User Service Requirements for the Polar Regions – the findings of Polar Expert Group

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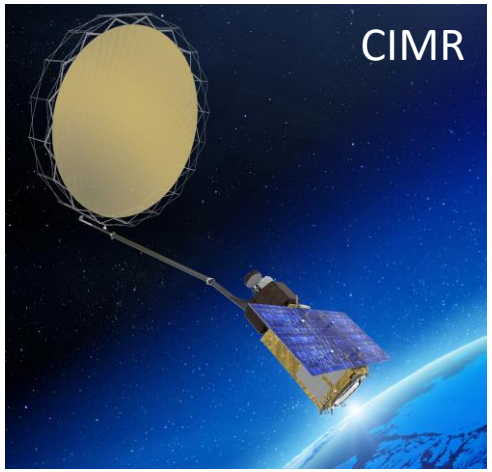
POLAR EXPERT GROUP

2016: Polar and Snow Cover Applications workshop

2017: Setting up of PEG (Polar Expert Group) by DG GROW

- Phase 1 : Focus on Review of key Users requirements and Priorities for a Copernicus Polar Mission- (external experts + EU DGs officers)
- Phase 2 : Definition of mission and (generic) sensor requirements for a dedicated Copernicus Polar Mission-(experts as above + ESA +Eumetsat)

3 All-weather day & night observation missions for polar regions



High Priority Variables in Polar Regions - PEG-I/II

Identified main variables requirements with high priority given for operational activities in polar regions and climate applications derived from MW satellites

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			

PEG 2017

Extension of Variables for Antarctica (PEG 2024)

User requirements on key products/physical variables over Antarctica to be provided by Copernicus (order does not indicate priority):

1. Ice sheet velocity
2. Grounding line location
3. Inland ice discharge/mass flux
4. Mass balance products (e.g. input output method (IOM) and elevation change)
5. Crevasse fields
6. Calving front position/inland ice extent
7. Front retreat rates
8. Iceberg size (volume) and drift
9. Surface melt extent
10. Supraglacial lake location and size
11. Sea ice thickness
12. Snow thickness on sea ice
13. Sea ice concentration
14. Sea ice extent
15. Sea ice drift
16. Flooded sea ice datasets (time series)
17. Altimeter-based tides
18. Snow cover over ice-free land
19. Snow thickness over ice-free land
20. Albedo
21. Spectral reflectance
22. Surface temperature (for all surface types, including sea, permafrost)
23. Vegetation datasets (time series with highest spatial resolution)
24. Terrain deformation datasets (extension of EGMS)

PEG III – Process and scope of work and reporting

Process

- PEG III set up by EC DG DEFIS in 2020 to explore/evaluate implications and benefits resulting of Copernicus Space Component evolution including the 3 Microwave Expansion missions
- The PEG III report is the result of six iterations between the Polar Expert Group members throughout the period of July to December 2020. The group was supported by ESA, EUMETSAT, EEA and the H2020 Kepler project.

Scope of work / reporting

- Review/update of requirements of previous Polar Expert Groups as well as requirements of Copernicus Services for data from microwave instrumentation, with *"all-weather"*, day and night observation capability. Requirements partially fulfilled using other sensors are also described
- Describing the synergies across satellite missions/instrumentations and identification of orbit phasing scenarios
- Addressing potential gaps and the needs for non-space assets (in-situ data)
- Highlighting the ground segment reflections, ensuring that all components are well orchestrated

Review of operational Polar user and observation requirements

- Detailed review and updating of polar requirements to account for the evolution of Copernicus services, also considering results of parallel H2020 research projects (e.g. Kepler, INTAROS…)
- Systematic review of space-based EO observation requirements for CMEMS, CLMS, C3S, CMS, CEMS when considering the 2020 situation and planned 2021-2027 requirements.
- Identification of specific contributions of each Expansion mission (as « stand alone ») for each Copernicus Service currently provided (except CAMS)
- Analysis by PEG-III experts, together with ESA and EUMETSAT, of the benefits/synergies of cross-sensor observations between existing Sentinels (primarily S-1 and S-3 series), relevant Contributing Third Party missions (.e.g. Canadian Radarsat) and the 3 Expansion missions.

Users and Observations Requirements focussing on day/night, all-year, *"all-weather"* sensors

Requirements for 44 variables are mapped with corresponding EO space assets over time:

1. with the year 2020 as a baseline;
2. followed by the time period 2021-2027
3. the period beyond 2027 including the Sentinel Expansion missions and the Next-Generation Sentinels.

Status and plans for 44 variables	S1 (3 units)	S2	S3	S6 (Jason)	CCM(PMR)	CCM(ALT)	ROSE-L/CCM L-band SAR*	CCM (C-, X-band) SAR
Status 2020	20	7	6	2	13	8		19
Plans 2021-2027	25(16)	7	12	2	14	8	*14*	9
Projections Post-HPCM	25	7	10	1	14	11	*23*	8

ROSE-L/CCM L-band SAR: Need for L-band SAR capabilities + general need for increased revisit time of SAR*

CCM – Copernicus Contributing Missions

Geophysical variables	Status 2020							Plans 2021-2027								Projections Post-HPCM							
	S1	S2	S3	S6 (Jason)	CCM(PMR)	CCM(ALT)	CCM (C-, X-band) SAR	S1	S2	S3	S6	CCM(PMR)	CCM(ALT)	CCM L-band SAR	CCM (C-, X-band) SAR	S1	S2	S3	S6	CIMR/CCM (PMR)	CRISTAL/CCM(ALT)	ROSE-L/CCM L-band SAR	CCM (C-, X-band) SAR
1. Floating ice																							
1.1.1 Sea ice thickness (SIT) - Marine					1	1						1	1							1	1		
1.1.2 Sea ice thickness (SIT) - Climate						1						1	1							1	1		
Marine	1				1		1	1				1		1	1	1				1		1	1
Climate					1							1								1			
1.3.1 Sea ice drift - Marine	1				1		1	3				1			1	1				1		1	1
1.3.2 Sea ice drift - Climate	1				1		1	3				1			1	1				1		1	1
1.4.1 Snow depth and snow cover on sea-ice - Marine					R&D							R&D								R&D	R&D		
1.4.2 Snow depth and snow cover on sea-ice - Climate					R&D							R&D								R&D	R&D		
1.5.1 Ice type-Ice stage of development - Marine	1				1		1	1				1			1	1				1		1	1
1.5.2 Ice type-Ice stage of development - Climate					1							1								1			
1.6.1 Iceberg (iceberg concentration charts and individual icebergs) - Marine	1						1	1							1	1						1	1
1.6.2 Iceberg (iceberg concentration charts and individual icebergs) - Climate	1						1	1							1	1						1	1
Marine					R&D							R&D								R&D			
1.7.2 Sea-ice surface temperature - Climate					R&D							R&D								R&D			
2. Glaciers and ice caps																							
2.1 Glacier extent		1							1								1						
2.2 Surface ice velocity	1	1					1	1	1						1	1	1						1
2.3 Surface elevation & Change and mass balance	3					1	1	3		1			1		1	3					1		
3. Seasonal snow																							
3.1 Snow water equivalent (SWE)					1							1		1						1		1	
3.2. Snow melt	1							1								1							
3.3 Snow Extent		1							1	1							1	1					
3.4 Snow depth on Land-ice																							
4. Ice sheets																							
4.1 Surface Topography						1				1			1					1			1		
4.2 Surface ice velocity	1	1					1	3	1					1		3	1					1	
4.3 Grounding line location	1					1		3		1			1	1		3					1	1	
4.4 Melt extent	1							3							1	3							1
4.5 Mass and mass change	1	1				1	1	3	1	1			1	1		1	1	1			1	1	
4.6 Ice margin (Extent)	1	1				1		1	1	1			1			1	1	1			1	1	
5. Ocean																							
5.1 Sea level anomaly			1	1		1				1	1		1					1	1		1	1	
5.2.1 Sea Surface Temperature (SST) - Marine			1		1					1		1						1		1	1		
5.2.2 Sea Surface Temperature (SST) - Climate			1		1					1		1						1		1	1		
5.3 Sea surface salinity					1							1								1			
6.Land surface and Surface fresh water																							
6.1 Soil moisture	1				1		1	3				1		1		1				1		1	
6.2 Lake ice extent	1	1	1					1	1	1						1	1	1				1	
6.3 Lake water level			1	1						1	1							1			1		
6.4 Land Surface Temperature			1		1					1		1						1		1			
6.5 Seasonal subsidence	1						1	1						1		1						1	
7. Emergency Management																							
7.1 Flood extent	1							3								1						1	
8. Security																							
8.1 Vessel Detection Service (VDS)*	1						1	3						1		1						1	
8.2 Feature Detection Service (FDS)*							1	3						1		1						1	
8.3 Oil Spill Detection	1						1	3						1		1						1	
8.4 Enriched Vessel Service (EVS)*							1	3						1		1						1	
8.5 Enriched Feature Service (EFS)* (eg: Fish farms, Debris,..)							1	3						1		1						1	
8.6 Wake Detection Service (WDS)*							1	3						1		1						1	
8.7 Activity Detection Service (ADS)* (eg: Fisheries control, Anti-piracy, ...)							1	3						1		1						1	

2 Instrument Synergies responding to the PEG requirements

Sensors	CIMR	CRISTAL	ROSE-L	S-1	S-3
CIMR			Land Ice, Snow Water Equivalent, Soil moisture, Melt extent (ice sheets)		Land Surface Temperature
CRISTAL	**Sea Ice Thickness, Sea Surface Temperature,** Snow depth and snow cover on sea-ice		Mass and mass change (ice sheets), Surface Topography, Grounding line information, Ice margin (ice sheets extent)		**Lake water level**
ROSE-L	**Sea Ice Concentration**, **Sea Ice Drift,** Sea Ice Type	Iceberg, Sea Ice Thickness		Ice Margin, Snow Water Equivalent, Lake Ice Extent, Snow melt, Seasonal Subsidence, Surface ice velocity, Flood extent	
S-1			Sea Ice Concentration, Sea Ice Drift, Iceberg, Sea Ice Type		
S-3					

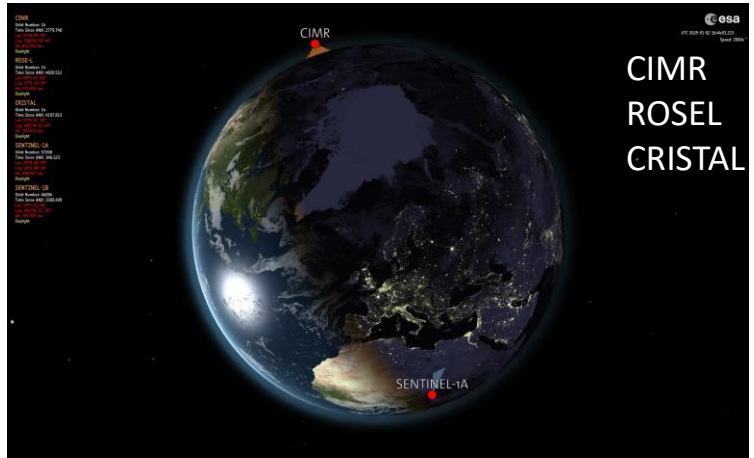
Composed by PEG III: cryosphere variables on land (green) and for floating ice and ocean (grey);. in bold: combinations already operational)

Orbit Phasing / Cross Instrument Operation Scenarios

Cross-mission/instrument combinations and synergies between S-1, S-3, CIMR, CRISTAL and ROSE-L taking into account:

- technical constraints (e.g. limited duty cycle for SARs, On/Off constraints…),
- operational users requirements (geographical polar region coverage, quasi simultaneity/collocation of L&C-band SAR observations, revisit frequency of observations…) as defined in Expansion mission MRDs
- operational ESA ground segment requirements (instrument operation planning, downlink of data to ground, NRT/QRT data processing and dissemination ..
- Non-polar users requirements (essentially for C- and L-band SAR imagery)

- Simulations of orbits phasing of various combinations of S1, ROSEL, CRISTAL and CIMR
  https://www.copernicus.eu/en/Copernicus-Animations-2021



Initial Cross Mission Requirements

Missions

- further Sentinels of the current series (C&D units)
- Expansion Sentinels as from 2027;
- Next Generation Sentinels as from 2031

Aim: Seek maximum synergy between observations of the same geographical areas from different instruments used for advanced products, e.g.

- C-band/C-band SARs
- Sentinel-1 SAR /ROSE-L- SARs
- Sentinel-1 SAR/CIMR and CIMR/MetOp-SG-B
- Sentinel-1 SAR-, ROSE-L SAR and CIMR
- S1, ROSE-L SAR, CIMR, CRISTAL
- ROSE-L SAR / CIMR / CRISTAL / S3
- ….

Important:

- Coordination of instrument-, imaging mode operations, according to the specified needs
- Planning of downlink, data acquisition and processing according to required latency time of products

	C-Band SAR			L-Band SAR		Radar Altimeter		PMR	
	S1	S1-NG	CCM	Rose-L	L-Contrib.	Cristal	Contr	CIMR	Contr
S1	daily coverage without gaps ;	Cross-cal, daily (or 6h) coverage without gaps	RCM to complement acquistion gaps	< 6 min (1 min*), align timeliness of Acq&NRT Processing, align acq plan/duty cycle		Sync in processing		<1h	
S1-NG	Cross-cal, daily (or 6h) coverage without gaps								
CCM	Compl. Planning S1/RCM								
Rose-L	< 6 min (1 min*), align timeliness of Acq&NRT Pro-cessing, align acq plan/duty cycle				Cross-Cal			<3h	
L-Contr									
Cristal				Overlap/ Repeat Mode alignement			Constel-lation with S3&S6	<3h	
CR-Contr						S3-RA sync			
CIMR	< 1h			<3h		<3h			Me-top-SG-B (1-7-10 min apart)
CIMR Contr								Sync with Metop NG; Contempory;	

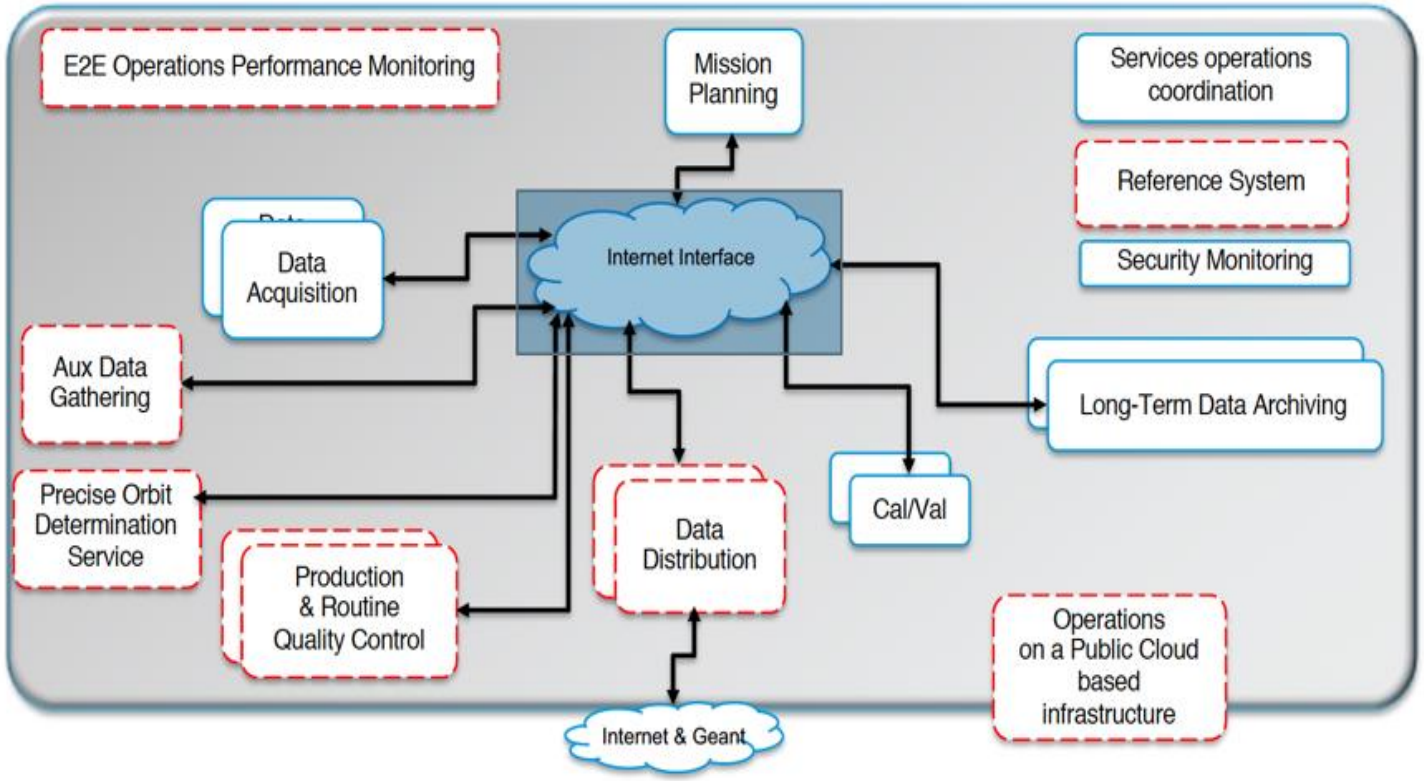
Polar In-Situ Observations

- In situ observations are collected by a variety of platforms (airborne, ship-borne, ocean surface floats and profilers/buoys …).
- In situ observations play a key role and are crucial and unique for :
  - Providing data which cannot be observed from space (subsurface parameters…)
  - Meeting requirements for local, high frequency and high spatial resolution data
  - Testing and calibration of models during the development phase (“to constrain models”)
  - Satellite instrumentation calibration (e.g. ground transponders) and product validation
- The present Arctic Observing System - especially the Central Arctic - is undersampled.
- **Severe gaps for in situ observations:** timely availability, quality, no efficient management system, difficulty to access no-EU data sustainability…
- Need for better international cooperation, further development of « Citizen Science » projects associating also indigenous populations

Sentinel Ground Segment and Data Access Architecture

The new ESA-developed Sentinel ground segment under development is based on a **system approach** making use of **common elements for all missions** (e.g. acquisition centres, network infrastructure, data dissemination).

Requirement: Longterm data archiving for Level-0 (Raw) data, allowing reprocessing campaigns with recent algorithms, cal/val data, and aux data (if required).



Main new aspects:

- Service operations based on public cloud environment(s)
- Streamlined interfaces between services
- Service inter-dependencies minimisation
- Reduction of network traffic between individual services
- Public internet for data transfers

Requirement: The transformation leads to improved production quality and major data access flexibility (e.g. **reprocessing** becomes possible with acceptable performance and cost)

Integration of new Sentinels / Expansion Missions in the new ground segment architecture

- Sentinels / HPCMs will be integrated (or “plugged-in”) in the Sentinel multi-mission ground segment architecture, with some mission-specific elements (processors, mission planning, specific auxiliary data, etc.)
- The cross operations of some missions (e.g. Sentinel-1 and ROSE-L) will require the specific setup of cross-mission elements, such as the mission planning to ensure joint observations .
- Timeliness requirements (e.g. Quasi-Real Time) will require the use of some specificities of the multi-mission ground segment in terms of acquisitions, processing, dissemination, … however common to the missions having similar requirements .

Findings and Recommendations from PEG

- **Need for continuity of Space and In situ observations is essential**
- Need for an efficient data management system for In-situ data + International cooperation
- Maximize use of Expansion missions in synergy with existing and forthcoming Next Generation Sentinels to improve existing/develop new products
- Continue/develop users consultation process with private sector/companies
- Develop/implement an End-to-End Integrated Polar Monitoring System
- Improve Telecommunications in Polar regions to meet timeliness requirements for data availability
- Increase role and contribution of Industry/Private sector (space and services)
- Further encourage Scientific research including Financing requirements and sources