian Meteorological Institute (MET Norway)

MET Norway is the meteorological service for both the Military and the Civil Services in Norway, as well as the public. Its mission is to protect life, property and the environment, and to provide the meteorological services required by society.

https://www.met.no/

Arctic Data Centre

The Arctic Data Centre (ADC) is a WMO Data Collection and Production Centre hosted by MET Norway. It is a legacy of the International Polar Year (IPY) when MET Norway coordinated operational data streams internationally and research data nationally. IPY was the starting point for distributed data management within geosciences in Norway, and this effort has been followed by relevant efforts like the Norwegian Satellite Earth Observation Database for Marine and Polar Research (NORMAP) and the Norwegian Marine Data Centre (NMDC).

The involvement of MET Norway in distributed data management efforts nationally and internationally is coordinated through ADC which is an internal project at the Institute.

https://pm.met.no/Arctic-data-centre

A5.3.7 Russian Federation

Beyond the existing data resources available through the Arctic SDI partnership with the Russian mapping agency, accessing data from the Russian Federation can be challenging. With increased dialogue, there may be good possibilities for obtaining additional geospatial data from the Russian meteorological institute (http://meteo.ru/english/index.php), and the Arctic and AntArctic Research Institute.

Arctic and AntArctic Research Institute

The oldest and largest Russian research institution in the field of comprehensive studies of the polar regions, belonging to the Russian Federal Service on hydrometeorology and environmental protection. The institute performs complex investigations in many scientific fields through its 17 Scientific Departments and collection of facilities.

The Federal Service for State Registration, Cadastre and Mapping (Rosreestr)

Representing the Russian Federation on the Arctic SDI, Rosreestr is the Russian National Mapping Agency (NMA). Rosreestr was founded in 2009 through the merger of three agencies: the Federal Registration Service, the Federal Agency for Real Estate Cadastre and the Federal Agency for Cartography. Rosreestr is now responsible for the performance of three functions: the registration of property rights, cadastre maintenance, and geodesy and cartography activities.

https://rosreestr.ru/site/en/about/

A5.3.8 Sweden

Swedish Polar Research Secretariat

Swedish Arctic data activities are carried out through the Swedish Polar Research Secretariat, a government agency that promotes and co-ordinates Swedish polar research. Their mission is to both plan and complete research and development and organize and lead research expeditions to the Arctic and AntArctic regions.

https://polar.se/en/

Swedish Meteorological and Hydrological Institute (SMHI)

SMHI is an expert agency under the Swedish Ministry of the Environment and Energy. Through unique expertise in meteorology, hydrology, oceanography and climatology, it offers many services that contribute to increased safety and a sustainable society.

NordGIS

NordGIS is a geographic metadata information system with the mission to collect metadata regarding the activities performed at a selection of Nordic field-stations, and to disseminate the information for station administration, public outreach, and inclusion in other metadata repositories. Its current focus is on research and monitoring regarding high-latitude environments, having been prototyped at the subArctic research and monitoring stations at Abisko and Tarfala in northernmost Sweden.

http://www.nordgis.org/sites/home/index.php

A5.3.9 United States of America

The U.S. Arctic system is complex. A full review of the system is beyond the scope of this document; however, selected key organisations are included. To facilitate organization at a national level, the Interagency Arctic Research Policy Committee was established by Congress and now also reports to the White House.

Interagency Arctic Research Policy Committee (IARPC)

IARPC is coordinated using in-person meetings and an online platform called IARPC Collaborations. IARPC Collaborations was created to connect Federal government and non-Federal government researchers and other stakeholders, including those overseas, to work together to solve the emerging Arctic challenges. Open to anyone who can contribute, IARPC Collaborations has realised an unprecedented degree of interagency communication, coordination and collaboration that has advanced Arctic science. IARPC includes the Arctic Data Sub-Team (ADST), which is part of the larger Environmental Intelligence Collaboration Team. The ADST coordinates discussion around all matters related to data infrastructure and is working to establish a common set of standards, policies and governance across the federal family over time. These elements will be used in a distributed system. Key nodes include the organisations briefly reviewed below.

NOAA's National Centers for Environmental Information (NCEI)

NCEI hosts and provides public access to one of the most significant archives for environmental data on Earth. Through the Center for Weather and Climate and the Center for Coasts, Oceans, and Geophysics, they provide over 25 petabytes of comprehensive atmospheric, coastal, oceanic and geophysical data.

https://www.ncei.noaa.gov

National Science Foundation (NSF) Arctic Data Center

The Arctic Data Center helps the research community reproducibly preserve and discover all products of NSF-funded science in the Arctic, including data, metadata, software, documents and provenance that link these in a coherent knowledge model. Key to the initiative is the partnership between The National Center

for Ecological Analysis and Synthesis (NCEAS) at University of California Santa Barbara, DataONE, and NOAA's NCEI, each of which brings critical capabilities to the Center.

https://Arcticdata.io/

Alaska Ocean Observing System (AOOS)

AOOS is the umbrella association for three Alaska regional observing networks (i.e., Gulf of Alaska, Bering Sea/Aleutian Islands and Arctic) being developed as part of the national Integrated Ocean Observation System (IOOS) under the National Ocean Planning Partnership (NOPP). AOOS represents a network of critical ocean and coastal observations, data and information products that aid our understanding of the status of Alaska's marine ecosystem and allow stakeholders to make better decisions about their use of the marine environment.

http://www.aoos.org

National Aeronautics and Space Administration (NASA)

Global Change Master Directory

The mission of the Global Change Master Directory is to offer a high quality resource for the discovery, access and use of Earth science data and data-related services worldwide, while specifically promoting the discovery and use of NASA data. The directory resource is targeted to serve as a valued location for sharing data from multinational sources and, in turn, will contribute to scientific research by providing direct access to Earth science data and services.

https://gcmd.nasa.gov

NASA Arctic-Boreal Vulnerability Experiment Science Cloud (ABoVE)

ABoVE is a NASA-led, 10-year field experiment designed to better understand the ecological and social consequences of environmental change in one of the most rapidly changing regions on Earth. Satellite, airborne and ground observations across Alaska and Canada will help us better understand the local and regional effects of changing forests, permafrost and ecosystems, and how these changes could ultimately affect people and places beyond the Arctic.

https://above.nasa.gov

Local Environmental Observer (LEO) Network

LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment and weather events. With LEO, one can connect with others in their community, share observations, raise awareness and find answers about significant environmental events. LEO Network was selected as a model program under the United States Chairmanship of the Arctic Council, to help raise awareness and improve communication about climate change in the circumpolar region.

http://www.leonetwork.org/en/docs/about/about

A5.4 UNIVERSITIES

A5.4.1 Universities Introduction

A very significant amount of the data generated and managed for the Arctic originates in the University sector. In some cases, these projects and programs are large enough to professionally manage data in the short to long-term. In other cases, sound partnerships with major data centers exist (e.g., Polar Data Catalogue in Canada; NSIDC, NSF Arctic Data Center in the U.S.). In other cases, the data are not professionally managed and are part of what is known as the "long tail of data". Recently, there have been many positive developments in moving university-based research data toward professionally managed, service-oriented infrastructure. A few key initiatives are described here.

A5.4.2 University of the Arctic

The University is a cooperative network of universities, colleges, research institutes and other organisations concerned with education and research in and about the North. It builds and strengthens collective resources and collaborative infrastructure that enables member institutions to better serve their constituents and their regions. University of the Arctic has started to engage in the data dialogue and has indicated interest in engaging in community activities, including the Polar Data Planning Summit. The executive of the University is actively considering data models for the network. As a network, a distributed, service oriented approach is being reviewed (Personal Communications, Lars Kullerud, June 2017).

https://www.uArctic.org/

A5.4.3 Canada

Canadian Consortium for Arctic Data Interoperability (CCADI)

The CCADI is currently composed of a group of Canada's foremost Arctic scholars and Arctic data managers at the University of Calgary (Arctic Institute of North America), the University of Waterloo (Canadian Cryospheric Information Network and Polar Data Catalogue), Carleton University (Geomatics and Cartographic Research Centre), the University of Manitoba (Centre for Earth Observation Science), Université Laval (Centre d'études nordiques), University of Ottawa (Faculty of Law), Inuit Tapiriit Kanatami, Inuvialuit Regional Corporation, Natural Resources Canada, Polar Knowledge Canada, Cybera Inc., Polar View Eartj Observation, and Sensor-Up Inc.

Although CCADI includes non-University partners, there is a strong university component in the membership. In addition to coordination, CCADI has applied for major funding. If successful, distributed data infrastructure using an SDI model will be implemented among the partners with connections to the national and international systems. This consortium is very relevant to Arctic SDI development.

http://ccadi.ca/

Carleton University Geomatics and Cartographic Research Centre (GCRC)

GCRC research focuses on the application, processing and management of geographic information to support the analysis of key socioeconomic issues at both the local and international level. GCRC is a leader in cyber-cartography, a new multimedia, multisensory and interactive online mapping discipline that

presents both quantitative and qualitative results in innovative formats. GCRC's community-focused projects in the Canadian Arctic are building northern atlases in this style; (e.g., Siku Atlas, Pan Inuit Trails Atlas and Arctic Bay Atlas).

GCRC is a core member of the CCADI and plays an active role in SDI development. They are particularly active with Indigenous communities in the Arctic. See for example:

- **Siku Atlas**
- **Pan-Arctic Trails Atlas**
- **Arctic Bay Atlas**

University of Calgary – Arctic Institute of North America (AINA)

The AINA was created by a Canadian Act of Parliament in 1945 as a non-profit research and educational organization. Originally based at McGill University in Montreal, the institute moved to the University of Calgary in 1976. AINA's mandate is to advance the study of the North American and circumpolar Arctic through the natural and social sciences, the arts and humanities and to acquire, preserve and disseminate information on physical, environmental and social conditions in the North.

As the lead organization of CCADI, AINA plays an important leadership role in developing university-based SDI in Canada.

AINA University of Calgary ArcticConnect

ArcticConnect is a network-enabled platform for realizing geospatial referencing of information about the Arctic system derived from research, education and private sector activities in the Arctic and subArctic.

http://Arcticconnect.org/Arcticconnect

AINA Arctic Science and Technology Information System (ASTIS)

The ASTIS database contains over 80,000 records describing publications and research projects about northern Canada. ASTIS, a project of the Arctic Institute of North America at the University of Calgary, also maintains subset databases about specific regions, subjects and projects.

University of Waterloo Canadian Cryospheric Information Network

Polar Data Catalogue (PDC)

The PDC is one of Canada's primary online sources for data and information about the Arctic and is Canada's National AntArctica Data Centre. With over 2,500 metadata descriptions of projects and datasets and almost 3 million data files, the PDC contains data on physical, social and health science and other research in Canada and globally. The records cover a wide range of disciplines from natural sciences and policy, to health and social sciences. The PDC Geospatial Search tool is available to the public and researchers alike and allows searching data using a mapping interface and other parameters.

The PDC is a core member of CCADI and has been a leader in the Canadian and international polar data community for two decades. Their metadata holdings are significant and their data holdings are increasing. If CCADI activities move forward, significant development of system-to-system interoperability will take place.

https://www.polardata.ca/

Centre D'Études Nordiques (CEN)

The CEN is a research centre involving three academic institutions: the Université Laval, the Université du Québec à Rimouski and the Centre Eau, Terre et Environnement of the Institut national de la recherche scientifique. CEN researchers also include professors from the Université du Québec à Trois-Rivières, Université de Sherbrooke, Université de Montréal, Université du Québec à Chicoutimi, Université du Québec à Montréal, McGill University, Concordia University and Cégep F-X Garneau. CEN brings together over 300 researchers, students, postdoctoral fellows and professionals from diverse disciplines (e.g., biology and microbiology, geography, geology, engineering, archeology, landscape management).

The CEN is a core member of CCADI and is a leader in the Canadian and international polar data community. They have established a data publication in the form of NORDICANA-D. CEN metadata holdings are also significant and their data holdings are increasing. If CCADI activities move forward, significant development of system-to-system interoperability will take place.

http://www.cen.ulaval.ca/en/

University of Manitoba – Centre of Earth Observation Sciences (CEOS)

The CEOS was established in 1994 with a mandate to research, preserve and communicate knowledge of Earth system processes using the technologies of Earth Observation Science. Research is multidisciplinary and collaborative and is seeking to understand the complex interrelationships between elements of Earth systems and how these systems will likely respond to climate change. Although researchers have worked in many regions, the Arctic marine system has always been a key focus of activity.

http://umanitoba.ca/ceos/

The CEOS is a core member of CCADI and is a leader in the Canadian and international polar data community, particularly in the domain of sea ice data. Their metadata and data holdings are particularly with respect to marine remote sensing data. If CCADI activities move forward, significant development of system-to-system interoperability will take place.

A5.4.4 United States of America

National Snow and Ice Data Center (NSIDC)

Located at the University of Colorado, US, NSIDC began in 1976 as an analog archive and information center, the World Data Center for Glaciology. Since then, it has evolved to manage all forms of cryosphere-related data. It is one of the largest cryospheric data centers in the world. Key data portals are the Distributed Active Archive Centre (DAAC), the Frozen Ground Data Center and the Arctic Data Explorer. NSIDC also hosts the ELOKA project outlined in the next section.

Distributed Active Archive Centre (DAAC)

The NSIDC DAAC provides data and information on snow, sea ice, glaciers, ice sheets, ice shelves, frozen ground, soil moisture, cryosphere and climate interactions in support of research in global change detection, model validation and water resource management. The NSIDC DAAC processes, archives, documents and distributes data from NASA's Earth Observing System (EOS) satellites, airborne campaigns and field measurement programs.

Frozen Ground Data Center

The International Permafrost Association (IPA) has developed a strategy for data and information management to meet the requirements of the cold regions science, engineering and modeling communities. A central component of this strategy is the Global Geocryological Data (GGD) system, an internationally distributed system linking investigators and data centers around the world. NSIDC, in collaboration with the International Arctic Research Center (IARC), serves as a central node of the GGD.

Arctic Data Explorer

The Arctic Data Explorer is a metadata aggregator and broker that brings together 13 metadata catalogues under a single window search. The system is being used as part of a joint effort between the Arctic Data Committee, the Standing Committee on AntArctic Data Management and the Southern Ocean Observing System and supporting partners to establish a common specification of metatada elements for use in federated search tools.

http://Arctic-data-explorer.labs.nsidc.org/

Polar Geospatial Center (PGC)

The PGC at the University of Minnesota provides geospatial support, mapping and GIS/remote sensing solutions to researchers and logistics groups in the polar science community. PGC supports U.S. polar scientists to complete their research goals in a safe, timely and efficient manner by providing a service that most groups do not have the resources or expertise to deliver. The PGC mission is to introduce new, state-of-the-art techniques from the geospatial field to effectively solve problems in the least mapped places on Earth. This includes Domain and institutional knowledge to solve a broad range of polar geospatial problems, access to sub-meter commercial satellite imagery for the AntArctic and Arctic and the expertise to task, manage, process and deliver high-level, value-added products. Most recently, they produced the high resolution Arctic DEM.

Pacific Marine Arctic Regional Synthesis (PacMARS)

PacMARS Data Archive

PacMARS is a research synthesis effort funded by the North Pacific Research Board, whose goal is to provide guidance for scientific research needs in the region, as well as to serve stakeholder needs for understanding this important ecosystem and its vulnerabilities.

http://pacmars.cbl.umces.edu/

A5.5 INITIATIVES FOCUSED ON INDIGENOUS AND COMMUNITY BASED MONITORING

Indigenous and local observations and knowledge and derived data and information are increasingly being recognised as valuable by researchers, governments and society. Community based monitoring programs as depicted on tools such as the Atlas of Community Based Monitoring (http://www.Arcticcbm.org) are producing data and, where appropriate, making them available. This can be an important part of the Arctic SDI. Working in this space can be challenging due to different ontology and epistemology, a wide variety of local contexts, variable funding models and technical challenges (http://www.inuitcircumpolar.com/community-based-monitoring.html; Johnson et al. 2015). However, significant investments are being made, (https://www.aadnc-aandc.gc.ca/eng/1509728370447/1509728402247) and we can expect data sharing capacity to increase in the coming years.

A number of organisations and programs focused on this type of data sharing already exist in Canada and beyond, including the Permanent Participants of the Arctic Council, They include the Inuit Knowledge Centre at ITK and regional organization partners, the Geomatics and Cartographic Research Centre at Carleton University, the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) program at the University of Colorado, the EU INTAROS project and many others.

A5.5.1 Permanent Participants of the Arctic Council

Indigenous peoples' organisations have been granted Permanent Participants status in the Arctic Council. The Permanent Participants have full consultation rights in connection with the Council's negotiations and decisions. Permanent Participants such as those listed below represent a unique feature of the Arctic Council, and they make valuable contributions to its activities in all areas.

https://www.Arctic-council.org/index.php/en/about-us/permanent-participants

Aleut International Association (AIA)

Arctic Athabaskan Council (AAC)

Gwich'in Council International (GCI)

Inuit Circumpolar Council (ICC)

Russian Association of Indigenous Peoples of the North (RAIPON)

Saami Council (SC)

A5.5.2 Inuit Tapiriit Kanatami (ITK) and Inuit Knowledge Centre

ITK is a national representational organization protecting and advancing the rights and interests of Inuit in Canada. Their work includes research, advocacy, public outreach and education on the issues affecting Inuit population. ITK works closely with the four Inuit regions to present unified priorities in Ottawa.

https://itk.ca/

Inuit Qaujisarvingat, the Inuit Knowledge Centre, aims to ensure an increasingly active role for Inuit in research that leads to the generation of innovative knowledge for improved research, science and policy making within a Canadian, circumpolar and global context. Inuit Qaujisarvingat supports those involved in Arctic and Inuit research and policy development from community to international levels. It consists of a diverse group, including Inuit organisations, researchers and policy makers, governments and Arctic research networks.

http://www.inuitknowledge.ca/

A5.5.3 Exchange for Local Observations and Knowledge of the Arctic (ELOKA)

ELOKA fosters collaboration between resident Arctic experts and visiting researchers to facilitate the collection, preservation, exchange and use of local observations and Indigenous knowledge of the Arctic. ELOKA provides data management and user support to Indigenous communities to ensure their data and knowledge are managed, visualised and shared in an ethical manner in order to work toward information and data sovereignty for Arctic residents. ELOKA engages in many activities, including hosting of data. Under its current activities, data are being made available where appropriate using OGC and other data standards and services

https://eloka-Arctic.org/index.html

See Appendix A6 for additional important programs.

A5.6 NOT-FOR-PROFIT INITIATIVES

The not-for profit sector is an increasingly important one. Not all data collection and management activity is well resourced by government or academically-oriented programs for a variety of different reasons (limited funding, beyond the mandate of the funder, difficulty in funding across borders, etc.) We are now seeing not-for-profits play a valuable role in the Arctic data domain.

A5.6.1 Polar View Earth Observation Limited (PVEO)

PVEO is a global organization providing leading-edge, satellite-based information and data services in the polar regions and the cryosphere. Services support safe and cost-effective marine operations, improved resource management, sustainable economic growth and risk protection across sectors and around the world. Using satellite earth observation data in combination with sophisticated models and automatic tools, PVEO converts the satellite images into information products that graphically illustrate the characteristics of the ice and snow.

http://www.polarview.org/

Polar Thematic Exploration Platform (Polar TEP)

Polar TEP, developed by Polar View for the European Space Agency, provides a complete working environment where users can access algorithms and data remotely, and use computing resources and tools that they might not otherwise have, to produce information products, avoiding the need to download and manage large volumes of data. This new approach removes the need to transfer large Earth

Observation data sets around the world, while increasing the analytical power available to researchers and operational service providers.

https://portal.polar-tep.eo.esa.int/ssoportal/pages/login.jsf

A5.6.2 Arctic Funders Collaborative

The Arctic Funders Collaborative promotes more informed and effective grant-making to support healthy Arctic communities and ecosystems. They leverage support for opportunities across the Arctic that advance land and water stewardship, capacity building for Indigenous peoples and community and cultural well-being.

The goal of the Collaborative is to facilitate continued growth in Arctic philanthropy by building capacity within the philanthropic sector to support Arctic initiatives and strengthening connections among philanthropic institutions and Northern, especially Indigenous, communities.

http://Arcticfunders.com/afc-members/ http://Arcticfunders.com/

A5.6.3 Mackenzie DataStream

An open access platform for sharing water data in the Mackenzie Basin, DataStream's mission is to promote knowledge sharing and advance collaborative, evidence-based decision-making throughout the Basin. Mackenzie DataStream currently contains data collected by 22 communities who monitor 70+ parameters and they actively seek partnerships to bring new data contributors onboard. Data are currently collected by community monitors with the help of scientists and accredited laboratories.

https://mackenziedatastream.ca/#/

A5.6.4 Tides Canada Initiatives

Tides Canada is a recognised national leader in social change philanthropy that has supported over 2,500 initiatives with grants totaling more than $158M in support of environmental and social change. Tides Canada has a Northern Well-Being program (http://tidescanada.org/focus/northern-well-being/). Led by program manager Steve Ellis, the initiative is funding a number of community-led projects focused on monitoring and capacity building. This includes the Clyde River Knowledge Atlas and a number of other Northern community-based data collection and management projects. On March 6th-7th, 2018, Tides Canada hosted a workshop in Yellowknife NWT, focused on data platforms and tools for community-based monitoring programs. Communities who benefit from these efforts may be in a position to contribute valuable data and information to the Arctic SDI.

A5.6.5 World Wildlife Fund – Global Arctic Programme

WWF-Canada is planning for an Arctic future that conserves wildlife while respecting the practices and traditions of local communities and promoting the responsible development of Arctic resources. WWF does this through its Global Arctic Programme. This programme sponsors scientific research, by working with communities, industry, Indigenous groups and government, by empowering young people to speak out for the Arctic, and by furthering national and international efforts to reduce greenhouse gas emissions and slow rapid climate change. The results of these efforts may include valuable data contributions to the Arctic SDI.

http://www.wwf.ca/conservation/Arctic/whatwwfisdoing/

Appendix A6

Selected Polar Data Portals and Initiatives

A6.0 SELECTED POLAR DATA PORTALS AND INITIATIVES

The following table summarizes a selection of data portals and initiatives that are relevant to polar information.

Types

- Scientific User: e.g., government research councils, academic researchers, individual "citizen" scientists.
- Operational User: e.g., oil and gas companies, mining companies, tourist vessels, commercial shipping, fisheries companies, Indigenous communities.
- Funding Agency: e.g., research and science foundations, European Commission, European Space Agency.
- Policy/Regulatory Organization: e.g., polar and conservation commissions, Arctic Council, European Polar Board, International Polar Foundation.
- Network/Consortium: e.g., Arctic Data Coordination Network, Network of Centres of Excellence, European Network for Arctic-Alpine Research.
- Data Portal: e.g., Polar Data Catalogue, National Snow and Ice Data Centre.

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Alaska Ocean Observing System (AOOS)	AOOS is the umbrella association for three Alaska regional observing networks (Gulf of Alaska, Bering Sea/Aleutian Islands and Arctic) being developed as part of the national Integrated Ocean Observation System (IOOS) under the National Ocean Planning Partnership (NOPP). AOOS represents a network of critical ocean and coastal observations, data and information products that aid our understanding of the status of Alaska's marine ecosystem and allow stakeholders to make better decisions about their use of the marine environment.	USA	http://www.aoos.org	●					●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Aleut International Association (AIA)	AIA was established in 1971 to address environmental and cultural concerns of the extended Aleut people whose well-being has been connected to the resources of the Bering Sea for millennia. Aleut International is actively pursuing collaboration with governments and scientists in developing programs and policies (related to trans-boundary contaminates, impacts of climate change, effects of commercial fisheries, to name a few) that could improve the well-being of the Aleut people and their environment. Aleut International was admitted as a permanent participant of the Arctic Council in 1998.	International	https://www.aleut-international.org	●			●		
Amundsen Science	The scientific program of the Canadian research icebreaker CCGS *Amundsen* is delivered under the initiative "Amundsen Science". Every year the *Amundsen* spends up to 152 days in Arctic regions in support of Canadian research programs and collaborations with industry and international partners. The ship's 65 scientific systems and 22 shipboard laboratories make it a versatile research platform for scientists in the natural, health and social sciences along with their partners from government, industry and Northern communities.	Canada	http://www.amundsen.ulaval.ca/home.php	●	●				
AntArctic and Arctic Data Consortium (a2dc)	The National Science Foundation (NSF) AntArctic and Arctic Data Consortium (a2dc) is a collaboration of research centers and support organisations that provide polar scientists with data and tools to complete their research objectives. From searching historical weather observations to submitting geologic samples, polar researchers utilize the a2dc to search and contribute to the wealth of polar scientific and geospatial data.	USA and others	http://www.a2dc.org/index.php					●	●
APPLICATE	APPLICATE (Advanced Prediction in Polar Regions and beyond: modelling, observing system design and Linkages associated with a Changing Arctic climate) is a four-year project funded by the EU's Horizon 2020 Research and Innovation programme with a budget of 8 million euro. The multinational and multidisciplinary consortium will work to enhance weather and climate prediction capabilities not only in the Arctic, but also in Europe, Asia, and North America.	European	https://applicate.eu/	●				●	
Arctic and AntArctic Research Institute (AARI)	AARI is the oldest and largest Russian research institution in the field of comprehensive studies of the polar regions, belonging to the Russian Federal Service on hydrometeorology and environmental protection. The institute performs complex investigations in many scientific fields through its 17 Scientific Departments and collection of facilities.	Russia	http://www.aari.ru/	●					

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Arctic Athabaskan Council (AAC)	AAC is an international treaty organization established to defend the rights and further the interests internationally of American and Canadian Athabaskan member First Nation governments in the eight-nation Arctic Council and other international fora. In addition, AAC seeks to foster a greater understanding of the shared heritage of Athabaskan peoples of Arctic North America. AAC is an authorised Permanent Participant in the Arctic Council.	Canada, USA	http://www.Arcticathabaskancouncil.com/aac/	●			●		
Arctic Contaminants Action Program - ACAP (Arctic Council)	ACAP became Arctic Council's sixth permanent Working Group in 2006. It acts as a strengthening and supporting mechanism to encourage national actions to reduce emissions and other releases of pollutants. Co-operative actions will make an important and significant contribution to the overall international effort to reduce environmental damage on a global level.	International	http://www.Arctic-council.org/index.php/en/acap-home	●			●		
Arctic Danish Technical University (DTU)	The aim of Arctic DTU is to further DTU's profile in the Arctic region. Arctic DTU, launched in 2018, will promote DTU's activities in Greenland and in an Arctic perspective within research, education, innovation, and scientific advice. The centre will be responsible for coordinating and disseminating DTU's Arctic activities across the University.	Kingdom of Denmark	http://www.Arctic.dtu.dk/english/about-Arctic-dtu	●					
Arctic Data Archive System (ADS)	The ADS collects and disseminates observation data and modeling obtained via a broad range of Japanese research projects. By centrally managing a wide variety of Arctic observation data this allows for the use of data across multiple disciplines. Researchers use these integrated databases to clarify the mechanisms of environmental change in the atmosphere, ocean, land-surface and cryosphere.	Japan	https://ads.nipr.ac.jp/portal/index.action	●					●
Arctic Data Committee (ADC)	The overarching purpose of the ADC is to promote and facilitate international collaboration towards the goal of free, ethically open, sustained and timely access to Arctic data through useful, usable, and interoperable systems. The Arctic Data Committee (ADC) is a merger of the former Data Standing Committee of the International Arctic Science Committee (IDSC) and the Committee on Data and Information Services (CDIS) of the Sustaining Arctic Observing Systems (SAON).	International	https://Arcticdc.org/					●	●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Arctic Data Coordination Network (ADCN)	A group within the Arctic Hub collaboration space, the ADCN aims to facilitate communication and coordination across individuals, projects, programs, initiatives and systems involved with Arctic data management. Its larger goal is to oversee Arctic data management practices within the larger global context.	International	*No active website*	●				●	
Arctic Eider Society SIKU mapping platform	SIKU, the Inuktitut word for sea ice, is a social media mapping platform and mobile app designed with and for Inuit combining traditional knowledge and tools with cutting edge technology. It will improve novel ways to document and mobilize youth, community health, education and environmental stewardship. It is recipient of 2017 Google Impact Challenge Award in Canada.	Canada	https://Arcticeider.com/siku						●
Arctic Monitoring and Assessment Programme – AMAP (Arctic Council)	Established in 1991, AMAP is one of six Working Groups of the Arctic Council. Its mandate directs it to: monitor and assess the status of the Arctic region with respect to pollution and climate change; document and propose actions relating to the impact of pollution on the region's ecosystems and humans; and to produce sound science-based, policy-relevant assessments and public outreach products.	International	https://www.amap.no/	●					
Arctic Observing Viewer (AOV)	AOV assists with visualization, strategic assessment, and decision support for initiatives tied to Arctic Observing. View the "who, what, where and when" of Arctic environmental monitoring activities. Funded initially by the U.S. NSF Arctic Sciences Section, it now includes international partners and is primarily for policy makers, program managers, science planners, logistics planners, and data management specialists.	International	http://www.Arcticobservingviewer.org/	●				●	●
Arctic Regional Ocean Observing System (Arctic ROOS)	Arctic ROOS was established in December 2007 by a group of 14 member institutions from nine European countries working actively with ocean observation and modelling systems for the Arctic Ocean and adjacent seas. Arctic ROOS goal is to promote, develop and maintain operational monitoring and forecasting of ocean circulation, water masses, ocean surface conditions, sea ice and biological/chemical constituents.	European	http://Arctic-roos.org					●	●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Arctic Research Centre (ARC)–Aarhus University	Established by Aarhus University in recognition of the need to adopt an interdisciplinary approach to adequately address contemporary and critical Arctic issues, the ARC takes an active role as a partner in the Arctic Science Partnership. The centre promotes synergy and continuous consolidation of specialist knowledge, with integration of fundamental and applied research.	Kingdom of Denmark	http://Arctic.au.dk/	●					
Arctic Research Consortium of the United States (ARCUS)	ARCUS was formed in 1988 to identify and bring together the distributed human and facilities resources of the Arctic research community. It is a non-profit corporation consisting of institutions organised and operated for educational, professional, or scientific purposes who make a commitment to furthering research in the Arctic and related fields. The organization provides a mechanism for members in the Arctic community to complement the advisory roles of relevant national organisations.	USA	https://www.arcus.org/	●					
Arctic Research Icebreaker Consortium (ARICE)	The consortium, launched in 2018 and funded by the EU, consists of fifteen partners from thirteen different countries with the objective of giving the Arctic science community fully funded access to six research icebreakers capable of venturing into the Arctic sea ice. At the same time, ARICE will liaison between science and industry to improve the collection of atmospheric and oceanic data and explore new technologies, which can improve ship-based and autonomous measurements in the Arctic Ocean. ARICE is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	International	https://www.arice.eu		●			●	●
Arctic Research Mapping Application (ARMAP)	ARMAP is designed for funding agencies, logistics planners, research investigators, students, and others to explore information about science being conducted across the Arctic. Hundreds of project locations and ship tracks are shown on the interactive web map, with easy access to details on funding agency, funding program, scientific discipline, principal investigator, project title, and much more. ARMAP is founded on collaborative efforts among many groups that support information exchange and interoperability.	USA and International	http://armap.org/					●	●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Arctic Science and Technology Information System database (ASTIS) – University of Calgary	ASTIS contains over 80,000 records describing publications and research projects about northern Canada and the circumpolar Arctic. ASTIS covers all subjects including the earth sciences, the biological and health sciences, engineering and technology, the social sciences, traditional knowledge, history, and literature. The database includes both peer-reviewed and grey literature and covers the three territories, the northern parts of seven provinces and the adjacent marine areas.	Canada	http://Arctic.ucalgary.ca/about-astis						●
Arctic Science Partnership (ASP)	An extensive research collaboration bringing together the world's leading Arctic scientists and headed by a group of Greenlandic, Danish, and Canadian researchers, ASP seeks to facilitate and integrate active scientific cooperation between its members.	International	http://www.asp-net.org/	●	●			●	
Arctic Spatial Data Infrastructure (Arctic SDI)	The Arctic SDI joint effort aims at creating a spatial data infrastructure for the Arctic region. It is a cooperation network of National mapping agencies in Norway, Kingdom of Denmark, Sweden, Finland, Iceland, Russia, Canada and USA. Its goal is to create an easy-to-use single point access for map and other geographic data of the Arctic region from various producers.	International	https://Arctic-sdi.org/					●	●
ArcticNet	ArcticNet is a Network of Centres of Excellence of Canada that brings together scientists and managers in the natural, human health and social sciences with partners from Inuit organisations, northern communities, federal and provincial agencies and the private sector to study the impacts of climate change in the coastal Canadian Arctic. Its central objective is to contribute to the development and dissemination of the knowledge needed to formulate adaptation strategies and national policies.	Canada	http://www.Arcticnet.ulaval.ca/	●				●	
Association of Arctic Expedition Cruise Operators (AAECA)	The association was founded in 2003 and has become an important international organization representing the concerns and views of Arctic expedition cruise operators. It is dedicated to managing responsible, environmentally-friendly and safe tourism in the Arctic and strives to set the highest possible operating standards.	International	https://www.aeco.no/		●				

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Aurora Research Institute	The Institute facilities and conducts research in the Northwest Territories (NWT), Canada, and acts as a hub of northern knowledge. They focus on generating and sharing Arctic knowledge and building strategic partnerships that expand the territory's research capacity. They also work to ensure that research in the NWT produces meaningful outcomes for its residents while contributing to global concerns. Research themes include environment, health, energy and education.	Canada	http://nwtresearch.com/	●		●			
Barents Portal	Barents Portal is a project implemented under the Joint Norwegian-Russian Commission on Environmental Protection. It is a joint Norwegian – Russian instrument designed for the exchange and presentation of information and environmental data relevant to the integrated environmental management of the Barents Sea. Barents portal serve as a tool for publishing of environmental status in the marine areas, and for further cooperation on ecosystem based management of the Barents Sea.	Norwegian-Russian	http://www.barentsportal.com/barentsportal/index.php/en/	●					●
Belmont Forum e-Infrastructure and Data Management-Collaborative Research Action (CRA)	The Belmont Forum e-Infrastructures and Data Management CRA is leveraging worldwide conversations on data sharing e-infrastructures to coordinate and promote access to transdisciplinary research data generated by Belmont projects. The Belmont Forum itself is comprised of 25 of the world's major funding agencies and international science councils. Established in 2009, it serves as a roundtable for these agencies to collectively address the challenges and opportunities associated with global change.	International	http://www.bfe-inf.org/	●		●		●	●
Blue Action Fund	Blue Action Fund supports national and international non-governmental organisations in their efforts to conserve the oceans and coastlines in the developing world. Their goal is to contribute to reducing the dramatic loss of marine biodiversity and to advancing local development, e.g., through stabilizing incomes in coastal communities or enhancing coastal protection.	International	https://www.blueactionfund.org/			●			
British AntArctic Survey (BAS)	BAS is a component of the Natural Environment Research Council (NERC). For over 60 years, it has undertaken the majority of Britain's scientific research on and around the AntArctic continent. The AntArctic operations and science programmes are executed and managed from Cambridge, UK. Its current science research strategy is called *Polar Science for Planet Earth*.	UK	https://www.bas.ac.uk/	●	●				●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Bureau of Ocean Energy Management (BOEM)	The mission of the BOEM is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way. To fill critical gaps in the information needed to inform the wide range of decisions within the bureau, BOEM facilitates world class research by talented scientists in many disciplines. The bureau also employs a significant number of scientists and technical experts across a range of relevant disciplines	US	https://www.boem.gov/	●	●				
Canada Foundation for Innovation (CFI)	CFI strives to build the nation's capacity to undertake world-class research and technology development to benefit Canadians. The CFI funding architecture covers the full spectrum of infrastructure: projects to attract a leading researcher; team-led innovative projects that have a structuring effect for an institution or a region; and large-scale national projects.	Canada	https://www.innovation.ca/			●			
Canada's Federal Geospatial Platform (FGP)	The FGP is an internal to federal government website where a collection of the government's most relevant data can be found easily and viewed on maps to support evidence-based decision making and foster innovation. The FGP allows for the integration of economic, social, and environmental geospatial data from multiple departments and agencies to better support location-based decision making on a range of complex issues.	Canada	http://maps.canada.ca/en/index.html						●
Canada's Geospatial Data Infrastructure (CGDI)	The CGDI helps Canadians gain perspectives into social, economic and environmental issues by providing an online network of resources that improve the sharing, use and integration of information tied to geographic locations in Canada. Collaboration between federal, provincial, territorial and regional governments; the private sector; non-government organisations; and academia ensure interoperability for the CGDI. This interoperability is achieved by the convergence of framework data, policies, standards and technologies necessary to harmonize Canada's location-based information.	Canada	https://www.nrcan.gc.ca/earth-sciences/geomatics/canadas-spatial-data-infrastructure/10783				●	●	●
Canadian Ice Service (CIS)	The mission of the CIS, which is part of the Canadian department of Environment and Climate Change Canada, is to provide the most accurate and timely information about ice in Canada's navigable waters. It works to promote safe and efficient maritime operations and to help protect Canada's environment. CIS provides clients and the Canadian public with a variety of products, representing accurate and timely information about ice and iceberg conditions in Canadian waters. These products are available most often in the form of a colour graphic chart (or map), but also in text format.	Canada	https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions.html	●	●				●

Organization	Description	Country	URL	Type					
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Canadian Network of Northern Researchers (CNNRO)	CNNRO's mission is to advance the collective interests of Canada's northern research infrastructure operators through coordination, outreach and joint action in order to help them achieve excellence in technical and logistical support individually and as a network. It works to address Canada's international obligations for Arctic data collection and knowledge exchange within the circumpolar world while at the same time strengthening the many northern communities and regions in which our facilities are based.	Canada	http://cnnro.ca/	●				●	
Canadian Space Agency (CSA)	The mandate of the CSA is: to promote the peaceful use and development of space, to advance the knowledge of space through science and to ensure that space science and technology provide social and economic benefits for Canadians. CSA has a Class Grant and Contribution Program to support research, awareness and learning in space science and technology.	Canada	http://www.asc-csa.gc.ca/eng/Default.asp	●		●	●		
Carleton University – Geomatics and Cartographic Research Centre (GCRC)	GCRC research focuses on the application, processing and management of geographic information to support the analysis of key socioeconomic issues at both the local and international level. GCRC is a leader in cyber-cartography, a new multimedia, multisensory and interactive online mapping discipline that present both quantitative and qualitative results in innovative formats. GCRC's community focused projects in the Canadian Arctic are building northern atlases in this style; Siku Atlas, Pan Inuit Trails Atlas and Arctic Bay Atlas	Canada	https://www.gcrc.carleton.ca/index.html	●	●				●
C-CORE – LookNorth	LOOKNorth is a national Centre of Excellence for Commercialization and Research (CECR) under the Government of Canada`s Networks of Centres of Excellence (NCE) program; it is hosted by C-CORE and dedicated to remote sensing innovation. In collaboration with a broad network of industry, business, research and northern partners, LOOKNorth develops, demonstrates and drives commercialization of monitoring technologies to support safe and environmentally responsible development and transportation of Canada's northern natural resources.	Canada	https://www.looknorth.org/about-looknorth	●	●			●	
Centre for Polar Observation and Modelling (CPOM)	CPOM studies land ice, sea ice and ice sheets using satellite observations and numerical models of the polar regions. The Centre provides UK national capability in earth observation and modelling of the cryosphere. Their work underpins world-leading research carried out in CPOM itself and also the British AntArctic Survey (BAS) and National Oceanography Centre (NOC).	UK	https://cpom.org.uk/	●					●

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Chinese Arctic and AntArctic Administration (CAA)	CAA has been playing an active role in the scientific research and international cooperation activities in the AntArctic continent and the Southern Ocean within the principles and the framework of the AntArctic Treaty System.	China	http://www.chinare.gov.cn/en/	●	●	●	●		
Circumpolar Conservation Union (CCU)	Founded in 1995, CCU works to protect the ecological and cultural integrity of the Arctic by promoting understanding and cooperation among Arctic Indigenous peoples, environmental organisations and other diverse interests. Along with promoting public awareness, its mission is to advocate on behalf of the Arctic community and its peoples and for policies that protect the environment and promote sustainability.	International	http://circumpolar.org/				●	●	
Climate and Cryosphere (CliC) (World Climate Research Program)	The CliC project encourages and promotes research into the cryosphere and its interactions as part of the global climate system. It seeks to focus attention on the most important issues, encourage communication between researchers with common interests in cryosphere and climate science, promote international co-operation, and highlight the importance of this field of science to policy makers, funding agencies, and the general public.	International	http://www.climate-cryosphere.org/	●					
Comité Polar Español (CPE)	The Spanish Polar Committee (CPE) was created by agreement of the Commission of the Inter-Ministerial Commission of Science and Technology (CICYT) in 1998. The Committee is the official polar authority for the coordination of all the Spanish activities pertaining to the polar regions. It is responsible for the general coordination of the activities in the polar zones, the approval of the environmental permits and the fulfillment of the corresponding polar regulations.	Spain	http://www.idi.mineco.gob.es/portal/site/MICINN/menuitem.7eeac5cd345b4f34f09dfd1001432ea0/?vgnextoid=9b6fefb8b7c0f210VgnVCM1000001d04140aRCRD&lang_chosen=en				●		

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Committee on Observations and Networks Sustaining Arctic Observing Networks (SAON)	The Committee gives advice to the SAON Board on how to fund, coordinate and expand the scope of Arctic observational activities and address the questions of how to ensure sustainability of observational platforms in the Arctic and how easier access to them can be achieved. It also ensure the promotion of community-based monitoring within SAON and work on best practices for the utilization of traditional knowledge within Arctic observing activities.	International	https://www.Arcticobserving.org/committees				●	●	
Committee on Polar Research of the Polish Academy of Sciences	Committee on Polar Research of the Polish Academy of Sciences was established in 1977. It brings together a group of scientists, both experienced researchers and junior experts, engaged in research of the polar regions of the Earth. Members of the Committee represent many disciplines of the natural sciences, social sciences and the humanities and it co-ordinates more than 20 scientific institutions in Poland.	Poland	http://www.kbp.pan.pl/index.php?lang=en	●		●	●		
Cooperative Institute for Research in Environmental Sciences (CIRES)	At CIRES, more than 800 environmental scientists work to understand the dynamic Earth system, including people's relationship with the planet. CIRES is a partnership of NOAA and the University of Colorado Boulder, and their areas of expertise include weather and climate, changes at Earth's poles, air quality and atmospheric chemistry, water resources, and solid Earth sciences.	USA	https://cires.colorado.edu/	●					
Council of Managers of National AntArctic Programs (COMNAP)	COMNAP is the international association, formed in 1988, which brings together its Members, who are the National AntArctic Programs. National AntArctic Programs are those organisations that have responsibility for delivering and supporting scientific research in the AntArctic Treaty Area on behalf of their respective governments and in the spirit of the AntArctic Treaty.	International	https://www.comnap.aq/SitePages/Home.aspx	●		●	●		
Danish Meteorological Institute (DMI)	Established in 1872, DMI is an institution under the Danish Ministry of Climate, Energy and Building. Its main objective is to provide meteorological services in the Kingdom of Denmark, the Faroe Islands, Greenland and the surrounding waters and airspace. To this end, part of its responsibilities is to monitor and produce maps of sea ice in and around Greenland.	Kingdom of Denmark	http://ocean.dmi.dk/english/index.php	●	●				

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
DataArc Search Tool	A project funded by the National Science Foundation, this search tool allows users to find contextualised data from ecological, archaeological, and historical sources for the North Atlantic. Users can search and filter by any combination of keyword, time, space and concept.	USA	http://beta.data-arc.org/					●	●
Emergency Prevention Preparedness and Response (EPPR) (Arctic Council)	Members of this Arctic Council working group exchange information on best practices and conduct projects to include development of guidance and risk assessment methodologies, response exercises, and training. EPPR's goal is to contribute to the protection of the Arctic environment from the threat or impact that may result from an accidental release of pollutants or radionuclides as well as the consequences of natural disasters.	International	https://Arctic-council.org/index.php/en/about-us/working-groups/eppr	●			●		
Environment Climate Data Sweden (ECDS)	ECDS is an infrastructure project intended to improve Swedish researchers access to environmental and climate data. ECDS is hosted by the Swedish National Data Service at the University of Gothenburg. On ECDS's self–service database portal one is able to search for climate and environmental data, register metadata as well as deposit data.	Sweden	https://ecds.se						●
Environmental Protection Agency – Local Environmental Observing Network (LEO)	LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment, and weather events. With LEO, one can connect with others in their community, share observations, raise awareness, and find answers about significant environmental events. LEO Network was selected as a model program under the United States Chairmanship of the Arctic Council, to help raise awareness and improve communication about climate change in the circumpolar region.	USA	http://www.leonetwork.org/en/docs/about/about					●	●
ESA Space Situational Awareness Program – Space Weather Segment (SSA-SWE)	ESA's Space Situational Awareness Programme was launched in January 2009. The objective of the programme is to support Europe's independent utilization of, and access to, space through the provision of timely and accurate information and data regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground. Its Space Weather Segment studies the scientific properties of environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and solar wind.	Europe	http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness	●					

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
EU PolarNet	EU-PolarNet is the world's largest consortium of expertise and infrastructure for polar research. Seventeen countries are represented by 22 of Europe's internationally-respected multi-disciplinary research institutions. From 2015-2020, EU-PolarNet is developing and delivering a strategic framework and mechanisms to prioritize science, optimize the use of polar infrastructure, and broker new partnerships that will lead to the co-design of polar research projects that deliver tangible benefits for society. EU PolarNet is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	Europe	http://www.eu-polarnet.eu/	●					
EUMETSAT	EUMETSAT is a global operational satellite agency at the heart of Europe. Its purpose is to gather accurate and reliable satellite data on weather, climate and environment around the clock, and to deliver them to member and cooperating states, international partners, and to users located worldwide.	Europe	https://www.eumetsat.int/website/home/index.html		●				
European Climate Research Alliance	The alliance aims to strengthen, expand and optimise EU climate research capabilities through the sharing of world-class national facilities in Europe and the collaborative realisation of pan-EU programmes. By optimising use of human resources, modelling capacities, field activities, and infrastructures, it hopes to optimise the impact of scientific results and reinforce the European Research Area for climate change science.	Europe	http://www.ecra-climate.eu/	●	●				
European Commission	The European Commission is the executive body of the European Union (EU). It represents the interests of the EU as a whole (not the interests of individual countries). The Horizon 2020 Research and Innovation Programme is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020)	Europe	https://ec.europa.eu/commission/index_en			●			
European Fisheries Control Agency (EFCA)	EFCA is an EU body established in 2005 to optimize operational coordination of fisheries control and inspection activities by the Member States. It also seeks to ensure the effective and uniform application of the Common EU Fisheries Policy.	Europe	https://efca.europa.eu/		●		●		
European Maritime Safety Agency (EMSA)	EMSA is a centralised EU agency providing technical assistance and support to the European Commission and Member States in the development and implementation of EU legislation on maritime safety, security and environmental concerns. It has also been given operational tasks in the field of oil pollution response, vessel monitoring and long-range identification and tracking of vessels.	Europe	http://www.emsa.europa.eu/		●				

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
European Network for Arctic-Alpine Environmental Research (ENVINET)	ENVINET is a network of 17 research infrastructures in Northern Europe. It focuses on multidisciplinary environmental research, primarily within atmospheric physics and chemistry, marine and terrestrial biology.	Europe	*No active website –only links to research papers*	●					
European Polar Board (EPB)	EPB is an independent European organization of directors and managers of the major European National Polar Programmes. It was established in 1995 by the European Science Foundation as a strategic advisory body on Polar Science. It is concerned with major strategic priorities in the Arctic and AntArctic, with members in national operators and research institutes in 17 countries. EPB is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	Europe	http://www.europeanpolarboard.org/				●		
European Space Agency (ESA)	ESA is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. In 2015, ESA's Earth Observation budget was € 1.25 billion.	Europe	http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/Arctic			●	●		
Exchange for Local Observations and Knowledge of the Arctic (ELOKA)	ELOKA fosters collaboration between resident Arctic experts and visiting researchers to facilitate the collection, preservation, exchange, and use of local observations and Indigenous knowledge of the Arctic. ELOKA provides data management and user support to Indigenous communities to ensure their data and knowledge are managed, visualised, and shared in an ethical manner in order to work toward information and data sovereignty for Arctic residents.	International	https://eloka-Arctic.org/index.html	●				●	●
Finnish Meteorological Institute (FMI)	FMI is a research and service agency under the Finnish Ministry of Transport and Communications. Its main objective is to provide the Finnish nation with the best possible information about the atmosphere above and around Finland, for ensuring public safety relating to atmospheric and airborne hazards and for satisfying requirements for specialised meteorological products.	Finland	http://en.ilmatieteenlaitos.fi/	●	●				

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Frozen Ground Data Centre (FGDC)	The International Permafrost Association (IPA) has developed a strategy for data and information management to meet the requirements of the cold regions science, engineering, and modeling communities. A central component of this strategy is the Global Geocryological Data (GGD) system, an internationally distributed system linking investigators and data centers around the world. The National Snow and Ice Data Center (NSIDC) in collaboration with the International Arctic Research Center (IARC) serves as a central node of the GGD. NSIDC developed a five-year compilation of permafrost and frozen ground-related data and information products with a global perspective, called the Frozen Ground Data Center (FGDC).	International	https://nsidc.org/fgdc						●
Future Earth Coasts – Arctic Regional Engagement Partner (REP)	REP coordinates transdisciplinary research and action in the northern circumpolar region to support the core agenda of enhanced sustainability in the Earth's coastal zone. Since April 2016, Memorial University of Newfoundland (MUN) has hosted the Arctic REP office in Canada's easternmost city of St.John's, Newfoundland and Labrador.			●				●	
Geological Survey of Denmark and Greenland (GEUS)	GEUS is a research and advisory institution in the Danish Ministry of Energy, Utilities and Climate. GEUS is a partner in Geocenter Denmark and is associated with EuroGeoSurveys. The workfield of GEUS – geoscientific studies, research, consultancy and geological mapping – primarily covers the Kingdom of Denmark and Greenland. GEUS supports the Isaaffik Arctic Gateway which is website supporting Arctic research and collaboration	Kingdom of Denmark	http://www.geus.dk/UK/Pages/default.aspx	●					●
German Research Foundation (DFG)	DFG is the self-governing organization for science and research in Germany. It serves all branches of science and the humanities. This includes support for individual projects and research collaboration, awards for outstanding research achievements, and funding for scientific infrastructure and scientific cooperation.	German	http://www.dfg.de/en/			●			
Global Arctic Programme World Wildlife Fund for Nature (WWF)	The WWF's Global Arctic Programme's international office is headquartered in Canada and coordinates all WWF Arctic work. Its observer status at the Arctic Council gives the WWF access to policy discussions between Arctic states, Indigenous peoples, and other observers. Through this programme, the WWF stays active with Arctic species, governance, climate research and communication, responsible industry, and a blueprint for conservation.	International	http://wwf.panda.org/what_we_do/where_we_work/Arctic/				●		

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Global Atmosphere Watch (GAW) World Meteorology Organization	The mission of GAW is to reduce environmental risks to society and meet the requirements of environmental conventions, strengthen capabilities to predict climate, weather and air quality and contribute to scientific assessments in support of environmental policy. This is accomplished by maintaining and applying global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere and delivering integrated products and services of relevance to users. The GAW Programme is implemented and undertaken by WMO Members and supported by international scientific communities.	International	http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html	●				●	●
Global Biodiversity Information Facility (GBIF)	GBIF is an international network and research infrastructure funded by the world's governments and aimed at providing open access to data about all types of life on Earth. Coordinated through its Secretariat in Copenhagen, the GBIF network of participating countries and organisations, working through participant nodes, provides data-holding institutions around the world with common standards and open-source tools that enable them to share information about where and when species have been recorded.	International	https://www.gbif.org/	●				●	●
Global Climate Observing Systems (GCOS)	The vision of GCOS is for all users to have access to the climate observations, data records and information they need to address pressing climate-related concerns. GCOS is sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization, the United Nations Environment Programme, and the International Council for Science.	International	https://public.wmo.int/en/programmes/global-climate-observing-system					●	●
Global Cryosphere Watch (GCW) World Meteorological Organization	TGCW is an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere.	International	https://globalcryospherewatch.org/					●	●
Global Ocean Observing System (GOOS)	GOOS coordinates observations around the global ocean for three critical themes: climate, ocean health, and real-time services. These themes correspond to the GOOS mandate to contribute to the UNFCCC Convention on climate change, the UN convention on biodiversity and the IOC/WMO mandates to provide operational ocean services, respectively.	International	http://www.goosocean.org/					●	●

Organization	Description	Country	URL	Type					
				Scientific User	Operational User	Funding Agency	Policy / Regulatory Organization	Network / Consortium	Data Portal / Platform
Global Terrestrial Observation System (GTOS)	GTOS is a US program for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change. It is delivered as a program under the National Centres for Environmental Information.	USA	https://www.ncdc.noaa.gov/gosic/global-terrestrial-observingsystem-gtos	●				●	●
Gordon Foundation Mackenzie DataStream	An open access platform for sharing water data in the Mackenzie Basin. DataStream's mission is to promote knowledge sharing and advance collaborative, evidence-based decision-making throughout the Basin. Mackenzie DataStream currently contains data collected by 22 communities who monitor 70+ parameters and they actively seek partnerships to bring new data contributors onboard. Data are currently collected by community monitors with the help of scientists and accredited laboratories.	Canada	https://mackenziedatastream.ca/#/					●	●
GRID-Arendal	The centre, which was established in 1989 to support the UN Environment Programme, has a mission to create environmental knowledge that will enable positive change. This is achieved by organizing and transforming available environmental data into credible, science-based information products, delivered through innovative communication tools and capacity-building services targeting relevant stakeholders.	Norway	https://www.grida.no/	●					●
Group on Earth Observation (GEO)	GEO is a partnership of more than 100 national governments and in excess of 100 participating organisations that envisions a future where decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations. Two key projects include: GEOCRI (GEO Cold Regions Initiatives) to provide coordinated Earth observations and information services across a range of stakeholders to facilitate well-informed decisions and support the sustainable development of the cold regions globally. GEOPortal provides interactive open access to EO data and maps across the globe.	International	https://www.earthobservations.org/index2.php					●	●
Gwich'in Council International (GCI)	GCI represents 9,000 Gwich'in in the Northwest Territories (NWT), Yukon and Alaska as a Permanent Participant in the Arctic Council; the only international organization to give Indigenous peoples a seat at the decision-making table alongside national governments. GCI supports Gwich'in by amplifying their voice on sustainable development and the environment at the international level to support resilient and healthy communities.	Canada, USA	https://gwichincouncil.com/	●			●		

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Ice, Climate, Economics – Arctic Research on Change (ICE-ARC)	ICE-ARC is a 4 year programme funded by the European Union's 7th Framework Programme that will assess the current and future changes in Arctic sea ice – both from changing atmospheric and oceanic conditions. ICE-ARC will also investigate the consequences of these changes both on the economics of the area, and social aspects such as on Indigenous peoples. As part of this work they have developed 2 interactive data portals. ICE-ARC is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	European	https://www.ice-arc.eu/	●					●
Iceland Meteorological Office (IMO)	The main purpose of IMO is to contribute towards increased safety and efficiency in society by monitoring, analyzing, interpreting, informing, giving advice and counsel, providing warnings and forecasts and, where possible, predicting natural processes and natural hazards. IMO is a governmental institution under the Ministry of the Environment and Natural Resources.	Iceland	http://en.vedur.is/						●
IFREMER-French Research Institute for the Exploitation of the Sea	IFREMER, a public institution created in 1984, contributes, through its work and expertise, to the knowledge of the oceans and their resources, to the surveillance of the marine and littoral environment and to the sustainable development of maritime activities. To support this work, it designs and implements tools for observation, experimentation and monitoring, and manages oceanographic databases.	French	http://wwz.ifremer.fr/L-institut	●			●		●
Indigenous People Secretariat – IPS (Arctic Council)	IPS was established in 1994 under the guidance of the Arctic Environmental Protection Strategy (AEPS). IPS, as recognised in the Ottawa Declaration, is an entity within the Arctic Council Secretariat with its own board, designated budget and work plan. It works to facilitate the participation of Indigenous Peoples' organisations in the work of the Arctic Council and has played an important and vital role in shaping Arctic global policy for the past 20 years.	International	https://www.Arcticpeoples.com/				●		
Institut Polaire Français (IPEV)	IPEV is the government agency responsible for furthering French research in the polar regions. IPEV makes provides expertise and technical support as well as logistical and technical resources and funding, but also sets the legal framework necessary for developing national polar and subpolar scientific research.	France	http://www.institut-polaire.fr/ipev-en/the-institute/	●		●	●		

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Integrated Arctic Observation System (INTAROS)	In order to ensure sustainable development in the Arctic it is necessary to collect more data and build up knowledge on its climate and environment. To address these challenges, an integrated pan-Arctic observation system is required. As such, INTAROS' objective is to develop an efficient integrated Arctic Observation System by extending, improving and unifying existing and evolving systems in the different regions of the Arctic. INTAROS will support the implementation of the EU´s Arctic Policy. INTAROS is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	International	http://intaros.eu/	●				●	●
Interagency Arctic Research Policy Committee (IARPC)	IARPC created IARPC Collaborations to connect Federal government and non-Federal government researchers and other stakeholders, including those overseas, to work together to solve the emerging Arctic challenges. Open to anyone who can contribute, IARPC Collaborations has realised an unprecedented degree of interagency communication, coordination and collaboration that has advanced Arctic science.	US	https://www.iarpccollaborations.org/index.html	●				●	
Intergovernmental Panel on Climate Change (IPCC)	IPCC is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme and the World Meteorological Organization in 1998 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. As a scientific body under the auspices of the UN, it reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change.	International	http://www.ipcc.ch/	●			●		
International Arctic Research Center (IARC)	IARC was established in 1999 at the University of Alaska Fairbanks as a cooperative research institute supported by the U.S. and Japanese governments. It strives to play a pivotal role in facilitating international collaboration in Arctic environmental change studies, with a focus on attributing changes in climate and ecosystem to their causes.	International	https://uaf-iarc.org/	●					
International Arctic Science Committee (IASC)	IASC is a non-governmental, international scientific organization. Its mission is to encourage and facilitate cooperation in all aspects of Arctic research, in all countries engaged in Arctic research and in all areas of the Arctic region. IASC promotes and supports leading-edge multi-disciplinary research in order to foster a greater scientific understanding of the Arctic region and its role in the Earth system.	International	https://iasc.info/	●					

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International Arctic Social Science Association (IASSA)	IASSA was founded in 1990 in Fairbanks, Alaska, at a meeting held in conjunction with the 7th Inuit Studies Conference. IASSA was established an international body to both promote and represent Arctic social scientists. It works to promote and stimulate international cooperation and to increase the participation of social scientists in national and international Arctic research.	International	https://iassa.org/	●				●	
International Arctic Systems for Observing the Atmosphere (IASOA)	IASOA coordinates the activities of individual observatories around the world (including Canada) to provide a networked, observations-based view of the Arctic. IASOA has an emphasis on the installation of new instrumentation, development of operating procedures, creation of the data sets and support of an access portal to digital files suitable for fundamental research.	International	https://www.esrl.noaa.gov/psd/iasoa/	●				●	●
International Association of Cryospheric Scientists (IACS)	The objectives of IACS is to promote studies of cryospheric subsystems of the Earth solar systems as well as encourage research of the cryospheric community, national and international institutions and programmes through collaboration and international co-ordination and to provide an opportunity for the international community to discuss and publish the results of their research.	International	http://www.cryosphericsciences.org/index.html	●					
International Association of Oil & Gas Producers (IOGP)	The voice of the international oil and gas industry, the association also provides industry regulators with a global partner for improving safety, environment and social performance. IOGP encompasses most of the world's leading publicly-traded, private and state-owned oil and gas companies, industry associations and major upstream service companies.	International	http://www.iogp.org/		●				
International Chamber of Shipping (ICS)	ICS is the principal international trade association for the shipping industry, representing ship owners and operators in all sectors and trades. It comprises national ship owners' associations in Asia, Europe and the Americas.	International	http://www.ics-shipping.org/		●				
International Ice Charting Working Group (IICWG)	IICWG was formed in 1999 to promote cooperation between the world's ice centers on all matters concerning sea ice and icebergs. Made up of 13 national agencies, IICWG is presently co-chaired by the US National Oceanic and Atmospheric Administration and the Danish Meteorological Institute.	International	https://nsidc.org/noaa/iicwg		●				
International Ice Patrol (IIP)	IIP was established in 1913 as a direct result of the sinking of Titanic in 1912. IIP monitors iceberg danger in the north Atlantic and provides relevant iceberg warning products to the maritime community. IIP archives iceberg reports that it receives from all sources at the National Snow and Ice Data Center.	International	https://www.navcen.uscg.gov/?pageName=IIPHome		●				

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International Maritime Organization (IMO)	As a specialised agency of the United Nations, IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.	International	http://www.imo.org/en/Pages/Default.aspx				●		
International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT)	INTERACT is an infrastructure project under the auspices of SCANNET, a circumArctic network of 71 terrestrial field bases in northern Europe, Russia, US, Canada, Greenland, Iceland, the Faroe Islands and Scotland. INTERACT specifically seeks to build capacity for research and monitoring in the European Arctic and beyond, and offers access to numerous research stations. Nunataryuk is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects. INTERACT is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	International	https://eeas.europa.eu/Arctic-policy/eu-Arctic-policy/20116/interact-international-network-terrestrial-research-and-monitoring-Arctic_en	●	●				
International Oceanographic Data and Information Exchange (IODE)	IODE of the Intergovernmental Oceanographic Commission (IOC) of UNESCO was established in 1961. Its purpose is to enhance marine research, exploitation and development, by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products.	International	https://www.iode.org/	●				●	●
International Polar Foundation (IPF)	Based in Brussels, Belgium, the foundation provides an interface between science and society. IPF seeks to bring about a keener appreciation of the role of science, particularly research in the polar regions, through a re-examination of the planet's interconnections, its fragility, the impact of human actions on the environment, and the evolution of millennial climate cycles.	International	http://www.polarfoundation.org/			●	●		
Inuit Circumpolar Council (ICC)	Founded in 1977, ICC has flourished and grown into a major international NGO representing approximately 150,000 Inuit of Alaska, Canada, Greenland, and Russia. The organization represents the united voice of the Inuit people on issues of common concern and combines their energies and talents towards protecting and promoting the Inuit way of life.	International	http://www.inuitcircumpolar.com/				●		

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Inuit Knowledge Center (Inuit Qaujisarvinga)	Inuit Qaujisarvingat aims to ensure an increasingly active role for Inuit in research that leads to the generation of innovative knowledge for improved research, science and policy making within a Canadian, circumpolar and global context. Inuit Qaujisarvingat supports those involved in Arctic and Inuit research and policy development from community to international levels. It consists of a diverse group, including Inuit organisations, researchers and policy makers, governments, and Arctic research networks.	Canada	http://www.inuitknowledge.ca/	●			●	●	
Inuit Tapiriit Kanatami (ITK)	ITK is a national representational organization protecting and advancing the rights and interests of Inuit in Canada. Their work includes research, advocacy, public outreach and education on the issues affecting Inuit population including community based food – initiative mapping projects.	Canada	https://itk.ca/				●		●
Inuvialuit Regional Corporation (IRC)	Established in 1984 to manage the settlement outlined in the Inuvialuit Final Agreement (IFA), IRC represents the collective Inuvialuit interests in dealings with governments and the world at large. IRC's goal is to continually improve the economic, social and cultural well-being of the Inuvialuit through implementation of the IFA and by all other available means.	Canada	http://www.irc.inuvialuit.com/about-irc	●			●		●
Korean Polar Research Institute	Korean's active involvement in the polar regions began in March 1987 when the Polar Research Institute was opened at the Korea Ocean Research & Development Institute (KORDI). A government sponsored research institute dedicated to polar science and logistic support. It's goal is to contribute to the development of national science and technology capacities and advance global knowledge by undertaking world-class scientific research in cooperation with national and international partners.	Korea	http://www.kopri.re.kr/#	●		●	●		
Makivik	Makivik is mandated to protect the rights, interests and financial compensation provided by the 1975 *James Bay and Northern Quebec Agreement*, the first comprehensive Inuit land claim in Canada, and the more recent offshore *Nunavik Inuit Land Claim Agreement* that came into effect in 2008. The Corporation's mandates ranges from owning and operating business enterprises and generating jobs; to social economic development, improved housing conditions, to protection of the Inuit language and culture and the natural environment.	Canada	http://www.makivik.org/corporate/		●				

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Met Norway	The Norwegian Meteorological Institute (MET Norway) is the meteorological service for both the Military and the Civil Services in Norway, as well as the public. Its mission is to protect life, property and the environment, and to provide the meteorological services required by society.	Norway	https://www.met.no/	●	●				
Nansen Environmental and Remote Sensing Centre	The Nansen Environmental and Remote Sensing Center was established in 1986 as a Norwegian non-profit research foundation. The foundation's goal is to perform interdisciplinary research and development with focus on remote sensing and modelling with respect to scientific problems within the natural environment. The Center is a national environmental research institute with basic funding from the Norwegian government's Ministry of Climate and Environment.	Norway	https://www.nersc.no	●					
NASA Arctic Boreal Vulnerability Experiment Science Cloud (ABoVE)	ABoVE is a NASA-led, 10-year field experiment designed to better understand the ecological and social consequences of environmental change in one of the most rapidly changing regions on Earth. Satellite, airborne, and ground observations across Alaska and Canada will help us better understand the local and regional effects of changing forests, permafrost, and ecosystems – and how these changes could ultimately affect people and places beyond the Arctic.	USA	https://above.nasa.gov	●					
NASA Global Change Master Directory (GCMD)	The mission of the GCMD is to offer a high quality resource for the discovery, access, and use of Earth science data and data-related services worldwide, while specifically promoting the discovery and use of NASA data. The directory resource is targeted to serve as a valued location for sharing data from multinational sources and, in turn, will contribute to scientific research by providing direct access to Earth science data and services.		https://gcmd.nasa.gov						●
National Center for Environmental Information (NCEI)	NOAA's NCEI hosts and provides public access to one of the most significant archives for environmental data on Earth. Through the Center for Weather and Climate and the Center for Coasts, Oceans, and Geophysics, NCEI provides over 25 petabytes of comprehensive atmospheric, coastal, oceanic, and geophysical data.	USA	https://www.ncei.noaa.gov						●

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U.S. National Ice Center (NIC)	NIC is a multi-agency operational center operated by the United States Navy, the National Oceanic and Atmospheric Administration, and the United States Coast Guard. The NIC mission is to provide the highest quality, timely, accurate, and relevant snow and ice products and services to meet the strategic, operations, and tactical requirements of the United States interests across the global area of responsibility	USA	http://www.natice.noaa.gov/		●				
National Science Foundation (NSF)	NSF is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" With an annual budget of $7.3 billion (FY 2015), NSF is the funding source for approximately 24 percent of all federally supported basic research conducted by America's colleges and universities.	USA	https://www.nsf.gov/			●			
National Science Foundation (NSF) – Arctic Data Centre	The NSF Arctic Data Center helps the research community reproducibly preserve and discover all products of NSF-funded science in the Arctic, including data, metadata, software, documents, and provenance that link these in a coherent knowledge model. Key to the initiative is the partnership between NCEAS at UC Santa Barbara, DataONE, and NOAA's NCEI, each of which bring critical capabilities to the Center.	USA	https://Arcticdata.io/						●
National Snow & Ice Data Center (NSIDC)	Located in Colorado, US, NSIDC began in 1976 as an analog archive and information center, the World Data Center for Glaciology. Since then, it has evolved to manage all forms of cryosphere-related data. Key data portals include DAAC – Distributed Active Archive Centre, Arctic Data Explorer and GLIMS Glacier Database.	USA	https://nsidc.org/		●				
National Weather Service (NWS) (National Oceanic and Atmospheric Administration)	NWS provides weather, water, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. These services include Forecasts and Observations, Warnings, Impact-based Decision Support Services, and Education in an effort to build a Weather-Ready Nation. NWS has community offices across the US supported by regional and national centres.	USA	https://www.weather.gov/about/	●					●

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UK National Environment Research Council (NERC) Arctic Office	The Arctic Office is funded by NERC) and hosted at British AntArctic Survey (BAS). It is tasked with supporting and helping coordinate research and logistical activities in the Arctic region by the UK Arctic science community. It incorporates the management of the UK Arctic Research Station at Ny-Ålesund on Svalbard and is closely linked to the NERC Arctic Research Programme.	United Kingdom	https://www.Arctic.ac.uk	●					●
NERC Arctic Research Programme (ARP)	The ARP was launched in 2010 to address specific topics of scientific uncertainty in the Arctic region and is co-ordinated and managed at NERC's British AntArctic Survey. The £15m research effort is working over a five-year period to address key questions about what is behind the environmental changes occurring in the Arctic and how they can impact on levels of greenhouse gas and influence extreme weather events in the future.	United Kingdom	http://arp.Arctic.ac.uk	●					
NordGIS	NordGIS is a geographic metadata information system – with the mission to collect metadata regarding the activities performed at a selection of Nordic field-stations, and to disseminate the information for station administration, public outreach, and inclusion in other metadata repositories. Its current focus is on research and monitoring regarding high-latitude environments, having been prototyped at the subArctic research and monitoring stations at Abisko and Tarfala in northernmost Sweden.	Sweden	http://www.nordgis.org/sites/home/index.php	●					●
North American Ice Service (NAIS)	NAIS is a collaborative partnership between the Canadian Ice Service, the National Ice Center and the International Ice Patrol. This organization was established to leverage the strengths of all three services in order to better meet the needs of the maritime interests of the US and Canadian governments.	International	https://www.navcen.uscg.gov/?pageName=NAIceService		●			●	
North East Atlantic Fisheries Commission (NEAFC)	NEAFC is the Regional Fisheries Management Organisation for the North East Atlantic. The commission's objective is to ensure the long-term conservation and optimum utilisation of the fishery resources in the NEAFC Convention Area (southern tip of Greenland, east to Barents Sea and south to Portugal). It provides sustainable economic, environmental and social benefits.	International	https://www.neafc.org/				●		
Northern Research Institute (Norut)	Norut is a Norwegian research and innovation company that produces knowledge that is applicability and relevant to the high north with a focus on combining emerging technologies and social science. Norut carries out research commissions for both private and public sectors.	Norway	http://norut.no/en	●	●				

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Northwest Atlantic Fisheries Organization (NAFO)	An intergovernmental fisheries science and management body, NAFO succeeded the International Commission of the Northwest Atlantic Fisheries. Its overall objective is to contribute through consultation and cooperation to the optimum utilization, rational management and conservation of the fishery resources of the NAFO Convention Area.	International	https://www.nafo.int/	●			●		
Norwegian Computing Centre (NR)	NR is a private, independent, non-profit foundation that carries out contract research and development projects in the areas of information and communication technology and applied statistical modeling.	Norway	https://www.nr.no/en	●	●				
Norwegian Institute for Air Research (NILU)	NILU is an independent, non-profit institution established in 1969. Through its research NILU increases the understanding of processes and effects of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within the analytical, monitoring and consulting sectors.	Norway	https://www.nilu.no/Forsiden/tabid/41/language/en-GB/Default.aspx	●					
Norwegian Polar Data Centre (NPDC)	NPDC manages and provides access to scientific data, environmental monitoring data, and topographic and geological map data from the polar regions. The scientific datasets are ranging from human field observations, through in situ and moving sensor data, to remote sensing products. The institute's data holdings also include photographic images, audio and video records.	Norway	https://data.npolar.no/home/						●
Norwegian Polar Institute	Norway's central government institution for scientific research, mapping and environmental monitoring in the Arctic and the Ant Arctic. The Institute advises Norwegian authorities on matters concerning polar environmental management and is the official environmental management body for Norway's Ant Arctic territorial claims.	Norway	http://www.npolar.no/en/	●			●		
Norwegian Satellite Earth Observation Database for Marine and Polar Research (NORMAP)	NORMAP is a 6 year project (launched in 2010) funded by the Norwegian Research Council (NRC) under the Infrastructure programme. It is currently working to secure sustainability beyond this 6 year period. Its main objective is to create and maintain a data repository, including metadata of the high latitude and Arctic regions based on Earth Observation data from polar orbiting satellites to facilitate and stimulate high quality and original multidisciplinary Earth System research, application and education in marine, polar and climate sciences.	Norway	https://normap.nersc.no/home	●					●

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Nunataryuk	Nunataryuk brings together world-leading specialists in natural science and socio-economics to develop quantitative understanding of organic matter released from thawing permafrost; assess what risks are posed to infrastructure, Indigenous and local communities and people's health, and from pollution; and to use this understanding to estimate the long-term impacts of permafrost thaw on global climate and the economy. Nunataryuk is part of EU Arctic Cluster, which is composed of all currently funded Horizon 2020 Arctic projects.	International	https://nunataryuk.org/	●				●	
Nunatsiavut Government	As a self-governing Inuit regional government, Nunatsiavut Government continues to set new standards for their people and the way in which they interact with the provincial government and other entities. Although Nunatsiavut Government remains part of Newfoundland and Labrador, the Government has authority over many central governance areas including health, education, culture and language, justice, and community matters.	Canada	http://www.nunatsiavut.com/				●		
Nunavut Tunngavik Inc. (NTI)	NTI ensures that promises made under the Nunavut Agreement are carried out. Inuit exchanged Indigenous title to all their traditional land in the Nunavut Settlement Area for the rights and benefits set out in the Nunavut Agreement. NTI coordinates and manages Inuit responsibilities set out in the Nunavut Agreement and ensures that the federal and territorial governments fulfill their obligations.	Canada	http://www.tunngavik.com/				●		
Ny-Alesund Science Managers Committee (NySMAC)	Ny-Ålesund is a Norwegian research and monitoring infrastructure, hosting national and international research projects and programmes. Ny-Ålesund serves both as an observatory, laboratory, and field base for Arctic research. NySMAC was established to enhance cooperation and coordination among researchers and research activities in Ny-Ålesund, and includes representatives from all parties with major vested interests in Ny-Ålesund.	Norway	http://nysmac.npolar.no	●					

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Observing System Capability Analysis and Review (OSCAR) Tool – World Meteorology Organization	OSCAR is a resource developed by World Meteorology Organization (WMO) in support of Earth Observation applications, studies and global coordination. It contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e., related to weather, water and climate). OSCAR also provides detailed information on all earth observation satellites and instruments, and expert analyses of space-based capabilities.	International	https://www.wmo-sat.info/oscar/	●	●				
Ocean Networks Canada	Ocean Networks Canada operates the NEPTUNE and VENUS cabled ocean observatories for the advancement of science and the benefit of Canada. These observatories collect data on physical, chemical, biological, and geological aspects of the ocean over long time periods, supporting research on complex Earth processes in ways not previously possible.	Canada	http://www.oceannetworks.ca/		●				
Pacific Arctic Group (PAG)	Organised under the International Arctic Science Committee (IASC), the PAG's mission is to serve as a Pacific Arctic regional partnership to plan, coordinate, and collaborate on science activities and data of mutual interest. The four PAG principle science themes are climate, contaminants, human dimensions and structure and function of Arctic ecosystems.	International	https://pag.Arcticportal.org/	●					
Pacific Marine Arctic Regional Synthesis (PacMARS) Data Archive	PacMARS is a research synthesis effort funded by the North Pacific Research Board whose goal is to provide guidance for scientific research needs in the region, as well as to serve stakeholder needs for understanding this important ecosystem and its vulnerabilities. The PacMARS Data Archive and Map Server is hosted by the Earth Observing Laboratory National Center for Atmospheric Research.	International	http://pacmars.cbl.umces.edu/	●					●
Polar Bears International	The world's leading polar bear conservation group, dedicated to saving polar bears by saving their sea ice habitat. Their focus is on research, education and action.	Canada/USA	https://polarbearsinternational.org/	●			●		

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Polar Data Catalogue (PDC)	The Polar Data Catalogue (PDC) is one of Canada's primary online sources for data and information about the Arctic and is Canada's National AntArctica Data Centre. With over 2,500 metadata descriptions of projects and datasets and almost 3 million data files, the PDC contains data on physical, social, and health science and other research in Canada and globally. The records cover a wide range of disciplines from natural sciences and policy, to health and social sciences. The PDC Geospatial Search tool is available to the public and researchers alike and allows searching data using a mapping interface and other parameters.	Canada	https://www.polardata.ca/	●	●				●
Polar Knowledge Canada (POLAR)	POLAR is on the cutting edge of Arctic issues and strengthens Canada's position internationally as a leader in polar science and technology. POLAR also promotes the development and distribution of knowledge of other circumpolar regions, including AntArctica. It will provide a world-class hub for science and technology research in Cambridge Bay, Nunavut called the Canadian High Arctic Research Station. As part of Canada's Northern Strategy, POLAR improves economic opportunities, environmental stewardship and quality of life for Northerners and other Canadians.	Canada	https://www.canada.ca/en/polar-knowledge.html	●		●	●		
Polar Prediction Project (PPP)World Meteorological Organization	PPP is a long-term initiative by the World Meteorological Organization's (WMO) World Weather Research Programme (WWRP) together with the World Climate Research Programme (WCRP). The project was set up to understand and evaluate predictability and enhance prediction information and services in the polar regions.	International	http://www.polarprediction.net/	●	●				
Polar Research Board (PRB)	The PRB, part of the National Academy of Science, has a long history of distinguished service to the polar community. First established in 1958, the PRB exists to promote excellence in polar science and to provide independent scientific guidance to federal agencies and the nation on science issues in the Arctic, the AntArctic, and cold regions in general.	USA	http://dels.nas.edu/prb	●			●		

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Polar Space Task Group – (PSTG) World Meteorological Organization	The PSTG has been established under the auspices of the World Meteorological Organization's (WMO) Executive Council Panel of Experts on Polar Observations Research and Services (EC-PORS) to provide coordination across Space Agencies to facilitate acquisition and distribution of fundamental satellite datasets, and to contribute to or support development of specific derived products in support of cryospheric and polar scientific research and applications.	International	http://www.wmo.int/pages/prog/sat/pstg_en.php	●					
Polar View	Polar View is a global organization providing leading-edge satellite-based information and data services in the polar regions and the cryosphere. Services support safe and cost-marine operations, improved resource management, sustainable economic growth and risk protection across sectors and around the world. Using satellite earth observation data, in combination with sophisticated models and automatic tools, the satellite images are converted into products that graphically illustrate the characteristics of the ice and snow.	International	http://www.polarview.org/	●	●			●	●
Polar View – The Polar Thematic Exploitation Platform (Polar TEP)	Polar TEP, developed by Polar View for the European Space Agency, provides a complete working environment where users can access algorithms and data remotely, providing computing resources and tools that they might not otherwise have, avoiding the need to download and manage large volumes of data. This new approach removes the need to transfer large Earth Observation data sets around the world, while increasing the analytical power available to researchers and operational service providers.	International	https://portal.polar-tep.eo.esa.int/ssoportal/pages/login.jsf					●	●
Russian Association of Indigenous Peoples of the North (RAIPON)	RAIPON is a public organization that aims to protect the interests of Indigenous peoples of the North, Siberia and the Far East of Russia as well as develop solutions for ongoing social and economic problems, environmental protection, cultural development and education. RAIPON is also working to secure the habitat and the traditional way of life of the Indigenous peoples of the North, as well as to ensure their right to self-government in accordance with national and international legal standards.	Russia	http://raipon.info/index.php	●			●		
Saami Council	The Saami Council is a voluntary non-governmental Saami organization with membership from Finland, Russia, Norway and Sweden. Since its foundation in 1956, the Saami Council has actively dealt with Saami policy tasks and worked to promote Saami rights and interests in the four countries where the Saami are living.	International	http://www.saamicouncil.net/en/			●	●		

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Scientific Committee on AntArctic Research (SCAR)	This inter-disciplinary committee of the International Council for Science is charged with initiating, developing and coordinating high quality scientific research in the AntArctic region and on its role in the Earth system. The scientific business of SCAR is conducted by its Standing Scientific Groups which represent the scientific disciplines active in AntArctic research.	International	https://www.scar.org/	●				●	
Scott Polar Research Institute	The Institute is the oldest international centre for Polar Research within a university (Cambridge). Its mandate is to investigate a range of issues in both the environmental sciences and social sciences of relevance to the Arctic and AntArctica.	United Kingdom	https://www.spri.cam.ac.uk/	●					
SnowChange Cooperative	SnowChange was started in late 2000 to document and work with local and Indigenous communities of the Northern regions. Snowchange has developed into a major force in international climate and Indigenous policy and research.	Finland	http://www.snowchange.org/	●			●	●	
Sustainable Development Working Group (SDWG) (Arctic Council)	SDWG was established in 1998 as one of the six working groups of the Arctic Council. Its vision was to adopt steps to be taken by the Arctic States to advance sustainable development in the Arctic, including opportunities; to protect and enhance the environment and the economies, culture and health of Indigenous Peoples and Arctic communities, as well as improve the environmental, economic and social conditions of Arctic communities as a whole.	International	http://Arctic-council.org/index.php/en/about-us/working-groups/sdwg	●			●		
Sustaining Arctic Observing Networks – (SAON) (Arctic Council)	The organization's initiating group, composed of international organisations, agencies and northern residents involved in research, operational and local observing, was formed in 2007. SAON's aim is to develop a set of recommendations on how to achieve long-term Arctic-wide observing activities that provide free, open, and timely access to high-quality data that will realize pan-Arctic and global value-added services and provide societal benefits.	International	https://www.Arcticobserving.org/	●	●			●	●
Svalbard Integrated Arctic Observing System (SIOS)	SIOS is a regional observing system for long-term measurements in and around Svalbard addressing Earth System Science questions. SIOS integrates the existing distributed observational infrastructure and generates added value for all partners beyond what their individual capacities can provide. The search interface was updated November 2017 and is now harvesting and testing data from contributing repositories. The current version of the search interface connects to remote datasets using OPeNDAP where possible to determine the feature type (e.g., time series, grid, trajectory, etc.) while doing the search.	Norway	https://sios-svalbard.org						●

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Sweden Oden Mapping Data – Bolin Centre Database	The Bolin Centre is a multi-disciplinary consortium of over 300 scientists in Sweden that conduct research and graduate education related to the Earth´s climate. The Centre manages numerous databases of scientific information, of which one is the Oden Mapping database which is a repository for mapping data retrieved by Icebreaker Oden available for download.	Sweden	https://oden.geo.su.se	●					●
Swedish Meteorological and Hydrological Institute (SMHI)	SMHI is an expert agency under the Swedish Ministry of the Environment and Energy. Through unique expertise in meteorology, hydrology, oceanography and climatology, it offers many services that contribute to increased safety and a sustainable society.	Sweden	https://www.smhi.se/en	●	●				
Swedish Polar Research Secretariat	A government agency that promotes and co-ordinates Swedish polar research, the Secretariat's mission is to both plan and complete research and development, as well as organise and lead research expeditions to the Arctic and AntArctic regions.	Sweden	https://polar.se/en/	●	●				
Swiss Committee on Polar and High Altitude Research	The Swiss Committee on Polar and High Altitude Research is a committee of the Swiss Academies of Arts and Sciences and the Platform Science and Policy of the Swiss Academy of Natural Sciences (SCNAT). The committee's main objectives are to provide the legal body to represent Switzerland in international committees on polar and high altitude research such as the Scientific Committee on AntArctic Research (SCAR) and the International Arctic Science Committee (IASC). Furthermore, the committee plays an active role in early recognition of research needs and issues in the thematic fields such as climate change, ice and snow climate models, etc.	Switzerland	http://www.polar-research.ch/e/index.php	●			●		
SYKE – Finnish Environmental Institute	SYKE's research and expertise support the protection and use of the sensitive environments in the Arctic regions. SYKE is extensively involved in the Arctic Council's work and in various projects in northern areas. They act in the Arctic region with the aim of resolving various environmental problems, the most significant of these are climate change and environmental toxicants. They also carry out regular research of the Arctic marine environment.	Finland	http://www.syke.fi/en-US	●					

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Tekes – Finnish Funding Agency for Innovation	Tekes is the main government financing and expert organization for research and technological development in Finland. Tekes finances company R&D projects as well as projects in universities and research institutes. Tekes funding incentives and Tekes programmes have had a significant impact on the innovation cooperation between companies and research organisations.	Finland	https://www.businessfinland.fi/en/			●			
The Alfred Wegener Institute (AWI)	Established as a public foundation in 1980, the institute is a member of the Association of German Research Centres. AWI's research mission is to improve our understanding of ocean-ice-atmosphere interactions, the animal and plant kingdoms of the Arctic and AntArctic, and the evolution of the polar continents and seas.	German	https://www.awi.de/en.html	●					
The Arctic Portal	The Arctic Portal is a comprehensive gateway to Arctic information and data on the Internet, increasing information sharing and co-operation among Arctic stakeholders and granting exposure to Arctic related information and data. The Arctic Portal is managed as non-profitable organization, located in Akureyri, Iceland, under an international board of directors. It is operated in consultation and co-operation with members of the Arctic Council and its Working Groups, Permanent Participants, Observers and other Stakeholders.	Iceland	https://Arcticportal.org/					●	●
The Nautical Institute	The Nautical Institute is an international representative body for maritime professionals involved in the control of sea-going ships.	International	https://www.nautinst.org/		●				
The Polar Learning and Responding Climate Change Education Partnership (PoLAR)	Supported by the National Science Foundation, PoLAR seeks to inform public understanding of and response to climate change through the creation of novel educational approaches that utilize fascination with shifting polar environments and are geared towards today's adult learners.	USA	https://thepolarhub.org/		●				
United States Arctic Research Commission (USARC) – Arctic Science Portal	The Arctic Science Portal is a gateway to a broad collection of Arctic science websites that are distributed among the five categories – Society, Environment, Economics, Reference and Organizations. A list of abbreviations and an organizational chart are also included. The entry for each website includes a name, the link (URL), and a brief description. The purpose of this site is to provide information to broad cross-sections of users.	USA	https://www.Arctic.gov/						●

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United States Geological Survey – Digital Object Identifier (USGC DOI)	USGS Core Science Analytics, Synthesis and Libraries, in collaboration with Department of Energy's Oak Ridge National Laboratory (ORNL) Mercury Consortium, has established a Digital Object Identifier (DOI) service for USGS. To generate the DOIs, users need to prepare citation metadata for their digital content; this includes information about creator, title, and publication date.	USA	https://www1.usgs.gov/csas/doi/						●
University of Alaska Fairbanks – International Arctic Research Center (IARC)	IARC serves as a focal point of excellence for international collaboration and provides the Arctic research community with an unprecedented opportunity to share knowledge about science in the Arctic, with an emphasis on global climate change research.	USA	https://uaf-iarc.org	●					
University of Breman	The University of Bremen is a medium-sised German university with approximately 20,000 students. The University teaches and research in a wide range of disciplines including natural sciences, engineering, the social sciences and the humanities as well as in teacher training, they have a long established tradition in interdisciplinary cooperation and excellent research.	Germany	https://www.uni-bremen.de/en/university/profile.html	●					
University of Calgary – Arctic Institute of North America	The Arctic Institute of North America was created by a Canadian Act of Parliament in 1945 as a non-profit research and educational organization. Originally based at McGill University in Montreal, the institute moved to the University of Calgary in 1976. Its mandate is to advance the study of the North American and circumpolar Arctic through the natural and social sciences, the arts and humanities and to acquire, preserve and disseminate information on physical, environmental and social conditions in the North.	Canada	http://Arctic.ucalgary.ca/	●					
University of Calgary – Arctic Science and Technology Information System (ASTIS)	The ASTIS database contains over 80,000 records describing publications and research projects about northern Canada. ASTIS, a project of the Arctic Institute of North America at the University of Calgary, also maintains subset databases about specific regions, subjects and projects.	Canada	http://www.aina.ucalgary.ca/astis/						●

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University of Calgary – ArcticConnect	ArcticConnect is a network-enabled platform for realizing geospatial referencing of information about the Arctic system derived from research, education and private sector activities in the Arctic and subArctic.	Canada	http://Arcticconnect.org/Arcticconnect						●
University of Leeds – Changing Arctic Oceans (ChAOS)	ChAOS will provide fundamental data and quantify the effects of changing sea ice cover on the resulting ecosystem function on the Arctic seafloor, which will contribute to improving the predictive capacity of the numerical models. The University of Leeds is a key funding and research partner.	United Kingdom	https://www.changing-Arctic-ocean.ac.uk/project/chaos/	●					●
University of Manitoba-Centre of Earth Observation Sciences (CEOS)	CEOS was established in 1994 with a mandate to research, preserve and communicate knowledge of Earth system processes using the technologies of Earth Observation Science. Research is multidisciplinary and collaborative seeking to understand the complex interrelationships between elements of Earth systems, and how these systems will likely respond to climate change. Although researchers have worked in many regions, the Arctic marine system has always been a key focus of activity.	Canada	http://umanitoba.ca/ceos/	●					
University of the Arctic	The University is a cooperative network of universities, colleges, research institutes and other organisations concerned with education and research in and about the North. It builds and strengthens collective resources and collaborative infrastructure that enables member institutions to better serve their constituents and their regions.	International	https://www.uArctic.org/	●				●	
VTT Technical Research Centre of Finland	VTT Technical Research Centre of Finland Ltd is one of the leading research and technology organisations in Europe. Their research and innovation services give partners, both private and public, all over the world a competitive edge. In particular, they have expertise on extreme harsh and demanding cold climate environments. They work in the area of sustainable and safe solutions for offshore, marine, coastal and infra structures and operations in harsh and demanding cold climate environments.	Finland	http://www.vttresearch.com/	●					

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Word Ocean Council (WOC)	WOC is an international, cross-sectoral industry leadership alliance interested in "corporate ocean responsibility". It brings together the diverse ocean business community to collaborate on stewardship of the seas. This unique coalition is working to improve ocean science in support of safe and sustainable operations, educate the public and stakeholders about the role of responsible companies in addressing environmental concerns, more effectively engaging in ocean policy and planning, and developing science-based solutions to cross-cutting environmental challenges.	International	https://www.oceancouncil.org/		●		●		
World Climate Research Program (WCRP)	WCRP facilitates analysis and prediction of Earth system change for use in a range of practical applications of direct relevance, benefit and value to society. WCRP aims to determine the predictability of climate and the effect of human activities on climate. One of its core programs is Climate and Cryosphere (CliC): CliC encourages and promotes research into the cryosphere in order to improve understanding of the cryosphere and its interactions with the global climate system, and to enhance the ability to use parts of the cryosphere for detection of climate change. The WCRP Data Advisory Council (WDAC) acts as a focal point for all WCRP data, information, and observation activities with its sister programmes, and coordinates their high-level aspects across WCRP, ensuring cooperation with main partners such as GCOS and other observing programmes.	International	https://www.wcrp-climate.org/	●				●	
World Meteorological Organization Information System (WIS)	WIS is the single coordinated global infrastructure responsible for the WMO telecommunications and data management functions. It is the pillar of the WMO strategy for managing and moving weather, climate and water information in the 21st century. WIS provides an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centres and Member countries in the framework of any WMO Programme.	International	http://www.wmo.int/pages/prog/www/WIS/					●	●
World Shipping Council (WSC)	The goal of WSC is to provide a coordinated voice for the liner shipping industry. WSC and its member companies partner with governments and other stakeholders to collaborate on actionable solutions for some of the world's most challenging transportation problems.	International	http://www.worldshipping.org/		●				

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World Weather Watch - World Meteorological Organization (WMO)	To predict the weather, modern meteorology depends upon near instantaneous exchange of weather information across the globe. Established in 1963, the World Weather Watch – the core of the WMO Programmes – combines observing systems, telecommunication facilities, and data-processing and forecasting centres – operated by Members – to make available meteorological and related environmental information needed to provide efficient services in all countries: Global Observing System (GOS), Global Telecommunication System, Global Data-Processing and Forecasting System.	International	http://www.wmo.int/pages/prog/www/index_en.html					●	●
World Wildlife Fund (WWF) - Global Arctic Programme	WWF-Canada is planning for an Arctic future that conserves wildlife while respecting the practices and traditions of local communities, and promoting the responsible development of Arctic resources. WWF does this through its Global Arctic Programme. This programme sponsors scientific research, by working with communities, industry, Indigenous groups and government, by empowering young people to speak out for the Arctic, and by furthering national and international efforts to reduce greenhouse gas emissions and slow rapid climate change.	International	http://www.wwf.ca/conservation/Arctic/whatwwfisdoing/	●			●		