CIMRL2PAD–UVEG–TEC–RAS–D2

Retrieval Algorithms R&D Technical Note

DD–RAS D2

XX/XX/2025

The CIMR L2PAD Team

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Document Change Log

Issue	Section	Change Description	Date
0.1		Preliminary version of the DD-RAS-D	05/03/2024
1.0		Updated version of DD-RAS-D2 prepared for PDR	08/11/2024
1.1	2.8, 2.10	Add R&D items for Ocean Wind Vectors (2.8) and Sea Surface Salinity (2.10)	10/11/2024

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1. Introduction

1.1 Purpose and Scope

In the CIMR L2PAD study, baseline approaches for all L2 products were identified and documented in 16 ATBDs. Developing baseline algorithms that meet the MRD requirements is a significant effort since existing heritage approaches need to be adapted to the instrument characteristics of CIMR (available frequency channels, OZA, spatial resolution, sampling characteristics, overpass time, and forward/backward scans, amongst others). In addition, for some of the L2 variables, there are no existing off-the-shelf heritage algorithms or mature algorithms only exist for a region (e.g. Sea Ice Type, Snow Depth algorithms have been so far mainly evaluated in the Arctic and not specifically adapted for the Southern Hemisphere sea ice).

The purpose of this Technical note is to identify R&D development activities, first and foremost, the ones that are required to consolidate the proposed baseline approaches, but also the ones that would be needed (beyond the efforts initially accounted for R&D in CIMR L2PAD) to ensure the CIMR L2PAD project is adopting the most advanced geophysical retrieval algorithms for each product.

1.2 Acronyms and Abbreviations

AMSR-E	Advanced Microwave Scanning Radiometer EOS
AMSR2	Advanced Microwave Scanning Radiometer 2
ATBD	Algorithm Theoretical Basis Document
CCI	Climate Change Initiative
CIMR	Copernicus Imaging Microwave Radiometer
DMI	Danish Meteorological Institute
DET	Digital Effects Table
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF Reanalysis v5
ESA	European Space Agency
IGBP	International Geosphere Biosphere Programme

ISMN	International Soil Moisture Network
LAI	Leaf Area Index
LFMC	Live Fuel Moisture Content
L2PAD	Level-2 Product Algorithm Development
LST	Land Surface Temperature
LSWT	Lake Surface Temperature
ML	Machine Learning
MMD	Multi Matchup Dataset
MMVI	Microwave Multichannel Vegetation Indicators
NDVI	Normalized Difference Vegetation Index
N/A	Not Assigned
OE	Optimal Estimation
OZA	Observation Zenith Angle
RFI	Radio Frequency Interference
SIST	
SITS	Sea Ice Type and Snow
SM	Soil Moisture
SMAP	Soil Moisture Active Passive
SMM/I	Special Sensor Microwave/Imager
SMOS	Soil Moisture and Ocean Salinity
SSMIS	Special Sensor Microwave Imager / Sounder
SOTA	State of the Art
SST	Sea Surface Temperature
TB	Brightness temperature
TSIT	Thin Sea Ice Thickness

1.3 Definitions

If applicable, specific definitions for terms used in this document.

1.4 Applicable and Reference Documents

The table below lists the applicable documents that shall be complied with during the project.

Applicable Documents

Reference	Title	Issue
[AD-1]	Statement of Work for CIMR Level-2 Product Algorithm Development, ESA-EOPG-EOPGMQ-SOW-55, dated 03/04/2023.	1
[AD-2]	METNO-led proposal for CIMR L2PAD, reference 2023/534, dated 14/06/2023 and updated on 24 October 2023.	2

The table below lists the reference documents that shall be considered during the project.

Reference Documents

Reference	Title	Issue
[RD-1]	CIMR Missions Requirement Document MRD, dated 11/02/2023	5
[RD-2]	CIMR L2PAD L1B/L2 Bridge ATBD, CIMRL2PAD-METNO-TEC-ATBD02-D	D

1.5 Executive Summary

This technical note describes research and development (R&D) activities identified for the 16 ATBDs proposed by L2PAD.

For each ATBD, the proposed R&D activities are listed in order of priority (if applicable). For each R&D activity, a table details the rationale of the activity, the expected impact, and the approach to verify the impact. The table also indicates the responsible partner, the estimated complexity, and whether or not the activity directly relates to implementing the baseline algorithm. Note that this report contains both R&D activities that are critical for the implementation of the baseline algorithms (Baseline=Yes) and R&D activities that would improve the proposed algorithms beyond the current state of the art and/or strengthen the consistency of the different CIMR L2 products (Baseline=No).

This current document contains a list of R&D tables and summary reports for each R&D activity that have been updated according to progress made on prototype development for PDR (V1 ATBDs). The evolution status of each R&D activity is summarized in section 3. The chapters 2.8. Ocean Winds and 2.10. Ocean Salinity are empty in this version and will be added in later versions.

2. Identified R&D to include in the algorithms

2.1. Overall, Consistency and TPDs

This section captures the R&D items to be covered in the Overall Process ATBD.

The following R&D activities are identified for the Overall Process ATBD:

- RD_Overall_001 : Selection and preparation of geographical masks
- RD_Overall_002 : Design of the Extra Consistency Step

RD_Overall_001	Selection and preparation of geographical masks	METNO	Complexity Low	Baseline Yes
Rationale and summary: The L2 algorithms and the L2 GPP rely on several geographical masks. This R&D item deals with the selection and preparation (formatting) of these geographical masks, including: ● the Product Family mask (where each L2 Product Family is processed); ● the Land/Ocean mask; ● the Hydrology mask (for lakes and rivers); ● the Maximum Ice Climatology mask (including lake ice climatology); ● possibly Land Cover, Digital Elevation Model, etc… It is critical that the selection process and preparation software are open and well documented, to ease changing the masks later in the project (or in-flight).				
Expected impact: Allow a shared source of geographical masks for the L2 GPP (and possibly shared with the L1 GPP).				
Approach to verify the impact: Geographical masks are available for the L2 algorithms and the L2 GPP.				
Summary report (if selected for implementation):				
Track Change / History: ● 26-02-2024 (added by Thomas Lavergne) ● 03-11-2024: not started (T. Lavergne). Will be in early 2025.				

RD_Overall _002	Design of the Extra Consistency Step	METNO	Complexity Medium	Baseline Yes
Rationale and summary: The L2 GPP is modular and the different L2 products will be retrieved by modules (some variables are retrieved jointly). The Extra Consistency Step allows to ensure consistency between the variables before they are formatted into the Thematic Data Products (TDPs) and reach the users. The content of this R&D item is not known at this stage, as many L2 GPP and TDP design decision will impact this step.				
Expected impact: Geophysical consistency ofin the TDPs				
Approach to verify the impact: Geophysical consistency is tested as part of the in-flight performance and validation test harness.				
Summary report (if selected for implementation):				
Track Change / History: ● 26-02-2024 (added by Thomas Lavergne) ● 03-11-2024: not started (T. Lavergne)				

2.2. L1B/L2 Bridge

The L2PAD L1B/L2 Bridge implements a set of pre-processing steps before the L2 processors run. The main objective of the Bridge is to apply various corrections and adjustments that transform the input main-beam TOA TB (in the L1B file) into Level-2 Pre-Process (L2PP) TBs that are ingested by the L2 processors.
The L1B/L2 Bridge ATBD [RD-2] describes two sub-systems inside the Bridge:

- The L1B post-processing sub-system, which is mostly technical and should not require any R&D from CIMR L2PAD;
- The L2 pre-processing sub-system in which scientific R&D is needed in CIMR L2PAD.

The following R&D activities are identified for the L1B/L2 Bridge:

- RD_Bridge_001 : Ocean OZA adjustment
- RD_Bridge_002 : Coastal land/water spill-over correction
- RD_Bridge_003 : RTM-based atmospheric correction
- RD_Bridge_004 : All-surfaces OZA adjustment
- RD_Bridge_005 : Dynamic (sea-ice and snow) spill-over correction
- RD_Bridge_006 : ADF Collocation strategies

We note that, although it will run as part of the Bridge, we do not include here R&D items pertaining to the CIMR RGB at this stage. We have a dedicated activity and deliverable [DD-ATBD-RGB] to specify how the RGB should evolve, but the evolution itself will not take place in CIMR L2PAD.

RD_Bridge_ 001	Ocean OZA adjustment	METNO & ODL	Complexity Medium	Baseline Yes

<u>Rationale and summary:</u>
CIMR imaging geometry requires several feeds per microwave band (4 feeds at C/X, 8 feeds at K/Ka). These feeds image the Earth scenes at different OZAs, leading to differences in TBs that must be adjusted for (to a "reference" OZA) before the remapping step (RGB). This is especially relevant for Ocean scenes on which this R&D item focuses on. In addition to the feed-dependent OZA, OZA of a given feed will vary along the scanline, and this can be adjusted for in the same way. The following activities are foreseen:

- Define the strategy for OZA adjustment over the ocean : RTM-based (requires ADFs) vs Parametric (fewer or no ADFs). If RTM-based, propose an RTM, in collaboration with RD_Bridge_003. Keep in mind the possible later extension to other surfaces (RD_Bridge_004).
- Define the strategy for defining theta_ref in a typical L1B granule.
- Develop, implement and demonstrate the OZA adjustment strategy and/or simulated L1B files and on L1B data from similar missions (although the range of OZA will be more limited).
- Define uncertainty propagation strategy (from non-adjusted to OZA-adjusted TB uncertainties).
- Define the strategy to adapt the algorithm when CIMR is in orbit.
- Document the R&D efforts (e.g. notebook, TN) and the selected strategy in the Bridge ATBD.

We note that it is critical to aim at a compute-efficient strategy since the OZA-adjustment will be one of the first steps in the L2 GPP.

<u>Expected impact:</u>
This step is critical to achieve an acceptable TB remapping by the RGB, and thus for all the downstream L2 algorithms. Sub-optimal results might translate into "striping" in the L1c and L2 products.

<u>Approach to verify the impact:</u>
Assess the homogeneity of the adjusted TB field, in particular the magnitude of residual "stripes", keeping in mind that the simulated TBs result from non-perfect simulations.

<u>Summary report (if selected for implementation):</u>

- <u>PDR:</u> an RTM-based OZA compensation step is implemented using pre-computed atmospheric fields (see RD_Bridge_003) and the W&M2000 ocean surface model. Sea ice detected using a fastL2 SIC algorithm (KKA). At this stage: single theta_ref value. Demonstrated on SCEPS Polar Scene 1 simulated TB. See JNB in L1B/L2 Bridge ATBD V1.

Track Change / History:

- 23-02-2024 (added by Thomas Lavergne)
- 03-11-2024: started (Thomas Lavergne)

RD_Bridge_ 002	Land/water spill-over correction	UVEG	Complexity Medium	Baseline Yes

Rationale and summary:
All CIMR L2PAD L2 products will suffer from Land/Water contamination effects to different degrees depending on the microwave bands they use and the sensitivity of the algorithms to water/land TBs. “Water” L2 products (Polar Oceans and Lake products) need TBs that are corrected for land spillover contamination, while “Land” L2 products need TBs that are corrected for water spillover contamination. Strategies exist in literature to correct these effects, but they need adaptation to serve all L2PAD products globally.

The following R&D activities are foreseen:

- Consolidate the strategy for application of the algorithm to the different CIMR frequencies (e.g. threshold on the fraction of land to apply the correction, radius of neighbourhood field of views to be considered).
- Define the strategy for uncertainty propagation.
- Define the strategy to adapt the algorithm when CIMR is in orbit.
- Document the R&D efforts (e.g. notebook, TN) and the selected strategy in the Bridge ATBD.

We note that it is critical to aim at a compute-efficient strategy since the land/water spill-over correction will be one of the first steps in the L2 GPP. On the other hand, only the TB samples near coastal regions or permanent water bodies need processing.

Expected impact:
This step is critical to achieving better L2 retrievals closer to the coast (especially for lake products LIC and LSWT, and for all land products) and reporting increased uncertainties closer to the coast. Sub-optimal results might translate into biases following the coastal areas, and ultimately to more stringent masking in the L2 products.

Approach to verify the impact:
Demonstrate the added value by looking at the TBs in all bands vs “distance-to-coast” (with and without correction).

Summary report (if selected for implementation):

- PDR: In the prototype developed for V1, an initial land/water spillover correction strategy for CIMR has been implemented and demonstrated using AMSR2 L1R data. It corrects for both water and land spillover (separately) and work in regions with in-homogenous emissivities (thus without knowledge of surface type).

Track Change / History:

- 23-02-2024 (added by Thomas Lavergne)
- 01-11-2024 started (María Piles)

RD_Bridge_003	RTM-based atmospheric correction	DMI	Complexity Medium	Baseline Yes

Rationale and summary:
All CIMR L2PAD L2 products are surface products. The atmosphere is thus a contamination rather than a signal. There is thus an interest to investigate if an RTM-based approach can correct for the atmospheric contamination in the Bridge, so that downstream algorithms are more performant. The following R&D activities are foreseen:

- Review existing strategies for RTM-based atmospheric corrections, and define the strategy for CIMR L2PAD. Key requirements are that it should rely on existing and well supported RTM, that it uses established NWP ADFs, that it works over all surfaces. If this is not possible, adopt a strategy to compute atmospheric contributions (transmittance, down- and up-welling radiation).
- Develop, implement, and demonstrate the strategy on simulated L1B files and/or on L1B data from similar missions.
- Define the strategy for uncertainty propagation.
- Define the strategy to adapt the algorithm when CIMR is in orbit.
- Document the R&D efforts (e.g. notebook, TN) and the selected strategy in the Bridge ATBD.

We note that it is critical to aim at a compute-efficient strategy since the RTM-based correction will be one of the first steps in the L2 GPP.

Expected impact:
This step would be a useful add-on, but might not be critical because of the selection of CIMR frequency bands, and in particular the availability of L- and C/X-band. The investment must be weighted against the expected gain in L2 product accuracy. On the other hand, this is very linked to RD_Bridge_001 (use of an RTM).

Approach to verify the impact:
Demonstrate the added-value by looking at the temporal stability of TBs above known, stable targets. O-B metrics (Observation vs NWP Background) can also be used.

Summary report (if selected for implementation):
- PDR: A JNB implementing pre-computation of tau, Tup, Tdown for a range of OZAs is presented. It uses RTTOV (python interface) and ERA5 column-fields. The pre-computed fields are passed to the JNB implementing the OZA compensation (see RD_Bridge_001). The tau, Tup, and Tdown fields are also used in the L2 SIST JNB, demonstrating one L2 application of atmospheric correction.

Track Change / History:
- 23-02-2024 (added by Thomas Lavergne)
- 03-11-2024 started (Hoyeon Shi and Thomas Lavergne)

RD_Bridge_004	All-surfaces OZA adjustment	ODL	Complexity Medium	Baseline No

Rationale and summary:
See RD_Bridge_001. This R&D item attempts to extend the OZA-adjustement to all surfaces (not only ocean). The following R&D items are foreseen:
- Assess / Review the expected ranges of TB variations over other surfaces (soil, vegetation, snow, sea ice). Source: literature review, models, other microwave missions. Trade-off decision on which other surfaces (and at which band) the OZA-adjustement should be conducted.
- Starting from the strategy selected in RD_Bridge_001, develop, implement, and demonstrate the extension of OZA-adjusment to other surfaces, including the uncertainty propagation.
- Define the strategy to adapt the algorithm when CIMR is in orbit.

• Document the R&D efforts (e.g. notebook, TN) and the selected strategy in the Bridge ATBD.
Expected impact: This step would be a useful add-on to RD_Bridge_001. The difficulty resides in finding robust OZA-variation information (RTMs lacking for some surfaces), otherwise the implementation should not be too difficult (extending the work in RD_Bridge_001).
Approach to verify the impact: Same as for RD_Bridge_001.
Summary report (if selected for implementation):
Track Change / History: • 23-02-2024 (added by Thomas Lavergne) • 03-11-2024 not started (Thomas Lavergne)

RD_Bridge_005	Dynamic mask (sea-ice and snow) spill-over correction	N/A	Complexity High	Baseline No
Rationale and summary: See RD_Bridge_002. This R&D item attempts to extend the land/water spill-over correction to other (dynamic) masks such as Snow Cover and Sea Ice Concentration. This would allow some products (e.g. SM, LST, SST, SSS, ITY,...) to be retrieved closer to these sharp TB transitions. A key complexity is that the masks are dynamic: CIMR L2 SIC and TSA must be used. The following R&D items are foreseen: • Review existing strategies for ice/snow spill-over corrections (e.g. from AMSR, SMAP, …). Assess if such corrections and flagging are better done within the L2 processors (e.g. see RD_SST_003) or once for all in the Bridge. • Develop, implement, and demonstrate the extension of RD_Bridge_005 to the sea-ice/snow edges, including the uncertainty propagation. • Define the strategy to adapt the algorithm when CIMR is in orbit. • Document the R&D efforts (e.g. notebook, TN) and the selected strategy in the Bridge ATBD.				
Expected impact: This step would be a useful add-on to RD_Bridge_002. The difficulty resides in the fact that the mask that defines the sharp edge is not fixed.				
Approach to verify the impact: Allow the retrieval of L2 products closer to the ice/snow boundary.				
Summary report (if selected for implementation):				
Track Change / History: • 23-02-2024 (added by Thomas Lavergne) • 03-11-2024: not started (Thomas Lavergne)				

RD_Bridge_006	ADF Collocation strategies	S&T	Complexity Low	Baseline Yes

Rationale and summary:
Most (if not all) steps in the L1B/L2 Bridge, and the L2 processors, require Auxiliary Data Files (ADFs). These 2D (gridded), sometimes 3D (+column), sometimes 4D (+time) fields must be collocated with the CIMR TB samples (both before and after the RGB resampling) to be effectively used in the algorithms. Sometimes, the spatial resolution of the ADFs must be adapted to that of the TB channel. The following steps are foreseen:

- Assess what elements (of the processing chain) require collocated ADFs, and how a common step (and/or toolbox) could benefit the L2 GPP.
- Assess if a new toolbox is required or ADF collocation could be handled by existing software (e.g. the CIMR RGB).
- Assess trade-off between collocation at each sample vs collocation at tie-points followed by interpolation.
- Develop, implement, and demonstrate an ADF collocation strategy, including support for 2D/3D/4D fields and handling of channel resolution.

We note that it is critical to aim at a compute-efficient strategy since the CIMR has many samples to collocate, and collocation will happen all along the L2 GPP chain.

Expected impact:
Collocated ADFs are required for the L2 GPP to work, this R&D activity is mostly about testing different collocation strategies to achieve compromise between computation time and quality of the collocation.

Approach to verify the impact:
ADFs are collocated using a unified strategy.

Summary report (if selected for implementation):

Track Change / History:

- 23-02-2024 (added by Thomas Lavergne)
- 03-11-2024 not started (Thomas Lavergne)

2.3. SI Concentration and Edge (and Lake Ice Cover)

RD_SIC_001	Atmospheric (and surface) correction	METNO	Complexity Medium	Baseline Yes

Rationale and summary:
Modern state-of-the-art SIC retrievals like those in OSI SAF or ESA CCI use an RTM to correct the TBs for atmosphere (e.g. water vapour, liquid water,...) and selected surface contributions (e.g. wind roughening). This improves the retrieval accuracy of SIC algorithms using Ka and K bands.

RD_Bridge_003 will look at atmosphere correction in the Bridge. Depending on their approach and results, the present R&D item will decide how to add the surface correction in the SIC L2 algorithm.

Expected impact:
Improved SIC accuracy, but also SIED and LIC (bc of shared algorithm baseline).

Approach to verify the impact:
Improved SIC accuracy in the pre-flight performance assessment.

Summary report (if selected for implementation):

Track Change / History:
- 23-02-2024 (added by Thomas Lavergne)
- 03-11-2024: not started (Thomas Lavergne)

RD_SIC_002	NRT1H SIC, use of samples for improved spatial resolution	METNO	Complexity Medium	Baseline Yes

Rationale and summary:
The NRT1H SIC product requires a trade-off between algorithm complexity (to achieve better accuracy) and timeliness. At the same time the NRT1H must achieve a fine spatial resolution to support safe navigation, which means relying more on K and Ka-bands (with more retrieval noise). This R&D item looks at these trade-off in details, including:
- Testing different configurations for the CIMR RGB remapping to increase spatial resolution.
- Test different channel configurations in the SIC NRT1H algorithm to improve accuracy yet keep acceptable production latency.
- Liaising with CIMR L1 GPP efforts to define the NRT1H L1B product.

Expected impact:
High-resolution, acceptable accuracy NRT1H SIC product.

Approach to verify the impact:
Pre-flight performance assessment and latency estimates.

Summary report (if selected for implementation):

Track Change / History:
- 23-02-2024 (added by Thomas Lavergne)
- 03-11-2024: not started (Thomas Lavergne)

RD_SIC_003	Improved uncertainty model	METNO	Complexity Medium	Baseline Yes

Rationale and summary:
Improve the SIC uncertainty model, e.g. adding propagation from L1B and RGB (residual footprint mismatch). Assess if operational uncertainty propagation can use PunPy or has to rely on own, parametrized, software.

Develop the uncertainty model for SIED (from the uncertainties of SIC).

Expected impact: An improved total uncertainty model for SIC (and SIED).
Approach to verify the impact: More realistic uncertainty fields when applied on simulated scenes.
Summary report (if selected for implementation):
Track Change / History: ● 23-02-2024 (added by Thomas Lavergne) ● 03-11-2024 not started (Thomas Lavergne)

RD_LIC_001	Lake / Freshwater tie-points for LIC algorithm	METNO	Complexity Medium	Baseline Yes
Rationale and summary: A 0% and 100% LIC tie-points are needed for LIC retrieval. A first approximation is to use the same tie-point as for SIC, but will be better to derive a Lake / Freshwater tie-point. This will be addressed in this R&D item, e.g. using AMSR-E and AMSR2 TBs over larger lakes. The aim is a fixed TB tie-point, but we will also investigate if using ADF like NWP T2m can help with temporally-varying tie-points to handle the early surface melt.				
Expected impact: An improved LIC product.				
Approach to verify the impact: More realistic LIC fields.				
Summary report (if selected for implementation):				
Track Change / History: ● 23-02-2024 (added by Thomas Lavergne) ● 03-11-2024 not started (Thomas Lavergne)				

2.4. SI Motion

The Sea-Ice Motion continuous maximum cross-correlation technique is well-developed (Lavergne et al. 2010) and has been developed further to produce sea-ice motion vectors between pairs of swaths explicitly for the CIMR instrument (Lavergne et al. 2021). A preliminary implementation of the algorithm has been made within the CIMR DEVALGO project for forward scans of Ka data (V and H polarisations), and what now remains is:

- To devise a strategy to optimise the product timeliness for NRT3H and NRT1H delivery while including as many swath-intersections as possible.
- To define an uncertainty model to provide day 1 uncertainty estimates which will be further refined during operations by tuning against on-ice drifting buoy data.

- To extend the algorithm to include more wavebands (at least K) and the backward scan.
- Further to the last point, to create new test cards which simulate swaths separated in time so that the improvements in the algorithm can be verified.

RD_SID_001	Optimise product timeliness vs number of products processed per swath	METNO	Complexity Medium	Baseline Yes
Rationale and summary: The high number of swaths available make it impractical to provide a sea-ice drift product between every available swath with every other swath in a 24-hour window. In addition, there is a requirement for an NRT1H product, which makes fast delivery a priority. Therefore it is required to investigate and define which swaths intersection should be used to create each product.				
Expected impact: This is a critical step to produce a timely product which makes best use of the maximum data.				
Approach to verify the impact: Demonstrate that the algorithm runs in a timely fashion.				
Summary report (if selected for implementation):				
Track Change / History: • 23-02-2024 (added by Emily Down) • 03-11-2024 not started (Thomas Lavergne)				

RD_SID_002	Define a pre-flight uncertainty model	METNO	Complexity Medium	Baseline Yes
Rationale and summary: There is no model to assess uncertainties of sea-ice drift directly from the data, and so during operations this is done by collocating the product sea-ice motion vectors with on-ice drifting buoy vectors in time and in space, and thus retrieving uncertainties. A pre-flight model of uncertainties should be defined, which can give day 1 estimates of uncertainty, and which can later be tuned with in-situ buoy data.				
Expected impact: Necessary for day 1 uncertainties and to give a basis for the uncertainty model later on.				
Approach to verify the impact: Reasonable uncertainties available, according to known uncertainties from previous satellite sensors.				
Summary report (if selected for implementation):				
Track Change / History: • 23-02-2024 (added by Emily Down) • 03-11-2024 not started (Thomas Lavergne)				

RD_SID_003	Extend algorithm to exploit more bands and forward/back scans	METNO	Complexity High	Baseline No
Rationale and summary: In CIMR DEVALGO, a simple algorithm using Ka band (V and H polarisations) was implemented. It should now be extended to use at least K band as well as both forward and back scans to make best use of the data. This should be relatively straightforward, but we require in addition a method to validate. This workpackage should therefore include the creation of test cards of at least two swaths separated in time, created from swath simulations and drift data from a sea-ice model (e.g. neXtSIM), used as input to the CIMR simulator.				
Expected impact: Optimal use of CIMR data in the SID product.				
Approach to verify the impact: Checking that the result achieved from using extra bands and forward/back scans most closely matches the original sea-ice model data used as input for the test cards.				
Summary report (if selected for implementation):				
Track Change / History: ● 23-02-2024 (added by Emily Down) ● 03-11-2024 not started (Thomas Lavergne)				

2.5. SI Thickness of Thin Ice

The Thin Sea Ice Thickness (TSIT) retrieval is based on a regression of modeled TSIT to L-band TB at horizontal and vertical polarization from SMOS observations. For mitigation of current shortcomings of the retrieval, the following R&D is planned or proposed:

- RD_TSIT_01 on the adaptation of regression coefficients for CIMR
- RD_TSIT_02 on a sea ice concentration correction for an additional SIC corrected SIT variable
- RD_TSIT_03 on a melt influence on TSIT detection and flagging
- RD_TSIT_04 on a spatial consistent simultaneous retrieval of SIC and TSIT
- RD_TSIT_05 on a parameter adaptation for a more generalized TSIT retrieval and uncertainty estimation
- RD_TSIT_06 on a physical forward model for emission of growing first year ice.

RD_TSIT_01	TSIT adaptation of regression coefficients for CIMR	UBremen	Complexity Low	Baseline Yes
Rationale and summary: The TSIT algorithm uses an empirical relation of L-band brightness temperature at horizontal and vertical polarization to thin sea ice thickness. This regression was originally performed with SMOS satellite data, which has different instrument characteristics (synthetic antenna) and measures at a different incident angle range as CIMR’s 53°. Thus the empirical relation needs to be adjusted for direct application to CIMR. The SMOS TB				

are also not absolutely calibrated (differences of several K exist between SMOS and SMAP) and need to be adapted to CIMR. This could be achieved in two ways. Most desirable would be the translation of SMOS brightness temperatures to CIMR equivalent with a fit function (ideally a linear regression) if this relation is known pre-launch. This allows a translation of the empirical regression parameters from SMOS to CIMR. The second way would require actual CIMR observations over a certain time period to refit the empirical regression with modeled thin ice thicknesses, which would be only possible after launch of CIMR.
Expected impact: A more accurate estimation of thin sea ice thickness, reducing biases. And better pre-launch uncertainty estimates.
Approach to verify the impact: The impact can be demonstrated with SMOS TB to SMAP TB example impact on TSIT retrieval. SMAP measures at a constant OZA of 40° and thus an adaptation of SMOS to SMAP is conceptually similar.
Summary report (if selected for implementation)
Track Change / History: ● 23-02-2024 (added by M.Huntemann) ● 06-11-2024 not started (M. Huntemann)

RD_TSIT_02	TSIT SIC correction	UBremen	Complexity High	Baseline Yes
Rationale and summary: The TSIT retrieval assumes 100% Sea Ice Concentration (SIC) for the retrieved footprint. A correction for SIC by using the CIMR SIC product as auxiliary data is planned as another output for the TSIT processing. At higher ice thickness (>30 cm), the sensitivity of the ice thickness to ice concentration is very high so that the resulting product may inherit large uncertainties from small uncertainties in the SIC input (Pațilea et al. 2019). The stabilization of the SIC corrected TSIT is to be developed. This can be achieved through the resolution difference of the higher resolving SIC product compared to the CIMR lower resolution L-band footprints. Also, a lower limit of SIC values, where this correction can be performed with reasonable accuracy will be investigated. We expect this lower SIC limit between 40% and 80%.				
Expected impact: A SIC corrected TSIT product.				
Approach to verify the impact: The impact can be demonstrated with SMOS and AMSR2 data (even though the comparison suffers from the time lack between two satellite overflights)				
Summary report (if selected for implementation)				
Track Change / History: ● 23-02-2024 (added by M.Huntemann)				

• 06-02-2024 not started (M. Huntemann)

RD_TSIT_03	TSIT individual validity estimation (melt detection)	UBremen	Complexity Medium	Baseline No
Rationale and summary: The TSIT retrieval was trained under freezing conditions. The current formulation does not detect the melt state of the ice. A fixed start and end date for the winter season is used. Thus, it is unclear from the data alone if the retrieval is still applicable. Different methods exist to determine melt from passive microwave observations (Markus & Dokken 2002, Bliss et al. 2017). The effect of melt on L-band brightness temperatures and thus influence on the SIT retrieval should be investigated using SMOS and AMSR2 data.				
Expected Impact: A better individual estimate of the validity of the TSIT product when transition to the melt phase. Possibly, a pixel wise flag and determination of season end for TSIT retrieval. This will reduce SIT uncertainties as melting conditions and thus wrong SIT are better detected. It also can lengthen the season for SIT retrieval in some regions, which are still under freezing conditions when the current fixed end date for the retrieval is reached.				
Approach to verify the impact: The impact can be verified with SMOS and AMSR2 data				
Summary report (if selected for implementation)				
Track Change / History: • 23-02-2024 (added by M.Huntemann) • 06-11-2024 not started (M. Huntemann)				

RD_TSIT_04	TSIT SIC simultaneous consistent retrieval and higher resolution TSIT	UBremen	Complexity High	Baseline No
Rationale and summary: The TSIT SIC correction (RD_TSIT_01) does use the standard CIMR SIC product to correct TSIT on the scale of a single L-band footprint. As SIC is the highest error influence on the TSIT retrieval, a spatially consistent variant of the TSIT and SIC retrieval, optimizing for the most probable state where TSIT and SIC can be optimized together is desirable. Minimizing the error of the brightness temperatures neighboring footprints at higher frequency channels, allows for an increase in the resolution of the TSIT product.				
Expected impact: This would add a SIC and resolution enhanced TSIT product to the output of the SIT retrieval.				
Approach to verify the impact: The impact can be verified with SMOS and AMSR2 data and simulated CIMR L1b test scenes				

<table>
<tr><td>Summary report (if selected for implementation)</td></tr>
<tr><td>Track Change / History:
● 23-02-2024 (added by M.Huntemann)
● 06-11-2024 not started (M. Huntemann)</td></tr>
</table>

<table>
<tr><td>RD_TSIT_05</td><td>TSIT parameter adaptation</td><td>UBremen</td><td>Complexity
Medium</td><td>Baseline
No</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
The fit parameter for the regression of L-band TB and TSIT is currently based on a regression of a single ice growth season in the Kara and Barents Seas. New fits were already performed, and new parameters were estimated for 12 years of data across the entire Arctic and Antarctic regions. These new fits need to be implemented and the distribution of the parameters need to be integrated into the uncertainty estimates of the TSIT product.</td></tr>
<tr><td colspan="5"><u>Expected impact:</u>
More generalized TSIT estimates and more accurate uncertainty estimation.</td></tr>
<tr><td colspan="5"><u>Approach to verify the impact:</u>
The impact can be verified with existing SMOS data.</td></tr>
<tr><td colspan="5">Summary report (if selected for implementation)</td></tr>
<tr><td colspan="5">Track Change / History:
● 23-02-2024 (added by M.Huntemann)
● 06-02-2024 not started (M. Huntemann)</td></tr>
</table>

<table>
<tr><td>RD_TSIT_06</td><td>Physical sea ice forward model implementation</td><td>UBremen</td><td>Complexity
Medium</td><td>Baseline
Yes</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
The current forward model is a regression of brightness temperatures to modeled thin ice thickness. No external influences are included or can be accounted for. This RD item implements a physical forward model, accounting for ice temperature, snow depth, salinity, brine inclusion geometry, and sea ice thickness as main parameters. The new forward model will be based on an incoherent approximation of a coherent radiative transfer model solution for L-band and C-band.</td></tr>
<tr><td colspan="5"><u>Expected impact:</u>
Additional physics based SIT estimate including the uncertainty of main contributors to sea ice emission at L-band and C-band.</td></tr>
<tr><td colspan="5"><u>Approach to verify the impact:</u>
The comparison to the base algorithm is planned to be applied to SMOS+AMSR2 data.</td></tr>
<tr><td colspan="5">Summary report (if selected for implementation)
The preliminary forward model is included and documented in the SIT ATBD</td></tr>
</table>

Track Change / History: ● 06-11-2024 (added by M.Huntemann) ● 06-11-2024 add current state Summary (M. Huntemann)

2.6. SI Type and Snow

The CIMR Sea Ice Type (ITY) baseline algorithm is a statistical algorithm based on the Bayesian approach, that is also the backbone in the operational sea-ice type retrievals in both EUMETSAT OSI SAF and Copernicus Climate Change Service (C3S). The CIMR ITY retrieval will be developed jointly and consistent with CIMR Snow Depth on sea ice (SND) retrieval, which is based on an empiric regression analysis of snow depth from the NASA Operation Ice Bridge flight campaigns to the gradient ratio of TBs. The coupling between ITY and SND includes a joint dynamic start and end freezing season detection and a joint development of uncertainty estimation. Neither ITY nor SND retrievals have heritage from the CIMR DEVALGO project.

To adapt the two algorithms to the CIMR sensor characteristics and provide improvements over the state-of-the-art, we propose the following R&D activities:

- RD_SITS_001 on how to adapt the ITY and SND retrievals into a combined approach
- RD_SITS_002 on the transformation of SND regression into a retrieval
- RD_SITS_003 on the adaptation of ITY and SND retrieval to Antarctic sea ice
- RD_SITS_004 on the post-processing correction schemes for ITY
- RD_SITS_005 on the inclusion of additional ITY categories
- RD_SITS_006 on an physically consistent simultaneous retrieval of ITY and SND

RD_SITS_01	Consistent combination of ITY and SND	METNO, UBremen	Complexity Medium	Baseline Yes
<u>Rationale and summary:</u> Existing retrievals of ITY and SND are separate, and they have not been used in conjunction yet. The CIMR implementation will combine the two retrievals in such a way that the ITY algorithm runs first as this methodology at present is independent of snow depth estimates. The SND algorithm will use the outcome from ITY taking it as absolute truth. The resulting combination of ITY and SND has to be evaluated for temporal and spatial consistency on available data from AMSR2. The combined retrieval will include joint detection of a dynamic start and end of the freezing season, where the products can be provided. Development of uncertainty estimates will be carried out jointly for ITY and SND.				
<u>Expected impact:</u> This is required in order to have a consistent ITY and SND product.				
<u>Approach to verify the impact:</u> The impact can be verified with AMSR2 data and simulated CIMR L1b test scenes				
Summary report (if selected for implementation)				
Track Change / History: ● 22-02-2024 (added by M.Huntemann)				

• 05-11-2024 not started (Emily Down)

RD_SITS_02	Transformation of SND regression into retrieval	UBremen	Complexity Medium	Baseline Yes
Rationale and summary: The current estimation method for SND is based on a regression only. Since this approach cannot be used as a forward model and consequent inversion, which limits the estimation of uncertainties. A new formulation as a forward model will ensure that the estimates are consistent and brightness temperatures and ITY uncertainties are accurately propagated into the SND variable output and its uncertainty values.				
Expected impact: Better uncertainty estimates and consistent retrieval of SND.				
Approach to verify the impact: The impact can be verified with AMSR2 data.				
Summary report (if selected for implementation)				
Track Change / History: • 22-02-2024 (added by M.Huntemann) • 06-11-2024 not started (M.Huntemann)				

RD_SITS_03	Evaluation of Antarctic SND retrieval parameters and ITY distributions	METNO, UBremen	Complexity Medium	Baseline Yes
Rationale and summary: The current fit parameters for SND are based on a regression of observations in the Arctic only. In order to apply the retrieval also in the Antarctic, the parameters need to be validated or reevaluated for the specific region as the physical sea ice properties differ. Similarly, for ITY, distributions need to be estimated for the Antarctic sea ice, since sea ice of different age or development stages differs radiometrically among hemispheres.				
Expected impact: This is required to have a valid retrieval of snow depth and ice type for the Antarctic.				
Approach to verify the impact: The impact can be verified with AMSR2 data.				
Summary report (if selected for implementation)				
Track Change / History: • 22-02-2024 (added by M.Huntemann) • 05-11-2024 not started (Emily Down)				

RD_SITS_004	Adaption of the ITY post-processing correction	METNO	Complexity Medium	Baseline Yes

	schemes to CIMR L2 design			

Rationale and summary:
Correction schemes for ITY exist in both literature and in operational retrievals (e.g. OSI SAF and C3S), but they must be adapted to the CIMR Level-2 processing design.

- One scheme is based on the surface air temperature history of the previous days and therefore these data must be adapted to the Level-2 grid.
- Another correction scheme will take into account the drift history of the ice parcel and requires Level-4 information on both sea-ice concentration and drift for several days back in time. These data must be adapted to the Level-2 grid.

Expected impact:
The post-processing of correcting direct output from the Bayesian computation is crucial to eliminating erroneously classified sea ice.

Approach to verify the impact:
Monitoring of the multiyear ice areal extent can verify the impact of the correction schemes.

Summary report (if selected for implementation):

Track Change / History:

- 23-02-2024 (added by Signe Aaboe)
- 05-11-2024 not started (Emily Down)

RD_SITS_005	Inclusion of more age categories	METNO	Complexity Medium	Baseline No

Rationale and summary:
CIMR ITY retrieval builds upon the existing retrievals from OSI SAF and C3S which map the ice type into the two classes of multiyear ice (MYI) and first-year ice (FYI). To include a third class, e.g. second-year ice and/or young ice, will require some R&D study on a larger test data set to get the right tuning of the algorithm for the extra class. The same applies for evolving from ice type classes to ice type concentrations. For this spectral unmixing for individual footprints of the radiometric probability distributions for the different ice classes needs to be researched.

Expected impact:
More ice categories are important to, e.g., better capture the transition from first-year ice to the youngest part of the multiyear ice, i.e. second-year ice. This transition is where the largest brine rejection occurs which largely changes the ice properties. Having an additional young ice class would allow to identify areas of new ice growth like in polynyas or leads. Also these are areas of high brine rejection and ocean-ice interaction.
Having ice type concentrations will allow to move away from only having the dominating ice class per footprint and having concentrations of all ice types per footprint.

Approach to verify the impact:
Verification can be carried out by comparison with independent sources of the ice types, such as e.g navigational ice charts of the stage of development and drift trajectory classification.

Summary report (if selected for implementation):

Track Change / History: ● 23-02-2024 (added by Signe Aaboe) ● 01-03-2024 (updated by Gunnar Spreen) ● 05-11-2024 not started (Emily Down)

RD_SITS_06	Physical, simultaneous retrieval of SND and ITY	UBremen	Complexity High	Baseline No
Rationale and summary: Recent developments in multi-parameter retrieval may allow a more sophisticated, physical retrieval of sea ice and snow parameters (Rückert, et al. 2023). These include snow depth on sea ice and ice-type fractions, while depending less on empirical relations and including more physical interpretable parameters. The method, however, in particular the snow depth and ice type variables, would require more validation efforts and tuning of parameters before adaptation to CIMR and inclusion into the ice type and snow depth product.				
Expected impact: This would allow an output of an additional set of variables for snow depth and ice type fractional values in the product which are physically consistent with the measured TBs and include uncertainties. The output variables would include a consistent SIC.				
Approach to verify the impact: The impact can be verified with AMSR2 data.				
Summary report (if selected for implementation)				
Track Change / History: ● 22-02-2024 (added by M.Huntemann) ● 05-11-2024 not started (Emily Down)				

2.7. SI Surface Temperature

The baseline algorithm chosen for SIST retrieval stands on several assumptions: 1) The snow-ice interface is an effective emitting layer for the C-band, 2) The atmosphere and snow layer on sea ice is transparent, and 3) Sea ice surface is specular and its reflectivity can be described by Fresnel equations. To make the retrieval algorithm less dependent on assumptions and improve the quality of its output, the following R&D activities are proposed for SIST leveraging the capability of CIMR:

- RD_SIST_001 is about the first and second assumptions, developing the correction method for the possible systematic bias between the C-band effective temperature and SIST.
- RD_SIST_002 is about the second assumption, developing the correction method for the atmospheric noise from the TB.
- RD_SIST_003 is about extending the applicable area of the baseline algorithm, which is currently limited to areas where sea ice concentration is greater than 95%.

RD_SIST_001	Bias correction method for C-band effective temperature	DMI	Complexity High	Baseline Yes

Rationale and summary:
Although it has been demonstrated that the C-band effective temperature has a significantly high correlation with SIST (Tonboe et al., 2011; Lee and Sohn, 2015), this does not mean that they are always the same. There is a possibility of having a systematic bias between the retrieved C-band effective temperature and actual SIST, depending on the snow condition. Therefore, it is essential to develop a correction method for such possible systematic bias, and the following activities are foreseen:

- To compare satellite-derived C-band effective temperature and in situ SIST from buoy measurements in order to analyze such difference/bias.
- To test various combinations of the higher frequency brightness temperatures, which contain information on snow conditions, the predictors for correcting the bias will be explored.
- To develop and implement an empirical correction method to the processor. Before CIMR becomes operational, AMSR2 will be used for the development. The developed correction method can be adjusted with CIMR observations afterward.

Expected impact:
With the developed correction method, the SIST retrieval algorithm will be able to provide more realistic values of SIST. Therefore, it can be said that this is an essential task and the expected impact is significant. Moreover, a better quantitative understanding of the relationship between C-band effective temperature and SIST will be obtained through a direct comparison of satellite retrievals with in situ measurements.

Approach to verify the impact:
Buoy measured SIST dataset will be divided into two sets: training and validation sets. The correction method will be obtained based on the training set. Then, uncorrected and corrected SIST retrievals will be compared against the validation set to verify the impact. If the developed correction method is functional, we expect to see better agreement with the validation set for the retrievals with the correction than those without the correction.

Summary report (if selected for implementation):

Track Change / History:

- 23-02-2024 (added, by Hoyeon Shi)
- 08-11-2024 not started (Thomas Lavergne)

RD_SIST_002	Atmospheric correction method for SIST retrieval	DMI	Complexity Medium	Baseline Yes

Rationale and summary:
The baseline algorithm takes advantage of the C-band's characteristics in which there are negligible atmospheric effects. However, we expect a product with better quality when we remove the atmospheric noises in C-band brightness temperatures. Moreover, as planned in RD_SIST_001, brightness temperatures at higher frequencies, where atmospheric effects are more significant, will be used for the SIST correction. Therefore it is necessary to consider including atmospheric correction in the process. We expect the following tasks for this package:

- To find a way to solve the radiative transfer equation with atmospheric contribution terms to get the C-band effective temperature

- To calculate effective emissivity for the higher frequencies (up to Ka-band), which is the atmospheric signal-removed radiative property of sea ice
- To use effective emissivity instead of brightness temperature when applying the correction method developed in RD_SIST_001 (with adjustment of coefficients)

Expected impact:
We expect to have SIST retrieval with better accuracy and stability by taking into account the atmospheric correction in the retrieval process. We also expect that the practices made for this will benefit the development of a more generally applicable atmospheric correction method, which would be covered by RD_Bridge_003.

Approach to verify the impact:
A similar approach that was taken by RD_SIST_001 will be used. Comparison will be made between retrieved SISTs (with/without the atmospheric correction) and the validation set. The positive impact can be verified if we can observe the retrieved SIST with atmospheric correction having better accuracy.

Summary report (if selected for implementation):

- The atmospheric terms tau, Tup, and Tdown pre-computed in the L1B/L2 Bridge are used in a modified Fresnel equation to derive C-band SIST. See ATBD V1.

Track Change / History:

- 23-02-2024 (added, by Hoyeon Shi)
- 08-11-2024 started (Thomas Lavergne)

RD_SIST_003	Extending applicable area by correcting ocean signal	DMI	Complexity Medium	Baseline No

Rationale and summary:
The baseline algorithm is applicable exclusively over closed sea ice pixels (i.e. SIC > 95%) because the radiative characteristics of sea ice and ocean surface are different so the brightness temperature of ice-ocean-mixed pixels cannot be described by the simplified equation currently used. Thus, to expand the applicable area of the algorithm, we propose the following task:

- To develop a correction method removing ocean signals in observed brightness temperatures using sea ice concentration and representative brightness temperature of open ocean (i.e., ocean tie-points).

Expected impact:
The retrieval area will be extended; Pixels with sea ice concentration from 0% to 95% will also be processed.

Approach to verify the impact:
We can quantify the area additionally included as the retrieval area after the implementation of this correction method. In addition, it will be checked if there is any anomaly in the spatial variability (discontinuity, etc.) introduced by the applied correction.

Summary report (if selected for implementation):

Track Change / History:

- 23-02-2024 (added, by Hoyeon Shi)
- 08-11-2024 not started (Thomas Lavergne)

2.8. Ocean Winds

The following R&D activities are proposed for Ocean Wind Vector retrieval algorithm :

- RD_OWV_001 : work on the atmospheric correction in both rain-free and rainy conditions. Implement and test multi-parameter retrieval allowing for variation of columnar vapor and liquid water.
- RD_OWV_002 : work on developing a rain flag for the wind product at the three resolutions
- RD_OWV_003 : for wind direction, continue to analyze approaches to resolving the ambiguity problem, including using consistency in wind direction among neighboring retrievals

Tables similar to the other variables will be included in the next version of the DD-RAS.

2.9. Ocean and Lake Surface Temperature

The CIMR Sea Surface Temperature (SST) baseline algorithm is a statistically based retrieval, originally developed within the European Space Agency Climate Change Initiative (ESA CCI) SST project [Alerskans et al., 2020]. It has been used to generate the first European climate data record of SST from AMSR-E and AMSR2 microwave observations, with good accuracy and consistency throughout the record. The development work to adapt this algorithm to the CIMR sensor characteristics has already begun in the CIMR-DEVALGO project, where a simplified version using a CIMR-like configuration has been developed. To fully adapt the SST retrieval algorithm to the CIMR sensor characteristics and provide improvements over the baseline, the following R&D activities are proposed for SST:

- RD_SST_001 is necessary to consolidate and prepare the baseline algorithm implementation.
- RD_SST_002 is necessary for developing a state-of-the-art uncertainty model with reliable uncertainty estimates.
- RD_SST_003 shall provide insights into how SST can be retrieved in coastal areas and closer to the sea-ice edge. The research and findings will be highly relevant and applicable for LSWT as well.
- RD_SST_004 will provide valuable insight into the performance of the selected CIMR SST retrieval algorithm against other types of retrieval algorithms. Furthermore the benefits of using a physical-based retrieval and of using a machine learning approach, which is able to emulate more complex relationships than a regression-based model, will be given.

RD_SST_001	Adaptation of the SST baseline algorithm to CIMR sensor characteristics and mission requirements	DMI	Complexity Medium	Baseline Yes
Rationale and summary: The CIMR SST baseline algorithm is a statistically-based retrieval algorithm. The original approach [Alerskans et al., 2020] utilizes AMSR2 brightness temperature measurements at 6.9, 10.6, 18.7, 23.6 and 36.5 GHz (dual polarization). The approach needs to be tuned and translated to the CIMR sensor characteristics. The development work has begun in the CIMR-DEVALGO project, where a simplified SST retrieval algorithm, using a 1-stage approach with a global algorithm, for a CIMR like configuration (6.9, 10.6, 18.7 and 36.5 GHz channels) has been developed. To account for CIMR's unique sensor characteristics and to meet the mission requirements, the following R&D activities are necessary for the CIMR SST baseline algorithm: ● Adapt the SST baseline algorithm developed in CIMR-DEVALGO to a 2-stage approach. Determine suitable localized algorithms for the two stages. To account for differences between the Northern and Southern Hemispheres localized latitude algorithms are proposed for the first stage and to account for non-linear effects localized wind speed and SST algorithms are proposed for the second stage. Development and tuning will be based on the ESA CCI AMSR2 multi-matchup dataset (MMD), where a CIMR like configuration will be used. ● From the CIMR-DEVALGO project it has been shown that the feed-dependent OZA has a significant impact on the SST retrieval performance. To account for this, the correction for feed-dependent OZA developed in the L1B/L2 Bridge will be tested.				
Expected impact: The R&D activity is necessary for the development of the proposed CIMR SST retrieval algorithm. A 2-stage algorithm is needed to account for non-linear effects and to achieve the required performance. Furthermore, it is necessary to derive the SST regression coefficients for the CIMR configuration, such that the SST retrieval algorithm is ready to retrieve SST given CIMR brightness temperature measurements upon launch. (Note: After launch, the coefficients will need to be refined based on training with CIMR C-,X-,K- and Ka-band measurements and OZAs).				
Approach to verify the impact: To verify that a suitable retrieval algorithm is established, assessments using independent SST observations from the ESA CCI AMSR2 MMD will be carried out. Furthermore, the algorithm performance will be assessed using synthetic test data sets in combination with modified test scenes created from AMSR2 measurements.				
Summary report (if selected for implementation): ● PDR: A 2-stage SST retrieval algorithm, making use of localized algorithms, is implemented. For the first stage, localized latitude algorithms are used, whereas localized algorithms based on wind speed and SST are applied in the second stage. The development and tuning is done based on the ESA CCI AMSR2 MMD. See JNB in Sea Surface and Lake Surface Water Temperature ATBD V1.				
Track Change / History: ● 21-02-2024 (added by E. Alerskans) ● 05-11-2024: started (E. Alerskans)				

RD_SST_002	SST uncertainty model development	DMI	Complexity Medium	Baseline Yes
Rationale and summary: In the CIMR-DEVALGO project, SST uncertainties are obtained through the use of a regression model [Alerskans et al., 2020]. For an improved state-of-the-art uncertainty model, the estimated uncertainties in L1b can be propagated through the SST retrieval to derive traceable retrieval uncertainty estimates for the L2 SST product. Such work has already been initiated in the CIMR-MACRAD project where the tool punpy (https://www.comet-toolkit.org/tools/punpy/) is used together with Digital Effects Tables (DETs) to propagate uncertainties through a simplified version of the CIMR L2 SST retrieval algorithm. Here, we will build upon these results and experiences to develop a state-of-the-art uncertainty model. For this, the following R&D activities are proposed: ● Adaptation of the CIMR L2 SST retrieval code to be compatible with punpy ● Propagation of uncertainties using DETs containing L1b TB uncertainties				
Expected impact: A state-of-the art and improved total uncertainty model for SST.				
Approach to verify the impact: More realistic uncertainty fields when applied on simulated scenes.				
Summary report (if selected for implementation):				
Track Change / History: ● 22-02-2024 (added by E. Alerskans) ● 05-11-2024: not started (E. Alerskans)				

RD_SST_003	Retrieval of SST in coastal areas and close to the sea-ice edge	DMI	Complexity High	Baseline No
Rationale and summary: The improved resolution of CIMR and stringent beam forming (“distance-to-coast”) requirements mean that baseline L2 SST retrievals can be achieved closer to the coastline. Still, coastal regions and water bodies will be challenging for the CIMR L2 products when the main beam overlaps different surface types. This can lead to erroneous coastal SSTs and is particularly critical to correct in the retrieved LSWT. Similar challenges exist for retrieval of SST and LSWT close to the sea-ice edge. A land-spill over correction is planned for the L1B/L2 Bridge to reduce land contamination. However, in this R&D activity we propose the following to mitigate land and sea-ice contamination for both the SST and LSWT retrieval ● Investigate the use of methods for mitigating land contamination and retrieving SST in coastal areas [e.g. Olmedo et al., 2017,2018]. ● Investigate the use of methods to reduce sea-ice contamination and retrieve SST closer to the sea-ice edge [e.g. Meissner et al., 2021].				
Expected impact: Reliable and more accurate SST retrievals in coastal areas and closer to the sea-ice edge.				
Approach to verify the impact: The impact of the methods investigated will be evaluated using synthetics test data sets,				

where the performance as a function of distance-to-coast and distance-to-sea-ice will be evaluated (with and without correction).
Summary report (if selected for implementation):
Track Change / History: ● 22-02-2024 (added by E. Alerskans) ● 05-11-2024: not started (E. Alerskans)

RD_SST_004	Investigation of alternative retrieval algorithms	DMI	Complexity High	Baseline No
Rationale and summary: The selected CIMR L2 SST retrieval algorithm is a statistical algorithm based on multiple linear regression and has been used to generate the first European climate data record of SST from AMSR-E and AMSR2 PMW observations, with good accuracy and consistency throughout the record. Other types of retrieval algorithms have shown a good performance as well, such as the Optimal Estimation (OE) approach [Nielsen-Englyst et al., 2018] and machine learning (ML) approaches [Alerskans et al., 2022]. ● The OE retrieval algorithm will be adapted to the CIMR sensor characteristics ● The ML retrieval algorithm of Alerskans et al., [2022] will be further developed and enhanced.				
Expected impact: The OE algorithm will provide physically consistent SST retrievals and several options for assessing the quality and sensitivity of the individual retrievals, which will provide useful insights into the physics of the retrieval. ML models will likely provide the most accurate SST retrievals, since ML models enable the development of much more complex functional forms that may better approximate the actual physical processes as well as the unknown instrument effects.				
Approach to verify the impact: The performance of the OE and ML retrieval algorithms will be verified by comparison with the CIMR SST baseline algorithm and independent in situ observations.				
Summary report (if selected for implementation):				
Track Change / History: ● 22-02-2024 (added by E. Alerskans) ● 05-11-2024: not started (E. Alerskans)				

The approach taken for the CIMR LSWT baseline retrieval algorithm is to tune an existing SST retrieval algorithm for LSWT. The baseline algorithm for the LSWT retrieval algorithm is the SST retrieval algorithm developed in the ESA CCI SST project [Alerskans et al., 2020]. The R&D activities for the CIMR LSWT retrieval algorithm will be based on the work carried out in the CIMR-DEVALGO project, where a version of this retrieval algorithm has been adapted to a CIMR-like configuration. To tune the algorithm for LSWT and to adapt it for the CIMR sensor characteristics, the following R&D activities are proposed for LSWT:

- RD_LSWT_001 is necessary to consolidate and prepare the baseline algorithm implementation.
- RD_LSWT_002 is necessary for developing a state-of-the-art uncertainty model with reliable uncertainty estimates. Note that this activity is closely linked with RD_SST_02.

RD_LSWT_001	Tuning of the LSWT baseline algorithm	DMI	Complexity High	Baseline Yes
Rationale and summary: There is no existing off-the-shelf mature heritage algorithm for LSWT. The approach taken for the CIMR LSWT baseline retrieval algorithm is to tune an existing SST retrieval algorithm for LSWT. The CIMR LSWT baseline retrieval algorithm is based on the SST retrieval algorithm developed in the ESA CCI SST project [Alerskans et al., 2020]. This work will build upon the developments carried out in the CIMR-DEVALGO project, where a simplified SST retrieval algorithm with a CIMR-like configuration has been developed. The SST algorithm will be tuned for LSWT retrievals and for the CIMR sensor characteristics. The following R&D activities are necessary for the CIMR LSWT baseline algorithm: ● The first step towards developing a microwave-based LSWT retrieval algorithm is to develop a microwave-based matchup dataset for LSWT on which the development and tuning can be performed. The matchups dataset will be generated by matching in situ LSWT observations with AMSR2 brightness temperature observations and ERA5 auxiliary data. ● The simplified SST algorithm developed in the CIMR-DEVALGO project will be implemented as a baseline and the prototype version will be trained using the SST ESA CCI AMSR2 MMD. The algorithm will be demonstrated using AMSR2 data for selected large lakes (e.g. the Great Lakes). This will give a measure of how transferrable an SST retrieval algorithm is to LSWT retrievals and an inclination of the necessary fine-tuning needed using in situ lake observations. ● Tune the proposed CIMR LSWT retrieval algorithm on the generated LSWT MMD. ● Evaluate the LSWT retrieval with respect to factors that might impact the retrieval, such as local climatic conditions (e.g. air temperature, wind speed, solar irradiance) , lake size, and elevation. Adapt the LSWT retrieval algorithm based on these findings. ● Investigate the use of a 2-stage LSWT retrieval algorithm, similar to what is proposed for the CIMR SST retrieval algorithm. With this approach, the LSWT retrieval algorithm will be able to partly include non-linear effects as well, enhancing the performance of the retrieval. Adapt the LSWT retrieval algorithm based on these findings.				
Expected impact: The R&D activity is necessary for the development of the proposed CIMR LSWT retrieval algorithm as there is no existing off-the-shelf mature heritage algorithm for LSWT. The LSWT MMD is essential for the development and tuning of the retrieval algorithm. It is necessary to derive the LSWT regression coefficients, such that the LSWT retrieval algorithm is ready to retrieve LSWT given CIMR brightness temperature measurements upon launch. (Note: After launch, the coefficients will need to be refined based on training with CIMR C-,X-,K- and Ka-band measurements).				
Approach to verify the impact: To evaluate the LSWT retrieval algorithm, assessments using independent LSWT				

observations from the generated LSWT MMD will be carried out. Furthermore, the algorithm performance will be assessed using synthetic test data sets in combination with modified test scenes created from AMSR2 measurements.
Summary report (if selected for implementation): • PDR: The baseline LSWT retrieval algorithm has been implemented and tuned on the SST ESA CCI AMR2 MMD (see JNB in Sea Surface and Lake Surface Water Temperature ATBD V1). Work has been initiated to collect lake in-situ observations for generating the LSWT matchup dataset.
Track Change / History: • 23-02-2024 (added by E. Alerskans) • 05-11-2024: started (E. Alerskans)

RD_LSWT_002	LSWT uncertainty model development	DMI	Complexity Medium	Baseline Yes
Rationale and summary: This R&D activity is closely linked with RD_SST_002. In RD_SST_002 a state-of-the-art uncertainty model for SST will be developed. The estimated uncertainties in L1b will be propagated through the SST retrieval algorithm to derive traceable retrieval uncertainty estimates. Because the CIMR LSWT baseline retrieval algorithm is based on the CIMR SST baseline retrieval algorithm, it is possible to build upon the uncertainty model developed for SST and adapt it for LSWT. Therefore work in RD_LSWT_002 will be performed in parallel to RD_SST_02 and state-of-the-art uncertainty models for both SST and LSWT will be developed.				
Expected impact: A state-of-the art and improved total uncertainty model for LSWT.				
Approach to verify the impact: More realistic uncertainty fields when applied on simulated scenes.				
Summary report (if selected for implementation):				
Track Change / History: • 22-02-2024 (added by E. Alerskans) • 05-11-2024: not started (E. Alerskans)				

2.10. Ocean Salinity

The following R&D activities are proposed for Sea Surface Salinity retrieval algorithm :

- RD_SSS_001: develop wind and rain flagging based upon higher frequency Tbs
- RD_SSS_002: compare retrievals using ancillary wind speed/direction with those using wind speed/direction from higher frequencies.
- RD_SSS_003: when using wind information from higher frequencies, evaluate the potential impact of imperfect footprint matching between fore and aft views.

- RD_SSS_004: examine the possibility of using atmospheric vapor and liquid water derived from higher frequencies to compute atmospheric correction at L-band

Tables similar to the other variables will be included in the next version of the DD-RAS.

2.11. Terrestrial Snow Area

The CIMR Terrestrial Snow Area (TSA) baseline algorithm is a static dry snow detection approach, previously applied within the EUMETSAT H SAF H11 Snow Status product using AMSR-E observations over Europe [Pulliainen *et al.*, 2010a] and further validated for the whole Northern Hemisphere by Zschenderlein *et al.* (2023). To expand the algorithm's capability and further exploit the CIMR sensor characteristics, we propose the following R&D activities:

- RD_TSA_001 is necessary to consolidate and expand the baseline algorithm implementation further supporting and enhancing the quality of other dependent L2 products.
- RD_TSA_002 shall contribute to the baseline algorithm verification and uncertainty characterization.
- RD_TSA_003 shall contribute to the baseline algorithm verification and uncertainty characterization.
- RD_TSA_004 is necessary to consolidate and expand the baseline algorithm implementation further supporting and enhancing the quality of other dependent L2 products.

<table>
<tr><td>RD_TSA_001</td><td>Investigation of wet snow detection and flagging</td><td>FMI</td><td>Complexity: Medium</td><td>Baseline: No</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
Passive microwave dry snow detection algorithms are known to underestimate global snow cover area [see e.g. Zschenderlein et al., 2023]. One of the main challenges is to capture wet snow areas especially on a global scale, due to fundamentally different radiometric properties [Mätzler, 1994]. However, CIMR sensor characteristics encourage a review of existing approaches for operational implementation in the L2 TSA product, namely detecting wet snow by means of diurnal amplitude variations [e.g. Semmens et al., 2014], (horizontally polarized) L-band brightness temperatures [Pellarin et al., 2016; Rautiainen et al., 2012], or NWP temperature data [Tuttle and Jacobs, 2019]. The following R&D items shall be carried out to investigate those methods:
Review of potential methodologies and selection of viable approaches for operational use.
Implementation of the wet snow detection module(s) and preliminary coupling with the TSA dry snow detection baseline approach.
Assessment of the overall algorithm performance.
If any of the selected methodologies or a combination thereof prove viable, they shall be fully incorporated into the TSA baseline algorithm.</td></tr>
</table>

Expected impact: This R&D activity is necessary to expand the capabilities of the TSA product to reliably map not only dry but also wet snow. Implementing a wet snow detection module will benefit other L2 products that rely on TSA as input to restrict their respective retrievals, such as the Snow Water Equivalent and Soil Freeze/Thaw State L2 products.
Approach to verify the impact: To verify that a suitable wet snow detection approach is established, comparisons with independent reference datasets shall be carried out, such as snow maps of the Interactive Multisensor Snow and Ice Mapping System (IMS).
Summary report (if selected for implementation): ●
Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Not started (L. Zschenderlein)

RD_TSA_002, RD_FT_004	Development of uncertainty scheme	FMI	Complexity: Medium	Baseline: Yes
Rationale and summary: We lack an established approach to quantify uncertainty estimates through uncertainty propagation for binary/classification products, such as the L2 TSA and FT products. The following R&D items shall be carried out to investigate the feasibility and possible implementation of a comprehensive uncertainty characterization: ● Review of applicable quantitative and/or qualitative uncertainty characterization approaches. ● Investigation of the incorporation of a snow cover area climatology, the effect of brightness temperature uncertainties on the (dry/wet) snow detection results, and the estimates of snow area from swath data as possible uncertainty sources feeding into the TSA uncertainty flag. ● Implementation and assessment of feasible candidates for uncertainty characterization and flagging.				
Expected impact: The R&D activity is necessary to establish comprehensive and traceable uncertainty estimates for binary TSA maps. If found viable, this qualitative or quantitative uncertainty approach will be implemented in order to provide uncertainty flags as part of the L2 TSA product.				
Approach to verify the impact: To verify that a suitable uncertainty propagation/characterization approach is established, comparisons with independent snow area reference datasets (e.g. based on in situ and visible/NIR data) shall be carried out.				
Summary report (if selected for implementation): ● PDR: The TSA uncertainty includes a fore/aft component in the V1 implementation.				

Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Started (L. Zschenderlein)

RD_TSA_003	Investigation of algorithm performance for Southern Hemisphere	FMI	Complexity: Medium	Baseline: No
Rationale and summary: Seasonal terrestrial snow cover is predominantly found in the Northern Hemisphere. In the Southern Hemisphere, the land proportion at mid to high latitudes is much smaller, limiting the amount of snow outside Antarctica. In Antarctica itself, snow is generally deposited on glacial ice. Similarly, most snow cover outside Antarctica occurs on high-elevation glaciers in South America. Due to fundamentally different radiometric properties, snow on glaciers cannot be treated equally to snow on ground [Grody and Basist, 1996]. Therefore, passive microwave snow products commonly do not cover the Southern Hemisphere [Foster *et al.*, 2011; Luojus *et al.*, 2021]. With regard to CIMR's high spatial resolution and ambitions to provide a global snow cover area product, the usefulness of applying dry and/or wet snow detection also over land areas in the Southern Hemisphere has to be revisited. While computationally feasible, the following R&D items are proposed to investigate the reliability of TSA product: ● Review of past investigations [e.g. Foster *et al.* (2001)] as well as current snow products available for the Southern Hemisphere and their performance [e.g. CryoClim Snow and Ice Manager (2018)]. ● Curation of a dataset of AMSR2 brightness temperature measurements at K-band (18.7 GHz) and Ka-band (37 GHz) over land areas in the Southern Hemisphere. ● Application of the TSA baseline algorithm to AMSR2 brightness temperatures and assessment of the algorithm performance through collocation with in situ snow observations.				
Expected impact: The R&D activity is necessary to investigate the reliability of the TSA product over the Southern Hemisphere. If found viable, this R&D activity enables full global coverage of the TSA product.				
Approach to verify the impact: To verify the reliability of the TSA product over the Southern Hemisphere, comparisons with independent snow area reference datasets (e.g. based on in situ and visible/NIR data) shall be carried out.				
Summary report (if selected for implementation): ●				
Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Not started (L. Zschenderlein)				

<table>
<tr><td>RD_TSA_004</td><td>Assessment of the impact of look direction on algorithm performance</td><td>FMI</td><td>Complexity: Medium</td><td>Baseline: Yes</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
The impact and opportunity arising from CIMR’s full circular scanning geometry have not yet been explored in the context of snow mapping. In combination with high spatial resolution, CIMR brightness temperatures have the potential to provide further insights into terrestrial snow conditions. Detection approaches are often affected by certain terrain features, vegetation conditions, and water spill-over effects along shorelines [see e.g. Grody and Basist (1996)]. While technical aspects such as scanning geometry and data acquisition may feed into such challenges, their precise contributions are unclear.
The following R&D items are proposed with the aim to assess the usefulness of CIMR’s dual look brightness temperatures for snow mapping purposes:
● Application of CIMR’s TSA dry snow detection algorithm to WindSat brightness temperatures (18.7 and 37 GHz), using both fore and aft look data.
● Evaluation of the algorithm performance for either look direction or a combination thereof.</td></tr>
<tr><td colspan="5"><u>Expected impact:</u>
The R&D activity is required to understand the implications of near-instantaneous dual look data, which are expected to improve algorithm performance by counteracting underestimation. Such an understanding will provide the basis for possible further algorithm optimization not only of the TSA but also of the SWE product, whose frameworks would ideally exploit CIMR’s dual-look capability to its full extent.</td></tr>
<tr><td colspan="5"><u>Approach to verify the impact:</u>
To verify the effect of dual-look brightness temperatures on snow detection performance, mapped snow cover extent is compared against spatially complete snow cover estimates, such as from the Interactive Multisensor Snow and Ice Mapping System (IMS).</td></tr>
<tr><td colspan="5"><u>Summary report (if selected for implementation):</u>
● PDR: Combining separate snow detection for fore/aft brightness temperatures is found to overall increase performance, based on an evaluation using WindSat data. This approach is hence used for the V1 implementation of the TSA product..</td></tr>
<tr><td colspan="5"><u>Track Change / History:</u>
● 24-10-2024 Added (L. Zschenderlein)
● 06-11-2024 Started (L. Zschenderlein)</td></tr>
</table>

2.12. Snow Water Equivalent

The CIMR Snow Water Equivalent (SWE) baseline algorithm is a retrieval framework based on a radiative transfer model inversion coupled with data assimilation as implemented in similar fashion in the ESA DUE GlobSnow and ESA Snow CCI SWE products [Pulliainen, 1999; Takala *et al.*, 2011; Luojus *et al.*, 2021]. To adapt and optimize this algorithm to the CIMR sensor characteristics, we propose the following R&D activities:

- RD_SWE_001 is necessary to consolidate the baseline algorithm implementation and exploit the capabilities of CIMR.
- RD_SWE_002 shall contribute to the baseline algorithm verification and uncertainty characterization.
- RD_SWE_003 shall enhance the baseline algorithm implementation and further exploit the capabilities of CIMR.
- RD_SWE_004 shall contribute to the baseline algorithm verification and uncertainty characterization.

<table>
<tr><td>RD_SWE_001</td><td>Incorporation of X-band brightness temperatures</td><td>FMI</td><td>Complexity: Medium</td><td>Baseline: No</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
Previous studies highlight the benefit of X-band brightness temperatures for SWE retrieval purposes [Derksen (2008); Foster et al., 2011]. When combined with K-band brightness temperatures, the sensitivity to deep snowpacks is improved, preventing signal saturation while proving (mostly) insensitive to forest cover and related erroneous scattering effects. To date, this has not been applied in operational standalone passive microwave SWE retrievals, partially due to the coarse resolution of X-band data in comparison to Ka-band data. However, CIMR sensor characteristics encourage a review thereof for operational implementation in the L2 SWE product. The following R&D items shall be carried out to investigate the feasibility to implement X-band brightness temperatures in an operational environment:
• Review of SWE retrieval approaches incorporating X-band brightness temperatures.
• Investigation of combining X and K-band data to address signal saturation and vegetation effects on a global scale [e.g. Derksen (2008)].
• Comparison of brightness temperature difference against pure gradient ratio.</td></tr>
<tr><td colspan="5"><u>Expected impact:</u>
The R&D activity is necessary to ensure a comprehensive SWE retrieval framework exploiting CIMR sensor characteristics.</td></tr>
<tr><td colspan="5"><u>Approach to verify the impact:</u>
To verify that a suitable approach is selected, a comparison with independent ground-based reference SWE measurements shall be carried out.</td></tr>
<tr><td colspan="5"><u>Summary report (if selected for implementation):</u></td></tr>
<tr><td colspan="5"><u>Track Change / History:</u>
• 23-02-2024 Added (L. Zschenderlein)
• 06-11-2024 Not started (L. Zschenderlein)</td></tr>
</table>

RD_SWE_002	Investigation of non-satellite snow depth data	FMI	Complexity: High	Baseline: Yes

Rationale and summary: The proposed baseline approach relies on pointwise in situ depth observations and assimilates the same with passive microwave estimates to compute the final SWE map [Takala *et al.*, 2011; Luojus *et al.*, 2021]. Replacing those ground-based observations with other forms of non-satellite snow depth information may prove beneficial for algorithm performance, efficiency and/or NRT computation. The following R&D items shall be carried out to investigate possible alternatives to current pointwise observations: ● Comparison of sparse in situ measurements against available snow depth fields and now-cast data. ● Investigation of using a snow climatology in combination with machine learning. ● Evaluation of the available options for operational processing and implementation. ● Assessment of required further changes to the baseline algorithm required to adjust for the possible input of alternative non-satellite snow depth data.
Expected impact: The R&D activity is necessary to ensure optimal operability of the L2 SWE product by using appropriate non-satellite snow depth data.
Approach to verify the impact: To verify that a suitable approach is selected, a comparison with SWE estimates based on the original (kriged) ground-based SWE measurements shall be carried out.
Summary report (if selected for implementation):
Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Not started (L. Zschenderlein)

RD_SWE_003	SWE retrieval in mountainous and complex terrain	FMI	Complexity: High	Baseline: No
Rationale and summary: Current operational SWE retrieval approaches commonly mask out mountainous and/or complex terrain [Luojus *et al.*, 2021], because of large retrieval uncertainties due to coarse spatial resolution data and large local snow depth variability [Lievens *et al.*, 2019]. The high spatial resolution of CIMR brightness temperatures encourages a review of SWE retrieval feasibility and reliability in such areas. To address this, the following R&D items are proposed: ● Review of studies, campaigns and/or products using space- and/or airborne passive microwave snow observations in mountain regions [e.g. Pulliainen *et al.*, 2010b]. ● Angle studies through modelling using the Snow Microwave Radiative Transfer (SMRT) framework [Picard *et al.*, 2018], complementing a test SWE retrieval with adjusted incidence angles reflecting the terrain characteristics as observed by (ideally airborne) brightness temperature data over regions of interest. ● Assessment of prospective performance and uncertainty of SWE retrieval using CIMR brightness temperatures of high spatial resolution and investigation of possible algorithm adjustments.				

Expected impact: The R&D activity is necessary to ensure a spatially complete L2 SWE product, covering also mountainous and/or complex terrain.
Approach to verify the impact: To verify whether SWE retrieval can be reliably applied to mountainous and/or complex terran, comparisons with independent reference datasets (e.g. based on in situ, visible/NIR and/or active microwave data) shall be carried out.
Summary report (if selected for implementation):
Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Not started (L. Zschenderlein)

RD_SWE_004	Revision of uncertainty scheme	FMI	Complexity: Medium	Baseline: Yes
Rationale and summary: Depending on other R&D activities, the current uncertainty scheme [Luojus *et al.*, 2021] may have to be revised in order to provide accurate and traceable uncertainty estimates. The following R&D items are proposed to investigate required updates to the current uncertainty model: ● Determination of uncertainty inducing parts within the L2 SWE retrieval. ● Familiarisation with the punpy tool (as used in the CIMR-MACRAD project) and adaptation of the CIMR L2 SWE retrieval code for compatibility with punpy. ● Formulation of an updated uncertainty scheme.				
Expected impact: The R&D activity is expected to provide improved retrieval uncertainty estimates, thereby ensuring a high quality of the L2 SWE product.				
Approach to verify the impact: Comparison of uncertainty fields against e.g. land cover data or simulated scenes, to evaluate whether more realistic uncertainty estimates are being achieved.				
Summary report (if selected for implementation):				
Track Change / History: ● 23-02-2024 Added (L. Zschenderlein) ● 06-11-2024 Not started (L. Zschenderlein)				

2.13. Soil Freeze/Thaw State

The CIMR Soil Freeze and Thaw State (FT) baseline algorithm is a threshold detection approach, similar to SMOS and SMAP FT algorithms [Rautiainen *et al.*, 2016 and Derksen *et* *al.*, 2017]. Both are using passive microwave measurements at L-band frequency channel reserved for the radio astronomy. To expand the algorithm's capability and further exploit the CIMR sensor characteristics, we propose the following R&D activities:

- RD_FT_001 is necessary to consolidate the baseline algorithm implementation and exploit the capabilities of CIMR.
- RD_FT_002 is necessary to consolidate the baseline algorithm implementation and exploit the capabilities of CIMR.
- RD_FT_003 shall enhance the baseline algorithm implementation and further exploit the capabilities of CIMR.
- RD_FT_004 shall contribute to the baseline algorithm verification and uncertainty characterization.
- RD_FT_005 shall enable the use of the baseline algorithm from the beginning of the CIMR mission.

<table>
<tr><td>RD_FT_001</td><td>Soil state detection with combined use of L-band and C-band channels</td><td>FMI</td><td>Complexity: High</td><td>Baseline: Yes</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
L-band is recognized as the optimum channel for soil FT detection using passive microwave frequencies. C-band faces more challenges compared to L-band: the permittivity contrast between ice and free liquid water is lower, vegetation layer affects the signal more, the penetration depth to ground is smaller. Observations at C-band can provide early “warnings” on the onset of soil freezing. C-band also provides better spatial resolution. Even if the C-band information is from a different soil layer or only from the vegetation layer, C-band could be used to improve the overall spatial resolution provided by the L-band channel. The combined use of the two lowest CIMR frequency channels will provide additional information compared to the currently available operational soil FT products (SMOS and SMAP).
● Application of the FT baseline algorithm to AMSR2 brightness temperatures at 6.9GHz
● Assessment of the algorithm performance using C-band data through collocation with in situ soil temperature and soil moisture observations at various land covers
● Comparisons of SMOS and SMAP L-band FT estimates and AMSR2 FT estimates at different land cover types.
● Investigate how to use C-band data to pan-sharpen the L-band information to achieve better spatial resolution for the FT estimates.
● Review and investigate methods for combining the L-band and C-band data to provide the best possible product for the users.</td></tr>
<tr><td colspan="5"><u>Expected impact:</u>
The R&D activity is expected to improve the soil FT estimates, especially the timing of the onset of the soil freezing, which is of high importance e.g. for the methane emission models. In addition, the spatial resolution is expected to be improved.</td></tr>
<tr><td colspan="5"><u>Approach to verify the impact:</u>
To verify the use of combined product (L-band + C-band), comparisons with independent reference datasets (e.g. based on in situ, other FT products) shall be carried out.</td></tr>
</table>

Summary report (if selected for implementation):
Track Change / History: ● 26-02-2024 Added (K. Rautiainen) ● 06-11-2024 Not started (L. Zschenderlein)

RD_FT_002	Effect of the onset of snow cover	FMI	Complexity: High	Baseline: No
Rationale and summary: At L-band, the onset of dry snow cover affects the measurement signal in a similar way to ground freezing. Higher frequency channels are exploited to investigate how the onset of snow cover can be distinguished from the onset of soil freezing. The usefulness of using CIMR products such as TSA and LST are investigated. TSA provides information on the snow cover area. It is not fully clear what is the expected minimum depth of snow cover that TSA detects and what is the minimum depth of snow that affects the detection of soil freezing. ● Review of potential methods to detect the onset of snow cover, how to distinguish between dry and wet snow cover. ● Review of past studies and campaigns on the effect of the snow layer on the L-band and C-band brightness temperature – further investigation with emission models taking into account the snow/soil/vegetation layers. ● Investigation on the possibility of using CIMR TSA and LST products together with L- and C-band brightness temperatures.				
Expected impact: The R&D activity is expected to improve the soil FT estimates, especially the timing of the onset of the soil freezing by mitigating the uncertainties caused by the early snow onset.				
Approach to verify the impact: To verify the effects of the snow cover on the FT estimates and how these are correctly compensated, comparisons with independent reference datasets (e.g. based on in situ, other FT products) shall be carried out on selected test sites.				
Summary report (if selected for implementation):				
Track Change / History: ● 26-02-2024 Added (K. Rautiainen) ● 06-11-2024 Not started (L. Zschenderlein)				

RD_FT_003	Link between melting snow and thawing soil	FMI	Complexity: High	Baseline: No

Rationale and summary: In spring, the wet snow layer effectively blocks the emission from ground, limiting the direct observations of the soil thawing. However, the snow melt can be observed with CIMR channels. Different channels are providing information from the various depths of the snow layer. The idea is to investigate how to monitor the evolution of the snow melt, from the onset of snow melt to the final melt of all snow. This R&D action has synergies with the RD_TSA_001 R&D action from CIMR TSA. This R&D action aims to investigate how snow melt can be related to the soil thawing. The study requires currently available observations (satellite, tower-based, in-situ), physical snow model(s) and thermodynamical model(s). ● Review of potential methodologies and selection of viable approaches for operational use (Synergy with RD_TSA_001). ● Implementation of the wet snow detection module(s) (Synergy with RD_TSA_001). ● Review of snow models and thermodynamical models to link snow melt and soil thaw ● Development of a method to link snow melt and soil thaw
Expected impact: Snow cover and soil conditions (frozen/thawed) together with temperature and daylight availability determine the start of the growing season in spring. Frozen soil effectively limits the availability of water, and snow cover delays the warming of the soil. Melting snow can be observed directly from orbit, while it blocks direct observations from the ground. Linking snow melt to soil thaw would greatly improve estimates of soil FT states and the timing of soil thaw.
Approach to verify the impact: Verification of the wet snow detection method and the link between snow melt and soil thaw using existing tower or satellite (SMOS/SMAP AMSR2) based measurements, in-situ observations of snow and soil and snow and thermodynamic models
Summary report (if selected for implementation):
Track Change / History: ● 26-02-2024 Added (K. Rautiainen) ● 06-11-2024 Not started (L. Zschenderlein)

RD_FT_004, RD_TSA_002	Investigation of uncertainty characterization	FMI	Complexity: Medium	Baseline: Yes
Rationale and summary: We lack an established approach to quantify uncertainty estimates through uncertainty propagation for binary/classification products, such as the L2 FT and TSA products. The following R&D items shall be carried out to investigate the feasibility and possible implementation of a comprehensive uncertainty characterization: ● Review of applicable quantitative and/or qualitative uncertainty characterization approaches.				

• Investigation of the effect of brightness temperature uncertainties on the soil FT state detection results. • Implementation and assessment of feasible candidates for uncertainty characterization and flagging.
Expected impact: The R&D activity is necessary to establish comprehensive and traceable uncertainty estimates for FT maps. If found viable, this qualitative or quantitative uncertainty approach will be implemented in order to provide uncertainty flags as part of the L2 FT product.
Approach to verify the impact: To verify that a suitable uncertainty propagation/characterization approach is established, comparisons with independent reference datasets shall be carried out.
Summary report (if selected for implementation):
Track Change / History: • 23-02-2024 Added (L. Zschenderlein) • 26-02-2024 Updated (K. Rautiainen) • 06-11-2024 Not started (L. Zschenderlein)

RD_FT_005	Initial frozen and thaw ground references using existing satellite data (L and C-band)	FMI	Complexity: Low	Baseline: No
Rationale and summary: The soil FT algorithm is based on threshold detection approach and on empirically defined pixel-wise frozen and thaw ground references. Ultimately, these references are to be defined using CIMR observations. However, to provide estimates on soil FT state from the beginning of the mission, observations from SMOS (L-band) and AMSR2 (C-band) can be used to determine the initial references. Both missions cover the CIMR incidence angle. • Compile pixel-wise frozen and thaw ground references for L-band and C-band using SMOS and AMSR2 observations and CIMR incidence angles.				
Expected impact: Verification of the selected algorithm and detection method is possible from the beginning of the mission, similarly the performance of the algorithm can be assessed. However, one needs to remember that the performance is expected to improve after a full year of CIMR observations are acquired, required to define the references using CIMR data.				
Approach to verify the impact: The soil FT algorithm is tested with independent reference datasets (e.g. based on in situ, other FT products).				
Summary report (if selected for implementation):				

Track Change / History:
• 26-02-2024 Added (K. Rautiainen) • 06-11-2024 Not started (L. Zschenderlein)

2.14. Land Surface Temperature

The CIMR Land Surface Temperature (LST) baseline algorithm is a neural network retrieval proposed by [Prigent *et al.*, 2016; Jimenez *et al.*, 2017]. To adapt this algorithm to the CIMR sensor characteristics and provide improvements over the SOTA, we propose the following R&D activities:

- RD_LST_001 is necessary to consolidate the LST baseline algorithm implementation.
- RD_LST_002 shall establish an additional reference dataset to aid the uncertainty characterization of the baseline.
- RD_LST_003 shall improve the current SOTA and contribute to the consistency of LST estimates with other CIMR land products.
- RD_LST_004 expands the LST model over frozen land to include permanently frozen areas, particularly Greenland and Anctartica into an Ice Surface Temperature (IST) product.

<table>
<tr><td>RD_LST_001</td><td>Adaptation of the LST baseline algorithm to CIMR sensor characteristics</td><td>UVEG</td><td>Complexity: Medium</td><td>Baseline: Yes</td></tr>
<tr><td colspan="5"><u>Rationale and summary:</u>
The CIMR LST baseline algorithm is a neural network (NN) retrieval based on the methodology proposed by Prigent et al. [2016]. The original approach establishes a transfer function between SSM/I brightness temperature measurements at 19, 22, 37, and 89 GHz and a training dataset of LST estimates [Aires et al., 2001]. Monthly global emissivity maps [Aires et al., 2011] are added as auxiliary data. The following R&D activities shall be carried out to consolidate and evolve prototype V1:
• Consider the feasibility of extending the training dataset with the pairs of LST and TBs quality-controlled used in Phase 3 of the ESA CCI Land Surface Temperature product [Darren Ghent, 2023]. It includes inversions of observations from four microwave instruments (SSM/I, SSMIS, AMSR-E and AMSR2), and an updated TELSEM database using optimal interpolation for both cloudy and clear atmospheres.
• Develop LST estimation models for frozen land conditions: one for ascending and one for descending orbits.
• Further develop the uncertainty characterization with probabilistic models (e.g. TensorFlow Probability)</td></tr>
</table>

Expected impact: The R&D activity is necessary to establish a NN architecture that is ready to ingest CIMR brightness temperature measurements upon launch. The neural network parameters (weights and biases) will determine a transfer function that can be used to retrieve LST from CIMR available brightness temperatures. (Note: After launch, the parameters shall be refined based on training with CIMR K-/Ka-band measurements)
Approach to verify the impact: To verify that a suitable neural network architecture is established, the fit with the global training database shall be the first priority. Additionally, comparisons with independent reference datasets (e.g., ground-based, infrared-based, or microwave-based [see RD_LST_002]) shall be carried out.
Summary report (if selected for implementation): ● PDR: The prototype implemented for V1 is a sequential NN with four layers that was trained on a curated dataset of WindSat observations to emulate CIMR available frequencies and overpass times [Meissner *et al*., 2023], collocated ERA5 skin temperature, and TELSEM emissivities [Aires *et al*., 2001]. Two separate models have been developed, one for ascending and one for descending orbits, over non-frozen land conditions.
Track Change / History: ● 07-02-2024 (added by Moritz Link) ● 31-10-2024 started (María Piles, Moritz Link, and Andrés Terrer)

RD_LST_002	Develop a suite of alternative models to benchmark the baseline approach	UVEG	Complexity: Low	Baseline: No
Rationale and summary: To benchmark the proposed baseline approach, a linear regression model (similar to the one proposed by Holmes, et al. [2009]) as well as alternative non-linear approaches based on Gaussian Processes and regression trees shall be developed to confront the results obtained with our proposed NN. In addition, an independent reference dataset for evaluating the different algorithms shall be established. The following R&D activities are proposed: ● Develop a linear regression model to fit CIMR-like TBs to target LST. ● Develop a Gaussian Process Regression (GPR) model to fit CIMR-like TBs to target LST. Evaluate the feasibility of application in operations to provide both predictions and their associated uncertainty. ● Develop a model based on Regression Trees (e.g. RadomForest or XGBoost) to fit CIMR-like TBs to target LST. While these models typically excel at accuracy, it is important to note they have the limitation that they cannot exceed the range of values of the target variable used in training. ● Apart from the performance assessment using the training database, it would be ideal to have access to an independent LST reference dataset.This shall include all available infrared- or ground-based LST estimates, ideally as part of a CIMR LST MMD.				

Expected impact: The R&D activity shall assist the CIMR LST algorithm verification and uncertainty characterization in two ways: ● Compare the proposed NN approach with alternative state-of-the-art statistical approaches. The approaches should match the sensing depth, overpass time, and spatial support of the baseline algorithm ● Quantify the added value of the baseline algorithm over the use of a simple linear regression and over two alternative non-linear approaches: Gaussian Process Regression and Regression Trees.
Approach to verify the impact: The linear regression fit with the LST training dataset shall serve as a lower bound for uncertainties. Comparisons of the results obtained with the baseline NN approach, the linear regression, the GPR and the regression tree shall be carried out to confirm the choice of the NN as baseline.
Summary report (if selected for implementation)
Track Change / History: ● 07-02-2024 (added by Moritz Link) ● 31-10-2024 not started (María Piles, Moritz Link, and Andrés Terrer)

RD_LST_003	Investigation of physics-aware machine learning approaches for CIMR LST retrievals	UVEG	Complexity: High	Baseline: No
Rationale and summary: The CIMR baseline algorithm is based on a neural network that is trained to an LST reference dataset [Prigent *et al.* 2016]. While proven to be highly effective, this approach can lead to a number of potential shortcomings: ● The algorithm implicitly assumes that the reference dataset is unbiased and contains the dynamic range necessary to characterize LST globally. ● The algorithm performance can be degraded for extreme or unusual conditions, e.g., snow, ice, or below-zero temperatures [Prigent *et al.* 2016] (Note: this refers to the LST algorithm for non-permanently ice-covered conditions). ● The algorithm is dependent on auxiliary emissivity information (Note: Prigent *et al.* [2016] show that the auxiliary information can be omitted at the cost of accuracy). ● It is not straightforward to derive uncertainty estimates from the neural network retrievals. ● The algorithm is not constrained to respect physical consistency with other CIMR land products. To mitigate these potential shortcomings, a physics-aware machine-learning approach shall be developed. This approach shall include relevant physical constraints and domain knowledge, such as energy conservation, microwave radiative transfer, and surface scattering theory, into the architecture and/or cost function of the neural network.				

Expected impact:
The physics-informed machine learning approach shall:
- improve the accuracy of the retrieval over conditions that are poorly or sparsely represented in the training dataset,
- improve the generalization of the model to available input data (e.g., satellite data of different noise levels, overpass times, or potential RFI contamination),
- reduce the dependency on auxiliary data,
- improve the characterization of uncertainties,
- ultimately contribute to physical consistency with other CIMR land products (e.g., surface water fraction or terrestrial snow area).

Approach to verify the impact:
The improvements of the physics-aware machine learning approach shall be verified by comparison with the CIMR baseline algorithm and independent reference datasets.

Summary report (if selected for implementation)

Track Change / History:
- 07-02-2024 (added by Moritz Link)
- 04-11-2024 not started (María Piles)

RD_LST_004	Estimation of Land Ice Surface Temperature (LIST) over permanently frozen land including Greenland and Antarctica	UVEG	Complexity: High	Baseline: No

Rationale and summary:
There is a growing interest in the retrieval of LST over permanently frozen areas and, in particular, over Greenland and Antarctica. Retrieval of Land Ice Surface Temperature (LIST) is challenging due to ice sheets' unique surface characteristics, yet CIMR offers great capabilities to provide an IST product. T. Liu et al [2024] have recently demonstrated high accuracy on a variety of ML models to predict LIST over Antarctica from AMSR2 microwave brightness temperatures, including 18.7 (K) and 36.5 (Ka) GHz. We propose to expand our current developments to model LST over frozen land conditions to include Greenland and Antarctica in an LIST product. To develop and train a dedicated model to retrieve IST, the following R&D activities are needed:
- Review state-of-the-art LIST retrieval approaches with passive microwaves over Greenland and Antarctica.
- Curate a dedicated Brightness Temperature database for Greenland and Anctartica, based on K and Ka-band WindSat TBs and ERA5 skin and air temperatures
- Build and train a Neural Network to retrieve LIST over permanently frozen areas. Build a ML model based on Regression trees as a benchmark.

Expected impact:
- Providing LIST estimates over permanently frozen areas, including Greenland and Antarctica, will be valuable for derived products such as Surface Melting and downstream services. CIMR LIST estimates could also be helpful for other CIMR products such as freeze/thaw and SWE.

Approach to verify the impact: A Train-Test split validation approach would be followed to test the performance of the developed models. Additionally, comparisons with independent reference datasets such as in-situ stations from Antarctic Meteorological Research Center (AMRC) and NASA's swath IST products (MOD/MYD11_L2) shall be carried out.
Summary report (if selected for implementation)
Track Change / History: ● 02-04-2025 (added by Andrés Terrer and María Piles)

2.15. Surface Water Fraction

The baseline algorithm for retrieving Surface Water Fraction (SWF) is based on K-band brightness temperature measurements. It involves the creation of a lookup table for different environmental conditions and calculating a differential ratio for water detection on a pixel level. To adapt this algorithm to CIMR sensor characteristics and provide improvements over the SOTA, a list with a priority rank of the R&D activities is provided hereafter:

- RD_SWF_001: Consolidate the proposed V1 prototype by performing and initial performance assessment with reference datasets, assessing the need and impact of using CIMR SM/VOD fields and the CIMR hydrography target mask, and develop the uncertainty characterization.

- RD_SWF_002: Develop a ML-based SWF retrieval approach to account for non-linearities and exploit CIMR multi-frequency capabilities by assessing the benefits of different CIMR frequency combinations for SWF, and considering the benefits of a ML-based joint LST and SWF retrieval approach from K/Ka bands.

RD_SWF_001	Consolidation of the proposed baseline approach	UVEG	Complexity: Medium	Baseline Yes
Rationale and summary The baseline SWF algorithm for CIMR is inspired by the methodology outlined by Du et al. (2018), and utilizing the Double Differential Ratio (DDR) technique introduced by Du et al. (2016). The proposed algorithm for CIMR SWF estimation is based on K-band (18.7 GHz) TB data. The choice of K-band strategically balances high spatial resolution with minimal atmospheric disturbances such as oxygen absorption and cloud interference. K-band has successfully been applied for SWF estimation in previous studies (e.g. Du et al. (2017)). The following R&D activities shall be carried out to consolidate and evolve prototype V1: ● Perform an initial performance assessment of SWF retrievals by comparing them				

with LPDR SWF reference (Du et al., 2017) and through validation against the MODIS-SRTM (MOD44W) static open water database. ● Refine the proposed approach using the CIMR hydrology target mask and including a quality-control to screen out frozen land conditions based on CIMR L2 TSA and FT products as well as other filters TBD. ● Identify and quantify all sources of uncertainty in SWF retrieval, including those from Soil Moisture (SM), Vegetation Optical Depth (VOD), and the effects of assumptions like constant soil and water surface roughness.
Expected impact: The proposed prototype for SWF estimation utilizing the K-band (18.7 GHz) is designed to meet CIMR spatial resolution specifications (≤15 km), uncertainty (≤10%), and daily coverage. It shall be capable of detecting water, particularly in challenging weather conditions, and under (sparse) vegetation, and be consistent with CIMR hydrography target mask. The SWF could allow for enhanced retrievals of SM and MMVI in seasonally inundated areas.
Approach to verify the impact Validation of SWF retrievals by comparing them with LPDR SWF reference (Du et al., 2017) and through validation against the MODIS-SRTM (MOD44W) land water mask.
Summary report (if selected for implementation) ● PDR: For V1 prototype implementation, a Look-Up Table (LUT) with reference K-band microwave emissivities for a range of soil moisture (SM) and vegetation optical depth (VOD) values was created based on SWF estimations from the LPDR dataset (Du et al., 2017). Retrieval of SWF is obtained as the disparity between the observed emissivity and the reference pure land emissivity, relative to the difference in emissivities between pure water and pure land using the DDR.
Track Change / History: ● 23-02-2024 (added by Roberto Fernandez-Moran) ● 01-11-2024 started (Roberto Fernández-Moran and María Piles)

RD_SWF_002	Data-driven SWF retrieval approaches	UVEG	Complexity: Medium	Baseline: No
Rationale and summary By integrating advanced ML algorithms with multi-frequency data from CIMR, this proposal aims to overcome the limitations of conventional SWF retrieval techniques, which often fail to capture the complex interactions of environmental variables. The following activities are proposed to fully exploit CIMR multi-frequency capabilities at K/Ka-bands over non-frozen land: ● Development of ML-based Approach: A Machine Learning (ML)-based methodology to enhance the SWF retrieval, exploiting the full capabilities of CIMR by exploring complex non-linearities between channels and better capturing the spatiotemporal dynamics of the SWF. ● Simultaneous retrieval of LST and SWF from K and Ka bands through data-driven				

approaches, where some reference datasets must be established from satellite and in situ-based sources. Both machine learning and hybrid (physics-aware) approaches shall be considered.
Expected impact The aim is to decrease the reliance on SWF on other CIMR products and reduce the uncertainty in estimating both SWF and LST, while avoiding oversimplifications by imposing linear relationships.
Approach to verify the impact MODIS LST estimates and measurements from in-situ stations will be used as a benchmark to validate the different approaches.
Summary report (if selected for implementation)
Track Change / History: ● 23-02-2024 (added by Roberto Fernandez-Moran) ● 01-11-2024 not started (María Piles)

2.16. Soil moisture and microwave vegetation properties

The baseline retrieval algorithm chosen for the SM and MMVI products requires consolidation and adaptation of heritage approaches that have been proposed and validated with SMOS, SMAP, and AMSR-series data. Adaptation to CIMR geometry requires to account for the impact of different incidence angles for the case of L-band (which is a range of OZAs for SMOS and 40° for SMAP) and different overpass times for the case of C-/X-bands (which is 1.30 AM/PM for ASMR-series data). In addition, the analysis of vegetation properties with passive microwaves is challenging, given the inherent heterogeneity and variability of landscape conditions at the radiometer resolution and the lack of representative vegetation measurements at ecosystem scales. Also, up to now, retrievals have often been performed with observations from a single frequency. To adapt the baseline SM and MMVI algorithm to the CIMR sensor characteristics and provide improvements over the SOTA, we propose the following R&D activities:

- RD_SM_MMVI_001 is necessary to consolidate and prepare the CIMR SM (L) baseline algorithm.
- RD_SM_MMVI_002 is necessary to consolidate and prepare the CIMR SM (L-/C-/X-).
- RD_SM_MMVI_003 is necessary to consolidate and prepare the CIMR MMVI baseline algorithm.
- RD_SM_MMVI_004 shall improve L-band TB sharpening over land, which is central to the performance of SM L-/C-/X- and MMVI.
- RD_SM_MMVI_005 shall advance in the understanding and applicability of CIMR microwave multi-channel vegetation indicators.

RD_SM_MMVI_001	Consolidation of the CIMR SM (L) baseline algorithm	UVEG	Complexity: Medium	Baseline: Yes

<u>Rationale and summary</u>
The CIMR SM baseline algorithm relies on heritage approaches to estimate soil moisture from multi-angular L-band TBs from ESA's SMOS mission [Fernandez-Moran et al., 2017] or from L-band TBs at 40° OZA from NASA's SMAP mission [Chaubell et al., 2022]. These approaches rely on the use of global reanalysis data to account for the soil and skin temperature. The following R&D activities are proposed to consolidate and evolve prototype V1 to account for CIMR's unique sensor characteristics (OZA, available frequency channels):

- Curate and harmonize a dataset of SMOS 52.5° L-band (1.4 GHz) TB measurements (alternatively, SMAP 40° TB measurements). The dataset shall be matched with ground-based observations of the International Soil Moisture Network (ISMN) to enable verification. The dataset shall also be matched with coincident higher frequency datasets (e.g., the WindSat dataset of [Meissner, et al., 2023], AMSR2 data, and/or SSMIS data) to enable tests of the sharpening algorithm [RD_SM_MMVI_002] and joint R&D activities with MMVI and LST retrievals [see RD_SM_MMVI_003 and RD_LST_001].
- Application and testing of the algorithm of [Fernandez-Moran et al., 2017] to the curated dataset, with the following tasks to be completed:
    - Cost function selection (regularization via VOD and/or SM)
    - Cost function initialization (choice and methodology to derive initial values for VOD and/or SM)
    - Static auxiliary parameter calibration (derivation of global maps of vegetation scattering albedo ω and soil roughness parameter *h* adjusted to the CIMR incidence angle at L-band)
    - Dynamic auxiliary data choice (land surface temperature from ECMWF or CIMR LST retrievals [see RD_LST_001])

<u>Expected impact</u>
The R&D activity is necessary to establish a cost function architecture, initialization, and static auxiliary data layer that is suitable to ingest CIMR L-band TB measurements upon launch. The activity shall also provide a recommendation on a suitable dynamic auxiliary dataset of land surface temperature.

<u>Approach to verify the impact</u>
The verification of the algorithm shall be based on comparisons with ground-based SM reference estimates from the ISMN (Dorigo et al., 2021) and model-based reference estimates from ECMWF ERA5-land (Muñoz-Sabater et al., 2021).

<u>Summary report (if selected for implementation)</u>

- PDR: In the prototype developed for V1, an initial strategy for CIMR L2 SM (L) has been implemented and demonstrated using a CIMR simulated test scene.

<u>Track Change / History:</u>

- 16-02-2024 (added by Moritz Link/María Piles/Roberto Fernandez-Moran)
- 01-11-2024 started (Moritz Link and María Piles)

RD_SM_MMVI_002	Consolidation of the CIMR SM (L-/C-/X-) baseline algorithm	UVEG	Complexity: Low	Baseline: Yes
Rationale and summary CIMR will provide an enhanced resolution SM product (≤ 15 km resolution), which relies on a sharpening procedure to combine L-band TB measurements with higher-resolution C/X-band TB measurements. SFIM is the main heritage algorithm for sharpening multi-frequency radiometric observations [Santi, et al., 2010] and shall be the basis for sharpening CIMR L-band TBs by means of higher resolution C-/X-band. While SFIM has been tested extensively at higher frequencies (on AMSR-series), it has not yet been applied to sharpen L-band observations with C-band observations. Crucially, the sharpening of L-band TB measurements with both C-band and X-band measurements shall be assessed, which can provide resilience to possible RFI contamination. CIMR also has different overpass times than the AMSR-series. Consequently, the performance and uncertainties of SFIM under the unique conditions of CIMR are yet to be quantified. This is necessary to assess uncertainties in downstream products (L2 SM L-/C-/X- and MMVI). The following R&D activities are proposed to consolidate the L-band sharpening approach on V1 prototype: ● Application and testing of the proposed L-band sharpening algorithm to the curated dataset of L/C/X-band radiometric observations from [RD_SM_MMVI_001]. ● Quantification of uncertainties of the sharpening procedure. This shall include using X-band in the sharpening when RFI affects the C-band. ● Note: The MMVI algorithm relies on the same sharpening procedure as is tested here.				
Expected impact The R&D activity is necessary to consolidate the CIMR L-band baseline sharpening algorithm and characterize its uncertainties. This is a necessary precondition to quantify uncertainties in downstream products (L2 SM L-/C-/X- and MMVI).				
Approach to verify the impact The verification of the algorithm shall be based on comparisons with ground-based SM reference estimates from ISMN and model-based reference estimates from ECMWF ERA5-land.				
Summary report (if selected for implementation) ● PDR: In the prototype developed for V1, an initial strategy for CIMR L-band sharpening using C- or X-bands based on an adaptation of SFIM has been implemented and demonstrated using a CIMR simulated test scene.				
Track Change / History: ● 26-02-2024 (added by Moritz Link) ● 01-11-2024 started (Moritz Link and María Piles)				

RD_SM_MMVI_003	Consolidation of the CIMR MMVI baseline algorithm	UVEG	Complexity: Medium	Baseline: Yes
Rationale and summary Across CIMR bands, L-band has the highest sensitivity to SM, whereas L-, C-, and X-bands have a unique sensitivity to different parts of the canopy. The proposed retrieval				

approach is based on the use of SM (L-/C-/X-) as an input to estimate vegetation attenuation (VOD) and scattering albedo (ω) parameters from L-, C-, and X-bands, following the approach of [Baur et al., 2021]. MMVI estimation involves inversion of the tau-omega model three times, one per each channel (L-, C-, and X-) and minimization of a regularized cost function. Prior studies commonly assume ω to be a time-invariant calibration parameter (globally or per land use class), but this assumption may lead to improper representation of vegetation dynamics given the strong association between ω and VOD in tau-omega model, particularly when the canopy is sensed at different frequency channels, as is the case for CIMR. The following R&D activities are foreseen to consolidate and evolve prototype V1: ● Application and testing of the algorithm of [Baur et al., 2021] to the curated dataset of L/C/X-band data from [RD_SM_MMVI_001], with the following tasks to be completed: ○ Cost function selection (regularization via two consecutive overpasses) ○ Cost function initialization (choice and methodology to derive initial values for VOD and/or albedo) ○ Derivation of a global map of roughness per frequency. One global value could be chosen following from the empirical formula by [Montpetit et al., 2015] although alternative roughness maps shall be considered. ○ Dynamic auxiliary data choice (land surface temperature from ECMWF or CIMR LST retrievals [see RD_LST_001]) ● Curate and harmonize an analysis-ready dataset with vegetation indicators for indirect evaluation of MMVI estimates. It shall include optical indices such as Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI), existing VOD products from SMAP/SMOS and AMSR-series, canopy height and above ground biomass.
Expected impact The multi-frequency capability of CIMR will, for the first time, allow for a complete characterization from a single platform of a set of Microwave Multichannel Vegetation Indicators (MMVI) to characterize water and biomass properties of different vegetation compartments e.g. stems, branches, leaves, and buds. This R&D activity is necessary to consolidate the CIMR MMVI baseline algorithm and characterize its uncertainties. Note: the retrieval and uncertainty quantification of scattering albedo have no operational heritage and thus have an overall low SRL.
Approach to verify the impact The verification of the algorithm shall be based on indirect evaluation of vegetation dynamics: (1) spatio-temporal agreement with optical indices (correlation should be stronger in low vegetation areas where optical indices do not saturate) and existing VOD products, (2) analysis of temporal signatures of VODs, NDVI, LAI on specific sites, (3) spatio-temporal agreement at annual scales with canopy height, density, and above-ground biomass.
Summary report (if selected for implementation) ● PDR: In the prototype developed for V1, an initial strategy for CIMR MMVI has been implemented and demonstrated using a CIMR simulated test scene.
Track Change / History:

- 26-02-2024 (added by María Piles)
- 01-11-2024 started (Moritz Link and María Piles)

RD_SM_MMVI_004	Investigation of enhanced L-band sharpening algorithms for CIMR	UVEG	Complexity: Medium	Baseline: No

Rationale and summary
SFIM is the main heritage algorithm for sharpening multi-frequency radiometric observations [Santi, et al., 2010] and a variation of it shall be developed as a baseline for CIMR. However, more complex procedures shall be explored, which shall, amongst others, aim to improve the variance and slope matching of SFIM and explore potential non-linear effects not captured by SFIM.The following R&D activities shall be carried out:

- Exploration and testing of advanced L-band sharpening approaches beyond SFIM (such as linear regression or machine-learning-based approaches). The L/C/X-band dataset created in [RD_SM_MMVI_001] shall be used for this.
- Quantification of uncertainties of the sharpening procedures.

Expected impact
The R&D activity shall improve the performance of the L-band sharpening algorithm, which shall improve the performance of downstream products (L2 high-resolution SM and MMVI).

Approach to verify the impact
The verification of the algorithm shall be based on comparisons with ground-based SM reference estimates from ISMN and model-based reference estimates from ECMWF ERA5-land.

Summary report (if selected for implementation)

Track Change / History:

- 26-02-2024 (added by Moritz Link)
- 04-11-2024 not started (María Piles)

RD_SM_MMVI_005	Investigation of microwave multi-channel vegetation sensing capabilities	UVEG	Complexity: High	Baseline: No

Rationale and summary
The CIMR MMVI L2 product shall use soil moisture information (from the inversion of sharpened L-band TB measurements) as an input to invert the tau-omega radiative transfer model and estimate time-dynamic vegetation attenuation and scattering from CIMR L-, C-, and X-bands, one frequency at a time (following [Baur et al., 2021]). The spatial scale of CIMR MMVI (of about 15 km) is still coarse for the relation of the obtained parameters to individual plant properties such as water content or biomass of different plant

<table>
<tr><td>compartments. Yet, these new vegetation measurements shall relate to emerging ecosystem properties, i.e. properties that become apparent and result from various interacting components within a system but do not belong to the individual components themselves. The proposed work will:
Develop a multi-frequency advanced retrieval algorithm to perform a joint retrieval of VOD and vegetation scattering albedo from L-/C-/X-bands. Our working hypothesis is that CIMR multi-frequency TBs shall allow for the joint retrieval of microwave vegetation parameters, provided some landscape properties can be scaled across frequencies.
Investigate the relation of microwave vegetation indicators with models or collections of in situ measurements and satellite estimates, such as above-ground biomass, Live Fuel Moisture Content (LFMC), and canopy density, structure, and height. Ultimately, the combination of these factors shall allow relating MMVI to plant hydraulic traits and soil-vegetation-atmosphere fluxes.
Investigate the development of a forward operator directly relating TB measurements to the ecosystem-scale properties mentioned above. This task will allow evaluation of the sensitivity of the different CIMR frequencies to the vegetation parameters at regional and global scale and complement radiative transfer simulations, which may not be able to represent the full complexity of emission mechanisms over land.</td></tr>
<tr><td><u>Expected impact</u>
Identify relationships between MMVI and emerging ecosystem properties.
Extend current Copernicus vegetation sensing capabilities -mainly based on optical data- with microwave multichannel vegetation parameters to monitor vegetation leafy and woody components, water status, and aboveground biomass at the ecosystem scale (≤ 15 km).</td></tr>
<tr><td><u>Approach to verify the impact</u>
The verification of the algorithm shall be based on comparisons with available modeled or ground-based measurements of vegetation properties (e.g., LFMC) and with lidar and radar-based estimates of canopy height, density, and above-ground biomass.</td></tr>
<tr><td><u>Summary report (if selected for implementation)</u></td></tr>
<tr><td>Track Change / History:
26-02-2024 (added by María Piles)
04-11-2024 not started (María Piles)</td></tr>
</table>

2.17. Integrated retrievals

3. Status of Evolution of Algorithms

This section is empty in V1. In later versions, it will capture the list of R&D items, those that are started, and their progression.

R&D item ID	*Team responsible*	*Progress*		
		Not started	*Started*	*Completed*
RD_Overall_001	*METNO*	*x*		
RD_Overall_002	*METNO*	*x*		
RD_Bridge_001	*METNO & ODL*		*x*	
RD_Bridge_002	*UVEG*		*x*	
RD_Bridge_003	*DMI*		*x*	
RD_Bridge_004	*ODL*	*x*		
RD_Bridge_005	*N/A*	*x*		
RD_Bridge_006	*S&T*	*x*		
RD_SIC_001	*METNO*	*x*		
RD_SIC_001	*METNO*	*x*		
RD_SIC_001	*METNO*	*x*		
RD_LIC_001	*METNO*	*x*		
RD_SID_001	*METNO*	*x*		
RD_SID_002	*METNO*	*x*		
RD_SID_003	*METNO*	*x*		
RD_TSIT_01	*UBremen*	*x*		
RD_TSIT_02	*UBremen*	*x*		
RD_TSIT_03	*UBremen*	*x*		
RD_TSIT_04	*UBremen*	*x*		
RD_TSIT_05	*UBremen*	*x*		
RD_TSIT_06	*UBremen*		*x*	

RD_SITS_01	*UBremen, METNO*	*x*		
RD_SITS_02	*UBremen*	*x*		
RD_SITS_03	*UBremen, METNO*	*x*		
RD_SITS_04	*UBremen*	*x*		
RD_SITS_05	*UBremen*	*x*		
RD_SITS_06	*UBremen*	*x*		
RD_SIST_001	*DMI*	*x*		
RD_SIST_002	*DMI*		*x*	
RD_SIST_003	*DMI*	*x*		
RD_OWV_001	*ODL*	*x*		
RD_OWV_002	*ODL*	*x*		
RD_OWV_003	*ODL*	*x*		
RD_SST_001	*DMI*		*x*	
RD_SST_002	*DMI*	*x*		
RD_SST_003	*DMI*	*x*		
RD_SST_004	*DMI*	*x*		
RD_LSWT_001	*DMI*		*x*	
RD_LSWT_002	*DMI*	*x*		
RD_SSS_001	*ODL*	*x*		
RD_SSS_002	*ODL*	*x*		
RD_SSS_003	*ODL*	*x*		
RD_SSS_004	*ODL*	*x*		
RD_TSA_001	*FMI*	*x*		
RD_TSA_002	*FMI*		*x*	
RD_TSA_003	*FMI*	*x*		
RD_TSA_004	*FMI*		*x*	

RD_SWE_001	*FMI*	*x*		
RD_SWE_002	*FMI*	*x*		
RD_SWE_003	*FMI*	*x*		
RD_SWE_004	*FMI*	*x*		
RD_FT_001	*FMI*	*x*		
RD_FT_002	*FMI*	*x*		
RD_FT_003	*FMI*	*x*		
RD_FT_004	*FMI*	*x*		
RD_FT_005	*FMI*	*x*		
RD_LST_001	*UVEG*		*x*	
RD_LST_002	*UVEG*	*x*		
RD_LST_003	*UVEG*	*x*		
RD_SWF_001	*UVEG*		*x*	
RD_SWF_002	*UVEG*	*x*		
RD_SM_MMVI_001	*UVEG*		*x*	
RD_SM_MMVI_002	*UVEG*		*x*	
RD_SM_MMVI_003	*UVEG*		*x*	
RD_SM_MMVI_004	*UVEG*	*x*		
RD_SM_MMVI_005	*UVEG*	*x*		

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