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

D2.1
Gaps and Impact Analysis Report

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Prepared for:
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Prepared by:
Polar View Earth Observation Limited

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1 INTRODUCTION

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, and governmental and non-governmental organizations. The study results are intended to help develop new space mission concepts for the polar regions that address evolving scientific and operational information needs.

This report addresses the second objective of the Polaris study: Identify information gaps considering existing and planned earth observation (EO) and integrated (EO/nav/telecom) systems, space and non-space based. It provides the results of the analysis of information gaps and their impacts. Chapter two identifies and assesses existing EO-based information products and integrated services responding to the identified information needs in Deliverable 1.1 Environmental Information Requirements Report. The third chapter provides an analysis of how information provided by space-based telecommunications, navigation and AIS capabilities can be combined with information from EO space missions to develop products and integrated information services that meet current user needs. Chapter four identifies sources of the broad range of information provided by atmospheric, land and ocean sensor networks that can be integrated with EO space missions focused on the polar regions to develop products and integrated information services to meet current user needs. The fifth chapter identifies gaps in information from current and planned EO missions, as well as from other relevant space and non-space information sources and characterizes the gaps in terms of their sectorial implications for geophysical parameters, user categories and geographic regions. Chapter six identifies new EO-based products and innovative integrated services required to address information gaps, which are currently unavailable and that will not be realized within the next 5, 10 and 15 years from planned missions or other developments, and describes them in terms of applications supported, information requirements, data attributes and delivery formats. The seventh chapter assesses the socioeconomic and environmental implications of alternative gap-fillers and the final chapter analyses the potential legal and political implications of implementing the most promising integrated services.

2 STUDY METHODOLOGY

This chapter summarizes the study methodology for the identification of gaps in currently available environmental information in the polar regions, and the contents of the four primary study deliverables. The methodology is illustrated in Figure 1. Overall, there are three technical reports and a summary report. The study findings are based on four lines of enquiry: a literature review, a review of polar data web portals, stakeholder consultations, and a stakeholder workshop. At each step of 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 composition of the steering committee is listed in Appendix 2.

The *Environmental Information Requirements Report* (D1.1, this report) addresses the Polaris study objective to review, identify and consolidate user community environmental information requirements for the polar regions. Input to this report was derived from two primary lines of enquiry for the study – literature review and stakeholder consultations. Some 250 documents were reviewed to identify user requirements and the scientific and operational drivers of those requirements. Fifty representatives of the broad range of user communities active in the polar regions were consulted (see organization list in Appendix 5). The report provides the findings from the literature review and consultations and the results of a first level analysis of current information needs and gaps. It also summarizes user input on how needs are expected to change over the next 5-15 years and how key political/policy, economic, social/cultural and technological trends may impact users' future information needs.

The *Gaps and Impact Analysis Report* (D2.1, under separate cover) addresses the study objective to identify information gaps considering existing and planned earth observation (EO) and integrated (navigation/telecommunications/surveillance) systems, space and non-space based. A literature review was conducted of available sources of EO-based products and services, as well as information available from other space assets (e.g. global navigation satellite systems (GNSS), telecommunications and space automatic identification systems (S-AIS)) and non-space assets (e.g. ground- and airborne-based sensors). The first level analysis of information needs and gaps was then refined and reviewed by experts in the information provider community and by a cross-section of users and providers at a workshop as part of the second level analysis of information gaps. Finally, new integrated products and services to address the gaps were specified at a high level and the possible impacts and political and legal implications of their development were analyzed.

The *Preliminary Observation Requirements Report* (D3.1, under separate cover) addresses the study objective to establish a set of endorsed, high-level mission requirements reflecting

the gaps and perform a preliminary assessment of the high-level operations requirements for supplying these integrated services.

The *Summary Report* (under separate cover) provides an overview and summary of the overall study findings and the conclusions drawn from the analysis of findings. It contains a synthesis of critical elements of the Environmental Information Requirements, Gaps and Impact Analysis and Preliminary Observation Requirements Reports.

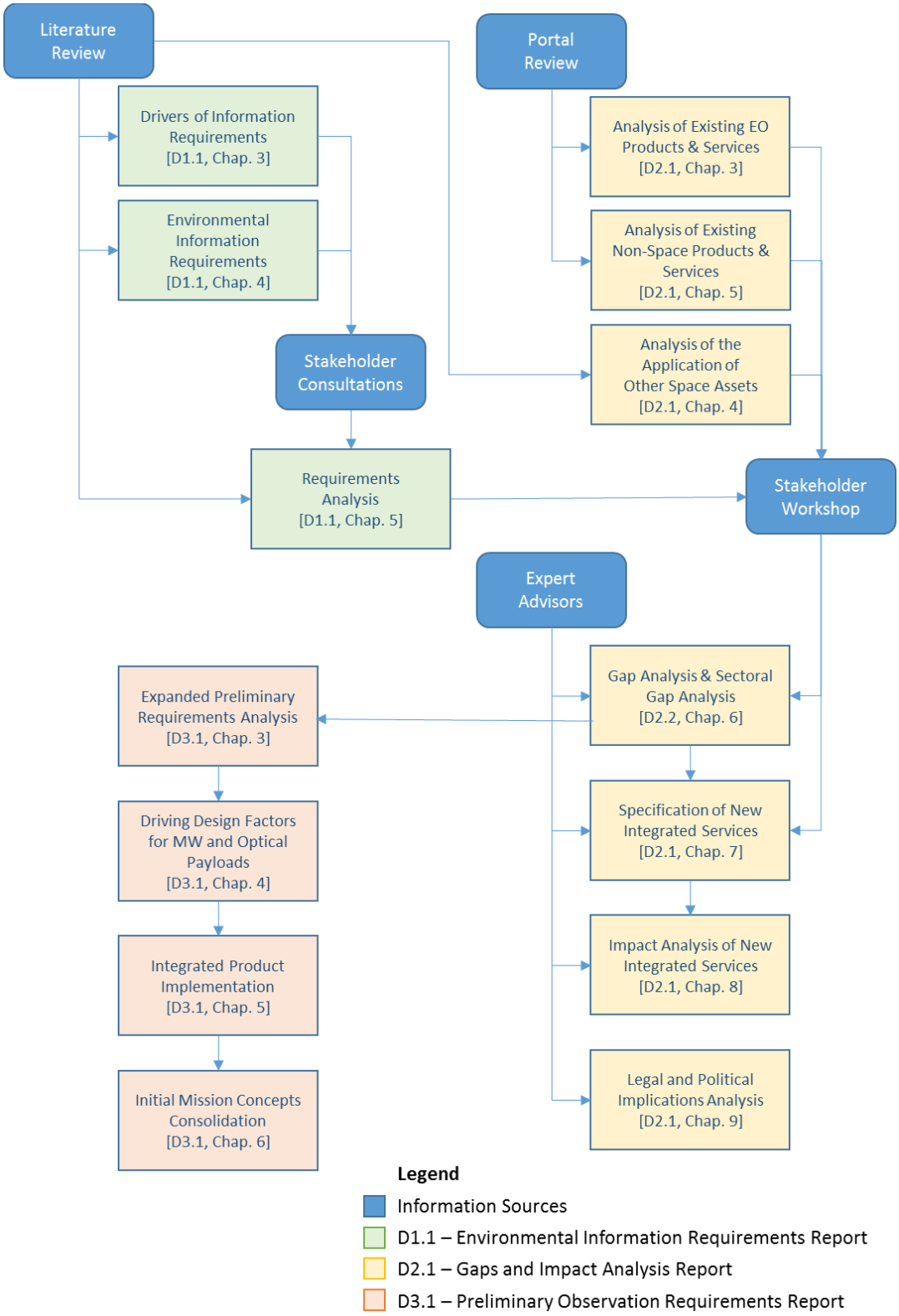

Figure 1: Study Methodology

3 ANALYSIS OF EXISTING EO-BASED PRODUCTS AND SERVICES

This chapter identifies sources of information about EO-based products and services, and provides a summary of those that are available from different sources and a brief analysis of the key information gaps.

3.1 PORTALS AND SERVICES INVENTORY

The approach taken to identify existing EO-based products involved the identification and review of portals and services providing access to these products and services. Table 1 lists those services and portals where relevant polar EO-based information products were found.

Table 1. Portals and Services for EO-based Information Products Covering Polar Regions

Portal / Service	Product Examples	Provider	URL
General ocean and sea-ice products available from the ESA/EU Copernicus Space Program	▪ Sea surface temperature ▪ Currents ▪ Sea surface salinity ▪ Sea-Level ▪ Sea ice concentration, edge, type and drift ▪ Sea ice charts – Greenland ▪ Iceberg concentration ▪ Snow density and depth	European Space Agency (ESA)/European Union (EU) Copernicus (MyOcean)	http://marine.copernicus.eu/ (http://www.myocean.eu) http://marine.copernicus.eu/web/69-interactive-catalogue.php
Land Monitoring Services	▪ Land cover ▪ Land cover changes ▪ Land surface temperature ▪ Soil water index ▪ Dry matter productivity	Copernicus	http://land.copernicus.eu
ESA Earth Online	▪ Soil moisture	ESA	https://earth.esa.int/web/guest/data-access/browse-data-products
Ice Analysis Products	▪ Ice charts ▪ Ice edge ▪ Ice concentration ▪ Polar marginal ice zone (MIZ)	Bundesamt für Seeschifffahrt und Hydrographie/International Ice Charting Working	http://www.bsis-ice.de/IcePortal/

		Group/ WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology (BSH/IICWG/JCOMM)	
Sea ice imagery from active and passive microwave sensors	▪ Sea ice concentration ▪ Sea ice charts ▪ Sea ice edges ▪ Sea ice drift ▪ Sea ice forecasts ▪ Sea ice thickness ▪ Sea ice pressure ▪ Sea ice edge ▪ Iceberg detection ▪ Iceberg drift ▪ River and lake ice extent ▪ Snow cover	Polar View Earth Observation Limited (Polar View)	http://www.polarview.org/services/ http://www.polarview.aq/arctic http://www.polarview.aq/antarctic
ESA Sea Ice CCI-Antarctic	▪ Sea ice concentration ▪ Sea ice thickness and freeboard	The Sea Ice Climate Change Initiative (CCI)	http://esa-cci.nersc.no/?q=products
Products generated by the CCI Ice Sheets project (Greenland, and since 2015, Antarctica)	▪ Surface elevation changes ▪ Ice velocity ▪ Calving front location (Greenland only) ▪ Grounding line locations ▪ Gravimetric mass balance (from GRACE)	ESA	http://products.esa-icesheets-cci.org/login/?next=/products/downloadlist/
PolarPortal	▪ Greenland daily surface mass balance ▪ Monthly mass balance from GRACE ▪ Greenland albedo ▪ Sea ice cover – Greenland and Arctic Ocean	Danish Meteorological Institute in cooperation with DTU Space and GEUS	www.polarportal.dk (for sea ice also www.seaice.dk)

NASA Cryosphere Science Research Portal	▪ Greenland land/ice mask ▪ Sea ice thickness and freeboard ▪ Early melt, melt , freeze and late freeze ▪ Snow depth on sea ice	National Aeronautics and Space Administration (NASA)	http://neptune.gsfc.nasa.gov/csb/index.php?section=272
MODIS Data Products	▪ Sea ice extent ▪ Sea surface temperature ▪ Snow cover ▪ Land cover type / dynamics ▪ Total precipitable water	NASA	http://modis.gsfc.nasa.gov/data/dataprod/
Data at NSIDC	▪ Sea ice concentration ▪ Sea ice extent ▪ Snow depth on ice ▪ Ice velocity of the Amundsen Sea Embayment, Antarctica ▪ Antarctic 1 km digital elevation model (DEM) ▪ Snow depth	National Snow and Ice Data Center (NSIDC)	http://nsidc.org/data/ http://nsidc.org/data/icesat/data.html http://nsidc.org/data/seaice_index/ http://nsidc.org/data/modis/data_summaries/
Ocean and Sea Ice Satellite Application Facility (OSI SAF)	▪ Global sea ice concentration ▪ Global sea ice type ▪ Global sea ice edges ▪ Low and medium resolution sea ice drift	Eumetsat Network of satellite application facilities High Latitude Processing Centre (OSI SAF)	http://saf.met.no/p/ice/index.html
GlobSnow Snow Products – European Space Agency (ESA) global database of snow parameters for climate research purposes	▪ Snow extent ▪ Snow water equivalent	Finnish Meteorological Institute (FMI) GlobSnow Project	http://www.globsnow.info/index.php?page=Products
Collaborative Antarctic Sea-Ice Charts with Russian,	▪ Sea ice type ▪ Sea ice age	Arctic and Antarctic Russian Institute	http://ice.aari.aq/antice/

United States, and Norwegian inputs	▪ Iceberg detection	(AARI)	
AARI Center of Ice, Hydrological and Meteorological Information	▪ Ice charts (Arctic) ▪ Ice drift forecasts ▪ Wave forecasts ▪ Meteocharts ▪ Surface pressure forecasts ▪ Wind forecasts ▪ Ocean currents ▪ Sea level	AARI	http://www.aari.nw.ru/index_en.html
PSD Climate and Weather Data	▪ Precipitation ▪ Sea surface temperature ▪ Soil moisture ▪ Surface temperature ▪ Snow cover ▪ Wind profiles	National Oceanic and Atmospheric Administration (NOAA)	http://www.esrl.noaa.gov/psd/data/
National Environmental Satellite, Data and Information Service (NESDIS)	▪ Sea ice concentration ▪ Precipitable water	NOAA	http://www.ospo.noaa.gov/Products/index.html http://www.ospo.noaa.gov/Products/ocean/sea_ice.html
Ice Analysis Products	▪ Ice edge ▪ Ice concentration ▪ Polar marginal ice zone (MIZ)	United States (U.S.) National Ice Center (NIC)	http://www.natice.noaa.gov/Main_Products.htm
Arctic Data archive System (ADS)	▪ Sea ice concentration ▪ Sea ice drift speed ▪ Sea ice thickness ▪ Sea surface temperature ▪ Snow depth	National Institute of Polar Research (NIPR)	https://ads.nipr.ac.jp/vishop/vishop-monitor.html
GLIMS Glacier Database	▪ Glacier extent	Global Land Ice Measurements from Space (GLIMS)	http://glims.colorado.edu/glacierdata/
Global Terrestrial Network for Permafrost - Database	▪ Arctic permafrost zones	Global Terrestrial Network for Permafrost (GTN-P) Programme	http://gtnpdatabase.org/
GCOM-W1 Data Providing Service	▪ Total precipitable water	Japan Aerospace Exploration Agency	http://gcom-w1.jaxa.jp/search.html

	▪ Cloud liquid water ▪ Precipitation ▪ Sea surface temperature ▪ Sea surface wind speed ▪ Sea ice concentration ▪ Snow depth ▪ Soil moisture content ▪ Brightness temperature	(JAXA)	

3.2 Inventory of Available EO-based Products and Services

The following sections identify the kinds of products and services that were discovered by searching the portals referenced in the previous section. Details are provided in Appendix 1.

3.2.1 Ocean Parameters

Sources of ocean products include the Copernicus Marine Environment Monitoring Service, MODIS, JAXA and AARI portals.

The Copernicus portal provides access to a broad range of ocean information products including:

- Marine ecosystem functioning products (Arctic surface chlorophyll concentration from satellite observations, Arctic chlorophyll concentration from satellite observations (daily average) reprocessed L3 (ESA-CCI), and algal pigment concentration)
- Sea surface temperature products (sea surface temperature, Arctic ocean physics reanalysis, global ocean OSTIA sea surface temperature and sea ice reprocessed, Arctic ocean high resolution sea surface temperature reanalysis, and Arctic ocean sea and ice surface temperature)
- Wave directional energy frequency spectrum products (ocean wave spectra)
- Ocean dynamic topography products (sea surface height, significant wave height, tide height, Arctic ocean physics reanalysis and global ocean along-track sea level anomalies NRT, global ocean along-track sea level anomalies reprocessed, Arctic ocean along-track sea level anomalies NRT and global ocean mean dynamic topography, and global ocean mean sea surface)
- Sea surface salinity products (Arctic ocean physics reanalysis)

- Ocean suspended sediments concentration products (TSM concentration)
- Colour dissolved organic matter products (colour dissolved matter absorption)

Products available from the MODIS portal include MODIS sub-surface chlorophyll-a concentration, global high resolution sea surface temperature, and MODIS sea surface temperature. The JAXA portal provides sea surface temperature, sea surface wind speed products and the AARI portal provides access to wave forecast, ocean currents and sea level information.

3.2.2 Atmospheric Parameters

Atmospheric information products are available from a number of sources, including the Copernicus Atmosphere Monitoring Service, MODIS, AARI, JAXA and NOAA PSD and NESDIS portals.

The Copernicus Atmosphere Monitoring Service portal provides access to a broad range of atmospheric information products including:

- Precipitation products (integrated water vapour, and rain rate)
- Atmospheric gas products (O_3 total column, O_3 profile, O_3 tropospheric profile, O_3 tropospheric column, NO_2 total column, NO_2 tropospheric column, SO_2 total column, HCHO total column, and CH_4 total column)
- Wind speed products (ocean wind field, ocean surface vector wind, sea surface wind speed, windscan, surface radial velocity, global ocean wind L4 near real time 6 hourly observations, global ocean wind observations, global ocean daily gridded sea surface winds from scatterometer, and global ocean wind observations climatology reprocessed (monthly means))
- Cloud top height products (cloud top height)

The MODIS portal provides access to the MODIS total precipitable water product. The NOAA NESDIS portal provides total precipitable water (SSM/I), total precipitable water (MSPPS), and total precipitable water (ATOVS) products. The PSD Climate and Weather Data portal contains a broad range of atmospheric information including precipitation, sea surface temperature, land surface temperature, snow cover, wind profiles, etc. Atmospheric information on the AARI portal includes meteocharts, surface pressure forecasts and wind forecasts, and the JAXA portal provides total precipitable water, cloud liquid water and precipitation products.

3.2.3 Sea Ice Parameters

A number of major sources of sea ice products are available, including the Polar View, MODIS, Copernicus, CCI, OSI SAF, NASA, NOAA NESDIS, US NIC, NSIDC, BSH/IICWG/JCOMM[1], AARI and ADS portals.

Sea ice cover (concentration) products are available, for example, from:

- ADS (ice concentration)
- BSH/IICWG/JCOMM (ice concentration)
- CCI (sea ice concentration)
- Copernicus (sea ice concentration, Arctic ocean physics reanalysis, global ocean – arctic and Antarctic –sea ice concentration, global ocean sea ice concentration time series reprocessed, Arctic ocean sea ice charts – Greenland, and Arctic ocean sea ice concentration charts – Svalbard)
- JAXA (sea ice concentration)
- NASA (sea ice concentration, and Greenland land/ice mask)
- NOAA OSPO (sea ice concentration)
- NSIDC (sea ice concentration, brightness temperature, sea ice concentration, snow depth, sea ice index, sea ice extent, radiance and sea ice concentration, and MODIS sea ice extent)
- OSI SAF (global sea ice concentration)
- Polar View (sea ice concentration, and sea ice forecasts)
- US NIC (polar marginal ice zone (MIZ))

Sea ice motion products are available, for example, from:

- AARI (ice drift forecasts)
- ADS (sea ice drift speed)
- Copernicus (global ocean – Arctic and Antarctic – sea ice drift, global ocean – high resolution SAR sea ice drift, and Arctic ocean sea ice drift reprocessed)
- NASA (QuikSCAT & SSM/I merged sea ice motion)
- OSI SAF (low resolution sea ice drift, medium resolution sea ice drift)
- Polar View (sea ice drift, and sea ice forecasts)

Sea ice thickness products are available, for example, from:

- CCI (sea ice thickness and freeboard)
- NASA (sea ice thickness and freeboard)
- Polar View (sea ice thickness, and sea ice forecasts)
- Sea ice freeboard (sea ice freeboard)

[1] The BSH/IICWG/JCOMM portal provides access to the ice information products provided by the IICWG members (i.e. all of the national ice services like Norwegian Meteorological Institute, Danish Meteorological Institute, Canadian Ice Service, British Antarctic Survey, etc.)

Sea ice type products are available, for example, from:

- AARI (ice types)
- Copernicus (global ocean – Arctic and Antarctic – sea ice type)
- NASA (QuikSCAT Arctic sea ice age product, and OSCAT arctic sea ice age product)
- OSI SAF (global sea ice type)
- Polar View (sea ice types)

Sea ice edge products are available, for example, from:

- BSH/IICWG/JCOMM (ice edge)
- OSI SAF (global sea ice edges)
- NOAA
- Polar View (ice edge)
- US NIC (ice edge)

A sea ice surface temperature product is provided by MODIS (MODIS sea ice extent SST); a sea ice melt product is provided by NASA; and a sea ice pressure product is provided by Polar View.

3.2.4 Ice Sheet Parameters

The Antarctic ice sheet extent product is available from NASA QuikSCAT and from the NASA MEaSUREs project through NSIDC. The ESA CCI project is producing the following parameters for Greenland: Surface Elevation Change; Ice Velocity; Calving Front Location; and Grounding Line Location, and from 2016, Gravimetric Mass Balance. Data for the Antarctic Ice Sheet will be available from 2016 for the similar parameters, except Calving Front Locations.

3.2.5 Glacier Parameters

A limited number of glacier information products were found. NSIDC provides two glacier motion products (MEaSUREs InSAR-based ice velocity of the Amundsen Sea Embayment, Antarctica, and compilation of Antarctic radar data, Siple Coast, 2000-2002) and a glacier topography product (Antarctic 1 km digital elevation model (DEM) from combined ERS-1 Radar and ICESat Laser Satellite Altimetry). The GLIMS project provides a database of the extents of glaciers around the world. The ESA CCI project on Glaciers and Ice Caps produces glacier outlines, glacier elevation changes and glacier velocities, in close cooperation with the World Glacier Monitoring Service.

3.2.6 Iceberg Parameters

Iceberg information products are provided by Polar View (iceberg detection, iceberg drift, and iceberg historical trends), Copernicus (Arctic ocean – SAR sea iceberg concentration) and AARI (iceberg detection).

3.2.7 River / Lake Ice Parameters

The only river and lake ice information products that were discovered are provided by Polar View (river ice and lake ice).

3.2.8 Snow Parameters

A variety of snow information products are available from a few information providers.

Snow cover / extent products are available, for example, from:

- GlobSnow project (snow extent)
- MODIS (MODIS snow cover)
- Polar View (snow cover)

Snow water equivalent products are available, for example, from:

- GlobSnow project (snow water equivalent)

Snow depth products are available, for example, from:

- Copernicus (snow density and depth)
- JAXA (snow depth)
- NASA (snow depth on sea ice)
- NSIDC (snow depth)

3.2.9 Permafrost Parameters

Permafrost information products are primarily available from three sources: the ESA Data User Element (DUE) Permafrost project (land surface temperature (LST), surface soil moisture (SSM), surface frozen/thawed state (freeze/thaw), and terrain and terrain displacement); GTN-P project (Arctic permafrost zones, Active Layer - Annual Thaw Depths, and Boreholes - Permafrost Temperatures); and NSIDC (borehole and environmental protection descriptive and numerical data, Yamal Peninsula, Russia).

3.2.10 Land Parameters

As indicated by the following list, Copernicus is the primary source for land information products.

Land use/cover and change products are available, for example, from:

- Copernicus (CORINE land cover, CORINE land cover changes)
- MODIS (land cover type/ Dynamics)

Land surface temperature products are available, for example, from:

- Copernicus (land surface temperature)

Soil moisture products are available, for example, from:

- Copernicus (soil water Index)
- ESA Earth Online (SMOS level 2 soil moisture)
- JAXA (soil moisture content)

Above ground biomass products are available, for example, from:

- Copernicus (dry matter productivity)

3.3 Analysis of EO-Based Product and Service Findings

Although our research revealed many available sources of EO-based products and services and portals/catalogues that combine metadata from many databases, there remain considerable gaps regarding environmental information coverage and resolution, both temporally and spatially. In particular, the offering is not yet adequate for many of the operational requirements, which often are related to near real-time, high resolution information (e.g. high resolution ice concentration and thickness data that are vital for tactical risk assessment and decision-making). A number of ongoing or recently finished projects that provide products and services were also investigated, and while these are of interest, there are uncertainties regarding continuity of the services and it is sometimes unclear as to what extent the services are offered to a larger community or are targeted towards only a small group of users.

Lack of product quality, and particularly product validation, is an important gap. It is relatively easy to generate automated products from satellite data that a majority of users will accept at face value, but they may never have been validated and their accuracy may be unknown. The best known example is the passive microwave ice concentration products; they do not identify ice in concentrations less than 15-20%, which are the locations in ice where most of the ships are operating.

Table 2 identifies some of the more notable gaps in meeting user needs for the products and services of highest interest identified in the User Requirements Report. A more detailed examination of gaps is provided in Chapter 5.

Table 2: EO-based Product and Service Gaps Identified through Literature and Consultations

Information Theme	Product and Service Gaps
Sea Ice	▪ Extent – inadequate spatial and temporal resolution for operations; inadequate discrimination between first year and multi-year ice; integration with ice concentration information required; lack of product quality information ▪ Freeze/Thaw – lack of necessary sensor frequencies ▪ Motion – inadequate spatial and temporal resolution for operations, which need near real-time service delivery; lack of product quality information ▪ Snow Depth – inadequate spatial and temporal resolution for operations, which need near real-time service delivery; insufficient quality with current sensor and algorithm combinations; integration with ice thickness information required ▪ Structure/Age – inadequate spatial and temporal resolution for operations, which need near real-time service delivery; lack of nested products to satisfy large to small scale applications; lack of product quality information ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers. ▪ Thickness – inadequate spatial and temporal resolution for operations, which need near real-time service delivery; lack of product quality information ▪ Topography – inadequate spatial resolution for operations; lack of product quality information
River and Lake Ice	▪ Extent – inadequate spatial and temporal resolution ▪ Freeze/Thaw Cycle – lack of necessary sensor frequencies ▪ Structure/Age – inadequate temporal resolution ▪ Thickness – inadequate spatial and temporal resolution for operations
Ice Sheets	▪ Grounding Line – inadequate accuracy in determining location. ▪ Iceberg Calving – inadequate spatial and temporal resolution ▪ Mass Change – inadequate spatial resolution ▪ Motion – inadequate spatial resolution ▪ Snow Depth – inadequate spatial resolution; insufficient quality with current sensor and algorithm combinations ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers. ▪ Thickness – inadequate spatial and temporal resolution
Glaciers	▪ Extent – inadequate spatial resolution ▪ Ice Dammed Lakes – inadequate spatial and temporal resolution ▪ Iceberg Calving – inadequate spatial and temporal resolution ▪ Mass Change – inadequate spatial and temporal resolution ▪ Motion – inadequate temporal resolution ▪ Snow Depth – insufficient quality with current sensor and algorithm combinations ▪ Structure/Age – lack of necessary sensor frequencies ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers. ▪ Thickness – inadequate spatial and temporal resolution

	▪ Topography – inadequate spatial and temporal resolution
Snow	▪ Depth – inadequate spatial resolution; insufficient quality with current sensor and algorithm combinations ▪ Extent – inadequate spatial resolution ▪ Freeze/Thaw – time series product that allows identification of ice layers within snow required ▪ Snow Water Equivalent – inadequate spatial resolution; insufficient use of integrated satellite and in situ observations and inadequate models ▪ Structure/Age – lack of necessary sensor frequencies ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers.
Icebergs	▪ Calving – lack of frequent image acquisitions ▪ Extent – inadequate spatial and temporal resolution for operations, which need near real-time service delivery ▪ Location – lack of product quality information ▪ Motion – lack of frequent image acquisitions ▪ Size – inadequate spatial and temporal resolution
Permafrost	▪ Chemistry – detection of methane emissions ▪ Elevation Change – lack of necessary sensor frequencies ▪ Extent – inadequate spatial resolution ▪ Freeze/Thaw – inadequate spatial resolution ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers.
Ocean	▪ Biota – information not available on sustained and regular timescales ▪ Salinity – inadequate spatial resolution around glaciers ▪ Temperature – inadequate quality near ice edge and marginal ice zone ▪ Waves – inadequate wave height/period information with penetration into ice cover ▪ Wind – increased performance in the lower troposphere, insufficient use of integrated satellite and in situ observations and inadequate integration with other weather and ocean data
Land	▪ Biota – inadequate spatial and temporal resolution ▪ Surface State/Albedo – inadequate resolution and ability to detect surface detail and subsurface layers. ▪ Vegetation/Land Cover – lack of consistency in products that will allow phenology studies over long timescales
Atmosphere	▪ Chemistry/Particulates – detection of methane, ozone, black carbon, volcanic ash ▪ Precipitation/Clouds/Humidity – inadequate temporal resolution ▪ Temperature – inadequate spatial and temporal resolution ▪ Wind – increased performance in the lower troposphere, insufficient use of integrated satellite and in situ observations and inadequate integration with other weather and ocean data

4 ANALYSIS OF THE APPLICATION OF OTHER SPACE ASSETS

This chapter provides an analysis of how information provided by space-based telecommunications, navigation and AIS capabilities are being combined with information from EO space missions to develop products and integrated information services that meet current user needs.

4.1 SATELLITE TELECOMMUNICATIONS

Arctic activities must be supported by robust, accessible and cost-effective telecommunications and information technology systems in order to have an impact in the development of a prosperous and sustainable northern region. Delivering on infrastructure projects in the Arctic has particular challenges that are not common in southern communities given the remote areas and extreme climates, including the risks associated with permafrost. Long lead times are required to plan for shipping and delivery of materials and to secure contractors from a competitive and limited pool of experts (Polar View, 2012).

In the context of synergy with EO, telecommunications systems provide remote real-time access to in situ data (that can be fused with EO data to create products) and allow users to access EO-derived products in the field. Some traditional EO-derived products have been designed for transmission over low bandwidth systems. For example, in the Canadian ice Service's *Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE)* (Canadian Ice Service, 2013) a text file format is provided for reporting on sea ice and iceberg conditions. Nonetheless, modern telecommunication systems have facilitated the ability to transmit high resolution EO data to vessels and remote field locations. This has created a user demand from their use at lower latitudes that constrain telecommunications systems at higher latitudes. This has led to a significant telecommunications gap at these higher latitudes. The authors of this study have experienced these gaps first hand in trying to access ice charts in the field while on seismic and ice charting vessels.

These telecommunications gaps have been identified in the Nordic, Canadian and Russian Arctic policies. There was a joint International Marine Organization (IMO) / International Hydrographic Organization (IHO) / World Meteorological Organization (WMO) Group formed to address the lack of proper telecommunications at higher latitudes for maritime safety, navigation and security purposes. Several gaps have been identified in previous studies; such as the Norwegian Space Centre/SINTEF study on user needs in the Arctic, detailing a number of parties from various sectors that have an interest in improved communication in the Arctic. An increase in aircraft traffic in the high latitudes will require improved Aeronautical Traffic Services and Operational Communications and emerging commercial shipping activity

in the North East Passage will is also producing an increase in communication requirements (Zeppenfeldt, 2009).

Other previous projects, such as the Norwegian Research Council MarCom, MarSafe North and MARENOR projects and the European Space Agency's ArctiCOM project, have investigated the state-of-the art of Arctic communications and the future needs for satellite communication and proposed several solutions.

Ships operating in the open ocean use maritime communication systems based on geostationary (GEO) satellites that orbit the earth above the equatorial line, such as Inmarsat and VSAT. However, these satellites have little or no coverage in the Arctic and low sun angles make them vulnerable to external sources. Field tests performed during the Norwegian MarSafe North project showed instability and signal drop-offs as low as 70°N in certain conditions, even though the theoretical coverage limit is 81.3°N. This gap in coverage above ~75°N with existing systems means communications are unreliable and of limited capacity with low data rates. Most of the demand above 75°N will be from vessels and aircraft. The only satellite system that provides full coverage in the Arctic is Iridium, which offers its digital coverage through their OpenPort services, but users have reported unstable performance throughout the Arctic.

The ArtiCOM project investigated the needs for satellite capacity in the Arctic from 2010 to 2020 and their study showed that demands are expected to increase in all areas of the Arctic (i.e. in the Northeast and Northwest Passages, Russia, North America and European parts of the Arctic), with the largest increase within the European parts of the Arctic from the maritime domain (Kvamstad, 2013).

In addressing these gaps, several initiatives are underway that could facilitate better and more cost effective telecommunications solutions in polar regions. The solutions involve multiple satellites, some which may be in highly-elliptical polar orbits. They include, for example, Iridium NEXT, Polar Communication and Weather Mission (PCW), Arktika and Thor 7. Services may still require trade-offs between data speed and number of users (capacity). Technical verification of some future systems is still under investigation. However, there appear to be delays in many of these systems being launched. While the list is not exhaustive, it is meant to be representative of what to expect in the timeframe of the next generation ESA polar satellite mission.

4.1.1 Iridium NEXT

Iridium NEXT is the next global satellite constellation for U.S.-based Iridium Communication Inc., which plans to replace its current LEO satellite constellation with a total of 72 new satellites, including 6 in-orbit spares from 2015 to 2017. The mission will provide enhanced as well as entirely new services for a growing range of industries and geographical areas

including the high north. Iridium NEXT will offer innovation in areas such as: enterprise global voice and data connectivity, asset tracking and other machine-to-machine (M2M) applications, new data-centric applications and more power, enabling new opportunities. Iridium NEXT will continue to remain the only system to provide real-time communication services above 75 degrees north as well as providing 24/7 real-time visibility over the entire Earth's surface and atmosphere. This will allow it to provide critical technology for communication services as well as environmental, economic, security and social concerns across the Arctic.

The plan is for Iridium NEXT to offer higher data speeds, more flexible bandwidth allocation and IP-based routing. More specifically, improvements will include data rates up to 1Mbps, Ka-band service (two 20/30 GHz steerable feeder links to terrestrial gateways and four 23 GHz cross links to adjacent Iridium NEXT satellites for relay communications), private network gateways and broadcast and network services. Iridium NEXT will also offer commercial, government and scientific organizations a potential opportunity to place secondary payloads on its satellite constellation to address a variety of near- and long-term requirements (i.e. dedicated communications, EO, signals collection, space weather, etc.).[2] The launch of the first satellite from Iridium NEXT has been delayed until April 2016, with plans to launch another one in August 2016 and have six more launched by September 2017.[3]

4.1.2 PCW

The Polar Communication and Weather Mission (PCW) is a Canadian project funded by the Canadian Space Agency (CSA) in partnership with Environment Canada (EC), the Department of National Defence (DND), and other Government departments, which recognized the gaps in the communications and weather observation coverage over the Arctic. PCW aims to support Canadian sovereignty and security, to improve quality of life and to facilitate economic development and world-class scientific research in the Arctic by providing reliable 24/7 high data rate (HDR) communications services. PCW also aims to monitor Arctic weather and climate change for the benefits of Canadians and the Global community. PCW is meant to be launched in a highly-elliptical polar orbit to provide better coverage at high latitudes. The main instrument planned for the meteorological payload is an imaging spectroradiometer, similar to imagers being developed for the next generation of geostationary weather satellites. A secondary weather instrument (broadband radiometer) is also being considered. The primary Ka-band telecommunications payload consists of a high-speed two-way system capable of providing continuous broadband services to users throughout the Arctic. A suite of compact space weather instruments to study ionizing

[2] Iridium NEXT webpage Information: http://www.iridium.com/about/IridiumNEXT.aspx
[S] SpaceNews website: http://spacenews.com/component-issue-delays-iridium-next-launches-by-four-months/

radiation completes the list of primary payloads. A list of secondary scientific payloads is currently being evaluated with possible atmospheric science applications.[4] As of the writing of this report, the PCW mission is still under review and awaiting internal Canadian government approval.

4.1.3 Arktika

The Arktika system, estimated to be worth around 70 billion rubles ($2.5 billion US), will monitor climatic changes, survey energy resources in the Arctic region as well as provide high-speed communications services. The system has been recently approved by the Russian Economic Development Agency and according to ROSCOSMOS has also received support from the World Meteorological Organization. The new Arctic Satellite cluster will be based on already operational remote-sensing weather and telecommunication satellites and will also receive radio signals from the COSPAS-SARSAT international search and rescue system. The planned system will be comprised of six satellites that will feature optical systems; the Arktika-R satellites will carry radars, and the Arktika-MS telecommunications satellites will handle telephone communications and relay television and FM radio broadcasts to aircraft and ships in northern Russia and other polar countries.[5] The first satellite of this mission was supposed to be launched in 2014 and then this year up until 2020; however none have been launched to date and no new launch information could be obtained.

4.1.4 Thor 7

The Norwegian Telnor Thor family of satellites provides coverage over northern parts of Europe with existing satellites including Thor 4, Thor 5, and Thor 6 that are operational Ku-band satellites. THOR 7, which was successfully launched into space on April 26, 2015, offers Ka-band capacity for high-bandwidth transmissions to maritime customers in Northern Europe as well as the Baltic and Mediterranean Seas. Thor 7 will also provide Norway's Troll research station in Antarctica with increased satellite capacity for the distribution of meteorological data.[6]

4.1.5 Other initiatives

Several other initiatives are underway to improve telecommunications in the Arctic. For example, the U.S. Navy's Mobile User Objective System (MUOS), a next-generation narrowband tactical satellite communications system, could be used for Arctic communications. This system will replace the legacy Ultra High Frequency Follow-On (UHF-FO) communications system and is designed to provide smartphone-like communications to mobile forces at rates 10 times faster than the legacy system. The ability to send and receive clear messages quickly to prevent or respond to a maritime emergency is vital to the safety

[4] PCW website: http://www.asc-csa.gc.ca/eng/satellites/pcw/
[5] Arktika website: http://www.russianspaceweb.com/arktika.html
[6] Telnor website: http://www.telenor.com/media/press-releases/2015/launch-success-for-thor-7/

of crews travelling the Arctic. [7] While it appears that MUOS will be restricted to military users, the system could be used in search and rescue and emergency response operations.

A Canadian company called ArcticFibre plans to build a 24-terabit-per-second undersea cable that will connect Japan and the U.K. and also bring broadband to remote Arctic communities. This project was supposed to start in the Spring of 2015 and be fully operational in 2016.[8] The latest available information, published in June 2015, indicates that the cable will not be built until 2017-2018, contingent on other customer commitments being confirmed.[9]

4.2 Global Navigation Satellite Systems

Satellite navigation, more generally termed Global Navigation Satellite System (GNSS), refers to systems of satellites that allow earth receivers to determine their location to a high level of precision (within metres or centimetres, depending on the technology). GNSS includes, for example, the U.S. Global Positioning System (GPS), the European Union's Galileo system, Russia's GLONASS and others. GNSS has become ubiquitous, with receivers built into cars, vessels, airplanes, cell phones and other mobile devices, emergency locators and a large variety of in situ sensors that provide earth measurements and the associated geolocation.

The accuracy and integrity of a GNSS in the Arctic can be improved through the use of space-based augmentation systems (SBAS), which are often developed with specific applications in mind (e.g. the North American Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay Service (EGNOS), developed primarily for aviation purposes). These augmentation systems can improve integrity monitoring of GNSS and position accuracy and availability of GNSS within the SBAS coverage area. However, there are limitations since the geosynchronous satellites used for augmentation of GNSS signals do not reach to the high Arctic, as illustrated by the WAAS and EGNOS coverage maps in Figure 2.

[7] Next Generation SATCOM System: http://www.doncio.navy.mil/CHIPS/ArticleDetails.aspx?id=5407
[8] Arctic Fibre Project to Link Japan and UK: http://spectrum.ieee.org/telecom/internet/arctic-fibre-project-to-link-japan-and-uk; http://motherboard.vice.com/read/twenty-four-milliseconds-why-the-arctic-is-going-fiber-optic
[9] Northern News Services Online: http://www.nnsl.com/preview/newspapers/stories/jun8_15af.html

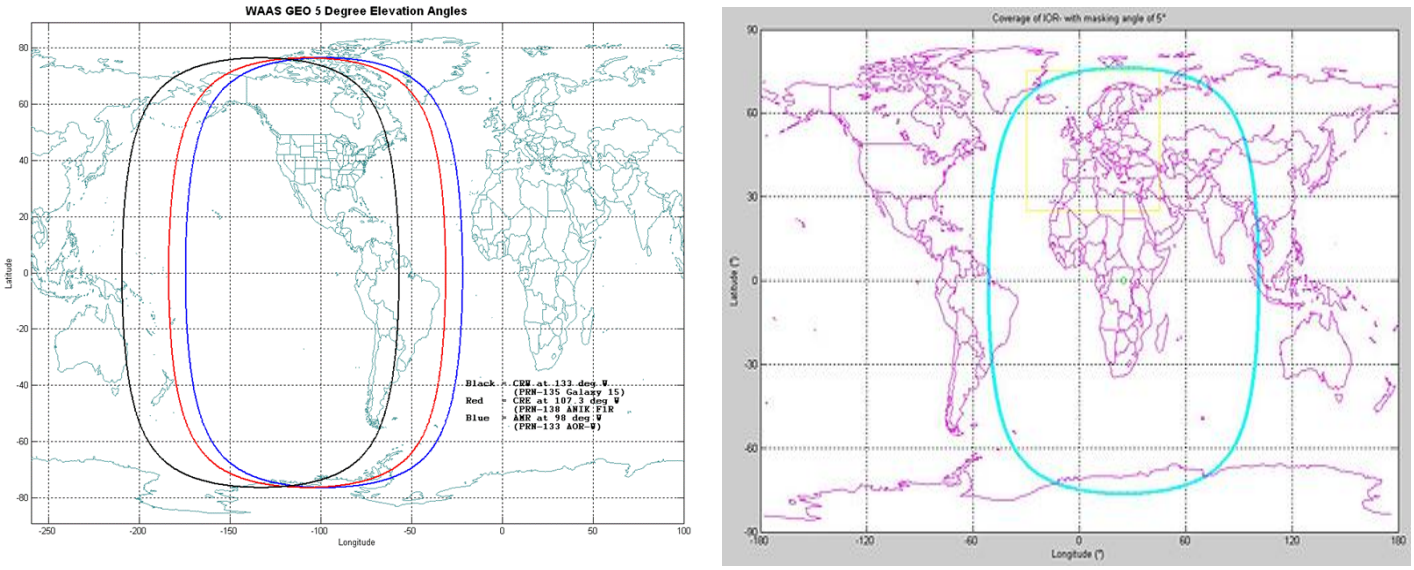

Figure 2: Coverage of WAAS (left map) and EGNOS (right map)

Given the ubiquitous nature of GNSS, there are synergies that exist in combining this technology with EO in an application. Among the many important applications of integrated EO and GNSS are:

- EO Validation: In situ or mobile sensors combined with GNSS receivers allow real-time feedback of ground information that can be used to validate remotely sensed information in a satellite image. For example, a field technician equipped with a GNSS locator can provide information on land and vegetation classes to support supervised classification of EO imagery.
- Sensor Fusion: GNSS equipped sensors can provide real-time measurements to fuse with EO to provide enhanced information products. For example, ocean buoys can provide real-time information on currents, winds and sea surface temperatures (SSTs) to fuse with satellite-derived SSTs, winds and surveillance data, along with ocean models to allow for drift forecasting. The fusion of these data can be used to forecast drifted positions of icebergs or search and rescue targets (abandoned vessels, persons in the water).
- General Navigation: GNSS equipped vehicles, vessels and aircraft can be used to locate one's position within an EO image. Navigation through ice is a good example of this, whereby EO imagery provides details of ice conditions, and GNSS provides real-time positions to allow vessels to avoid hazardous ice conditions.
- Crowdsourcing: In the age of the smart phone, crowdsourcing allows citizen scientists to engage in real-time collection of vast quantities of data over vast regions (countries, continents). In the context of EO, crowdsourcing can be thought of as a

specific example of EO validation or sensor fusion. For example, tourists that are participating in adventure tourism site visits in Northern regions can provide information on wildlife, icebergs or sea ice that would be of interest to other tourists. These data, being geolocated, can be integrated with satellite derived information to provide a total picture, in map format, of conditions in the field. Additionally, many community-based monitoring programs based on Indigenous knowledge use geolocationing technology to complement their efforts to monitoring their local environment (see for example Figure 13 in Section 5.3.4).

4.3 SPACE-BASED AIS

4.3.1 Context of AIS and Space-based Missions

In 2000, as a part of the Safety of Life At Sea (SOLAS) regulations, the IMO added Automatic Identification Systems (AIS) to the shipboard navigational carriage requirement for a number of ship categories. These categories are ships of 300 tons (gross) or greater that travel internationally, cargo ships of 500 tons gross or greater, and all passenger ships. The requirement came into force for these ships in December 31, 2004 and the system is known as “Class A” AIS. After this date, all ships in service in the said categories were mandated to operate their AIS equipment continuously except where international agreements allow navigational data to be protected. In 2007, “Class B” AIS was introduced for small craft, including pleasure vessels. National governments can add carriage requirements onto those specified by the IMO. For example, requirements in the United States are described on the U.S. Coast Guard Navigation Center website.[10]

AIS was conceived mainly as a collision avoidance system and is based on regular VHF transmission and reception of short binary messages containing information about the ship’s identity and includes its position, speed and course. These are “dynamic data”. “Static data”, such as the ship’s name, IMO number, cargo type and estimated time of arrival (ETA), are also transmitted but less frequently. The AIS system is specified in an International Telecommunication Union (ITU) document ITU-R M1371. The latest version is #5, published in February 2014. AIS systems can also be used for other types of safety-related messaging as well as base station interrogations and commands.

The AIS systems are based on Time Domain Multiple Access (TDMA) channel access method. This means that short messages are sent during specific time slots. To avoid confusion when signal traffic is high, schemes are adopted to ensure that signals are not transmitted simultaneously by different ships into the same time slot. For Class A, this is an automated process known as Self-Organizing TDMA (SOTDMA). In this method, a transceiver actively

[10] United States Coast Guard Navigation Centre website: http://www.navcen.uscg.gov/

searches for an appropriate empty slot before transmitting. For Class B, a transceiver first listens to a slot to determine if anyone is using it and, if it is free, proceeds to transmit. This is known as Carrier-Sense TDMA (CSTDMA).

AIS messages are divided into various types as defined by the National Marine Electronics Association (NMEA) in the NMEA 0183[11] and ITU protocols. There are a total of 24 Class A and Class B messages defined in the protocols.

When AIS is operated as a terrestrial system, the SOTDMA protocols ensure that signals from different ships do not, for the most part, interfere with one another. However, the number of time slots is limited to 2,250 on each of two VHF channels with slots reassigned every 60 seconds. The obvious limitation to this arrangement is in areas with very high shipping density where some signals may be dropped. To avoid this, the system is configured so that weaker signals at far ranges are omitted. The end result is a reduction in the size of a communications cell, thereby maintaining the primary functionality as a collision avoidance system.

The cellular structure of the SOTDMA system implies that the use of AIS, as a means for building or adding to a Recognized Maritime Picture (RMP), requires receiving stations spaced along the coast at regular intervals. As a VHF-based system, AIS signals are “line of sight” with typical ranges dependent on the height of the transmit and receive antennas. This is normally on the order of tens of kilometers. When the coastline is long, establishing a network of receiving stations for complete coastal coverage is extremely expensive. Even with the complete coastline covered, the AIS signals only allow the detection of vessels within a few tens of kilometers from the coast. AIS transponders on buoys or ships can function as AIS repeaters with received signals from vessels offshore piped to a station on the coast; however, using this as a means to extend signal range is impractical.

4.3.2 S-AIS Advantage

The placement of an AIS receiver on a satellite seems to be an appropriate means of addressing the wide area surveillance requirement. The receiving antenna pattern can extend from horizon to horizon and provide a large swath width; the power transmitted in Class A AIS is sufficient to result in a signal to noise ratio of more than 10 dB for orbital altitudes of less than 1,000 km even at the horizon. The situation with regard to Class B signals is marginal, depending on the satellite orbit and the antenna.

In recent years, work has been undertaken by a number of government and commercial entities to deploy S-AIS receivers for the purpose of satellite-based ship information and tracking. As a result, a number of current and planned AIS-capable missions are operational

[11] National Marine Electronics Association website: http://www.nmea.org/store/index.asp?show=cprd&cid=8

or pending. Orbcomm, exactEarth and Spire are notable examples of commercial S-AIS surveillance service providers.

4.3.3 Limitations of S-AIS

4.3.3.1 Signal Collisions

The main problem with satellite reception of AIS signals is message collisions resulting in a significant number of lost messages. This is due to the coverage area provided by the satellite-based antenna receiving signals from a number of different AIS cells on the surface. The effect of signal collisions is to reduce the probability of receiving an uncorrupted AIS signal and, unless special signal processing efforts are made, more than 20 percent of signals tend to be lost when the number of ships in the receiver footprint is greater than about 1,000[12]. The probability of detection for S-AIS systems is typically expressed in conjunction with a defined number of vessels within the field of view of the receiving antenna. Detection rates of 90% when there are 2,000 vessels or less in the field of view are thought to be achievable; however, many believe that practical detection rates are expected to be 70-80% based in part on processing of exactEarth Aprizesat-3 data. For the most part, the achievable performance is still being determined through trials in which S-AIS data is combined with that from other sensors.

Signal collisions can be reduced by increasing the directivity of the receiving antenna at the expense of the Area Coverage Rate (ACR). However, the number of signals transmitted during the time the ship is in the antenna footprint affects the probability of detection so that a determination of the optimum choice of antenna pattern is not trivial. Moreover, the design and mounting of a large VHF antenna on a small satellite may be troublesome.

Over some parts of the globe, interference from ground stations can occur because there remain active frequency allocations in the VHF bands nominally reserved for AIS. In North America, the few remaining allocations should lapse in a few years. In the Baltic, Russia and South East Asia, land-based transmitters interfere with the AIS signals from ships. These reduce the probability of detection, sometimes to near zero.

Signal processing can be applied to enhance reception performance by partitioning the signals according to their properties. For example, the satellite motion will cause the signals from ships ahead of the satellite to be Doppler shifted. This can be interpreted as a form of beam sharpening, which at least can enable signals from ahead of the satellite to be separated from signals from astern.

[12] London Research and Development Corporation website: http://www.london-research-and-development.com

A further problem arises on occasions when messages do not fit into the AIS time slot at the satellite. This occurs due to the variation in range between the transmitter and satellite receiver within the antenna footprint. The range can vary by 2,000 km. This results in a time spread up to 7 ms when compared with the length of one bit transmitted at 9,600 bps (or about 0.1 ms per bit). This represents a shift of over 70 bits in the message. The problem can be overcome by shortening the message by reducing the number of message information bits and increasing the number of trailing bits. The United States Coast Guard (USCG) Joint Spectrum Center has proposed a new message along these lines – AIS message type 27. This would be transmitted at a reduced rate to accommodate a large number of ships in the satellite receiver antenna footprint. New protected frequencies have also been recommended (AIS channels 3 and 4) to facilitate more effective satellite detection of AIS. This has been recommended by the ITU as a part of report ITU-R M.2169. Nonetheless, the recommendation has not yet been adopted by the IMO, and so the new frequencies are not mandated as yet. In spite of this, some manufacturers have implemented the ITU recommendations within new AIS transponders and satellite manufacturers are designing AIS receivers to receive the new frequencies and messages. If IMO formally adopt the ITU recommendations, it appears that transition to the new satellite AIS format should be swift and smooth.

4.3.3.2 Time Latency

Time latencies are dependent on the data transmission path and processing time required to decode messages. In order to receive information, S-AIS receivers must be within the field of view of the transmitting vessel. This observation time is on the order of transmission frequency for Class A messages, which is at maximum three and six minutes for dynamic and static information, respectively. Typical observation times are on the order of 10-15 minutes for a single satellite pass. Once received on the satellite, data must be transmitted to the ground via downlink. Downlink availability is very much dependent on the number and location of ground stations available in the network.

The time latency required for the reception of an AIS signal from a ship located anywhere in the world is dependent on the number of satellites available for signal reception. The minimum number for a specified time latency can be estimated by assuming that it is possible to construct a constellation that samples the earth's surface more or less uniformly. The rate of scanning of a single satellite can be estimated in terms of the swath width and the speed of a satellite over the ground. Assuming a circular orbit, the number of satellites required as a function of altitude can be derived for a given time latency. Nominally, 20-25 satellites are required for a time latency of 10 minutes. This assumes that there is a ground station in view of the satellite to provide a data downlink. In practical application, if the satellite must travel some distance after signal reception before coming in range of a ground

station for downlink, this additional time must be included in the overall time latency determination.

4.3.4 Synergy of S-AIS and EO

The primary synergy expected between S-AIS and EO is in applications involving ocean surveillance. These include, for example, fisheries surveillance and Exclusive Economic Zone (EEZ) monitoring, drug and piracy interdiction, defence and sovereignty, iceberg surveillance and others. The synergy is achieved by fusing targets from both data sources into one information map. The benefits of this data fusion include:

- Dark target detection: identification of suspicious marine vessels that do not transmit an AIS signal.
- Spoof detection: detection of vessels that alter their AIS-reported position to appear to be in a different location (e.g. to be just outside an EEZ).
- False alarm detection: discrimination between ships and other ship-like targets in EO imagery (e.g. icebergs, sea ice fragments) to improve vessel surveillance or ice hazard charts.
- Target confidence: improvement of the confidence of EO-derived vessel surveillance through S-AIS-based target confirmation.
- Oil slicks: S-AIS confirmation and tracking of vessels responsible for oil slicks detected in EO data.

The above list of fusion benefits is by no means exhaustive, but it is representative of the types of products that could be derived or enhanced by using S-AIS in combination with EO. These benefits have translated into new EO missions that include AIS receivers to maximize the synergy of co-located sensors. Examples of these missions include RADARSAT Constellation Mission (RCM) and TerraSAR-X Next Generation (TSX-NG).

4.3.5 S-AIS and EO Performance in Polar Regions

In the context of determining gaps and impacts of S-AIS and EO integration, consider the following two scenarios of EO missions:

- Constellation approach: fusing data from virtual constellations of EO satellites with data from constellations of AIS satellites.
- Co-located Sensor approach: building missions that co-locate AIS receivers onboard EO missions, and fusing the data from the two sensors.

The constellation approach is one that is available by default, considering that there are an increasing number of S-AIS satellites being launched each year. Therefore, a new mission can benefit from this synergy without any additional effort, beyond developing the infrastructure, applications and methodologies to effectively fuse the data. However, there is a legitimate question to the value of including an AIS receiver onboard an EO mission. In

the case of RCM, this question was studied by Defence R&D Canada (Parsons et al., 2013) to support the inclusion of an AIS receiver on each of the three RCM SARs. In this study, a statistical model was created on AIS detection performance using a global ship density map. Measures were created on probability of detection (POD) and probability of SAR to AIS association (POA). Two case studies were examined:

- Fusion of RADARSAT-2 ship detection information with a commercial AIS satellite provider (exactEarth); and
- Fusion of single satellite RCM ship detection information with AIS data from its onboard receiver, and with data from the AIS receivers from its two sister satellites (RCM is a three satellite constellation).

Aside from the imaging differences between RCM and RADARSAT-2, the primary difference between the two scenarios is twofold:

- The RADARSAT-2 scenario has a data latency between its imaging time and that of the commercial AIS satellites, creating a situation that could lead to ambiguities in SAR to AIS association, especially in high ship density areas.
- The RCM scenario uses AIS receivers with the new message format and additional AIS channels (3 and 4). The RADARSAT-2 scenario used the S-AIS data that were available commercially at the time of the study, which did not include data from the new channels.

The study derived vessel POD and POA for a number of different locations, primarily because POD and POA are highly dependent on ship density (and other factors). For the purposes of brevity, only the relevant Polar Region[13] scenarios are considered here.

- Canadian Arctic: this region has a relatively low ship density (343 – 2,141 ships in the AIS field of view) and thus the POD and POA are high for both scenarios. The POA was 100% for RCM and 62-94% for RADARSAT-2.
- North Sea: this region has a relatively high ship density (9,166 – 22,068 ships in the AIS field of view) and thus the POD and POA are poor for RADARSAT-2, but higher for RCM thanks to the reduced latency and additional channels. The RADARSAT-2 POA varied from 16% to 50%, while the RCM POA was 100%.

The summary above is an oversimplification of the study output since there are many details that have not been discussed. Nonetheless, it shows that there is value associated with including an AIS receiver on a mission that also has a maritime surveillance role, such as a SAR. However, the context of this study was preparation for RCM, a mission that will be launched in 2018. In addition, the study was conducted in 2012/13, and since the study was completed, there has been a proliferation of commercial AIS missions to reduce EO to AIS

[13] Antarctica was not considered to be a relevant scenario to DRDC within this study.

ambiguities. Furthermore, these new AIS missions are expected to include channels 3 and 4, thus improving AIS POD. As an example, the SPIRE constellation will include 10 satellites with a 34 minute revisit time, including channels 3 and 4[14]. In contrast, the RADARSAT-2 scenario used data latencies of 3-6 hours. The reduced latency coupled with the additional channels should significantly increase the SAR to AIS association.

[14] Spire website: http://spire.com, retrieved Oct 1, 2015.

5 ANALYSIS OF EXISTING NON-SPACE PRODUCTS AND SERVICES

This chapter provides an analysis of how information provided by atmospheric, land and ocean sensor networks are being integrated with EO space missions focused on the polar regions to develop products and integrated information services to meet current user needs.

5.1 INTRODUCTION

Observing systems are an important part of understanding and adapting to Arctic environmental, and by extension, social change across a number of domains (Brigham, 2011; Eicken, Lovecraft, & Druckenmiller, 2009; Krupnik, Igor & Jolly, Dyanna, 2002; Lovecraft, Meek, & Eicken, 2012; Serreze & Barry, 2011; Smit, Hovelsrud, & Wandel, 2010). Information provided by atmospheric, land, ocean and other in situ sensors and sensor networks are complementary to space-borne EO systems. Data from in situ sensors can be used for geospatial ground-truthing and rectification, model calibration, supporting increased understanding of environmental and social processes, and multiple levels of regulatory compliance where the spatial or temporal resolutions of in situ may fill information needs that cannot be met by EO (Bartsch, Heim, Buchhorn, Ottlé, & Debart, 2012; Doxaran et al., 2012; Fichot, Kaiser, & Hooker, 2013; Gardner & Richter-Menge, 2012; Hill et al., 2013; Shuman & Hall, 2014; Tesche & Zieger, 2014; Wang et al., 2012).

Understanding the past and current status and future trajectory of the Polar in situ observing system is an important aspect of establishing a comprehensive vision and plan for the European Space Agency (ESA) moving forward. This section of the report is focused on providing a broad overview of this system across disciplines and scales ranging from local to global.

5.1.1 Overview of the Polar In Situ Observing System

Considering the planning and cost involved in the deployment of EO systems, space-borne remote sensing data collection programs are typically well documented and have accessible, long-term data archiving and dissemination mechanisms in place. This is not necessarily the case for in situ sensors and networks. While this may be the situation for cases such as weather sensor systems (i.e. the World Weather Watch system), many sensors are deployed for specific, time-limited scientific or operational purposes without long-term data archiving and dissemination systems in place (Lee, Eicken, Kling, & Lee, 2015; NAS (National Academy of Sciences), 2006, 2014).

The Needs Analysis component of this study identifies a number of parameters that do not meet minimum requirements particularly with respect to spatial resolution. Parameters identified include *snow depth on sea ice*, *snow water equivalent, snow depth,* and *snow*

cover. In situ data for these parameters exist, for example see Brown and Brasnett (2010). Although these data are measured in situ or through aviation methods as part of an operational program, the authors are clear that the data are not homogeneous. It is derived from operational data that is subject to frequent changes. The data are presented as interpolated grid with a low spatial resolution of 24km x 24km cell spacing. While these data are useful, they are not optimal for use with the high spatial and temporal resolution polar EO systems being developed by ESA. On the other hand, Gardner et al. (2012) report a study where very high spatial resolution in situ, airborne and submarine observations of *combined snow and ice thickness*, *sea ice freeboard*, *snow depth on sea ice, and ice open water identification* are available for use in assessing uncertainty of EO platforms. This work was not, however, part of systematic observing system activity but rather was a specific study for this purpose. A similar study is reported by Wang *et al.* (2012). These studies confirm the need for high-resolution in situ (including aerial) data for use with EO data, while concurrently highlighting the sporadic, opportunistic nature of in situ observations in the polar regions.

The NASA IceBridge program, initiated in 2009, with yearly flight campaigns both over Greenland, the Arctic Ocean and Antarctica, and less frequently over Arctic Canada and Svalbard ice caps, is an example of a well-documented multisensory airborne campaign, with well-defined parameters available through NSIDC. Data includes many types of parameters currently not available from space, including snow depth on sea ice and radar thickness of ice caps. A similar but smaller ESA programme to validate the CryoSat-2 mission (CryoVEx campaigns 2003-16, irregular annual intervals) also provides systematic data sets on ice thickness, Ku-band radar, scanning lidar and high-resolution imagery over land and sea ice, including data from field camps, for Arctic Ocean regions north of Greenland, Canada and Svalbard as well as selected ice cap data from Canada, Greenland and Svalbard. Data are available through the ESA Campaigns web site.

Permafrost parameters were also identified in the Needs Analysis as failing to meet minimum requirements in terms of spatial resolution. There are some preliminary positive results indicating that airborne and space-borne remote sensing can partly address this deficit (Gangodagamage, 2014; L. Liu & Schaefer, 2012). In situ measurements are still required to meet the temporal requirements of permafrost monitoring that can involve situational awareness and to validate and calibrate remote sensing techniques. The Global Terrestrial Network for Permafrost (GTN-P, http://gtnp.arcticportal.org) (Burgess, Smith, Brown, Romanovsky, & Hinkel, 2000) was established to monitor permafrost and the active layer using over 850 bore holes and 168 stations respectively. While this is an important achievement, maps of the distribution of observation sites (http://gtnp.arcticportal.org/index.php/resources/maps) indicate that the network is not well distributed over space and there are large areas without coverage. This is problematic

both in terms of the direct need for in situ data and the need for these data to support EO methods. If in situ data does not exist, EO data cannot be validated and calibrated for these areas, potentially limiting its usefulness. Thus in situ data are integral to EO and establishing an effective system is important for ESA in terms of meeting their goals.

While an integrated polar sensor system does not yet exist, significant global effort towards a sustained, global observing system in both polar regions has been expended over the past decade. The Arctic system is emerging under formal bodies such as the Arctic Council and the Sustaining Arctic Observing Systems (SAON) program (an advisor on this report) as well as more ad-hoc and opportunistic methods such as the International Polar Year and individual research projects. The Antarctic operates under the Antarctic Treaty System in conjunction with activities of the Committee on Environmental Protection and research bodies such as the Standing Committee on Antarctic Research (SCAR). To assist ESA in understanding how in situ observations can be discovered and used to complement EO products, this report section presents a multi-scale model of the emerging polar sensor networks (Figures 3 and 4) that if supported by the global community, including ESA, has the potential to make significant progress towards establishing a global polar in situ observation system.

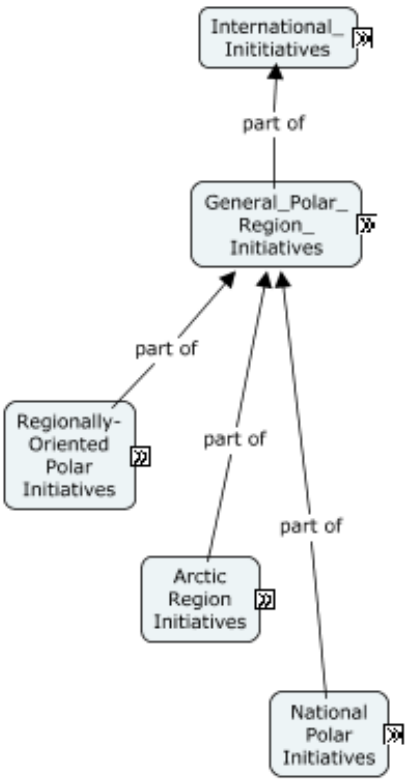

Figure 3: A subset visualization of the model developed depicts the nested geography of observing networks

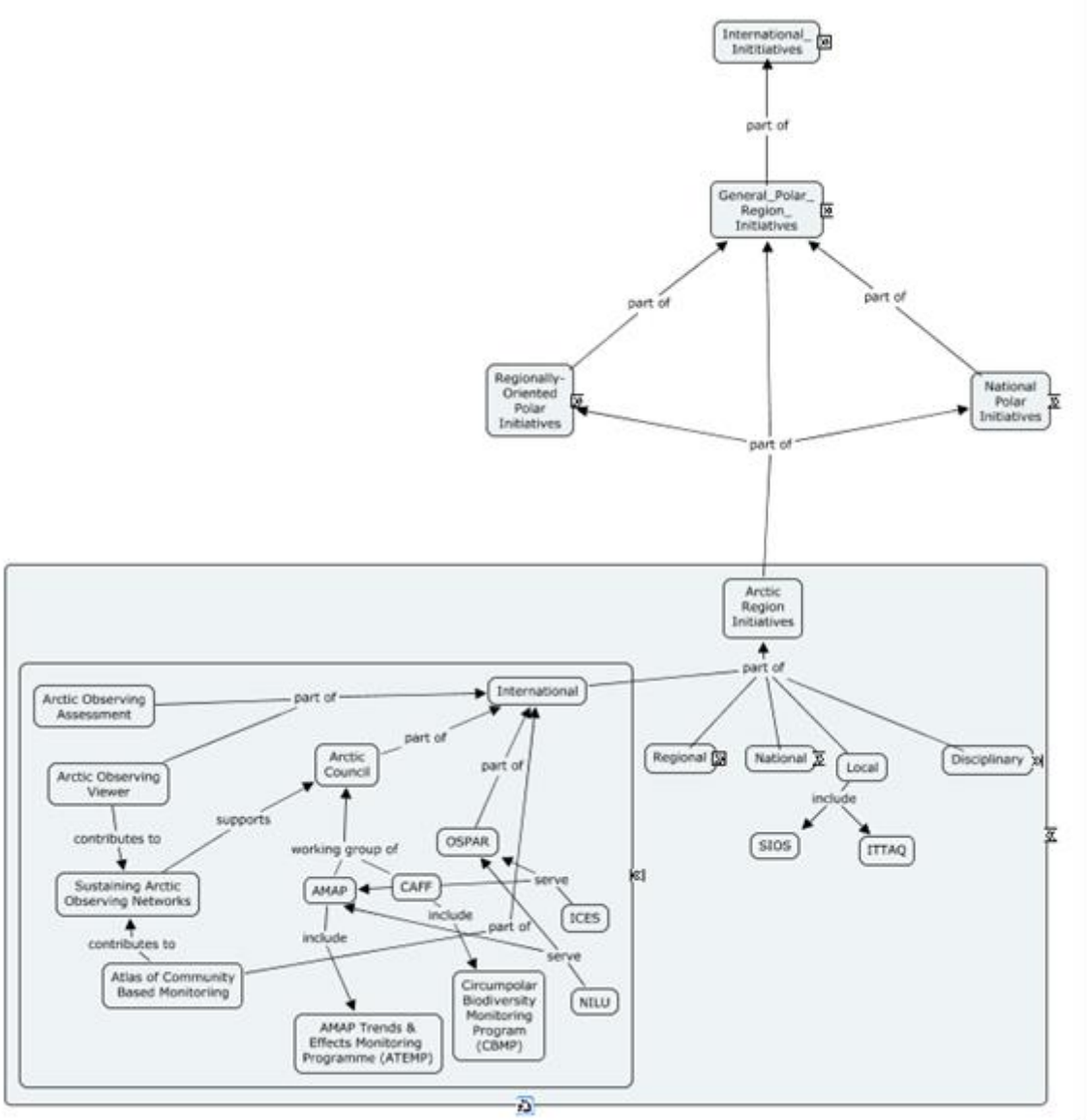

Figure 4: Exploring the model reveals individual observing projects and programs at different geographic scales.

To establish the elements of this network model, this report starts with a review of selected historical projects. While these projects were completed in the past, they are still important. It is well established that a long-term, systematic polar observing system does not exist and has never existed. Establishing a long-term observing record in support of change detection, for example, necessarily involves incorporating data from a number of disparate historical projects.

5.2 Historical Review

Polar observing is not new. The challenges of collecting, managing, discovering and accessing polar observations have existed for centuries. The First International Polar Year took place in 1882-1883 and some of these observational data still exist and are freely available (see http://www.arctic.noaa.gov/aro/ipy-1/). More than fifty years ago, the International Council for Science (ICSU) World Data Center (WDC) system was developed to manage observational data resulting from the International Geophysical Year of 1957-58. These data centers still exist or have been merged for inclusion in the World Data System, the successor to the WDC system. There are many other historical data sets in existence in various archives around the world in addition to the traditional knowledge held by Arctic Indigenous peoples. All of these data are important in understanding global environmental change. While a detailed review of historical resources is beyond the scope of this report, a small selection of resources is summarized.

The International Geophysical Year (IGY), often considered the third International Polar Year, resulted in the establishment of the WDC system (Ruttenberg, 1992). The WDC system included many data centers and sets relevant to the polar regions:

- WDC for Biodiversity and Ecology
- WDC for Climate
- WDC for Geology
- WDC for Glaciology, Boulder
- WDC for Glaciology, Cambridge
- WDC for Glaciology and Geocryology, Lanzhou
- WDC for Human Interactions in the Environment
- WDC for Marine Environmental Sciences
- WDC for Oceanography, Obninsk
- WDC for Paleoclimatology
- WDC for Remote Sensing of the Atmosphere

These resources have now been migrated to the World Data System (http://www.icsu-wds.org/), which can act as an important resource of in situ observations in support of EO applications. Several past observation projects focused on Europe and were driven by the European research community. SCANNET was a network of field site leaders, research station managers and user groups in northern Scandinavia and Europe that collaborated from 2001 to 2010 to improve comparative observations and access to information on environmental change in the North. SCANNET partners provided facilitated long-term observations in terrestrial and fresh water systems. The partners also acted as a portal to information on existing environmental data sets from key locations in the Arctic and easy

access to important environmental information and research activities within the SCANNET region. In 2010, the SCANNET collaborators were successful in obtaining FP7 funding for the International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT) initiative, discussed in Section 4.3.4.

DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) was an integrated ice-atmosphere-ocean monitoring and forecasting system designed for observing, understanding and quantifying climate changes in the Arctic. DAMOCLES was specifically concerned with the potential for a significantly reduced sea ice cover, and the impacts this might have on the environment and on human activities, both regionally and globally. The DAMOCLES Project officially ended on 31st May 2010, however it made a major contribution to the IPY and the observation data resources have persisted through the follow-on ACCESS project (see http://access.met.no/metamod/search/topics_and_variables)

As indicated, the International Polar Years (1882-83, 1931-33, 1957-58 (IGY), and 2008-09) are seminal milestones in the history of polar observing. A number of major observation systems and coordination efforts were established or matured during the last IPY including (Summerhayes, 2011: 359):

- Sustaining Arctic Observing Systems (SAON)
- Integrated Arctic Ocean Observing System (iAOOS)
- Pan-Antarctic Observing System (PAntOS)
- Southern Ocean Observing System (SOOS)
- Global Cryosphere Watch (GCW)
- Polar Satellites Constellation
- Polar Climate Outlook Forum
- International Arctic System for Observing of Atmosphere (IASOA)
- AMAP Trends and Effects Monitoring Programme (ATEMP) (established 1991)
- Circumpolar Biodiversity Monitoring Program (CBMP)
- A variety of human-based observational activities and indigenous monitoring (e.g. Bering Sea Sub-Network, Exchange for Local Observations and Knowledge of the Arctic (ELOKA))

An extensive and detailed treatment of all of these initiatives is provided by Summerhayes *et al.* (2011). The lifespan of some of these initiatives are limited to the duration of IPY, while others continue (e.g. SAON, GCW, SOOS, ATEMP, CBMP). The major ongoing initiatives are included in the network model presented in this report.

The preceding review is a small sampling of the legacy in situ observation data collection initiatives and in many cases these data are readily available. These data are relevant to EO applications whether the case is using the in situ measurements to ground truth historical

EO data, or training, calibrating or validating models. Because Arctic in situ data are difficult and expensive to collect, the legacy data outlined here is a valuable resource in an integrated polar observing system. To meet the needs identified in the User Requirements Report, ESA may need to access legacy data and possibly invest in "data rescue" to make important data sets available.

5.3 A Review and Model of Current In situ Observing System Initiatives and Networks

As indicated, a comprehensive integrated polar (or Arctic or Antarctic) observing system does not yet exist to readily support or integrate with EO applications (Lee et al., 2015; NAS (National Academy of Sciences), 2014). Systems are fragmented at many levels including funding, operational, and technical. Progress is being made as indicated through the organizations and networks documented in the subsequent review. Lacking a complete network, we present a partial network model that includes key initiatives at a number of geographical and organizational scales (Figure 5). The top-level category (Figure 5, Level 1) includes broad global initiatives for observing all regions of the planet. An example of this is the WMO World Weather Watch system and its component Global Observing System (GOS). Level 2 includes broad regional initiatives that address both polar regions across a range of disciplines, for example the Global Cryosphere Watch or initiatives that address both poles but are driven by narrower regional interests and/or funding such as the European Union (e.g. EU-PolarNet). Level 3 includes national programs engaged in monitoring both polar regions. These entities include projects and programs focused on or driven by a specific nation (e.g. Canada, Norway). This level includes regions with national and local initiatives (e.g. Community Based Monitoring). The fourth and fifth levels include initiatives that are specific to the Arctic or Antarctic regions respectively (e.g. Sustaining Arctic Observing Networks, Southern Ocean Observing System). Note that the categories are not mutually exclusive. Local initiatives can be part of international initiatives and vice-versa. The objective of this model is to provide a framework to allow systematic discovery of and access to observation data identified in the Environmental Information Requirements Report and useful in conjunction with EO applications.

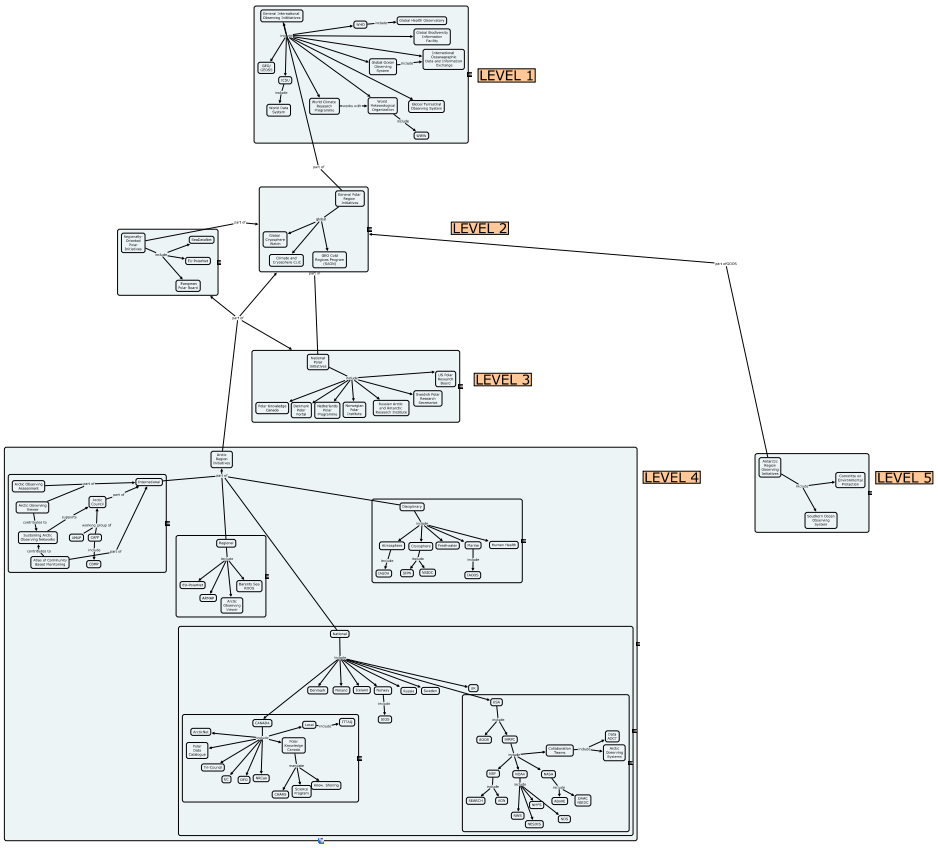

Figure 5: Although the details are obscured, this diagram provides a sense of the overall nature of the model observing system presented. Detailed sub-network diagrams are presented in subsequent figures.

5.3.1 Level 1: General International Observing Initiatives

This level groups broad global initiatives that look at observing for all regions of the planet. The model is not comprehensive; however, the initiatives included in Figure 6 have been identified as highly relevant to polar research and policy.

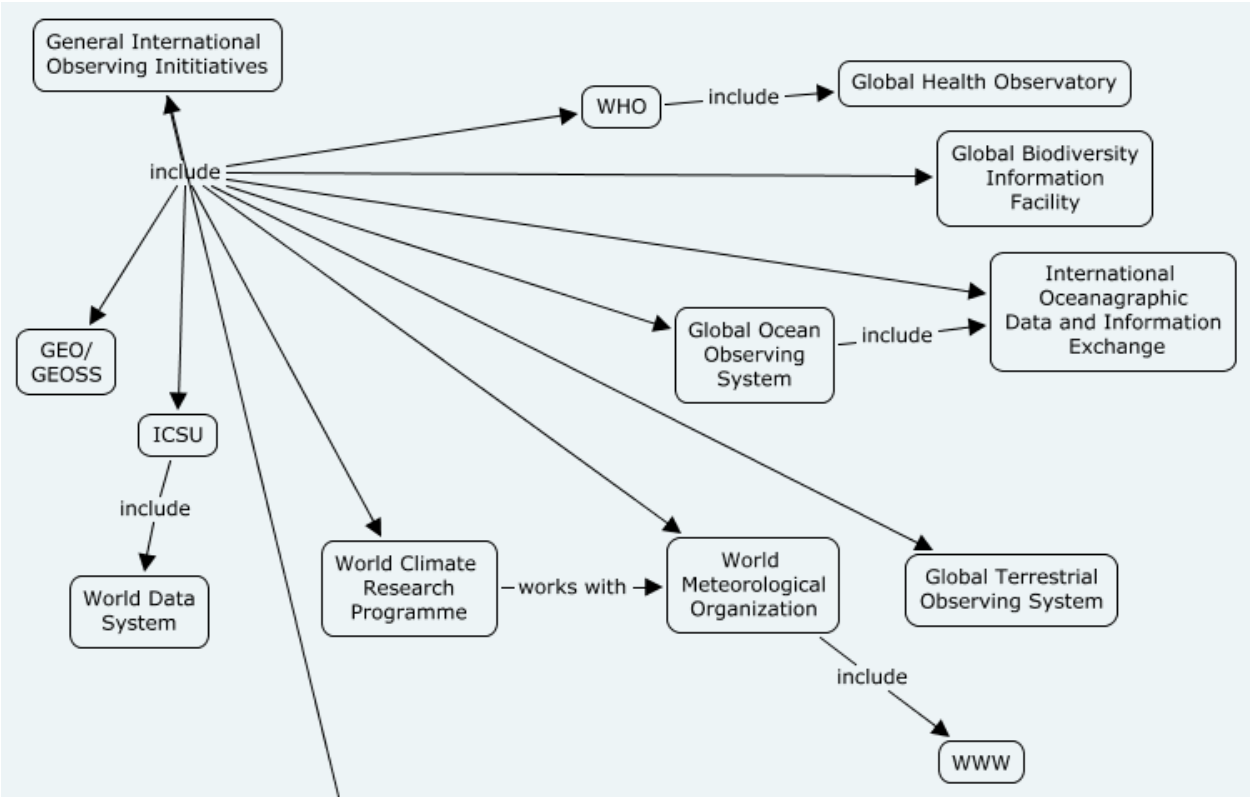

Figure 6: Selected general international initiatives relevant to polar in situ observing systems across disciplines.

The Group on Earth Observations (GEO) (https://www.earthobservations.org/): GEO envisions decision- and policy-making supported by Earth observations and information that is coordinated, comprehensive and sustained. GEO's primary technical activity is the development of a Global Earth Observation System of Systems (GEOSS) that will use world-wide Earth observation resources across multiple Societal Benefit Areas (e.g. agriculture, biodiversity, climate, ecosystems, health, water and weather) and make those resources available for better informed decision-making. At the time of writing, there are discussions underway between members of GEO, SAON and other members of the Arctic science community to more closely align GEO and SAON and thus we should expect a closer link between GEO and polar region activities.

World Climate Research Program (WCRP) (http://wcrp-climate.org/): The WCRP is aiming to facilitate analysis and prediction of variability in the Earth system. Specifically, broad objectives of the WCRP are to: determine the predictability of climate; and determine the effect of human activities on climate. A focus of WCRP research is on observing changes in the components of the Earth system (atmosphere, oceans, land and cryosphere) and in the interfaces among these components. WCRP includes specialty groups on observation and analysis (http://www.wcrp-climate.org/index.php/unifying-themes-data/) and data (http://www.wcrp-climate.org/WDAC.shtml/). While WCRP does not provide data services,

they do have significant intellectual capacity in the area of polar observations both in situ and EO.

International Council for Science *(ICSU)* World Data System *(WDS)* (*http://www.icsu-wds.org/*)**:** The WDS is an Interdisciplinary Body of the ICSU. The goals of the WDS are to: enable universal and equitable access to quality-assured scientific data, data services, products and information; ensure long term data stewardship; foster compliance to agreed-upon data standards and conventions; and provide mechanisms to facilitate and improve access to data and data products. WDS does not manage an observing system; however they are very engaged in a number of initiatives including science policy and science data management through CODATA and the WDS. WDS is very involved in the data publication and citation movement which will help organizations such as ESA and their clients to more readily discover and access data. Additionally, they were a convener of the 2013 Polar Data Forum and are serving in the same role for the 2015 Polar Data Forum.

World Meteorological Organization (WMO) (*http://www.wmo.int/*): The WMO is a specialized agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. WMO promotes cooperation in the establishment of networks for making meteorological, climatological, hydrological and geophysical observations, as well as the exchange, processing and standardization of related data, and assists technology transfer, training and research. A flagship WMO program relevant here is the World Weather Watch and its components (https://www.wmo.int/pages/prog/www/index_en.html) including its polar activities (e.g. see Global Cryosphere Watch in next section).

UN Global Terrestrial Observation System (GTOS) (*http://www.fao.org/gtos/*): GTOS is a programme 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. While no strong link to the polar regions is apparent, GTOS has the potential to contribute to a polar observing system.

Global Ocean Observing System (GOOS) (*http://www.ioc-goos.org/*): GOOS is designed and being implemented to embrace the oceans as a single entity, to provide a global view of the ocean system. GOOS is the oceanographic component of GEOSS, the Global Earth Observing System of Systems and IOC, UNEP, WMO and ICSU. Additionally, *IODE* (*http://www.iode.org/*) the International Oceanographic Data and Information Exchange (IODE) aims 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 and is part of GOOS. Polar

initiatives such as the Southern Ocean Observing System are also part of GOOS which is effectively acting as a global aggregator of oceans data.

Global Climate Observing System (GCOS) (http://www.wmo.int/pages/prog/gcos/index.php?name=AboutGCOS): GCOS is a corresponding WMO programme for development of inventories of essential climate variables (ECV's), and has been the main inspiration for the ongoing ESA Climate Change Initiative. Examples of the latest GCOS proposed set of ECV's can be found in *Implementation Plan for the Global Observing System for Climate in support of the UNFCCC, GCOS-138, October 2010 (WMO-TD/No. 1523),* available online at http://www.wmo.int/pages/prog/gcos/index.php,

Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/): GBIF is an international open data infrastructure, funded by governments. GBIF operates through a network of nodes, coordinating the biodiversity information facilities of Participant countries and organizations, collaborating with each other and the Secretariat to share skills, experiences and technical capacity. There are already strong connections between GBIF and the Antarctic biodiversity community through http://www.biodiversity.aq/ and the Arctic community through CBMP.

WHO Global Health Observatory (GHO) (http://www.who.int/gho/en/): GHO is an initiative of the World Health Organization to share data (through their website) on global health, including statistics by country and information about specific diseases and health measures. While health cannot be directly observed using EO technology, "environmental health"[15] is a major concern in the Arctic as indicated by formation of initiatives such as the Arctic Monitoring and Assessment Program. EO products can be used to establish many relevant parameters and phenomena. Additionally, data from systems like GHO can be considered for ancillary use in processing EO data, providing indicators for key societal issues that are of utmost importance in the Arctic region as implied by development of nationally focused tools such as the Nasautit tool published by Inuit Tapiriit Kanatami (http://www.inuitknowledge.ca/naasautit). Moving forward, tools such as this can be used to help guide ESA in establishing societal priorities.

Level 1 Summary: The review presented demonstrates that there are many general international observing initiatives that are highly relevant to the polar regions. For example, the WMO World Weather Watch can serve needs identified in the Environmental Information Requirements Report Section 3.1.1 *Atmosphere, Climate and Weather Change Information*, or GOOS and the IODE can serve Section 3.1.3 *Ocean State and Coastal Zone*

[15] Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments. http://www.who.int/topics/environmental_health/en/

Change Information. These initiatives are both a source of and conduit to relevant in situ data; however they can also act as initiatives through which ESA can identify potential EO applications and users. Currently, in the Arctic, SAON and its Committee on Observing Networks and Arctic Data Committee (http://arcticdc.org) are working to create a working model to ensure communication and data sharing between these initiatives and the Arctic research community. Similar efforts are being discussed within the Standing Committee on Antarctic Data Management. ESA can benefit from engaging in these efforts to ensure connectivity to these global initiatives.

5.3.2 Level 2: General Polar Region Initiatives

Figure 7 illustrates a sample of initiatives that address in situ observing in both polar regions.

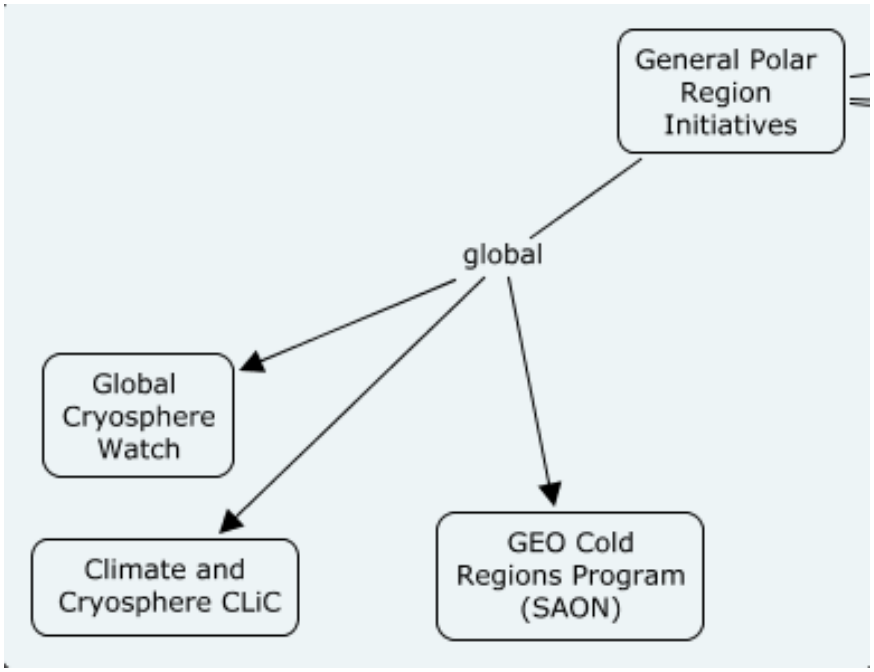

Figure 7: Selected initiatives addressing observing in both polar regions.

WMO – Global Cryosphere Watch (GCW) (http://globalcryospherewatch.org/about/): GCW[1] is an international mechanism for supporting all key cryospheric in situ and remote sensing observations. GCW includes observation, monitoring, assessment, product development, prediction, and research. It provides the framework for reliable, comprehensive, sustained observing of the cryosphere through a coordinated and integrated approach on national to global scales to deliver quality-assured global and regional products and services. The observing component of GCW is a component of the WMO Integrated Global Observing System (WIGOS). Through WIGOS and the WMO Information System (WIS), GCW provides a fundamental contribution to the Global Earth Observation System of Systems (GEOSS). There is also a connection between GCW and the SAON Arctic Data Committee (http://arcticdc.org).

Climate and Cryosphere Project (CLIC) (http://www.climate-cryosphere.org/): CliC 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 cryospheric 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. CliC also publishes significant findings regarding the role of the cryosphere in climate and recommends directions for future study. While CLiC does not provide data services, they do have significant intellectual capacity in the area of polar observations both in situ and EO.

GEO Cold Regions (GCR) Initiative: The previously documented GEO program includes the GCR initiative, which will soon be effectively linked to the Sustaining Arctic Observing Networks program. GCR aims to archive, manage, and provide access to in situ and remotely-sensed metadata and data sets for monitoring the cryosphere through appropriate national, regional and global systems and centres. This includes development of a distributed cyber(e)-infrastructure to collect, manage, publish and share polar research results and implementation of multi-disciplinary interoperability following a brokering approach, supporting the SCAR data policy and the IASC statement on data management (IASC (International Arctic Science Committee), 2013) and in accordance with European and international standards, including GEO/GEOSS and Infrastructure for Spatial Information in the European Community (INSPIRE).

5.3.2.1 Level 2.1: Regionally-Oriented Polar Initiatives

Besides general global polar initiatives there are also polar-focused projects and programs that originate from a particular region. Three examples from Europe, shown in Figure 8, are briefly discussed here as an indication of initiatives that are of relevance to ESA.

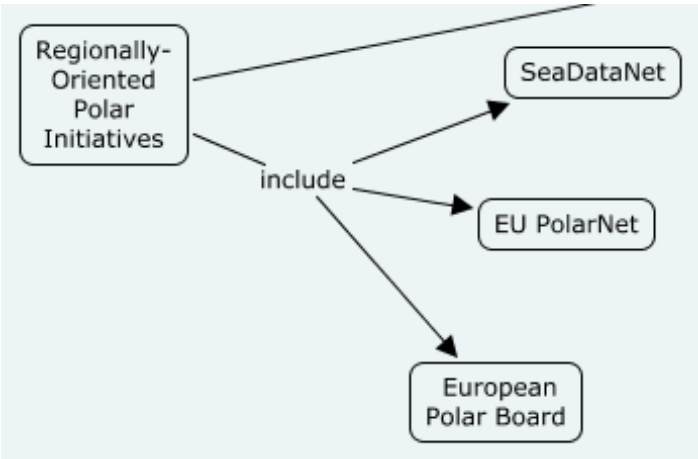

Figure 8: Initiatives that address both poles but are driven by regional interests and/or funding.

European Polar Board (EPB) http://www.europeanpolarboard.org/: The EPB is an independent European Organization of Directors and Managers of the major European National Polar Programmes. Thus it provides an important hub for connecting to individual national programs (sampled in Section 5.3.3). The EPB is concerned with major strategic priorities in the Arctic and Antarctic and has members from national operators and research institutes in 17 countries. The European Polar Board Strategy Action Group (http://www.europeanpolarboard.org/activities/action-groups/epb-strategy-group/) is, at the time of writing, seeking input on strategic directions.

A new program, *EU-PolarNet http://www.eu-polarnet.eu/* is a large consortium (17 countries, 22 institutions) that will develop and deliver a strategic framework and mechanisms to prioritise science, optimise 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 benefits from its close cooperation with the European Polar Board (EPB), as outcomes from EU-PolarNet will add long-term value to EPB activity in providing strategic science policy advice to the European Commission and other international bodies. The EU-PolarNet strategic framework includes *Task 3.1– Polar Platforms: research ships, stations, aircraft and autonomous instrumentation*, *Task 3.2– Satellites, communication and remote sensing*, *Task 3.3 – Data Management and Interoperability.* Although EU-PolarNet is in the early stages of its development, and is a time limited Horizon-2020 project, it could potentially develop into an important node in the in situ data network that will support EO applications.

SeaDataNet http://www.seadatanet.org/ is a European regional initiative focused on the marine domain. SeaDataNet has developed an efficient distributed Marine Data Management Infrastructure for the management of large and diverse sets of data deriving from in situ and remote observation of the seas and oceans. Professional data centres, active in data collection, constitute a Pan-European network providing on-line integrated databases of standardized quality. The on-line access to in situ data, meta-data and products is provided through a unique portal interconnecting the interoperable node platforms constituted by the SeaDataNet data centres. The SeaDataNet infrastructure already links 90 national oceanographic data centres and marine data centres from 35 countries riparian to all European seas.

Level 2 Summary: This section presented a sample of general initiatives that cover both polar regions. GCW and CLiC are science-focused but recognize observation and data systems as a foundational component of polar science. GCR is focused on data with recognition of the importance of serving societal needs and communities of practice. Like the Level 1 global initiatives, these are both a source of or conduit to relevant in situ data, and a method for ESA to connect to the user community. They are important as data

aggregator nodes and as hubs for intellectual capacity and connections to the polar research community. As such they should be closely monitored and included in ESA's strategy for linking in situ observations with EO applications. Regionally-oriented polar Initiatives based in Europe may be of particular interest to ESA as they can provide links to important regional initiatives that may act as a good staging ground for global applications.

5.3.3 Level 3: National Polar Initiatives

5.3.3.1 Level 3.1: National Initiatives for Both Polar Regions

Monitoring and observing systems are often initiated at the national level whether by government agencies or university-based researchers. In many cases, countries have established one or more organizations to coordinate polar research and observation programs. This report necessarily outlines a small sampling of national programs; however we attempt to provide a sense of the types of observing activities carried out under national programs. These programs are critically important when considering influencing the design of observing systems and discovery of and access to in situ observation data. Thus organizations like SAON are placing a major focus on inventories of national programs. ESA can take advantage of organizations such as SAON and the EU Polar Board (and eventually EU-PolarNet) to make connections to national programs. This discussion does not provide a detailed account of these programs, but does provide links to a sample, illustrated in Figure 9, to provide a sense of how different countries coordinate national efforts.

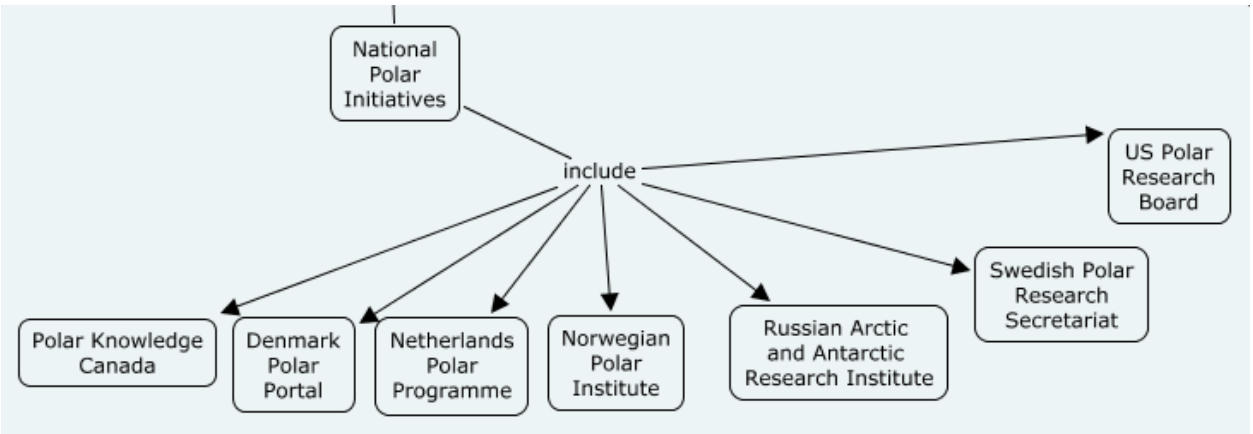

Figure 9: Selected National Polar (Arctic, Antarctic) Initiatives, includes projects and programs focused on or driven by a specific nation (e.g. Canada, Norway). This level includes regions with nations and local initiatives.

A number of countries coordinate polar science and related data collection through a national polar institute. This includes the Norwegian Polar Institute (NPI) (http://www.npolar.no/en/), which is Norway's central governmental institution for scientific research, mapping and environmental monitoring in the Arctic and the Antarctic. Similarly, the National Institute of Polar Research (NIPR) in Japan

(http://www.nipr.ac.jp/english/) is a nationally recognized inter-university research institute that is conducting comprehensive scientific research and observations in polar regions. This model does not guarantee that all polar observation activities are managed by the national institute as there may be some university research or operational activities that are carried out independently. However, it does provide a high level of national coordination in Japan that in turn engages with regional and international coordination efforts. In Denmark, a consortia of research organizations have come together to disseminate EO and climate model based data through the Polar Portal (http://polarportal.dk/en/home/) and recently the government has moved to facilitate polar research cooperation on observing, monitoring and other matters through the formation of a small Polar Secretariat (http://ufm.dk/en/research-and-innovation/international-cooperation/the-polar-secretariat/the-polar-secretariat),), which has established a coordination web site for logistics and projects at (www.isaaffik.dk). The Polar Secretariat works closely with the Greenland Self Rule government departments of Nature, Climate and Research.

Canada has recently merged the Canadian Polar Commission and the Canadian High Arctic Research Station (CHARS) to form Polar Knowledge Canada (http://www.canada.ca/en/polar-knowledge/). This body has responsibility for overseeing strategy and activities in both polar regions and is directly contributing to understanding in situ observing activities through national level reporting (see http://bit.ly/1iEtvEZ). The system in the U.S. is a complex one that encompasses organizations like the U.S. Polar Research Board (http://dels.nas.edu/prb/) and the relatively new Interagency Arctic Research Policy Committee http://www.iarpccollaborations.org/index.html. These bodies are working to coordinate relatively heterogeneous systems that comprise thirteen federal agencies including the National Science Foundation (NSF) that has its own Arctic Observing Network and Antarctic programs. While there is still an improvement in coordination required, strategic statements from the White House are providing an impetus for coordination.

National bodies focused on both polar regions can provide a high organization of in situ observations for EO applications. However, as indicated in the next section, details are often found through programs specific to a polar region.

5.3.3.2 Level 3.2: National Initiatives for the Arctic

A brief review of national Arctic data initiatives in the U.S. and Canada reveals a complex web of agencies and other organizations. Despite the complexities, the network nodes identified are often hosting actual data resources rather than playing a coordinating role as with the Level 1 and 2 organizations. Thus, ESA and its users need to be aware of these nodes when aiming to fulfill in situ data requirements in support of EO applications.

However, the Level 1, 2 and 3.1 actors can still play an important role of carrying out the challenging and time consuming task of identifying and coordinating data resource centres.

Canada

Arctic data in Canada is managed across many agencies and organizations with a sample presented in Figure 10. Organizations such as the aforementioned Polar Knowledge Canada and the Tri-Council of federal research funders (National Science and Engineering Research Council (NSERC), Social Sciences and Humanities Research Council (SSHRC), Canadian Institutes of Health Research (CIHR)) provide funding and high level coordination, while federal departments and agencies engage in specific monitoring and data activities. For example, Environment Canada is very engaged in the Circumpolar Biodiversity Monitoring Program (CBMP) described later in this section. Research networks such as ArcticNet (http://www.arcticnet.ulaval.ca/) perform research and have established an observing network (http://www.arcus.org/files/page/documents/19695/arcticnet_document.pdf). ArcticNet data are distributed by the Polar Data Catalogue (https://www.polardata.ca/), a data directory and centre.

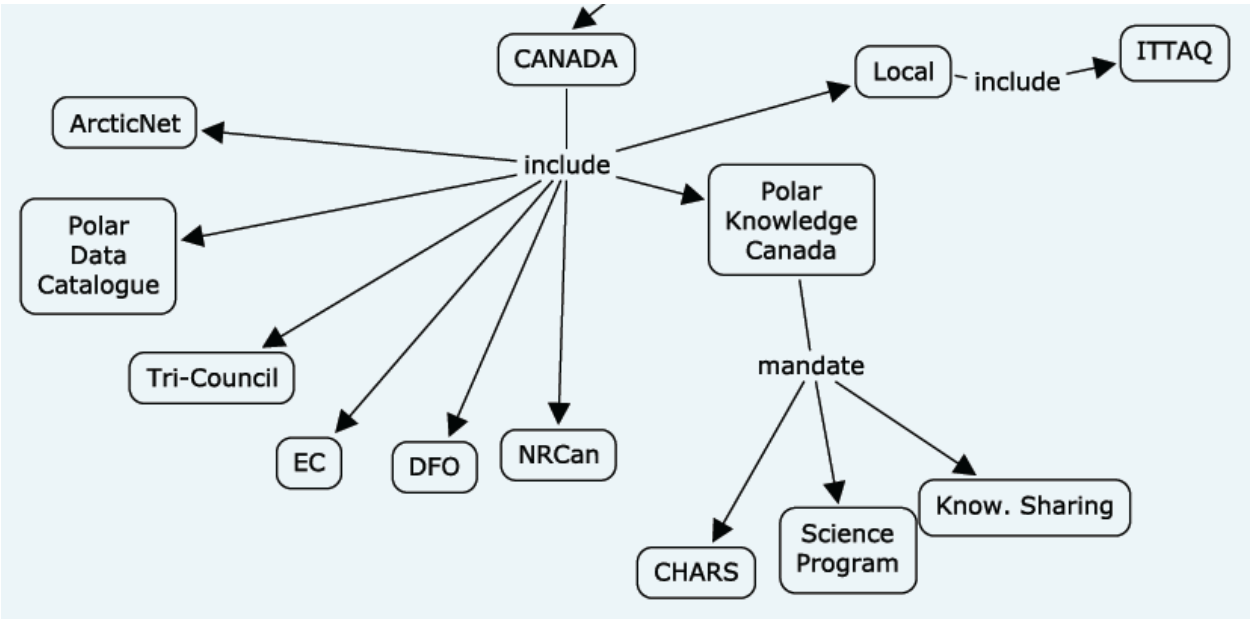

Figure 10: Arctic agencies and bodies in Canada providing or facilitating Arctic observing data collection and management.

United States

As illustrated in Figure 11, the U.S. has a complex system of national Arctic initiatives with coordinating bodies such as the relatively new Interagency Arctic Research Policy Committee (IARPC) (http://www.iarpccollaborations.org) that aims to coordinate federal agency activities. The IARPC Arctic Data Coordination Team and the Arctic Observing Systems Team play a coordination role along with programs such as the National Science Foundation Arctic

Observing Network. The agencies in turn fund individual projects and data centres to work together to make in situ data available. This includes many programs; for example, the NSF-funded Study of Environmental Arctic Change (SEARCH) program, the NOAA-led Alaska Ocean Observing System (http://www.aoos.org/), and the National Snow and Ice Data Center (http://nsidc.org) funded primarily by NASA and NSF, to name but two.

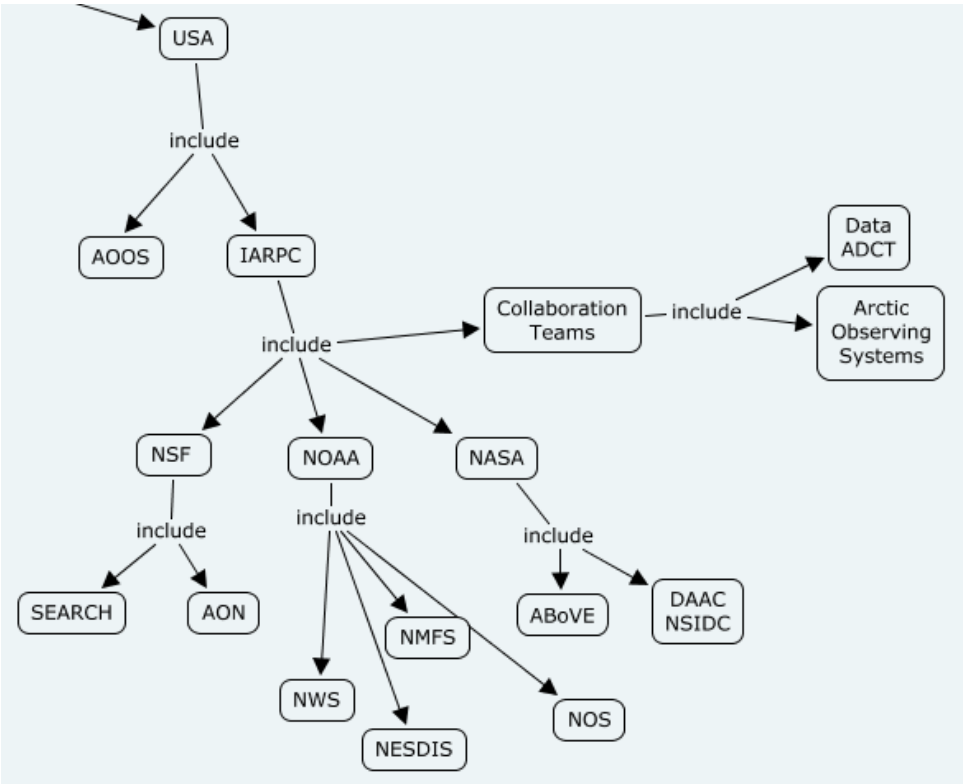

Figure 11: Selected Arctic agencies and bodies in the U.S. providing or facilitating Arctic observing data collection and management.

Level 3 Summary. Whether originating from operational or research activities, national programs are the level at which many polar in situ data resources are made available. Two examples of Arctic national networks were presented. For an organization such as ESA this presents an opportunity and a challenge. Working through national networks and programs will provide access to a wide variety of different in situ data for use in EO applications. However, the number and complexity of these networks and programs is high resulting in potentially large engagement effort. Supporting and using Level 1 and Level 2 nodes would reduce the effort required on the part of ESA as many of these initiatives work with, coordinate and make data available from national programs (e.g. SAON, European Polar Board, etc.).

5.3.4 Level 4: Arctic Region Initiatives

Like the global system, the Arctic region initiatives are nested and complex ranging from general pan-arctic initiatives to disciplinary initiatives and others, as illustrated in Figure 12.

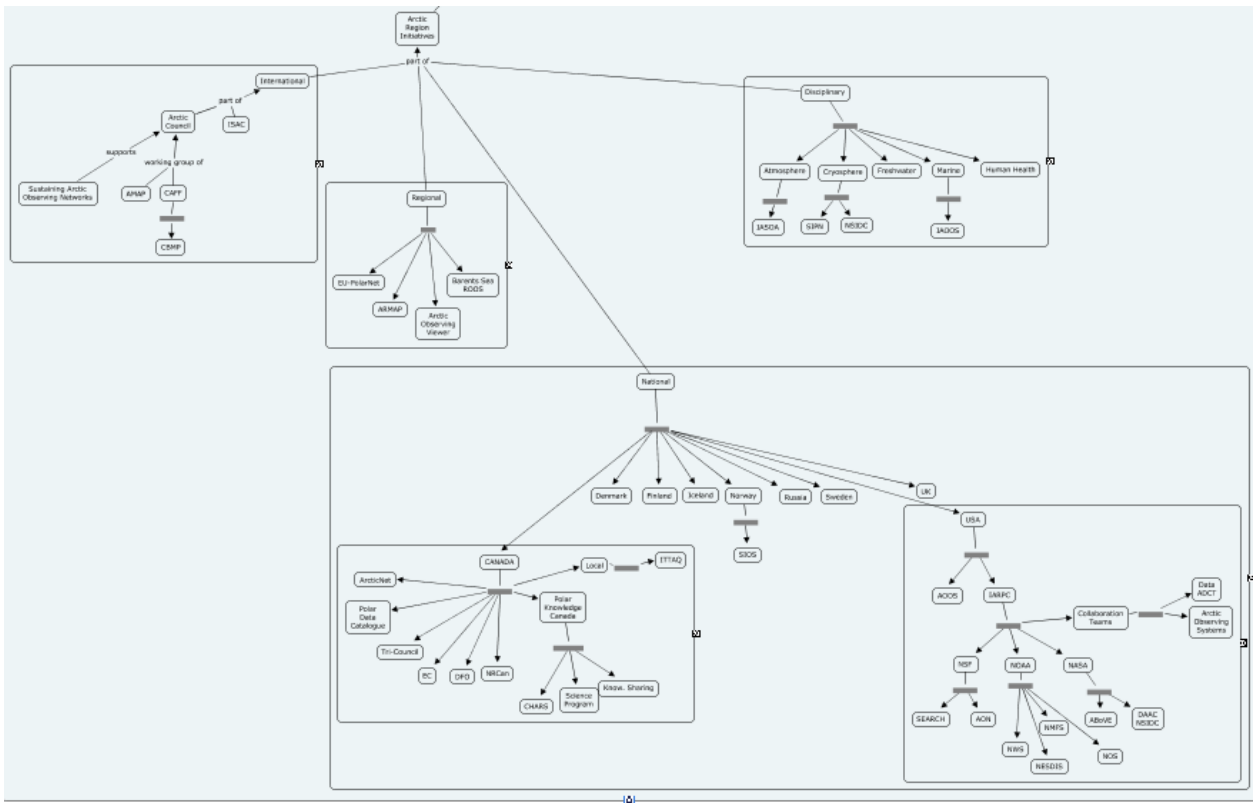

Figure 12: Nested and complex Arctic region initiatives.

5.3.4.1 Level 4.1: Pan-Arctic Systems and Initiatives

Figure 13 identifies some of the major pan-Arctic initiatives dealing with in situ observations.

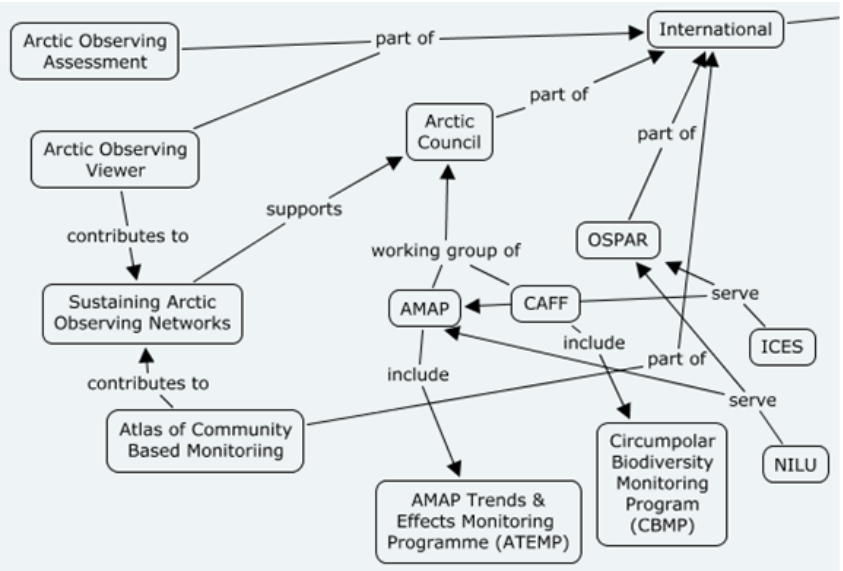

Figure 13: Pan-Arctic initiatives dealing with in situ observations.

The Arctic Council (http://www.arctic-council.org/) 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. Through its working groups, the Arctic Council is engaged in a number of in situ monitoring activities. The Arctic Monitoring and Assessment Program (AMAP) (http://www.amap.no/) has many related activities. For example, the AMAP Project Directory, which has existed for most of AMAP's lifetime, is a web facility for entry and retrieval of information about Arctic research and monitoring activities/projects. It holds descriptions of approximately 300 projects (http://www.amap.no/amap-project-directory). The AMAP Trends and Effects Monitoring Programme (ATEMP) is a harmonized programme for monitoring the trends and effects of contaminants and climate change across the circum-Arctic region.

The AMAP Trends and Effects Monitoring Programme (ATEMP) is a harmonized programme for monitoring the trends and effects of contaminants and climate change across the circum-Arctic region. ATEMP is based largely on ongoing national and international monitoring and research activities and AMAP national implementation plans (NIPs). ATEMP is coordinated with and complements the Circumpolar Biodiversity Monitoring Programme (CBMP) and both of these programmes contribute to the Sustaining Arctic Observing Systems (SAON) initiative. The AMAP Trends and Effects Monitoring Programme is currently being updated. Detailed specifications of the recommended monitoring elements under the various sub-programmes of the ATEMP will be available soon.

OSPAR (http://www.ospar.org/) is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. OSPAR started in 1972 with the Oslo Convention against dumping and was broadened to cover land-based sources and the offshore industry by the Paris Convention of 1974. These two conventions were unified, up-dated and extended by the 1992 OSPAR Convention.

The International Council for the Exploration of the Sea (ICES) (http://www.ices.dk/) is a global organization that develops science and advice to support the sustainable use of the oceans. 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. ICES delivers scientific publications, information and management advice requested by member countries and international organizations and commissions such as the Oslo Paris Commission (OSPAR), and the Arctic Monitoring and Assessment Program (AMAP).

NILU, the Norwegian Institute for Air Research (http://www.nilu.no/) is an independent, nonprofit 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. NILU monitors climate change, global air quality and air pollution transport pathways via observatories in Norway (Birkenes and ALOMAR – Andøya), in the Arctic (Svalbard, Zeppelin) and in Antarctica (Troll). NILU serves as a data centre for AMAP and OSPAR.

The Arctic Council Conservation of Arctic Flora and Fauna (CAFF) is the biodiversity working group of the Arctic Council program and includes the Circumpolar Biodiversity Monitoring Program (CBMP). CAFF/CBMP have created the Arctic Biodiversity Data Service (http://www.abds.is/), which a major aggregator node for in situ Arctic biodiversity data. These data can be used to support EO applications and also require remote sensing data to support biodiversity monitoring and research. The Arctic Council has a number of other relevant working groups including the Protection of the Arctic Marine Environment (http://www.pame.is/), Emergency Prevention, Preparedness and Response (www.eppr.arctic-council.org), and Sustainable Development (www.sdwg.org) and others. All of these groups have connections to in situ data and are users of EO data and thus they are central to this level of the Arctic observing system.

The Sustaining Arctic Observing Networks (SAON) organization (http://www.arcticobserving.org/) was conceived during the International Polar Year (IPY) 2007-08 and formally established in 2012. 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 was established on the initiative

of the Arctic Council (AC) and the International Arctic Science Committee (IASC). SAON has worked with the Arctic research and operational communities and Arctic Indigenous peoples organizations to establish the state of Arctic observing (e.g. through national inventories), observing needs, and organized events to bring communities together to further the discussion (e.g. co-organizing the Arctic Observing Summit series). Starting in late 2014, this work is continuing through two committees: the Arctic Data Committee (ADC) (http://arcticdc.org) and the Committee on Observations and Networks (CON). These committees are actively working to move SAON forward in its mission. This includes further developing the Atlas of Community-Based Monitoring in a Changing Arctic project (http://arcticcbm.org) led by the Inuit Circumpolar Council, which is described below, as well as continuing work by CAFF. SAON is working to understand the state and user requirements of Arctic observing; however, the body does not directly undertake science planning, policy setting, observations, data archival, or funding of these efforts.

In SAON's early stages of development, the so-called SAON Steering Group developed a questionnaire and asked SAON stakeholders to provide information about their Arctic projects. From this and related efforts, a number of tools were developed including partnering in developing the aforementioned AMAP project directory and a prototype system that is available (programmatically) that restructures existing information from external sources:

- http://saon.met.no/metamod/
- http://jrl.dk/SAON/Platforms/ (search for instance for 'Germany'. Source: FARO, INTERACT) ;
- http://jrl.dk/SAON/Programmes/ (search for instance for 'AMAP') ;
- http://www.jrl.dk/SAON/Projects/ (search for instance for 'Canada'. Source: ArcticNet)

Although SAON is relatively early in its development (established in 2012), a new structure and recently renewed executive is resulting in a number of active initiatives to provide the research community and Arctic residents with access to in situ data produced by a sustained observing system.

The Arctic Council and SAON are recognizing the value of community-based monitoring (CBM). While interest in CBM is growing, there has been little coordination of initiatives at a circumpolar level. The Atlas of Community-Based Monitoring was initiated as a task of SAON to help address this gap. It 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. A secondary phase of the project will draw on CBM initiatives inventoried by the atlas, as well as a literature review, and interviews and input from practitioners, to draft a review of the state of CBM in the Arctic (see illustration in Figure 14).

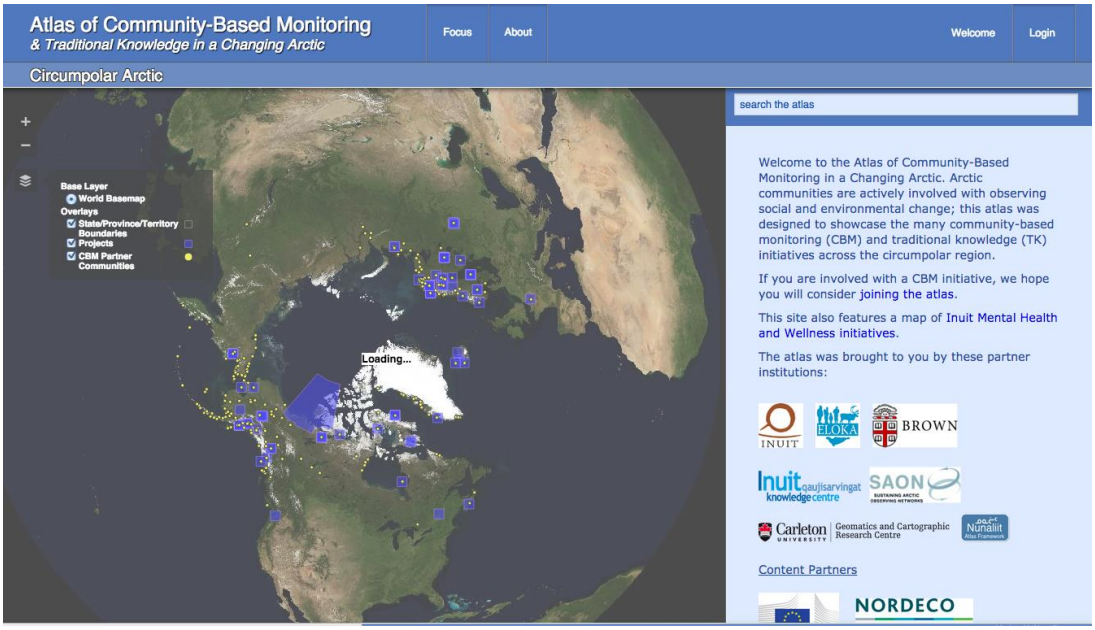

Figure 14: The Atlas of Community-Based Monitoring and Traditional Knowledge in a Changing Arctic provides a spatially organized inventory of CBM initiatives.

There are a number of other projects and initiatives that can inform ESA with respect to Arctic in situ observations. The Arctic Observing Assessment (AOA) is an international effort under the auspices of the Sustaining Arctic Observing Networks and the Interagency Arctic Research Policy Committee to document and visualize available scientific information relevant to Arctic priorities and to measure the relevance of current observing capabilities to user needs (http://www.arctichub.net/arctic-observing-assessment). The Arctic Spatial Data Infrastructure (http://arctic-sdi.org/), an emerging program that will focus on framework data but could act as a conduit for observations, could benefit from remote sensing data.

Level 4.1 Summary: Like those discussed in Levels 1 and 2, pan-Arctic initiatives have a broad scope with respect to the Arctic region; however, they are relatively focused in terms of coordinating Arctic in situ observation systems and making specific observation data available. While much of the data-specific work is being carried out at the disciplinary level (Level 4.3), these bodies are making significant progress in organizing the complexity of operational and discipline-based scientific observations into a coherent system for the Arctic region. In terms of value of engagement effort, this level would be very efficient in terms of a point of connection into the polar in situ observations systems for ESA. These initiatives are neither top-down (global and the potential vagueness), nor are they bottom-up (local and the potential large volume of connections); rather they present a good mediator level that connects to both the global and the local.

5.3.4.2 Level 4.2: Arctic Regional Systems and Initiatives

There are important initiatives that are regionally focused or driven but make important contributions to the overall Arctic observing system, as illustrated in Figure 15.

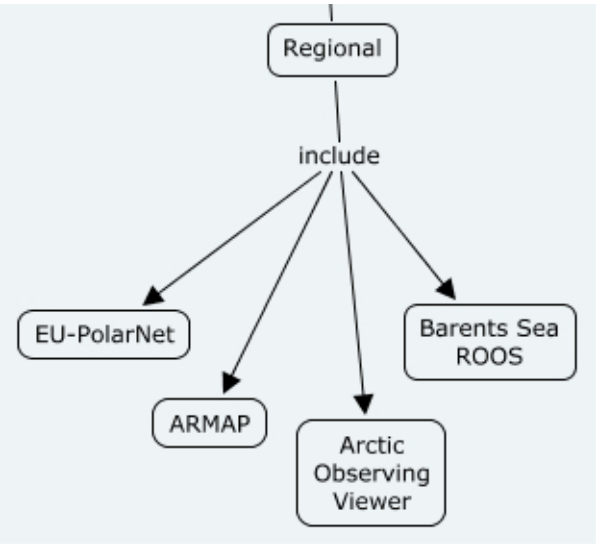

Figure 15: Selected Arctic Regional Initiatives and Systems

Focused primarily on North America, The Arctic Research Mapping Application (ARMAP) (http://armap.org/) 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. The Arctic Observing Viewer (AOV) (http://www.arcticobservingviewer.org) (see Figure 16) helps with visualization, strategic assessment, and decision support for initiatives tied to Arctic Observing. This allows for viewing of the “who,” “what,” “where,” and “when” of Arctic environmental monitoring activities.

The EU-PolarNet observing components have already been discussed as a polar initiative; however, as a partnership of 17 institutions there will be Arctic-specific products that will be relevant to Arctic observing. The Barents Sea Arctic Regional Ocean Observing System (Europe) (http://arctic-roos.org) is another example of a regional observing initiative. 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.

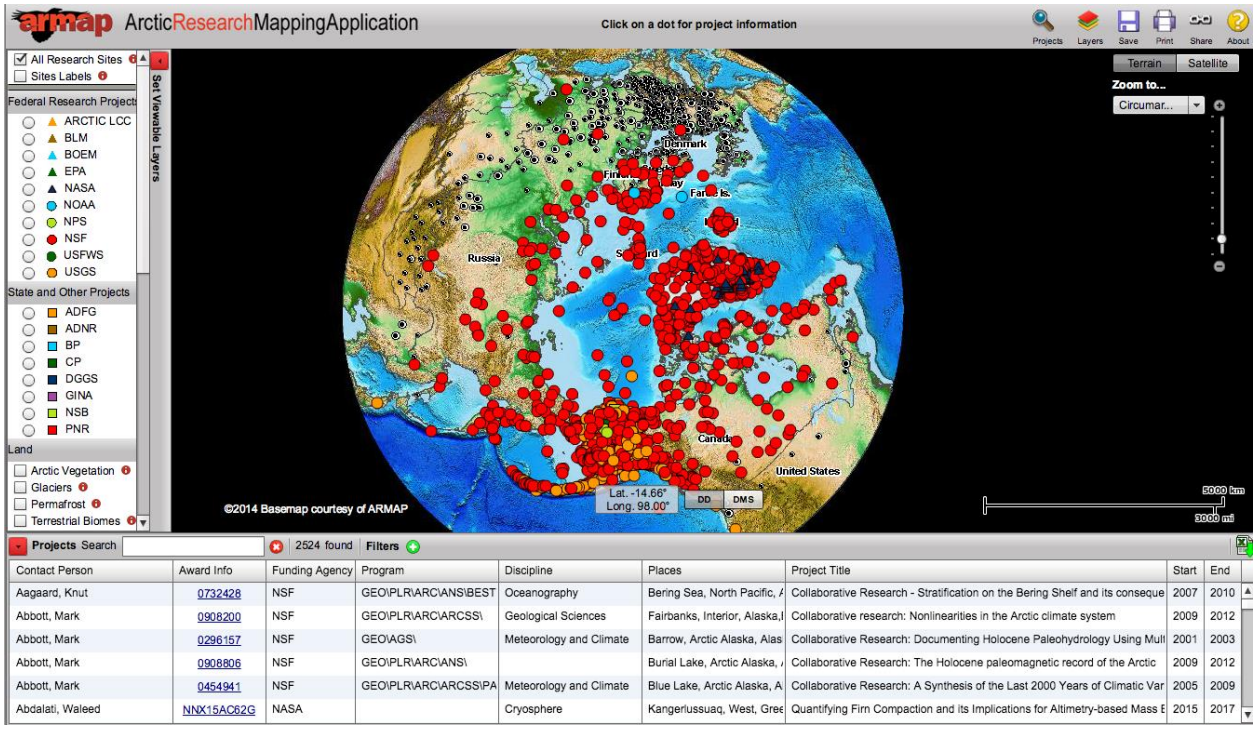

Figure 16: ARMAP provides location and descriptive data about Arctic research with a focus on North America

5.3.4.3 Level 4.3: Disciplinary Systems and Initiatives

Many in situ observing programs are coordinated under academic disciplinary communities. The number of initiatives is large and finding data is still a challenge. However, integrated discovery tools such as the Arctic Data Explorer (http://nsidc.org/acadis/search/) are federating data catalogues to establish "single window" search capabilities. The following discussion presents a small sample of important established or emerging systems.

Atmospheric

Atmospheric monitoring and in situ observations cover a wide range of parameters including but not limited to air temperature, precipitation, humidity, wind, pressure, clouds, greenhouse gas, solar radiation, and atmospheric composition. Many of these parameters are collected and monitored through national or regional programs including those contributing to the aforementioned WMO World Weather Watch. Additionally, there is a major international initiative in place with the mission to advance coordinated and collaborative 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 International Arctic System for Observing the Atmosphere (IASOA) (http://iasoa.org/; http://www.esrl.noaa.gov/psd/iasoa/) is operational and represents the main access point

for Arctic atmospheric observations. In addition to national initiatives, there are also local initiatives in place that are collecting and providing these data. For example, the Silalirijiit project has established a weather station network in the Clyde River region of Nunavuut, Canada and the ELOKA project has made these data broadly available on a day-to-day basis and is working to make the archive available (http://www.clyderiverweather.org/).

Freshwater

There are numerous freshwater observation and monitoring systems and networks in place. While there have been international efforts in this domain for the Arctic, no system has emerged with observations being collected as part of national efforts (e.g. Canada through Environment Canada, http://www.ec.gc.ca/eaudouce-freshwater/). Regional projects are being developed such as the observation and data management system being developed by the Gordon Foundation (http://gordonfoundation.ca/water/mackenzie-river-basin-initiative). Data are also available from historical sources such as the IPY Arctic Great Rivers Observatory project (https://www.aoncadis.org/project/arctic_great_rivers_observatory.html).

Terrestrial

Terrestrial monitoring is spread across many different geographic scales and actors involved in the process. There are several major international initiatives that in turn draw on local and regional activities. The International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT) brings together scientists from diverse domains to study and assess environmental change in the European Arctic and more broadly (quoted from http://www.eu-interact.org/). INTERACT builds on the SCANNET initiative and recognizes the value of effective data management (see (http://www.eu?interact.org/joint?research?activities/data?management/). The permafrost and active layer research community is becoming increasingly organized through the Global Terrestrial Network for Permafrost (GTN-P, http://gtnp.arcticportal.org/). This network includes coordination and data management and dissemination components.

Cryospheric

Activities in the area of cryospheric observations and monitoring cover a broad range of topics including permafrost (categorized under Terrestrial here), snow, glaciers, ice sheets, icebergs and sea ice. Observations originate from both the science and operations communities. The operations (e.g. shipping) community is particularly focused on sea ice and icebergs. Scientific observations of the cryosphere are collected and managed through a number of different projects and programs. For example, the National Snow and Ice Data Center in the U.S. (http://nsidc.org) manages a broad range of cryospheric in situ and EO data from a variety of different programs by NASA, NOAA, the National Science Foundation and others. Examples of this include the Greenland network (GC-Net) of unmanned weather

stations in the interior of the ice sheet. Similar climate stations are operated along outlet glaciers around Greenland in the Danish government PROMICE program, which also supports regular lidar and radar flights around the perimeter of the Greenland ice sheet for monitoring changes. The sea ice and climate observations observations are used in projects such as the Sea Ice Prediction Network http://www.arcus.org/sipn). Operational observations of the cryosphere (e.g. sea ice, icebergs) are collected and managed through a variety of different regional and national initiatives including the EU Copernicus service (http://marine.copernicus.eu/web/45-sea-ice.php) and the participating agencies of the International Ice Charting Working Group (http://nsidc.org/noaa/iicwg/services.html).

Marine

There are many marine observation systems in place such as the aforementioned *Barents Sea Arctic Regional Ocean Observing System* (http://arctic-roos.org/node/94), *SeaDataNet* (http://www.seadatanet.org/) and the regular monitoring of Greenland waters by the Greenland Nature Institute (www.natur.gl). The concept of an international Integrated Arctic Ocean Observing System is being developed; however, this system has not yet been implemented (http://www.arcus.org/files/page/documents/19695/iaoos_document.pdf). Regional efforts such as the Alaska Ocean Observing System (AOOS, http://www.aoos.org) are well established. Industry involvement in marine data collection (see K Reid interview notes, Q. 2 and M. McCammon interview notes, Q. 7) is also on the increase.

Human Health

As with other disciplines, human health monitoring is carried out at a variety of scales over many different programs. A landmark effort was carried out during the International Polar Year 2008-09 under the Inuit Health Survey (http://www.mcgill.ca/cine/resources/his). Inuit Tapiriit Kanatami in Canada hosts the Naasautit project (http://www.inuitknowledge.ca/naasautit). A good example of a health observation and monitoring network is the Circumpolar Health Observatory (http://circhob.circumpolarhealth.org/) (Young, Chatwood, & Bjerregaard, 2013). While health monitoring typically involves direct in situ monitoring (e.g. water sampling) and engagement with human subjects, the broad topic of environmental health is important and remote sensing can contribute to establishing environmental health parameters to complement in situ data (Bechle, Millet, & Marshall, 2013; H. Liu & Weng, 2012).

The aforementioned disciplinary activities and systems are important nodes in the virtual network model and can be used to meet data requirements established through the Environmental Information Requirements assessment. There are ongoing efforts (e.g. Arctic Data Committee, Standing Committee on Antarctic Data Management) to establish an interoperable polar data system that will make data from specific disciplines broadly

available and usable for a range of different applications. As these efforts mature, ESA and users supported by ESA projects can benefit from the in situ data systems established.

5.3.5 Level 5: Antarctic Region Initiatives

With respect to scientific and monitoring activity, the Antarctic region differs from the Arctic in a number of ways. The International Geophysical Year culminated in the ratification of the Antarctic Treaty (signed in 1959, ratified by 12 parties by 1961). The Treaty now has 52 parties with the Antarctic Treaty Consultative Meeting (ATCM) and the supporting Antarctic Treaty Secretariat coordinating scientific and operational activities, including monitoring and in situ observing programs on the continent, under international law. No comparable system exists in the Arctic. Individual circum-Arctic nation states manage activities on a sovereignty model in connection with non-Arctic states through bodies such as the Arctic Council; however, there is no associated legal regime and the Arctic is not considered a global commons.

In very practical terms, Antarctic observations are often more expensive and difficult to collect than in the Arctic. Recognizing that there are some promising possibilities, a recent report by the U.S. National Academies of Science (2015) recognizes that “pursuing a comprehensive coastal/terrestrial observing system across the Antarctic may not be a feasible goal in today’s constrained budget environment”. Lastly, there are no Indigenous inhabitants in Antarctica and thus Community-Based Monitoring programs are not viable. The Antarctic region is more coordinated than the Arctic through environmental protection and scientific bodies under the Treaty system, as illustrated in Figure 17. This section of the report is structured accordingly with a smaller number of categories presented as part of the review.

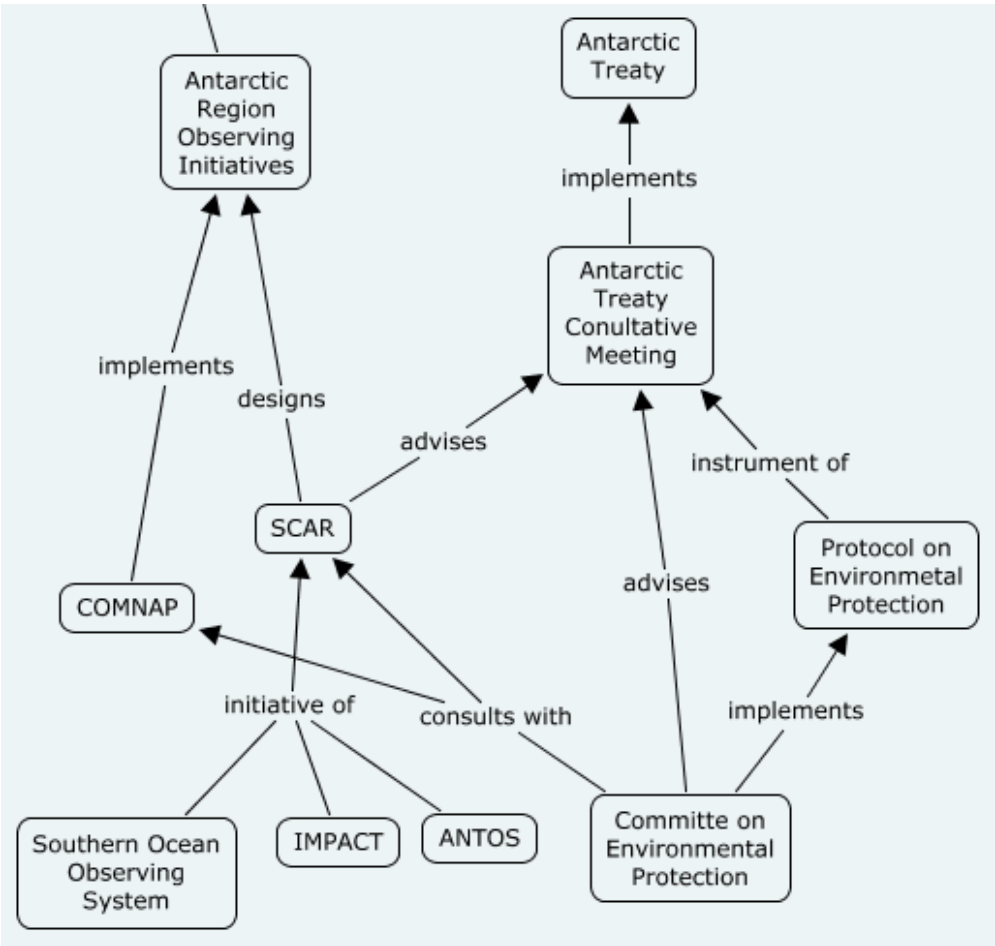

Figure 17: Antarctic observing initiatives exist within a scientific and environmental governance framework under the Antarctic Treaty but implemented by national bodies.

5.3.5.1 Context: Antarctic Environmental Protection Regime

The Antarctic region is complex and the continent and the surrounding ocean are critical components of the global environmental system. The area is remote and in some respects a pristine wilderness. Antarctica is particularly vulnerable to the effects of global environmental change and is increasingly a tourist destination. In an attempt to support the principles of conservation and the management of the impacts related to global and local human activity, a comprehensive legal and policy regime has evolved around Antarctic environmental protection. This includes a number of legal instruments that are directly related to in situ monitoring and observations.

The Protocol on Environmental Protection (The Madrid Protocol, http://www.ats.aq/e/ep.htm) came into force on January 14, 1998 and in doing so, established a comprehensive environmental protection regime for the Antarctic region. The primary advisor to the Antarctic Treaty Consultative Meeting (ATCM), the governance body for the Antarctic) on matters related to the protocol is the Committee on Environmental

Protection (CEP) (http://cep.ats.aq/cep/,) (Sánchez & McIvor, 2007). The CEP advises the ATCM on the protocol and the five annexes of the protocol while working with a number of observers including the Scientific Committee on Antarctic Research (SCAR), the Council of Managers of National Antarctic Programs (COMNAP; see AEMP 2000, https://www.comnap.aq/Publications/Comnap%20Publications/comnap-scar_env_monitoring_handbook_jun2000.pdf), the International Association of Antarctic Tour Operators (IAATO) (http://iaato.org/home), United Nations Environment Program and a number of others. Thus the Antarctic Treaty system, including partner organizations such as COMNAP and SCAR, are a primary driver in the area of monitoring and the collection of in situ observations (see details of AEMP).

5.3.5.2 Context: Antarctic Science Regime

As the primary organizing body for Antarctic science and the official advisory body to the Antarctic Treaty System (ATS), SCAR is also a major driver of monitoring and in situ observations in Antarctica. Through five year Scientific Research Programmes, long-term planning activities such as the recent SCAR Horizon Scan (Kennicutt, Chown, & Cassano, 2014), Standing Scientific Groups and specific projects, SCAR coordinates Antarctic scientific activity, including monitoring and the collection of in situ measurements. This includes an effort to coordinate the effective discovery of and access to data through the SCAR Standing Committee on Antarctic Data Management. Combined with the Environmental Protection Regime, SCAR and related activities comprise the major drivers for observing activities in the Antarctic and thus should be actors that are an ongoing part of the ESA strategy to connect in situ data with EO applications.

5.3.5.3 Summary Review of Existing and Emerging Antarctic Monitoring Initiatives

Environmental Protection

The ATS provides a number of potentially useful ancillary resources that can provide some data from reports and a broad sense of environmental context that may be useful in EO applications (e.g. for ground truthing).

Environmental Impact Assessment Database (http://www.ats.aq/devAS/ep_eia_list.aspx?lang=e): This searchable database allows users to find data resulting from or related to environmental impact assessment (EIA) activities. For example, for a given year or multiple years one can search on the topic of Monitoring Program to establish programs that have some link to the EIA processes. This can reveal specific monitoring programs that may provide or link to in situ data.

The Antarctic Environments Portal (https://www.environments.aq/): The Portal provides an important link between Antarctic science and Antarctic policy. The Portal makes science-based information available to the Antarctic Treaty System's Committee for Environmental

Protection (CEP) and all the Antarctic Treaty nations. The information in the Portal supports the CEP in its development of advice and recommendations to the Antarctic Treaty Consultative Parties on environmental protection. The Portal also enables Antarctic scientists, particularly through the SCAR, to provide independent scientific advice to the Antarctic Treaty including to bring new or emerging issues to the attention of policy makers. All scientific information available through the Portal, including studies including in situ measurements, is based on published, peer-reviewed science and has been through a rigorous editorial review process.

National State of the Environment Reporting: National governments will periodically produce SOE reports that bring together reference to in situ observations by theme or scientific domain (e.g. Australia: http://www.environment.gov.au/science/soe/2011).

Scientific

There are many historical and existing scientific research projects and programs producing in situ observations. The best method for accessing observations produced from these initiatives is through the Antarctic Master Directory (AMD) (http://gcmd.nasa.gov/KeywordSearch/Home.do?Portal=amd&MetadataType=0). Through the AMD, one can hierarchically select a theme (e.g. Cryosphere -> Frozen Ground -> Soil Temperature) and then filter by sensor type (i.e. in situ). This will provide a listing of registered data resources (Figure 18).

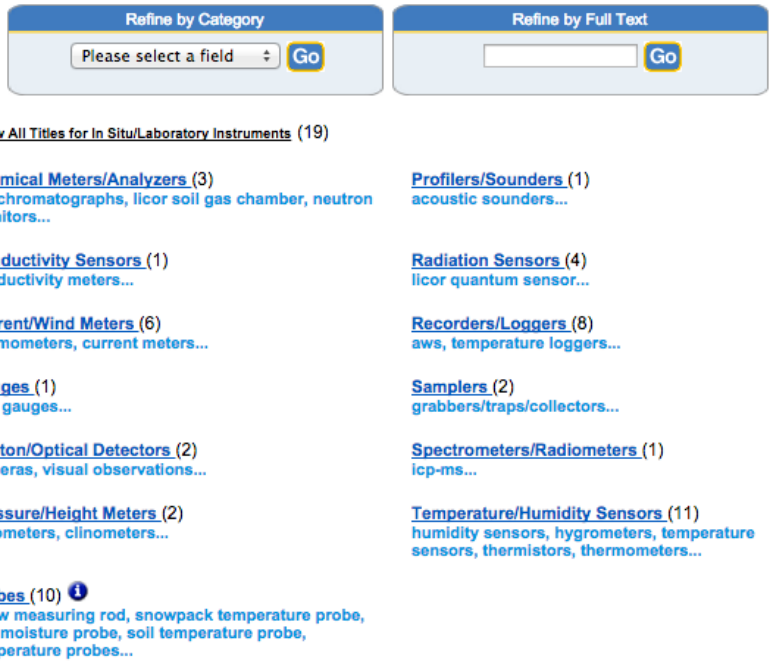

Figure 18: Using Antarctic Master Directory to find current and historical in situ observations

There are several current and emerging Antarctic observing initiatives of note:

Southern Ocean Observing System (SOOS) (http://www.soos.aq/): SOOS is an international initiative with the mission to facilitate the collection and delivery of essential observations on dynamics and change of Southern Ocean systems to all international stakeholders (researchers, governments, industries), through design, advocacy and implementation of cost-effective observing and data delivery systems.

Antarctic Sea Ice Processes and Climate (ASPeCt) (http://aspect.antarctica.gov.au/): ASPeCt is an expert group on multi-disciplinary Antarctic sea ice zone research within the SCAR Physical Sciences program. Established in 1996, ASPeCt has the key objective of improving our understanding of the Antarctic sea ice zone through focussed and ongoing field programs, remote sensing and numerical modelling. The program is designed to complement, and contribute to, other international science programs in Antarctica as well as existing and proposed research programs within national Antarctic programs. ASPeCt also includes a component of data rescue of valuable historical sea ice zone information.

The International Ice Charting Working Group (IICWG) (http://nsidc.org/noaa/iicwg/): The IICWG has been working for a few years to promote operational sea ice and iceberg information services in the Southern Ocean similar to what is available for the Arctic. Argentina, Chile and Australia are all at various stages of service implementation.

(emerging) Antarctic Near-shore and Terrestrial Observing System (ANTOS) (http://www.scar.org/ssg/life-sciences/antos): The ANTOS Action Group aims to establish an integrated and coordinated transcontinental and trans-regional environmental surveillance system to identify and track environmental variability and change at biologically relevant scales, and to use this information to inform biological, physical, and earth science studies.

Level 5 Summary: The Antarctic is different from the Arctic in terms of geopolitics, lack of indigenous people, and cost and ease of collecting data. Therefore, there is less in the way of current and historical in situ data available. The value of EO data is therefore higher, but the lack of in situ data creates a challenge in terms of ground truthing, model validation, etc. A well-developed environmental protection regime that is still emerging in the Arctic adds a driver and dimension to collection and use of Antarctic in situ observations. There are a number of emerging observation systems, particularly SOOS, that stand to make more data available through sharing and strategic (and more efficient) collection methods. Countries such as the U.S. (NAS (National Academy of Sciences), 2015) and, even smaller players like Canada (Dey Nuttal, 2009), are establishing scientific and investment strategies for the Antarctic. While development of in situ systems in the Antarctic will likely be more modest in scope than those emerging in the Arctic, ESA and partners will need to maintain knowledge of the observing programs and data sharing networks managed through the Treaty System and SCAR.

6 GAP ANALYSIS AND SECTORAL GAP ANALYSIS

This chapter identifies gaps in information from current and planned EO missions, as well as from the relevant other space and non-space information sources, and in the entire polar data value chain. The gaps are then characterized in terms of their sectorial implications for geophysical parameters, user categories and geographic regions.

6.1 INFORMATION FROM EO MISSIONS GAP ANALYSIS

6.1.1 Identification of Gaps

As shown in the previous chapters, a multitude of services and products based on EO and other space and non-space assets are available and planned. In the context of systems as the basis for services, the physical, technical and financial feasibility of observations plays a major role in their development.

For the gaps in information from current and planned EO missions, two kinds need to be differentiated – those resulting from termination of satellites (end of life) or observation programs, and the ones resulting from needs of the user community that are not so far adequately covered by an existing or planned EO system. As an example of the first case, the end of certain radiometer missions (e.g. NASA's Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSAT)), and for the second case the unresolved observation needs for high resolution snow water equivalent (SWE) or 'ice stability', can be mentioned. Gaps in physical and scientific solutions are also an important factor.

To identify the gaps, we first classified the EO systems in accordance with the physical parameters they are designed to retrieve. Each EO retrieval is based on the measurement of electromagnetic radiation, reflected or emitted from the surface (land, water, ice). From this logic, active and passive, and depending on the wavelength of the electromagnetic spectrum used, optical to microwave systems can be discriminated. In subcategories, the spatial and the temporal resolutions need to be considered. Spatial resolution is often a matter of spatial coverage (the area to be covered by one orbit / overflight) and the energy of the radiation that is measured. Passive sensors, which only record the emission of the earth (thermal to low microwave), have therefore only a low resolution to integrate the energy of larger areas. Radar and optical altimeters and gravitational field sensors (e.g. GRACE, GOCE) are specific cases, where the measurements represent various degrees of spatial sampling and filtering.

To provide an overview on the capabilities of existing and future systems, a large number of space-based instruments need to be investigated. Published lists (e.g. OSCAR, the World Meteorological Organization's Observing Systems Capability Analysis and Review Tool;

http://www.wmo-sat.info/oscar/) indicate that at least 28 instrument categories (Instrument Types) exist, as shown in Table 3.

Table 3: EO Instrument Types

	Instrument Types		Instrument Types
1	Moderate-resolution optical imager	15	Cloud and precipitation radar
2	High resolution optical imager	16	Radar scatterometer
3	Cross-nadir scanning SW sounder	17	Radar altimeter
4	Cross-nadir scanning IR sounder	18	Space lidar
5	SW and IR sounder	19	Imaging radar (SAR)
6	MW imaging radiometer, conical scanning	20	Positioning system
7	MW sounding radiometer, cross-track scanning	21	Gravity sensing system
8	MW imaging/sounding radiometer, conical scanning	22	Solar processes monitor
9	Special scanning or non-scanning MW radiometer	23	Solar wind and cosmic radiation monitor
10	Limb-scanning sounder	24	Magnetosphere/ionosphere sounder
11	Broad-band radiometer	25	Aurora imager
12	Solar irradiance monitor	26	Platform environment monitor
13	GNSS radio-occultation sounder	27	Data collection system
14	Lightning imager	28	Search & rescue system

Within these instrument types, about 900 single instruments on 640 satellites (1960 to 2060) are currently listed on OSCAR. Only half of them are geometrically suitable for polar observations, due to sun-synchronous / TAP / Tundra / Molinya orbits. For the polar regions, current and planned satellite coverage includes:

- Currently in operation: ~ 65 satellites
- For the next 10 years (2016-2025): ~ 55 satellites
- For the next 20 years (2026-2035): ~ 10 satellites

For applications in polar regions, geostationary earth observation systems are generally unsuitable. Due to image geometry, using an orbit 35,000 km above the equator, observation of the polar region is limited. But applications in atmospheric science and the increasing focus on polar – mid-latitude weather and climate interaction analysis, should be mentioned.

Based on their characteristics for the analysis of technical capabilities for services, six general and important main categories have been selected, as shown in Figure 19 and Table 4. The selection was made based on the wavelength (also accounting for passive or active sensing)

and the spatial resolution. Due to overlap between the categories, no sharp distinction can be made.

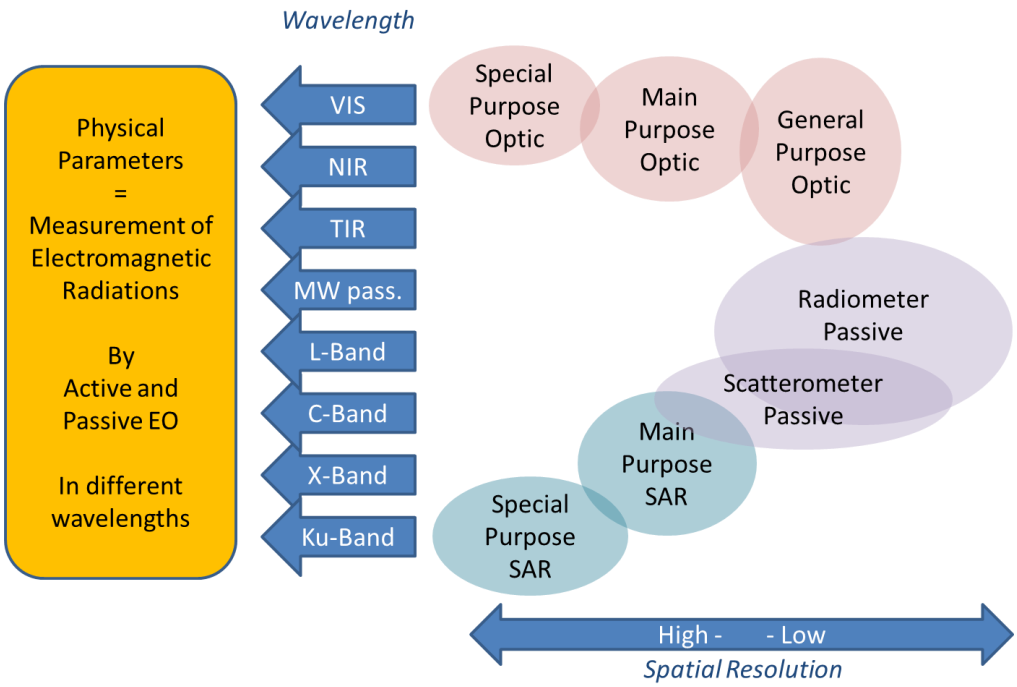

Figure 19: Distinction of EO sensors applied in Polar observations

Table 4: Main categories of EO sensors applied in Polar observations

A) Main Purpose Optic Multispectral / < 30m	B) Main Purpose SAR C-Band / L-Band / > 10 m
C) Special Purpose Optic Multispectral / < 10m or Hyperspectral	D) Special Purpose SAR C-Band / X-Band / < 10 m Ku or other Band
E) General Purpose Optic Multispectral / > 30m	F) Radiometer & Scatterometer Passive

Based on information from the previous chapters and work packages, the prime sensors/satellites for the different information themes were extracted, as shown in Figure 20. Outside these remote sensing categories are the gravitational change sensors (currently the only operational mission is the US-German GRACE), which provide a direct measurement of ice sheet changes, as well as integrated measurements of ocean mass and land hydrology.

The applicability of the main groups of different EO sensors is coded according to their characteristics and application in existing products and services (see Chapter 2). The symbols indicate the relative applicability of the sensor groups to the different information themes. For many of the themes (e.g. Sea Ice and Snow) all types of sensors are more or less suitable for operation. For smaller and more local features (e.g. Icebergs and River/Lake Ice) the application of passive instruments is absolutely limited.

	Special Purpose Optical	Main Purpose Optical	General Purpose Optical	Radio-meter Passive	Scattero-meter Passive	Main Purpose SAR	Special Purpose SAR
Sea Ice	■■	■■	■	■■	■	■■■	■■■
River and Lake Ice	■■	■	■	□	□	■■	■■■
Ice Sheets	■	■■	■■	■■	■	■■■	■
Glaciers	■■■	■■	■	□	□	■■	■■■
Snow	■■	■■■	■■	■■	■	■■■	■■
Icebergs	■■	■■	■	□	□	■■■	■■■
Permafrost	■	■	□	■■	■■	■	■
Ocean	■	■■	■■■	■■■	■■■	■■	■
Land	■■■	■■■	■■	■■	■	■■■	■■■
Atmosphere	□	□	■■	■■	■■	■	□

Legend:

Perfect ■■■ Good ■■ Suitable ■ N/A □

Figure 20: Application of different EO systems to information themes for Polar Regions

To identify the gaps for each of the themes, the number of existing and future EO systems (next 5 / 10 / 15 years) was first analyzed. Please note that systems are not equal to satellites, since often several sensors are applied on one satellite platform, especially in the meteorological domain (e.g. scatterometers and low resolution optical systems on Metop and NOAA satellites).

Based on the Committee on Earth Observation Satellites (CEOS) online CEOS Mission, Instruments and Measurements Database (http://database.eohandbook.com/index.aspx),

the number of systems providing at least one of the applied sensors was analysed, as shown in Figure 21. All geostationary or experimental systems (e.g. on the ISS) were excluded, so only systems with coverage of the polar regions are counted. In addition to these numbers (e.g. 96 systems for 2015), an additional 42 systems for special purposes (e.g. gravimetry or atmosphere lidars) were identified. These systems are mostly planned on a long time horizon, and the numbers of future systems for the next 10 and 15 years (until 2030) have larger numbers than the imaging systems. For 2030, eight special missions have already been approved, but only seven polar covering missions are listed.

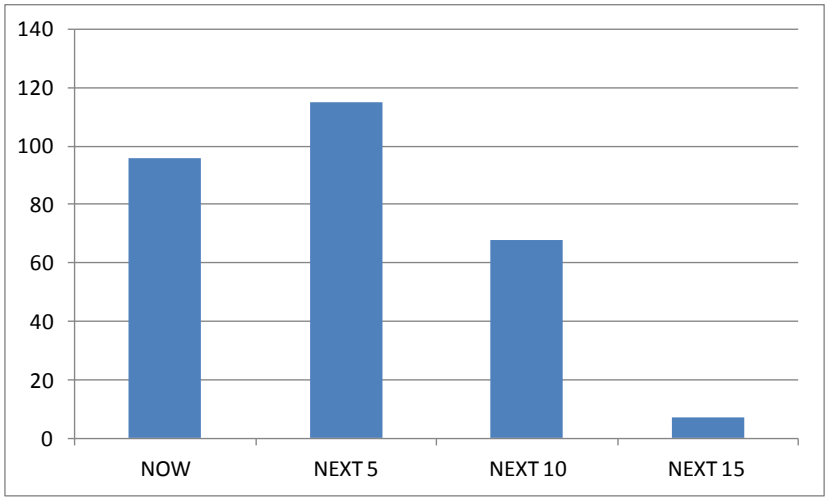

Figure 21: Number of EO systems covering the Polar Regions for the next 15 years

From the 96 systems currently available, the percentage of the different categories is presented in Figure 22.

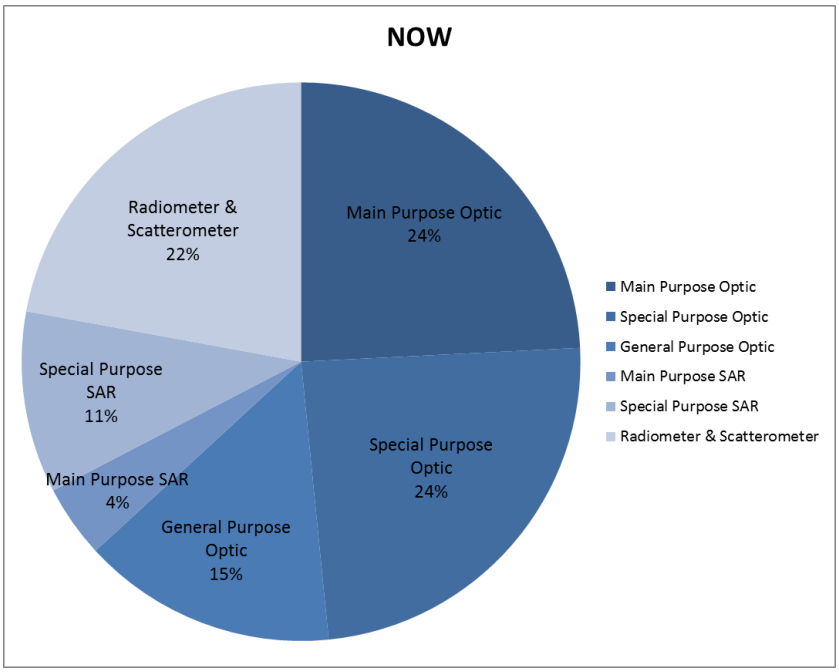

Figure 22: Proportion of EO Systems Covering the Polar Regions

In addition to total numbers, the progression for the different sensor groups over the next five, 10 and 15 years was analyzed, as illustrated in Figure 23. The increase in systems for the next five years is based on the fact that for NOW only the systems currently being flown are counted. The NEXT periods include all existing, planned and approved systems for the five year period.

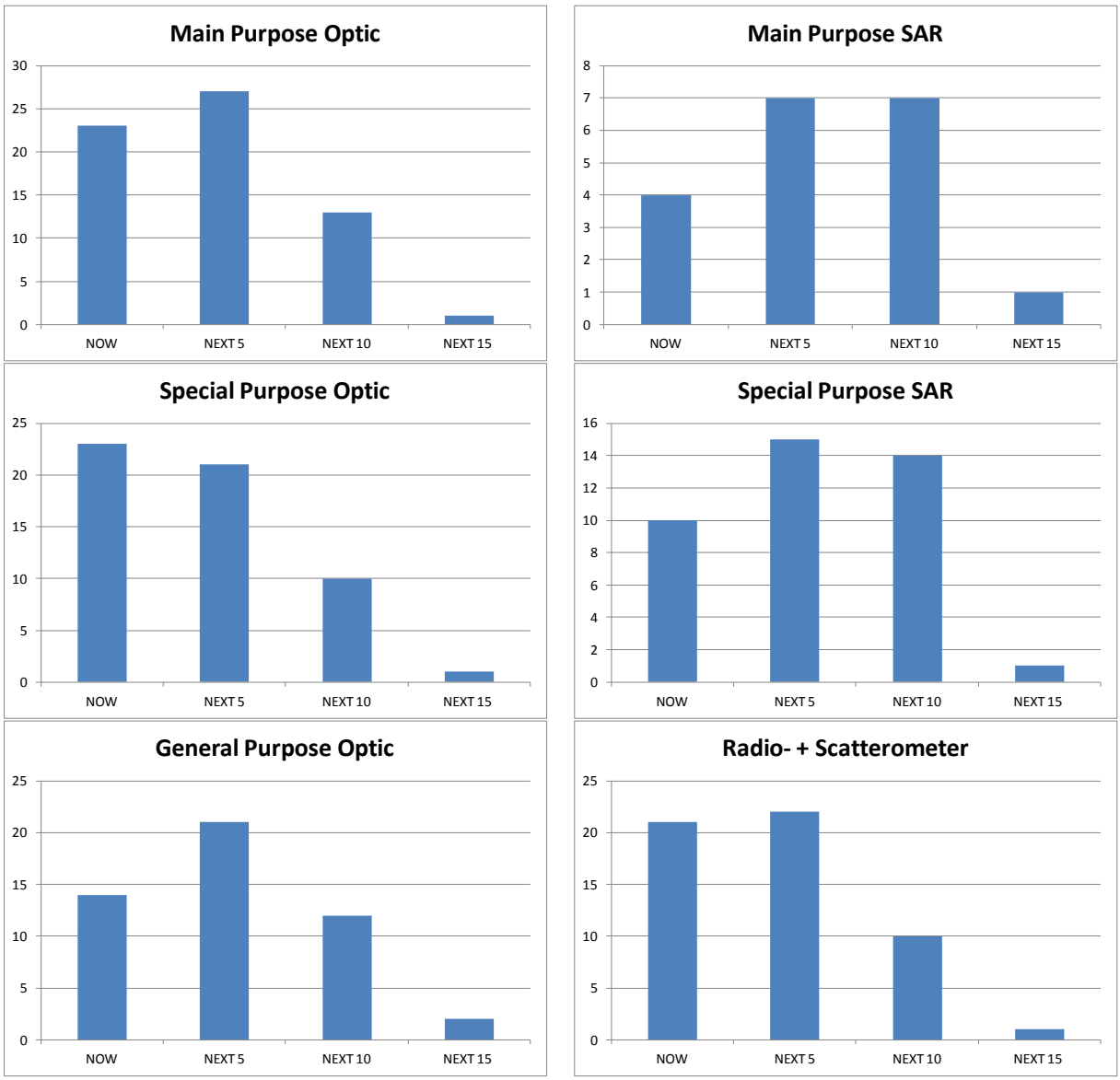

Figure 23: Absolute numbers of available EO systems for the next 15 years

Retrieving the relative numbers, the strongest decrease in the number of systems, between “now/next 5” and “next10/next15” can be found for the Main Purpose Optic, Special

Purpose Optic (high resolution and multi/hyper spectral) and the Radiometer/Scatterometer categories, as illustrated in Figure 24.

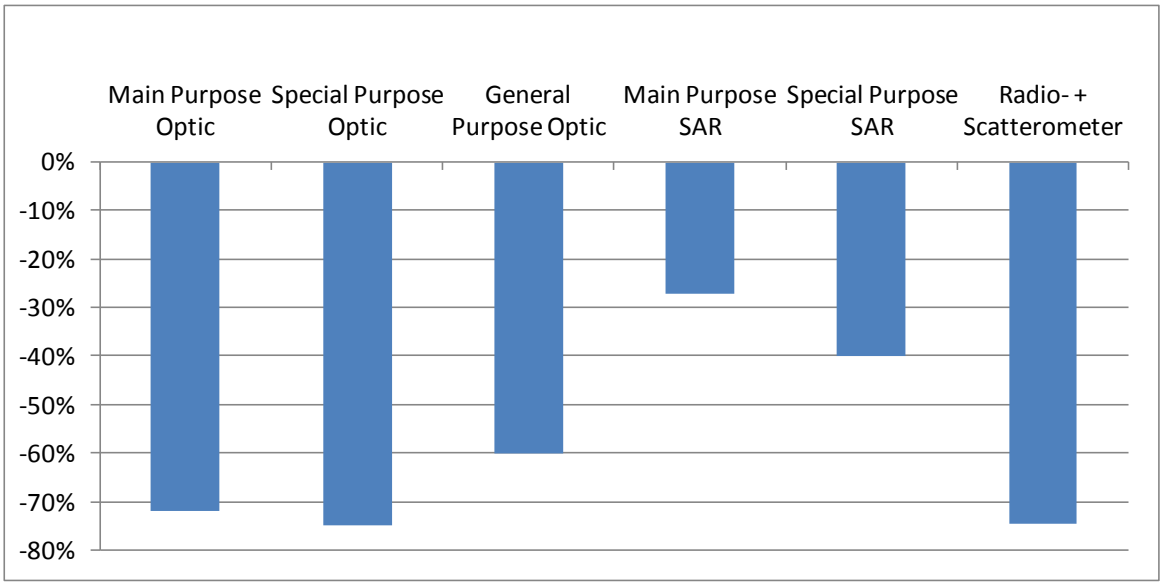

Figure 24: Decrease of EO systems by categories in the timeframe between 2015-2020 and 2020-2030.

Several general conclusions can be drawn from the information compiled on existing and planned EO missions. Firstly, all information themes are addressed by EO missions, although higher levels of applicability are apparent for some themes (e.g. Land and Ocean) than for others (e.g. Atmosphere and River/Lake Ice). This suggests a focus in future mission planning on making optimum use of existing, rather than development of new, sensor technology. Secondly, the majority of sensors covering the polar regions (63 %) are optical, while the sensors of most importance to cryospheric parameters (SAR, radiometers and scatterometers) are in the minority. This is perhaps not surprising, since there are widespread optical sensor applications outside the regions that drive the demand for these sensors. Finally, data continuity for all sensor types beyond 10 years is a concern, highlighting the importance of long term mission planning and execution for ESA.

For the gravitational mass change missions, with the important polar application to continue time series of Greenland, Antarctica and small ice cap mass loss, NASA/DLR is currently planning the GRACE follow-on mission, due for launch in 2017. Chinese CASC has plans for a similar mission to be launched in the 2017-18, and both ESA and NASA are currently discussing options for next generation gravity field missions for the 2025 time frame. This type of EO mission is therefore in relatively good shape for future polar mass change monitoring.

6.1.2 Analysis of Gaps

Table 5 identifies the primary gaps in existing environmental information in meeting user needs (i.e. existing products/services do not fully address needs) that were found from the literature review and consultations with representatives of user organizations, and further assessed and verified at a User Requirements Workshop attended by experts representing different segments of the user community. These 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.

For each of the information gaps identified in Table 5, the range of spatial and temporal resolution and timeliness requirements to meet user needs has been assessed; the results are shown in Table 6. The figures in the table are drawn from the OSCAR database (WMO, 2015-1) and in some cases modified based on input from the consultations and user workshop. Since the figures in the OSCAR database primarily reflect the needs of the scientific community, the modifications in large part indicate the more stringent requirements of the operational community. In many cases the requirements range is very large, reflecting the broad scope of usage of different information parameters across the many scientific and operational user communities. Blank cells in the table indicate where the requirements have not yet been documented by the user communities. It should be noted that some of the requirements that users would prefer to have met are beyond the capabilities of current satellite EO technologies (e.g. 10 m spatial resolution of sea ice thickness).

Table 5: Polar Information Gaps

Parameter Type

Parameter Theme	Ice Thickness	Extent	Structure/Age	Snow Depth	Freeze-Thaw	Topography	Mass Change	Motion	Iceberg Calving	Surface State/Albedo	Grounding Line	Elevation Change	Snow Water Equivalent	Location	Size	Ice Dammed Lakes and Rivers	Salinity	Wind	Waves	Chemistry/Particulates	Biota	Temperature	Precipitation/Clouds/Humidity	Vegetation/Land Cover
Sea Ice	■	■	■	■	■	■		■		■														
River and Lake Ice	■	■	■		■											■								
Ice Sheets	■			■			■	■	■	■	■													
Glaciers	■	■	■	■		■	■	■	■	■						■								
Snow		■	■	■	■					■			■											
Icebergs		■						■	■					■	■									
Permafrost		■			■					■		■								■				
Ocean																	■	■	■		■	■		
Land										■											■			■
Atmosphere																		■		■		■	■	

Table 6: Range of Requirements to Satisfy User Needs

	Parameter Type	Spatial Resolution[16]	Temporal Resolution[17]	Timeliness[18]
Sea Ice	Ice Thickness	10 m – 15 km	6 – 24 hours	12 – 24 hours
	Extent	25 m – 15 km	1 – 24 hours	1 hour – 3 days
	Structure/Age	10 m – 10 km	6 hours – 1 day	7 days
	Snow Depth	10 m – 5 km	10 minutes – 24 hours	10 minutes – 3 days
	Freeze-Thaw	25 m – 10 km	6 hours – 1 day	
	Topography	1 km	1 day	1 day
	Motion	10 m – 1 km	6 hours – 1 day	1 – 3 days
	Surface State/Albedo	0.5 – 5 km	30 minutes – 24 hours	3 days
River and Lake Ice	Ice Thickness	10 m	1 day	1 day
	Extent	3 – 30 m	1 – 7 days	
	Structure/Age	10 – 25 m	1 day	
	Freeze-Thaw	25 m	1 day – 1 year	1 day
Ice Sheets	Ice Elevation Change	5 km	1 year	A few months
	Snow Depth	1 km	6 months	
	Mass Change	200 km	Monthly	A few months
	Ice Sheet Velocity	500 m	Seasonally	A few months
	Iceberg Calving	500 m	3 months	1 month
	Surface State/Albedo	0.5 – 5 km	30 minutes – 24 hours	3 days
	Grounding Line	1 km	5 years	1 year
Glaciers	Ice Thickness	100 m	30 years	
	Extent	5 – 15 m	1 year	
	Structure/Age			

[16] Spatial Resolution – the level of detail that can be resolved in the information product
[17] Temporal Resolution – the repeat cycle of the satellite sensor over the same geograpical area
[18] Timeliness – the amount of delay between the data collection and its accessibility for subsequent use (i.e. latency)

Parameter Type		Spatial Resolution[16]	Temporal Resolution[17]	Timeliness[18]
	Snow Depth			
	Topography	1 – 30 m	1 year	1 year
	Elevation Change	200 m	1 year	
	Ice Velocity	250 m	Seasonally	
	Iceberg Calving			
	Surface State/Albedo	0.5 – 5 km	30 minutes – 24 hours	3 days
	Ice Dammed Lakes	15 – 50 m	5 days – 1 month	
Snow	Extent	1 m – 15 km	1 – 24 hours	1 hour – 30 days
	Structure/Age	100 m	30 minutes	1 day
	Snow Depth	1 m – 5 km	10 minutes – 24 hours	3 days
	Freeze-Thaw	10 m	1 day – 1 week	
	Surface State/Albedo	0.5 – 5 km	30 minutes – 24 hours	3 days
	Snow Water Equivalent	1 m – 15 km	1 hour – 1 month	1 hour – 30 days
Icebergs	Extent	100 m	2 hours	
	Motion	0.5 km/day	2 – 24 hours	
	Iceberg Calving	5 m	1 day – 1 month	
	Location	10 m – 1 km	2 hours – 3 days	
	Size	1 – 30 m	1 hour – 1 month	
Permafrost	Extent	25 m – 1 km	1 year	
	Freeze-Thaw	100 m – 1 km	7 days	
	Motion	10 m	1 year	
	Surface State/Albedo	0.5 – 1 km	1 hour – 24 hours	1 hour – 30 days
	Elevation Change	1 cm – 1 m	1 year	
	Chemistry/Particulates	250 m	1 day	
Ocean	Salinity	1 – 5 km	6 days	1 day
	Wind	100 m – 10 km	6 – 60 minutes	5 minutes – 12 hours
	Waves		1 day	

	Parameter Type	Spatial Resolution[16]	Temporal Resolution[17]	Timeliness[18]
	Biota		1 day	
	Temperature	0.5 – 10 km	30 minutes – 6 hours	5 minutes – 12 hours
Land	Surface State/Albedo	0.5 – 1 km	1 hour – 24 hours	1 hour – 30 days
Land	Biota	10 m	3 months – 1 year	1 month
Land	Vegetation/Land Cover	250 m	1 year	1 day
Atmosphere	Wind	0.5 – 100 km	1 minute – 12 hours	5 minutes – 30 days
Atmosphere	Chemistry/Particulates			
Atmosphere	Temperature	1 – 100 km	10 minutes – 12 hours	6 minutes – 24 hours
Atmosphere	Precipitation/Clouds/ Humidity	0.5 – 100 km	12 minutes – 1 hour	6 hours – 30 days

The key environmental information gaps can be summarized in the following way:

- Environmental information gaps supporting Polar earth sciences

  Despite considerable research progress in understanding the Arctic region 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 and prediction capabilities 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 uncertainties represented 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. Ice sheet (in particular Antarctica) 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. The parameters that are of most concern across multiple themes were extent (sea ice, river and lake ice, glacier, snow, iceberg and permafrost) and surface structure/ albedo (sea ice, ice sheet, glacier, snow, permafrost and land).

- Environmental information gaps supporting 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 sea ice snow information will be required to reliably establish these information parameters. The ability to identify icebergs within multi-year ice and detect and forecast iceberg motion is another capacity which is key to the communities carrying out Polar operations, and linked to this is of course 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 of interest were also identified as significant weaknesses in information provision for operations.

Information deficiencies can be addressed in two ways: i) by providing more capable earth observation technology (mission concepts), and/or by improving how well the overall information acquisition and delivery systems works (system concepts). These are examined in Chapter 7.

6.2 Information from Other Space Assets Gap Analysis

The material provided in Chapter 4 focuses on three other space assets of importance to the polar regions – satellite telecommunications, global navigation satellite systems (GNSS) and space-based automatic identification systems (S-AIS). Of these three classes of space assets, gaps in the first have the most widespread impacts on the user communities, especially those involved in operations in the Arctic and Antarctica.

While information from satellite telecommunications systems is not combined with earth observation information into integrated products and services per se, these systems provide the essential infrastructure for the delivery of such products and services to users. It is clear that the systems in place today neither meet present nor future demands. Infrastructure gaps are a particularly important concern for operations, which often require near real-time delivery of information to ensure safety of life and efficient production. Mariners accustomed to broadband service with little interference, enabling access to large data sets, are constantly compromised in their ability to navigate safely when entering polar regions where communications are spotty at best and access to vital information is problematic.

The proposed telecommunications systems appear to be designed to address future operational user requirements in the Arctic. There is a need for an intermediate solution and backup plan for higher bandwidth satellite telecommunications for Arctic users. There is also the limitation from the lack of telecommunications ground infrastructure in the Arctic. To date, none of the proposed new satellites has been launched and many are still under study or development. Thus, ESA should consider these present telecommunications gaps together with the future capabilities to determine what should be included in the next ESA mission. The goal for future telecommunications capability in the polar regions should be equivalent capability to what is available below 70°N latitude.

The use of global navigation satellite systems (GNSS) is ubiquitous in the polar regions, as it is elsewhere. While the accuracy of positioning with GNSS and space-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 geographical coverage of the two primary SBAS – WAAS and EGNOS – but no evidence has been found that this gap is of significant concern to the scientific and operational user communities.

As discussed in Section 4.3, there are a number of beneficial applications in the polar regions for integrated EO and AIS information. Although there are a few space-based AIS (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. There is demonstrable

value of a dual purpose AIS/EO mission; however, this value decreases as the number of third party AIS missions grows over time. Therefore, consideration should be given to the costs associated with adding AIS to any new surveillance mission. Due to the simplicity of AIS receivers, the additional cost is expected to be low, relative to the total mission build cost.

6.3 Information from Non-Space Assets Gap Analysis

The integration of, and synergies between, space-based EO data and data collected with airborne sensors and ground-based or in situ sensors and networks are well established. Examples include use of data from in situ sensors for geospatial ground-truthing and rectification, satellite validation (especially for new sensor types), model calibration, supporting increased understanding of environmental and social processes, and regulatory compliance where the spatial or temporal resolutions of in situ data may fill information needs that cannot be met by space-based EO data alone.

Chapter 5 discusses the extensive nature of in situ measurement of atmospheric, land, ocean and other environmental information parameters, at the local, national and international levels. A key conclusion, however, is that in situ ground and airborne data collection is fragmented, sensor networks are not well distributed geographically and there are large gaps in coverage, largely because many sensors are deployed for specific project-related, time-limited scientific or operational purposes. Specific examples of gaps in in situ data that can be integrated with space-based EO data to support operations in the polar regions are the systematic in situ measurement over large areas of snow depth and sea ice thickness.

The optimal system of sensors and sensor networks would be persistent, well-documented and with the resulting data being easily discoverable, broadly available and interoperable with EO systems. However, the challenges in developing such a system are considerable. An integrated observing system has many facets including funding, planning and managing sensor deployment, establishing observational data requirements, understanding institutional dimensions including regulatory regimes and establishing data management for interoperability and long term preservation. Moreover, 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 to 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 opportunity exists for the European Space Agency to influence and make strategic investments that will help to realize and shape such a system in a way that provides optimal support to EO systems. An especially good model for this is the NASA IceBridge program, which although initially designed to be a gap-filler between the failed IceSat

mission 2003-9, and the new IceSat-2 mission 2017-, has evolved into a much broader cryosphere monitoring and data gathering project, of wide global use.

6.4 Polar Data Value Chain Gap Analysis

The consultations with stakeholders and the User Requirements Workshop provided valuable insights on how the entire polar data value chain could be improved. The key points identified by environmental information users are summarized in Table 7.

Table 7: Polar Data Value Chain Gaps

Category	Type of Gap
Data Discovery	▪ Better tools are needed to help in discovering this data – a 'Google for polar data' – because Polar data is spread among a large number of sites and organisations. ▪ A central repository or 'one-stop-shop' would be beneficial, which would facilitate data discovery. ▪ Data discovery tools need to be easier for non-specialists to use. ▪ Better metadata is an important component of the data discovery process. ▪ Metadata must include better information on data quality and uncertainty.
Data Access	▪ Improvements in the ease of tasking satellites for imaging of specific geographic areas on short notice needs to be improved. ▪ Accessing data needs to be easier, with more commonality across access platforms. ▪ Cost is a significant barrier to data access and use for many groups. ▪ Licensing issues can be an impediment to data access. ▪ The bandwidth limitations faced by most northern communities are an impediment to data access and use.
Data Integration	▪ Non-specialist users want customized, integrated datasets developed by professionals who have the expertise to assess their needs and pick the best data from all the alternatives. ▪ 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 can be facilitated by data formats and access that adhere to recognized standards.
Data Platforms	▪ More use of open web services would help value-added partners in the development of applications and systems. ▪ Data platforms need to provide processing capacity. ▪ Data platforms can enable users to 'mash-up' data from multiple sources. ▪ Data platforms need to follow best practices for data management and storage. ▪ Some data should be heavily mediated for use by non-expert users. ▪ Mobile device apps would be useful to monitor key parameters.
Training	▪ Better user education tools would mitigate the risks of data misuse. ▪ Users need to be trained on how to process images.

6.5 Sectoral Gap Analysis

6.5.1 Implications for Geophysical Parameters

The gaps in information availability in relation to the ten primary geophysical parameter themes are discussed in detail in Section 6.1.2. While the identified gaps have implications for all themes, they are most significant for the cryosphere parameters and especially sea ice, ice sheets and glaciers.

6.5.2 Implications for Users

There are implications of the identified gaps for both scientific and operational users of environmental information in the polar regions. For example, the sea ice information gaps are an impediment to achieving optimum research results in a number of areas (e.g. research on the nature of changes in sea-ice distribution in response to climate change and variability, and on how sea ice moves and deforms over its first year of existence; process studies related to sea ice rheology (i.e. the relationship between ice stress and deformation); and improving understanding of how a thinner and weaker ice cover responds to wind and precipitation). For operational users, the sea ice and iceberg information gaps have critically important implications for basic navigational planning to ensure safety of life (e.g. planning of emergency response and search and rescue operations, fishing programs, tourism expeditions and resource extraction; navigation of vessels through ice-infested waters; positioning and emergency repositioning of offshore oil and gas platforms; and navigation to and along sea ice edge for hunting and fishing) and economical passage through the polar regions.

The ice sheet and glacier information gaps impede scientific and research activities such as: improving understanding of how effects at the base of ice sheets influence their flow, form and response to warming, and of mass balance of ice sheets and glaciers, their relative contributions to global sea-level change, their current stability and their sensitivity to climate change; and making better use of EO-based products in ice sheet models. A practical operational gap is the lack of sufficient resolution to be of use for hydropower use (several hydropower schemes in Greenland, Iceland and Norway rely on ice cap and glacier melt).

The permafrost information gaps have implications for both research and operational activities. Research efforts that are impeded include: development and validation of remote sensing algorithms to detect soil freeze/thaw cycles; and research on changes taking place in permafrost and frozen ground regimes, their feedback to the climate system and terrestrial ecosystems (e.g. carbon dioxide and methane fluxes). Inadequate information on freeze-thaw cycles, motion and surface stability has implications in a number of operational areas including: engineering design of buildings and large structures and assessing the risks of subsidence around them after they are built; planning of transportation routes over land; and travel by transport companies and local residents over ice roads.

6.5.3 Implications for Geographical Regions

Although the identified gaps in information have implications for both polar regions, given the relative differences in the environmental changes taking place, diversity of use and number and type of users, they are of greater consequence in the Arctic. For example, the greater opportunity for economic growth in the Arctic (e.g. resource development, fishing, ecotourism) due to the more rapid shrinking of sea ice, policy imperatives and the geographical proximity to economic centres means that this region has a much higher level of current and projected future operational activity. Therefore the gaps in information that are most critical for design activities, operational planning and deployment, and potential emergency response and search and rescue undertakings are of greater concern in the Arctic. However, despite the lower level and variety of activities in the Antarctic, the implications for users are similar but of a smaller scale and scope. Notwithstanding the differences with the Arctic, the information gaps have safety of life implications in the Antarctic for the research, shipping, fishing and ecotourism vessels that deal with hazardous navigation through the ice-infested waters of the Southern Ocean.

From the scientific perspective, the information gaps have implications for researchers in both polar regions. For example, much of the research on weather and climate change requires improved EO-based environmental information covering both poles (e.g. research on the changes taking place in the atmosphere over the polar regions and the impact this is having on global weather patterns, on how interactions between the atmosphere, ocean and ice control the rate of climate change, on fundamental roles of physical and biogeochemical air-sea-ice interaction processes in weather and climate, and on landfast (fast) sea ice distribution as a sensitive indicator of climate variability and change). Similarly, the identified information gaps impact the effectiveness of much of the research being undertaken in both poles on ocean state and coastal zone change (e.g. research on the impact of ocean currents and sea water properties on sea ice patterns, on regional and seasonal distribution of sea-ice mass and the coupling between sea ice, climate, marine ecosystems and biogeochemical cycling in the ocean and on the impacts of a changing sea-ice regime and wave climate on coastal stability, and understanding extremes such as coastal sea level surges and ocean waves).

Finally, for the Arctic region the information gaps have important implications for the local populations. For example, shortcomings in sea ice and river/lake ice thickness and structure information impact the ability of local food gatherers to safely navigate on the river/lake ice and sea ice edge for hunting and fishing purposes. This has significant implications in regions with very few roads. In addition, the required improvements in wind and wave information will enable local populations to more safely participate in near shore subsidence fishing. In Greenland, shortcomings of monitoring glacier-dammed lakes, which can provide sudden freshwater flows into river valleys and fjords, can affect local fisheries. Inadequate

permafrost information impacts the ability of public and private infrastructure officials to predict and mitigate the potential destructive impacts of subsidence on facilities such as oil and gas pipelines, power plants and buildings, with significant safety of life and cost implications. Costly infrastructure such as airport runways could also be at risk. For example, consideration is being given to shortening the runway at the main airport in Greenland – Kangerlussuaq – by 1000 m due to permafrost thaw damage. This will prevent wide-body long-range jets from landing in the future, which could have large socio-economic effects related to tourism and travel.

7 SPECIFICATION OF NEW INTEGRATED SERVICES

This chapter outlines synergistic products for the Polar Regions and places specific focus on new information products that are enabled through the spatiotemporal collocation of measurements from diverse EO sensors.

7.1 INTRODUCTION

An opportunity to operate diverse sensors on a single spacecraft, or operate diverse sensors on multiple formation-flying spacecraft, allows consideration towards the potential of combining the data output from sensors to retrieve information for new products or to improve the information content in existing products. Observations of the same location at the same time by diverse sensors produces individual data products whose information content may be spatiotemporally collocated despite variance in measurement attributes such as resolution. The algorithms that process and combine the differing information content to form what are termed "Level-4" products are complex and frequently evolve. For this reason, the following sections in this chapter present an overview of potential synergistic Polar Region products with a focus on the information content rather the technical production.

7.1.1 SAR and S-AIS

Synthetic Aperture Radar (**SAR**) imagery is typically used in Maritime Domain Awareness (**MDA)** applications for vessel detection with varying degrees of successful detection rates depending on imaging, target and environmental parameters. Classification and recognition of vessels in SAR imagery has traditionally met with lower success rates, primarily due to typical vessel dimensions with respect to the image resolution.

Satellite-Automatic Identification System (**S-AIS**) sensors intercept terrestrial AIS broadcasts from cooperating vessels. These broadcasts contain vessel positions in addition to other identifying information. The collocation of the position of these broadcasts with positions of vessels detected in SAR imagery allows the identification of vessels that are non-cooperating (i.e. non-broadcasting AIS).

The information content of the collocated SAR and S-AIS consequently has an improved utility for MDA through providing a new focus on non-cooperating vessels. Additionally, in the Polar Regions, detected non-cooperating vessels are potentially icebergs. This new information content can help improve iceberg detection and concentration products.

The information improvement identified above in combination with the relatively low cost, mass and power of S-AIS sensors means that they are now increasingly embarked as secondary payloads on SAR satellite missions.

7.1.2 Radiometer and Spectrometer

Radiometer imagery is typically used to derive skin surface temperatures (both land and sea) to high precision and accuracy. Spectrometer imagery is typically used to derive ocean and land surface biology parameters (such as colour) in addition to atmospheric parameters such as aerosols.

The collocation of measurement pixels in imagery from Radiometers and Spectrometers allows the generation of new information products by exploiting the spectral diversity of the measurements in new combinations. One such combination is to generate the Normalized Difference Vegetation Index (**NDVI**) which can be used to assess vegetation development and health.

The generation of NDVI to form a new product enhances the utility of imagery from both sensors. The Sentinel-3 mission will exploit this synergy of data sources to produce additional products.

7.1.3 Altimetry and SAR

Altimeters are able to measure elevation to high accuracy; with typical nadir pointing the primary retrieved measurement is the elevation of the sub-satellite point. SAR sensors look to one side of the spacecraft orbit direction and generally do not measure points close to the sub-satellite point. Consequently there is no direct overlap between altimeter data and SAR imagery when both sensors are on the same platform.

This limitation can be overcome if the spatial scale of the geophysical parameter derived from the altimetry measurement is sufficiently large to intersect the SAR image. One such example is ocean tides and geostrophic currents. An active area of research considers the utilization of SAR imagery to retrieve total surface motion of the ocean. If the contribution of the currents measured by altimetry can be subtracted from the total surface motion, new measurement of additional underlying currents can be made.

In this way, the exploitation of data from altimetry and SAR allows further clarity on ocean phenomenon occurring on small scales and potentially improves the input to, and formation of, climate models. New mission concepts to exploit this synergy are currently under investigation.

It should be noted that, over ice sheets and sea ice, users need increased spatial resolution for altimetry. This is demonstrated with the coherent processing of altimetry (called SAR processing, but separate from side-looking SAR) on ESA's CryoSat-2 mission, to be continued on Sentinel-3. The SAR processing only increases along-track resolution; cross-track resolution is increased by use of dual receiving antennas using SAR interferometry, which is

called SARin mode on CryoSat-2. There are currently no plans for continuing the SARin mode beyond the lifetime of CryoSat-2.

7.1.4 SAR and optical

Data fusion of SAR and optical imagery exploits the electromagnetic observation diversity to create new information products or improve the single data source products. Many applications of this data fusion exist, particularly regarding SAR and optical data of loose time correlation (i.e. order hours or days). One example application is land classification whereby the combination of data from Optical and SAR is demonstrated to improve the classification accuracy against known ground-truthing.

Time critical applications of SAR and Optical data fusion, such as change detection, place stricter constraints on the temporal collocation of the input data. For these applications, the collocated measurements enable additional information to be extracted and reduce uncertainty when monitoring surface conditions across time. Additional information can result because SAR can penetrate ground objects whilst optical measures light reflected from the surface; these properties allow improved characterization of the observed surface. One specific example is detection of surface excavations that are overgrown with vegetation.

The synergy of spatiotemporal collocated SAR and optical data is an active area of research despite the limited portfolio of currently operational collocated sensors. One driver behind this is the impending deployment of 8 SAR-Optical tandem pairs of satellites by urthecast in 2019.

7.1.5 SAR and radiometer

Collocated imagery from SAR and from scanning radiometers can be fused to increase the accuracy of existing information products and to generate new products. One particular example exploits both SAR imagery and microwave radiometer imagery to improve ice edge detection in sea ice concentration information products. Met offices with Polar activities are investigating the adaption of operational algorithms to exploit both these data sources to generate new fused products. This exploitation makes use of data input that is only loosely correlated in time and consequently uncertainty can be reduced through using temporally collocated SAR and radiometer imagery.

New information products for soil moisture can be generated by exploiting SAR and radiometer imagery that combine the desirable properties found in both. For example the high resolution, low accuracy retrieval of soil moisture content from SAR data can be fused with the low resolution, very high accuracy soil moisture retrieval from microwave radiometer data. This fusion provides an optimum resolution and accuracy within a single new information product as demonstrated by the NASA SMAP mission. Soil moisture

information has particular relevance to the Polar Regions to help inform on freeze-thaw cycles.

7.1.6 Scatterometry and SAR

Scatterometers are able to infer surface and atmospheric properties through measuring surface roughness. One primary application is to derive wind speeds and directions over areas of open ocean. The fusion of scatterometer data with SAR data generally exploits the relative advantages of SAR high resolution with scatterometry high accuracy. In particular SAR imagery is often used to downscale (i.e. improve the resolution) of scatterometry measurements.

This type of data fusion is particularly prevalent in applications such as wind field estimation, soil moisture estimation and soil surface roughness retrieval to improve resolution and maintain high accuracies.

Another data fusion technique relates to MDA applications, specifically oil spill modelling. SAR imagery is currently analysed to detect oil spills on the sea surface created through marine activity such as shipping or oil resource extraction. The evolution of oil spills, in particular their geographical location, is partly driven by local surface winds. The ability to predict the evolution is critical to inform the oil spill response and consequently large research activities are undertaken in the field of oil spill modelling. The input of wind derived scatterometry data into such models, when combined with the oil spill geographical extent from SAR data allows increasingly accurate predictions of oil spill evolution.

The spatiotemporal collocation of scatterometry and SAR data for oil spill monitoring improves prediction accuracy. This is through reduction of uncertainties introduced by state changes between observation times.

7.1.7 SAR and LiDAR

LiDAR can be used to infer accurate surface elevations through scanning a narrow laser beam across a target and recording the reflected response. The fusion of collocated LiDAR elevation data and SAR data is an active area of research in diverse fields such as land classification and biomass estimation. For forestry applications, LiDAR-SAR data fusion has demonstrated effective retrievals of aboveground biomass through improvement in spatial resolution and accuracies in new combined products.

The current research activity primarily uses airborne LiDAR with spaceborne SAR in applications to develop new products. This is driven by the limited amount of spaceborne LiDAR data that is available; however this situation is expected to change in the near future with several new LiDAR sensor missions planned. The NASA IceSat-2 mission (2017-), albeit not a true scanning lidar mission, will have several side beams of photon counting lidar. A

truly spaceborne laser scanning mission would have many uses over both sea ice and land ice, as well as for other applications (e.g. global biomass mapping), and technological developments in photon counting technology should make such a mission more feasible.

7.2 SUMMARY

Table 8 provides a summary of new synergistic products that exploit diverse spaceborne sensors on single or multiple formation-flying spacecraft. The availability of such products is indicated in the timeframe of now, within 5 or within 10 years. Note that some information products are not foreseen to be available; however the requisite sensor complement for the spatiotemporal collocated data may become available in the extended timeframe.

Table 8: New Synergistic Products

Data Synergy/Fusion	New Products	Availability (Years)		
		Now	5	10
SAR and S-AIS	• Maritime Domain Awareness products and Cryosphere products, e.g. non-cooperative vessels and iceberg detection	✓		
Radiometry and Spectrometry	• Vegetation products, e.g. NDVI		✓	
Altimetry and SAR	• Ocean products, e.g. mesoscale currents			?
SAR and Optical	• Land products, e.g. land usage, type classification • Change detection products, radar penetration in snow		✓	
SAR and Radiometer	• Cryosphere products, e.g. ice concentration • Land products, e.g. soil moisture estimation including freeze-thaw cycle			?
Scatterometry and SAR	• Land products, e.g. soil moisture including freeze-thaw cycle and roughness estimations • Maritime Domain Awareness products, e.g. oil spill evolution prediction			?

SAR and LiDAR	• Land products, e.g. biomass of forests • High resolution mapping of glaciers and ice sheets, snow depth on sea ice			?
New gravity change sensors (formation flying ranging, GOCE) gradiometers)	• High-resolution mass change of ice sheets, ice caps • Ocean mass change, global sea level, continental hydrology		(✓)	✓

8 IMPACT ANALYSIS OF NEW INTEGRATED SERVICES

The purpose of this chapter is to provide the results of an assessment of the impacts of filling the information gaps by realizing the new EO-based products and services. The socioeconomic and environmental impacts are characterized in relation to the following: addressing Earth science gaps; climate change understanding and monitoring; effects of human activities; improving safety of life; improving environmental safety; and improving competiveness of European and Canadian industries.

[R Forsberg: Remember here to include sea level rise; the contribution to global sea level from glaciers and ice sheets are spatially varying due to self-gravitation and earth rheology; signal from Antarctica melt is larger in Europe than for Greenland and Arctic ice cap melt; therefore of society interest to continue monitoring of ice sheet changes at both poles]

8.1 INTRODUCTION

Investments in satellite EO systems provide benefits to:

- Industry – Companies working to increase economic prosperity.
- Governments – Nations or regions acting on behalf of the common interests of their citizens.
- Citizens – Individual members of society in pursuit of their personal aims, rather than as part of a company or a nation.
- Society – Where the beneficiary cannot be individually identified, benefits are attributed to society in general.

Of course, these beneficiaries are all inter-related and a benefit to one may be a benefit to all. They each may benefit from EO derived information in a number of possible ways:

- Increase in economic activity – Better information allows economic activity to proceed where it might otherwise be too costly or dangerous.
- Reduction of operating costs – Better information increases efficiency or decreases the cost of economic activity.
- Reduction of risk to life and property – Better information allows better decisions to be made that reduce the likelihood of accidents and disasters.
- Protection of the environment – Better information allows the impact of human activities on the environment to be understood and mitigated.
- Contribution to knowledge – Better information increases knowledge of the physical and ecological sciences.

- Improvement in quality of life – Better information allows people to pursue activities of their choosing.
- Contributions to sovereignty and enforcement – Better information helps protect national borders and enforce laws.

Some of these benefits can be measured in economic terms, but the most significant are qualitative and intangible – safety of life and property, protection of the environment, quality of life, contribution to knowledge, and sovereignty and enforcement – which cannot be easily measured in monetary units.

Many benefits are inter-related, and in a sense cascade from one to the next. For example, a National Ice Service is publicly funded primarily to reduce risk to life and property for industry (i.e. for the safety of marine transport). The benefits from this single application justify the resources necessary to maintain the services. However, further benefits cascade from there. The ice information permits economic activity where it might not otherwise be possible, reduces operating costs, provides information for monitoring the environment, increases human knowledge, and facilitates a host of activities. All of these subsequent benefits come at a very small marginal cost once the ice information is produced.

Impacts from EO information result from activities at all points along the value chain:

1. Construction and launching of the satellite system (space and ground segments) by the system integrator and component manufacturers, and subsequent operation of the satellite system and sale of the data (if applicable) by the system operator and licensed resellers;
2. Analysis of satellite data on behalf of end users by value-added geospatial companies, and
3. Use of satellite data by end users in different application communities.

The Impacts from a new Polaris satellite and integrated services considered in this analysis are those that will be incremental to the base case of the benefits that would accrue in the absence of such a satellite. Therefore, some benefits do not need to be considered since they are not considered incremental. For example, construction and operation of the satellite, and subsequent analysis of the data by value-added geospatial companies, are not considered incremental, as they will occur for some other satellite, if not a Polaris concept. Therefore, the focus here is on the incremental benefits to end users that would not accrue from other existing or proposed satellite systems.

No attempt has been made here to try to quantify the impact of the different scenarios for a number of reasons:

- Most of the benefits do not have applicable measurement units.

- There is no practical way to covert non-monetary benefits into monetary terms.
- Quantifying the economic benefits would be a task beyond the resources available in this study.

Instead, both the economic and non-economic benefits have been rated qualitatively.

8.2 METHODOLOGY

The methodology used to estimate the possible impacts of a Polaris mission consisted of the following steps:

1. Define environmental parameters:

The environmental parameters of interest to the operations and science communities are described in detail elsewhere (see D1.1 Environmental Information Requirements Report). In summary, those considered to have significant gaps are the following:

- Ice Thickness
- Extent
- Structure/Age
- Snow Depth
- Freeze-Thaw
- Topography
- Mass-Change
- Motion
- Iceberg Calving
- Surface State/Albedo
- Grounding Line
- Elevation Change
- Snow Water Equivalent
- Location (icebergs)
- Size
- Ice Dammed Lakes
- Salinity
- Wind
- Waves
- Chemistry/Particulates
- Biota
- Temperature
- Precipitation/Clouds/ Humidity
- Vegetation/Land Cover

2. Define mission capabilities

A mission capability defines the type of information that a mission can collect. A mission concept may integrate one or more mission capabilities, and consider other factors such as the type of orbit and the arrangement of multiple satellites in a constellation[19]. This analysis has reviewed the following seven mission capabilities:

- Dual and Tri-Band SAR – Two or more SAR frequencies, if measured co-temporally, can be used to differentiate the boundary layers in snow and ice, providing significantly more information than can a single frequency by itself.
- InSAR – SAR interferometry achieved using a passive companion can allow precise measurement of surface elevations.
- AIS with SAR – AIS can help in differentiating between icebergs and ships in SAR imagery.

[19] Mission concepts are analyzed in the "Future Mission Concepts for Polar Regions" project.

- Next-Generation Altimeter – There are a number of approaches to measuring topography, for example:
  - Passive GNSS reflections receiver
  - Stereo optical sensor
  - SAR Interferometer Radar Altimeter (as in Cryosat).
- Optical – Optical sensors covering a range of frequencies are of value for monitoring land use and vegetation. However, the use of optical sensors is constrained in the polar regions by the amount of cloud cover and darkness in the winter months.
- HEO Optical – An optical instrument in a highly elliptical orbit (HEO) to monitor the high latitudes not accessible to current geosynchronous weather satellites.

The ability of each mission capability to measure each environmental parameter has been assessed on a scale of 0 (no ability) to 5 (excellent ability) by the project team. The results are contained in Table 9 below.

3. Define integrated services:

A Polaris mission would provide integrated services for a number of information types. Such information could be historic (based on mission archives), current (near real-time), or forecast (model results based on mission data). See Chapter 5 in in "D1.1 Environmental Information Requirements Report" for more detail regarding information requirements. Examples of integrated information types include:

- Sea Ice – information on extent, thickness, structure, surface state, age, topography, motion, freeze-thaw process, snow depth, and other characteristics.
- Icebergs – information on extent, location, motion, size, shape, and other characteristics.
- River & Lake Ice – information on extent, thickness, structure, and freeze-thaw process, and other characteristics.
- Ice Sheets – information on extent, thickness, elevation change, snow depth, motion, grounding line, surface state, and other characteristics.
- Glaciers – information on extent, thickness, structure, topography, elevation change, snow depth, motion, grounding line, surface state, melt lake formation, and other characteristics.
- Snow – information on extent, thickness, structure, snow-water equivalence, surface state, and other characteristics.
- Permafrost – information on extent, depth, freeze-thaw process, motion, surface state, carbon emissions, and other characteristics.

- Land – information on the surface state, biota, land cover, and other characteristics.
- Ocean – information on salinity, wind, waves, temperature, biota, and other characteristics.
- Atmosphere – information on wind, chemistry, particulates, temperature, precipitation, clouds, humidity, and other characteristics.

The relevance of each environmental parameter to each integrated service is shown in Table 10. This is a binary choice such that a parameter has been either considered relevant or not.

4. Establish impact categories:

The following impact categories has been considered:

- Economy – increase in economic activity or decrease in operating costs.
- Safety – reduction in risk to life or property.
- Environment – protection of the environment and mitigation of the environmental impacts of human activity.
- Society – benefits to local, indigenous, and other peoples in their quality of life and other considerations not captured elsewhere.
- Knowledge – increase in the understanding of natural processes.

In general, economic, safety, environmental and societal impacts come from operational uses, while knowledge impacts come from science users.

- Operational Users – Operational users need information to enable the conduct of their activities in a manner that is safer, more efficient, and with less of environmental impact than would be possible otherwise. Examples of operational uses include weather forecasting, engineering design, operational planning, navigation, emergency response, and environmental impact analysis. In general, operational users require higher spatial and temporal resolution compared to science users. While they may use historical data for strategic planning and design, and forecasts for tactical planning, they often require current information as soon possible after it is acquired.
- Science Users – Science users need information to enable a better understanding of natural processes. Examples of scientific uses include research on climate change, weather, oceans, land, atmosphere, and ecosystems. In general, science users require data over larger areas and longer time-scales than operational users (although data requirements vary considerably depending on the subject of enquiry).

Of course, there is a transfer of impacts between these two communities. While the impact of ice and snow figures prominently for both communities, other information is also of interest.

The relative impact of each integrated service for each impact category was assessed on a scale of 0 (no impact) to 5 (significant impact) by the project team. The degree of impact is a product of the breadth of the impact (for example, the number of people impacted) and the magnitude of the impact (for example, how important the impact is to each person). The results are contained in Table 11 below. Examples of the types of impacts to be expected from each integrated service for each impact category are contained in Tables 12 to 16.

5. Calculate Impacts

- Impacts are calculated for each mission capability by multiplying the mission capabilities (Table 9) by the environmental parameter relevance (Table 10) by the integrated services impacts (Table 11). The results are then normalized such that the highest score for each impact category across all mission capabilities receives the highest score on a six-point scale, where:
  - (0) None – the benefit is not applicable to the user community.
  - (1) Minor – there is a benefit, but both size of the user community affected and the magnitude of the impact are small.
  - (5) Major – there is a significant benefit to a large user community.

The results of the impact analysis are contained in Tables 17 to 23 below. Table 24 summarizes the overall results for each mission capability. An analysis of the impact results is contained in Section 8.3 below.

Table 9: Relative Ability of Mission Capabilities to Measure Environmental Parameters

Parameter	Dual SAR	Tri SAR	InSAR	LEO Optical	Altimeter	HEO Optical	AIS
Ice Thickness	0	1	1	5	1	4	0
Extent	3	5	5	0	2	0	0
Structure/Age	1	4	5	3	1	0	0
Snow Depth	0	2	4	0	0	3	0
Freeze-Thaw	3	5	5	2	0	0	0
Topography	1	2	3	5	2	4	0
Mass-Change	1	3	4	5	2	4	0
Motion	2	3	3	1	2	0	0
Iceberg Calving	3	4	5	5	2	3	0
Surface State/Albedo	0	0	0	0	5	0	0
Grounding Line	0	1	3	3	0	4	0
Elevation Change	2	3	4	5	2	5	0
Snow Water Equivalent	1	3	4	0	0	0	0
Location (icebergs)	4	5	5	5	2	3	0
Size	3	4	5	5	3	2	0
Ice Dammed Lakes	3	3	4	5	2	4	0
Salinity	0	0	0	0	2	0	0
Wind	4	5	5	2	2	0	5
Waves	4	4	4	5	2	5	3
Chemistry/Particulates	0	0	0	0	4	0	0
Biota	0	0	0	0	5	0	0
Temperature	0	0	0	0	2	0	4
Precipitation/Clouds/Humidity	0	1	2	0	4	0	5
Vegetation/Land Cover	2	3	4	4	5	0	0

Table 10: Relevance of Environmental Parameters to Integrated Services

Parameter	Sea Ice	Icebergs	River and Lake Ice	Ice Sheets	Glaciers	Snow	Perma-frost	Land	Ocean	Atmo-sphere
Ice Thickness	1	0	1	1	1	0	0	0	0	0
Extent	1	1	1	0	1	1	1	0	0	0
Structure/Age	1	0	1	0	1	1	0	0	0	0
Snow Depth	1	0	0	1	1	1	0	0	0	0
Freeze-Thaw	1	0	1	0	0	1	1	0	0	0
Topography	1	0	0	0	1	0	0	0	0	0
Mass-Change	0	0	0	1	1	0	0	0	0	0
Motion	1	1	0	1	1	0	0	0	0	0
Iceberg Calving	0	1	0	1	1	0	0	0	0	0
Surface State/Albedo	1	0	0	1	1	1	1	1	0	0
Grounding Line	0	0	0	1	0	0	0	0	0	0
Elevation Change	0	0	0	0	0	0	1	0	0	0
Snow Water Equivalent	0	0	0	0	0	1	0	0	0	0
Location (icebergs)	0	1	0	0	0	0	0	0	0	0
Size	0	1	0	0	0	0	0	0	0	0
Ice Dammed Lakes	0	0	1	0	1	0	0	0	0	0
Salinity	0	0	0	0	0	0	0	0	1	0
Wind	0	0	0	0	0	0	0	0	1	1
Waves	0	0	0	0	0	0	0	0	1	0
Chemistry/Particulates	0	0	0	0	0	0	1	0	0	1
Biota	0	0	0	0	0	0	0	1	1	0
Temperature	1	0	0	0	0	0	0	0	1	1

Precipitation/Clouds/Humidity	0	0	0	0	0	0	0	0	0	1
Vegetation/Land Cover	0	0	0	0	0	0	0	1	0	0

Table 11: Relative Impacts of Polar Integrated Services

Integrated Service	Economy	Safety	Environment	Society	Knowledge
Sea Ice	3	4	2	2	4
Icebergs	4	5	2	1	1
River & Lake Ice	2	3	1	2	2
Ice Sheets	0	0	0	0	5
Glaciers	2	3	1	0	4
Snow	3	3	2	2	4
Permafrost	1	1	1	2	3
Land	3	1	3	1	5
Ocean	3	3	4	1	4
Atmosphere	5	4	3	3	5

Table 12: Example Economic Impacts of Integrated Services

Integrated Services	Example Economic Impacts
Sea Ice	▪ Allows more efficient shipping routes ▪ Allows higher fishing yields ▪ Reduces potential economic losses from property damage
Icebergs	▪ Reduces potential economic losses from property damage
River & Lake Ice	▪ Enables rivers and lakes to be used for winter transportation ▪ Reduces potential economic losses from property damage
Ice Sheets	
Glaciers	▪ Assists in hydroelectric power generation
Snow	▪ Assists in hydroelectric power generation
Permafrost	▪ Assists in planning of most cost- effective construction of facilities for mineral extraction ▪ Reduces potential economic losses from property damage
Land	
Ocean	
Atmosphere	▪ Reduces potential economic losses from poor weather prediction

Table 13: Example Safety Impacts of Integrated Services

Integrated Services	Example Safety Impacts
Sea Ice	▪ Allows safer shipping ▪ Improves design of ice-strengthened vessels ▪ Improves risk assessment effectiveness

	▪ Improves emergency response effectiveness
Icebergs	▪ Allows safer shipping ▪ Improves risk assessment effectiveness
River & Lake Ice	▪ Reduces danger from river flooding. ▪ Improves emergency response effectiveness
Ice Sheets	
Glaciers	▪ Reduces danger from glacier flooding
Snow	▪ Reduces danger from snow flooding
Permafrost	▪ Improves design of buildings and structures
Land	▪ Reduces danger from landslides
Ocean	▪ Improves emergency response effectiveness
Atmosphere	▪ Improves emergency response effectiveness

Table 14: Example Environmental Impacts of Integrated Services

Integrated Services	Example Environmental Impacts
Sea Ice	▪ Reduces potential for environmental accidents
Icebergs	▪ Reduces potential for environmental accidents
River & Lake Ice	▪ Reduces potential for environmental accidents
Ice Sheets	
Glaciers	▪ Improved management of freshwater resources
Snow	
Permafrost	
Land	▪ Improves ability to reduce ecosystem damage

Ocean	▪ Improves ability to reduce ecosystem damage
Atmosphere	▪ Improves weather prediction effectiveness

Table 15: Example Societal Impacts of Integrated Services

Integrated Services	Example Societal Impacts
Sea Ice	▪ Enables Inuit hunters to pursue traditional ways of life ▪ Reduces potential loss of life
Icebergs	▪ Reduces potential loss of life
River & Lake Ice	▪ Allows travel on rivers and lakes to support northern communities. ▪ Reduces potential loss of life
Ice Sheets	
Glaciers	▪ Improved management of freshwater resources
Snow	▪ Enables Sami herders to pursue traditional ways of life
Permafrost	▪ Reduces the risk of disruption from damaged buildings ▪ Reduces potential loss of life
Land	
Ocean	▪ Helps assess need for community relocations due to sea level rise
Atmosphere	▪ Helps facilitate adaptation to climate change ▪ Reduces inconveniences resulting from poor weather prediction

Table 16: Example Knowledge Impacts of Integrated Services

Integrated	Example Knowledge Impacts

Services	
Sea Ice	▪ Provides information on climate change ▪ Helps improve weather prediction ▪ Improves knowledge of how melting sea ice affects marine ecosystems
Icebergs	▪ Provides information on climate change
River & Lake Ice	▪ Provides information on climate change ▪ Helps improve weather prediction
Ice Sheets	▪ Provides information on climate change ▪ Improves understanding of role of ice sheet melting on sea level rise
Glaciers	▪ Provides information on climate change ▪ Improves understanding of role of glacier melting on sea level rise
Snow	▪ Provides information on climate change ▪ Improves understanding of snow impact on polar hydrological cycle
Permafrost	▪ Provides information on climate change ▪ Improves knowledge of impacts of changing permafrost regimes on terrestrial ecosystems
Land	▪ Provides information on climate change ▪ Improves knowledge of impacts of human activities on the land
Ocean	▪ Provides information on climate change "Improves knowledge of coupling between sea ice, climate, marine ecosystems and biogeochemical cycling ▪ Improves knowledge of role of the ocean in the stability of the Antarctic ice sheet ▪ Improves knowledge of impacts of a changing sea-ice regime and wave climate on coastal stability
Atmosphere	▪ Provides information on climate change

Table 17: Mission Capability 1 – Dual Band SAR

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall

Sea Ice	3.6	3.8	4.2	4.2	3.2	**3.8**
Icebergs	4.6	4.6	4.0	2.0	0.8	**3.2**
River & Lake Ice	2.0	2.3	1.7	3.5	1.3	**2.2**
Ice Sheets	0.0	0.0	0.0	0.0	2.6	**0.5**
Glaciers	2.9	3.5	2.6	0.0	4.0	**2.6**
Snow	3.1	2.5	3.7	3.7	2.8	**3.1**
Permafrost	0.7	0.6	1.3	2.5	1.4	**1.3**
Land	0.5	0.1	0.9	0.3	0.6	**0.5**
Ocean	1.5	1.2	3.5	0.9	1.3	**1.7**
Atmosphere	1.6	1.0	1.7	1.7	1.1	**1.4**
Overall	**4.3**	**4.3**	**4.4**	**4.4**	**4.1**	**4.3**

Table 18: Mission Capability 2 – Tri Band SAR

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	4.2	4.5	5.0	5.0	3.8	**4.5**
Icebergs	5.0	5.0	4.4	2.2	0.8	**3.5**
River & Lake Ice	2.2	2.6	1.9	3.8	1.5	**2.4**
Ice Sheets	0.0	0.0	0.0	0.0	3.7	**0.7**
Glaciers	3.7	4.4	3.3	0.0	5.0	**3.3**
Snow	3.8	3.0	4.4	4.4	3.4	**3.8**
Permafrost	0.8	0.6	1.3	2.7	1.5	**1.4**
Land	0.7	0.2	1.2	0.4	0.7	**0.6**
Ocean	1.5	1.2	3.5	0.9	1.3	**1.7**
Atmosphere	1.9	1.2	2.0	2.0	1.3	**1.7**
Overall	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**

Table 19: Mission Capability 3 – InSAR

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	2.6	2.8	3.1	3.1	2.4	**2.8**
Icebergs	3.5	3.5	3.1	1.5	0.6	**2.4**
River & Lake Ice	1.6	2.0	1.4	2.9	1.1	**1.8**
Ice Sheets	0.0	0.0	0.0	0.0	3.5	**0.7**
Glaciers	3.2	3.8	2.8	0.0	4.3	**2.8**
Snow	0.8	0.7	1.0	1.0	0.7	**0.8**
Permafrost	0.4	0.3	0.7	1.3	0.8	**0.7**
Land	0.7	0.2	1.2	0.4	0.7	**0.6**
Ocean	1.1	0.9	2.7	0.7	1.0	**1.3**
Atmosphere	0.5	0.3	0.6	0.6	0.4	**0.5**
Overall	**3.0**	**3.2**	**3.0**	**2.7**	**3.3**	**3.1**

Table 20: Mission Capability 4 – LEO Optical

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	2.4	2.6	2.9	2.9	2.2	**2.6**
Icebergs	2.4	2.4	2.1	1.1	0.4	**1.7**
River & Lake Ice	0.7	0.8	0.6	1.2	0.4	**0.7**
Ice Sheets	0.0	0.0	0.0	0.0	2.2	**0.4**
Glaciers	2.1	2.5	1.8	0.0	2.8	**1.8**
Snow	1.3	1.0	1.5	1.5	1.2	**1.3**
Permafrost	0.7	0.6	1.3	2.5	1.4	**1.3**
Land	2.4	0.7	4.3	1.4	2.8	**2.3**
Ocean	2.1	1.7	5.0	1.3	1.9	**2.4**
Atmosphere	3.3	2.1	3.5	3.5	2.2	**2.9**
Overall	**3.7**	**3.1**	**4.3**	**3.6**	**3.8**	**3.7**

Table 21: Mission Capability 5 – Next Generation Altimeter

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	1.8	1.9	2.1	2.1	1.6	**1.9**
Icebergs	1.7	1.7	1.5	0.8	0.3	**1.2**
River & Lake Ice	0.9	1.0	0.8	1.5	0.6	**1.0**
Ice Sheets	0.0	0.0	0.0	0.0	3.3	**0.7**
Glaciers	2.4	2.9	2.1	0.0	3.2	**2.1**
Snow	0.5	0.4	0.6	0.6	0.4	**0.5**
Permafrost	0.3	0.2	0.5	1.0	0.6	**0.5**
Land	0.0	0.0	0.0	0.0	0.0	**0.0**
Ocean	0.8	0.7	1.9	0.5	0.7	**0.9**
Atmosphere	0.0	0.0	0.0	0.0	0.0	**0.0**
Overall	**1.8**	**1.9**	**1.8**	**1.5**	**2.3**	**1.9**

Table 22: Mission Capability 6 – HEO Optical

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	0.7	0.7	0.8	0.8	0.6	**0.7**
Icebergs	0.0	0.0	0.0	0.0	0.0	**0.0**
River & Lake Ice	0.0	0.0	0.0	0.0	0.0	**0.0**
Ice Sheets	0.0	0.0	0.0	0.0	0.0	**0.0**
Glaciers	0.0	0.0	0.0	0.0	0.0	**0.0**
Snow	0.0	0.0	0.0	0.0	0.0	**0.0**
Permafrost	0.0	0.0	0.0	0.0	0.0	**0.0**
Land	0.0	0.0	0.0	0.0	0.0	**0.0**
Ocean	2.0	1.6	4.6	1.2	1.8	**2.2**
Atmosphere	3.8	2.4	4.0	4.0	2.6	**3.4**
Overall	**1.4**	**1.0**	**1.7**	**1.4**	**1.1**	**1.3**

Table 23: Mission Capability 7 – AIS

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Sea Ice	0.0	0.0	0.0	0.0	0.0	**0.0**
Icebergs	0.7	0.7	0.6	0.3	0.1	**0.5**
River & Lake Ice	0.0	0.0	0.0	0.0	0.0	**0.0**
Ice Sheets	0.0	0.0	0.0	0.0	0.0	**0.0**
Glaciers	0.0	0.0	0.0	0.0	0.0	**0.0**
Snow	0.0	0.0	0.0	0.0	0.0	**0.0**
Permafrost	0.0	0.0	0.0	0.0	0.0	**0.0**
Land	0.0	0.0	0.0	0.0	0.0	**0.0**
Ocean	0.0	0.0	0.0	0.0	0.0	**0.0**
Atmosphere	0.0	0.0	0.0	0.0	0.0	**0.0**
Overall	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**	**0.1**

Table 24: Mission Capability Summary

Integrated Service	Economy	Safety	Environment	Society	Knowledge	Overall
Dual SAR	4.3	4.3	4.4	4.4	4.1	4.3
Tri SAR	5.0	5.0	5.0	5.0	5.0	5.0
InSAR	3.0	3.2	3.0	2.7	3.3	3.1
LEO Optical	3.7	3.1	4.3	3.6	3.8	3.7
Next Generation Altimeter	1.8	1.9	1.8	1.5	2.3	1.9
HEO Optical	1.4	1.0	1.7	1.4	1.1	1.3
AIS	0.1	0.1	0.1	0.1	0.0	0.1

8.3 ANALYSIS

The results presented here should be examined with a few caveats in mind:

- The impact findings are relative and imprecise. The impact scores are ordinal scales[20] and are based on the opinions of experts.
- The analysis has only examined the relative impact of possible mission capabilities; relative costs have not been considered. Choices among the alternatives would also need to compare the benefits against the costs. The costs of alternative mission concepts are being evaluated in a separate study[21].
- Five impact categories have been evaluated. Each is orthogonal in the sense that each measures something different, using different interpretations of utility, and the categories cannot be added or otherwise be combined. No opinion has been offered here as to the relative importance of each impact category. In fact, the importance of an impact category will depend on the situation and the interests of the evaluator. This is particularly true for the differences between the Operations and Science communities. While, four impact categories are more relevant to the Operations community, this in no way implies that the Operations community has four times the impact of the Science community; their impacts are simply different.

Given these caveats, a number of observations can be made about the results:

- Multi-Frequency SAR – Not surprisingly, a large number of polar user communities are interested in variations of frozen water (sea ice, river and lake ice, glaciers and ice sheets, icebergs, and snow). Because of the ability of SAR sensors to see through cloud and in darkness (both of which are common at the poles), and their ability to penetrate ice and snow to see below the surface, SAR is the best sensor for monitoring polar frozen water. Different SAR frequencies reveal different information, and therefore there are benefits to having more frequencies available. As a result, this analysis has found tri-frequency SAR to have the greatest impact of the mission capabilities examined, followed by dual-frequency SAR.
- LEO Optical – For observing things other than frozen water, optical sensors are superior to SAR, although they are obstructed by darkness and cloud. The results show multi-spectral optical to have its greatest impact in environmental applications involving monitoring of land cover, vegetation, and ocean colour. The impact of multi-spectral optical was found to be below SAR, but above the other mission capabilities examined.

[20] An ordinal scale allows for rank order by which data can be sorted, but still does not allow for relative degree of difference between them. See for example: https://en.wikipedia.org/wiki/Level_of_measurement
[21] "Future Mission Concepts for Polar Regions"

- InSAR – The ability to determine surface topology is important in a number of application areas. Such information can be acquired in a number ways; however, interferometry using bi-static SAR offers the best combination of vertical resolution and wide area coverage compared to alternative altimeter options.
- AIS – The AIS mission capability does relatively poorly in the analysis here because it is only applicable to one environmental parameter – iceberg location. However, that is because the objective of this study is limited to the measurement of *environmental information*. While AIS does not measure environmental information, it is very valuable in other applications, such as ship safety and marine surveillance, the impacts of which have not been considered in this analysis.

9 LEGAL AND POLITICAL IMPLICATIONS ANALYSIS

This chapter provides an assessment of the potential legal and policy/political implications of implementing the most promising integrated services to address the current information gaps of importance to scientific and operational users.

9.1 POLITICAL/POLICY ENVIRONMENT

As discussed in Deliverable D1.1 *Environmental Information Requirements Report* for the Polaris study (Section 5.4.1 Impacts of Political/Policy Trends) the overall political and policy environment is conducive to the development of new integrated services to meet the needs of a growing collection of environmental information users in the polar regions.

A top priority for all arctic nations and the EU is sustainable economic development of renewable and non-renewable resources. For the main participants in economic development activities (i.e. oil and gas and mining companies, fisheries, shipping and tourism operators), the combination of a warming climate and a supportive political and policy environment will produce increasing demands for environmental information. Improved ice, snow and iceberg services are required to meet the operations and route planning needs of these users. For example, the EU Strategy for the Arctic "stresses that reliable, high-capacity information networks and digital services are instrumental in boosting the economic activity and welfare of people in the Arctic" (European Parliament, 2014).

A political priority of equal importance is protection of the fragile natural environment in the polar regions. In addition to the importance placed on environmental protection in the arctic policies of individual nations, an array of international agreements indicate the level of political significance of this goal (e.g. Stockholm, Basel, Helsinki, MARPOL and OSPAR Conventions plus the agreements under the Antarctic Treat System). Users need better ice, snow, land and atmospheric information to conduct required activities to ensure that the environment is protected (e.g. environmental impact assessments, engineering design and risk management) and to monitor environmental changes (e.g. land use, ocean state, coastal zone, ecosystem and species change research). The EU Strategy for the Arctic "stresses the need for reliable monitoring and observational systems that follow the changing conditions of the Arctic" (European Parliament, 2014).

A third political priority is safety of life and the built environment in the polar regions, which includes reducing the risk of adverse events and minimizing injury and loss of life and damage to facilities in the case of accidents and emergencies. Given the increase in marine vessel traffic in the polar regions, there is prominence in national and international policies on safety of marine transportation. For example, EU Strategy for the Arctic "calls on the

Commission to put forward proposals as to how the Galileo Project or projects such as Global Monitoring for Environment and Security that could have an impact on the Arctic could be developed to enable safer and faster navigation in Arctic waters" (European Parliament, 2014).

The most recent manifestation of the safety priority is the impending implementation on January 1, 2017 of the *IMO International Code for Ships Operating in Polar Waters* (known as the Polar Code), which will impose requirements for improved information use onboard vessels operating in the polar regions (e.g. "ships shall have means of receiving and displaying current information on ice conditions in the area of operation" and "the master shall consider a route through polar waters, taking into account the following:… current information on the extent and type of ice and icebergs in the vicinity of the intended route… [and] statistical information on ice and temperatures from former years"). In addition, the importance of safe subsistence food collection by indigenous populations in the Arctic is reflected in both national policies and international accords. For scientific and operational users working in the harsh and unpredictable polar environment, safety is of paramount importance. To improve safety, users need better environmental information for planning and undertaking navigation and operations on land and sea, designing vessels, buildings and structures, and responding to search and rescue calls and emergencies.

In summary, there is apparent strong political will to ensure that development of resources is undertaken in a sustainable manner that minimizes adverse environmental consequences and that measures are taken to ensure the safety of life and facilities in the polar regions. National policies and international agreements have been adopted to facilitate the exercise of this political will, and reliable environmental information and accessible information services are of implicit importance to the achievement of these goals.

9.2 DATA POLICIES

For the most part, policies determining the rights to access and use EO and related other space and non-space data are conducive to the development of the integrated services that will be required to address the current information gaps. There is, however, policy differentiation between the public and private sector providers of EO and AIS data, and there is some uncertainty with the policies covering the plethora of in situ data.

On the public sector side, for example, access to the ESA Copernicus Sentinel data and service information is regulated by Regulation (EU) No 377/2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 3 April 2014 establishing the Copernicus Programme and repealing Regulation (EU) No 911/2010 (European Union, 2014) and Commission

Delegated Regulation (EU) No 1159/2013 of 12 July 2013 supplementing Regulation (EU) No 911/2010 of the European Parliament and of the Council on the European Earth monitoring programme (GMES) by establishing registration and licensing conditions for GMES users and defining criteria for restricting access to GMES dedicated data and GMES service information (European Commission, 2013). Pursuant to these regulations, ESA's Copernicus Sentinel Data Policy, ESA/PB-EO(2013)30, rev. 1 provides users with free, full and open access to Copernicus Sentinel Data and Service Information without any express or implied warranty as regards quality and suitability for any purpose. Users are able to: develop altered products or derivative works; make unlimited copies of the data; and publish and distribute the Sentinel data, altered products or derivative works provided the user acknowledges ESA as the data source (European Commission, n.d.).

Another public sector example is NASA, which may be the source of some EO data that could be usefully included in integrated services to address current gaps. NASA promotes the full and open sharing of all EO data with the research and applications communities, private industry, academia, and the general public (NASA, 2011). Similar to ESA, NASA provides its data without any express or implied warranty and requires acknowledgement of the source data in the publication of any altered products or derivative works.

A third example, CSA, is currently finalizing the data policy for the Radarsat Constellation Mission (RCM), the launch for which is planned for Q3, 2018. In February 2014, the Government of Canada Deputy Ministers Governance Committee on Space approved the following policy principles (Chalifoux, 2015):

- Canadian Interests First – Give priority to GoC requirements in support of sovereignty, security and safety
- Economic Growth – Strengthen Canadian industry's capacity to commercialize value added application products and services, at home and abroad
- Support Partnerships – Enable cooperation with allies/partners to meet socio-economic and security objectives
- Commercial distribution of RCM data – Enable the commercial distribution of RCM data, while being compliant with the Open Government Strategy

Understandably, the data policies of industrial suppliers of EO data that might be included in integrated services are more restrictive, to protect intellectual property rights and ensure return on investment. For example, the provision by MDA of Radarsat-2 data is covered by a license agreement that grants the licensee for a fee a limited, non-transferable, non-exclusive, perpetual license to use data products under certain conditions (e.g. make an unlimited number of soft and hard copies of the product for internal use; publish the product in a secure format in research reports, journals, trade papers or similar publications, and post the product to Internet web sites; develop, reproduce and distribute derived value-

added products under specific conditions) (MDA, 2011). Similarly, a major supplier of optical imagery of potential interest for some polar region applications, DigitalGlobe, sells its EO imagery under license. Licensees are granted non-exclusive, non-transferable, limited rights to access, reproduce, store, display and create derivatives of the purchased data product under restricted conditions (DigitalGlobe, n.d.).

Concerning other space data, the principle of free and open data access prevails for most sources. GNSS data providers (e.g. GPS, Galileo, GLONASS) are generally providing unrestricted access to the type of positioning and navigation data required for polar applications. The exception is S-AIS, which is primarily in the purview of the private sector (with the exception of the AISSat series of the Norwegian Space Centre). The two major S-AIS commercial service providers, exactEarth and ORBCOMM, provide access to their AIS data feeds under license. For example, exactEarth grants licencees a limited, restricted, non-exclusive, non-transferable, revocable licence allowing them to use the products for stated internal business use only, and to create derived products, provided that they are used for internal business use or for other specifically pre-authorized uses (exactEarth, 2013).

Determining the data policies for in situ data is more problematic, since much of the data is project-oriented. However, there are many portals that provide free and open access to various types of in situ data on a global basis, as discussed in Chapter 5. For example, one major source is the ICSU World Data System, which has adopted Data Sharing Principles that are in line with the data policies of national and international initiatives, including those of the Group on Earth Observations, the G8 Science Ministers' Statement and Open Data Charter, the OECD Principles and Guidelines for Access to Research Data from Public Funding, as well as the Science International Accord on Open Data in a Big Data World (ICSU, 2015). Free and open access is also provided to a wide range of ocean in situ data in the World Ocean Database via the NOAA National Centres for Environmental Information (NOAA, 2015). A third example is the Global Biodiversity Information Facility (GBIF), which provides free and open access to some 639 million records on a named organism in nature under the condition that the data publisher is acknowledged (GBIF). The GBIF data sharing agreement states that “Biodiversity data accessible via the GBIF network are openly and universally available to all users within the framework of the GBIF Data Use Agreement and with the terms and conditions that the Data Publisher has identified in its metadata” (GBIF).

In summary, data policies do not generally appear to be an impediment to the implementation of the integrated services that will be required to address the current information gaps. With the exception of a few commercial sources of data that might be usefully integrated, most providers of EO, other space and in situ data provide relatively free, open and unrestricted rights to the use of their data.

9.3 SECURITY RESTRICTIONS

In some circumstances, security considerations may supersede for a period of time the normal open data policies. For example, under the *EC Regulation No 1159/2013*, the Commission can restrict the dissemination of Copernicus dedicated data and service information where its open dissemination presents an unacceptable degree of risk to the security interests of the European Union or its Member States due to the sensitivity of the data and information (European Commission, 2013). Similarly, Radarsat services may be disrupted under a provision of the *Remote Sensing Space Systems Act (S.C. 2005, c. 45)* (Government of Canada, 2007). The Canadian Federal Minister of Foreign Affairs may order the interruption of a remote sensing system licensed under the Act if the Minister believes that the continuation of that operation would be injurious to Canada's conduct of international relations or inconsistent with Canada's international obligations. In addition, the Minister of Defence may order the interruption of such a remote sensing system if the Minister believes that the continuation of that operation would be injurious to the defence of Canada or the safety of Canadian Forces.

APPENDIX 1: EXISTING EO-BASED PRODUCTS AND SERVICES

The tables in this appendix identify a cross-section of products available from some of the main sources of EO-based products and services.

Ocean Parameters

Marine ecosystem functioning

Table 25: Marine Ecosystem Functioning Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Arctic surface chlorophyll concentration from satellite observations	Satellite-Observation, Ocean-Chlorophyll	For the Arctic Ocean- Chlorophyll is estimated from the OC5 (case 2 waters), developed by Francis Gohin and others at Ifremer (Gohin, F., et al., 2008.), and from the OC488 (case 1 and 2 waters) algorithm developed at PML. Separate chlorophyll products are produced from MODIS and VIIRS data. Daily products are available in Near Real Time (NRT) and few days after in Delayed Time (DT). DT is of better quality as it uses hindcast meteorological and navigational data.	Since 2013-10-31 Arctic Daily mean Near-Real-Time and delayed time (few days after) 1.2 km			http://marine.copernicus.eu/web/69-interactive-catalogue.php?option=com_csw&view=details&product_id=OCEANCOLOUR_ARC_CHL_L3_NRT_OBSERVATIONS_009_047
Arctic chlorophyll concentration from satellite observations (Daily average) reprocessed L3 (ESA-CCI)	Satellite-Observation, Ocean-Chlorophyll, surface Chlorophyll (mg m-3, 1 km resolution) Daily average	REPROCESSED L3 (ESA-CCI) For the Arctic area, the ESA-CCI Remote Sensing Reflectance (Rrs) are used to compute surface Chlorophyll (mg m-3, 1 km resolution) using the regional OC5 and OC488 chlorophyll algorithms. The Rrs are generated by merging the data from SeaWiFS, MODIS-Aqua and MERIS sensors and realigning the	1997-2012 Multi-Year Annually Arctic-Ocean 1 km			http://marine.copernicus.eu/web/69-interactive-catalogue.php?option=com_csw&view=details&product_id=OCEANCOLOUR_ARC_CHL_L3

		spectra to that of the SeaWiFS sensor. The chlorophyll products produced at PML for MyOcean are based on the OC5 algorithm developed by Francis Gohin and others at Ifremer (Gohin, F., et al., 2008.), for case 2 waters, and on the newly developed OC488 developed at PML (Taberner, M., et al, 2014), for case 1 and case 2 waters.				_REP_OBSERVATIONS_009_069
MODIS Sub-surface Chlorophyll-a Concentration MOD21	The MODIS Chlorophyll a Pigment Concentration product (MOD21) provides two estimates of the concentration of chlorophyll a: Chlor_a_2 and Chlor_a_3.	Chlor_a_2 is based on an empirical algorithm, and is intended to provide continuity with the SeaWiFS chlorophyll product. Chlor_a_3 is derived from a semi-analytic algorithm for Case 1 and Case 2 waters. This involves the inversion of a radiance model to determine the absorption coefficient due to phytoplankton at 675 nm, and the absorption coefficient of CDOM (also called "yellow substance" or gelbstoff) at 400 nm.	Arctic, Antarctic Daily, 8-Day, Monthly	Underestimation in polar seas Arctic: RMS=0.17 RMSlin =0.41 (n=75) Antarctic: RMS1=0.22, RMSlin=0.53 (n=871)		http://modis.gsfc.nasa.gov/data/dataprod/chlor_a.php http://modis.gsfc.nasa.gov/data/atbd/atbd_mod19.pdf
Algal pigment concentration		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85

Sea surface temperature

Table 26: Sea Surface Temperature Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Sea surface temperature		Sentinel-3 ESA Climate Change Initiative SST Project for satellite era	From 2016-2017 For areas defined in ESA, 2013 <1.5h <1m ESA CCI: satellite era to present		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Arctic ocean physics reanalysis	Numerical-Model, Sea-Ice, Temperature, Currents, Salinity, Sea-Level	The TOPAZ4 Arctic Ocean Reanalysis provides 3D physical ocean and sea ice variables for the time period 1991-2013. The reanalysis uses the HYCOM model and a 100-members DEnKF to assimilate both in situ profiles and satellite data from different sensors.	1991-2010 Multi-Year, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global ocean OSTIA sea surface temperature and sea ice reprocessed	Satellite-Observation, Sea-Ice, Temperature, Foundation sea surface temperature (referred to as an L4 product) at 0.05deg.x 0.05deg. horizontal resolution	For the Global Ocean- The OSTIA global Sea Surface Temperature Reanalysis product provides daily gap-free maps of: Foundation sea surface temperature (referred to as an L4 product) at 0.05deg.x 0.05deg. horizontal resolution, using in situ and satellite data from infra-red radiometers..	1985-2007 Multi-Year, Global-Ocean, Iberian-Biscay-Irish-Seas, North-West-Shelf-Seas, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php

Global ocean OSTIA sea surface temperature and sea ice reprocessed	Satellite-Observation, Sea-Ice, Temperature, Sea Surface Temperature anomaly from the Pathfinder climatology at 0.25° x 0.25° horizontal resolution.	For the Global Ocean- The OSTIA global Sea Surface Temperature Reanalysis product provides daily gap-free maps of: Sea Surface Temperature anomaly from the Pathfinder climatology at 0.25° x 0.25° horizontal resolution. This product provides the foundation Sea Surface Temperature, which is the temperature free of diurnal variability.	1985-2007 Multi-Year, Global-Ocean, Iberian-Biscay-Irish-Seas, North-West-Shelf-Seas, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global Ocean Ostia Sea surface temperature and sea ice reprocessed	Satellite-Observation, Sea-Ice, Temperature, Monthly and seasonal means of the daily Sea Surface Temperature product at 0.25° x 0.25° horizontal resolution	For the Global Ocean- The OSTIA global Sea Surface Temperature Reanalysis product provides daily gap-free maps of: Monthly and seasonal means of the daily Sea Surface Temperature product	1985-2007 Multi-Year, Global-Ocean, Iberian-Biscay-Irish-Seas, North-West-Shelf-Seas, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Arctic ocean high resolution sea surface temperature reanalysis	Satellite-Observation, Temperature, gap-free maps of sea surface temperature, sea surface temperature operational nominal product for the Arctic.	For The Arctic Ocean- The MET.NO Sea Surface Temperature analysis aims at providing daily gap-free maps of sea surface temperature, referred as L4 product, at 0.03deg. x 0.03deg. horizontal resolution, using satellite data from infra-red (and microwave radiometers. It is the sea surface temperature operational nominal product for the Arctic.	Near-Real-Time, (daily) Arctic-Ocean 0.03 deg. x 0.03 deg. horizontal resolution			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Arctic ocean – sea and ice surface	Satellite-Observation,	Arctic Sea and Ice surface temperature	Near-Real-Time,			http://marine.copernicus.eu/web/6

temperature	Temperature, Sea-Ice, Arctic Sea and Ice surface temperature		Arctic-Ocean			9-interactive-catalogue.php
MODIS Sea Surface Temperature		OCI Ocean color index algorithm	2002 – present -90° – 90 ° -180° - 180° Daily, weekly (8 day), monthly and annual MODIS SST products are available at both 4.63 and 9.26 km spatial resolution and for both daytime and nighttime passes			http://modis.gsfc.nasa.gov/data/dataprod/
Global High resolution sea surface temperature		For the sea surface temperature (SST) radiometer channels in the 4, 11 and 12 um spectrum are used.	2006 – present 1 km			http://modis.gsfc.nasa.gov/data/dataprod/

Wave directional energy frequency spectrum

Table 27: Wave Directional Energy Frequency Spectrum Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Ocean wave spectra		Sentinel-1	2015-2016		Priorities	http://marine.cop

			For areas defined in ESA, 2013 <1.5 h 5m - 40 m		The transition time to switch from one imaging mode to another may result in some imaging gaps of geographical areas. Coverage unclear	ernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85

Ocean dynamic topography

Table 28: Ocean Dynamic Topography Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Sea surface height		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 2 d		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Significant wave		Sentinel-3	From 2016-2017		Solar	http://marine.cop

height			For areas defined in ESA, 2013 <1.5 h		illumination conditions Coverage unclear	ernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Tide height		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Arctic ocean physics reanalysis	Numerical-Model, Sea-Ice, Temperature, Currents, Salinity, Sea-Level	The TOPAZ4 Arctic Ocean Reanalysis provides 3D physical ocean and sea ice variables for the time period 1991-2013. The reanalysis uses the HYCOM model and a 100-members DEnKF to assimilate both in situ profiles and satellite data from different sensors.	1991-2010 Multi-Year, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global ocean along-track sea level anomalies NRT	Satellite-Observation, Sea-Level Along-track sea surface heights computed with respect to a twenty-	For the Global Ocean- Mono altimeter satellite along-track sea surface heights computed with respect to a twenty-year mean. All the missions are homogenized with respect to a reference mission which is currently Jason-2. The acquisition of various altimeter data is a few days at most. This	Near-Real-Time, Iberian-Biscay-Irish-Seas, Global-Ocean, North-West-Shelf-Seas, Arctic-Ocean, Baltic-Sea			http://marine.copernicus.eu/web/69-interactive-catalogue.php

	year mean	product is computed with a non-centered computation time window (6 weeks before the date)				
Global ocean along-track sea level anomalies reprocessed	Satellite-Observation, Sea-Level along-track sea surface heights computed with respect to a twenty-year mean	For the Global Ocean- Mono altimeter satellite along-track sea surface heights computed with respect to a twenty-year mean. All the missions are homogenized with respect to a reference mission which is currently Jason-2. This product is computed with an optimal and centered computation time window (6 weeks before and after the date).	1993-ONGOING Multi-Year, Baltic-Sea, Arctic-Ocean, North-West-Shelf-Seas, Global-Ocean, Iberian-Biscay-Irish-Seas			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Arctic ocean along-track sea level anomalies NRT	Satellite-Observation, Sea-Level along-track sea surface heights computed with respect to a twenty-year mean	For the Arctic Ocean - Mono altimeter satellite along-track sea surface heights computed with respect to a twenty-year mean. All the missions are homogenized with respect to a reference mission which is currently Jason-2. The acquisition of various altimeter data is a few days at most. This product is computed with a non-centered computation time window (6 weeks before the date).	Near-Real-Time, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global sea level changes	Global grids of sea level, including Arctic	ESA Climate Change Initiative Sea Level project	1991-present	<0.2 mm/yr		www.esa-cci.org
Global ocean mean dynamic topography	Satellite-Observation, Sea-Level Mean Dynamic Topography	For the Global Ocean- Mean Dynamic Topography computed on a 7 years period (1993-1999).	Time Invariant, Black-Sea, Iberian-Biscay-Irish-Seas, Global-Ocean, North-West-Shelf-Seas, Arctic-Ocean, Baltic-Sea			http://marine.copernicus.eu/web/69-interactive-catalogue.php

GLOBAL OCEAN MEAN SEA SURFACE	Satellite-Observation, Sea-Level Mean sea surface above Topex/Poseidon reference ellipsoid	For the Global Ocean- Mean sea surface above Topex/Poseidon reference ellipsoid available on a 1/30 deg. x 1/30 deg. regular grid.	Time Invariant, Mediterranean-Sea, Global-Ocean, Arctic-Ocean, North-West-Shelf-Seas, Iberian-Biscay-Irish-Seas, Baltic-Sea, Black-Sea 1/30 deg. x 1/30 deg. regular grid.			http://marine.copernicus.eu/web/69-interactive-catalogue.php

Sea surface salinity

Table 29: Sea Surface Salinity Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
ARCTIC OCEAN PHYSICS REANALYSIS	Numerical-Model, Sea-Ice, Temperature, Currents, Salinity, Sea-Level	The TOPAZ4 Arctic Ocean Reanalysis provides 3D physical ocean and sea ice variables for the time period 1991-2013. The reanalysis uses the HYCOM model and a 100-members DEnKF to assimilate both in situ profiles and satellite data from different sensors.	1991-2010 Multi-Year, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php

Ocean suspended sediments concentration

Table 30: Ocean Suspended Sediments Concentration Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
TSM concentration		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85

Colour Dissolved Organic Matter (CDOM)

Table 31: Colour Dissolved Organic Matter Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Coloured dissolved matter absorption		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Leve

						l+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85

Atmospheric Parameters

Precipitation (liquid or solid)

Table 32: Precipitation Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Integrated water vapour		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h 1 month		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Rain rate		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan

						/530fd782-6386-4d26-9e05-36970bf91b85
MODIS Total Precipitable Water		NIR day IR night 1x1 km2	2/day			http://modis.gsfc.nasa.gov/data/dataprod/
Total Precipitable Water (SSM/I)	Also referred to as Water Vapor, this product shows the total atmospheric moisture over oceans.	The water vapor is derived from the passive microwave sensor SSM/I, which has 7 channels of 19 GHz (H, V), 22 GHz (V), 37 GHz (H, V), and 85 GHz (H, V), where H is the horizontal polarization, V is the vertical polarization. The water vapor varies from 0 to 80 with accuracy of 0.1 kg/m^2. The product is updated once per day at 4 am EST.	Daily Every (at?) 4 hours 25 km	0.1 kg/m^2		http://www.ospo.noaa.gov/Products/atmosphere/clouds.html
Total Precipitable Water (MSPPS)	The Total Precipitable Water (TPW) is the vertically integrated water vapor content in a vertical column of unit cross-sectional area extending all the way from the earthâ€™s surface to the top of the atmosphere.	The NESDIS operational TPW product is derived from 23 and 31 GHZs channel measurements of the Advanced Microwave Sounding Units (AMSU) -A aboard on the NOAA POES satellites, and is expressed here in mm or kg/m2. The products are available at both pixel and grid levels.	Orbital or Daily 25 km			http://www.ospo.noaa.gov/Products/atmosphere/rain.html
Total Precipitable Water (ATOVS)	This product also known as Total Atmospheric Moisture (mm) with a 40 km resolution	It is derived from HIRS/3 channels 10-12 and is generated from the ATOVS processing system. Total precipitable water is defined as the vertically integrated water vapor in a column extending from the surface to the top of the atmosphere.				http://www.ospo.noaa.gov/Products/atmosphere/rain.html

Atmospheric gases

Table 33: Atmospheric Gas Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
O3 Total column		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5 h <14d		Coverage unclear	http://marine.copernicus.eu
O3 profile		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5h <14d		Coverage unclear	http://marine.copernicus.eu
O3 tropospheric profile		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5h <14d		Coverage unclear	http://marine.copernicus.eu
O3 trop.col.		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in		Coverage unclear	http://marine.copernicus.eu

			ESA, 2013 <14d			
NO2 total column		Sentinel-5P	From 2017, 2022 Daily revisit 2020 For areas defined in ESA, 2013 <1.5 h <14d		Coverage unclear	http://marine.copernicus.eu
NO2 trop.c.		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5h <14d		Coverage unclear	http://marine.copernicus.eu
SO2 total c.		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5 h <14d		Coverage unclear	http://marine.copernicus.eu
HCHO total c.		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5 h <14d		Coverage unclear	http://marine.copernicus.eu
CH4 total c.		Sentinel-5P	From 2017, 2022 Daily revisit		Coverage unclear	http://marine.copernicus.eu

			For areas defined in ESA, 2013 <14d			

Wind speed over the surface (horizontal)

Table 34: Wind Speed Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Ocean wind field		Sentinel-1	Limited regions For areas defined in ESA, 2013 <1.5 h 5-40 m 2015-2016		The transition time to switch from one imaging mode to another may result in some imaging gaps of geographical areas.	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Ocean surface vector wind		QuikSCAT OSVW NOAA QuikSCAT NRT processing, Wind/rain wind retrieval, wind direction ambiguity removal Said, Williams , Long				http://marine.copernicus.eu
Sea surface wind speed		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions	http://marine.copernicus.eu https://sentinel.esa.int/documents/

						247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Windscan	High resolution offshore wind speeds and directions on a 0.25° global grid	DMSP SSMI TRMM TMI AMSR-E QuikSCAT	2002 – 2009 6h Coverage 90%			http://marine.copernicus.eu
Surface radial velocity		Sentinel-1	Limited regions For areas defined in ESA, 2013 <1.5 h 5-40 m 2015-2016		The transition time to switch from one imaging mode to another may result in some imaging gaps of geographical areas.	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Global Ocean wind L4 near real time 6 hourly observations	Satellite-Observation, Wind, Blended Mean Wind Fields include wind components (meridional and zonal), wind module, wind stress. The associated error estimates are also provided.	L4, For the Global Ocean- The IFREMER CERSAT Global Blended Mean Wind Fields include wind components (meridional and zonal), wind module, wind stress. The associated error estimates are also provided. They are estimated from scatterometers ASCAT and OSCAT retrievals and from ECMWF operational wind analysis with a horizontal resolution of 0.25x0.25 degrees and 6 hours in time, and available at synoptic time 00h:00 06h:00 12h:00 18h:00 since	Near-Real-Time, Mediterranean-Sea, Black-Sea, Global-Ocean, Baltic-Sea, North-West-Shelf-Seas, Iberian-Biscay-Irish-Seas, Arctic-Ocean 6 hourly observations			http://marine.copernicus.eu/web/69-interactive-catalogue.php

		January, 1st 2013.				
Global ocean wind observations	Satellite-Observation, Wind, Blended Mean Wind Fields include wind components (meridional and zonal), wind module, wind stress. The associated error estimates are also provided.	For the Global Ocean- The IFREMER CERSAT Global Blended Mean Wind Fields include wind components (meridional and zonal), wind module, wind stress. The associated error estimates are also provided. They are estimated from satellite observations (QuikSCAT and ASCAT scatterometers and SSM/I radiometers) and from ECMWF operational wind analysis with a horizontal resolution of 0.25x0.25 degrees and 6 hours in time, and available at synoptic time 00h:00 06h:00 12h:00 18h:00 from the 1st April 2004 up to the 22th November 2009.	2004-2009 Near-Real-Time, Global-Ocean, Iberian-Biscay-Irish-Seas, North-West-Shelf-Seas, Mediterranean-Sea, Baltic-Sea, Black-Sea, Arctic-Ocean horizontal resolution of 0.25x0.25 degrees and 6 hours in time, and available at synoptic time 00h:00 06h:00 12h:00 18h:00 from the 1st April 2004 up to the 22th November 2009.			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global ocean daily gridded sea surface winds from scatterometer	Satellite-Observation, Wind, L3 gridded sea surface wind observations The reported wind is equivalent neutral wind, and in addition stress-equivalent wind and wind stress are provided.	For the Global Ocean- The product contains daily L3 gridded sea surface wind observations from available scatterometers with resolutions corresponding to the L2 swath products: 0.5 degrees grid for the 50 km scatterometer L2 inputs, 0.25 degrees grid based on 25 km scatterometer swath observations, and 0.125 degrees based on 12.5 km scatterometer swath observations, i.e., from the coastal products.	Near-Real-Time (daily) North-West-Shelf-Seas, Arctic-Ocean, Baltic-Sea, Iberian-Biscay-Irish-Seas, Mediterranean-Sea, Black-Sea, Global-Ocean 0.5 degrees grid for the 50 km			http://marine.copernicus.eu/web/69-interactive-catalogue.php

	Moreover, wind stress curl and divergence are also available from April 8 2015 onwards	Data from ascending and descending passes are gridded separately. The reported wind is equivalent neutral wind, and in addition stress-equivalent wind and wind stress are provided. Moreover, wind stress curl and divergence are also available from April 8 2015 onwards. The NRT L3 products follow the NRT availability of the EUMETSAT OSI SAF L2 products and are be available for: The ASCAT scatterometers on MetOp-A and MetOp-B at 0.125 and 0.25 degrees The OSCAT on Oceansat-2 with a resolution of 0.50 degrees	scatterometer L2 inputs, 0.25 degrees grid based on 25 km scatterometer swath observations, and 0.125 degrees based on 12.5 km scatterometer swath observations			
Global ocean wind observations climatology reprocessed (monthly means)	Satellite-Observation, Wind, Surface wind climatology Fields include wind components (meridional and zonal), wind module, wind stress. Monthly means	For the Global Ocean- the IFREMER CERSAT surface wind climatology Fields include wind components (meridional and zonal), wind module, wind stress. They are estimated from ASCAT retrievals. The analyses are estimated as monthly averaged data over global ocean with spatial resolution of 0.25x0.25 degrees in latitude and longitude. They are available since April 2007.	2007-2012 Multi-Year, Arctic-Ocean, Black-Sea, North-West-Shelf-Seas, Global-Ocean, Baltic-Sea, Iberian-Biscay-Irish-Seas, Mediterranean-Sea spatial resolution of 0.25x0.25 degrees			http://marine.copernicus.eu/web/69-interactive-catalogue.php

Cloud top height

Table 35: Cloud Top Height Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference

Cloud top height		Sentinel-5P	From 2017, 2022 Daily revisit For areas defined in ESA, 2013 <1.5 h <14d			http://marine.copernicus.eu

Sea Ice Parameters

Sea ice cover (concentration)

Table 36: Sea Ice Cover (Concentration) Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Ice Analysis Products	Ice concentration		Polar regions			http://www.bsis-ice.de/IcePortal/
Polar View Sea ice concentration	This sea ice service provides information about the area of the water surface covered by ice as a fraction or percentage of the whole ocean area of interest (e.g. <30% sea ice concentration is considered to be navigable by ship and		Polar regions			http://www.polarview.org/services/sea-ice-services/

	>90% is considered solid ice).					
ESA CCI sea ice project	Sea ice concentration, Arctic and Antarctica	Multi-satellite use, validated algorithms	Satellite era (1978-present)			www.esa-cci.org
Sea ice forecasts	Forecasts of ice motion, concentration, thickness, ridges and deformations for the Polar Regions	Numerous multi-category sea ice models used	On-demand, high-resolution forecasts for any area in the Arctic are available within as little as one hour (e.g. in case of an emergency).			http://www.polarview.org/services/sea-ice-services/
Global sea ice concentration	The sea ice concentration product from the EUMETSAT OSI SAF. 0 -100.0: Area fraction of ice in percentage -99.0: Over land -199.0: Unclassified -32767.0: No data	Ice concentration is computed from atmospherically corrected SSMIS brightness temperatures, using a combination of state-of-the-art algorithms. Utilises ECMWF forecast for atmospheric correction	Since 2005 Global Daily Spatial resolution is 10 km			http://saf.met.no/p/ice/index.html
Sea ice concentration		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-

						4d26-9e05-36970bf91b85
Arctic ocean physics reanalysis	Numerical-Model, Sea-Ice, Temperature, Currents, Salinity, Sea-Level	The TOPAZ4 Arctic Ocean Reanalysis provides 3D physical ocean and sea ice variables for the time period 1991-2013. The reanalysis uses the HYCOM model and a 100-members DEnKF to assimilate both in situ profiles and satellite data from different sensors.	1991-2010 Multi-Year, Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global ocean – arctic and Antarctic –sea ice concentration, edge, type and drift	Satellite-Observation, Sea-Ice Sea ice concentration, sea ice edge, sea ice type (OSI-401 OSI-402 and OSI-403). Sea Ice operational nominal product for the Global Ocean	For the Global - Arctic and Antarctic - Ocean. The OSI SAF delivers three global sea ice products in operational mode: sea ice concentration, sea ice edge, sea ice type (OSI-401 OSI-402 and OSI-403). These products are delivered daily at 10km resolution in a polar stereographic projection covering the Northern Hemisphere and the Southern Hemisphere. It is the Sea Ice operational nominal product for the Global Ocean.	Near-Real-Time, Arctic-Ocean, Global-Ocean Global - Arctic and Antarctic Ocean 10 km			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global ocean sea ice concentration time series reprocessed	Satellite-Observation, Sea-Ice Reprocessed sea ice concentration dataset error-bars for each grid cell (uncertainties)	The reprocessed sea ice concentration dataset of the EUMETSAT OSI SAF (OSI-409), covering the period from October 1978 to October 2009 (SMMR and SSM/I). Ice concentration is computed from atmospherically corrected SSM/I brightness temperatures, using a combination of state-of-the-art algorithms and dynamic tie-points. It includes error-bars for each grid cell (uncertainties). Version 1 of the dataset was released early 2010.	1978-2009 Multi-Year, Arctic-Ocean, Global-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Arctic ocean – sea ice charts –	Satellite-Observation, Sea-Ice	For Greenland waters - The operational sea ice service at DMI provides ice charts of the	Near-Real-Time, Arctic-Ocean			http://marine.copernicus.eu/web/6

Greenland	Provides ice charts of the sea ice area around Greenland, showing ice concentration in WMO defined ice concentration intervals	sea ice area around Greenland. Charts are produced at irregular intervals daily and show the ice concentration in WMO defined ice concentration intervals. A supplemental overview product is produced twice weekly.	At irregular intervals daily A supplemental overview product is produced twice weekly.			9-interactive-catalogue.php
Arctic ocean – sea ice concentration charts – Svalbard	Satellite-Observation, Sea-Ice ice charts show the ice concentration in WMO defined concentration intervals.	For the Arctic Ocean - The operational sea ice service at MET Norway provides ice charts of the Arctic area from east Greenland to Novaja Semlja. The charts are produced every weekday and show the ice concentration in WMO defined concentration intervals.	Near-Real-Time, Arctic-Ocean produced every weekday			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Sea ice concentration	Sea ice concentration based on passive microwave data from SSM/I (F10, F11, F13, F14, F15) (1992-2008) and AMSR-E (2002-2011), covering both Arctic and Antarctic. The ice concentration products are developed in collaboration with Eumetsat OSI SAF.		1992-2011 Arctic and Antarctic			http://esa-cci.nersc.no/?q=products
Sea ice concentration			1978-2015			http://esa-cci.nersc.no/?q=products

Sea Ice concentration	Open water, ice concentration %, land mask, missing data	Enhanced NASA team (NT2) algorithm derived using SSM/I data	Northern hemisphere Southern hemisphere 1/day 1992 - 2008			http://neptune.gsfc.nasa.gov/csb/index.php?section=55
Sea ice concentration	Sea ice concentration based on Ice Sat satellite data		Northern hemisphere Southern hemisphere 1/day 2002-2009 Daily			http://nsidc.org/data/icesat/data.html
Sea Ice Concentration	North and south polar regions gridded onto a polar stereographic projection with 25 x 25 km grid cells		1978 – 2007 NH: 31° – 90° SH: -40° - -90° NOAA/NSIDC CDR: at a daily and monthly resolution 25 x 25 km grid cells			http://nsidc.org/data/seaice/
Sea Ice Concentration	North and south polar regions gridded onto a polar stereographic projection with 25 x 25 km grid cells		1978 – NH: 31° – 90° SH: -40° - -90° NOAA/NSIDC CDR: at a daily , monthly, every other day resolution 25 x 25 km grid cells			http://nsidc.org/data/seaice/

Brightness temperature, sea ice concentration, snow depth	North and south polar regions gridded onto a polar stereographic projection		2002-2011 NH: 31° – 90° SH: -40° - -90° NOAA/NSIDC CDR: Daily 12.5 km		Data order	http://nsidc.org/data/seaice/
Brightness temperature, sea ice concentration	North and south polar regions gridded onto a polar stereographic projection with 25 x 25 km grid cells		2002-2011 NH: 31° – 90° SH: -40° - -90° NOAA/NSIDC CDR: Daily 25 x 25 km grid cells		Data order	http://nsidc.org/data/seaice/
Sea Ice Concentration	Approximately previous day North and south polar regions gridded onto a polar stereographic projection with 25 x 25 km grid cells		NRT N: 31° – 90° S: -40° - -90° NOAA/NSIDC CDR: daily 25 x 25 km grid cells			http://nsidc.org/data/seaice/
Sea Ice Concentration	North and south polar regions gridded onto a polar stereographic projection with 25 x 25 km grid cells		1972-1976 NH: 31° – 90° SH: -40° - -90° NOAA/NSIDC CDR: Daily, monthly 25 x 25 km grid cells			http://nsidc.org/data/seaice/

Sea ice index	Sea ice concentration		1978 - N: 31° – 90° S: -40° - -90° NOAA/NSIDC CDR: Monthly 25 km			http://nsidc.org/data/seaice/
Sea ice extent	Previous month sea ice extent		NH 4 km Daily FTP			http://nsidc.org/data/seaice/
Radiance and sea ice concentration			1978 - 1987 N: 31° – 90° S: -40° - -90° NOAA/NSIDC CDR: 1 / 2d 25 km FTP			http://nsidc.org/data/seaice/
MODIS Sea Ice extent MOD29x MYD29x	The MODIS/Terra Sea Ice Extent data set contains sea ice extent, ice surface temperature, and quality assessment data, plus 5 km resolution geolocation data		Since 2000 Global 1km, 4 km Temporal resolution 5 min, 1 day L2 Swath 1km 5 min L3 global 1 km night L3 global 1 km day			http://nsidc.org/data/modis/data_summaries
Greenland land/ice	Icesheet, water, non-		Greenland		Satellite?	http://neptune.gs

mask	icesheet land		2008			fc.nasa.gov/csb/index.php?section=56
Sea ice concentration	Product shows the percentage of sea ice within the instrument's field of view.	It is derived from AMSU-A channels 1-3 and 15 and AMSU-B channel 16 and is generated from the MSPPS processing system on an orbital basis or mapped on a polar stereographic 1/8 mesh grid. Ice concentration is defined as the fraction of a given area of sea water covered by ice.	Orbital Daily 45 km			http://www.ospo.noaa.gov/Products/ocean/sea_ice.html
Sea ice concentration	Product shows sea ice concentration over oceans.	The sea ice concentration is derived from the passive microwave sensor SSM/I, which has 7 channels of 19 GHz (H, V), 22 GHz (V), 37 GHz (H, V), and 85 GHz (H, V), where H is the horizontal polarization, V is the vertical polarization. The ice concentration is defined as the fraction of a given area of sea water covered by ice with accuracy of 5%. The product is updated once per day at 4 am EST.	Daily 25 km	5 %		http://www.ospo.noaa.gov/Products/ocean/sea_ice.html
Polar marginal ice zone (MIZ)	MIZ Overlay or MIZ shape	These products are constructed by NIC analysts using various imagery sources with resolutions down to 50 meters per pixel. Imagery sources include but are not limited to ENVISAT, DMSP OLS, AVHRR, and RADARSAT. NIC ice analysts provide the necessary value-added interpretation of these imagery sources to properly identify the extent of the ice edge contours.	Daily Polar Down to 50 meters			http://www.natice.noaa.gov/products/daily_products.html

Sea ice motion

Table 37: Sea Ice Motion Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View sea ice drift	This sea ice service provides information on the motion of sea ice caused by ocean currents and surface winds, with arrows indicating the magnitude and direction of the displacement of sea ice during a 48 hour period.					http://www.polarview.org/services/sea-ice-services/
Sea ice forecasts	Forecasts of ice motion, concentration, thickness, ridges and deformations for the Polar Regions	Numerous multi-category sea ice models used	On-demand, high-resolution forecasts for any area in the Arctic are available within as little as one hour (e.g. in case of an emergency).			http://www.polarview.org/services/sea-ice-services/
Global ocean – arctic and Antarctic – sea ice concentration, edge, type and drift	Satellite-Observation, Sea-Ice, Sea ice drift	For the Global - Arctic and Antarctic - Ocean. The OSI SAF delivers a sea ice drift product at 60km resolution in a polar stereographic projection covering the Northern and Southern Hemispheres. The sea ice motion	The sea ice motion vectors have a time-span of 2 days Arctic-Ocean, Global-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php

		vectors have a time-span of 2 days.	Global - Arctic and Antarctic – Ocean 60 km			
Global ocean – high resolution SAR sea ice drift	Satellite-Observation, Sea-Ice gridded ice displacement field	DTU Space produces polar covering Near Real Time gridded ice displacement fields obtained by MCC processing of Sentinel-1 SAR, Envisat ASAR WSM swath data or RADARSAT ScanSAR Wide mode data. The nominal temporal span between processed swaths is 24hours, the nominal product grid resolution is a 10km.	Near-Real-Time, Arctic-Ocean, Global-Ocean The nominal temporal span between processed swaths is 24hours, the nominal product grid resolution is a 10km.		The transition time to switch from one imaging mode to another may result in some imaging gaps of geographical areas.	http://marine.copernicus.eu/web/69-interactive-catalogue.php https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Arctic ocean sea ice drift reprocessed	Satellite-Observation, Sea-Ice, sea ice drift dataset at 3, 6 and 30 day lag	Arctic sea ice drift dataset at 3, 6 and 30 day lag during winter	1999-ONGOING Arctic-Ocean			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Low resolution sea ice drift	The low resolution sea ice drift product from the EUMETSAT OSI SAF.	Ice motion vectors with a time span of 48 hours are estimated by an advanced cross-correlation method (the Continuous MCC, CMCC) on pairs of satellite images. Several single-sensor products are available, along with a merged (multi-sensor) dataset.	Since 2006 Daily, time span of 48 hours Global 62.5 km grid	Standard deviation 2.5 – 4.5 km, depending on EO instrument used	Due to high atmospheric Liquid Water Content and to ice surface melting, it is not possible to track ice motion during Arctic summer, from the channels we are	http://saf.met.no/p/ice/index.html

					processing.	
Medium resolution sea ice drift	The Medium resolution sea ice drift product from the EUMETSAT OSI SAF.	Ice motion vectors with a time span of 24 hours are estimated by a maximum cross-correlation method (MCC) on pairs of satellite images. Input data are ~1km Infra Red or Visible data from the AVHRR instrument on board the METOP satellite.	Since 2005 Daily, time span of 24 hours Global 20 km grid		Due to pronounced cloud cover during summer, and occasional during winter periods, the daily data coverage can be very sparse.	http://saf.met.no/p/ice/index.html
QuikSCAT & SSM/I Merged Sea Ice Motion	Two product types are available: postscript images of the ice motion and self-describing ascii files describing the ice motion vectors.	Analysis by Antony Liu at GSFC has demonstrated the utility of scatterometer data in observing and tracking sea ice motion. He found that scatterometer and SSM/I data complement each other in this purpose: that scatterometer data can provide motion vectors in areas where passive data has difficulties and vice versa. Ice motion vectors are derived from sensor images using wavelet techniques.	Northern and southern hemispheres			http://www.scp.byu.edu/data/Quikscat/IceMo/Quikscat_icemotion.html

Sea ice thickness

Table 38: Sea Ice Thickness Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference

Polar View sea ice thickness	This sea ice service provides satellite data-based information on average thickness from sea ice surface to underside of a specified sea ice extent.					http://www.polarview.org/services/sea-ice-services/
Sea ice forecasts	Forecasts of ice motion, concentration, thickness, ridges and deformations for the Polar Regions	Numerous multi-category sea ice models used	On-demand, high-resolution forecasts for any area in the Arctic are available within as little as one hour (e.g. in case of an emergency).			http://www.polarview.org/services/sea-ice-services/
Sea ice freeboard		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Sea ice thickness and freeboard	Sea ice thickness and freeboard in the Arctic and freeboard in the Antarctic based on radar		2002-2012 Arctic Antarctic (no thickness)			http://esa-cci.nersc.no/?q=products

	altimeter data from Envisat RA-2 for the winter months (2002-2012)					
Sea ice thickness and freeboard						http://esa-cci.nersc.no/?q=products
Sea ice freeboard and thickness	Time, lat, long, Sea ice freeboard, sea ice thickness		Antarctic 13 campaigns 10/2003 – 3 /2008 >= 70 m			http://neptune.gsfc.nasa.gov/csb/index.php?section=272

Sea ice type

Table 39: Sea Ice Type Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View Sea ice types	This sea ice service provides information on the forms of ice found at sea which has originated from the freezing of sea water (e.g. new ice, young ice, first-year ice and old ice). These categories broadly reflect the					http://www.polarview.org/services/sea-ice-services/

	age of the ice and include different forms and thicknesses of ice at various stages of development.					
Global ocean – arctic and antarctic – sea ice concentration, edge, type	Satellite-Observation, Sea-Ice Sea ice concentration, sea ice edge, sea ice type (OSI-401 OSI-402 and OSI-403). Sea Ice operational nominal product for the Global Ocean	For the Global - Arctic and Antarctic - Ocean. The OSI SAF delivers three global sea ice products in operational mode: sea ice concentration, sea ice edge, sea ice type (OSI-401 OSI-402 and OSI-403). These products are delivered daily at 10km resolution in a polar stereographic projection covering the Northern Hemisphere and the Southern Hemisphere. It is the Sea Ice operational nominal product for the Global Ocean.	Near-Real-Time, Arctic-Ocean, Global-Ocean Global - Arctic and Antarctic – Ocean 10 km			http://marine.copernicus.eu/web/69-interactive-catalogue.php
Global sea ice type	The sea ice type product from the EUMETSAT OSI SAF. 1: Ice free 2: First year ice 3: Multi-year ice 4: Ambiguous ice type -1: Fill value	Ice classes are assigned from atmospherically corrected SSMIS brightness temperatures and ASCAT backscatter values, using a Bayesian approach. Utilises ECMWF forecast for atmospheric correction	Since 2005 Global Daily Spatial resolution is 10 km			http://saf.met.no/p/ice/index.html
Ice types	Expected values at least include: 1 - New ice, 3 - Young ice, 7 - Thin first-year ice, 6 - First-year ice for ice thicker than 7, 7* -	Integrated from NIC, NIS and AARIcharts	1/week			http://ice.aari.aq/docs/Specifications_for_collaborative_product(final).pdf http://polarview.

	Old ice, ^* - Iceberg					met.no/antarctic/antarctic.jpg
QuikSCAT Arctic Sea Ice Age Product	Daily maps of classified Arctic sea ice indicating whether it is first-year (FY) or multi-year (MY) derived from QuikSCAT data. -2 : no data -1 : land 0 : ocean 1 : first year (FY) ice 2 : multi year (MY) ice	Deroived from QuikSCAT data	1999-2009 Daily Arctic			http://www.scp.byu.edu/data/Quikscat/iceage_v2/Quikscat_MYFY.html
OSCAT Arctic Sea Ice Age Product	Daily maps of classified first-year (FY) and multiyear (MY) Arctic sea ice derived from OSCAT data for the years 2009-2014.	Derived from OSCAT data	2009-2014 Daily Arctic			http://www.scp.byu.edu/data/OSCAT/iceage_v2/Oscat_MYFY.html

Sea ice surface temperature

Table 40: Sea Ice Surface Temperature Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference

MODIS Sea Ice Extent SST MOD29x MYD29x	The MODIS/Terra Sea Ice Extent data set contains sea ice extent, ice surface temperature, and quality assessment data, plus 5 km resolution geolocation data		Since 2000 Global 1km, 4 km Temporal resolution 5 min or 1 day L2 Swath 1km 5 min L3 global 1 km night L3 global 1 km day L3 global 4 km daily	Maps of ice-surface temperature (IST) under clear skies have RMS errors of 1.2-1.3K during the "cold months," or when there is no surficial melt on the sea ice.		http://modis.gsfc.nasa.gov/data/dataprod/mod29.php http://nsidc.org/data/modis/data_summaries

Sea ice melt

Table 41: Sea Ice Melt Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Sea ice melt	Early melt, melt , freeze, late freeze		Arctic 1/year 1979			http://neptune.gsfc.nasa.gov/csb/index.php?section=54

Sea ice pressure

Table 42: Sea Ice Pressure Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View Sea ice pressure	This sea ice service provides sea ice deformation fields	Derived from ice drift observations (i.e. areas of divergence (openings) and areas of convergence (pressure)) and ice thickness information using satellite data.				http://www.polarview.org/services/sea-ice-services/

Ice edge

Table 43: Ice Edge Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Ice Analysis Products	Ice edge		Polar regions			http://www.bsis-ice.de/IcePortal/
Polar View ice edge	Up-to-date image maps showing the location of the floe edge, where the ice is mobile, and where it is immobile or "fast	The product integrates satellite SAR imagery with an analyst's interpretation of the location of the ice floe edge, and the location of historical ice edges for the same time period.	Arctic "Up-to-date"			http://www.polarview.org/services/ice-edge-monitoring/
Global sea ice edges	The sea ice edge product from the EUMETSAT OSI SAF.	Ice classes are assigned from atmospherically corrected SSMIS brightness temperatures and ASCAT backscatter values, using a	Since 2005 Global Daily			http://saf.met.no/p/ice/index.html

	1: No ice (less than 30% ice concentration) 2: Open ice (30-70% ice concentration) 3: Closed ice (more than 70% ice concentration) -1: Fillvalue	Bayesian approach. Utilises ECMWF forecast for atmospheric correction	Spatial resolution is 10 km			
Ice edge	.	These products are constructed by NIC analysts using various imagery sources with resolutions down to 50 meters per pixel. Imagery sources include but are not limited to ENVISAT, DMSP OLS, AVHRR, and RADARSAT. NIC ice analysts provide the necessary value-added interpretation of these imagery sources to properly identify the extent of the ice edge contours	Daily Arctic, Antarctic			http://www.natice.noaa.gov/products/daily_products.html

Ice Sheet Parameters

Ice sheet extent

Table 44: Ice Sheet Extent Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Surface Elevation Changes	Surface elevation changes of an ice sheet are directly linked to the	The prototype processing system consists of two different algorithms, crossover and repeat-track, which are merged in order to benefit from the accuracy of the former and	The observation period is 1995-2014, continuing to present	Validated by airborne campaigns	Insufficient resolution in marginal areas	www.esa-cci.org http://products.esa-icesheets-cci.org/login/?nex

	atmospheric forcing and hence climate changes.	the spatial resolution of the latter.				t=/products/downloadlist/
Ice Velocity (IV)	The IV products show the horizontal velocity, magnitude and direction of the glacier derived by applying feature tracking to ERS, EnviSat, ALOS/PALSAR or S-1-.	The IV measured with space-borne SAR and optical sensors represents the mean velocity within a temporal span ranging from the satellite repeat-cycle (between 1 and 46 days for past and current sensors) to several months.	Greenland coastal margins 1995-2012 Greenland-wide (Sentinel-1)	Validated by GPS in-situ velocities	Access to data and limited acquisition for older SAR missions	http://products.esa-icesheets-cci.org/login/?next=/products/downloadlist/
Calving Front Location (CFL)	This dataset shows the terminus position of the glacier in the summer and winter season. The calving front locations are obtained from a selection of ERS, ENVISAT and Sentinel-1 data.		Approx. 25 glacier systems around Greenland	Validated by high-resolution optical imagery	The positional accuracy is limited by the pixel size of the radar data. Manual delineation.	http://products.esa-icesheets-cci.org/login/?next=/products/downloadlist/
Grounding Line Location (GLL)	The grounding line location product is derived from InSAR data by mapping the tidal flexure and is generated for a selection of the few glaciers in Greenland, which	Currently, manual or semi-automated techniques are applied to map GLL on case-by-case basis. The GLL is derived either from observations of surface deformation, applying differential interferometric SAR, by means of repeat altimetry measurements, or from texture and shape in visible satellite images.	ERS data on select glaciers Sentinel-1 data		In general, the true location of the grounding line is is difficult to track, extends over a zone. No in-situ	http://products.esa-icesheets-cci.org/login/?next=/products/downloadlist/

	have a floating tongue.				validation data.	

Glacier Parameters

General

Table 45: General Glacier Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View glacier products	A variety of information products can be provided, such as glacier topography, glacier velocity fields, glacier facies distribution, snow retreat and glacier surface energy balance.	Our products and services employ a combination of Earth Observation data processing and analysis and surface energy balance modelling. Earth Observation methods include interferometric DEM and velocity map generations using repeat-pass data and the use of feature tracking where coherence is problematic. The overpass cycle of ENVISAT may mean feature tracking becomes a more important method for deriving velocity maps. Optical-thermal data will be used to support the energy balance modelling. The energy balance modelling is defined by data inputs and the role of the modelling in the analysis (timescale, scenario definition and objectives).	Polar regions Non-systematic By order		Non-systematic	http://www.polarview.org/services/glacier-monitoring/

Glacier motion

Table 46: Glacier Motion Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
MEaSUREs InSAR-Based Ice Velocity of the Amundsen Sea Embayment, Antarctica	This data set, part of the NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program, provides high-resolution, digital mosaics of ice motion in the Amundsen Sea Embayment (ASE) and West Antarctica, including Pine Island, Thwaites, Haynes, Pope, Smith, and Kohler glaciers.	The mosaics were assembled from interferometric synthetic-aperture radar (InSAR) data acquired in 1996, 2000, 2002, and 2006-2012 by various satellites.	Yearly time series 1996, 2000, 2002, 2006-2012 Amundsen Sea Embayment (ASE) and West Antarctica, including Pine Island, Thwaites, Haynes, Pope, Smith, and Kohler glaciers.			http://nsidc.org/data/search/#keywords=Glacier+Motion+satellite/startDate=2000-01-01/endDate=2015-09-01/sortKeys=score,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25
Compilation of Antarctic Radar Data, Siple Coast, 2000-2002	These data consist of ground-based, ice-penetrating radar profiles across satellite-detected lineations and terrains that were taken in the lower		2000, 2002 Siple coast			http://nsidc.org/data/search/#keywords=Glacier+Motion+satellite/startDate=2000-01-01/endDate=2015-09-01/sortKeys=score

	reaches of Ross Ice Stream C, also known as the Kamb Ice Stream (KIS); on Roosevelt Island; on the Siple Dome; and on the Shabtaie Ice Ridge					,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25

Glacier topography

Table 47: Glacier Topography Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Antarctic 1 km Digital Elevation Model (DEM) from Combined ERS-1 Radar and ICESat Laser Satellite Altimetry	This data set provides a 1 km resolution Digital Elevation Model (DEM) of Antarctica.	The DEM combines measurements from the European Remote Sensing Satellite-1 (ERS-1) Satellite Radar Altimeter (SRA) and the Ice, Cloud, and land Elevation Satellite (ICESat) Geosciences Laser Altimeter System (GLAS).	Temporal Coverage 1994-03-01 to 1995-01-31 2003-02-20 to 2008-03-21			http://nsidc.org/data/search/#keywords=Glacier+topography+satellite/startDate=2000-01-01/endDate=2015-09-01/sortKeys=score,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25
Glacier heights and outlines	Data on global outlines and glaciers from optical sensors	Processed in cooperation with Global Glacier Monitoring Service; global inventory close to complete			Detecting true glacier limits from seasonal	www.esa-cci.org and links therein

					snow fields and rock cover	

Glacier cover

Table 48: Glacier Cover Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
GLIMS Glacier database	Glacier extent Global Land Ice Measurements from Space (GLIMS) is an international project with the goal of surveying a majority of the world's estimated 160,000 glaciers	GLIMS uses data collected primarily by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the Terra satellite and the LANDSAT Enhanced Thematic Mapper Plus (ETM+), along with historical observations.	Global			http://glims.colorado.edu/glacierdata/

Iceberg Parameters

Iceberg concentration

Table 49: Iceberg Concentration Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and	Reference

					Constraints	
Arctic ocean – SAR sea iceberg concentration	Satellite-Observation, Sea-Ice, describes iceberg concentration as number of icebergs counted within 10x10 km grid cells	The iceberg product describes iceberg concentration as number of icebergs counted within 10x10 km grid cells. The product is derived by applying a Constant False Alarm Rate (CFAR) algorithm on data from Synthetic Aperture Radar (SAR) satellite sensors.	**Near-Real-Time,** Arctic-Ocean 10x10 km grid cells			http://marine.copernicus.eu/web/69-interactive-catalogue.php

Iceberg drift

Table 50: Iceberg Drift Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View iceberg drift	This iceberg service provides information on the forecast motion of icebergs using in situ measured metocean parameters, observed iceberg drift and size data, tidal currents and weather forecasts, with arrows indicating the magnitude and direction of the		Arctic NRT			http://www.polarview.org/services/iceberg-services/

	iceberg trajectories.					

Iceberg detection

Table 51: Iceberg Detection Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View iceberg detection	This iceberg service provides location information about icebergs in latitude/longitude coordinates. In addition to position, the service includes iceberg attribute information such as length, width, area, sigma nought pixel brightness and variance.		NRT Arctic			http://www.polarview.org/services/iceberg-services/
Iceberg Historical Trends	This iceberg service provides historical iceberg information from archived data that can yield quantification of length and geographic extent of		Arctic			http://www.polarview.org/services/iceberg-services/

	iceberg seasons (and trends), useful for identifying overall operational risk and defining ice management principles for development in particular areas (e.g. towing, burying of production facilities, provision of platform disconnect capabilities, etc.).					
Iceberg detection	Icebergs that exceed 10NM	They're usually not hard to find with MODIS (while daylight), or use previous analysis or our table to help find them. Many are grounded/fasted and do not move. Common layer of icebergs should be present on a collaborative product, with a common database managed by the partners, NIC database with NIC namings is a starting point for complementing by AARI and met.no	1/week?			http://ice.aari.aq/docs/Specifications_for_collaborative_product(final).pdf http://polarview.met.no/antarctic/antarctic.jpg

River /lake ice Parameters

River ice

Table 52: River Ice Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and	Reference

					Constraints	
Polar View river ice	The Polar View's river ice monitoring service delivers Earth Observation-derived information about the location and extent of riverine ice covers to decision makers in near real-time	Satellite synthetic aperture radar (SAR) imagery in particular has been shown to yield cost-effective information on ice type on medium and large rivers (i.e. more than 100 m wide) within an operational context.	Polar regions NRT			http://www.polarview.org/services/river-ice-monitoring/

Lake ice

Table 53: Lake Ice Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View lake ice	Polar View's lake ice monitoring service delivers Earth Observation derived information about the location and extent of ice covers to decision makers in near real-time.		NRT			http://www.polarview.org/services/lake-ice-monitoring/

Snow Parameters

Snow cover

Table 54: Snow Cover Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Polar View snow cover		Snow information and maps are derived from SAR (e.g. SENTINEL-1) and optical satellites.	Arctic		The transition time to switch from one imaging mode to another may result in some imaging gaps of geographical areas.	http://www.polarview.org/services/snow-monitoring/ https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
MODIS Snow Cover MOD10x MYD10x	The MODIS snow algorithm output (MOD10_L2 and MYD10_L2) contains scientific data sets (SDS) of snow cover, quality assurance (QA) SDSs, latitude and longitude SDSs, local attributes and global attributes. The snow cover algorithm identifies	These products are generated using the MODIS calibrated radiance data products (MOD02HKM and MYD02HKM), the geolocation products (MOD03 and MYD03), and the cloud mask products (MOD35_L2 and MYD35_L2) as inputs.	Sinc 2000 Global N: 90, S: -90, E: 180, W: -180 500 m and 0.05° Temporal resolution 5 min, 1 day, 8 day, 1 month Swath, Grid, and CMG MODIS Snow Cover 5-Min L2 Swath			http://modis.gsfc.nasa.gov/data/dataprod/mod10.php http://nsidc.org/data/modis/data_summaries

	snow-covered land; it also identifies snow-covered ice on inland water.		500m MODIS Snow Cover Daily L3 Global 500m Grid MODIS Snow Cover Daily L3 Global 0.05Deg CMG MODIS Snow Cover 8-Day L3 Global 500m Grid MODIS Snow Cover Daily L3 Global 0.05Deg CMG MODIS Snow Cover Monthly L3 Global 0.05Deg CMG			
Snow extent	Binary classification (snow/no-snow)		1995 - 2010 Global (excluding glaciers, Greenland, Antarctica and snow on ice: lakes/seas/oceans Weekly and monthly 1 km	Global total (pooled) error ≤ 5 % for open terrain, sparse forest and non-steep mountainous regions, at solar elevation > 20°		http://www.globsnow.info/index.php?page=Snow_Extent
Snow extent			2010 - Northern hemisphere Daily			http://www.globsnow.info/

Snow water equivalent

Table 55: Snow Water Equivalent Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
ESA GlobSnow Snow water equivalent	The European Space Agency (ESA) Global Snow Monitoring for Climate Research (GlobSnow) snow water equivalent (SWE) v2.0 data record contains snow information derived for the Northern Hemisphere since 1979 to present day. Also an error estimate. The snow water equivalent describes the amount of liquid water in the snow pack that would be formed if the snow pack was completely melted.	The GlobSnow SWE record, based on methodology in Pulliainen, 2006, and Takala, 2011, utilizes a data-assimilation based approach combining space-borne passive radiometer data (SMMR, SSM/I, and SSMIS) with data from ground-based synoptic weather stations. The satellite sensors utilized provide data at K- and Ka-bands (19 GHz and 37 GHz, respectively) at a spatial resolution of approximately 25 km	1979 - NH Weekly and monthly 25 km			http://www.globsnow.info/index.php?page=Snow_Extent
Snow water equivalent			2010 – Northern hemisphere			http://www.globsnow.info/

			Daily			

Snow depth

Table 56: Snow Depth Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Snow density and depth		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5 h		Solar illumination conditions Coverage unclear	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85
Snow depth on sea ice	Snow depth on floating sea ice Open water, snow depth, land		Antarctic 1/day 1992-2008			http://neptune.gsfc.nasa.gov/csb/index.php?section=52
Snow depth on sea ice	Snow depth on floating sea ice Open water, snow depth, land, multiyear ice cover, variability flag, summer melt		Arctic 1/day 1978 - 2008			http://neptune.gsfc.nasa.gov/csb/index.php?section=53

Snow depth			Polar SH and NH 2002-2011 Daily			http://nsidc.org/data/icesat/data.html

Permafrost Parameters

Permafrost

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
ESA DUE Permafrost		DUE Permafrost uses a suite of indicative space-borne-derived parameters: 'Land Surface Temperature' (LST), 'Surface Soil Moisture' (SSM), 'Sur-face Frozen/Thawed State' (Freeze/Thaw), 'Terrain' and 'Terrain Displacement', 'Land Cover' (LC), 'Surface Waters', and 'Snow' (Snow Extent and Snow Water Equivalent).	2011 circum-Arctic/ boreal permafrost area		High cloud coverage High fraction of surface water	http://www.geo.tuwien.ac.at/permafrost/index.php/products
Arctic permafrost zones	This map shows the boreholes/ active layer monitoring sites contained in the GTN-P Database versus permafrost zones for the Arctic.					http://gtnp.arcticportal.org/images/Pictures/Maps/GTN-P_map_permafrostzones_Arctic.jpg
Active Layer - Annual Thaw Depths	Provides information on soil moisture, vegetation, landform and lithology at					http://gtnpdatabase.org/activelayers

	borehole sites					
Boreholes - Permafrost Temperatures	Provides information on permafrost thickness determined by boreholes					http://gtnpdatabase.org/boreholes
Borehole and environmental protection descriptive and numerical data, Yamal Peninsula, Russia	This database of selected borehole records from the Yamal Peninsula, Russia, contains environmental descriptions (textual and numerical) of the units on the index map, and relevant borehole data. One of the tables for the boreholes includes the description of topography around the borehole; types of geological profiles through the active layer and depths down to the permafrost table; ground temperature at 10-m depth (close to the depth of zero annual amplitude in the area); macro-ice	The map was compiled by interpreting more than 1000 satellite images and aerial photos as well as from analysis of field data from several institutions. Dominating components of the landscape, composition of the surface deposits, geocryological conditions and natural protection of ground water were considered while distinguishing the Nature-Protection Regions within the limits of Environmental Regions (Melnikov, 1988).	1997-1990 Yamal Peninsula, Russia		Limited area	http://nsidc.org/data/search/#keywords=permafrost+satellite/sortKeys=score,,desc/facetFilters=%257B%2522facet_parameter%2522%253A%255B%2522Permafrost%2522%252C%2522Seasonally%2520Frozen%2520Ground%2522%255D%257D/pageNumber=1/itemsPerPage=25

	content; and salinity of permafrost.					
Remote sensing of permafrost in northern environment	Presentation	Permafrost maps from land cover and SAR imagery: TerraSAR-X, Envisat ASAR			Not opera-tionnal	https://earth.esa.int/documents/973910/1641786/AB3.pdf

Land Parameters

Land use/cover and change

Table 57: Land Use/Cover and Change Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
CORINE Land Cover	Land cover in 44 classes MMU 25 ha, linear minimum width 100m	CLC is produced by the majority of countries by visual interpretation of high resolution satellite imagery. In a few countries semiautomatic solutions are applied, using national in situ data, satellite image processing, GIS integration and generalisation	1990, 2000, 2006, 2012 The 2012 version of CLC is the first one embedding the CLC time series in the Copernicus programme, thus ensuring sustainable funding for the future.	Geometric accuracy 100 m Thematic accuracy > 85 %		http://land.copernicus.eu/pan-european/corine-land-cover
CORINE Land cover changes	MMU 5 ha		1990-2000, 2000-2006, 2006-2012	Geometric accuracy 100 m Thematic accuracy		http://land.copernicus.eu/pan-european/corine-land-cover

				> 85 %		
MODIS Land Cover type/ Dynamics	The MODIS Terra+Aqua Combined Land Cover product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method. The primary land cover scheme identifies 17 classes defined by the IGBP, including 11 natural vegetation classes, three human-altered classes, and three non-vegetated classes. The Land Cover Dynamics product includes layers on the timing of vegetation growth, maturity, and senescence that mark the seasonal cycles. Estimates of vegetation phenology are		LC Type: Yearly Global 500 m LC Type: Yearly Global 0.05 deg LC Dynamics: Yearly Global 1 km			http://modis.gsfc.nasa.gov/data/dataprod/mod12.php

	provided twice annually from the two 12-month focus periods, July-June, and January-December, allowing for hemispheric differences in the growing seasons, and enabling the product to capture two growth cycles if necessary.					

Land surface temperature

Table 58: Land Surface Temperature Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Land surface temperature		Sentinel-3	From 2016-2017 For areas defined in ESA, 2013 <1.5h <1m		Solar illumination conditions	http://marine.copernicus.eu https://sentinel.esa.int/documents/247904/351367/Sentinel+High+Level+Operations+Plan/530fd782-6386-4d26-9e05-36970bf91b85

Land surface temperature	The Land Surface Temperature (LST) is the radiative skin temperature of ground. It depends on the albedo, the vegetation cover and the soil moisture. In most cases, LST is a mixture of vegetation and bare soil temperatures. Because both respond rapidly to changes in incoming solar radiation due to cloud cover and aerosol load modifications and diurnal variation of illumination, the LST displays quick variations too. In turn, the LST influences the partition of energy between ground and vegetation, and determines the surface air temperature.	Empirical relationships with Top Of Atmosphere brightness temperature measured in one or more thermal infrared (TIR) channels: Generalized Split-Window (GSW) algorithm from two adjacent TIR channels of SEVIRI/MSG and MTSAT sensors Dual-Algorithm (DA) from GOES sensor	2009 – present Hourly Latitudes 70° S – 80°N Global Continental tiles 0.05° Timeliness within 1 day	Overall RMSE around 3°K Negative bias (-2°K) due to cloud contamination Night-time estimates more accurate than day-time estimates	Only small part of polar regions No estimate under cloudy conditions	http://land.copernicus.eu/global/products/lst

Soil moisture

Table 59: Soil Moisture Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
SMOS Level 2 Soil Moisture	The Level 2 SM product comprises soil moisture measurements geo-located in an equal-area grid system ISEA 4H9. The product contains not only the retrieved soil moisture, but also a series of ancillary data derived from the processing (nadir optical thickness, surface temperature, roughness parameter, dielectric constant and brightness temperature retrieved at top of atmosphere and on the surface) with the corresponding uncertainties.		2010 to current day -90°S – 90°N -180°W - 180° E 30-50 km			https://earth.esa.int/web/guest/data-access/browse-data-products/-/asset_publisher/y8Qb/content/level-2-soil-moisture-6900?redirect=https%3A%2F%2Fearth.esa.int%2Fweb%2Fguest%2Fdata-access%2Fbrowse-data-products%3Fp_p_id%3D101_INSTANCE_y8Qb%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_col_id%3Dcolumn-1%26p_p_col_pos%3D1%26p_p_col_count%3D2

Soil Water Index	The Soil Water Index quantifies the moisture condition at various depths in the soil. 8 SWI values are various soil depths are provided. It is mainly driven by the precipitation via the process of infiltration. Soil moisture is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Satellite measurements integrate over relative large-scale areas, with the presence of vegetation adding complexity to the interpretation. The soil moisture, up to 5cm soil depth, is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System	SWI calculated from the Surface Soil Moisture (SSM) from single MetOp/ASCAT sensor (MetOp-A or -B) using a two-layer water balance model. Soil texture not accounted for. Computational adaptation based on a recursive formulation	2007 - present 70° S to 80° N Daily Within 1 day Spatial resolution 0.1°	75% sites reach a SWI target accuracy of 0.1 m3/m3; 98% reach a SWI threshold accuracy of 0.2 m3/m3	Only small part of polar regions	http://land.copernicus.eu/global/products/swi

	(GCOS).					

Above ground biomass

Table 60: Above Ground Biomass Products

Product	Information Content	Required Processing	Availability, Current and Future	Documented Accuracy	Limitations and Constraints	Reference
Dry Matter productivity	DMP, or Dry Matter Productivity, represents the overall growth rate or dry biomass increase of the vegetation, expressed in kilograms of dry matter per hectare per day (kgDM/ha/day). DMP is directly related to NPP (Net Primary Productivity, in gC/m²/day), but its units are customized for agro-statistical purposes.	Light Use Efficiency model (similar to Monteith, 1972) driven by climatology (radiation and temperature), fAPAR and a number of conversion efficiency factors. Input FAPAR is calculated using a neural network (different from FAPAR version 1) applied on 10-days composites of Top-of-Canopy (TOC) reflectances.	Preoperational 2013 – onwards 70° S to 80° N	Large differences for DMP/NPP Fair agreement for GDMP/GPP	Only small part of polar region covered From archive only	http://land.copernicus.eu/global/products/dmp

APPENDIX 2: STEERING COMMITTEE OF EXPERT ADVISORS

Name	Organization
John Falkingham	International Ice Charting Working Group
Andrew Fleming	British Antarctic Survey
René Forsberg	Danish Technical University
Tiina Kurvits	GRID - Arendal
Peter Pulsifer	National Snow and Ice Data Center
Jan-René Larsen	Arctic Monitoring and Assessment Program
Duke Snider	The Nautical Institute

APPENDIX 3: REFERENCES

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