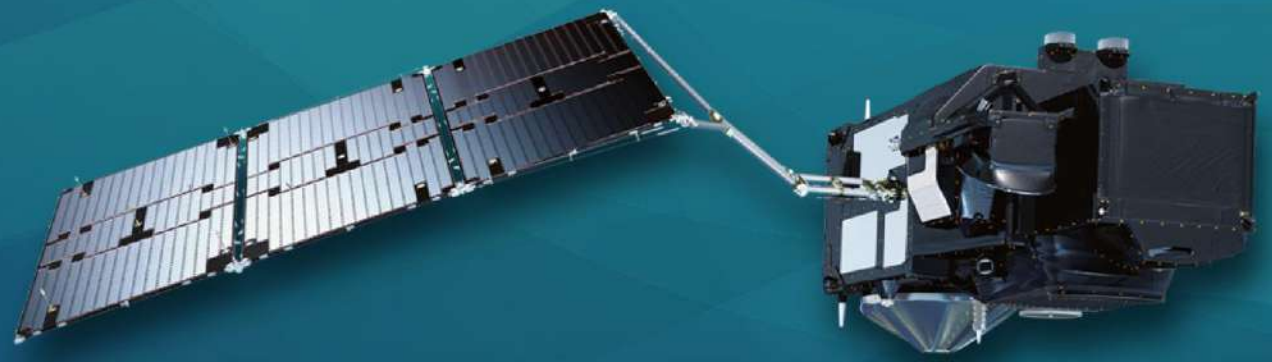
PROGRAMME OF THE EUROPEAN UNION

opernicus Europe's eyes on Earth

EUMETSAT

co-funded with esa



9th Sentinel-3 Validation Team meeting 2026

30 March–01 April 2026 | ESA–ESRIN | Frascati (Rome), Italy

Results of the Sea-Ice Thickness Intercomparison Exercise (SIN'XS) Project

C. Ribere[1], V. Ludwig[2], S. Fleury[3], C. Haas[2], M. Tsamados[4], V. Boulenger[1], J. Sarrau[1], J. Pastor[1], A. Carret[3], L. Amarouche[5], A. S-G Chaumet[5], M. El Hajj[1], J. Bouffard[5], M. Scagliola[5], and A. Di Bella[5]

1- NOVELTIS, 2- AWI, 3- LEGOS, 4- UCL, 5- CLS, 6-ESA

NOVELTIS AWI LEGOS from space to core earthsciences UCL CLS COLLECTE LOCALISATION SATELLITES

Context & Objectives

- Sea ice: Recognized as an Essential Climate Variable
  - Important component of the world's ocean and cryosphere
  - Sensitive climate change indicator
  - Highly variable on seasonal, interannual, and decadal scales
- Challenges for the measure of Sea Ice Thickness -> **Large number of different ice and snow thickness products**

SIN'XS
Sea Ice thickness iNter-comparison eXerciSe

An ESA project

Conducted by NOVELTIS, AWI, LEGOS, UCL and CLS

SIN'XS aims to provide a structured and coordinated framework to compare, document, and assess these products across both the Arctic and Antarctic.

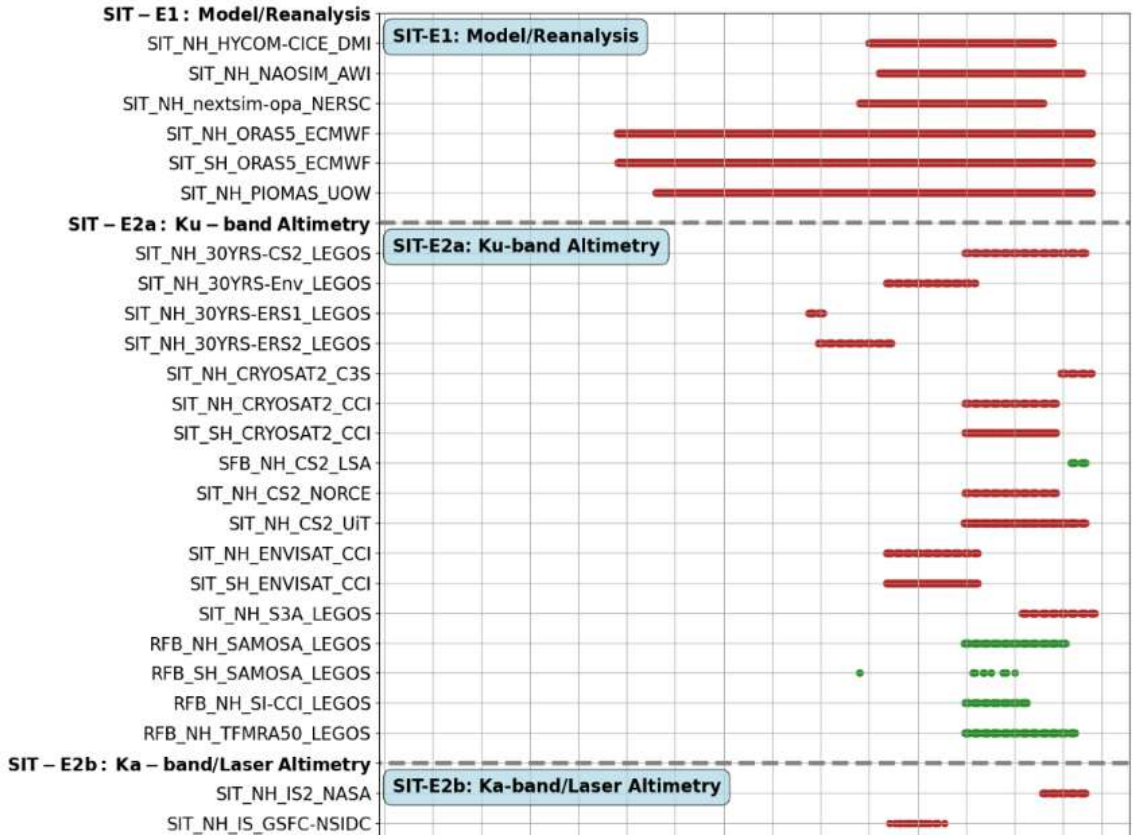
Achievements

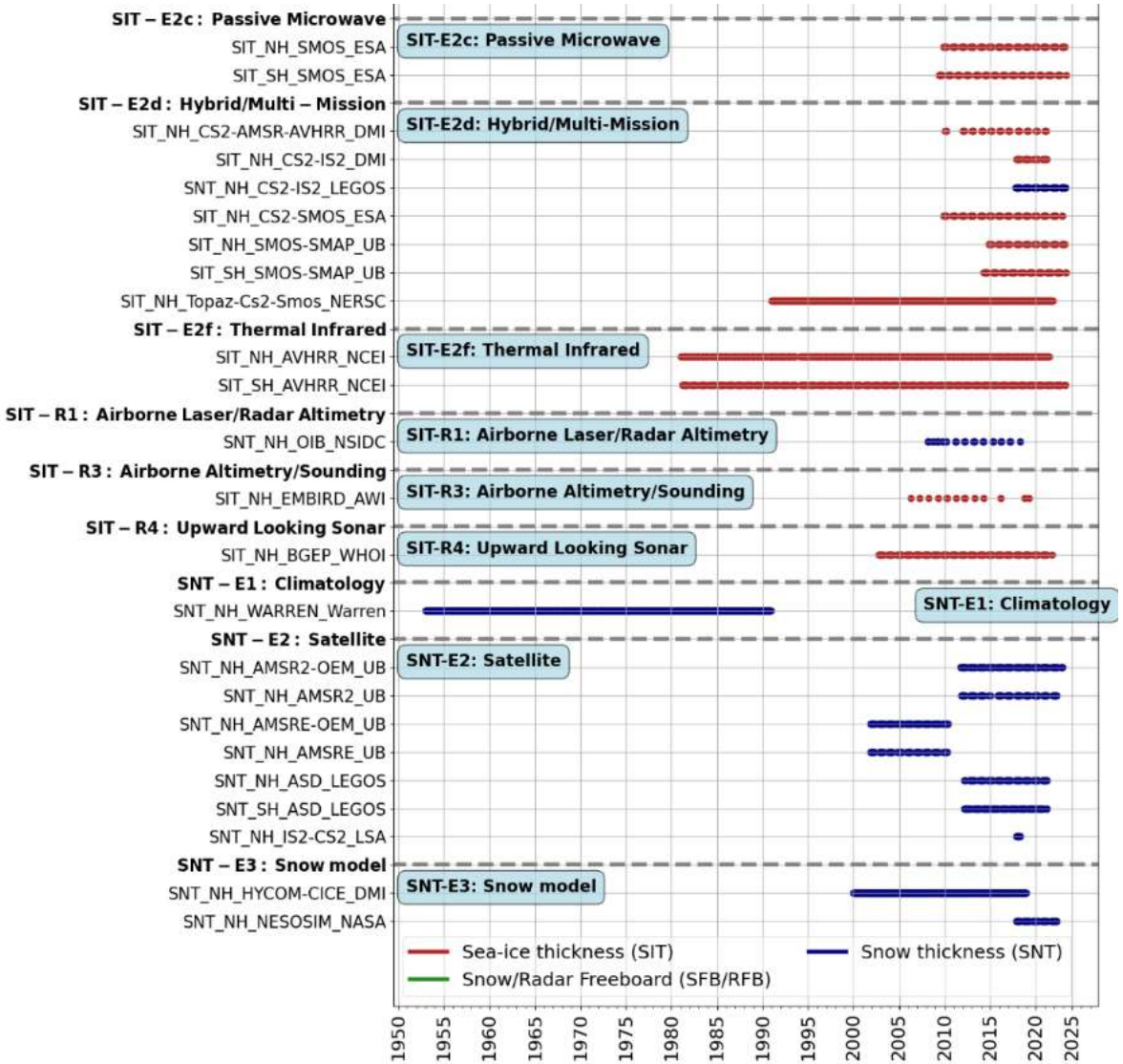
1. A global unique sea ice database

- **41 datasets**
- **Wide range of space observations and models**
  - Numerical models and reanalyses (e.g. PIOMAS, ORAS5, NESOSIM, HYCOM-CICE ...)
  - Satellite and hybrid products (e.g. Sentinel-3, CryoSat-2, IceSAT-2, SMOS, AMSR ...)
  - Climatology (e.g. Warren ...)
  - Reference SIT and SNT datasets (e.g. OIB, IceBird, BGEP ULS ...)
- **Arctic and Antarctic coverage**
- **Focus on SIT and SNT parameters**

1. A global unique sea ice database

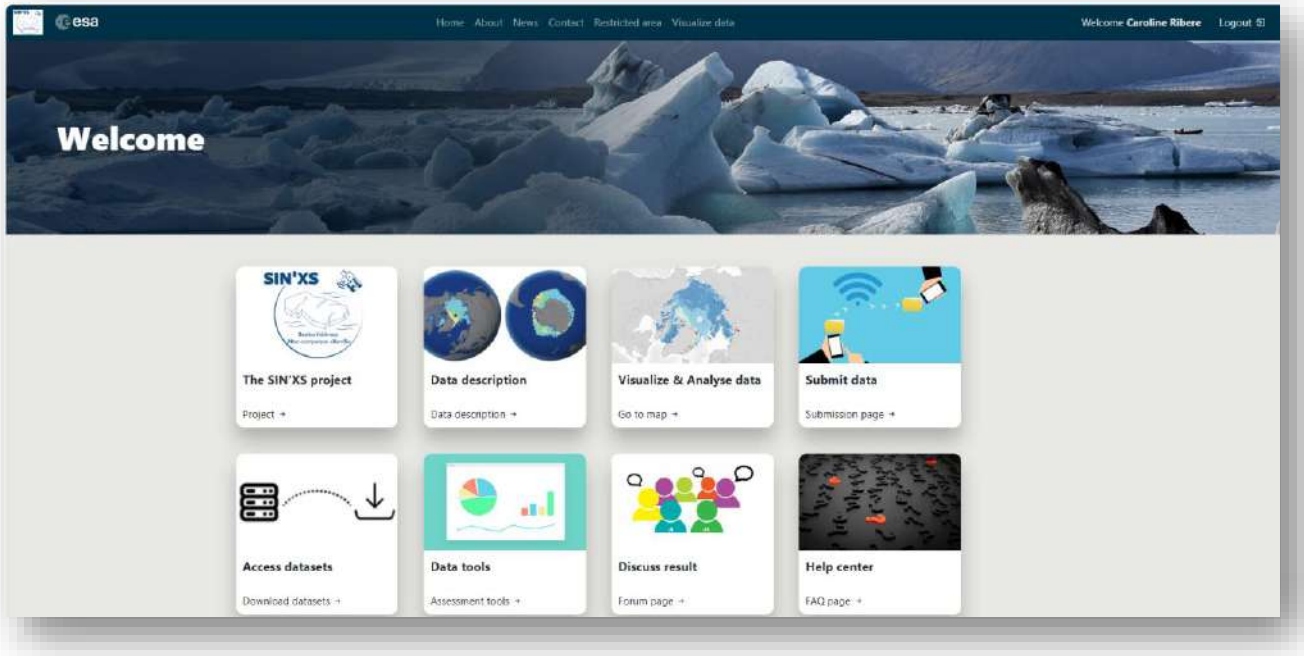
› Temporal coverage





2. SIN'XS Assessment protocol: a framework for evaluating the datasets

› A dedicated platform: https://sinxs-tools.noveltis.fr/



› Comparison with reference data

- Using airborne or in-situ measurements

› Sensitivity analysis

- Understand how uncertainties

can impact the final data product

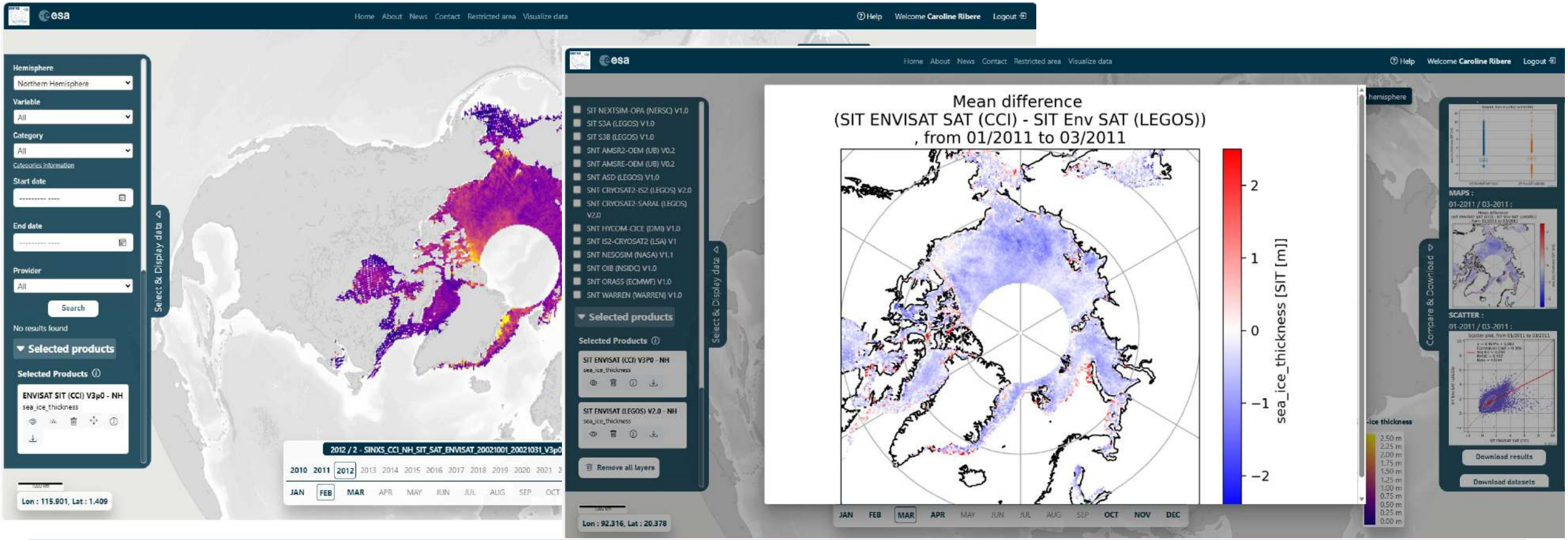
- Guide more informed use

› Inter-comparison of datasets

- Direct comparison with statistical plots
- Difference analysis to identify biases and agreement between datasets

2. SIN'XS Assessment protocol: a framework for evaluating the datasets

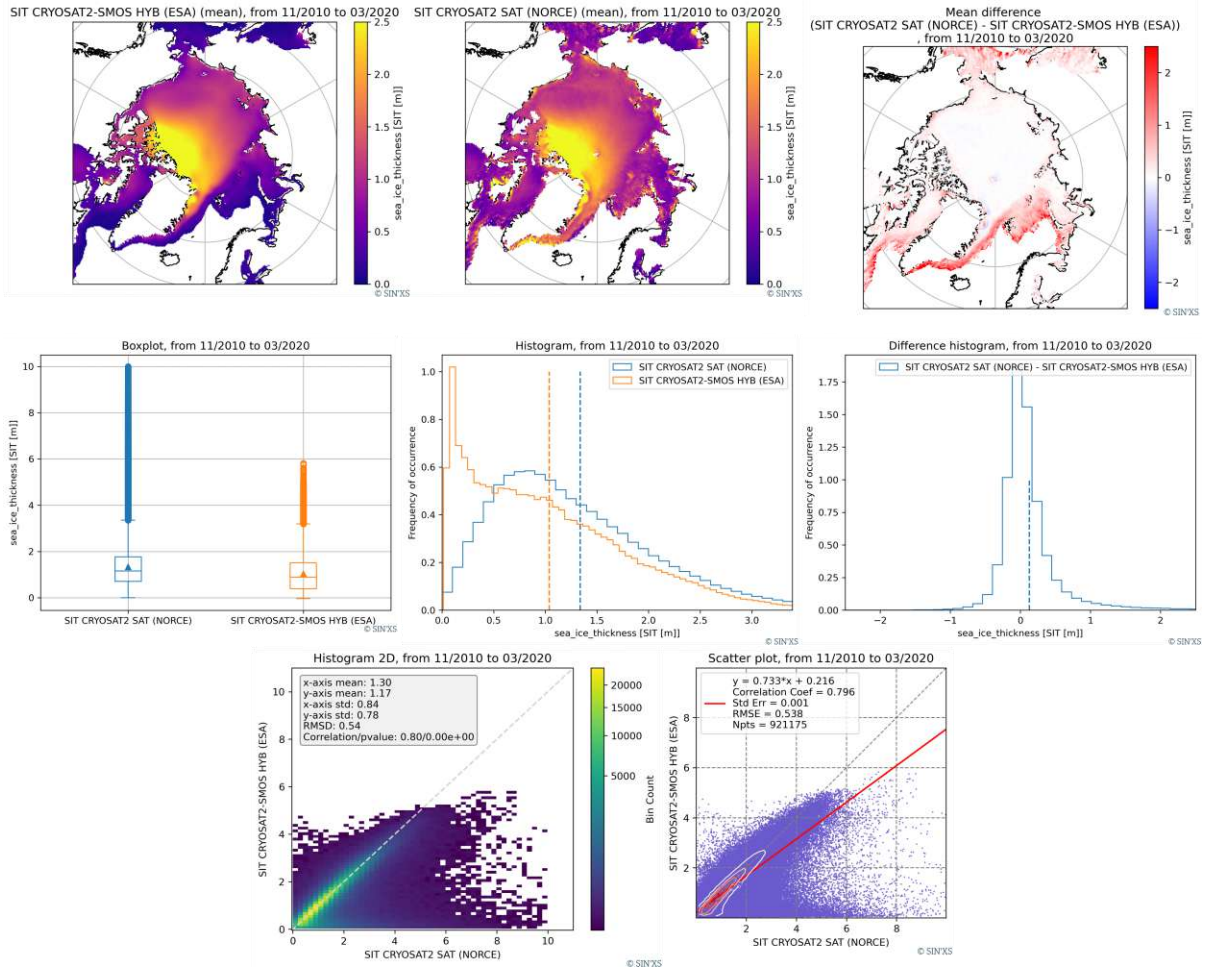
› Visualisation and comparison functionalities



2. SIN'XS Assessment protocol: a framework for evaluating the datasets

› Statistical evaluation

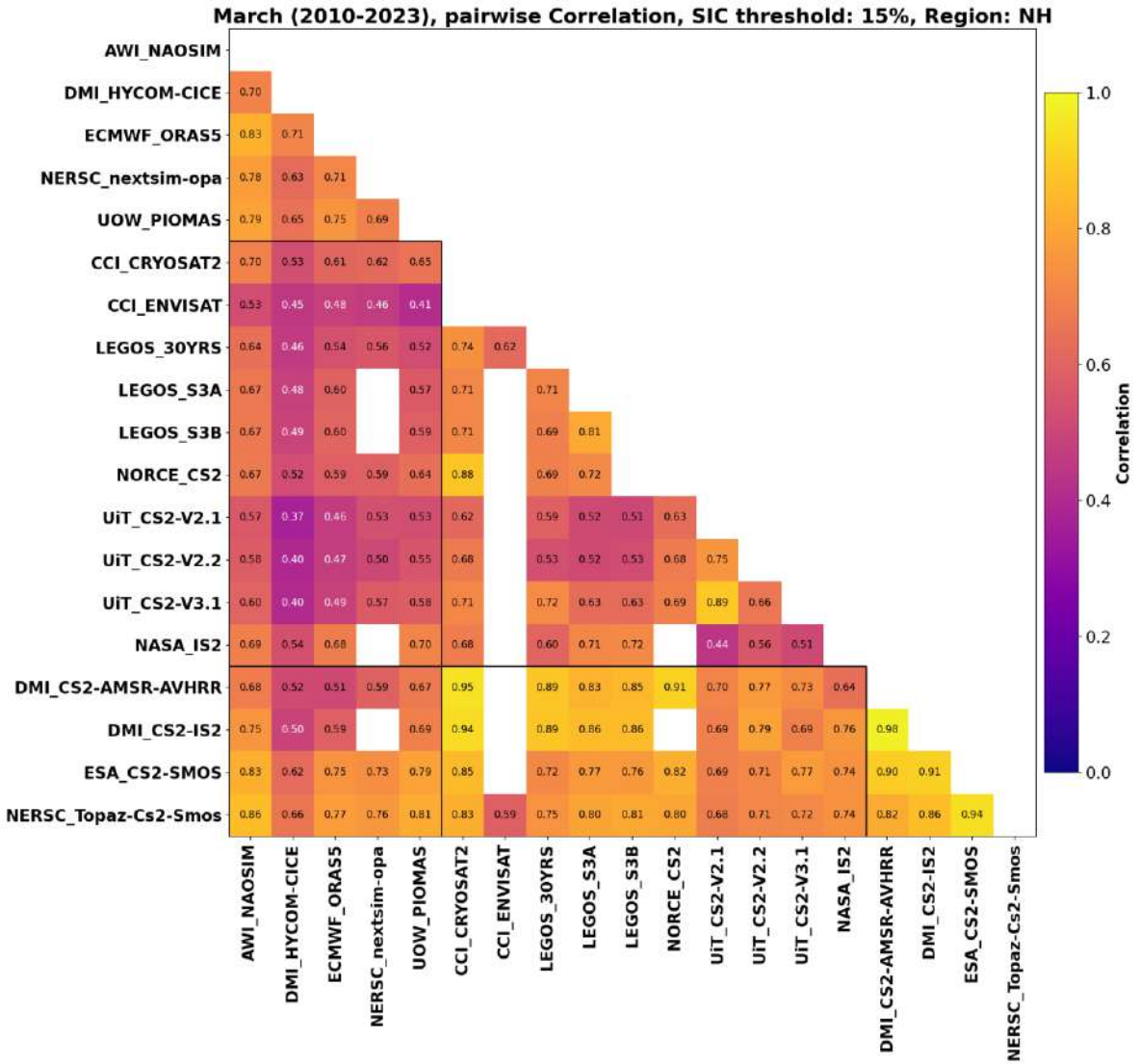
- High-performance calculation: results in less than 1 minute despite large volume
- Example comparison of the drift-aware CryoSat-2 product from NORCE and a CryoSat-2/SMOS hybrid
- Spatial patterns consistent across the two datasets, differences occurring at the ice margins due to the influence of SMOS data in the hybrid product
- CS2/SMOS hybrid product: on average 13 cm thinner, with a slightly broader distribution
- Correlation of 0.8 relative to the CryoSat-2-only dataset



2. SIN'XS Assessment protocol

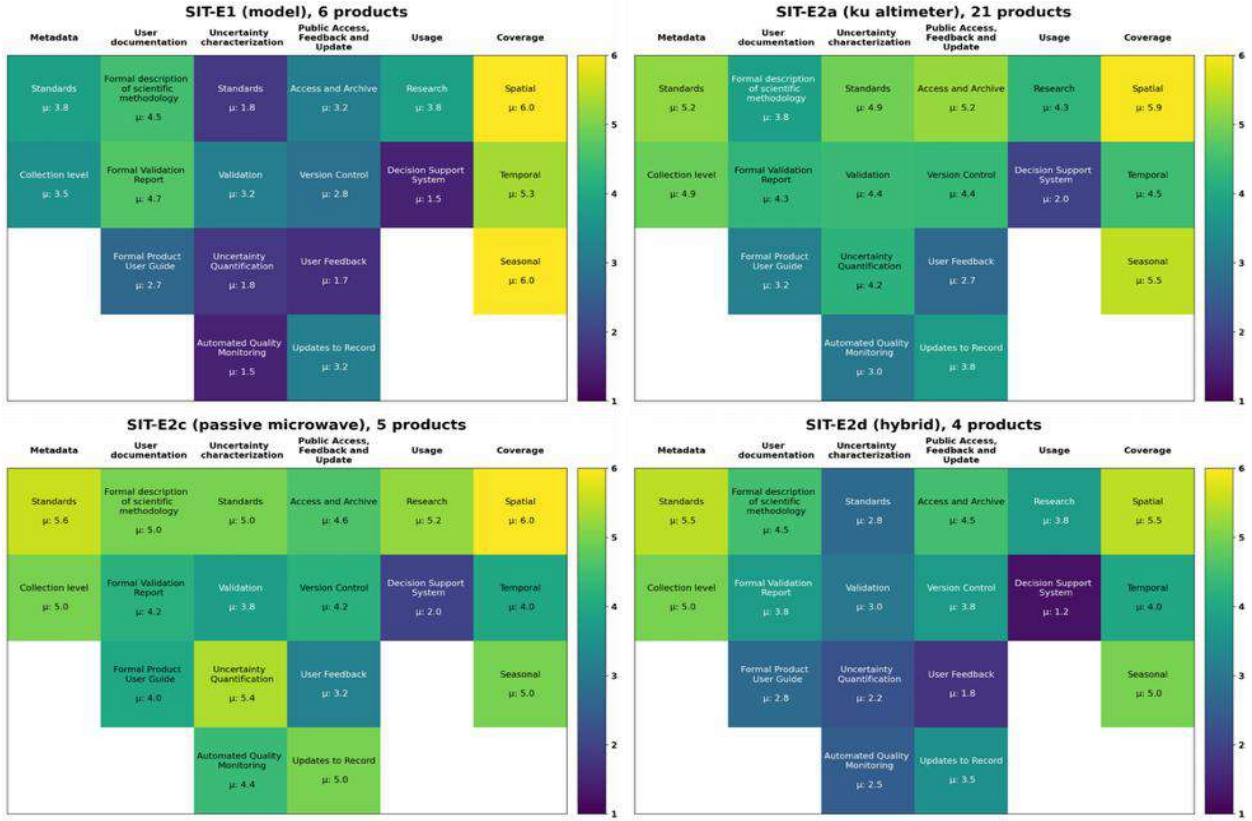
› Pairwise correlation

- Calculated for all datasets with adequate temporal and spatial overlap in March between 2010 and 2023
- Correlation: 0.41 to 0.98, with most values between 0.6 and 0.8
- Model-satellite correlations: lower / Hybrid-satellite correlations: highest (due to assimilation of satellite observations into hybrid products)
- Products derived from the same sensor (CryoSat-2): not always highly correlated, influence of factors such as snow thickness assumptions, density choices, and retracker algorithms

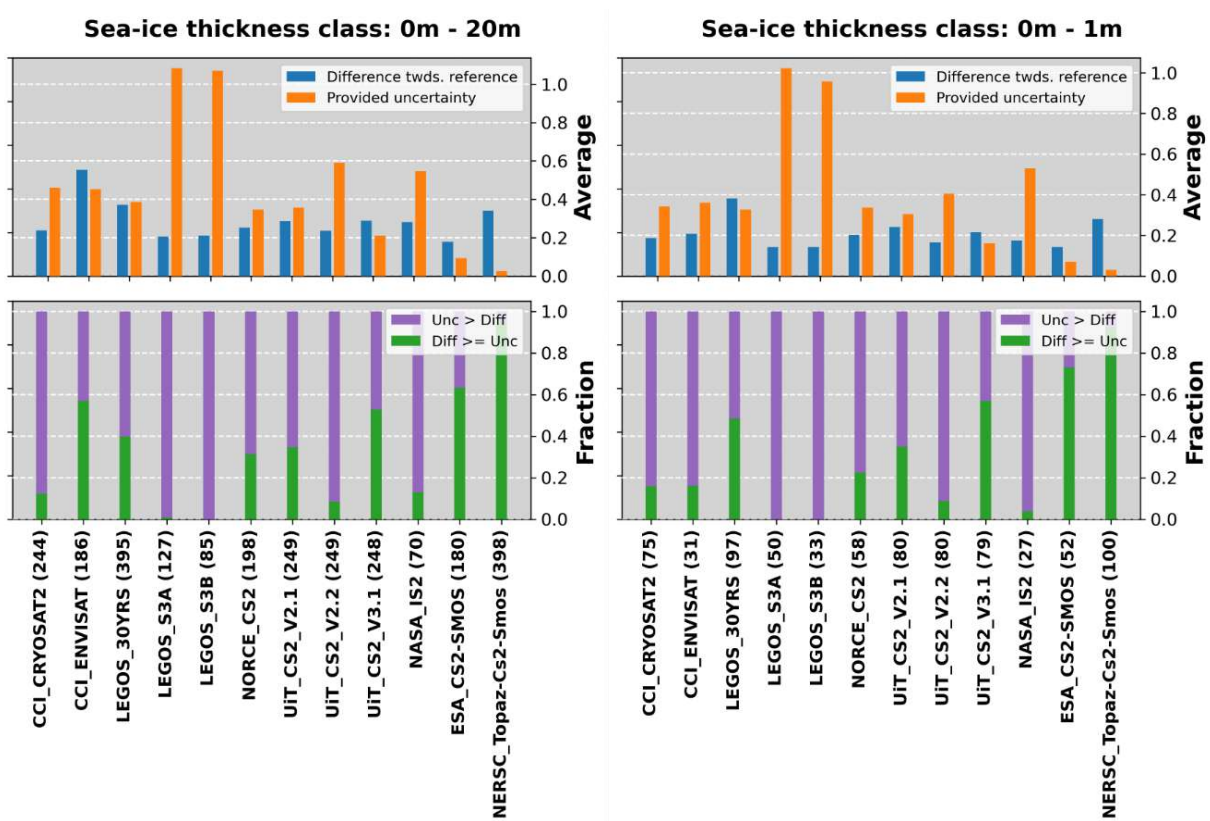


2. SIN'XS Assessment protocol

› Maturity Matrices



› Comparison of uncertainties



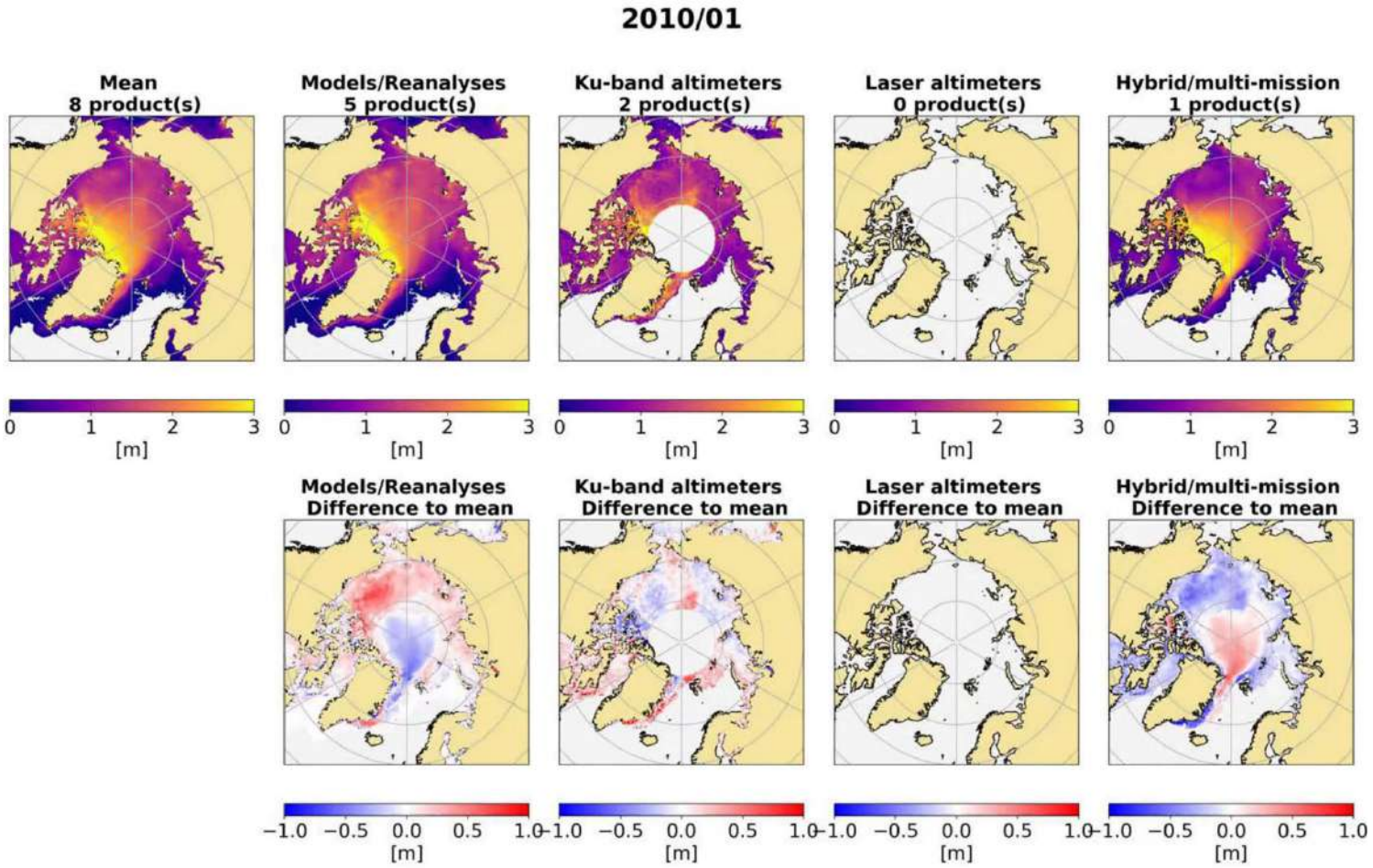
3. Towards a reconciled SIT estimate

- **A central objective: deliver to the community a best-guess product that synthetises all available datasets while capitalising on their respective strengths.**
- **Products combined in categories using arithmetic means**
  - Models/reanalyses
  - Ku-band altimeters
  - Ka-band altimeters
  - Hybrid products
- **Category-level averages combined to form cross-category estimate**

3. Towards a reconciled SIT estimate

› Results

- Cross-category and category-wide averages
- Produced monthly from January 2010 to April 2024
- Highlight areas of agreement and divergence between datasets
- Core outcome of the project



4. Scientific community engagement & Promotion

- Scientific Advisory Board (29 members) and Stakeholder Board (21 members)
- Two scientific papers under review: Scientific Data (Nature research), The Cryosphere

A community-provided collection of quality-controlled and standardized sea-ice and snow thickness datasets

Valentin Ludwig[1*], Caroline Ribere[2], Sara Fleury[3], Christian Haas[1], Michel Tsamados[4], Alessandro Di Bella[5], Vincent Boulenger[2], Eric Munesa[2], Javier Pastor[2], Jaoudat Sabalbal[2], Mahmoud El Hajj[2], Carole Belot[2], Elodie Da Silva[2], Stefan Hendricks[1], Stephan Paul[1], Michele Scagliola[5], and Jerome Bouffard[5]

Comprehensive assessment of model, reanalysis, satellite and hybrid sea-ice thickness products in the Arctic

V. Ludwig, C. Ribere, S. Fleury, C. Haas, M. Tsamados, M. El Hajj, J. Bouffard, M. Scagliola, M. Bocquet, E. de Boisseson, G. Boutin, L. Connor, L. Edel, S. Hendricks, F. Hernández-Macià, M. Huntemann, L. Kaleschke, F. Kauker, J. Landy, T. Megain, A. Petty, T. Rasmussen, Mads Hvid Ribergaard, R. Ricker, A. Schweiger, H. Shi, X. Tian-Kunze, D. Yi and A. Di Bella

- Community White paper
- Presentation at international conferences: AGU 2023, EGU 2024, IICWG 2024, Cryo2Ice 2024, 30YPRA 2024, Polar cluster 2022 & 2023, LPS 2025 …
- Dedicated project website: https://sinxs.noveltis.fr/

Roadmap and continuation

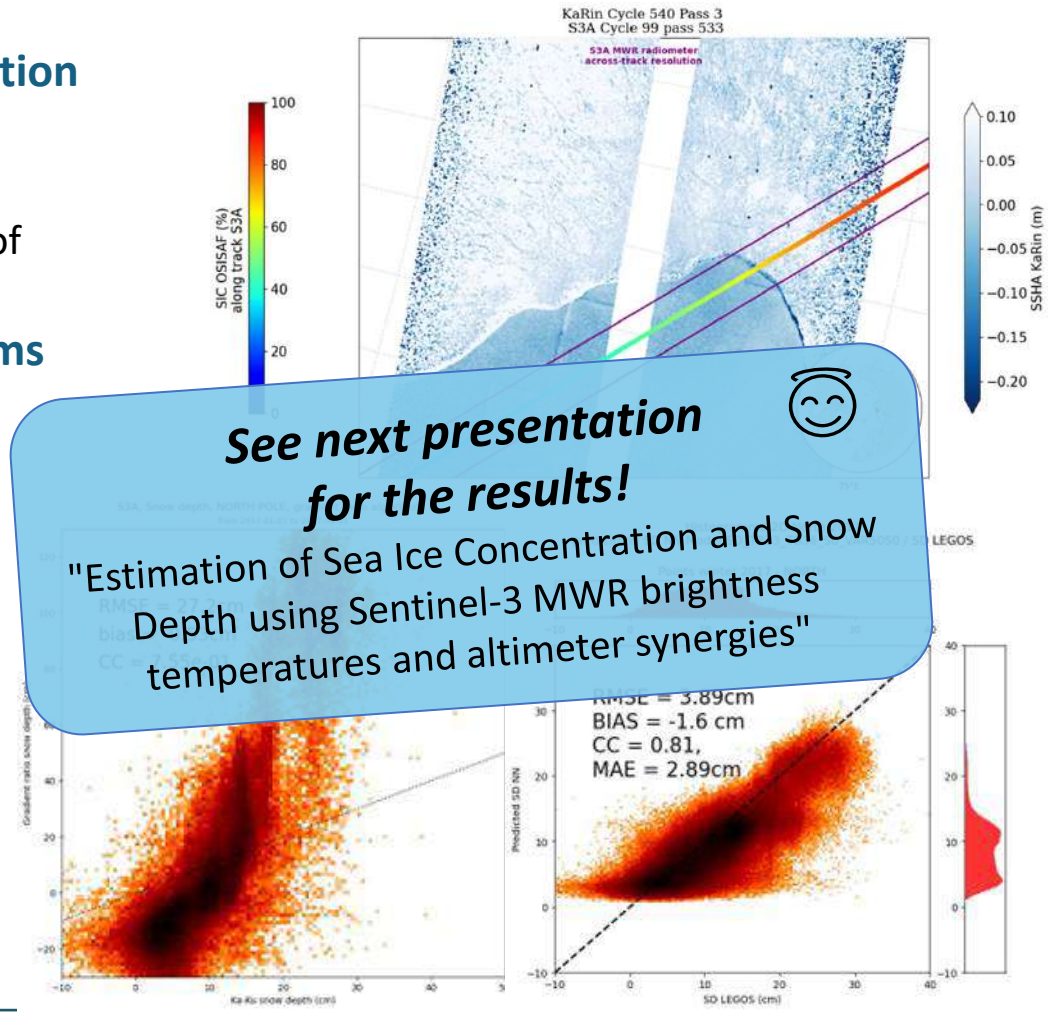
Activities conducted in the framework of ESA SIN'XS project CCN1

- ✓ WP1: Synergy of altimeter data – Microwave and altimetry synergies onboard S3
- ✓ WP2: Snow depth estimation from single-band waveform
- ✓ WP3: SIN'XS platform and maintenance
- ✓ WP4: Communication and outreach

CCN1 – WP1 – Task 1

Synergy of altimeter data – Microwave and altimetry synergies onboard S3

- **Rationale**
  - › **Sea Ice Concentration (SIC) and Snow Depth on Sea Ice (SD) estimation**
    - Essential variables for climate monitoring, SIT estimation...
    - Using radiometer data, collocated with altimeter measurements. **Potential improved accuracy in space and time,** compared to the use of external models.
  - › **For both variables, neural networks outperform literature algorithms**
  - › CCN Task1: Validate the results with detailed analyses
- **SIC**
  - › Neural network trained on OSI-SAF
    => significant improvement in spatial resolution
  - › Analysis of more specific cases
- **SD**
  - › Neural network trained on SD monthly grids
    => satisfying results with the Ka/Ku dataset
  - › Global analysis with the new La/Ku reference dataset



Synergy of altimeter data – Ku-band snow depth penetration hypothesis using the S3 SRAL C and Ku bands

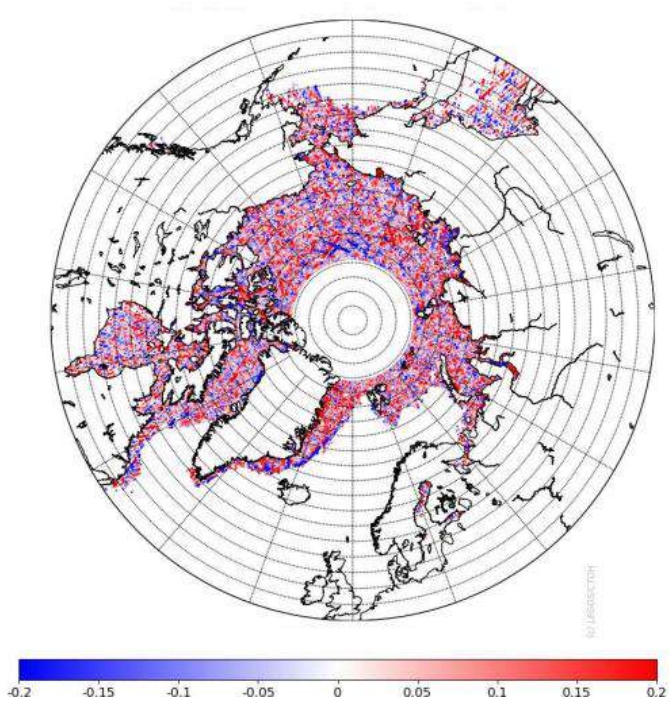
Objective:
- Retrieve the snow depth for C and Ku range differences.

Assumption:
- The C-band penetrates more than the Ku-band into snow.

Methodology:
- Comparison of C and pLRM Ku radar freeboards

Difficulties:
- C and Ku ranges can also differ because of the sea ice roughness and the ionospheric corrections

Differences between C and pLRM Ku radar-freeboard



Difference is positive! (+3 cm)

➢ Need for regional and seasonal analyses, including snow depth and weather information

Synergy of altimeter data – Synergy between SRAL and OLCI (1/2)

Objective

➔ **Create a sea ice classification from OLCI multi-spectral images**

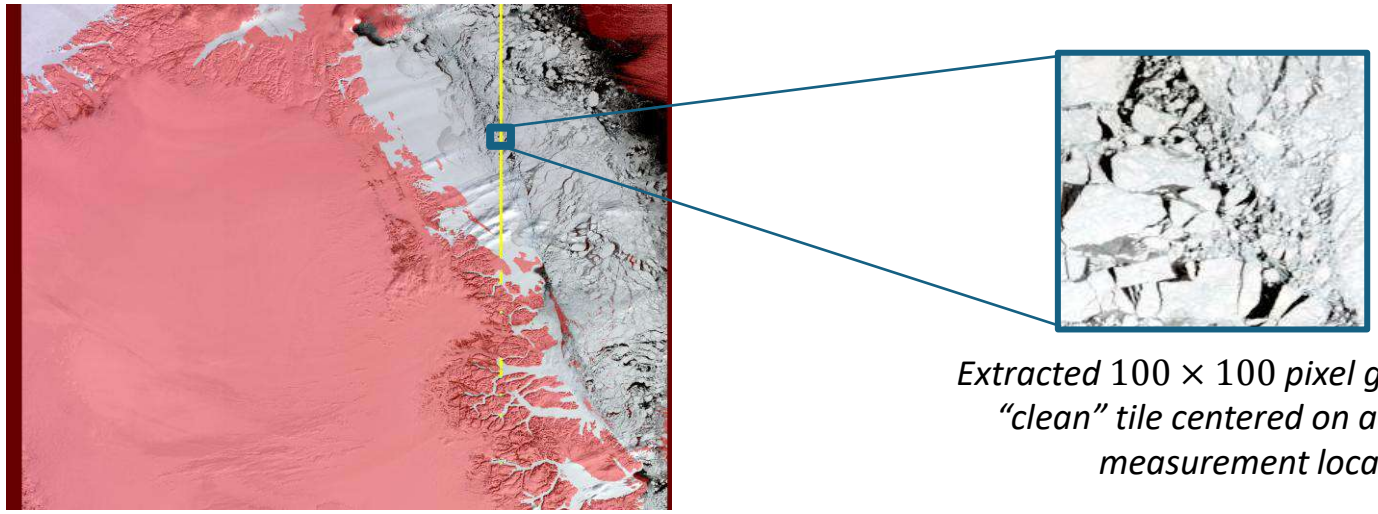
First step towards automated operational pipeline

Status

- Continuation of the work done by Laura Orgambide with ONERA
- In progress: Literature review done + preprocessing pipeline completed

See Laura's presentation this afternoon!

"Comparison of the floe/lead classification of the SRAL measurement with OLCI images"

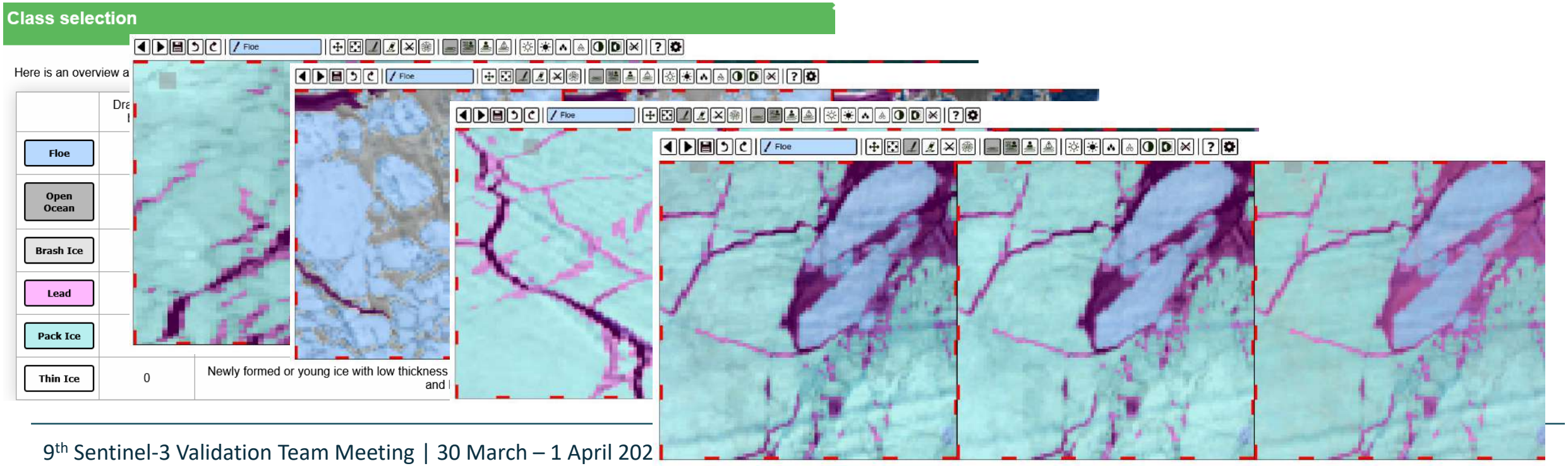


Extracted 100×100 *pixel georeferenced "clean" tile centered on a valid SRAL measurement location*

Synergy of altimeter data – Synergy between SRAL and OLCI (2/2)

Next steps

- **Test of semantic segmentation approaches (U-Net, CNN)**
  - Main challenge: creation of labelled dataset for training and validation
  - Explore the use of IRIS for semi-automated annotation, reusing ONERA's dataset
  - Challenging environment: low contrast boundaries, diffuse brash ice, partial cloud cover



Snow depth estimation from single-band waveform (1/2)

Objective

- Evaluate the capacity to retrieve the Snow Depth from Ku waveforms analyses

Methodology

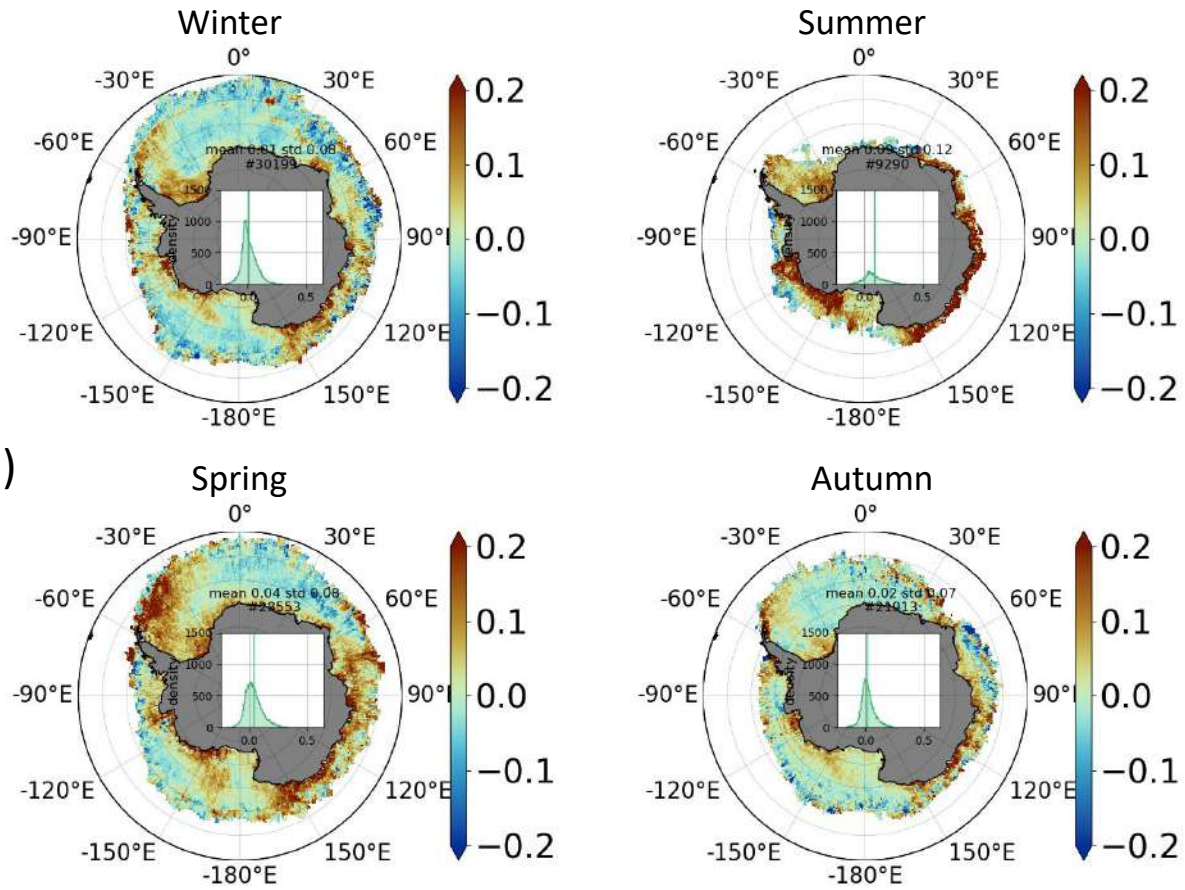
- Snow Depth computed with physical retracker CS2WFA in *[Fons, Kurtz and Bagnardi, The Cryosphere 2023]*

Evaluation

- Against Cryo-TEMPO LaKu Snow Depth
- Against OIB airborne snow depth measurements (next slide)

	Mean			STD		Nb of points	
	CS2WFA	LaKu CT	CS2WFA – LaKu CT	CS2WFA	LaKu CT	CS2WFA	LaKu CT
Winter	0.17	0.15	0.01	0.10	0.08	30920	35080
Summer	0.21	0.11	0.09	0.12	0.07	9624	15000
Spring	0.19	0.15	0.04	0.11	0.08	29787	32424
Autumn	0.15	0.13	0.02	0.08	0.07	22470	26636

Snow Depth CS2WFA - CryoTEMPO



Snow depth estimation from single-band waveform (2/2)

Objective

- Evaluate the capacity to retrieve the Snow Depth from Ku waveforms analyses

Methodology

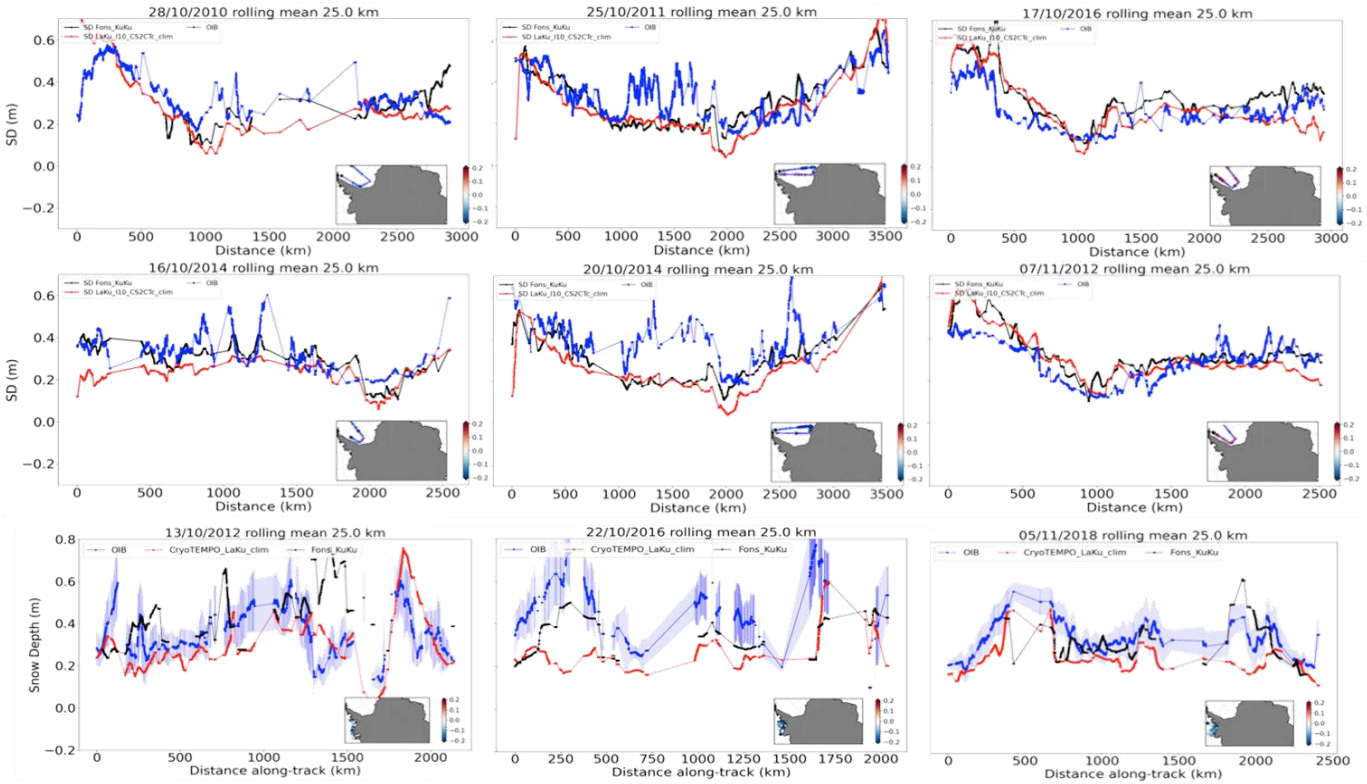
- Snow Depth computed with physical retracker CS2WFA in *[Fons, Kurtz and Bagnardi, The Cryosphere 2023]*

Evaluation

- Against Cryo-TEMPO LaKu Snow Depth (previous slide)
- Against OIB airborne snow depth measurements

➢ Very promising that Snow Depth estimation could be computed in Near Real Time from Ku waveforms.

Snow Depth CS2WFA and CryoTEMPO versus airborne snow radar OIB



Conclusion

Main takeaways

- ✓ **A unique harmonised and standardised global database with wide diversity of SIT and SNT datasets**
  - **41 SIT and SNT datasets over the Arctic and Antarctic**
  - **Wide range of instruments, spatial and temporal domains, and data providers**
- ✓ **An assessment protocol and an operational platform with tools available to the community: https://sinxs-tools.noveltis.fr/**
- ✓ **A first reconciled SIT estimate produced monthly from January 2010 to April 2024**
- ✓ **Availability of data on demand to perform further analysis**

Future perspectives

- ✓ **Reinforcement of snow thickness products – Please get in touch if you would like to contribute!**
- ✓ **Currently looking at complementary approaches to deepen analysis further: Radiometer for snow concentration; Synergy OLCI – SRAL; Measuring snow using only Ku, or Ku-C…**
- ✓ **Reproduction of Antarctic-based analysis over Arctic**

Thank you for attending the talk!

Get in touch:

sinxs@noveltis.fr