Response to the

Open Geospatial Consortium

Request for Information on

Arctic Spatial Data

by the

Polar Data Community

March 24, 2016

Overview

The polar data community welcomes the recent Request for Information (RFI) on Arctic spatial data interoperability and infrastructure issued by the Open Geospatial Consortium (OGC). The OGC's interest in this topic is timely since, as we will discuss below:

- The polar regions are of increasing interest to the whole world as a result of their linkage to global climate systems, opportunities for economic development, geo-political strategic importance, and their environmental importance as homes to Indigenous populations and other residents and sensitive ecosystems.

- Polar data are required by the scientific community and residents to support research on topics such as climate, atmosphere, land, oceans, ecosystems, ice and snow, permafrost, and social systems; and by the operations community to support impact assessments, engineering design, safe navigation and operations, risk management, emergency response, weather forecasting, and climate change adaptation. These activities contribute to environmental protection, heritage preservation, economic development, safety of life and property, and national sovereignty.

- The polar data community is well organized and is pursuing activities to improve data management for all of the diverse members of the polar community.

- Polar data infrastructure is evolving from a system where data are discovered in data catalogues and downloaded to the local machines of users, to a system of distributed data made interoperable using standards and providing users with storage and computational capacity close to large repositories of data.

- Indigenous Peoples of the Arctic and their representative organizations are increasingly active in using information and communications technologies (ICT) to access data and share their information and knowledge. This includes the establishment of protocols for ethical and culturally appropriate development of ICT.

- Interoperability and open standards are core to the future vision of the polar data community, and where possible, the community is already implementing OGC standards.

There is still much to be done to move towards a new model for polar data management, and by working together, we believe OGC and the polar community can achieve significant improvements in the use of standards to ensure data interoperability and provide a model for other data communities. Recommendations are provided at the end of this document. In summary, we believe that an Arctic spatial data pilot could be used to test and demonstrate the robustness of standards by delivering a set of distributed client applications and web server products that are interoperable. The focus should be on mature standards that are core OGC

services: WMS, WMTS, WCS, WFS, and CSW. The pilot should demonstrate the following elements:

1. Focus on discovery and metadata.

2. Enabling users to evaluate the qualities of the data being served.

3. Semantics – vocabularies, vocabulary services, and linked open data.

4. The ability of data owners to publish their own interoperable data services.

5. The ability of data owners to delegate the publishing of their data services through a third-party organization.

6. The ability to deploy client applications to address any domain-specific requirements.

7. The ability of any application or data provider to be interoperable with multiple data services from other participants. At least one of these data services should be a hybrid service such as a Hyrax server that also serves OPENDaP a common service used within the community.

Design of the pilot should incorporate the needs and potential contributions of Indigenous Peoples of the Arctic. This process can start by working closely with Indigenous representative organizations such as the Permanent Participants of the Arctic Council and national organizations such as Inuit Quajisarvingat/The Inuit Knowledge Centre at Inuit Tapiriit Kanatami in Canada. They can, in turn, facilitate connection to regional and community level organizations and individuals. Resources should be made available to support this engagement. The recent conference statement from the 2016 Arctic Observing Summit makes clear the importance of full engagement with Arctic Indigenous Peoples and other stakeholders (see http://www.arcticobservingsummit.org/aos-2016-conference-statement-0)

This response has been assembled by an ad hoc group of organizations that represent the broad interests of the polar data community. We understand that the OGC RFI is focused on the Arctic, with an emphasis on the northern portions of Canada and the United States. While this is an excellent starting point, we would suggest that it is important to leverage the significant work that is being done on polar data management in Europe and Asia, and to take advantage of the synergies with polar data management in the Antarctic.

Accordingly, the organizations represented here bring perspectives that include Arctic and Antarctic science, polar operations, the United States, Canada, Europe, and Asia. Those organizations are (see Appendix 1 for organization summaries and web links):

- **International Arctic Science** – The Arctic Data Committee (ADC) of the International Arctic Science Committee (IASC), Sustaining Arctic Observing Networks (SAON), and the Arctic Portal.

- **International Antarctic Science** – The Standing Committee on Antarctic Data Management (SCADM) of the Scientific Committee on Antarctic Research (SCAR); and the Southern Ocean Observing System (SOOS).

- **International Cryosphere Science** – Climate and Cryosphere (CliC)

- **International Polar Operations** – The International Ice Charting Working Group (IICWG) and Polar View Earth Observation.

- **United States** – The National Snow and Ice Data Center (NSIDC), the Interagency Arctic Research Policy Committee (IARPC) Arctic Data Coordination Team, the Alaska Data Integration Working Group (ADIwg), the NSF-funded Antarctic and Arctic Data Consortium (a^2dc), the Arctic Research Mapping Application, the Arctic Observing Viewer, and the Barrow Area Information Database.

- **Canada** – Polar Knowledge Canada, the Canadian Cryospheric Information Network (CCIN), the Geomatics and Cartographic Research Centre at Carleton University, and the Canadian Consortium for Arctic Data Interoperability (CCADI).

- **Europe** – EU-PolarNet and the European Space Agency (ESA).

- **Asia** – Japan's National Institute of Polar Research (NIPR)

All of these organizations represent wider assemblies of polar data stakeholders, who in some cases will be submitting individual responses. Many function as the official international fora for the interests of national bodies with responsibility for polar science and operations. Together, these organizations represent over 50 countries[1]. Collectively, our organizations would be pleased to work with OGC to leverage our existing coordination effort in the wider polar community and ensure that the OGC Arctic Spatial Data Pilot achieves the maximum possible impact.

[1] Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Cyprus, Czech Republic, Denmark/Greenland, Ecuador, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Iran, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Monaco, Netherlands, New Zealand, Norway, Pakistan, Peru, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, The Netherlands, Ukraine, United Kingdom, United States of America, Uruguay, and Venezuela.

Points of Contact

For further information, or to initiate collective discussions with the polar data community, please contact either of:

- Peter L. Pulsifer, Chair (U.S. Representative), Arctic Data Committee; Co-Chair U.S. IARPC Arctic Data Coordination Team; and National Snow and Ice Data Center, CIRES, University of Colorado, peter.pulsifer@colorado.edu
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Or contact individual signatories directly on specific matters.

Signatories

- Allison Gaylord, Alaska Data Integration Working Group, Nuna Technologies
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- Craig Tweedie, Principal Investigator, Arctic Research Mapping Application, Arctic Observing Viewer, Barrow Area Information Database
- D.R. Fraser Taylor, Director, Geomatics and Cartographic Research Centre, Carleton University
- Halldór Jóhannsson, Executive Director, Arctic Portal
- Jennifer Sokol, Manager, Partnerships and Engagement, Polar Knowledge Canada
- Joe Casas, NASA, Co-Chair Interagency Arctic Research Policy Committee (IARPC) Arctic Data Coordination Team
- John Falkingham, International Ice Charting Working Group
- Jonathan Pundsack, Principal Investigator, National Science Foundation Antarctic and Arctic Data Consortium (A_2DC)
- Julie Friddell, Associate Director, Canadian Cryospheric Information Network
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- Masaki Kanao, Associate Professor, Polar Data Center, National Institute of Polar Research (NIPR)
- Ola Gråbak, Applications Engineer, European Space Agency
- Phillippa Bricher, Data Officer, Southern Ocean Observing System

Polar Data Context

The OGC Arctic Spatial Data Pilot is being implemented in a time of rapidly increasing interest in the polar regions with an associated need to provide integrated information to support the research and operations of a growing range of user communities, including science, industry, government, and northern communities. A number of political, environmental, social, and technological trends are fueling this interest and activity in the polar regions, including:

- Political and Policy Trends – The interest of governments around the world in the polar regions is driven by perceived opportunities for economic development, more efficient shipping routes, and the regions' geo-political strategic and sovereignty importance. With these opportunities come concerns over their environmental impact and risks to life and property in an isolated and hostile environment where governments have a duty to mitigate through emergency response and search and rescue operations. The opportunities are also motivating countries to try to expand their jurisdictions and to better protect their borders.
- Economic Trends – Economic development opportunities include development of renewable resources such as fisheries and forests; non-renewable resources such as fossil energy resources and minerals; and other activities such as shipping and tourism. Closely associated with these opportunities is the need for related infrastructure development, such as offshore platforms, ice class ships, pipelines, railways, roads, sea ports, airports, and housing. There is also the potential for increased pollution and environmental accidents.
- Social and Cultural Trends – Concern about the impact of climate change is growing around the world and it is becoming evident that the impact is greatest in the polar regions. Of particular social relevance in the Arctic are the changes that are being imposed on Indigenous Peoples by climate change and increased economic activity. Such changes include impacts on hunting and fishing practices, impacts on infrastructure caused by coastal erosion and the melting of permafrost, and impacts on culture and social cohesion.
- Technological Trends – A number of technological trends are providing a flood of new data concerning the polar regions. Of particular relevance are space-based technologies such as earth observation, satellite telecommunications, global navigation satellite systems (GNSS), and ship-borne automatic identification systems (AIS), and a wide variety of in-situ observational networks. Each has a role to play in monitoring the vast and harsh polar regions and each is undergoing significant improvements in capabilities. However, ensuring the interoperability of these diverse data streams requires the development and implementation of appropriate data standards.

Polar Data Community

The polar data community consists of a wide variety of data producers, managers, and users in government, industry, academia and northern communities that need data for scientific research and to support operations and livelihoods in the Polar Regions. Not surprisingly, there is a large degree of overlap among both the organizations and people involved in these activities. The full breadth and complexity of this data 'ecosystem' is too complex to detail here; however, the IASC-SAON Arctic Data Committee has already initiated efforts to provide a 'map' that will document the participants and their interactions. This will be both a concept map indicating projects, services and relationships, as well as a geographic map indicating location[2]. The roadmap for this project includes establishing a linked open data end-point that will allow people to query the database using (Geo)SPARQL. In concert with activities under the EU-PolarNet project and other research initiatives (e.g. the Polar Data Catalogue, NSF-funded BCube Informatics Project), these efforts are establishing a clear picture of the data and computing services available within the community.

However, of most relevance to OGC are the activities of the polar data community to *manage* polar data. The community has created three organizations for the purpose of promoting and facilitating international collaboration towards the goal of free, ethically open, sustained and timely access to polar data through useful, usable, and interoperable systems. In the Arctic, this is the Arctic Data Committee of the International Arctic Science Committee and the Sustaining Arctic Observing Networks; in the Antarctic, this is the Standing Committee on Antarctic Data Management and the Southern Ocean Observing System.

These organizations:

- Advise their communities on matters related to data management and data sharing.
- Contribute to the understanding of the nature and structure of the polar data system in the context of the global data system.
- Promote and enable:
    - Ethically open access to data
    - Norms of fair attribution and use of data
    - Long term preservation of data

[2] The effort resulted from the first meeting of the ADC in Potsdam, Germany, November 2014 and is an ongoing activity.

- Facilitate the adoption, implementation and development (where necessary) of standards that will enable free, open and timely access to data.

- Facilitate interoperability of data and systems as needed to support the needs of researchers, Arctic residents, decision makers and others.

- Establish expert groups to examine specific questions or coordinate the implementation of data management and sharing solutions. Partnerships with existing or proposed initiatives driven by members of the polar science and data community and Northern communities will be encouraged.

In October 2015, more than 110 people gathered at the Second Polar Data Forum (PDF II) at the University of Waterloo, Canada, to address these challenges. Data managers, scientists, funding program managers, Indigenous people and their representatives, students, and others from eighteen nations shared their knowledge, experience, and ideas on how to make polar data more useful and valuable in solving global problems. For a high-level overview of the results of the Forum see polar-data-forum.org/programme/PDFII_Communique_FINAL.pdf. The First Polar Data Forum was held in Tokyo, Japan in 2013. See bit.ly/1nAF9D5 for a description and results.

The ADC, SCADM, SOOS, and the Polar Data Forum series are a few examples of how the polar data community is working together to coordinate efforts. There are also major regional and national initiatives established and emerging. For example, the EU-PolarNet project includes a major component focused on data and related infrastructure (www.eu-polarnet.eu/project-themes/infrastructures-facilities-and-data.html). In Canada, Polar Knowledge Canada is taking a lead in this area along with the Canadian Consortium on Arctic Data Interoperability, the Polar Data Catalogue, and other initiatives. In the U.S., the Interagency Arctic Research Policy Committee (IARPC) Arctic Data Coordination Team (ADCT) is taking a coordinating lead in partnership with initiatives such as the NSF-funded Antarctic and Arctic Data Consortium (a2dc).

We are seeing convergence and linkage of these efforts through strong cooperation across the groups. For example, the Arctic Data Committee and Standing Committee on Antarctic Data Management have drafted a Memorandum of Cooperation to enhance collaboration and efficiency between these groups and other global and national initiatives such as the IARPC ADCT, NSF a2dc, Southern Ocean Observing System, Research Data Alliance, World Data System, Group on Earth Observations, and others.

Polar Data Requirements

The requirements for information in the polar regions are being driven by a broad range of scientific, operational, and societal imperatives. The polar data community represented in this submission has established that researchers, practitioners and residents are involved in a host of studies on changes taking place across many domains, including climate, oceans, atmosphere, and ecosystems, 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. Examples of polar science activities are contained in Table 1.

Operations in the polar regions take place in 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 organizations, coast guards, and local communities, 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[3]) aimed at ensuring safety of life and mitigating negative environmental impacts. Examples of polar operational activities are contained in Table 2.

Table 1: 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 landfast 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 ice sheet and its contribution to sea-level rise

[3] 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 will take effect on 1 January, 2017.

	▪ Monitoring and understanding extremes such as coastal sea level surges and ocean waves ▪ Study of how the melting of landfast 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

Table 2: 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 northern 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 organizations ▪ Expeditious movement of responders and their equipment from bases of operation to the emergency site
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

More information on polar data requirements and sources of information can be found in the Polaris study of the European Space Agency. [4]

[4] The Polar Study reviewed user requirements for polar environmental information, considered current and proposed sources of such information from space-based and in-situ sensors, evaluated the information gaps and the impact of filling those gaps with new integrated products and services, and provided a preliminary discussion of the considerations that will shape new satellite missions to fill the gaps.

Polar Data Infrastructure Evolution

There is already a considerable wealth of polar data available on the Internet through portals that vary considerably in function, scope, capability, and content. Appendix 2 provides an overview of some of these existing polar data portals. The polar data community is aware that there are many opportunities for improvement in how polar data are stored, managed, discovered, and delivered to users, and they are working collaboratively, with limited resources, to improve the situation. The polar community would welcome the assistance of OGC in these efforts.

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 some common characteristics:

- Individual parameters by themselves are not nearly as valuable as integrated data sets. Therefore, the trend is to provide data platform users with access to a wide range of data types that they can be exploited together.

- With the explosion of the data that are available, data discovery and analysis is becoming increasingly challenging. As a result, the trend is to include sophisticated data visualization tools to enable data platform users to easily see and understand both the data they can utilize and the results of their analysis of that data.

- The quantity of data available, especially EO data, means that it is often not practical for each user to download the data they need to their local environment. Rather, the trend is to bring the algorithms to the data and only download the results of their calculations.

- Working with such large data sets is often computationally intensive. This means that modern data platforms need to provide users with highly capable ICT infrastructure for data processing, storage, and networking.

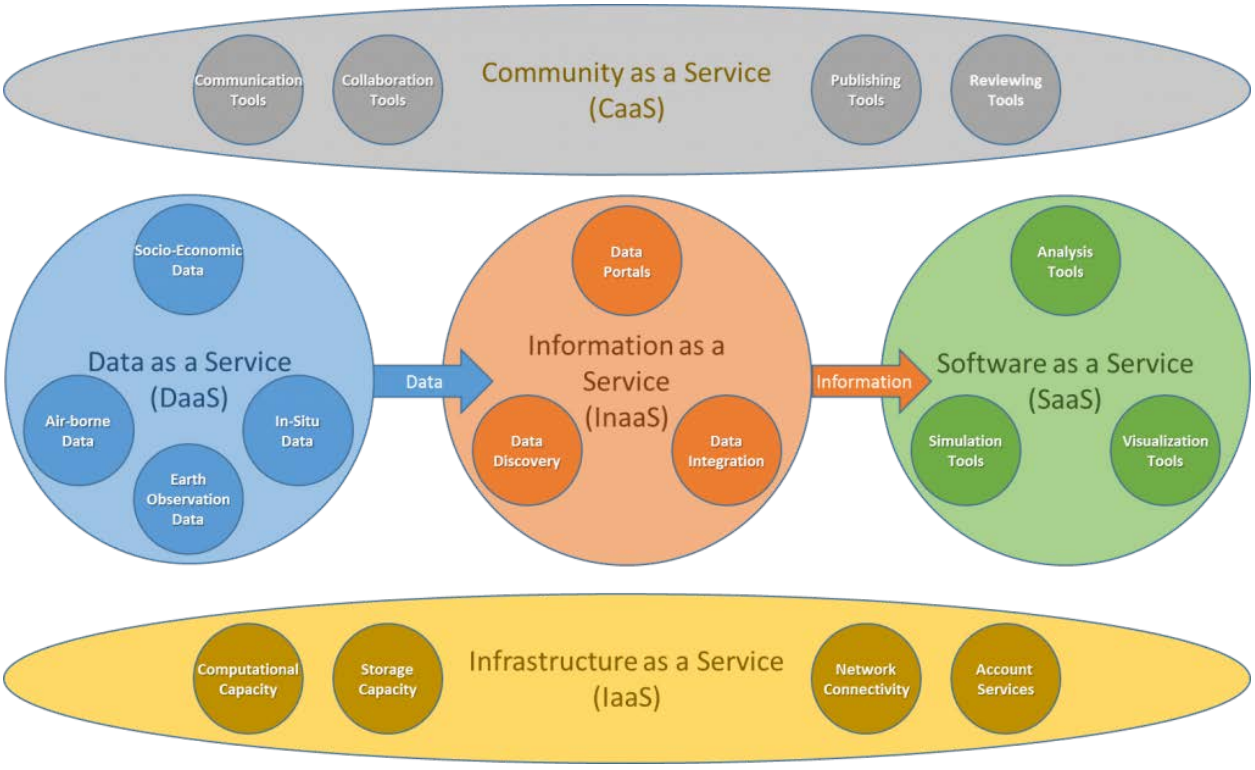
- Research is increasingly collaborative. Therefore, the trend is to combine data and computation capabilities with the tools required for such collaboration and the ensuing dissemination of research results.

- The increasing diversity of data sources and the need for scientific and operational communities to access data unfamiliar to them makes it essential that useable data quality information is available for all products.

- 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 1 and this represents and ideal architecture of an integrated Arctic information system for observing, research and community applications.

Figure 1: The Components of a Modern Data Platform



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 standardized 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.

One example of such efforts is the European Space Agency's Thematic Exploitation Platform (TEP) initiative. TEPs are being developed to respond to the opportunity for insight into how our oceans, atmosphere, land and ice operate and interact as part of an interconnected earth system by exploiting the unprecedented flow of high quality global data on the state of our planet, combined with long-term EO archives, in-situ networks and models.

Researchers will be able to use a TEP to develop processing algorithms online, with all the processing done in the cloud, eliminating the need for people to download data to their computers, install software, and wait while their computer copes with the processing load. A TEP will also host an online collaboration hub, where experts and users can exchange ideas, co-develop algorithms, and work together across the globe to refine and improve information extraction methods, and develop new ones. ESA is funding the development of six thematic platforms and one of them, Polar TEP, is focused on the needs of the polar community.

Another example is the Arctic-Boreal Vulnerability Experiment (ABoVE) Science Cloud. ABoVE is a large-scale study of environmental change and its implications for social-ecological systems under a NASA Terrestrial Ecology Program field campaign that is being conducted in Alaska and western Canada. The ABoVE Science Cloud combines high performance computing with emerging technologies and data management tools for analyzing and processing geographic information to create an environment specifically designed for large-scale modeling, analysis of remote sensing data, copious disk storage for "big data" with integrated data management, and integration of core variables from in-situ networks.

Standards and Interoperability

Interoperability can be defined as properties of cyberinfrastructure that allow it to work and share with other information products or systems, present or future, without unintended restrictions. Achieving interoperability is a multifaceted problem including technical (syntax and structure), semantic (how we define and label concepts), legal (intellectual property, etc.), and geopolitical (e.g. adherence to treaties) concerns, among others. The polar data community understands the importance of standards in achieving interoperability between systems. For example, the seventh recommendation from the 2016 Arctic Observing Summit sets the stage for an Arctic spatial data infrastructure and emphasizes the importance of standards to that goal:

> "7. Work, through the SAON Arctic Data Committee, to develop a broad, globally connected Arctic observing data and information system of systems that is based on open access data and standards, in addition to recognizing and addressing ethical use and proprietary rights of Indigenous Knowledge, and that delivers value to Arctic and global communities."[5]

Through published research[6] and analysis of catalogues such as the Global Change Master Directory, we know that the polar data community has adopted OGC standards. For example, the Atlas of the Cryosphere hosted at NSIDC (nsidc.org/data/atlas/ogc_services.html), the Arctic Sensor Web of the Arctic Institute of North America (sensorweb.arcticconnect.org), and the Polar Data Catalogue (polardata.ca) use OGC standards to make data and maps available for inclusion in external sites and applications. Additionally, the ESA thematic exploitation platforms (including Polar TEP) have been instructed to use OGC standards when available and develop best practices for implementation of the standards. The use of OGC standards will include resource catalogues, processing service execution, processing service packaging, and processing containers. It is anticipated that the resulting TEP best practices definitions will be contributed to OGC in the future.

We do not have sufficient evidence to assert that there is broad scale adoption of OGC protocols, however, as discussed, DaaS and SaaS approaches are increasingly being recognized as the way forward for the community[7]. This is conducive to further development of OGC protocols. OGC protocol implementation will need to recognize that the emerging DaaS and SaaS landscape in polar science is diverse and includes a number of services and protocols, for example:

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[5] See http://www.arcticobservingsummit.org/aos-2016-conference-statement-0

[6] For example, W. Li, C. Yang, D. Nebert, R. Raskin, P. Houser and H. Wu, 2011. Semantic-based service chaining for building a virtual Arctic spatial data infrastructure. Computers & Geosciences, 37 (11), 1752-1762.

[7] For example, Pundsack, J., Bell, R., Broderson, D., Fox, G. C., Dozier, J., Helly, J., … Yang, C. (2013). *Report on Workshop on Cyberinfrastucture for Polar Sciences*. St. Paul, Minnesota. Retrieved from http://www.pgc.umn.edu/system/files/NSF_2013_CyberPolar_Workshop_Report.pdf

- ISO-19115
- OAI-PMH (metadata)
- OpenSearch (metadata)
- THREDDS (serving NetCDF)
- Hyrax servers and others using OPeNDAP
- DataONE
- OBIS DIgIR
- OPeNDAP

Polar data are dominantly geographic in nature, though, and thus there are many OGC protocols and initiatives that are relevant:

- WM[T]S
- WFS
- WCS
- SOS
- SWE Model
- GeoSPARQL
- WPS

The major challenge in developing increased usage of the OGC approach will be in community building, adequate support (e.g. cookbooks, easily deployed stacks), and a clear value proposition.

Next Steps

While the polar data community has collaborated to make significant advances in data management and availability, there is still much to be done. The current activities of polar data management organizations include:

- **Interoperability**: Interoperability, the ability to easily share data across systems and users, 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. This will enhance understanding of how Indigenous and local knowledge and observations can be

used appropriately. See individual submissions to the RFI by the ELOKA Project and the Geomatics and Cartographic Research Centre, for example.

- **Community building**: Improved polar data sharing that is part of a broader global system will require community building, collaboration, and coordination of efforts. To do this we need to better understand the nature of the polar data community (who is doing the work, where, what systems, etc.) across many scales and what we are collectively trying to achieve. Through the established bodies discussed, improved communication, outreach, and coordination within the polar community is needed while we recognize the importance of engaging with broader global initiatives including OGC and GEO.

- **Data Preservation and Rescue**: We must continually re-use and re-purpose past observations to increase our current understanding. 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. Now, only seven years after the International Polar Year (IPY), we must develop a data rescue campaign for much valuable IPY data because adequate preservation support was being developed at the time and was limited in scope. Strategic data rescue programs must be developed, and preservation must be prioritized 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.

Recommended Arctic Spatial Data Pilot Activities

The assistance of OGC would be warmly welcomed in achieving the vision of the polar data community for the integration of data from multiple sources and of multiple types, including time series, parameters, regions, and sensors, facilitated by data formats and access protocols that adhere to recognized standards.

However, the deployment of interoperable geospatial solutions across many sites using solely OGC standards presents a number of challenges. The most critical issues originate from the ability of the standards to support decentralized infrastructure. During the last 10 years, many geospatial solutions based on OGC service standards have been deployed, but most (if not all) of these systems can be characterized as centralized systems where all the components and data are managed by and under the control of a single organization. To achieve true interoperability, the components of the Arctic SDI will need to be both centralized and decentralized.

We believe that an Arctic spatial data pilot could be used to test and demonstrate the robustness of standards by delivering a set of distributed client applications and web server products that are interoperable. The focus should be on mature standards that are core OGC services: WMS, WMTS, WCS, WFS, and CSW. The pilot should demonstrate the following elements:

1. Focus on discovery and metadata.
2. Enabling users to evaluate the qualities of the data being served.
3. Semantics – vocabularies, vocabulary services, and linked open data.
4. The ability of data owners to publish their own interoperable data services.
5. The ability of data owners to delegate the publishing of their data services through a third-party organization.
6. The ability to deploy client applications to address any domain-specific requirements.
7. The ability of any application or data provider to be interoperable with multiple data services from other participants. At least one of these data services should be a hybrid service such as a Hyrax server that also serves OPENDaP a common service used within the community.

The expected outputs will be reports from Arctic SDI Pilot participants describing successes, weaknesses, and failures in current OGC standard specifications and proposals of how to increase the interoperability of OGC standards.

The Arctic SDI Pilot project could build on the work of the Arctic Data Committee and related organizations and projects to bring together a number of data services under a single interface. The Pilot would then address the societal and scientific priority areas that have been identified under efforts such as GEO/GEOSS, the latest Arctic Science Summit Week and Arctic Observing Summit (Fairbanks, Alaska, 11-18 March 2016), the Polaris study of the European Space Agency, and other similar initiatives. These priorities are selected areas of societal significance including health and well-being, food security, freshwater security, built infrastructure, coastal and riverine vulnerability, and tele-connections. They are complex areas of interaction between humans and their environment.

Appendix 1: Organization Summaries

The following are brief introductions to the organizations that have contributed to this Request for Information response on behalf of the wider polar data community.

Arctic

The **International Arctic Science Committee** (IASC) has a broad mandate to "encourage, facilitate and promote cooperation in all aspects of Arctic research in all countries engaged in Arctic research and in all areas of the Arctic region". IASC cuts across all sciences and helps to promote science development, provides scientific advice and policy level documents, aims to maintain freedom and ethical conduct in science, and engages in long-term science visioning and planning. [iasc.info]

The **Sustaining Arctic Observing Networks** (SAON) activities are complementary to IASC's, focusing on the specifics of establishing a long-term Arctic-wide observing activities that provide free, open, and timely access to high-quality data.[www.arcticobserving.org]

The **Arctic Data Committee** (ADC) is a merger of the former IASC Data Standing Committee and SAON Committee on Data and Information Services. 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. [arcticdc.org]

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 a network of information and data sharing and serves as host to many web sites in a circumpolar context, supporting co-operation and outreach in science, education, and policy making. [arcticportal.org]

Antarctic

The **Scientific Committee on Antarctic Research** (SCAR) is an inter-disciplinary committee of the International Council for Science (ICSU). SCAR is charged with initiating, developing and coordinating high quality international scientific research in the Antarctic region (including the Southern Ocean), and on the role of the Antarctic region 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 and report to SCAR. [www.scar.org]

The **Standing Committee on Antarctic Data Management** (SC-ADM) helps facilitate co-operation between scientists and nations with regard to scientific data. It advises on the development of the Antarctic Data Directory System and plays a major role in the International Polar Year data system (IPYDIS). Members of SC-ADM are usually managers of the National Antarctic Data Centres or a relevant national contact. [www.scar.org/data-products/scadm]

The **Southern Ocean Observing System** (SOOS) was launched in August 2011 with the mission to establish a multidisciplinary observing system to deliver the sustained observations of the Southern Ocean that are needed to address key challenges of scientific and societal relevance (e.g., climate change, sea-level rise, impacts of global change on marine ecosystems). The SOOS Data Management Sub-Committee is charged with encouraging data sharing and discovery for essential observations of dynamics and change in the Southern Ocean. [www.soos.aq]

International Cryosphere

Climate and Cryosphere (CliC) aims 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. CliC was established as a core project of theWorld Climate Research Programme in 2003. [www.climate-cryosphere.org]

Canada

Polar Knowledge Canada (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. POLAR improves economic opportunities, environmental stewardship and quality of life for Northerners and other Canadians. [www.canada.ca/en/polar-knowledge.html]

) Since 1995, the main objectives of the **Canadian Cryospheric Information Network** (CCIN) have been: to provide a data and information management infrastructure for the Canadian cryospheric research community; to enhance public awareness and access to cryospheric information and related data; and to facilitate the exchange of information between researchers, northern communities, decision makers, and the public. CCIN operates the Polar Data Catalogue, a database of metadata and data that describes, indexes, and provides access to diverse data sets generated by Arctic and Antarctic researchers. The

metadata records follow ISO 19115 and Federal Geographic Data Committee (FGDC) standard formats to provide exchange with other data centres. [www.ccin.ca][www.polardata.ca]

The **Canadian Consortium for Arctic Data Interoperability** (CCADI) is composed of a group of Canada's foremost Arctic scholars and Arctic data managers that promote collaboration, nationally and internationally, in the development of an integrated national data management system. CCADI seeks to facilitate information discovery, establish metadata and data sharing standards, enable interoperability among existing data infrastructures, and provide access to the broadest possible audience of users.

Carleton UNIVERSITY | Geomatics and Cartographic Research Centre

The research of the **Geomatics and Cartographic Research Centre** of Carleton University focuses on the application of geographic information processing and management to the analysis of socio-economic issues of interest to society at a variety of scales from the local to the international and the presentation of the results in new, innovative cartographic forms. Cybercartography is a new multimedia, multisensory and interactive online cartography and its main products are cybercartographic atlases using location as a key organizing principle. [gcrc.carleton.ca]

United States

The **National Snow and Ice Data Center** (NSIDC) supports research into our world's frozen realms: the snow, ice, glaciers, frozen ground, and climate interactions that make up Earth's cryosphere. NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere. [nsidc.org]

The **Interagency Arctic Research Policy Committee** (IARPC) is chartered as a subcommittee under the National Science and Technology Council (NSTC). It consists of principals from 16 agencies, departments, and offices across the Federal government charged with enhancing both the scientific monitoring of, and research on, local, regional, and global environmental issues in the Arctic. [www.iarpccollaborations.org/teams/Arctic-Data]

The **Alaska Data Integration Working Group** (ADIwg) was formed to examine and address the technical barriers to efficiently integrate and share data within and among participating organizations. ADIwg evolved from, and supports the common interests of, the North Slope Science Initiative Oversight Group (NSSI), Alaska Ocean Observing System (AOOS), the Arctic Research Mapping Application (ARMAP), the North Pacific Research Board (NPRB), the Alaska Climate Change Executive Roundtable (ACCER), and their member agencies. [www.adiwg.org]

The NSF **Antarctic and Arctic Data Consortium** (a^2dc) is a collaboration of NSF funded research centers and support organizations 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 a^2dc to search and contribute to the wealth of polar scientific and geospatial data. [www.a2dc.org]

The **Arctic Research Mapping Application** 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.org]

The **Arctic Observing Viewer** is a web mapping application in support of U.S. SEARCH, AON, and other Arctic Observing networks. A collaborative effort, it helps answer the questions such as: How can we know where to go if we don't know where we've been? What resources already exist? Is there overlap? Where are the gaps? [www.arcticobservingviewer.org]

The **Barrow Area Information Database** (BAID) is a resource for learning about the types of data collection activities in the Barrow area on the North Slope of Alaska. The BAID team collaborates with scientists and the local community to compile and share information via online web mapping applications. [barrowmapped.org]

Asia

The **National Institute of Polar Research** (NIPR) is Japan's key institution for scientific research and observation in the polar regions. It maintains monitoring stations in Antarctica and the Arctic, conducts comprehensive polar research based on monitoring programs, and acts as a center for the cultivation of researchers. [www.nipr.ac.jp/English]

Europe

Approved by the European Commission in November 2014, the goal of **EU PolarNet** is to coordinate polar research in Europe and develop a comprehensive European polar research programme. Its purpose is to provide Europe with the capability to better understand the nature of environmental risks and allow policy-makers and governments better able to design measures to mitigate those risks. [www.eu-polarnet.eu]

The **European Space Agency** (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. [www.esa.int]

Operational

Polar View Earth Observation is a global organization providing satellite-based information and data services in the polar regions and the cryosphere that support safe and cost-effective marine operations, improved resource management, sustainable economic growth and risk protection across sectors and around the world. [polarview.org]

The **International Ice Charting Working Group** (IICWG) has provided a forum since 1999 for the world's ice services to cooperate and coordinate on all matters concerning sea ice and icebergs. Its primary focus is on operational support to marine activities in ice-affected waters accompanied by a strong interest in scientific developments for continuous improvement. [nsidc.org/noaa/iicwg]

Appendix 2: Selected Polar Data Portals and Initiatives

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

The Sustaining Arctic Observing Networks (SAON): The Sustaining Arctic Observing Networks (SAON) process was initiated by the Arctic Council (AC) and has been underway since early 2007. Its purpose is to support and strengthen the development of multinational engagement for sustained and coordinated pan-Arctic observing and data sharing systems that serve societal needs, particularly related to environmental, social, economic and cultural issues. SAON promotes the vision of well-defined observing networks that enable users to have access to free, open and high quality data that will realize pan-Arctic and global value-added services and provide societal benefits. Its goal is to enhance Arctic-wide observing activities by facilitating partnerships and synergies among existing observing and data networks ("building blocks"), and promoting sharing and synthesis of data and information. SAON also is committed to facilitating the inclusion of Arctic indigenous people in observing activities, in particular by promoting community-based monitoring (CBM) efforts.

Global Earth Observation System of Systems (GEOSS): The Group on Earth Observations (GEO) is an intergovernmental organization working to improve the availability, access to and use of Earth observations by building a Global Earth Observation System of Systems (GEOSS), which provides decision-support tools to a wide variety of users. As with the Internet, GEOSS will be a global and flexible network of content providers allowing decision makers to access an extraordinary range of information at their desk. The GEOSS Portal is the main entry point to Earth Observation data from all over the world. The GEOSS information services for cold regions coordinates joint, global efforts to provide Earth observations and information services to decision-makers over a vast cold regions area, including the North Pole, South Pole, Himalaya-Third Pole and mountain cold regions.

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 WMO Global Cryosphere Watch (GCW): GCW is an international mechanism for supporting all key cryospheric in-situ and remote sensing observations. To meet the needs of WMO members and partners in delivering services to users, the media, public, decision and policy makers, GCW provides authoritative, clear, and useable data, information, and analyses on the past, current and future state of the cryosphere.

Polar Data Catalogue: The PDC is a database of metadata and data files that describes, indexes, and provides access to diverse data sets generated by Arctic and Antarctic researchers. Geographic focus is on Canada, but the PDC holds international collections, too, such as hundreds of metadata records of the Circumpolar Biodiversity Monitoring Program. The records follow ISO 19115 and Federal Geographic Data Committee (FGDC) standard formats to provide metadata exchange with other data centres. Interoperability via OGC WMS, OGC WFS, OAI-PMH, and CSW (GeoNetwork) are in place for sharing metadata and data. The metadata records cover a wide range of disciplines from natural sciences and policy, to health and social sciences. Datasets are available for free public download, with new files being added on a regular basis as we work with researchers to prepare and submit their datasets.

Polar Knowledge Canada: Polar Knowledge Canada (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.

Arctic Data Centre: Arctic Data Centre is a WMO Information System Data Collection and Production Centre building on the IPY legacy.

Arctic Data Explorer: The Arctic Data Explorer (ADE) is a cross-domain data discovery tool for searching distributed repositories. The current search space includes the holdings of the ACADIS Gateway, NCAR's Earth Observing Lab, National Snow and Ice Data Center, Norwegian Meteorological Institute, the Polar Data Catalogue, and the US National Oceanographic Data Center, and others. The ADE features an ISO-based metadata store, an available OpenSearch (ESIP-compliant) endpoint for automated searching, and metadata brokering technologies that allow for ingest of feeds in many formats.

Arctic Observing Viewer (AOV): AOV is a web mapping application for Arctic Observing data collection sites. This prototype is now available for visualization, synthesis, strategic assessment, and decision support for U.S. SEARCH/AON and other initiatives. It provides the “who”, “what”, “where”, and “when” of data collection activities (sites with repeat measurements such as towers, boreholes, weather stations, etc).

Arctic Research Mapping Application (ARMAP): ARMAP is a suite of online, interactive maps and web services that support Arctic science. The application displays details and field locations for over 2300 research projects funded by the US NSF and seventeen other agencies. A variety of web data services are also available for use by other organizations.

The International Arctic System for Observing the Atmosphere's (IASOA) mission is to advance coordinated research objectives from independent pan-Arctic atmospheric observatories through (1) strategically developing comprehensive observational capacity, (2) facilitating data access and usability through a single gateway, and (3) mobilizing contributions to synergistic science and socially-relevant services derived from IASOA assets and expertise. The IASOA data access portal provides (through ISO-19115-2 metadata) discovery & access-level information for ~700 atmospheric datasets from the ten Arctic Observatories of IASOA.

Sustaining Arctic Observing Networks (SAON): SAON has a search facility for Arctic observational data and metadata harvested from a series of data management institutions.

AbiskoGIS: AbiskoGIS is a research station-based initiative from the Abisko Scientific Research Station, in sub-Artic Sweden, that contains a mix of project data and metadata of monitoring activities.

Arctic Data archive System (ADS): The purpose of the Arctic Data archive System (ADS) is to archive and distribute multiple observational (atmosphere, ocean, terrestrial, and ecology) and satellite and model simulation datasets, and promote utilization of these datasets. ADS is the central repository of archived data on Arctic research in Japan

Natural Environment Research Council Arctic Office (UK): The aim of the Office and its website is to coordinate UK scientific research in the Arctic. The Office does provide information in its own right through a web map service (map.arctic.ac.uk).

The Norwegian Polar Data Centre and Norwegian Polar Institute Maps and Services are infrastructure nodes in development at the Norwegian Polar Institute, primarily focused on managing and distributing data from the institute itself. The data centre holds scientific, environmental and topographic data from the Norwegian Arctic, and distributes the data through open web services. The data centre also holds the responsibility as a National Antarctic Data Centre (NADC) for Norway, and Antarctic metadata are harvested by the Antarctic Master Directory. The metadata services are being connected to other networks as well, including the Norwegian IPY data catalogue (DOKIPY).

Sea Ice Prediction Network (SIPN): Decline in the extent and thickness of Arctic sea ice is an active area of scientific effort and one with significant implications for ecosystems and communities in the Arctic and globally. Forecasting for seasonal timescales (i.e., the summer and into fall) is of particular interest to many stakeholders since many activities that take place in the Arctic are planned over the summer months, and many species are sensitive to the behavior of summer sea ice. However, seasonal forecasting is particularly challenging due to the variable nature of weather and ocean behavior over that timescale as well as current limits to data and modeling

capabilities. SIPN builds and expands on the Sea Ice Outlook project. The Sea Ice Prediction Network (SIPN), launched in the fall of 2013, will develop a collaborative network of scientists and stakeholders to advance research on sea ice prediction and communicate sea ice knowledge and tools.

Svalbard Integrated Arctic Observing System (SIOS): SIOS is an international infrastructure project. There are 28 partners from Europe and Asia involved. The essential objective is to establish better-coordinated services for the international research community with respect to access, data and knowledge management, logistics and training.

ECDS - Environment Climate Data Sweden: A data center that is part of the Swedish national infrastructure where research (meta)data can be stored and explored. This service has the potential to be a hub for exploring Swedish Arctic research data in a wider Arctic network.

The Norwegian Institute for Air Research (NILU) organises atmospheric contaminants data for AMAP. The data are accessible through their EBAS database.

The WMO Information system (WIS) is the single coordinated global infrastructure responsible for 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.

GAWSIS is related to, but more specific than, the WMO listing above. It is an over-arching, coherent metadata system for the six world data centers that support the WMO's Global Atmospheric Watch (GAW) program: WDCGG (Gases), WOUDC (Ozone/UV); WDCPC (Precipitation and Chemistry); WWRDC (Radiation); WDCA (Aerosols/AOD); and WDC-RSAT (Remote Sensing)

Arctic Biodiversity Data Service by CAFF (Conservation of Arctic Flora and Fauna) and Seabird Data portal ABDS will allow for the combination of geo-referenced data at various spatial, temporal, and taxonomic scales. The main data resource is currently on migratory seabirds.

Exchange for Local Observations and Knowledge of the Arctic (ELOKA): ELOKA provides data management and user support to facilitate the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA partners with Indigenous communities around the circumpolar Arctic to establish ethical and culturally appropriate mechanism (technical, policy, partnerships) for sharing Indigenous knowledge and information in digital and other forms.

National Snow and Ice Data Center (NSIDC): The National Snow and Ice Data Center (NSIDC) supports research into our world's frozen realms: the snow, ice, glaciers, frozen ground, and climate interactions that make up Earth's cryosphere. NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere.

World Glacier Monitoring Service Meta Data Browser: The WGMS collects standardized observations on changes in mass, volume, area and length of glaciers with time (glacier fluctuations), as well as statistical information on the distribution of perennial surface ice in space (glacier inventories). Such glacier fluctuation and inventory data are high priority key variables in climate system monitoring.

The ArcticROOS is a GOOS Regional Alliance for the Arctic: The secretariat is located at the Nansen Environmental and Remote Sensing Center in Norway. It has been established 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. The aim of the ArcticROOS is to promote, develop and maintain operational monitoring and forecasting of ocean circulation, water masses, ocean surface conditions, sea ice and biological/chemical ocean constituents in the Arctic Ocean. The ArcticROOS website contains metadata and results of long-term observations from partners. The main focus is on cryospheric and oceanographic data.

The International Council for the Exploration of the Sea (ICES) is an intergovernmental organization whose main objective is to increase the scientific knowledge of the marine environment and its living resources and to use this knowledge to provide unbiased, non-political advice to competent authorities. The ICES Marine Data Center organises marine data on, among other things, contaminants, and the biological effects of these, biological communities, oceanography, and fisheries. ICES is the data center for these data for AMAP.

International Bathymetric Chart of the Arctic Ocean (IBCAO): The goal of IBCAO is to develop a digital data base that contains all available bathymetric data north of 64° North, for use by mapmakers, researchers, institutions, and others whose work requires a detailed and accurate knowledge of the depth and the shape of the Arctic seabed.

Norwegian Satellite Earth Observation Database for Marine and Polar Research (NORMAP): The overall goal of NORMAP 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

Oden Mapping Data: Bathymetric data from multi-beam sounding on icebreaker Oden cruises. The data have been extensively downloaded and used and can be regarded as an example of a local initiative by an individual research group leading to a success story in sharing of research data. The data is one of the sources to the IBCAO.

Arctic Observation Network Social Indicator Project: The Arctic Observation Network Social Indicator Project (AON-SIP) was supported by the National Science Foundation from 2007 to 2011. This website is maintained to offer access to data compiled by the AON-SIP by researchers and policy makers.

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. 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.