Assessing CryoRad Mission Performance Using an End-to-End Simulator for Wideband Ocean Salinity Retrieval

V. González-Gambau[1], A. Ruiz-Sebastián[1], E. Olmedo[1], C. Gabarró[1], F. Hernández-Macià[1], M. Claret[1], A. Turiel[1], M. Arias[2], R. Onrubia[2], I. Nestoras[3], A. Jordão[3], A. Camps[4], R. Almirall[4], I. Grozea[5], A. Radulescu[5], S. Severin[5], G. Lopes[5], J. Barbosa[3], J. Boutin[6], J. L. Vergely[7] ,

(1) Barcelona Expert Center, ICM-CSIC
(2) Zenithal Blue
(3) RDA GmbH
(4) Universitat Politècnica de Catalunya
(5) INDRA
(6) L'OCEAN
(7) ACRI-ST

Ocean Salinity Science and Technology Team Meeting

University of Washington, Seattle
19th-21st May 2026

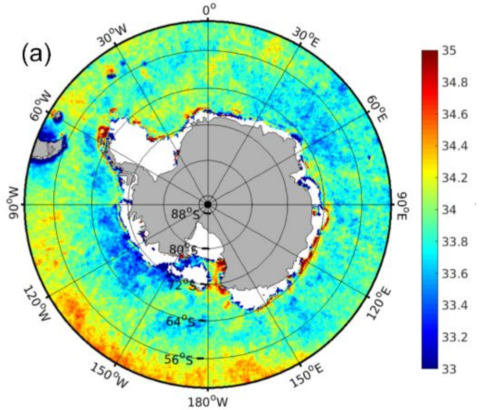
The work presented is performed under contract with the European Space Agency. The views, opinions, and materials presented in this presentation are those of the authors and do not necessarily represent the position of the European Space Agency.

Cryorad Mission

Candidate mission for ESA's Earth Explorer 12 *programme. It proposes the use of* ***wideband radiometry (0.4–2 GHz)*** *to extend and enhance current L-band (1.4 GHz) observation capabilities, with emphasis on monitoring* ***polar regions.***
[Macelloni et al., 2026]

Sea Surface Salinity

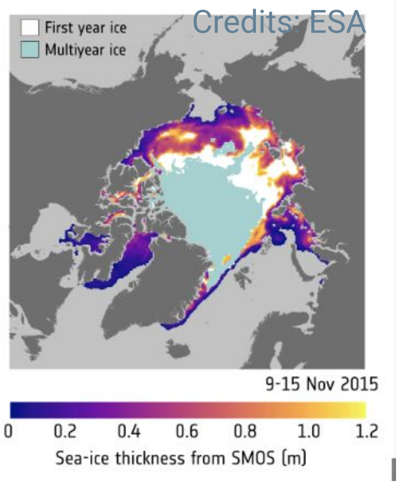
In polar oceans, the **sensitivity** is **3x greater** at 0.4 GHz than at L-band -> **uncertainty reduced by an order of magnitude**.



[González-Gambau et al., 2025]

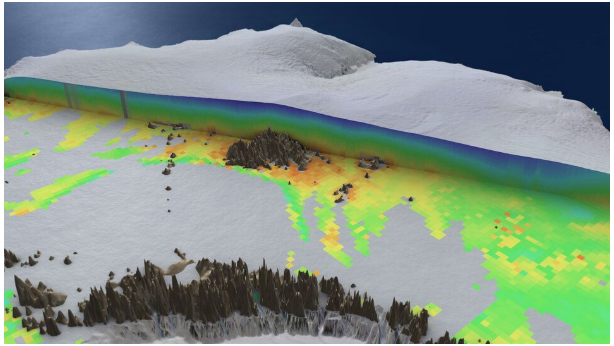
Sea Ice Thickness

100% increase in the penetration depth of the lower-frequencies -> **thickness measurements within the critical 0.5–1.5 m range** (<1 m in L-band).



Ice Sheet Temperatures

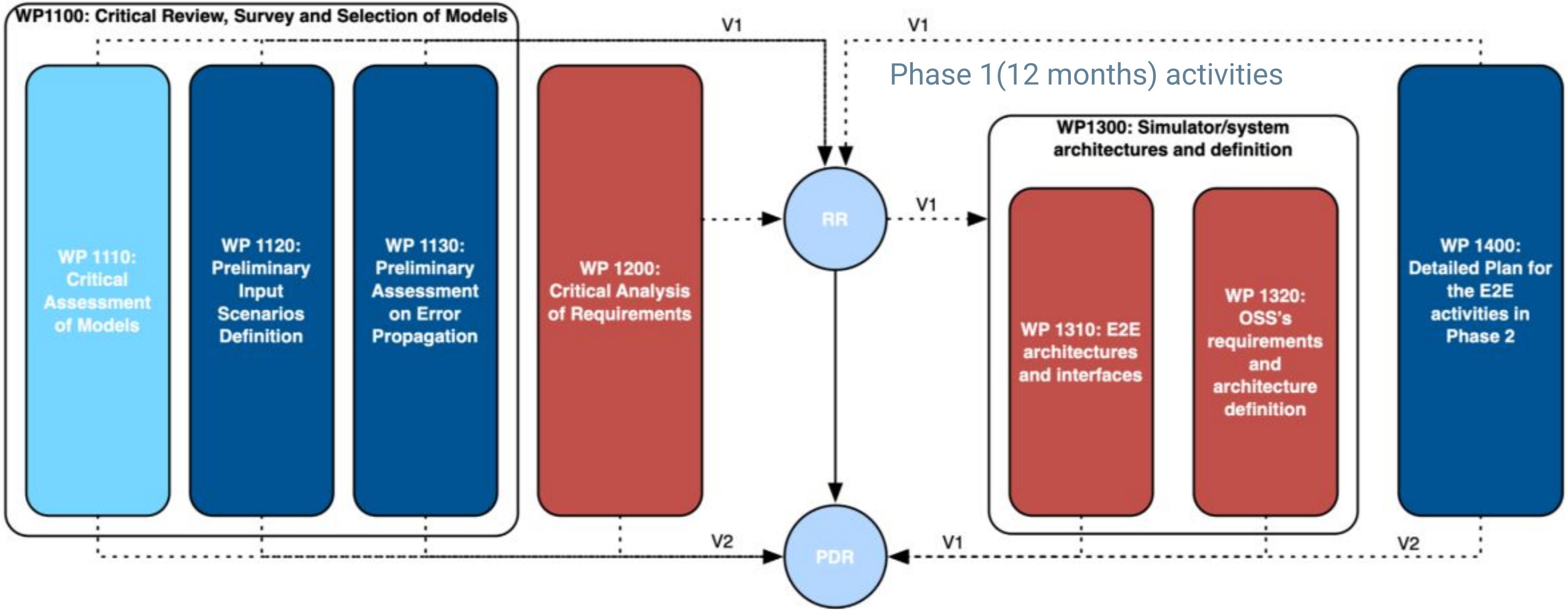
Lower frequencies increase penetration depth by >300%, enabling **monitoring of ice sheet temperatures below 2000 m** (1000–1500 m in L-band).



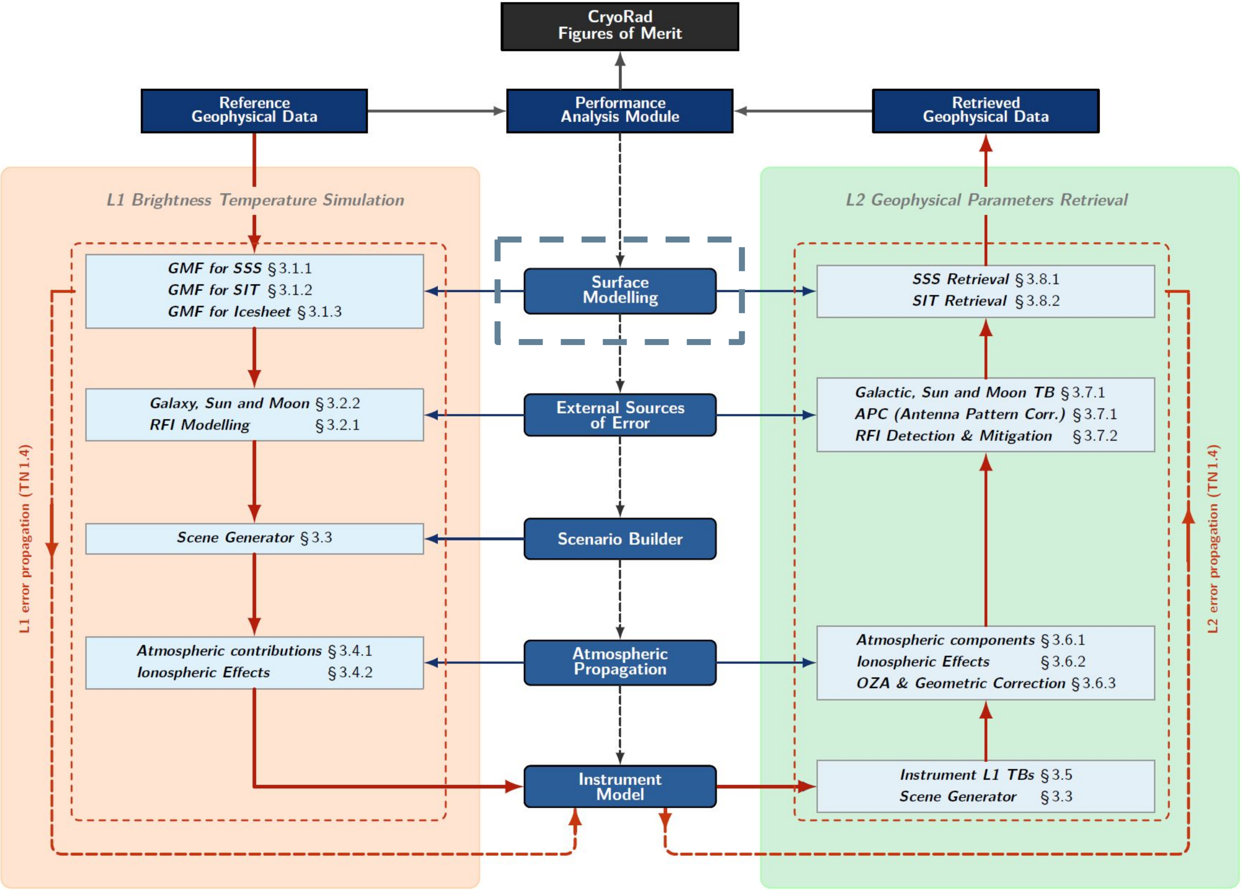
Credits: ESA

Cryorad End to End Performance Simulator Project

Cryorad EEPS main objective: Demonstrate CryoRad mission End-to-End performance for Level-1 and Level-2 products.

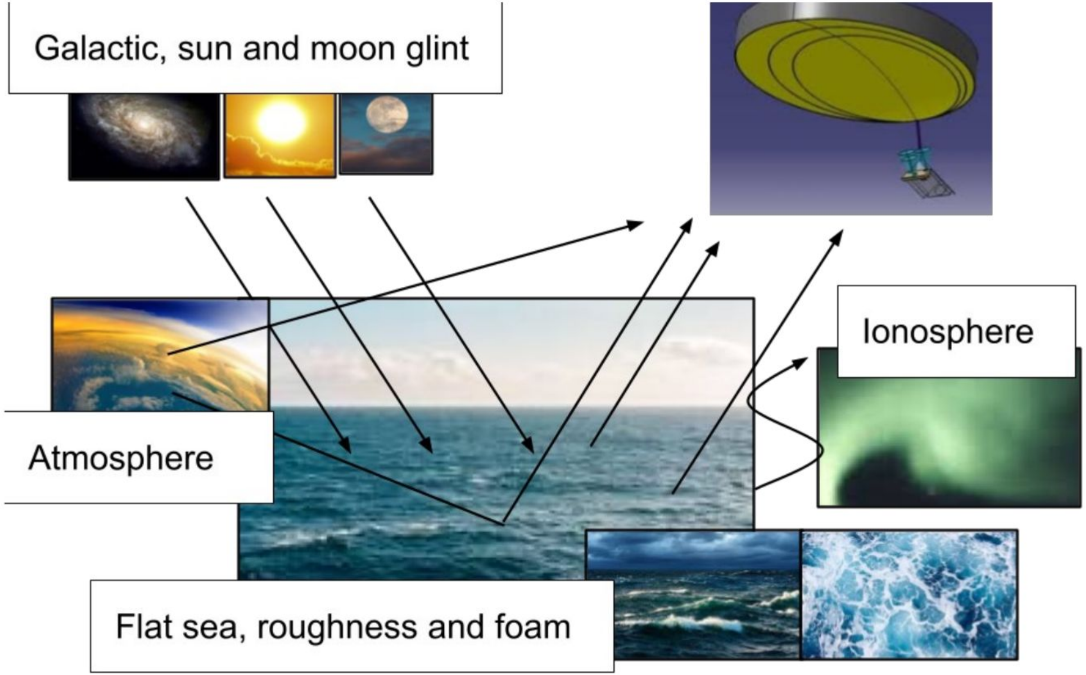


Cryorad End to End Performance Simulator



Sea Surface Salinity Modeling

Modelling ocean TB as a function of SSS



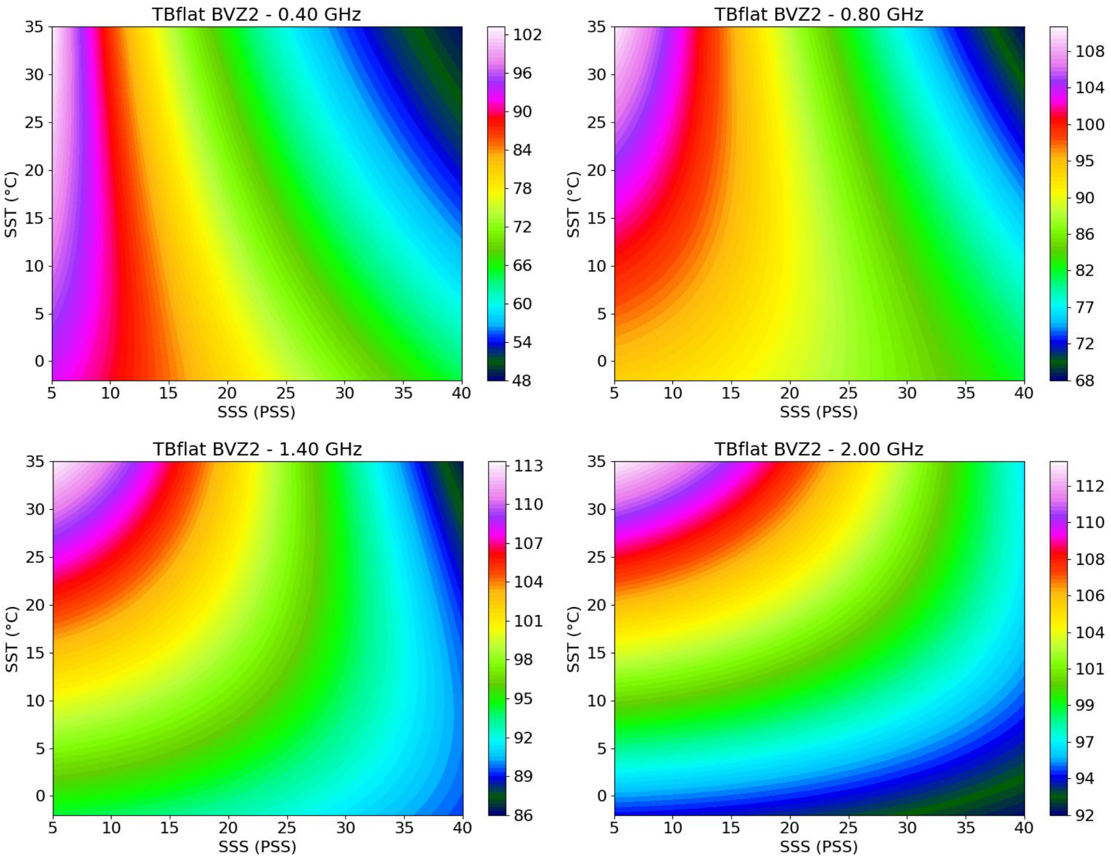
$$TB = (1 - F)(Tb_{flat} + Tb_{rough}) + FTb_{foam}$$

In agreement with SciReq studies (see Boutin's presentation) and MAG recommendations, we have implemented the following models:

Flat sea TB: Sea-water dielectric constant model by BVZ2 [Boutin et al., 2023].

Roughness + foam: 2-scale model with Durden & Vesecky x 1.25 for the wave spectrum and foam parametrizations from [Yin et al, 2016].

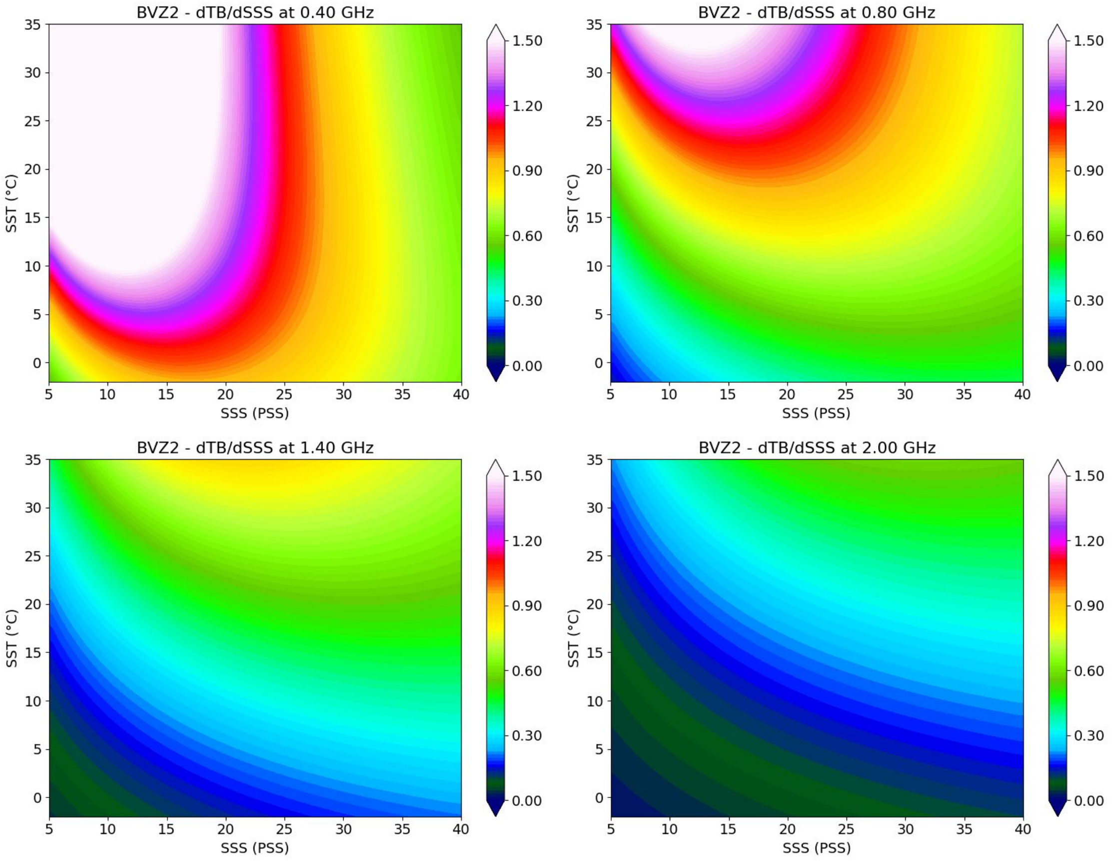
Sea Surface Salinity Modeling



Flat sea TB at different frequencies: 0.4, 0.8, 1.4 and 2 GHz

The range of variability of flat sea TB increases as frequency decreases:
~20 K at 2 GHz
~54 K at 0.4 GHz

Sea Surface Salinity Modeling



Sensitivity of TB flat to SSS increases as frequency decreases.

At 0.4 GHz sensitivity is up to 3 times the one at 1.4GHz

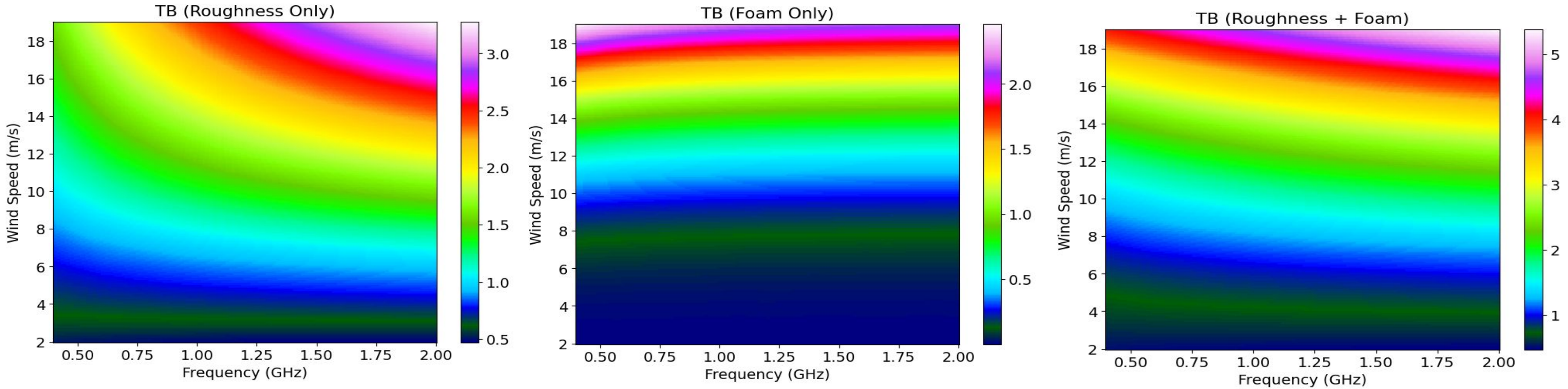
At 0.4 GHz, the sensitivity for low SSS values is larger than 1.5 K/psu: significant enhancement in regions influenced by river runoff and ice melting.

Sea Surface Salinity Modeling

BEC
Barcelona Expert Center

TB of roughness and foam contributions as a function of frequency:

First tests with PARMIO [Dinnat et al., 2023], followed by development of our own implementation in EEPS and cross-verification.



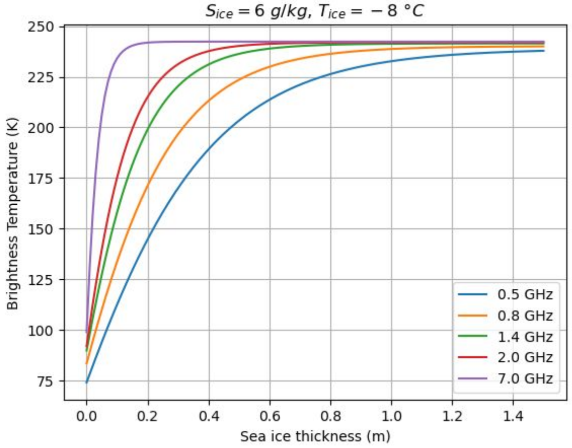
The roughness-induced TB increases with wind speed & frequency. Its contribution is larger at L-band than at P-band.

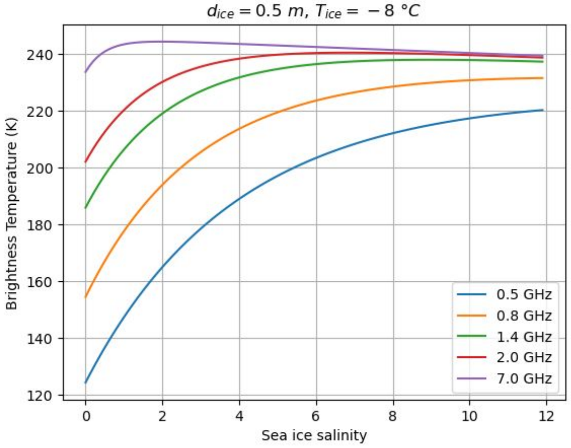
The foam contribution increases with wind speed and shows a slight increase as frequency decreases.

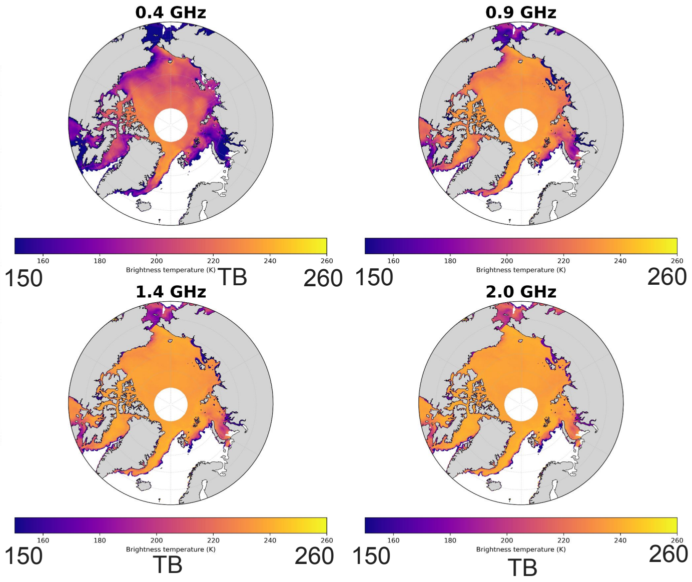
Sea Ice Thickness Modeling

Building on SMOS foundations, modeling approach from AWI/ESA operational product: Menashi et al., 1993 incoherent RT model combined with the Vant et al., 1978 empirical sea ice permittivity, extended within the CryoRad frequency range.

Input data from GLORYS (SIT, SSS → S_{ice} [Ryvlin 1974], SIC as mask) and L4 DMI Ice Surface Temperature product (T_{ice}).







Extension to P-band provides sensitivity to thicker ice than L-band (> 1 m).

Multi-frequency capabilities allow to jointly retrieve sea ice thickness and sea ice salinity (Optimal Estimation). [Rodgers, 2000]

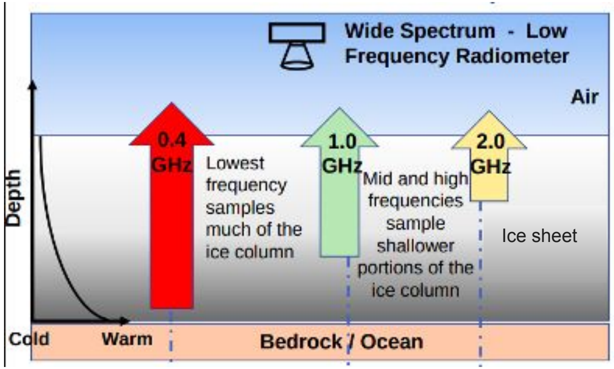
Ice Sheet Temperature Profiles Modeling

BEC
Barcelona Expert Center

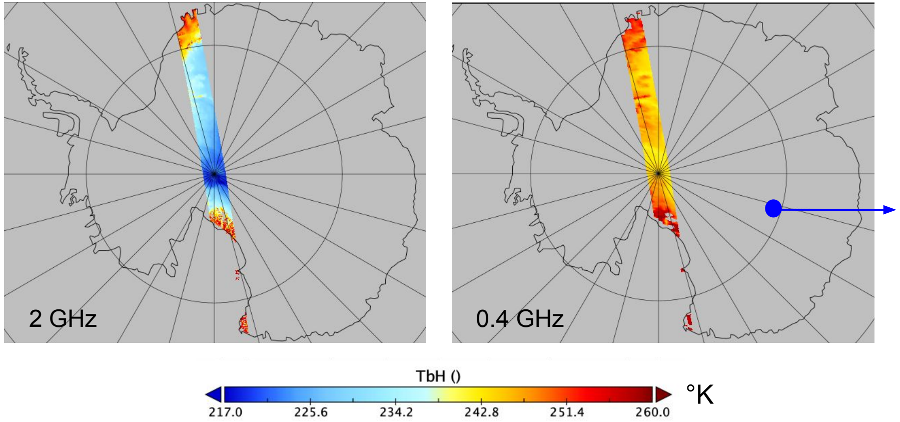
Multi-frequency satellite capabilities allow to retrieve temperature profiles of Antarctica and Greenland ice sheets. Algorithms based on the ones proposed by IFAC.]

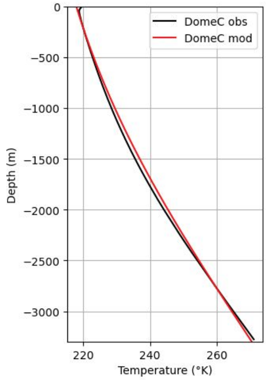
Low frequencies capture TB at deeper levels (1000s m) of the ice sheet than high frequencies (100s m). **Measuring at a range of frequencies allows reconstruction of the ice sheet temperature profile.**

The EEPS simulated TBs along an orbital path in Antarctica show spatial and frequency variability.
Spatial variability reflects colder skin temperatures inland than close to the coast.
Frequency variability reflects colder and higher heterogeneity at shallower depths (low frequencies) than deeper levels (high frequencies) in accordance with temperature profile observations. Geothermal heat flux from the ice sheet bottom causes temperature of the ice sheet to increase with depth.



Brogioni et al. (2023)



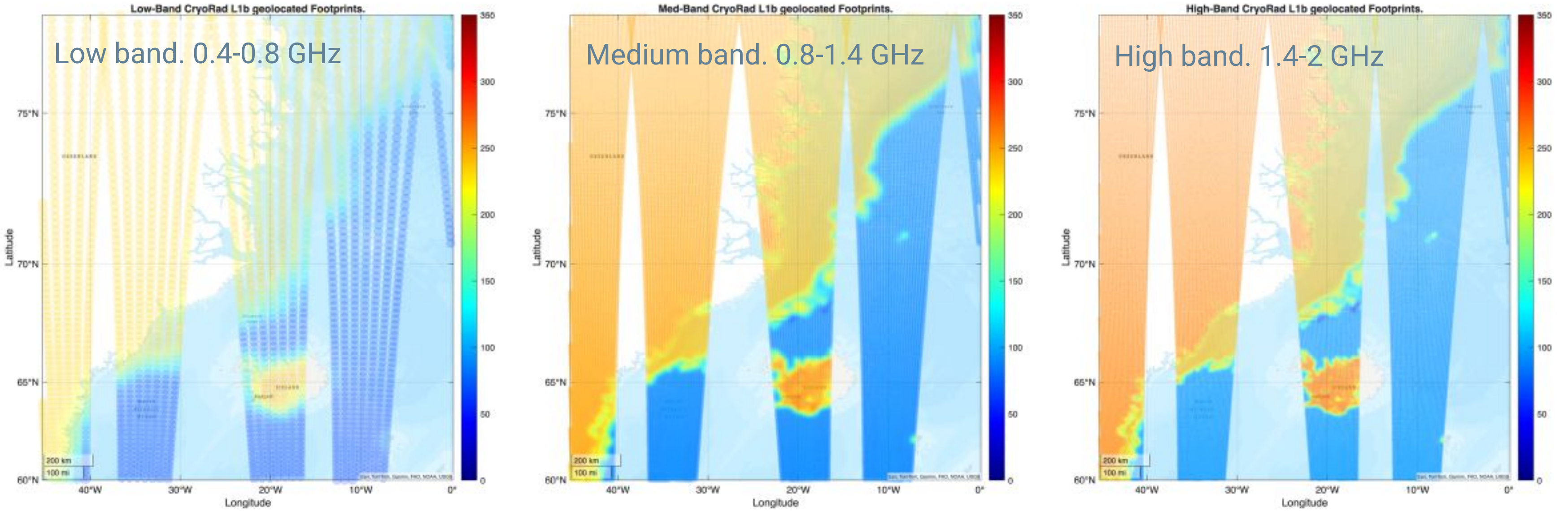


Modeled TB images from EEPS- Real instrument

BEC
Barcelona Expert Center

The **CryoRad EEPS** is able to generate **L1b products** over any location in the globe, using the **SSS and SIT available models and instrument simulation**.

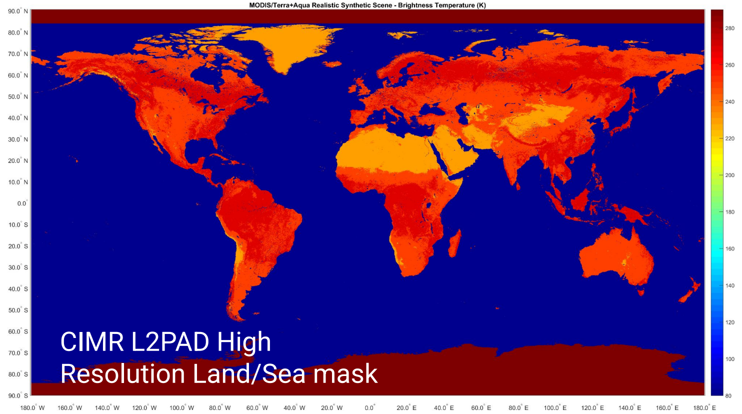
This is an **example instrument geometry.**

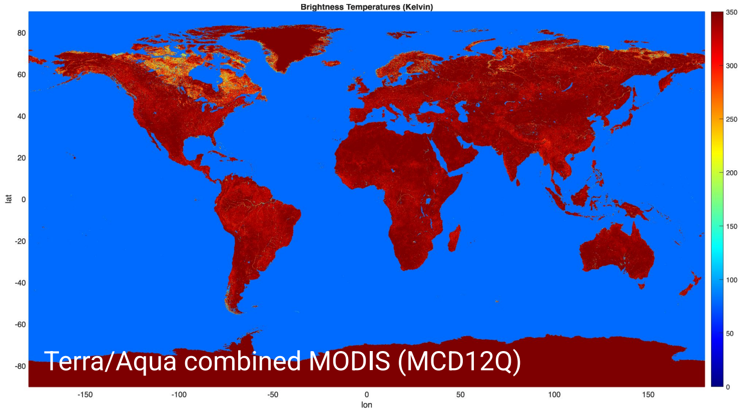


Auxiliary data used: GLORYS model for SSS, SST, SIC (to mask ocean/sea ice).

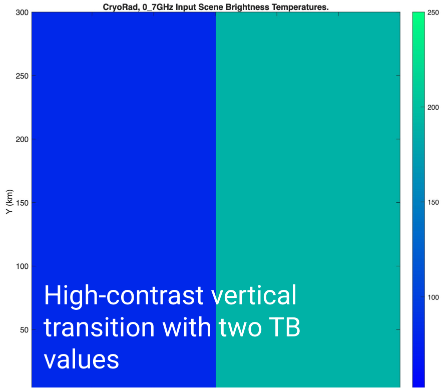
Definition of masks and synthetic input scenes

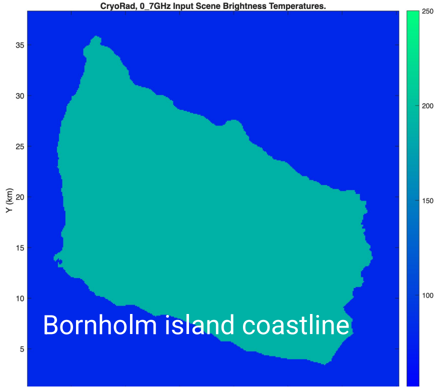
Land/Sea masks:

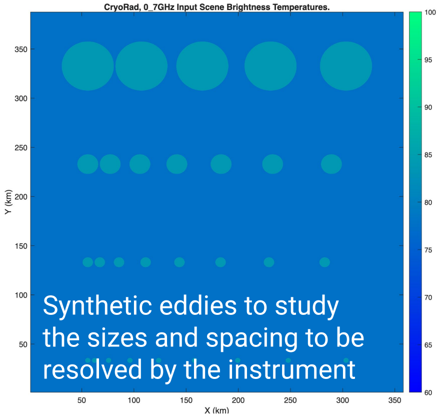


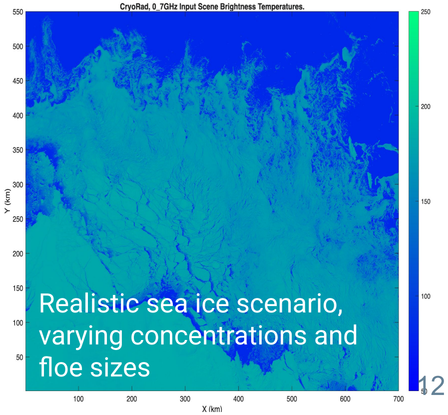


MATER synthetic inputs scenes supported









Error propagation

BEC
Barcelona Expert Center

1. The Measurement Function

Define the explicit physical or algorithmic relationship mapping inputs to the observable.
Conceptual form: $T_B^{obs} = f(\text{state parameters, climatological priors, physical constants})$

↓

2. Error Source Identification (The Causes)

Deconstruct the dependency graph to isolate the root origins of uncertainty.

- Auxiliary Data / Priors
- Representativeness
- Model Approximations

↓

3. QA4EO Effect Classification & Correlation

Assign Probability Density Functions (PDFs) and multi-dimensional correlation scales.

- Random Effects
- Systematic Effects
- Structural Limitations

↓

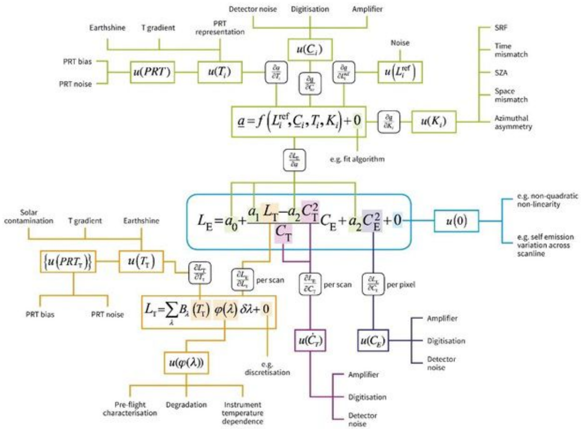
4. Formal Propagation (EEPS / CoMet Framework)

Propagate uncertainties through the measurement function to build the total error budget.

- Monte Carlo Engine
- Scenario Analysis

Methodological workflow for metrological uncertainty characterisation, mapped directly to the **QA4EO / FIDUCEO Process Document framework**.

The sequence progresses logically from defining the *mathematical constraints* **(1)**, through isolating the *physical root causes* **(2)**, to *formal metrological classification* **(3)**, and finally *numerical simulation* in the EEPS **(4)**.



Credit: Mittaz et al. 2019

CoMet

Scene Generation → OSS Model → L2 Retrieval

Key remarks and future directions

- Surface modeling has been implemented and validated in the EEPS for SSS, SIT, and IST.
- Brightness temperature images for a real instrument (using a simplified model) can be generated for the CryoRad geometry.
- The EEPS is ready to evaluate different instrument configurations.

Current activities focus on:

- Level-2 SSS retrieval: we are currently testing the joint retrieval of sea surface salinity, sea surface temperature, and wind speed using a simplified instrument configuration and a Bayesian framework that exploits multi-frequency capabilities.
- Error propagation analysis: assessing the propagation of errors on SSS through the forward model.

Next events

BEC
Barcelona Expert Center

https://atpi.eventsair.com/ee12ucm/

CryoRad presentation on 8th of July starting from 13.00 EEST, with the possibility of online participation

IGARSS2026
Washington D.C.

Presentation by ESA on CryoRad at IGARSS in TH3.R17: Passive Microwave Missions: New Instruments, Tropical Cyclones, and Calibration Advances

Assessing CryoRad Mission Performance Using an End-to-End Simulator for Wideband Ocean Salinity Retrieval

Thanks for your attention!

Contact: vgonzalez@icm.csic.es

BEC
Barcelona Expert Center