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User Requirements for a Copernicus Polar Mission

Phase 1 Report - User Requirements and Priorities

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Step1/Phase 1 polar expert group report

Contents

1. Background

The Joint Communication by the European Commission and the High Representative of the Union for Foreign Affairs and Security Policy issued on 27 April 2016 to the European Parliament and the Council, proposing 'An integrated European Union policy for the Arctic', highlights the strategic, environmental and socioeconomic importance of the Arctic region including the Arctic Ocean and adjacent seas. The Arctic's fragile environment is also a direct and key indicator of the climate change, which requires specific mitigation and adaptation actions as agreed with the global agreement reached during the Conference of the Parties (COP)-21 held in Paris in December 2015. To this end, the 'integrated EU policy for the Arctic' has identified and is addressing three priority areas.

1. Climate Change and Safeguarding the Arctic Environment (livelihoods of indigenous peoples, Arctic environment).
2. Sustainable Development in and around the Arctic (exploitation of natural resources e.g. fish, minerals, oil and gas), 'the Blue economy', safe and reliable navigation (North-East (NE) passage etc.)
3. International cooperation on Arctic Issues (e.g. scientific research, EU and bilateral cooperation projects, fisheries management/ecosystems protection, commercial fishing).

To monitor on a continuous basis the vast and harsh Arctic environment, considering the sparse population and the lack of transport links, space technologies are definitely essential tools including Earth observation (EO), navigation and communication satellites. Although the existing Copernicus programme already offers operational thematic services in the fields of atmosphere monitoring, marine environment monitoring, land monitoring, climate change, emergency management and security, new requirements from key Arctic user communities for a dedicated polar and snow satellite mission have emerged over the recent past. These requirements were reviewed at a polar and snow workshop held in June 2016 and organised at the initiative of the Directorate-General (DG) for Internal Market, Industry, Entrepreneurship and SMEs and involving relevant EU DGs as well as 70 attendees coming from EU Member States and working on various domains.

This strong interest for a "Polar and Snow mission" was further reinforced when discussed in a wider international context, considering UN Conventions and pan-Arctic cooperation activities. This situation led DG Internal Market, Industry, Entrepreneurship and SMEs to set up a new group of European polar experts with the mandate to update and/or complete the review and analysis of the user needs, thus allowing the Commission to assess the relevance of the development of a *Copernicus Sentinel Expansion mission* dedicated to polar and snow monitoring.

2. Selected approach for polar user requirements review

The approach taken by DG Internal Market, Industry, Entrepreneurship and SMEs for the review/refinement of the Copernicus core user requirements for a Polar and Snow monitoring mission included the following activities.

- Setting up by DG Internal Market, Industry, Entrepreneurship and SMEs of a group of European polar and snow experts (Polar Expert Group (PEG)).
- Organisation of a 2-day Workshop on 4-5 April 2017 in Brussels with the participation of PEG members, representatives of Copernicus services and members of relevant EC DGs. (Composition and list of attendees in Annex 1 and agenda is provided in Annex 2).
- Provision of individual contributions by PEG members (according to an agreed Excel template), describing their specific discipline/application domains requirements for further analysis.
- Drafting of the Step 1/ Phase 1 report providing the following.
    - Identification of EU policies to be addressed by the future polar mission.
    - Identification of the key users requirements in main cryosphere domains including atmosphere, sea ice, snow, glaciers, permafrost, ice sheets, iceberg, Arctic ocean and adjacent seas.
    - List and priority of set of key users' requirements in terms of observations, parameters and/or products.

This report concerns Step 1/Phase 1 activities and it was further discussed and refined at the second 'Polar and snow workshop' held on 16/17 May 2017 in Brussels. This revised final version will be used for the Step 2/Phase 2 involving space experts (from the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat)) for the establishing of high-level mission/instrumentation requirement specifications of a dedicated polar and snow mission.

3. Scope of Polar Expert Group (PEG) contributions

A large number (> 21) of Excel input files were received from PEG members, complemented by additional relevant documentation such as ESA Polaris study reports from Polar View project (April 2016), IGOS cryosphere 2007 report, Copernicus maritime surveillance service user workshop report by European Maritime Safety Agency (EMSA) (December 2016), report of Polar Space Task Group (PSTG) on 'Strategic plan: 2015-2018' (November 2015), DG Research and Innovation/ESA Climate Task Force report (November 2016) and Copernicus Marine Environment Monitoring Service (CMEMS) 2016 Position Paper on polar and snow cover applications.

The PEG contributions cover eleven application domains and nine geophysical themes as per Tables 1 and 2 and are related to seven major EU policies as outlined in Table 3.

Table 1: Application domains relevant to this report

Meteorology	Climatology	Hydrology	Oceanography
Ecology	Natural and technical hazards (preparedness)	Emergency response (including search and rescue)	
Energy	Transport/navigation	Other infrastructure	Security

Table 2: Geophysical themes relevant for polar regions

Atmosphere	Ocean	Surface fresh water	
Land surface and vegetation	Permafrost and soils		
Sea ice/ iceberg/ice shelves	Ice sheets	Glaciers and ice caps	Snow (seasonal)

Table 3: EU policy areas for arctic regions

Climate-change impact	Ice and snow cover, ice sheets, permafrost extent
Security and defence	Border control Search and rescue
Environmental protection	Ice, ice sheets Marine protected areas (including no-take marine reserves) Biodiversity Water quality Nuclear (ice breakers, submarines, coastal facilities/waste)
Natural resources	Snow, ice, water resources Fishing, hunting and gathering Mineral extraction Oil and gas
Maritime transport	Safe transport (sea ice, ice sheets, icebergs, navigation, waves, currents)
Pollution	Heavy fuel oil (HFO)/black carbon/methane Oil contamination Other pollution — heavy metals
Indigenous people and local communities	Ice, ice sheets, snow, marine biodiversity Climate-change adaptation/resilience (herding, weather change, melting permafrost buildings/infrastructure) Development (environmental impact assessments) Tourism

PEG members were asked to provide, for themes and domains listed in Tables 1 and 2 relevant to their expertise, a description of their specific parameter requirements according to the template in Table 4.

Table 4: Parameter specification scheme used in PEG survey

AOI (coverage)	Area of interest to be covered, options are: [0] global, [1] high latitude (> 60º), [2] regional — in this case provide details (bounding box, shapefile) or map (raster mask at 10-100 km resolution)
Spatial resolution	The sampling distance of measurements in [m], equal spacing in x and y is assumed
TOY (seasonality)	Time of year (TOY) for measurements, options are: [0] year-round, [1] seasonal — in this case provide the time window for measurements (months)
Frequency	Temporal frequency, options are: [0] 'on demand' acquisitions — estimate No. of acquisitions per year, [1] regular measurements — provide repetition rate in [min, hr, dy, mo, yr]
Leadtime	In the case of 'on demand', what should the minimum lead time be for an acquisition to be scheduled in [hr]
Timeliness (TL)	How long after acquisition should the product be available, options are: [0] non time critical, [1] Near-Real-Time (NRT) within 6hr [2] Quasi-Real-Time (QRT) within 1hr
Unit	How is the variable assessed: [0] as continuous scale, in this case give (physical) units (SI) [1] in different categorical classes — in this case provide reference
Range	Dynamic range of measurements in physical units or number (and name) of categories
Accuracy	95 % confidence interval for uncertainty (continuous scale variable) or commission and omission errors (categorical variable)
In situ (I)	Availability of *in situ* observations, options are: [0] hardly accessible, [1] irregular measurements available, [2] various sources exist and (non-harmonised) data are made available on a regular basis, [3] international standardised network
Status (S)	Is variable currently monitored by means of EO: [0] no [1] experimental research ongoing, [2] operational service, (ATBDs available); for [1] and [2] provide references
Continuity (C)	What are the expectations with respect to future availability of this variable: [0] current status of EO and *in situ* (IS) ensured or likely to improve, [1] *in situ* at risk, [2] EO not available or at risk [3] availability/quality of both IS and EO at risk to deteriorate
Priority (P)	[0] low, nice to have, dispensable, models and/or proxies available [1] low, but continuity must be guaranteed [2] high, improvements are essential for progress in the domain

4. Exploitation of PEG contributions/selection rationale

From the extensive list of identified polar and snow parameters (>> 100), a shorter list was drafted considering the following.

- The key priority objectives as defined in the 'integrated European Union policy for the Arctic', namely: climate change, environment safeguarding, sustainable development, support to indigenous populations and local communities and international cooperation.
- The top priority of the Copernicus programme being put on the provision of operational, reliable and timely products and services to well-identified user communities, with priority being given to Copernicus core users as described in Article 4 of the Copernicus regulation.
- The focus of Copernicus services for polar zones being put more on continuous monitoring, the polar mission being an expansion mission which will fly in parallel with the current constellation, the assumption has been made therefore that the paradigm will rely on the same approach implemented with the current Sentinel constellation and based on a stable operations plan (and not on highly reactive operations with short-notice tasking).

The rationale for the parameters selection, based on PEG contributions, takes into account the availability of existing Copernicus products and services of direct relevance to the Arctic and, more generally to polar zones, such as those for the following.

- Copernicus Marine Environment Monitoring Service (CMEMS) providing the physical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. Main areas of CMEMS product application which are of key importance for polar zones include marine safety, marine resources and coastal and marine environments.
- Existing operational users agencies/organisations from member states of the EU, ESA, and Eumetsat
  - Ice services from European Nordic countries for safe navigation and transport in sea-ice-infested zones.
  - Meteorology/hydrology agencies in charge of hydropower facilities for energy production.
  - Emergency management and rescue operation authorities such as EMSA associated to national/European civilian protection authorities.
- C3S (Copernicus Climate Change Services) providing key indicators on climate-change drivers including, in particular, consistent estimates of essential climate variables (ECVs). Focus has been put on ECVs specific to polar zones (C3S sea ice, C3S glaciers and ice caps), snow cover, permafrost, river run-off, lakes etc.

The selection process integrated additional considerations emerging from PEG contributions as follows.

- A number of products are already available today to address identified parameters using existing space systems with guaranteed continuity (e.g. the Sentinel 1, 2 and 3 series, MetOp polar-orbiting meteorological satellites series, complementary polar meteorological satellites from other agencies, contributing polar satellite missions from national European (EU and non-EU) and non-European operators). However, some of these products require significant improvements in terms of spatial resolution, accuracy, revisit frequency etc. as described in Tables 8 to 16.
- Three of the four main EMSA services are focused on the detection of small-size vessels (up to 3 meters), on debris classification (containers etc.) and of fish cages and farms. This requires very high/high resolution (~ 1 m), all-weather, day-and-night imagery together with very demanding performances in terms of geographical coverage and revisit frequency as well as specific requirements on the spacecraft (S/C) capability (in-orbit tasking) and on-the-ground processing/product dissemination (near real time (NRT) and quasi real time (QRT) as described in Table 16. This set of requirements is wider than the strict case of a dedicated Copernicus polar mission (with the possible exception of the oil-spill-detection service) and will be considered in a different context, in particular in the security expert group put in place by the Commission.
- Copernicus Atmosphere-Monitoring Service (CAMS) for atmospheric composition (greenhouse gasses GHGs, air quality) and Copernicus Climate Change Service (C3S) atmosphere parameters were not considered in the priority list, the focus of the PEG workshop being on land-, ocean- and ice-surface processes and parameters. As stated by the European Centre for Medium-Range Weather Forecasts (ECMWF) for the atmosphere, the MetOp series program and complementary polar satellites from other agencies guarantee the continuation of provision for most of the operational C3S-atmosphere variables (with the exception of some cloud properties).
- The current level of technical and/or scientific maturity required for some candidate parameters: this status questions the feasibility of monitoring them from space when considering a polar mission due to be in orbit around 2025, therefore having to rely on already-sound-and-validated technologies and demonstrated scientific knowledge.
- In some cases, only *in situ* and/or unmanned aerial vehicle (UAV) observations can/will ensure provision for the selected parameter(s).

After a critical review (performed during the second PEG meeting) of the initial list of parameters derived from the first PEG meeting, the final list of selected parameters is presented in Table 5 and Table 6, **the higher priority parameters being marked in red** as requiring the most urgent attention. It should be noted that the requirements specific to the scientific research community for the improvement of the understanding of cryosphere processes and their contribution to climate modelling are, to a large extent, covered by these priorities.

5. List of requirements and related priorities

A summary list of selected parameters is given here in order of priority.

1. **Floating-ice parameters** including sea ice extent/concentration/thickness/type/drift velocity, thin sea-ice distribution, iceberg detection/volume change and drift, ice-shelve thickness and extent. These parameters are key to operational services (navigation, marine operations) as well as to climate modelling. The operational feature will be of great importance when setting out the mission concept, introducing specificities in terms of timeliness impacting the end-to-end chain.
2. **Glaciers, caps and ice-sheet parameters** including extent/calving front/grounding line/surface elevation and surface-elevation change/surface velocity/mass balance and mass change/melt extent. These parameters are essential for climate change/sea-level rise.
3. **Sea level/sea-level anomaly (SLA) parameters** are essential parameters for oceanic large-scale and mesoscale circulation /variability and currents, marine forecasting.
4. **All-weather sea surface temperature (SST)** for climate modelling, mesoscale analysis, oceanic predictions and as climate-change indicator.
5. **Surface albedo** as major determinant for the energy balance between atmosphere and surface it is crucial for many application domains including climate, meteorology, numerical weather modelling, hydrology and more.
6. **Surface fresh water** (river run-off and discharge, river and lake-ice thickness) as an important resource for the supply of water to populations as well as for transport activities and impact on ocean changes/climate modelling.
7. **Snow** (extent/fraction and snow equivalent water, melt extent) important for many applications in hydrology, meteorology, water management and climate modelling.
8. **Permafrost** (extent/fraction and topography/deformation monitoring) important for operational activities (transport, construction/ground movement) as well as indicator of climate change.

Table 5: Summary of relevant parameters by theme, priority ones are highlighted in red

Floating ice (sea ice/iceberg)	Glaciers/caps	Ice sheets	Snow (seasonal)
Extent/fraction/conc.	Extent	Extent/calving front	Extent/fraction
Polynias/leads		Grounding line	
Sea-ice (Iceberg) drift	Surface velocity	Surface velocity	
Sea level in leads	Surface elevation (topography)	Surface elevation (topography)	
Thickness (freeboard)	Bedrock topography/ ice thickness	Bedrock topography/ ice thickness	Depth
Surface roughness			
Surface temperature		Surface temperature	Surface temperature
Melt pond fraction/depth	Surface melt extent	Surface melt extent	Snow melting extent (dry or wet)
Snow depth and density (liquid water)	Mass balance (mass, mass change)	Mass/mass change	Snow water equivalent (*)
	Accumulation	Surface accumulation	Accumulation (snowfall)
		Loss (melt, evap., calving)	
Deformation/ridging		Calving mass flux (*) (derived from velocity and thickness	
Surface albedo	Surface albedo	Surface albedo	Surface albedo
Salinity/brine distribution			
Type (First Year (FY) / Multiyear (MY) / new / thin ice) crystal structure, air bubble content		Ice-sheet morphology (crevasses, shear margins)	Impurity (*)
		Basal melt	Grainsize (*)
Floe size distribution			Density (*)
Fast ice detection			

(*) Parameters that are normally a function of the layer depth, where applicable it is to be mentioned whether surface values or columnar means may serve as proxies and specify accordingly.

Table 6: Summary (continued) of relevant parameters by theme, priority ones are highlighted in red

Atmosphere	Ocean	Surface water (freshwater)	Land surface/ vegetation	Permafrost and soils
		Extent/fraction	Extent/fraction	Extent/fraction
		Bathymetry		Permafrost table
	Surface currents	Water body shape	Coast lines	Taliks
	Sea Level and Anomalies	Water level	Surface elevation (Topography)	Surface elevation (Topography)
	Waves	Waves		
	Surface roughness		Surface roughness	
Temperature (*)	Temperature (*)	Temperature (*)	Temperature	Temperature (*)
	Salinity	Salinity	Liquid water content	Ice and liquid water content (*)
Precipitation	Swell	Discharge	Interception	Loss (melt)
Wind (*)	Surface wind	Surface wind	Surface displacement	Surface displacement
Albedo	Albedo	Albedo	Albedo	
Cloud (*)	Objects, oil on surface	Ice thickness	Land cover	Thickness
	Size/type of objects and debris [ice, wood, metal, synthetic polymer (plastic), oil] (**)		Size (incl. height) /type of objects vegetation/buildings	
	Acidification	Mass	Biomass (above/ below ground)	Mass
Earth radiation budget (*)	Ocean colour (including in MIZ-marginal ice zones)	Lake colour	Plant funct. type veg. structure (layers, communities, canopy types, shading etc.)	Ice type: pore, segregated, intrusive, vein ice
Constituents (*): [H_2O,O_3,NO_x,GHG, C, etc.]	Total Suspended Matter (TSM) (Particulate Organic Carbon (POC)/Particulate Inorganic Carbon (PIC)) (*), Chromophoric Dissolved Organic Matter (CDOM) (*)	Light penetration		Heat conductivity (*)
	Chlorophyll, fluorescence primary production phytoplankton types	Impurity (*) (anorganic), impurity (*) (organic)	Leaf area (*) carbon uptake/loss, water uptake/loss	Soil composition (*) (anorganic), soil composition (*) (organic)

(*) Parameters that are normally a function of the layer depth, where applicable it is to be mentioned whether surface values or columnar means may serve as proxies and specify accordingly.

(**) This box includes EMSA requests on detection of fish cages, containers, vessels and oil spills which will be treated under a separate Copernicus service (Security).

6. PEG comments and explanations

There is a general and common key requirement from all PEG members concerning all priority parameters and quantities mentioned in the report.

- Uncertainty information is to be delivered together with the parameter-related product. This is critical for the design and set up of assimilation systems and for prediction quality assessment to users.
- While the focus of the Copernicus programme is on the Arctic, comprising all areas north of the southernmost tip of Greenland (~ 60° N), the parameters specified in this report for polar regions should equally be provided for its southern counterpart the Antarctic, as well as all snow and ice covered surfaces.
- Future polar missions should be planned in complementation to intended *in situ*-based measurements; the latter being different from the calibration and validation activities of the satellite instrumentation.

The exploitation of PEG contributions has made it possible to draft a short list of high-priority parameters and associated required performances (Table 8 to Table 16), based on the following explanations/comments as expressed by the PEG experts.

6.1. Floating ice

Sea ice plays a critical role in Earth's climate system. Recent trends of Arctic warming and sea-ice retreat challenge future climate projections. The monitoring capabilities for polar regions are of vital importance for improved predictions. Special care should be taken for safe maritime operations, bearing in mind the highly sensitive ecology. Long-term continuity is essential for climate observations and for prediction systems at operational centres.

➢ Sea-ice thickness

Sea-ice modellers and operational ice services consistently rank improved measurement of **sea-ice-thickness distribution as their top priority**. Thin sea-ice thickness estimates from Soil Moisture and Ocean Salinity (SMOS) retrievals have been assimilated successfully into dynamic sea-ice models resulting in more accurate forecasts. The complete daily coverage and the NRT availability of SMOS sea-ice data are crucial for operational applications. For thicker ice (thickness > 0.5 m), there is a need for continuity in the altimeter-derived thickness estimates, taking into account improved accuracy on the freeboard measurements. Better short-range sea-ice forecasts support ship routing and hence economic interests in polar regions leading to societal benefits. **Accurate sea-ice thickness measurements** are indispensable for a better **understanding of the impact of climate change** in one of the most sensitive regions.

This is reiterated in the CMEMS position paper presented at the 'Polar and snow cover applications — user requirements workshop' for future Sentinels, 23 June 2016, Brussels, which states: 'Sea ice thickness is a very important indicator of climate change in the Arctic. In view of the uncertainty in the freeboard to sea ice thickness inversion, a CryoSat-type mission is an attractive option, preferably in combination with a laser altimeter. However, for operational sea-ice monitoring, input to sea-ice models and sea-ice charting, satellite measurements of the thin sea-ice (below 0.5 m) (SMOS-like L-band microwave radiometer) is indeed also required.'

Sea-ice thickness is important for navigational purposes but the requirement for spatial and temporal resolution will not be fulfilled with a combination of SMOS and CryoSat. Bistatic synthetic aperture radar (SAR) may be the best solution, but further investigation needs to be conducted.

- **Sea-ice concentration/extent**

Actual data from the CMEMS catalogue are available at coarse resolution. It will be likely that an **increase in resolution and time availability** of products from operational systems will require a **sub-daily frequency and a resolution of less than 5 km** in the future. The future microwave imaging (MWI) on meteorological operational satellite — second generation (MetOp-SG) will possibly secure continuation of the Special Sensor Microwave Imager/Sounder (SSMI(S)) series of coarse-resolution radiometry for climate monitoring, but will not fulfil the requirements for medium-resolution (< 10 km) sea-ice concentration and lead fraction which is needed soon by operational ice/ocean models. Improvements of the accuracy of passive-microwave-derived concentrations in the small-concentration range (e.g. near the ice edge) are also needed.

The CMEMS catalogue also contains high-resolution ice-concentration products provided by the national ice services and covering dedicated areas. These products are based on a manual interpretation of Sentinel-1 data and are essential for navigational purposes. The production is time-consuming and they have limited spatial and temporal coverage. To meet a **continuously increasing product demand for navigation** as well as for higher-resolution forecasting models, the production needs to be automatised. Such a product will probably need a **multi-sensor approach where SAR will be the core input in combination with concentration derived from medium-resolution PMW**.

- **Sea ice drift**

The CMEMS Arctic Monitoring Forecasting Centre (MFC) is actually assimilating **sea-ice drift** and the actual product is available from the CMEMS catalogue at coarse resolution. In order to better constrain the high sea-ice-drift variability and better understand its response to high-frequency forcing (tides, wind), an **increase of the spatial resolution and frequency** of the currently available data will be required.

➢ Snow depth on sea ice

Snow-depth measurements are needed for an accurate determination of the sea-ice freeboard. The specification should follow the ice-thickness specifications in terms of resolution and time sampling.

➢ Icebergs

Icebergs play a major role in redistributing the freshwater from calving glaciers and platforms at the ocean surface. Icebergs present a significant hazard to marine operations in those ocean areas where they occur. **Detecting large icebergs (> 100 m) with SAR and scatterometers is a maturing science** although significant **challenges remain relative to small icebergs**, bergy bits and growlers and icebergs **in differing sea states**. Detection of icebergs in open water and in sea ice generally places a **priority on wider satellite swaths to obtain greater geographic coverage**. Observing the characteristics of individual icebergs generally sacrifices swath width in favour of other parameters such as higher spatial resolution and multi-polarisations. There is a **need for automatic detection of icebergs** for navigation safety and chart production.

Iceberg concentration is given in the CMEMS catalogue at 10 km resolution covering waters off Greenland. **SAR imagery is the core input** for iceberg detection. Iceberg detection (in particular small ones) is also possible by using **high resolution altimeter waveforms**. The remaining major gap is the provision of a reliable automated product that can detect small icebergs (< 100 m) in NRT for navigational aid. This will require **SAR instrumentation with higher spatial resolution**.

6.2. Glaciers and ice caps

Glaciers are active bodies of ice (and debris), they are sensitive to global cooling or warming, and therefore **monitoring** them is **crucial**. Increase or decrease of glacier extent offers an **undeniable signal of climate evolution/change** in particular in polar regions such as the Arctic and sub-Antarctic islands, but also in the case of glaciers in mid latitudes. The melt of glaciers is a major contribution to sea-level rise observed in recent decades. Especially in the case of tidewater glaciers, continuous monitoring of glacier termini with high resolution helps in the understanding of high variability of front oscillation, iceberg calving and glacier-ocean interaction. Additionally, glaciers are also important for hydrology and water management, as they are an important resource for providing water for irrigation and hydropower generation, especially during dry periods.

High-priority parameters of glaciers are; glacier extent, glacier mass balance, surface-elevation change and surface ice-velocity as well as mapping of glacier facies. As glaciers are located in complex terrain, **high-resolution observations are required at specified times of the year** e.g. at the end of the ablation period with minimum season snow. Among these parameters **high-resolution surface-elevation change is not covered** operationally by current and near-future EO satellites.

➢ Glacier extent

Glacier extent as well as glacier facies (winter snow, firn, glacier ice) are monitored using **high-resolution optical images** (Landsat, Sentinel-2). Continuation is provided using Sentinel-2 data, but both parameters require a suitable acquisition planning over glaciated areas.

➢ Surface ice-velocity

Generating maps of surface ice-velocity requires **repeat observations of high-resolution SAR systems or optical sensors**. While Sentinel-1 Interferometric Wide Swath (IW) mode is suitable for ice caps and large mountain and tidewater glaciers, higher-resolution SAR is needed for small alpine-type mountain glaciers. Repeat-pass **Sentinel-2 images** can also contribute to map surface ice-velocity.

➢ Surface elevation and mass balance

Repeat **surface-elevation mapping** (carried out through digital-elevation models (DEMs)) is the **most essential parameter** to determine the mass balance of glacier and ice caps and their sea-level contribution by means of EO data. Altimeter systems such as CryoSat-2 and on-board Sentinel-3 are measuring surface elevation at a spatial resolution which is suitable for the smooth terrain of the interior of ice caps, but this resolution is not sufficient for monitoring tidewater glaciers and mountain glaciers in complex terrain. Additionally, altimeter systems require a time interval of several weeks to months for getting the required coverage and do not have the short time stamp needed to monitor the high temporal variability of ice boundaries and mountain glaciers. Currently, the single-pass SAR interferometry of the TanDEM-X mission provides maps of surface elevation and elevation change with sufficient high spatial detail and accuracy, but continuation of the mission in the near future is not guaranteed. Another option for high-resolution-DEM generation is high-resolution optical-stereo images, but they are often limited by clouds and show quality issues in the accumulation area of glaciers.

6.3. Seasonal snow

Seasonal snow is a main element of the global water cycle and climate system. Due to its strong influence on the radiation and energy balance, **changes in snow extent** tend to amplify climate fluctuations. Terrestrial snow covers up to 50 million km^2 of the northern hemisphere in winter and is characterised by high spatial and temporal variability. Seasonal snow is an important resource, supplying major parts of Europe but also many other regions in the world with water for human consumption, agriculture, hydropower generation, support of geotechnical and construction-planning activities, management of water supply for the agricultural industry, and other economic activities. Seasonal snow is also important for hydrological forecasting in the context of flood prevention.

High-priority parameters to monitor the seasonal snow are; snow water equivalent (snow mass: SWE), snow extent/fraction, and the snow melt extent (presence of liquid water in the snow pack). Among those parameters **SWE is the most-needed parameter** of the seasonal snow. For many applications (e.g. in hydrology, climate, meteorology and water-resource management) high-resolution SWE is required with improved accuracy and appropriate spatial resolution for complex terrains and forests.

- **Snow water equivalent (SWE)**

SWE is observed by current passive microwave systems on-board Defense Meteorological Satellite Program (DMSP) (United States (US)) satellites at coarse spatial resolution (a few tens of km), but retrieval algorithms are saturating for deep snow and are not capable of measuring SWE in complex terrain. The availability of passive microwave sensors on-board DMSP satellites is uncertain. Observations might be continued by MetOp-SG MWI, but this does not improve spatial resolution or retrieval skill. Satellite concepts (e.g. ESA Earth Explorer 9 candidate Mission CoReH2O/selected for Phase A: dual frequency X- and Ku-band SAR; L-Band SAR Interferometry) for monitoring SWE at high resolutions are currently under investigation in the scientific community.

- **Snow extent**

Snow Extent is an important parameter for climate-change assessment, but also important for water management, hydrology and meteorology. Snow extent (binary and fractional) is monitored by means of multi-spectral, medium-resolution optical sensors like AVHRR, MODIS, ATSR-2/ AATSR, and monitoring is continued by Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) and Ocean and Land Colour Instrument (OLCI), providing improved spectral properties and spatial resolution. Long-time series of satellite data are available from the beginning of the 1980s.

- **Snow melt**

The extent of the snow melt is important for hydrology, water management and snow melt flood forecasting. At coarse resolution, passive microwave and scatterometer systems are used and observations are continued by sensors on-board MetOp. Sentinel-1 interferometric wide-swath (IWS) and the extra wide swath (EWS) modes are suitable to map the melt snow extent, but this approach requires a suitable acquisition planning.

6.4. Ice sheets

The **two ice sheets of Antarctica and Greenland** store the **major amount of Earth's fresh water resources** and are important for climate change and contributions to sea-level rise. Due to the remoteness, the extreme climate conditions and their large extent, **satellite data are most suitable** to monitor these regions.

There **are several parameters** to be monitored by Earth observation (EO) as a high priority including **surface-elevation change** and **ice-surface velocity, extent and calving fronts as well as grounding line (zone), melt extent, and mass and mass changes**. There are other parameters which are important, but which cannot be directly measured by current EO sensors, such as bedrock topography or ice thickness.

➢ Surface topography

Surface topography of ice sheets is a relatively easily accessible parameter to monitor which makes it possible to assess volume changes and lateral displacements over time. It therefore can serve as a proxy for modelling ice velocity, mass and mass changes. It is so far most accurately measured by altimeter at km resolution using ERS (European Remote Sensing satellite), Envisat (Environmental Satellite) and lastly, CryoSat-2. CryoSat-2 was designed for mapping of ice-sheet topography with a small polar gap. In order to generate maps of surface elevation, data acquired over several months are merged, which is not critical as the rate of surface-elevation change in the interior of ice sheets is low. Major changes in surface elevation are observed at outlet glaciers and boundaries of Greenland and Antarctica. In these regions monthly to seasonal maps of surface elevation are needed. Altimeter systems including CryoSat-2 SAR interferometric (SARIn) mode require acquisition-time intervals of several months to 1 year to get coverage (too long) and do not provide sufficiently high resolution to monitor boundaries with complex terrain. Currently no operational missions are planned to provide regular updates for 10-30 m-class DEM data.

➢ Surface-ice velocity

Surface-ice velocity is important for determining the dynamics of ice sheets, studying influences of climate change on these and for anticipating future developments. It is monitored by applying offset tracking and SAR interferometry to repeat-pass SAR data. Short time intervals as can be provided by Sentinel-1 A/B IW mode with 6 and 12 days are successfully used to generate ice-sheet-wide velocity maps and to monitor the boundaries and outlet glaciers with 6/12 day intervals year-round. Desirable improvements include more operational-monitoring capacities and future higher spatial resolutions (about 3 m) and swath widths.

➢ Grounding-line location

The change of grounding-line location is an indication for the mass changes of the ice sheets and is an important indicator for climate change. Grounding-line location is measured indirectly by observing the tidal flexure of the floating ice. Sentinel-1 A/B is suitable to measure the tidal-flexure zone with high accuracy by means of interferometric SAR (InSAR), but short time intervals are needed to preserve signal coherence. At coarse resolution, an altimeter is proposed to contribute to grounding-line observation by breaking slope method, but its usability for monitoring changes of grounding-line location needs to be proven.

➢ Melt extent

The change of the maximum melt extent on ice sheets shows the regional warming and contributes to climate change and sea-level rise. For coarse resolutions, passive microwave sensors and scatterometer systems are used to monitor the melt extent. Contributions are the passive MWI and the Advanced Scatterometer (ASCAT) on-board MetOp.

SAR, e.g. Sentinel-1, is also used for mapping the melt extent on ice sheets (significant decrease of backscatter when surface starts melting); for continuous monitoring the acquisition plan needs to be adapted.

➢ Mass and mass change

Mass and mass change is a primary parameter of ice sheets. It can be measured by different methods. Gravimetry provides direct measurements of large-scale mass and mass changes; a continuation of the Grace mission is planned for 2018. Indirect methods for estimating mass changes are by means of altimeter (surface-elevation change) and by means of the input/output method which calculates the calving fluxes from ice velocity and ice thickness, as well as surface-mass balance (e.g. from high-resolution maps of surface-elevation change, or models).

6.5. Ocean

Of the Earth's surface, 70 % is covered by oceans**. Oceans play a major role in the regulation of the climate** and, at the same time, are of **vital importance to populations as a source of food, energy and as a place for economic/commercial activities**. Exponential expansion of human activities has major consequences on climate and climate change and is particularly affecting ocean processes and vulnerability (sea-level rise, acidification, loss of biodiversity, pollution etc.).

➢ Sea-level anomaly

The altimeter sea-level anomaly (SLA) is an essential variable for oceanic operational system as it gives outstanding information both on the small-scale dynamics (if sufficient resolution is available which, currently, is not the case) and climate change. A continuity is at least required with however a coverage closer to the North Pole with measurements in the leads. Global ocean along-track sea-surface height is a CMEMS product given in NRT. No data is however available within the leads, nor is the spatial resolution high enough to retrieve meaningful statistics on mesoscale currents. Actual data from the CMEMS catalogue does not allow a satisfactory sampling north of 82° N. It is of **prime importance that the orbit configuration allows covering the central Arctic Ocean**.

6.6. Freshwater

Surface fresh water (lakes, rivers, wetlands etc.) contains less than 0.01 % of Earth's total water but **is very important as it affects both the Earth's climate** (exchanges of heat, water vapour between land surface and the atmosphere) and **our daily life** for industrial activities, production of energy (hydraulic, thermoelectric), irrigation, farming, tourism etc. In the Arctic, surface fresh water also forms part of transport networks all year-round, including during the icy winter season.

➢ River run-off/discharge

River runoff is highly variable as it is very low during winter and peaks after snow melt. It reflects the state of the basin and is of relevance to freshwater input to the ocean. It also plays a role in the transport of organic matter. Discharge of a number of draining Arctic basins ranges between 3 000 and 20 000 m^3/s, exceeding this by far during the spring peak (e.g. Yenissei > 100 000 m^3/s). Water courses are also important transport routes in the Arctic.

➢ Freshwater ice properties

Ice properties, especially thickness, are of high relevance for transport by vehicles (winter roads) and animals (including reindeer herding, migration routes in general). The maximum annual thickness changes due to climate change, indicating also ground-temperature variations (and thus changes in permafrost). Unfrozen parts during winter are important as habitats and used as winter fishing areas. Their presence supports year-round decomposition of the organic matter. Ice-cover presence impacts meteorological conditions and thus plays a role for weather forecasting. The formation of ice jams on rivers in spring after break-up are hazards to infrastructure along river courses.

6.7. Permafrost

Permafrost is permanently frozen soil, and occurs mostly at high latitudes. **Permafrost comprises 24 % of the land in the northern hemisphere, and stores massive amounts of carbon**. As a result of climate change, permafrost is at risk of thawing, releasing the stored carbon in the form of carbon dioxide and methane, which are powerful heat-trapping gases. In addition, permafrost is structurally important and its thawing has been known to cause erosion, disappearance of lakes, landslides and ground subsidence. It also causes changes in plant-species composition at high latitudes.

➢ Extent

Changes of permafrost extent over time reflect permafrost thaw and climate-change impacts.

6.8. All themes

Surface albedo and surface temperature are key parameters for the determination of the energy transfer between the Earth's surface and the atmosphere. Although they are two independent parameters they are related as one can, directly or indirectly, significantly affect the other.

➢ Surface albedo (all themes)

The energy balance between the atmosphere and surface is significantly determined by the surface albedo, and needs to be monitored for all land surfaces, ocean and floating ice. It is an input for many application domains including climate, meteorology, numerical weather modelling, hydrology and more.

Spectral surface-albedo maps are generated from the individual bands of medium-resolution optical sensors, requiring atmospheric and (in complex terrain) topographic correction of radiance components. Atmospheric input parameters and aerosols are important for applying atmospheric correction. To calculate spectral surface-albedo maps, data e.g. from Advanced Very-High-Resolution Radiometer (AVHRR), MODIS, Sentinel-3 SLSTR and OLCI can be used, providing the reflectance at a single (or dual) observation direction. In order to improve albedo products, multi-angle measurements are needed to take the bi-directional reflectivity of the surface into account.

➢ **Surface temperature (all themes)**

Global surface temperature is a key parameter closely linked to the energy budget of the Earth. It's an indicator of climate variability and used for climate modelling. Surface temperature is normally measured by passive infrared sensors and provides direct information on the state of oceans and freshwater, snow and ice, land and vegetation.

Sea surface temperature (SST) is a key variable for short-term and seasonal meteorological forecasts. These data are also likely to be the oldest variables being assimilated in oceanic forecast systems. Continuity of this at least is required.

Ice-surface temperature (IST) is potentially as important as the SST in terms of assimilation for vertical heat diffusion. IST is a CMEMS product provided daily with 5 km resolution for the Arctic domain (> 58° N) only. Currently there is a gap in operational Sentinel-3 products where no SLSTR IST product is planned over sea ice.

Land surface temperature (LST) is related to various components of the energy balance between land and atmosphere. Although not directly indicative for permafrost, it is currently the only parameter from space that supports permafrost modelling. Frequent, high-resolution LST observations are therefore crucial for monitoring permafrost extent and variation.

7. Detailed parameter performance requirements

Performance requirements are summarised in Table 8 through to Table 16. The following table serves as key explaining the abbreviations used in the subsequent tables. See also Table 4 for parameter abbreviations. Where applicable the specifications distinguish between minimum (threshold, 'T:') and optimum (goal, 'G:') requirements.

Table 7: Abbreviations used in parameter specification tables

Themes (THM)		Domains (DOM)	
AT	atmosphere	ME	meteorology
OC	ocean	CL	climatology
FW	surface water (freshwater)	HY	hydrology
SN	snow (seasonal)	OC	oceanography
GL	glaciers, caps	EC	ecology
IS	ice sheets	HZ	natural and technical hazards
SI	sea ice/iceberg	EM	emergency response (incl. search and
LA	land surface and vegetation	EN	energy
PF	permafrost and soils	TR	transport/navigation
		OI	other infrastructure
		SE	security
		GEN	general — all domains

Table 8: Specification table for parameter: surface elevation (various themes)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
FW LA PF	ME	Surface elevation (topography)	0	T: 1 km G: 50 m	snow free season	T: 100 yr G: 10 yr	n/a	0	0: [m]	[-500, 9000]	horizontal: T: 5 m, G: 1 m vertical: T: 0.5 m, G: 0.01 m	2	2	2	2
AT	GEN		0	T: 100 m G: 10 m	0	T: 100 yr G: 10 yr	n/a	0	0: [m]	[-500, 9000]	horizontal: T: 5 m, G: 1 m vertical: T: 1 m, G: 0.5 m	2	2	2	1
GL IS	GEN		0	T: 100 m G: 50 m 1 km for interior ISs	0	T: 3 yr G: 1 yr 1-3mo for boundaries/outlets	n/a	0	0: [m]	[0, 8000]	vertical: T: 2 m G: 0.5 m absolute (abs), 0.2 m relative (rel)	0	2	2	2
FW LA SN PF	HY CL EC HZ EM EN OI SE		0	T: 5 m G: 1 m	snow free season	T: 10 yr G: 0.5 yr	n/a	0	0: [m]	[-500, 9000]	horizontal: T: 5 m, G: 1 m vertical: T: 0.5 m abs, 0.2 m rel G: 0.1 m abs	2	2	2	2
PF LA	HY CL EN HZ TR OI	Surface displacement	0	T: 5 m G: 1 m	0	T: 1 yr G: 14 dy	n/a	0	0: [m/yr]	[0, 100]	horizontal: T: 5 m/yr, G: 1 m/yr vertical: T: 0.01 m/yr, G: 0.001 m/yr	1	1	2	2

Table 9: Specification table for parameter: EXTENT/FRACTION (various themes)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SN	GEN	Snow fraction	0	500 m	0	1 dy	n/a	1	0: [%]	[0,100]	1 %	2	2	0	2
			2 Europe	100 m	0	1 dy	n/a	1	0: [%]	[0,100]	1 %	2	2	0	2
SI	OC	Sea ice fraction	0	T: 5 km	0	6 hr	n/a	2	0: [%]	[0,100]	5 %	0	0	3	2
	CL		1	T: 10 km G: 1 km	0	1 dy	n/a	0	0: [%]	[0,100]	1 %	0	2	2	2
	TR		0	T: 20 m G: 2 m	0	T: 1 dy G: 12 hr	24h	1	0: [%]	[0,100]	5 %	1	2	2	2
PF LA FW	GEN	Permafrost extent	0	T: 10 m G: 1 m	0	T: 10 yr G: 1 yr	n/a	0	1	[0,1] absence/pres.	T: 85 %, G: 95 %	0	1	2	2
IS	GEN CL HY ME	Ice-sheet extent calving front	2 Antarctica Greenland	T: 200 m G: 50 m Calving front: T: 200 m: G: 10 m	0	T: 3 yr G: 1 yr Calving front: T: 1 yr, G: 3 mo	0	0	1	[0,1] absence/pres.	T: 85 %, G: 95 %	0	1	0	1
GL	HY CL EN	Glacier extent	0 (areas of permanent snow/ice; excluding Greenland and Antarctica)	T: 30 m G: 10 m	1 End of Summer (ablation period)	Complete Inventory: T: 5 yr, G: 1 yr significant changes: T: 1 yr	0	0	1	[0,1] absence/pres.	T: 85 %, G: 95 %	0	2	0	1

Table 10: Specification table for parameter: snow water equivalent (SWE)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SN	GEN CL ME	Snow water equivalent	T: northern hemisphere G: global	T: 10 km G: 1 km	0	T: 5 dy G: 1 dy	n/a	1	[mm (kg/m^2)]	[0,500]	For SWE < 200 mm: T: 40 mm, G: 20 mm For SWE > 200 mm: T: 20 %, G: 10 %	1)	2	2	2
SN	GEN HY EN ME		2: T: northern hemisphere G: global:	T: 1 km G: 200 m	0	T: 5 dy G: 1 dy	n/a	1	[mm (kg/m^2)]	[0,500]	For SWE < 200 mm: T: 40 mm, G: 20 mm For SWE > 200 mm: T: 20 %, G: 10 %	2)	1	2	2
SN	GEN PF		2: G: mountain regions, permafrost regions;	T: 50 m G: 10 m	1 snow covered period	T: 5 dy G: 1 dy	n/a		[mm (kg/m^2)]	[0,500]		0	1	3	2

Table 11: Specification table for parameter: ice thickness (various themes)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SI	OC	Sea-ice thickness (thin and thick), freeboard	0	< 5 km	0	1 dy	n/a	1	0: [m]	[0, 20]	0.1	0	2		
SI	ME		0	T: 3 km G: 1 km	0	T: 1 dy G: 6 hr	n/a	1	0: [m]	[0, 10]	horizontal: T: 10 %, G: 5 % vertical: T: 0.5 m G: for thickness > 0.5 m: 0.5 for thickness < 0.5 m: 0.1 m	0			2
SI	TR		0	T: 20 m G: 2 m	0	T: 2 dy G: 1 dy	24 hr	1	0: [m]	[0, 30]	T: 0.1 0.02	1	1		
SI	TR		0	25 m	0	T: 24 hr G: 12 hr	n/a	2	0: [m]	[0, 10]	vertical: T: 0.5 m, G: 0.1 m	0			2
FW PF	GEN	Fresh water freezing depth (lake-ice thickness)	0	T: 10 m G: 1 m	1 winter season	T: 7 dy G: 1 dy	n/a	0	0: [m]	[0, 2]	horizontal: T: 5 m, G: 1 m, vertical: T: 0.1 m, G: 0.01 m	0	1	0	1
GL	HY	Glacier ice thickness/bedrock topography	0 (areas of permanent snow/ice; excluding Greenland and Antarctica)	T: 200 m G: 50 m	1 end of summer	T: 10 yr G: 5 yr	n/a	0	0: [m]	[0, 500]	T: 5 m G: 2 m				2
IS	CL, HY, ME	Ice-sheet thickness	2: (interior of Ice sheet)	T: 1 km G: 100 m	0	1 yr	n/a	0	0: [m]	[0, 4000]	T: 50 m G:10 m	1	1		2
			2: (at margins)	T: 100 m G: 50 m	T: 0 G: summer/ winter	T: 1 yr G: 6 mo	n/a	0	0: [m]	[0, 4000]	T: 50 m G:10 m	1	1		2

Table 12: Specification table for parameter: thin sea ice/ice type/iceberg detection and drift

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SI	CL	Thin sea ice	1	T: 10 km G: 1 km	0	1 dy	n/a	0	0: [m]	[0, 0.5]	5 %	1	2		2
SI	OC		0	T: 5 km	0	T: 6 hr	n/a	2	0: [%]	[0,100]	5 %	0	0	2	2
SI	TR		0	T: 20 m G: 2 m	0	T: 2 d G: 1 d	24 hr	1	0: [m]	[0, 0.3]	T: 0.03 G: 0.01	0	1		1
SI	TR	Ice type	0	T: 20 m G: 2 m	0	T: 2 d G: 1 d	24 hr	1	1	[New ice, nilas/level ice, rafted ice, ridged ice, hummocked ice, brash ice]	T: 85 %, G: 95 %	1	0	2	2
SI	TR		0	T: 40 m G: 25 m	0	T: 1 dy G: 6 hr	n/a	2	1	FY/MY/ New Ice	T: 85 %, G: 95 %	0		2	0
SI	ME, OC		0	T: 3 km G: 1 km	0	T: 1 dy G: 12 hr	1	0	1	FY/MY	T: 85 %, G: 95 %				
THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SI	CL ME	Iceberg detection	0	T: 10 km G: 5 km	0	T: 24 hr G: 12 hr	n/a	1	0: [%]	[0,100]	1 %				
SI	OC		0	T: 25 m G: 10 m	0	T: 2 dy G: 1 dy	n/a	2	1	[0,1] absence/pres.	T: 85 %, G: 95 %			0	2
SI	TR		0	T: 20 m G: 2 m	0	T: 2 dy G: 1 d	24 hr	1	1	[0,1] absence/pres.	T: 85 %, G: 95 %				
SI	TR		0	G: 25 m marginal ice zone G: 50 m inner ice zone	0	T: 24 hr G: 6 hr to capture diurnal and tide effects	n/a	2	1	[0,1] absence/pres.	T: 85 %, G: 95 %			0	1
SI	OC	Iceberg drift	0	T: 10 km	0	3 hr	n/a	2	0: [m/s]	[0,10]			2	2	1

Table 13: Specification table for parameter: sea level/freshwater discharge/snow depth and density

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
OC	CL	Sea-level anomaly (along-track and gridded product)	0	T < 10 km G: 1 km	0	1 dy	n/a	0	0: [m]	[-2,2]	0.02 m-0.03 m	0	2	2	2
OC	OC	Sea-level anomaly (including in leads) (along-track products)	0	T< 10 km	0	T: 10 dy G: 1 dy	n/a	1	0: [m]	[-2,2]	0.02 m-0.03 m	0	2	2	2
OC	CL	Mean dynamic topography (along-track and gridded product)	0	T< 10 km G: 1 km	0	10 dy	n/a	0				1	2	2	2
OC	OC	Mean dynamic topography (along-track products)	0	T < 10 km	0	10 dy	n/a	1	0: [m]			1	2	2	2
THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
FW	HY CL HZ EM EN TR	Discharge	0	T: 100 m G: 10 m	0	T: 1 dy G: 12 hr	n/a	0	0: [m³/s]	[0,120000]	T: 100 m³/s G: 1 m³/s	2	1	1	1
FW	HZ EM		0	T: 100 m G: 10 m	0	T: 1 dy G: 1 hr	n/a	1	0: [m³/s]	[0,120000]	T: 100 m³/s G: 1 m³/s	2	1	1	1
THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SI	OC	snow depth and density	0	< 5 km	0	1 dy	n/a	1	0: [m]	[0,10]		0	0		1
SI	CL		1	1-10 km	0	1 dy	n/a	0	0: [m]	[0,1]	0,01 m	1	1		2
SI	TR		0	25 m	0	T: 1 dy G: 12 hr	n/a	2	0: [m]	[0,10]	0,1 m	0		2	2
SI	OC ME		0	T: 3 km G: 1 km	0	T: 12 hr G: 6 hr	n/a	2	0: [m]	[0,10]	horizontal: T: 10 %, G: 5 % vertical: T: 0.1 m	0	1	2	2
SI	OC		0	T: 10 km G: 1 km	0	30 dy	n/a	0	0: [m]	[0,0.5]	T: 0.05 m, G: 0.02 m	1	1	2	2
SN	ME EM TR OI		0	T: 1 km G: 5 m	snow covered period	T: 1 dy G: 1 hr	n/a	1	0: [m]	[0,4]	vertical: T: 0.1 m G: 0.01 m	3	1	2	2

Table 14: Specification table for parameter: surface albedo (various themes)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
SN	ME CL HY EC NH EM TR OI	Surface Albedo	0	T: 500 m	0	1 dy	n/a	1	0: [%]	[0,100]	T: 1 %	0	1	3	1
			2: Europe	T: 100 m	0	1 dy	n/a	1	0: [%]	[0,100]	T: 1 %	0	1	3	1
SI	CL		1	10 km	0	1 dy	n/a	0	0: [%]	[0,100]	T: 5 % G: 1 %	1	1		
LA	CL, HY, ME, EC, EN		global regional	T: 1 km G: 500 m T: 500 m G: 100 m	0	T: 6 dy G: 1 hr	n/a	1	0: [%]	[0,100]	T: 5 % G: 1 %			0	0
IS	CL, HY, ME		Antarctica Greenland	T: 1 km G: 100 m	0	T: 1 mo G: 7 dy	n/a	0	0: [%]	[0,100]	T: 10 %		2		
GL	HY		global (areas of permanent snow/ice; excluding Greenland and Antarctica)	T: 300 m G: 30 m	0	T: 1 mo G: 7 dy	n/a	0	0: [%]	[0,100]	T: 10 %	1	2		

Table 15: Specification table for parameter: SURFACE TEMPERATURE (various themes)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
OC	CL	SST		T: 10 km G: 1 km	0		n/a	0	0: [K]	[271,283]	0.1 K	1			2
OC	OC		0	T: 5 km	0	6 hr	n/a	1	0: [K]			0	2		1
FW	HY ME CL EC HZ EM OTH	FWST	0	T: 100 m G: 30 m	0	T: 7 dy G: 1 dy	n/a	0	0: [K]	[223,323]	T: 0.5 K G: 0.1 K	1	1	0	1
LA	HY ME CL EC EN	LST	0	T: 100 m G: 30 m	0	T: 7 dy G: 1 dy	n/a	0	0: [K]	[223,323]	T: 1 K G: 0.1 K	1	2	0	2
PF	HZ EM EN TR OI		0	T: 10 m G: 1 m	0	T: 1 yr G: 3 dy	n/a	0	0: [K]	[223,323]	T: 1 K G: 0.1 K	3	0	2	2
SI	OC	IST	0	T: 5 km	0	6 hr	n/a	2	0: [K]	[210,290]	0.5 K	0	2	2	1
SI	TR		0	T: 150 m G: 50 m	0	T: 2 dy G: 1 dy	24h	1	0: [K]	[173,278]	T: 1 K G: 0.25 K	1	2		0
IS	CL ME HY		2 Antarctica Greenland	10 km	0	T: 1 yr G: 1 mo	n/a	0	0: [K]	[178,278]	1 K	1	1		0

Table 16: Specification table for: object/debris detection oceans (EMSA)

THM	DOM	Parameter	AOI	Resolution	TOY	Frequency	Leadtime	TL	Unit	Range	Accuracy	I	S	C	P
OC	OC EC TR HZ EM SE	Vessels detection	3)	(i) small vessels detection (up to 3 m): 1 m to 15 m (ii) Vessel characterisation : 3 to 10 m	0	On demand (4 to 6 acquisitions per day or more)	In-orbit tasking (less than 1 hour)	2 (*)			90 % detection reliability NRT product geolocated < 100 m				
		Debris detection	Global minimum swath: 100 km	For debris classification: 1 m	0	On demand (4 to 6 acq. per day or more)	In-orbit tasking (less than 1 hour)	2			90 % detection reliability NRT product geolocated < 100 m				
		Oil-spill detection	Global minimum swath: 100 km	20 to 50 m	0	On demand (3 000 acq./year) + regular daily	In-orbit tasking (less than 1 hour)	2 (*)			90 % detection reliability NRT product geolocated < 100 m				
		Fish cage and Farms detection	Global minimum swath: 100 km	Up to 1 m	0	On demand acq: daily	Rapid tasking not so relevant	2			90 % detection reliability NRT product geolocated < 100 m				

(*) QRT within 15 min

8. Conclusions/recommendations

This document reflects the contributions and views of PEG members as expressed at the Brussels workshop 4-5 April 2017 and reviewed/amended at the second workshop on 16-17 May 2017. These two workshops led to the identification of high-priority parameters together with their associated performance requirements. It provides a well-supported input from the polar and snow community to space agencies.

The top priorities are detailed in section 5 and are briefly summarised below in order of priority:

1. floating-ice parameters,
2. glacier, cap and ice-sheet parameters,
3. sea level/SLA parameters,
4. all-weather SST,
5. surface albedo,
6. surface fresh water,
7. snow,
8. permafrost.

There are a number of points deserving further consideration.

- Geographical coverage: The focus has been placed by most of the PEG members on the Arctic and adjacent seas (latitude > 59-60° N), in line with the Joint Communication and considering the current geopolitical situation/ambitions of surrounding States. The cases of Greenland and Antarctica region will have to be included as regard to their key role as indicators of climate change.
- Although many 'polar parameters/products' already exist today (CMEMS Arctic products for example) and are available on an operational or quasi-operational basis, users often look for improved performances/quality (spatial and temporal resolution, accuracies, timeliness etc.) as specified in Tables 8 to 16. Particular attention is to be given to the provision of uncertainty estimates for each selected parameter/product.
- The case of EMSA operational services require particular attention as the four application areas (of major importance) require very demanding performances of space systems and associated ground segment. This particular case has to be considered in a wider context than the present PEG. The EMSA services requirements will be discussed in the context of Copernicus Security Expert Group.
- There is a real worry about the long-term continuity of space observations from European and non-European satellite missions (e.g. AMSR-2). Strong and close coordination between space agencies (through different existing mechanisms e.g. the Committee on Earth Observation Satellites (CEOS), the Group on Earth Observations and its Global Earth Observation System of Systems (GEO/GEOSS) and the World Meteorological Organization (WMO)) are to tackle these issues and ensure that at least an optimum number of dedicated space missions are firmly planned (concept of virtual constellations discussed within CEOS/GEO partners).

Additional recommendations are as follows.

— The need for new products derived from new/improved space observations should be analysed, taking into account the experience gained since operational Copernicus services have been delivered to users (importance of regular users feedback, User Forum).
— *In situ* observations are essential not only for the parameter validation and calibration but as complement to space observations. The maintenance of existing capacities and the deployment of additional *in situ* observation systems are unanimously supported by PEG members.
— Aspects related to communications — which are not part of Copernicus activities — in polar regions were not discussed and will deserve some attention in another framework.

Annex 1: List of experts, kick-off attendance list

Chairpersonship

Name	Affiliation
Peter Strobl	Joint Research Centre
Vincent Toumazou	European Commission

Expert Users

Name	Affiliation	Domains
Guy Duchossois		Rapporteur
Patrick Eriksson	Finnish Meteorological Institute	European Ice Services
Frode Dinessen	Norwegian Ice Service	search and rescue
Annett Bartsch	Austrian Polar Research Institute	climate change, cryosphere
Marie-Noëlle Houssais	LOCEAN	polar ocean, sea ice

Copernicus Services

Name	Affiliation	Domains
Gilles Garric	Mercator Ocean	marine
Joaquín Muñoz-Sabater	ECMWF	atmosphere, climate
Sonia Antunes	EMSA	maritime security
Marketa Jindrova	EEA	
Thomas Nagler	LAND/ENVEO	land

Commission DGs

Name	Affiliation	Domains
Amanda Regan	Research and Innovation	
Rikke Nielsen	Mobility and Transport	

Copernicus Unit

Name	Affiliation
Peter Breger	European Commission
Ola Nordbeck	European Commission
Lieven Bydekerke	European Commission

Annex 2: Agenda of kick-off meeting

EUROPEAN COMMISSION
Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Space policy, Copernicus and defence
Copernicus

Brussels, 27 March 2017
Grow.i2/VT

KICK-OFF MEETING: POLAR EXPERT GROUP
4-5 April 2017
Meeting room BREY 05/F. BRAUN, Breydel Building

Draft agenda

Tuesday 4 April 2017		
1. Welcome and introduction by European Commission, Copernicus unit	P. Breger	14:00
2. Summary of polar and snow workshop's conclusion and status of the file.	V. Toumazou	14:30
3. Expert Group Milestones and calendar	V. Toumazou	14:45
4. Presentation of each expert group member: domain of expertise and main areas of interest for space based observation	All	15:00
5. Beyond 2022-2025: What are the challenges for polar-, snow- and arctic-related domains?	All	16:30
6. Summary of initial discussion and identification of main topics for discussion (sub-groups for specialised discussions?)	Moderator + all	18:00
End of Day 1		18:30
Wednesday 5 April 2017		
7. Brainstorming of sub-groups: a. Requirements for observations addressing the main challenges b. Status of current observation capacity c. Gap identification d. Ranking of main requirements	Sub-groups	9:00
Lunch break		12:00
8. Presentation of sub-groups conclusions	Sub-groups	13:00
9. Identification of conflicts and synergies	Moderator + all	
10. Next steps and specification of expected contributions	Moderator + all	
End of Day 2		17:00

KJ-NA-29144-EN-N

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