DOCUMENT

White Paper

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

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1 EXECUTIVE SUMMARY

The demand for environmental information in the Arctic region is evolving rapidly influenced by a multitude of drivers, including climate change science, exploration of natural resources, environmental sustainability, shipping, local communities etc. Developing appropriate next generation observation systems therefore require a holistic approach where all drivers and stakeholders' interest are fully taken into account and consolidated into priority actions with high socio-economic impact.

Space based solutions are clearly at an advantage in the Polar Regions, given the remoteness, lack of ground-based measurements, and the excellent repeat coverage provided by polar orbiting satellites. Even though space proven technology and access to space is becoming more reliable and affordable, building, launching and operating space based infrastructure remains a significant investment of substantial risk. Sharing the risk and investment amongst the different stakeholders would be desirable and probably necessary to ensure the need for long term monitoring. In this context the European Space Agency Polaris initiative is establishing next generation space based mission concepts for satellite remote sensing systems. In doing so, gaps in Arctic environmental information requirements are identified via close dialog with a wide range of national and international user community representatives, which is being fed into mission concepts studies. This white paper is presenting the Polaris initiative and initial results.

2 INTRODUCTION

There has been a growing interest in the Polar Regions in recent years, fuelled by concerns about amplification of anthropogenic climate change. Increased economic and transportation activities are leading to greater demands for sustained and improved availability of integrated observations and predictive weather, climate and water information to support decision-making, on all time scales. Whilst polar-orbiting remote sensing satellites already play an important role in providing observations of the polar regions, new environmental, political and socio-economical factors are creating a demand for more detailed and frequent monitoring than is presently available.

This White Paper defines the ESA activities being be executed in establishing user and high-level mission requirements for the next generation of satellite Earth observation systems covering the Polar Regions and preliminary analysis of mission concepts to meet these information requirements. Other coordinated activities will cover the architectural and technical definition of space systems candidate to implement those concepts.

3 BACKGROUND

The Polar Regions are key drivers of the Earth system and changes in these regions will have a significant impact on global factors such as weather systems and sea level. Conversely, the Polar Regions are known to be especially vulnerable to on-going climate changes, largely as a result of polar amplification.

The Intergovernmental Panel on Climate Change (IPCC) reports that over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide and Arctic sea ice has continued to decrease in extent (IPCC Fifth Assessment Report, chapter 13.4). Satellite EO derived measurements played an essential role in arriving to these conclusions. Furthermore, the IPCC fourth assessment identified the contributions of ice from glaciers and ice sheets as the major remaining uncertainty in projections of sea level changes (IPCC Fifth Assessment Report, chapter 13).

Despite considerable research progress in understanding the Polar Regions over the last decade [RD17], many gaps remain in observational capabilities. These gaps limit present numerical weather prediction capabilities and sub-seasonal and seasonal forecasting in Polar Regions, thereby hampering reliable decision-making. The goal of the WMO Global Cryosphere Watch (http://globalcryospherewatch.org/) is to improve the integrated observing system capabilities at high latitudes, while the complementary goal of the WMO-WWRP Polar Prediction Project (http://www.polarprediction.net) is to promote development of improved weather and environmental prediction services for the polar regions on time scales from hours to seasonal. However, whilst both of these endeavours are expected to improve representation of polar atmosphere, land, ocean and cryosphere processes in models, there remains a clear demand for both initiatives to be sustained in the future by basic improvements to existing satellite observation capabilities.

Over the last decade a much more variable and unpredictable sea-ice regime has been observed in the Arctic and Southern Oceans. Velocities of some major Greenland glaciers are accelerating, causing increased iceberg calving rates. Both the new Arctic sea-ice regime and increased glacier/iceberg calving are creating new challenges for operations in polar waters. The need for tactical real time snap shots and forecasts for sea-ice and icebergs is increasingly becoming a priority to operate safely and efficiently in ice-infested waters, as is the need for reliable and timely information on the sea state and local winds and other meteo parameters, which are known to be naturally more challenging in polar regions. Coastguards executing search and rescue missions, shipping companies planning trans Arctic passages, engineers building new infrastructure, and oil and gas companies undertaking exploration/production operations will all need this type of information, which can only be derived from EO satellites in an efficient manner.

All Arctic nations are providing satellite-based ice monitoring services as part of their national weather forecasting services. The International Ice Charting Working Group (IICWG) was formed in October 1999 to promote cooperation between the world's ice centres on all matters concerning sea ice and icebergs. Over the last years IICWG has played a key role in establishing a global user community able to formulate operational standards and provide ESA and other satellite operators clear and consolidated requirements for satellite missions such as RADARSAT-2, Sentinel-1, etc. In their 2014 IICWG included the following statement in their annual press release "Accurate, timely analyses and forecasts of ice conditions are essential for safe and efficient navigation in polar waters" [RD16]

According to the US Geological Survey (2009), the Arctic holds 13% of undiscovered oil and 30% of undiscovered gas supplies. A significant part of these oil and gas is located offshore Greenland in waters where sea-ice and icebergs pose challenges in terms of accessibility and safety. Supporting oil and gas tactical operations in ice-infested waters will require satellite based information products, which are currently not yet available. Conversely, oil and gas prospection, exploration and production operations imply very high environmental risks for local ecosystems that are known for their fragility. Space EO is the primary choice for extending environmental monitoring to the Polar Regions with an approach that is adapted and optimised for the specific characteristics of the polar environment.

As the Arctic sea-ice extent is shrinking year by year there is also an increased interest for new shipping routes from Europe to Asia with the potential of reduced sailing times (Smith and Stephenson, 2013). In 2009, Beluga Shipping became the first shipping company to transport goods through the 'Northeast Passage' escorted by a pair of Russian icebreakers, travelling from South Korea to Siberia. The prospect of an ice-free Arctic sea during the summer months is definitely attractive, but also extremely challenging due to the freeze over during the winter months. A seamless trans-Arctic sea-ice and iceberg navigation satellite-based service is still not available, but will have to be developed to support safe navigation of vessels through these future routes.

In 2012 the European Commission and the High Representative issued a Joint Communication on “Developing a EU Policy towards the Arctic Region: progress since 2008 and next steps”. This communication sets out the case for increased EU engagement in Arctic issues and proposed to further develop EU’s policy towards the Arctic. With the EU having invested over €1.14 billion in the European Arctic since 2007, the EU is also a key investor and actor in the Arctic region.

Space Weather, the physical and phenomenological state of natural space environments, should also be taken into consideration when discussing the Polar Regions. In general, the associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them, and also at forecasting and nowcasting the potential impacts on biological and technological systems. The effects of Space Weather are observed in the degradation of spacecraft communications, performance, reliability, and lifetime. In addition, it leads to enhanced risks to human health on manned space missions. Space weather also has numerous effects on the ground including damage to aircraft electronics, enhanced radiation dose for air passengers and crew, damage and disruption to power distribution networks and pipelines and degradation of radio communications as well as errors of GNSS signals.

The ability to predict Space Weather (SWE) impacts on Earth, thus allowing users to enact the measures needed to protect critical infrastructures, is one of the key goals of the ESA SSA-SWE program. To this end, a number of measurements are needed. Observation of the auroral oval, measurement of the radiation and plasma environment and the local magnetic and electric fields in geo-space supports the monitoring and prediction of space weather impacts for the benefit of end users. These observations are feasible from high inclination LEO, MEO and HEO orbits [RD18]

The provision of environmental information products and services responding to these drivers and challenges will not be possible without the appropriate exploitation of other space based systems, like; GNSS, telecommunication and Automatic Identification System (AIS) services.

For Global Navigation Satellite Systems (GNSS), presently GPS and Glonass but in the future also for Galileo, the performance in the Polar Regions is reduced compared to the performance obtained by users at mid latitudes. The reasons are mainly the satellite-receiver geometry and the ionospheric effects on the satellite signals. High reliability navigation through the European Geostationary Navigation Overlay Service (EGNOS) is presently also not possible in the Arctic because of the inability of geostationary satellites to reach high latitudes. On-going developments, like the Arctic Testbed and second generation EGNOS, are exploiting Satellite-based augmentation systems (SBAS) based on accurately-located reference stations and the future introduction of Dual Frequency Multi-Constellation navigation services to compensate for these limitations. EGNOS delivers navigation services with guaranteed integrity of position that could make a valuable contribution to safe navigation in the region.

Geostationary telecommunication satellites do not cover the Polar Regions at all or only partly with reduced efficiency. A number of satellite constellations that are in a low-Earth orbit such as Iridium, Globalstar, OrbComm and Gonets, are serving the Polar Regions with low data-rate and/or messaging services. There are presently no broadband communications solutions available for defence or military users; all European forces currently use U.S. systems.

The Canadian and Russian governments have initiatives to develop high elliptical orbit solutions, respective PCW (Polar Constellation for Communication and Weather) and ARKTIKA systems. The Canadian PCW system is planned to offer broadband services only to certain areas of the Arctic. The Russian ARKTIKA system is planned to offer low data rate communications for government and aeronautical communications with a navigation signal overlay, and broadband communications. The planned coverage is more extensive than the Canadian, but for the moment mainly targeting government and institutional use.
ESA supports a Private-Public Partnership with Inmarsat called ICE (Inmarsat Communication Evolution). This initiative will redefine the provision of mobile satellite communication services though innovative ground, space and user segments and will include the provision of truly global coverage, including polar areas.

Automatic Identification Systems (AIS) is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. Due to the lack of land based AIS infrastructure in the Polar Regions, satellite based AIS is essential. The availability of satellite based AIS in the Polar Regions is increasing rapidly, especially due to commercial telecommunication operators adding AIS to the payloads.

This study shall consider these and other relevant issues and establish the needs and requirements for the next-generation integrated environmental information products and services for the Polar Regions, and associated high-level requirements for space based systems responding to these.

Current and planned polar-0rbiting EO space systems (e.g. MetOp, CryoSat-2, Sentinel-1 and ICESat-2) are and will be providing important data sets and services addressing some of the challenges, but the demand for new information as well as better detail and timeliness of information requires enhanced monitoring capabilities for the Polar Regions. In considering these, the concept of integrated observing systems shall be applied, i.e. data sets from different techniques (possibly not only spaceborne), missions and different sources are collected and combined in a coordinated manner to address information needs. These data sets can be integrated to obtain a more complete and comprehensive picture of the Earth system and underlying processes that would be beyond the capabilities of single satellite missions.

ESA has traditionally engaged in addressing scientific issues related to the Polar Regions, e.g. with the CryoSat mission. Now, wider European EO operational capabilities are being rapidly put in place, starting with the first Sentinel mission (Sentinel-1A), launched in April 2014. The missions that shall provide long-term stable, robust streams of EO data in a reliable manner include:

- The Copernicus Sentinels
- The meteorology/climatology missions part of the International Joint Polar System, namely the MetOp series of satellites
- The Copernicus contributing missions
- Earth Explorer follow on missions that may be realised in other frameworks from the ones above.

These operational missions will provide a solid basis from which the next-generation operational satellite missions can be designed. These additional missions would provide rich and valuable synergetic EO measurements resulting in novel synergetic data products and complementary data sets, which would be able to respond to scientific and operational needs not addressed thus far.

A separate EO system study is anticipated for start later in 2015 based on the results of this study, as they become available, in order to elaborate detailed mission concepts analysis

4 POLARIS OBJECTIVES

The objectives of the Polaris study are to:

- Review, identify and consolidate user community environmental information requirements for the polar regions,
- Establish consensus and endorsement for these requirements via close dialogue with key user representative bodies across the user categories in scope
- Identify information gaps considering existing and planned EO and integrated (EO/nav/telecom) systems, space and non-space based
- Consolidate and prioritize information gaps together with key user representatives bodies
- Establish a set of endorsed, high-level mission requirements reflecting the gaps in connection and dialog with stakeholders
- Identify potential new integrated information services possibly provided by synergetic use of space assets (EO, navigation and telecommunications etc.)
- Perform a preliminary assessment of the high-level operations requirements for supplying these integrated services.

In the long-term the project aims at stimulating the development of novel space mission concepts for the Polar regions that may exploit new and existing European operational capacity in order to address in a cost-effective manner new scientific and operational information needs.

5 RELEVANT DOCUMENTS

5.1 Reference documents

RD1	Earth Observation Science Strategy for ESA: A new Era for Scientific Advances and Societal Benefits (ESA SP-1329, 2015)
RD2	Sea-Ice monitoring, GLOBAL SATELLITE OBSERVATION REQUIREMENTS FOR FLOATING ICE by John Falkingham (http://nsidc.org/noaa/iicwg/docs/IICWG-2014/Global-Satellite-Observation-Requirements-for-Floating-Ice-Final.pdf)
RD3	ESA EO Convoy Studies: Earth Observation Capabilities, Gaps and Opportunities, EOSC-ASU-RP-001 Issue 3 Revision 0 (http://congrexprojects.com/2013-events/13m12/measurement-gap-analysis)
RD4	Snow Monitoring White paper prepared by the Group of European Satellite Snow Monitoring Perspectives), http://www.globsnow.info/docs/White_Paper_European_Satellite_Snow_Monitoring_25062014.pdf
RD5	IGOS-P Cryosphere Theme requirements document, WMO/TD-No. 1405, Aug 2007. (http://globalcryospherewatch.org/reference/documents/files/igos_cryosphere_report.pdf)
RD6	2014 SCAR Antarctic and Southern Ocean Science Horizon Scan (http://www.nature.com/news/polar-research-six-priorities-for-antarctic-science-1.15658)
RD7	Final Report - Workshop on Future Directions for Arctic Research (http://www.arcus.org/logistics/2013-workshop/report)
RD8	A community white paper in response to the WMO Polar Space Task Group (PSTG), Requirements for Monitoring of Permafrost in Polar Regions (https://www.dropbox.com/s/w6i6dlmt1b3kiw8/WMO_PSTG_permafrost_recommenadtions_final-1.pdf?dl=0)
RD9	Lloyd's, Arctic Opening: Opportunity and Risk in the High North, Chatham House, (http://www.chathamhouse.org/publications/papers/view/182839)
RD10	Laurence C. Smith and Scott R. Stephenson (2013), New Trans-Arctic shipping routes navigable by midcentury, PNAS, (www.pnas.org/cgi/doi/10.1073/pnas.1214212110)
RD11	Outline of a Technical Solution to a Global Cryospheric Climate Monitoring System, (http://www.nr.no/en/nrpublication?query=/file/4403/Solberg_-_Outline_of_a_Technical_Solution_to_a_Global_Cryosp.pdf)
RD12	Strategic Arctic Impact Assessment of Development of the Arctic (http://www.arcticinfo.eu/en/sada)
RD13	ESA-CliC Cryosphere Workshop on snow (http://www.congrexprojects.com/2014-events/14c19/workshop-report)
RD14	The Polar Communication and Weather Mission: Addressing remaining gaps in the Earth Observing System, by Louis Garand, Alexander P. Trischenko, Larisa Trischenko, and Ray Nassar
RD15	WWRP Polar Prediction Project Implementation Plan WWRP/PPP No. 2 – 2013 – (http://www.polarprediction.net/fileadmin/user_upload/redakteur/Home/Documents/WWRP-PPP_IP_Final_12Jan2013_v1_2.pdf (see pg. 38 – link to space agencies))
RD16	2014 Meeting of the IICWG (http://nsidc.org/noaa/iicwg/meetings.html#iicwg-15)
RD17	WMO PSTG reports (http://www.wmo.int/pages/prog/sat/pstg_en.php)
RD18	SSA-SWE-RS-RD-0001, I1r4 (http://swe.ssa.esa.int/DOCS/SSA-SWE/SSA-SWE-RS-RD-0001_i1r4.pdf)

6 SCOPE

6.1 User communities

The following key polar user community categories are within the scope of the Polaris study (non exhaustive examples):

User community category	Community member examples	User representative bodies (examples)
Scientific research groups (Earth science and climate research)	Universities, science laboratories, national institutes etc.	WMO-WWRP PPP, WCRP-CliC, Global Cryosphere Watch
Governmental organizations and working groups	Coast guards, Navies, civil protection, national meteorological and hydrological services/institutes, etc.	Arctic Council working groups (PAME, AMAP), International Maritime Organization (IMO), International Ice Charting Working Group (IICWG), European Maritime Safety Agency (EMSA), European Fisheries Control Agency (EFCA)
Industry	Oil and Gas, Mining, Shipping, Tourism etc.	OGP, IAATO, AECO
Non-governmental organisations involved with polar environment	Environmental interest groups, foundations, UN bodies etc.	TBD

6.2 Geographic scope

In this study the Polar Regions shall for the purpose of this study include all regions at latitudes greater than 55 N and 55 S latitude, which are considered to be outside of the regions of coverage provided by geostationary satellites.

6.3 Thematic scope

The following environmental information parameters are within the scope of the Polaris study

- Ocean parameters (sea surface temperature, salinity, currents and circulation, roughness, sea state, colour etc.)
- Sea-ice parameters (marginal ice zones, ice edge characterisation, ice motion, freeze thaw cycles, etc.)

- Atmospheric parameters (chemistry, composition and meteorology e.g. clouds, water vapour, atmospheric motion, ozone, aerosols etc.)
- Land surface parameters (land surface type, snow cover, albedo, permafrost, etc.)
- Ice sheet parameters (ice elevation, thickness, surface type, albedo, surface temperature etc.)
- Ice shelf parameters (ice front position, thickness, calving rate, etc.)
- Interaction and coupling between geophysical parameters
- Vessel and oil spill monitoring
- Space weather and its impact on activities in the polar region.

7 POLARIS TASKS

7.1 Task objectives

The overall objective of the tasks include the identification and consolidation of environmental information needs and priorities within relevant Polar user communities, current state of the art in term of EO use and of utilisation of supporting space techniques for navigation and telecommunications, gaps analysis, PEST analysis for future needs identification, and elaboration of high level observation requirements that could fill these information gaps.

Both scientific challenges [RD1, RD5, RD6, RD7, RD8], and operational needs derived from governmental, non-governmental and industrial organizations [RD 2, RD4] shall be considered. The socioeconomic impacts realized by closing information gaps shall also be analysed.

The objectives of each task are as follows.

Task 1: Information needs gathering

Establish a clear and credible description of the current and future environmental information needs for key user communities in the Polar Regions including operational, institutional, research users of both Artic and Antarctic regions. This task will involve close dialogue with key individual users to document their current and future information needs. Structured individual input will form the basis for a needs consolidation exercise. Key user representative bodies shall be engaged in establishing a clear and consolidated consensus for what represents key needs for different user sectors

Task 2: Gaps and impact analysis

Based on the consolidated needs identified in Task 1, Task 2 shall define the gaps taking into account existing and planned observation systems (space and non-space). Previous studies [e.g. RD 3] have addressed this issue and shall be thoroughly taken into account as part of the analysis. The main output of this task will be a preliminary set of new (EO based) products and innovative integrated services, which cannot be realized with current and planned future satellite missions. In this context an integrated service shall be considered as a solution combining space based EO observations with in-situ measurements, modelling tools etc., in addition to exploiting other space based capabilities such as telecoms, navigation, AIS etc. in order to meet user requirements. These new services shall become the input for defining preliminary high-level operations requirements for future space missions as part of Task 3. Key in this analysis will be to identify which gap-fillers will provide the highest socioeconomic benefit and impact given trends and drivers in the Polar Regions.

Task 3: Preliminary observation requirements analysis
Based on the gap analysis, and identified products and integrated services, high-level observation requirements shall be identified and analyzed. Preliminary data products shall be defined in-line with most promising integrated services for further development in a separate system study.

8 PRELIMINARY STUDY FINDINGS

8.1 Information Gaps

Table 1 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. 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.

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 the following sections.

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 present ability to understand and interpret on-going processes, prediction capabilities and forecasting in the Arctic region, thereby hampering evidence-based decision-making. Amongst these sea-ice and ice sheet mass balance were identified as high priority gaps, both hampered by 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 and ice sheet (in particular Antarctica) mass balance measurements are key to understanding and predicting sea level fluctuations. Improving the knowledge of terrestrial snow, lake ice dynamics, permafrost extent and biodiversity were also highlighted as areas were significant gaps exist.

- Environmental information Gaps supporting Polar operations

The dominant information gaps in operations 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 currently available. Sea-ice thickness, stage of development, structure, motion, extent and topography were identified as parameters were significant gaps exist. In addition, having more accurate sea-ice snow information will be required to reliably establish these information parameters. The ability to 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).

8.2 Mission Concepts

A number of aspects of earth observation missions can be varied in order to better meet the needs of polar data users. Some examples of mission concept attributes that have emerged from the study include:

Sensors

- Active Microwave
  - Multi-frequency (a combination of C,L,X,Ku)
  - Multi-polarization, cross polarization (H, VV, HV, VH, consider circular)
  - Integrated AIS
- Altimeter
  - Radar, Lidar
- Radiometer
- Gravity
- Optical
- Hyper/Multi-Spectral

Table 1: 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	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																		■		■		■	■	

Performance

- Spatial resolution – (high resolution plus wide swath)
- Low Revisit time (at least daily)
- Vary revisit time of day
- Low Latency
- Complete coverage
- Mission continuity
- Operational systems

Orbits

- Tandem (active + passive, along track and cross track)
- Constellation (small sats)
- True polar coverage

8.3 System Concepts

However, an end-to-end data service value chain includes much more than just data acquisition by an earth observation satellite. The value of the end-product may also depend on the attributes of data analysis, discovery, access, and dissemination. Such issues mentioned in the consultations include:

- Better integration of data parameters (space, in-situ, analysis)
- Better discovery and dissemination of information
- Integration of data with computation capacity
- Data visualization
- Delivering data over low bandwidth channels (such as to ship bridges)
- Reducing latency (the time from acquisition to delivery) and near-real-time delivery of products
- Vessel identification & tracking integration
- Indication of the uncertainty/quality of information
- Open web service links to data
- Data archive access
- Licensing agreements to make more EO data available to the community at lower cost
- Better metadata
- Training and education

8.4 Product and Service Concepts

Many end users are not in a position to work directly with earth observation data. Rather, they need products and services that provide the processed information that they require. Examples of such products that are not currently available or do not fully meet user needs include:

- Ice thickness at high spatial resolution
- Ice age and stage of development
- Snow depth on ice
- Melt and freeze onset for lake ice and river ice
- Detection of icebergs in sea ice
- Detection of iceberg calving
- Weekly mass balance changes for glaciers and ice sheets
- Snow water equivalence
- Consistent vegetation information – structure, biomass, health

9 FUTURE WORK

The remaining tasks in the project are:

- **Impact Analysis**: Assess the socioeconomic and environmental implications of implementing the most promising systems.

- **Legal and Political Implications**: Assess the potential legal and political implications of implementing the most promising systems.

- **System Analysis**: Define preliminary integrated systems for further development in a separate system study.