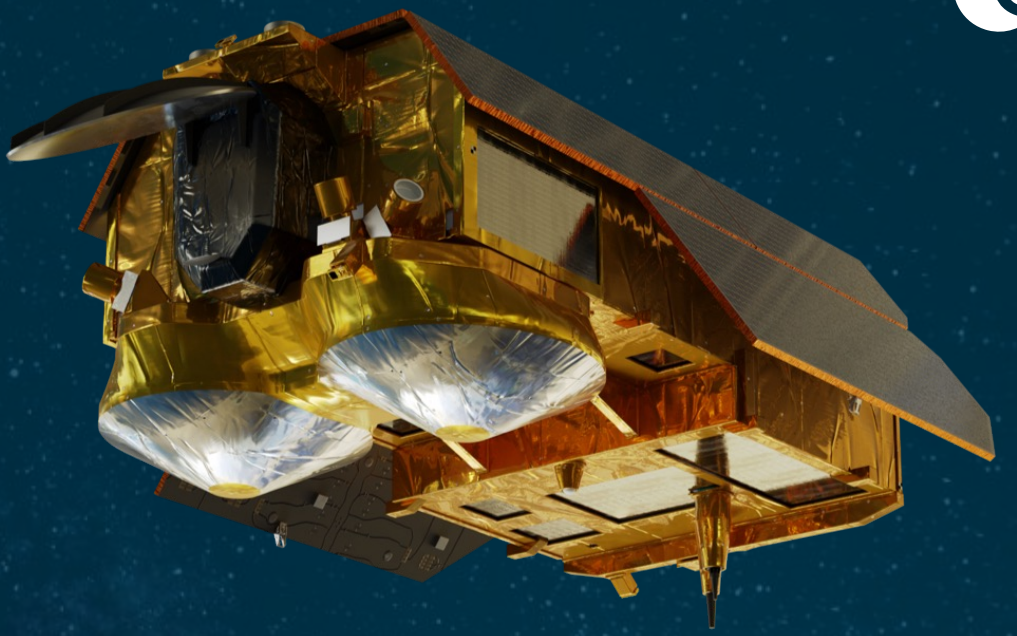

CRISTAL Mission Status

Paolo Cipollini (CRISTAL Mission Scientist, ESA), Cristina Martin-Puig (EUMETSAT), Jérôme Bouffard (CRISTAL Mission Manager, ESA)

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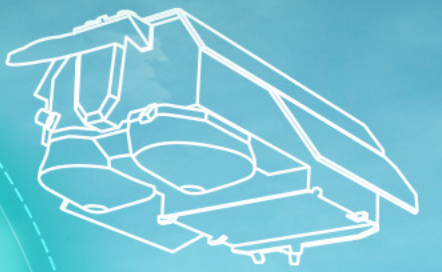
OSTST 2023, Puerto Rico

PROGRAMME OF THE EUROPEAN UNION

copernicus
Europe's eyes on Earth

co-funded with esa



CRISTAL

Copernicus Polar Ice and Snow Topography Altimeter

A Copernicus Expansion mission to support Copernicus Services, polar science and oceanography

AiC team/Steffen Graupner

CRISTAL MISSION OBJECTIVES

CRISTAL will provide (Primary mission objectives):

- ❑ high resolution **sea ice thickness** and **snow depth** measurements in polar regions
- ❑ high resolution **land ice elevation** measurements of glaciers, ice caps and of the Antarctic and Greenland ice sheets

Secondary Mission objectives:

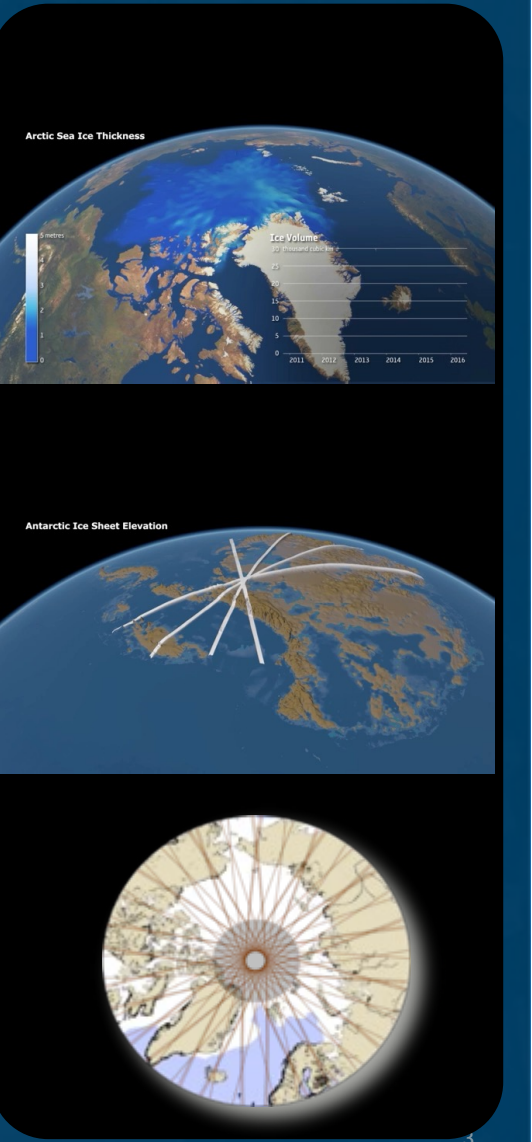
- Provide **Ocean Topography measurements extended to polar seas**
- Support applications related to snow and permafrost
- Support applications related to **coastal and inland waters**

CRISTAL directly addresses the **EU Arctic Policy** and **Primary User Requirements** expressed in **Polar Expert Group reports**

Responds to need for **continual altimetric monitoring of Arctic Region North of 81.5°N**

First high-resolution operational Radar Altimeter mission for the cryosphere

Only Radar Altimeter reaching high latitudes after Cryosat-2 !

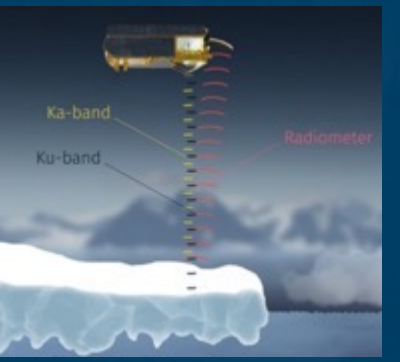


CRISTAL MISSION IMPROVEMENTS

Based on CryoSat-2 heritage but with significant improvements

Instrument suite improvements:

- Ku-band Interferometric Synthetic Aperture Radar Altimeter with **Ka-Band channel for snow depth** retrieval
- Addition of **Passive Microwave Radiometer (AMR-CR provided by NASA/JPL)** for
  - wet troposphere correction (secondary mission objective)
  - Potential contribution to ice and snow classification (primary mission objective)



Performance & operation improvements:

- **36% improvement of Sea ice freeboard measurement** resolution, by increasing bandwidth to 500MHz (CryoSat 320MHz)
- **Improved interferometric measurements** with **50%** improvement on elevation error
- **Higher precision monitoring of icebergs, ice lead discrimination** etc. with very high along-track resolution (up to **0.5m** with fully-focused SAR processing)
- **Tracking of glaciers** with added Open Loop operational mode

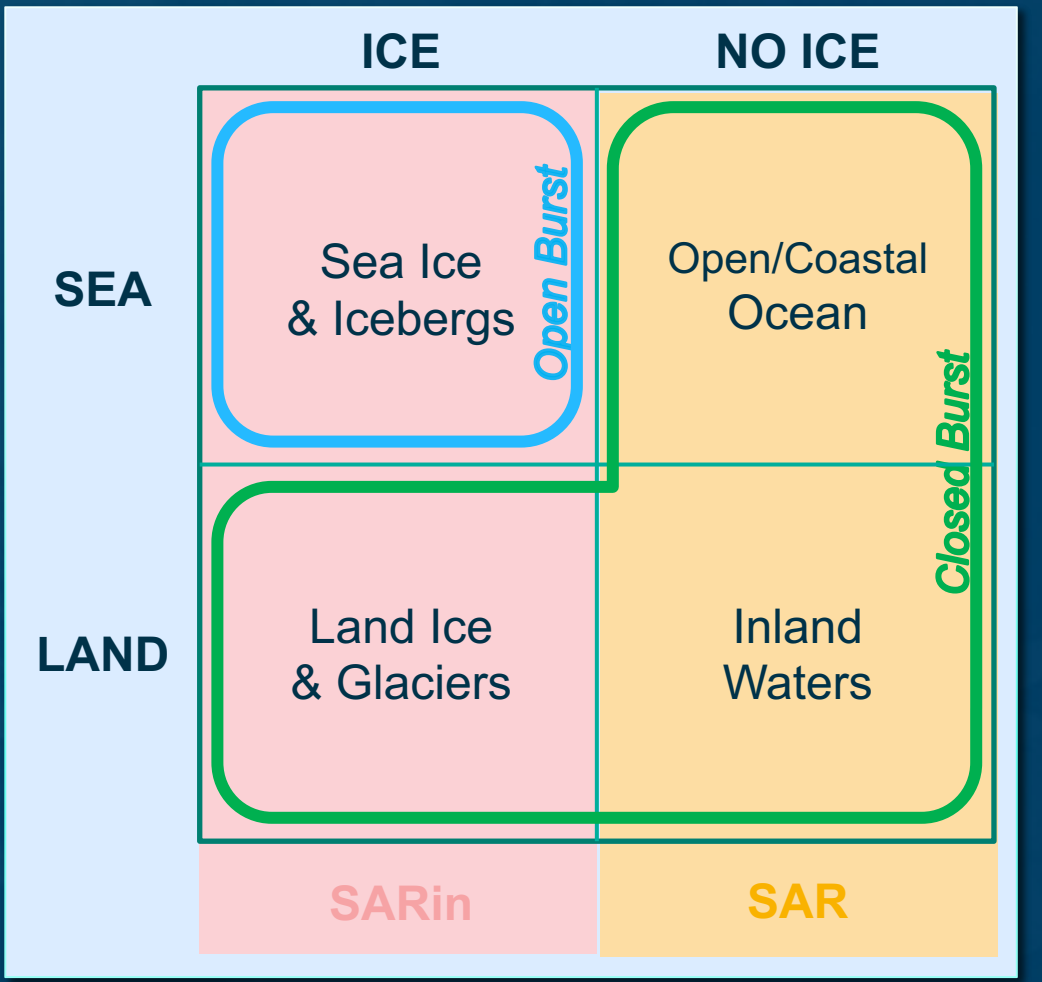
CRISTAL's many 'firsts' and 'boons'

"FIRSTS"

- ✓ First operational radar altimeter for the cryosphere
- ✓ First Ka-band SAR mode altimeter in space
- ✓ First Ku/Ka dual-band frequency altimeter
- ✓ First combination altimeter/radiometer poleward of 82°

"BOONS"

- ✓ Increased bandwidth: 500 MHz Ku/Ka
- ✓ Interferometric in Ku
- ✓ Flexible tracking (closed/open loop)
- ✓ Open Burst over sea ice – allows Fully-Focused processing
- ✓ Full coverage of all hydrological targets



→ R&D needed to exploit this novel science for the operational applications

Data production responsibilities mirror Sentinel-3 →

ESA: cryosphere (sea ice, icebergs, land ice), inland waters

EUMETSAT: ocean and coastal, large lakes, ssh into the leads

ESA OPERATIONAL PRODUCTS

Main Characteristic

Toward thematic processing *a la CRYO-TEMPO/ S3 TDP*, including CEOS-compliant & traceable uncertainty parameters

ESA Level-1

- L1a
- L1b (LR, HR, FFSAR)

ESA "**Thematic**" Level-2 & Cal/Val over

Sea Ice

NRT	NTC
Sea Ice Thickness Sea Ice Freeboard Sigma0	Sea Ice Thickness Sea Ice Freeboard Snow Depth Sigma0

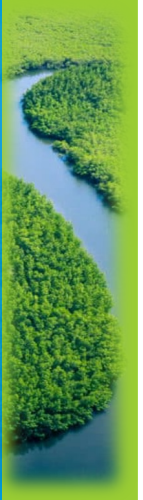
Iceberg

NRT	NTC
Iceberg elevation and volume	Iceberg elevation and volume

Land ice

NTC
Elevation at POCA Elevation across the range window (Swath) Sigma0

Inland



NTC
Water elevation over rivers and lakes Ice thickness over frozen lakes Sigma0

COPERNICUS SERVICES, PARTNERS & END-USERS

L2 DEVELOPMENTS & SCIENCE SUPPORT

ESA R&D studies (e.g Polar Cluster, block#3 CryoSat activities, CRISTAL Science studies …)

PDR ✓ CDR IOCR

2022 2023 2024 2025 2026 2027 LAUNCH

PHASE C | PHASE D | E 1 | E 2

CRISTAL Science Plan

PHASE 1 ITT process (CLEV2ER)

- Sea Ice and Iceberg L2 GPP + R&D
- Land Ice L2 GPP + R&D
- Inland Water L2 GPP + R&D

These two include science elements *(see posters in Science IV)*

L2 GPP

Thematic L2 products: one L2 GPP for each thematic area (i.e. sea ice, land ice and inland water)

L2 GPP to be developed following open source software development practices

…and CRISTALair, a new Ku/Ka airborne demonstrator, is being commissioned

1-GHz bandwidth,

both Ku and Ka interferometric

(see presentation in Science IV, Fri pm)

Planned additional / complementary studies

- **OLTC study: d**efinition of the Land Ice and glaciers OLTC, Inland Water Virtual stations and validation, generation of the on-board OLTC table (additional study about to be commissioned by ESA)
- **Open and Coastal Ocean multi-band altimetry studies** - including impact of Water Vapour on Ka and multi-band investigation of Sea State bias (to be coordinated by EUMETSAT)

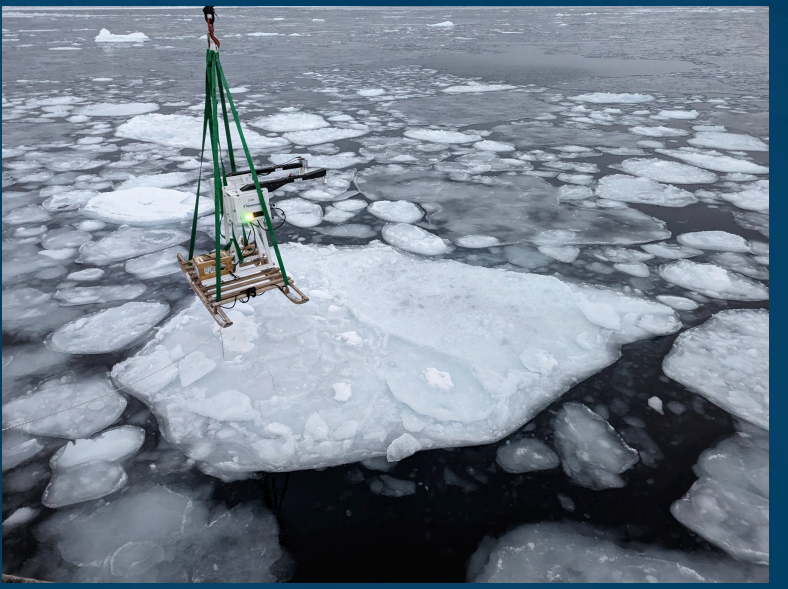
→ There is strong scope for complementary studies over different targets (sea ice, land ice, glaciers, inland water, permafrost, open ocean, coastal zone) that exploit the information of the radiometer in combination with the dual-band altimeter

→ Also, as in situ data are essential for algorithm development, calibration, validation, we need to plan and conduct campaigns in synergy (using CRISTALair, NASA's HAMMR, CReSIS snow radar, etc…. and also with the CIMR airborne demonstrator CIMRair)

Example: planning the CEMSIE campaign

CEMSIE - The joint **C**opernicus **E**xpansion **M**issions CIMR, CRISTAL and ROSE-L **S**ea **I**ce **E**xperiment, proposed by John Yackel (U Calgary) and Rasmus Tonboe (DTU)

- Proposed for Cambridge Bay (2025 to take advantage of CRISTALair)
- To reduce uncertainties and to improve retrieval accuracy in the CIMR, CRISTAL and ROSE-L primary products: sea ice concentration, snow depth and sea ice thickness.
- Expands on what was started during the MOSAiC and focuses on natural first-year ice

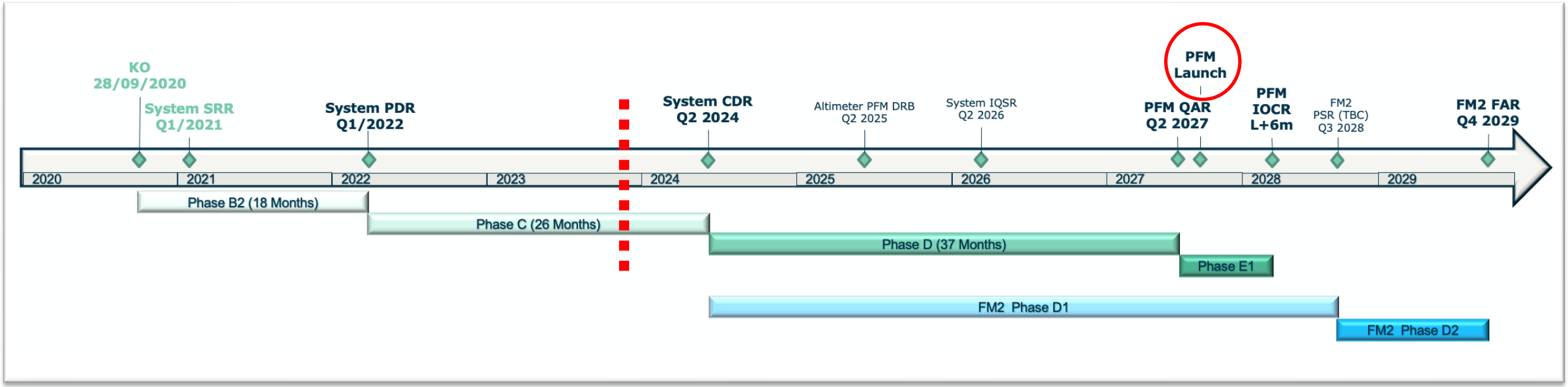


Lots of proposed in-situ instrumentation:

1) Ku and Ka-band scatterometer (see pic on the right) + altimeter/stare mode from J. Stroeve relating to CRISTAL, CryoSat, AltiKa, Sentinel-3
2) 6-36 GHz microwave radiometers relating to CIMR, AMSR-3 and several past microwave radiometer datasets (HutRad)
3) L-band scatterometer relating to ROSE-L, NISAR, ALOS/PALSAR, SAOCOM
4) C- and X-band scatterometers relating to RCM, Sentinel-1, TerraSAR-X
5) Infrared camera covering the thermal infrared relating to Sentinel-3 and several past missions, Snow radar on drone (R. Ricker)

- Good discussions are underway with NASA/JPL to coordinate a joint campaign by the two agencies.

CRISTAL Main project phases and milestones



	KO	SRR	PDR	CDR	PFM QAR	FM2 FAR
Satellite	28/09/20 ✓	Feb-Mar'21 ✓	Feb-Mar'22 ✓	May'24	Jun'27	Oct'29
Altimeter	28/09/20	Feb-Mar'21	Feb-Mar'22	Apr'24	May'25	Jan'26

CRISTAL-A on track for launch in late 2027
Followed (towards EOL) by CRISTAL-B

CRISTAL MARINE DATA CENTRE

Cristina Martin Puig
Remote Sensing Scientist
CRISTAL EUMETSAT Mission Scientist

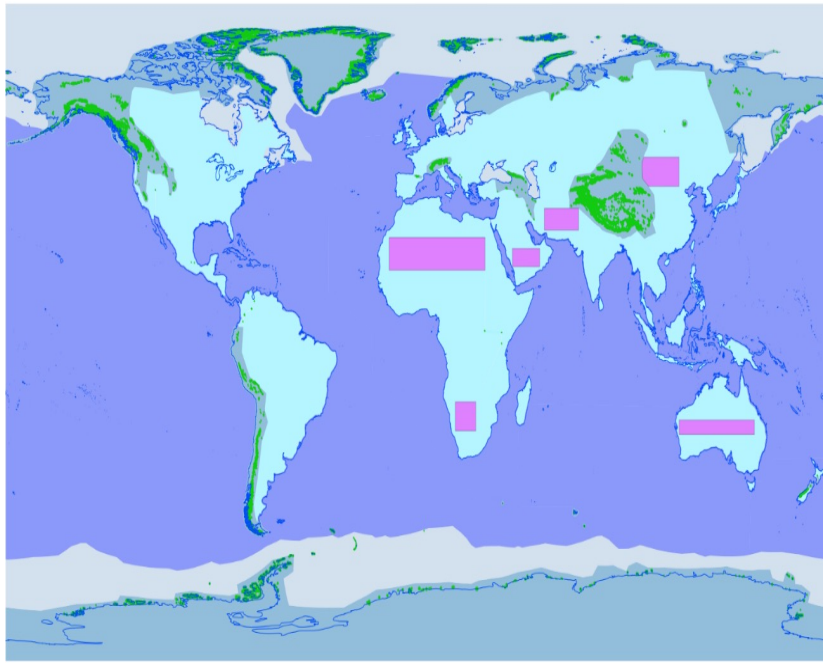
With the support of: Salvatore Dinardo, Carolina Nogueira Loddo and Julia Figa

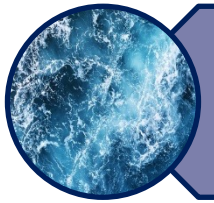
OSTST 2023, San Juan, Puerto Rico.

Marine data centre IRIS acquisition modes of interest

	Open Ocean (OCO)	Sea Ice and icebergs (SII)	Land Ice and Glaciers (LIG)
Ku band acquisition mode	SAR Closed Burst[1]	SARin Open Burst	SARin Closed Burst
Ka band acquisition mode	SAR Closed Burst	SAR Open Burst	SAR Closed Burst

IRIS main science acquisition modes





OCEAN

- **OCO (incl. RMC)**

SSH INTO THE LEADS and over LARGE LAKES

- **SII (not incl. RMC)**

COAST

- **Mostly OCO, but some in SII**

EUMETSAT CRISTAL products heritage

- Adopt from Sentinel-6 the products format as much as possible.
- Adopt from Sentinel-6, when possible, algorithms at Level-1 and Level-2 for open ocean.
- Adopt from Sentinel-6 standards.
- Extend Sentinel-6 baseline to include dedicated coastal and polar ocean algorithms for the CRISTAL mission.
- Extend Sentinel-6 baseline to include SARin will be investigated.

CRISTAL		

• **≤ 3-hours latency**
• **Level 2:**
  • **Standard** (1-Hz and 20-Hz)
  • **Reduced** (1-Hz)
  • **BUFR** (1-Hz and 20-Hz)
• **MWR L2:** 16-Hz AMR-C and HRMR measurements
	• **≤ 48-hours latency**
	• **Level 1A:** TBC
	• **Level 1B:** TBC
	• **Level 2:**
	  • **Standard & Reduced**
	• **MWR L2:** 16-Hz AMR-C and HRMR measurements
		• **TBC**
		• **Level 1A:** Individual echoes
		• **Level 1B:**
		• **Level 2:**
		  • **Standard & Reduced**
		• **MWR L2 :** 16-Hz AMR-C and HRMR measurements

Currently working on SPECIFICATIONS

- Specification activities at EUMETSAT have initiated this 2023, and will extend until 2024 for day-1 design with the tentative goal of starting the marine data center development beginning of 2025.
- Due to the optimisation/re-use w.r.t. S6 and the early start of the prototyping activities for the innovative part of the mission, our Ground Segment development is not on the critical path and will be ready for launch.

Scientific studies to support GS development activities

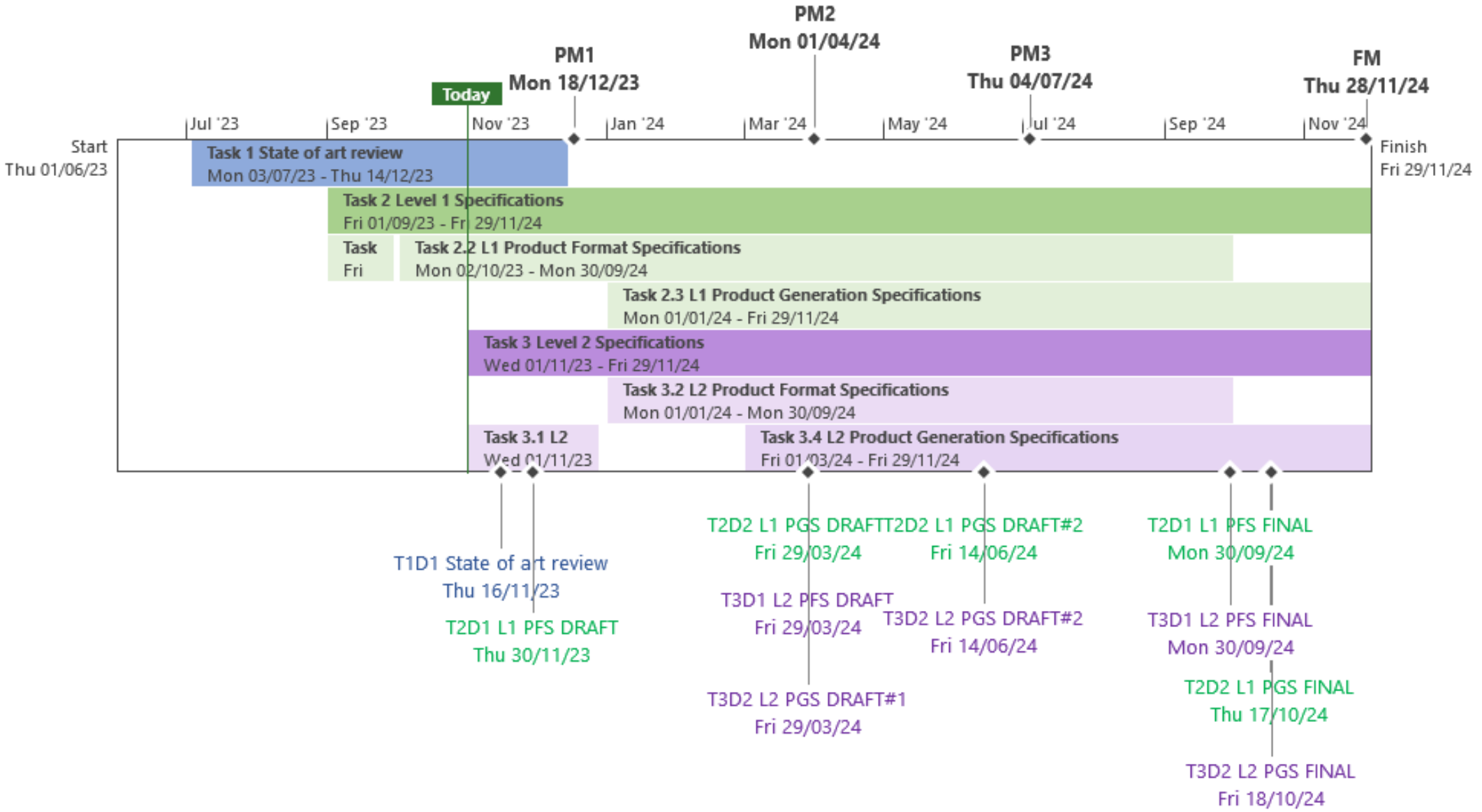
Adaptation of S6 specifications to CRISTAL

- To set a state of the art for the CRISTAL marine data centre. Highlighting the challenges of the CRISTAL mission.
- To define the CRISTAL marine data centre Level-1 and Level-2 product generation
- specifications.
- To define the CRISTAL marine data centre Level-1 and Level-2 product formats.

L1/L2 TDS

- This second study, will be aiming at the generation of Test Data to verify and validate the correct implementation in the Ground Segment of the algorithms defined by the first study.

Timeline for the S6 Adaption to CRISTAL activities

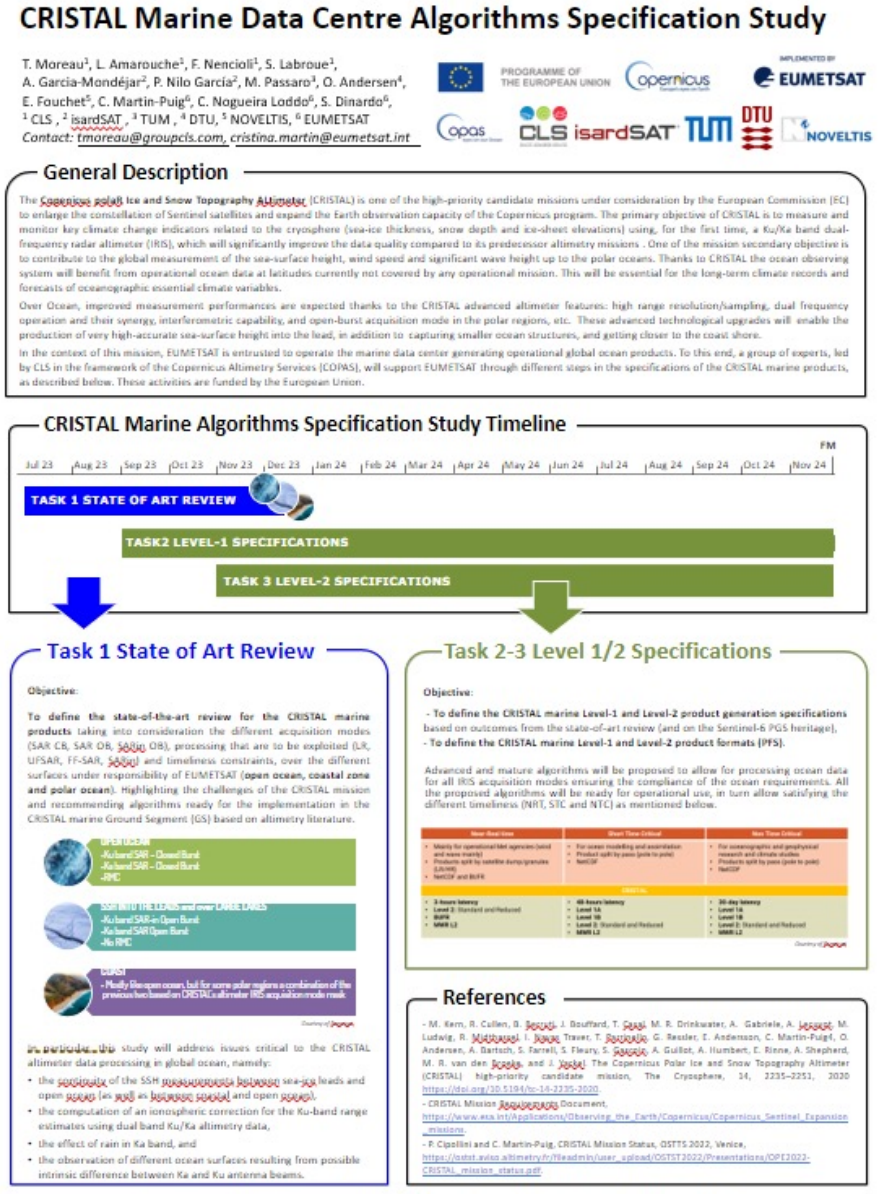


Main points the study will address

- State of art – **ready for implementation** - of Ku and Ka altimetry algorithms for global ocean, including open ocean, coastal and ssh into the leads.
- Algorithms exploiting **interferometric capabilities** will also be taken into consideration.
- The state of art on how to **avoid measurement discontinuity** between SSH over open ocean and SSH over leads.
- Advantages and disadvantages of Ka vs C band.
- Based on the previous, the outcome of this study will be used for the specifications of the L1 and L2 Operational Processor in the Marine Data Centre.

CRISTAL Marine Poster

Come and visit us !



CRISTAL Marine Data Centre Algorithms Specification Study

T. Moreau[1], L. Amarouche[1], F. Nencioli[1], S. Labroue[1], A. Garcia-Mondéjar[2], P. Nilo Garcia[2], M. Passaro[3], O. Andersen[4], E. Fouchet[5], C. Martin-Puig[6], C. Nogueira Loddo[6], S. Dinardo[6]
[1] CLS , [2] isardSAT , [3] TUM , [4] DTU, [5] NOVELTIS, [6] EUMETSAT
Contact: tmoreau@groupcls.com, cristina.martin@eumetsat.int

General Description

The Copernicus polar Ice and Snow Topography Altimeter (CRISTAL) is one of the high-priority candidate missions under consideration by the European Commission (EC) to enlarge the constellation of Sentinel satellites and expand the Earth observation capacity of the Copernicus program. The primary objective of CRISTAL is to measure and monitor key climate change indicators related to the cryosphere (sea-ice thickness, snow depth and ice-sheet elevations) using, for the first time, a Ku/Ka band dual-frequency radar altimeter (IRIS), which will significantly improve the data quality compared to its predecessor altimetry missions . One of the mission secondary objective is to contribute to the global measurement of the sea-surface height, wind speed and significant wave height up to the polar oceans. Thanks to CRISTAL the ocean observing system will benefit from operational ocean data at latitudes currently not covered by any operational mission. This will be essential for the long-term climate records and forecasts of oceanographic essential climate variables.

Over Ocean, improved measurement performances are expected thanks to the CRISTAL advanced altimeter features: high range resolution/sampling, dual frequency operation and their synergy, interferometric capability, and open-burst acquisition mode in the polar regions, etc. These advanced technological upgrades will enable the production of very high-accurate sea-surface height into the lead, in addition to capturing smaller ocean structures, and getting closer to the coast shore.

In the context of this mission, EUMETSAT is entrusted to operate the marine data center generating operational global ocean products. To this end, a group of experts, led by CLS in the framework of the Copernicus Altimetry Services (COPAS), will support EUMETSAT through different steps in the specifications of the CRISTAL marine products, as described below. These activities are funded by the European Union.

CRISTAL Marine Algorithms Specification Study Timeline

Jul 23 | Aug 23 | Sep 23 | Oct 23 | Nov 23 | Dec 23 | Jan 24 | Feb 24 | Mar 24 | Apr 24 | May 24 | Jun 24 | Jul 24 | Aug 24 | Sep 24 | Oct 24 | Nov 24 | FM

TASK 1 STATE OF ART REVIEW

TASK2 LEVEL-1 SPECIFICATIONS

TASK 3 LEVEL-2 SPECIFICATIONS

Task 1 State of Art Review

Objective:

To define the state-of-the-art review for the CRISTAL marine products taking into consideration the different acquisition modes (SAR CB, SAR OB, SARin OB), processing that are to be exploited (LR, UFSAR, FF-SAR, SARin) and timeliness constraints, over the different surfaces under responsibility of EUMETSAT (**open ocean, coastal zone and polar ocean**). Highlighting the challenges of the CRISTAL mission and recommending algorithms ready for the implementation in the CRISTAL marine Ground Segment (GS) based on altimetry literature.

In particular, this study will address issues critical to the CRISTAL altimeter data processing in global ocean, namely:

- the sensitivity of the SSH parameterization between sea-ice leads and open water (ex: MSS as function of sea-ice and open water),
- the computation of an ionospheric correction for the Ku-band range estimates using dual band Ku/Ka altimetry data,
- the effect of rain in Ka band, and
- the observation of different ocean surfaces resulting from possible intrinsic difference between Ka and Ku antenna beams.

Task 2-3 Level 1/2 Specifications

Objective:

- **To define the CRISTAL marine Level-1 and Level-2 product generation specifications** based on outcomes from the state-of-art review (and on the Sentinel-6 PGS heritage),
- **To define the CRISTAL marine Level-1 and Level-2 product formats (PFS).**

Advanced and mature algorithms will be proposed to allow for processing ocean data for all IRIS acquisition modes ensuring the compliance of the ocean requirements. All the proposed algorithms will be ready for operational use, in turn allow satisfying the different timeliness (NRT, STC and NTC) as mentioned below.

References

- M. Kern, R. Cullen, B. Berruti, J. Bouffard, T. Casal, M. R. Drinkwater, A. Gabriele, A. Lecuyot, M. Ludwig, R. Midthassel, I. Navas Traver, T. Parrinello, G. Ressler, E. Andersson, C. Martin-Puig, O. Andersen, A. Bartsch, S. Farrell, S. Fleury, S. Gascoin, A. Guillot, A. Humbert, E. Rinne, A. Shepherd, M. R. van den Broeke, and J. Yungel. The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) high-priority candidate mission, The Cryosphere, 14, 2235–2251, 2020 https://doi.org/10.5194/tc-14-2235-2020
- CRISTAL Mission Requirements Document, https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions
- P. Cipollini and C. Martin-Puig, CRISTAL Mission Status, OSTST 2022, Venice, https://ostst.aviso.altimetry.fr/fileadmin/user_upload/OSTST2022/Presentations/OPE2022-CRISTAL_mission_status.pdf

Ocean Surface Topography Science Team Meeting, 7-11 Nov 2023

Thank you!

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