Corresponding Author: Verónica González-Gambau
vggambau@gmail.com
Career Status: Postdoc
Affiliation/Country: Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

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

Abstract: CryoRad is a candidate mission for the European Space Agency's (ESA) Earth Explorer 12 programme that proposes the use of wideband radiometry (0.4–2 GHz) to significantly extend and enhance current L-band (1.4 GHz) observation capabilities. A primary objective of the mission is the retrieval of sea surface salinity (SSS) with unprecedented accuracy, with particular emphasis on polar oceans. Previous L-band missions such as SMOS, Aquarius, and SMAP have established 1.4 GHz as a key frequency for monitoring the global water cycle. However, the sensitivity of brightness temperature (TB) to salinity decreases significantly in cold waters, limiting the performance of L-band observations in high-latitude regions. The main technical advantage of CryoRad arises from the increased sensitivity to salinity at lower frequencies. In polar oceans, the sensitivity of TB to SSS is approximately three times higher at 0.4 GHz than at 1.4 GHz. This enhanced sensitivity is expected to reduce the uncertainty of salinity estimates in cold waters by nearly an order of magnitude, providing critical information for the study of ocean circulation and the impact of polar ice melting on the global climate system.

The retrieval of SSS relies on an inversion scheme that determines the optimal salinity value by minimizing the difference between observed and modeled brightness temperatures. The use of multi-frequency observations from P-band to S-band increases the robustness of the inversion by improving the separation between the effects of sea surface temperature (SST), surface roughness, and salinity. Accurate modeling of TB is therefore essential for mission performance assessment. The emission from a flat ocean surface is described using dielectric constant models dependent on SST and SSS. Several dielectric formulations are currently being evaluated, including models validated at L-band (e.g., Boutin et al., 2023) and recent developments extending their applicability to P-band frequencies (e.g., Le Vine et al., 2025). In addition to the flat surface emission, the total signal measured by the instrument includes contributions from sea surface roughness and foam, which are primarily driven by wind speed and direction. These effects are being evaluated using the PARMIO (Passive and Active Reference Microwave to Infrared Ocean) model, which provides roughness parameterizations over a broad frequency range from 0.5 GHz to the infrared and allows the comparison of analytical, empirical, and semi-empirical formulations. Additional sources of error must also be considered, including reflections from the Galaxy, Sun, and Moon, as well as atmospheric and ionospheric propagation effects.

The performance of the proposed system will be assessed using the CryoRad End-to-End Performance Simulator (EEPS), currently being developed within the framework of the Phase 0 studies under an ESA contract (4000150528/24/NL/FF/ab). The simulator will constitute a central element of the mission design and analysis. EEPS is a modular simulation framework that reproduces the complete observation and processing chain, from scene generation to Level-2 geophysical retrievals. The simulator will integrate modules describing orbital geometry, instrument acquisition, radiometric noise, forward modeling of brightness temperatures, and the multi-frequency SSS inversion algorithm. By generating physically consistent ocean scenes and propagating them through the full measurement process, EEPS will enable a quantitative evaluation of retrieval errors and sensitivities under a wide range of environmental conditions. This capability is essential for assessing the impact of instrumental characteristics, environmental uncertainties, and modeling assumptions on the final salinity products, and for verifying that the mission can meet its scientific accuracy requirements.

Author 2: Arnau Ruiz-Sebastián
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

Author 3: Ferrán Hernández-Macià
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

Author 4: Antonio Turiel
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

Author 5: Aina García-Espriu
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

Author 6: Raul Onrubia
Zenithal Blue Technologies, Spain

Author 7: Manuel Arias
Zenithal Blue Technologies, Spain

Author 8: Jose Barbosa
RDA GmbH, Switzerland

Author 9: Carolina Gabarró
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain

Author 10: Estrella Olmedo
Barcelona Expert Center, Institute of Marine Sciences, CSIC, Spain