St3TART-FO Project

Sentinel-3 Topography mission Assessment through Reference Techniques Follow-On

E. Le Merle[1], *M. Dechamp-Guillaume*[2], *H. Skourup*[3], *V. Favier*[4], *C. Miller*[1], *V. Boulenger*[1], *J. Sarrau*[1], *R. M. Fredensborg Hansen*[3], *G. Picard*[4], *J. Renou*[5], *M. Chapellier*[5], *L. Fayon*[4], *V. Fouqueau*[2], *M. El Hajj*[1], *M. Restano*[6], *F. Catapano*[7], *et al.*

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ESA FRM Workshop

May 19, 2026

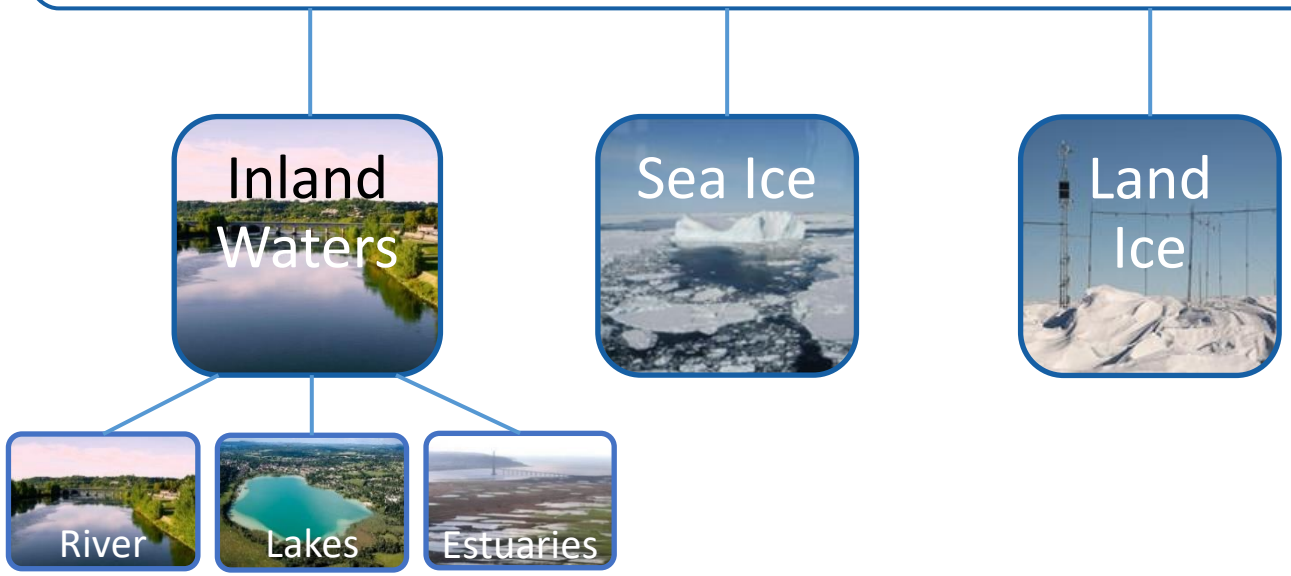
Context & objectives

St3TART-FO project

From May 2024 to May 2028 – ESA funded

→ **Operationaly provides FRMs**

to support the validation activities of the S3 STM Land Altimetry data products over:



- The project's aim to ensure the successful operational provision of FRMs ultimately contributes to the broader goals of S3 mission in providing **accurate** and **reliable Earth observation data**.
- Built on the St3TART activities led between 2021 and 2023 that provided roadmaps, protocols, and procedures for FRM provision.
- It will pave the way for other future altimetry missions such as **CRISTAL** and **S3 Next-Generation Topography**, as well as for potential synergies with the **Copernicus** expansion mission.

Context & objectives

	Inland waters	Sea ice	Land ice
			
FRM sites identification and operational preparation	• **Identify** and **operate super sites** and **opportunity sites** for FRM operational provision • **Equip sites** with additional instrumentation and **prepare operational plans**		
FRM operational provision	• **Acquisition**, **processing** and **delivery** of FRM data • Ensure **good performance** of the FRM sensors and data processing • **Prepare roadmap for future** Altimetry missions beyond S3		
FRM data exploitation and uncertainty assessment	• Characterize the **uncertainties** associated to each FRM data product and measurand • **Exploitation** of **FRM data** for Cal/Val activities for S3		

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Announcements of Opportunities (AOs)	• **Complementary** to existing sites and activities • **Foster/contribute** to ongoing/planned **campaigns** for FRM provision to federate the community via **Announcement of Opportunity** (AO) calls			

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				• Platform **for a centralized access** to FRM data • Fully characterized and **documented FRM** processing and measurements	• **Execute** the approved **AOs** • **Produce, process** and **deliver** FRM data

Timeline

May 2024 — December 2024 — February 2025 — June 2028

Set up phase → Rehearsal → Operational phase

Set up phase

- Station set-ups on sites
- Development of the FRM processing chain
- Set-up and finetuning of FRM Data Hub
- Initiation of collaborations and campaigns

Rehearsal

- Test of all the processing chains from data collection to FRM dissemination
- Demonstration of operational readiness

Operational phase

- Production of FRMs on all super sites and opportunity sites including campaigns
- Validation activities by all the scientific team
- Dissemination on FRM Data Hub
- Complementary to core activities, execution of selected AO proposals

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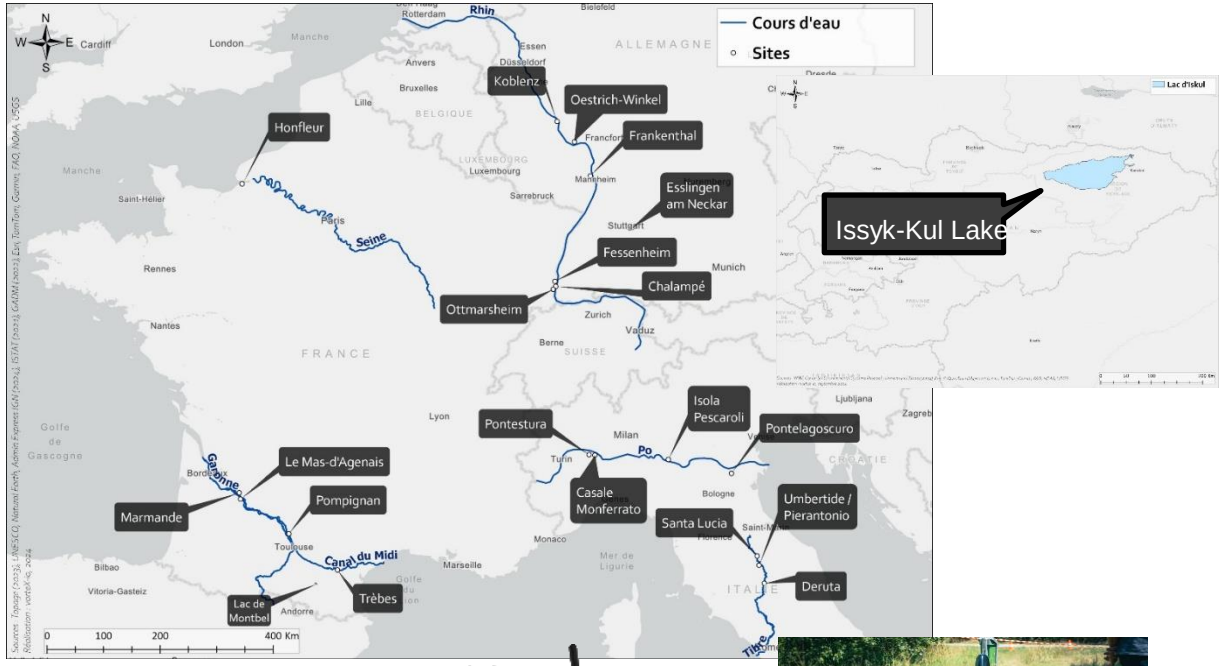
Jean-Christophe Poisson (jeanchristophe@vortex-io.fr)
Marine Dechamp-Guillaume (m.dechamp@vortex-io.fr)

- **~20 super sites over 4 countries**

Sensors distribution in France, Italy, Germany and Kyrgyzstan



vorteX-io V2.1 micro-station

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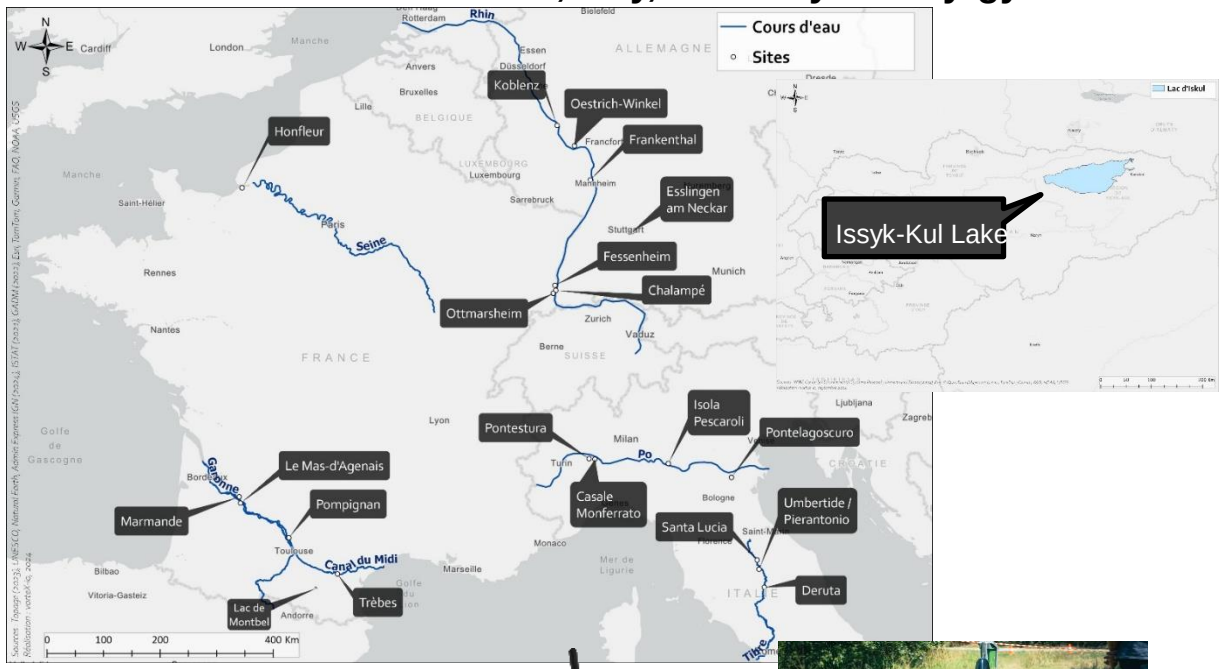
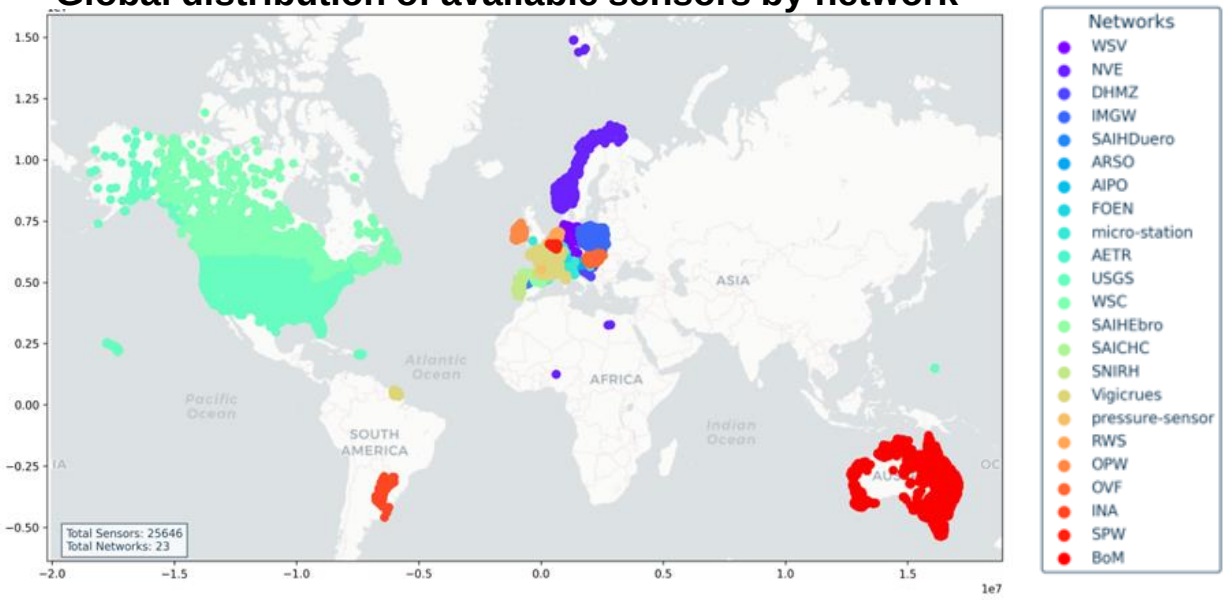


vorteX-io V2.1
micro-station

- **FRM opportunity sites**

Increase data volume and geographic coverage

Global distribution of available sensors by network



9 public networks were identified in St3TART.

961 opportunity sites have been selected.

Require **no particular processing** to **produce FRMs.**

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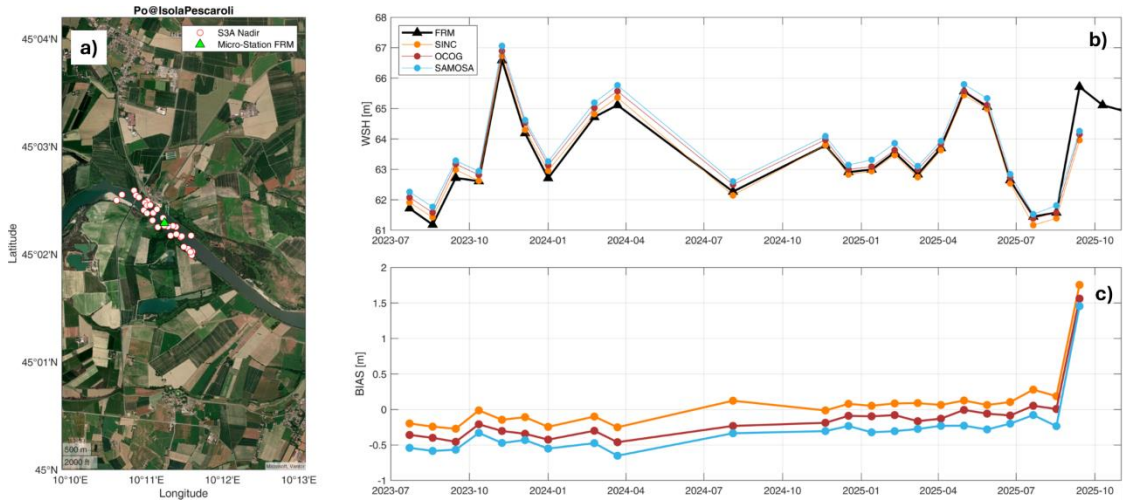
Benefit of assessment

› FRM on Po River

Example of Isola Pescaroli

- Stable STD (~1.4 m) across retrackers.
- Small biases (between 0.06 m and -0.31 m).
- Very high correlation (ρ ≈ 0.9–1) → Sentinel-3 captures well water level dynamics.



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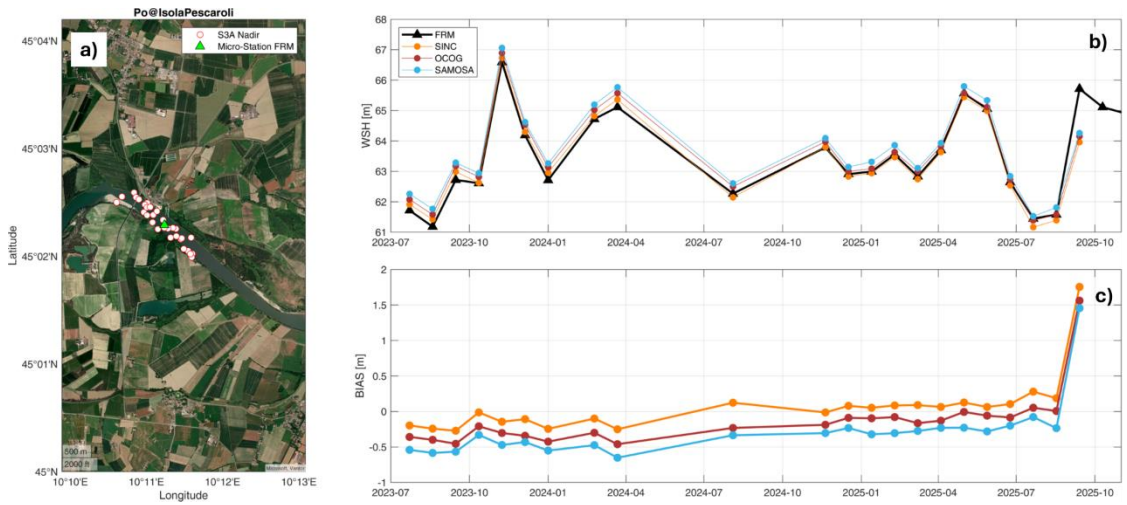
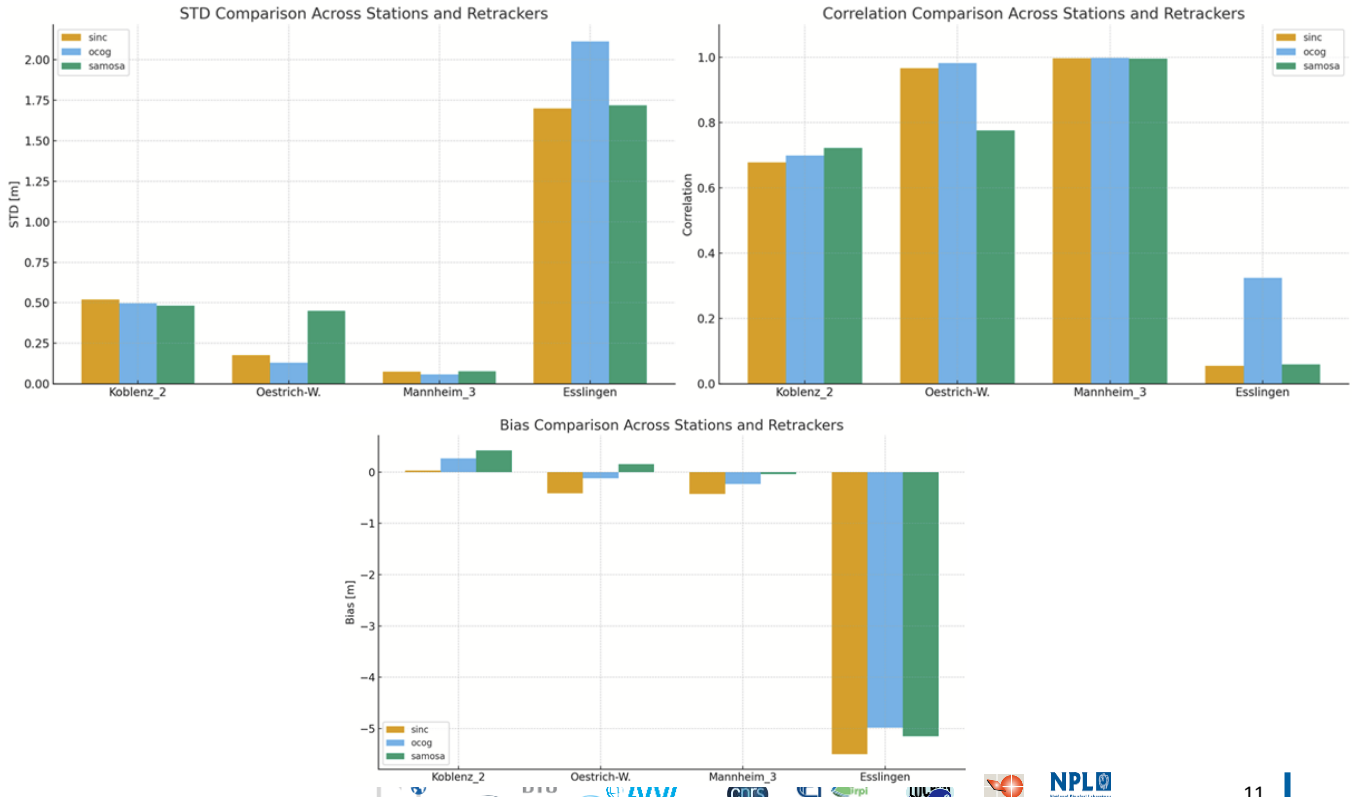


› FRM on Rhine River

- A significant bias for Esslingen-am-Neckar site → Sentinel ground track passes directly over the Esslingen sluice, capturing data from both the upper and lower levels of the structure.



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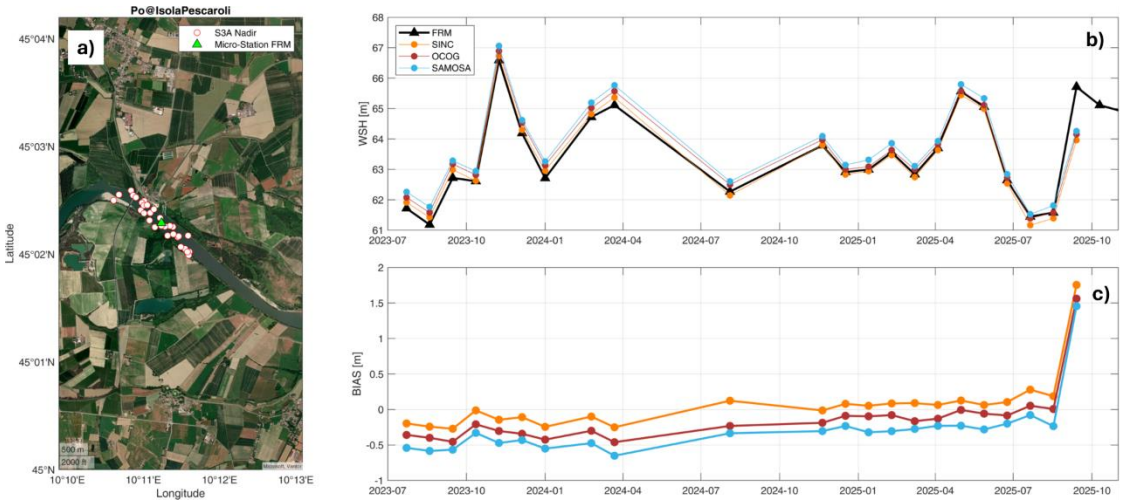

See Chapellier et al., poster for more results on inland waters validation

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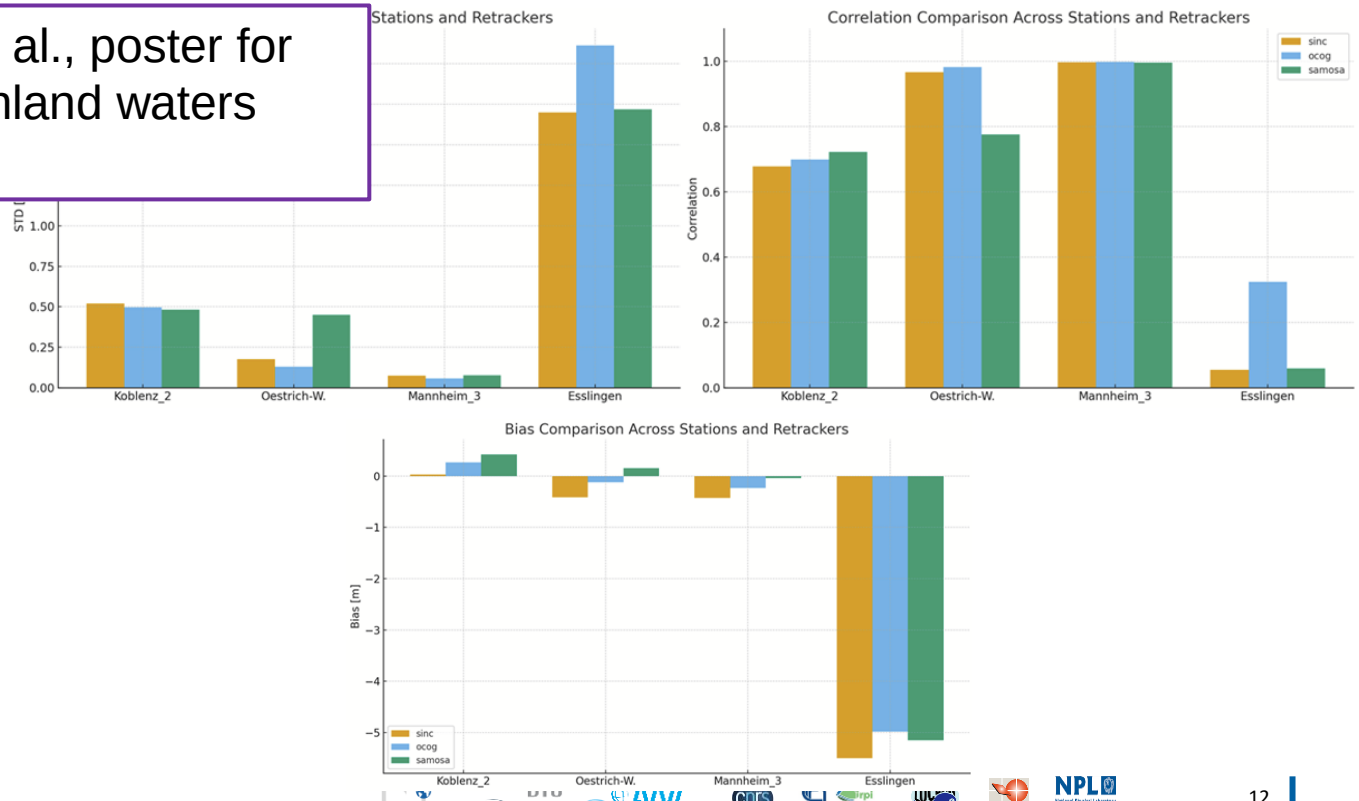

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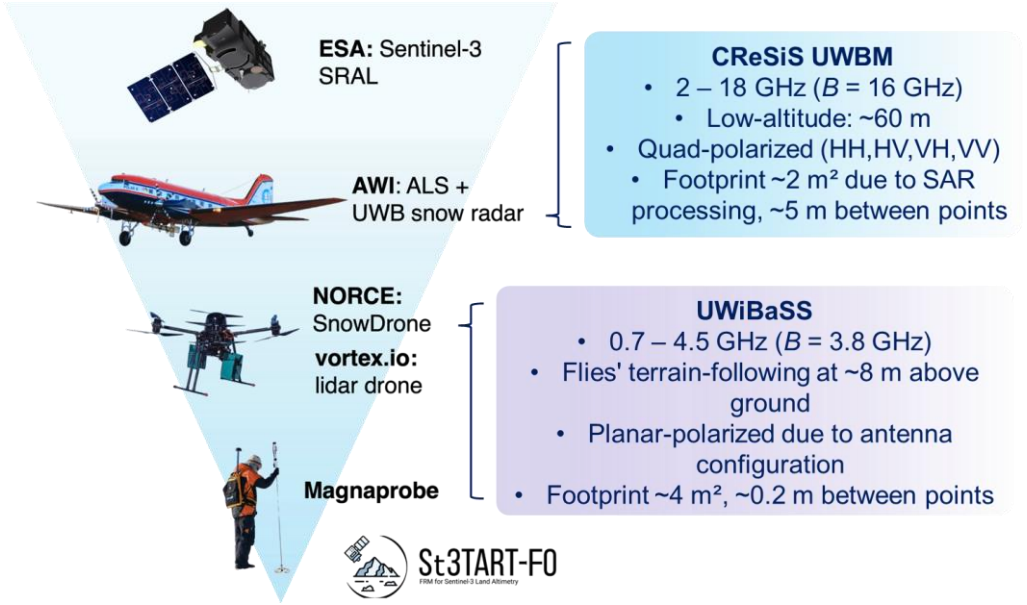
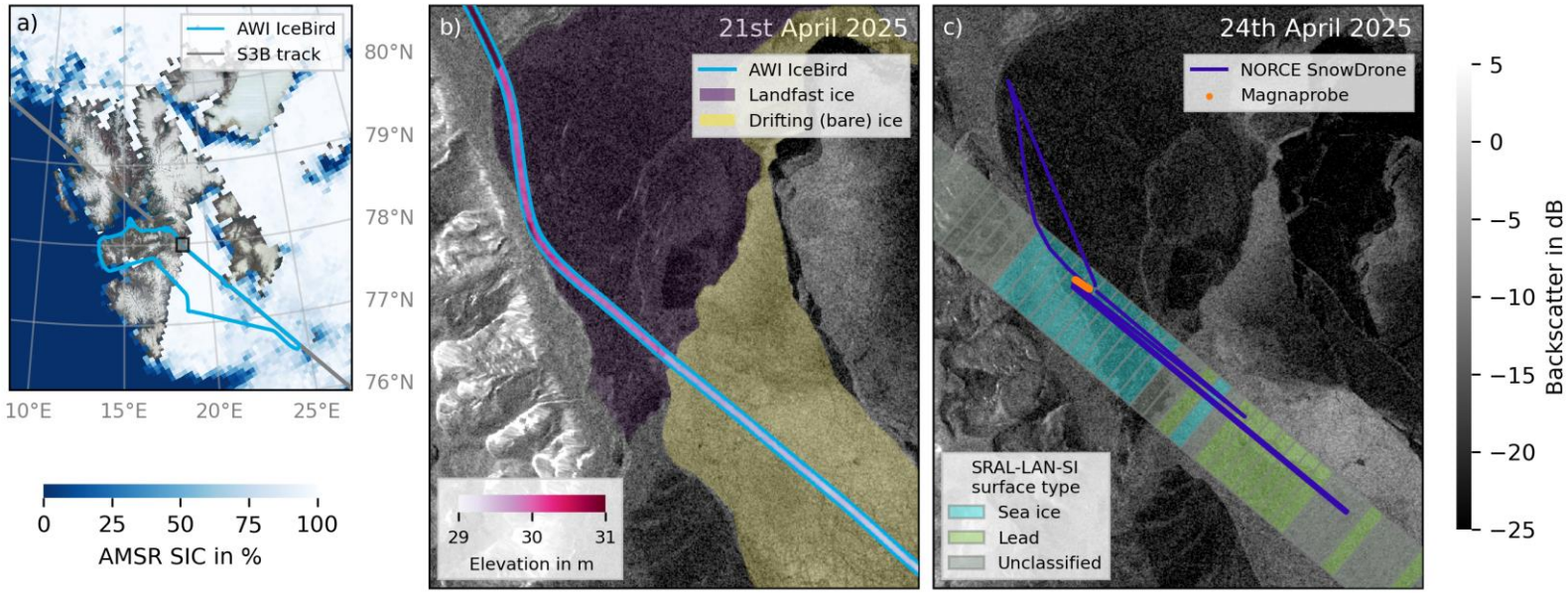
• Svalbard campaign 2025

- Approximately 7-km overlap between AWI + NORCE snow radars over landfast ice.
- Little overlap with MagnaProbe data in Storfjorden (more in Adventdalen, no S3 track).
- Bare and loose sea ice floes in Storfjorden (only 93 S3 SRAL footprints classified as sea ice in LAN).
- An IPS mooring was deployed at a S3 and ICESat-2 crossover point by LOCEAN in summer 2025.



• AWI IceBird

- Has collected data along dedicated S3 orbits in Beaufort Sea, Canadian Archipelago and Svalbard. In total:
  - ~1,200 km in 2025
  - ~500 km in 2024



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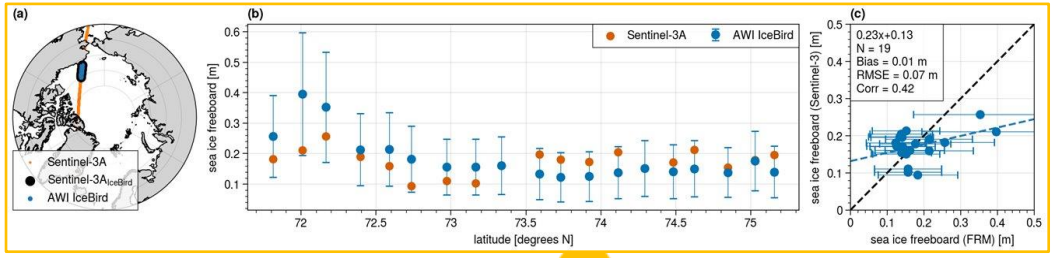
FRM data analysis

See Skourup et al., poster for more details on sea ice validation methodologies



Level 3

Ice freeboard
Ice thickness
Snow depth
Ice draft
(air-snow/total freeboard)
(snow-ice/ice freeboard)

Total thickness
Total freeboard
Snow depth

Snow depth

Total freeboard

Third-party

DTU/LEGOS

Module I:
space-time averaging

Spatial: SEGMENTATION, GRIDDING, *TRACKING*

Temporal: SEGMENTATION, GRIDDING, *TRACKING*

Module II:
estimate uncertainties

Best practices for estimation of uncertainties (w/ NPL)

- Estimation of uncertainties (propagation or Monte Carlo)
- Build on traceability diagrams and effects tables

External library:
sinxs/tools/convert.py, CCI+, CoMet toolkit

Convert one measurand to other 8 comparable measurands

Uncertainty propagate with provided uncertainties

FRM

Sentinel-3 thematic data product (freeboards)

St3TART

Sentinel-3 Data Hub

Maturity Matrix (MM)

Grade
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal

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Svalbard campaign 2026

Drone campaign with **snow radar and lidar** and **in-situ** observations with magnaprobe in collaboration with UNIS/University of Würtzburg/iTechDrone, April 20-28

- Target S3 track on April 27

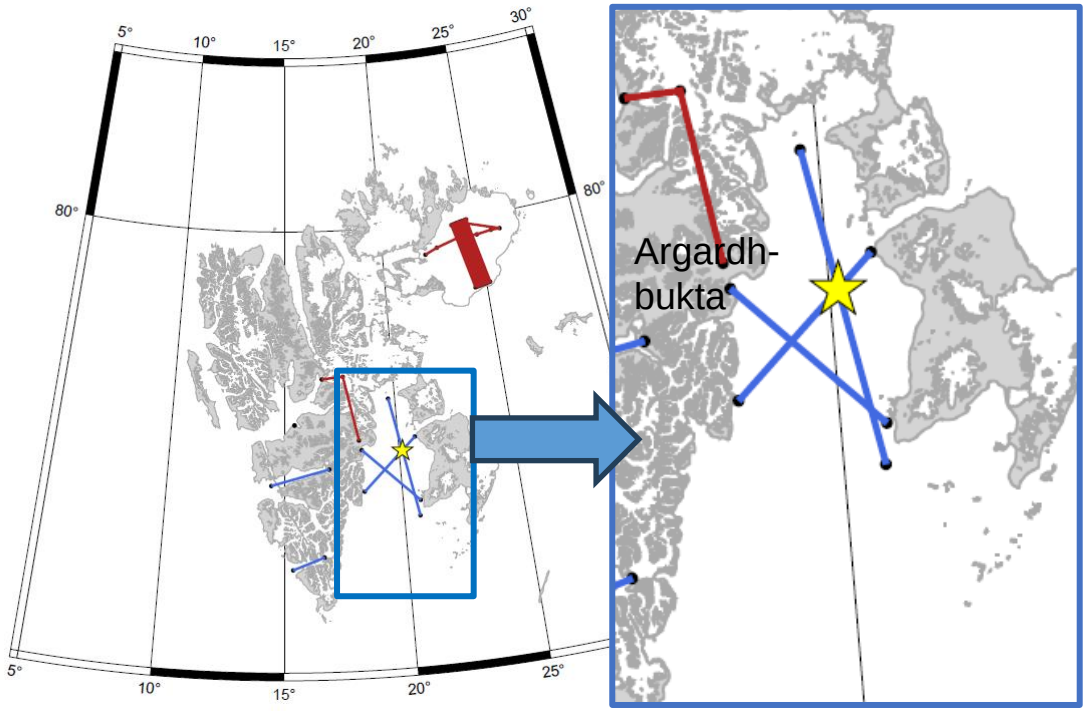
AWI IceBird, April 23-28

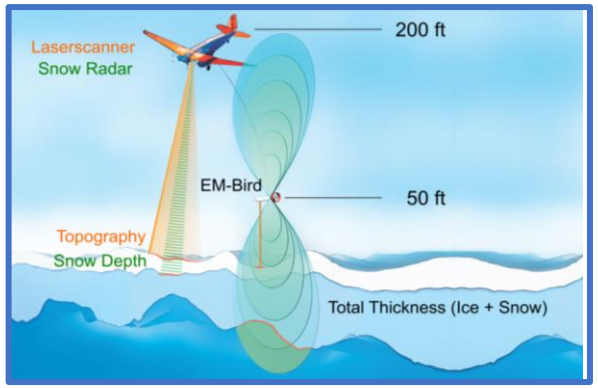
- S3 track and drone campaign
- Overflight of IPS mooring site along IS2 and S3 tracks

ESA **CRISTALair** will be in Svalbard, April 19-23

Target area:

- Storfjorden





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Svalbard campaign 2026

Drone campaign with **snow rad** **lidar** and **in-situ** observations with magn oration with UNIS/University nDrone, April 20-28

- Target S3 tra pril 27

Canceled due to poor ice conditions

AWI IceBird, April 23-28

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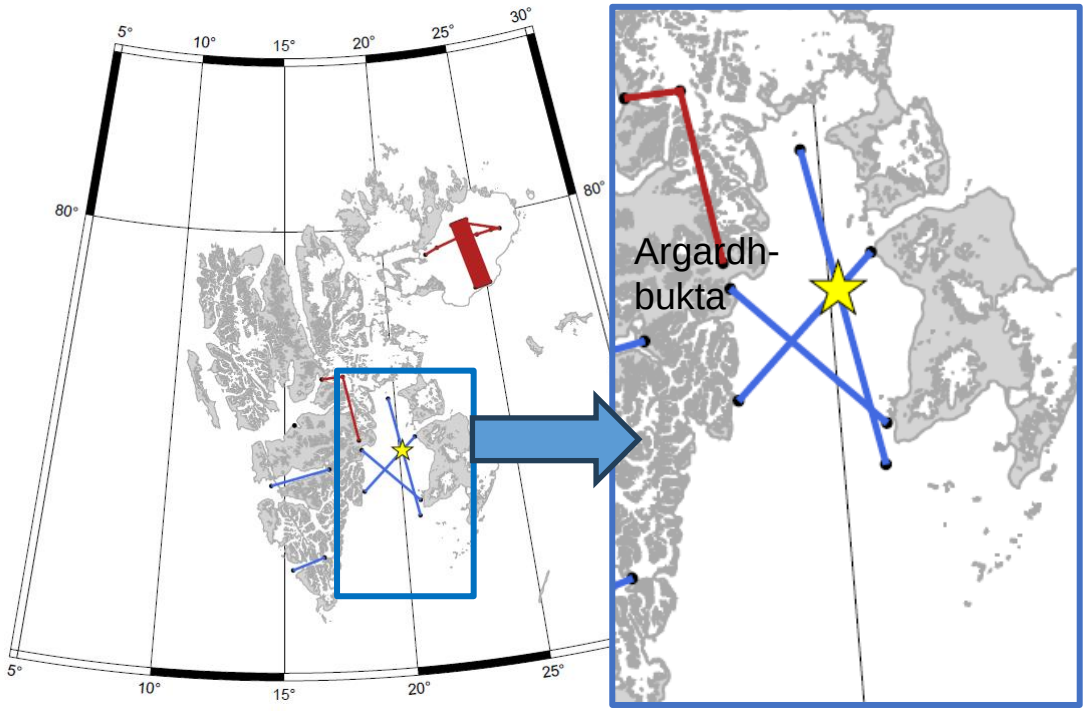

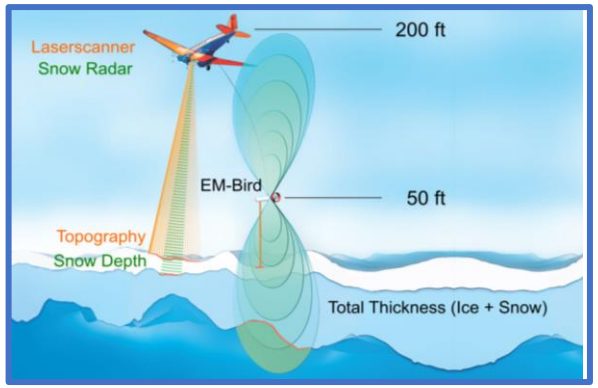

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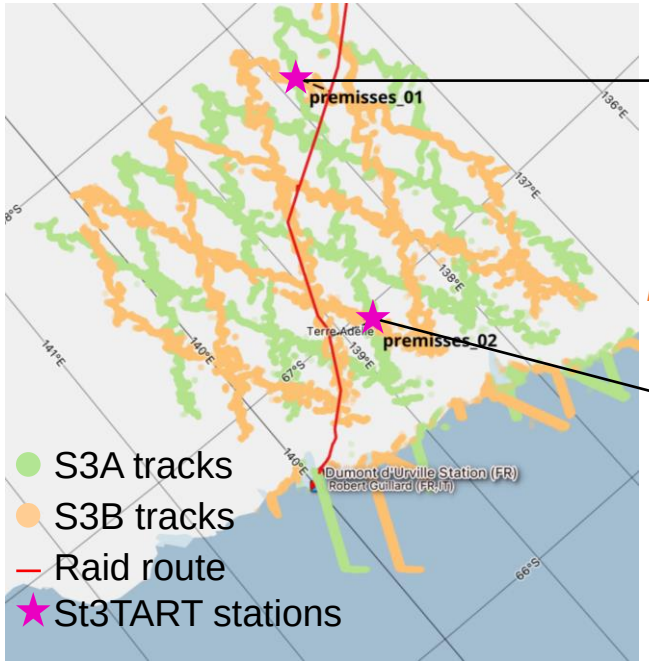
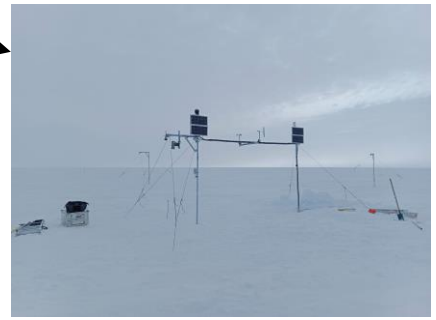
Antarctica field campaign 2025-2026

Traverse dates: from December 27, 2025 to January 19, 2026

350 km in harsh climatic conditions…



Installed from January 1 to 5, 2026



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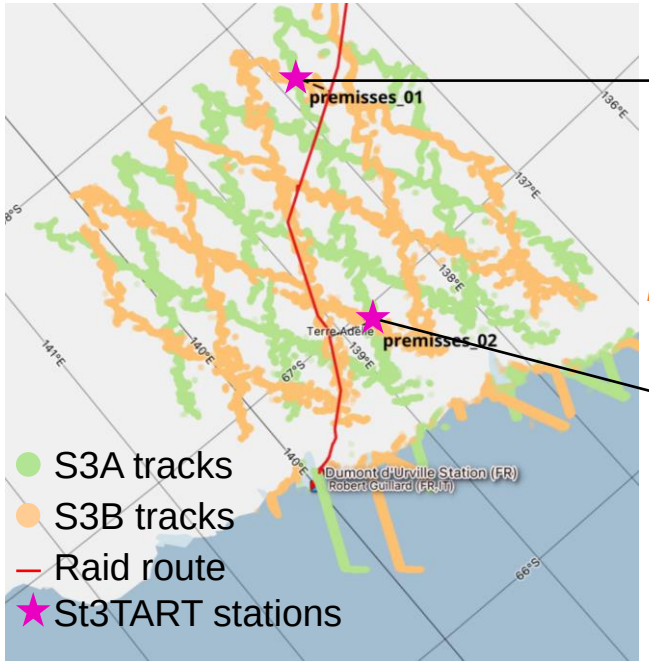

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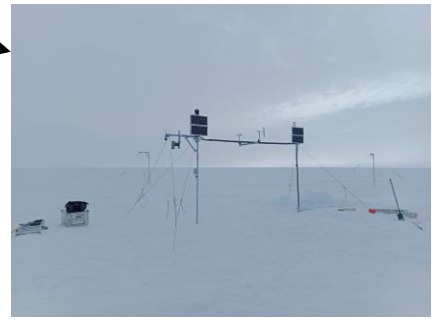

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GNSS wheel survey

M300 takeoff at premisses01

Deployment and GNSS positioning of ground control points

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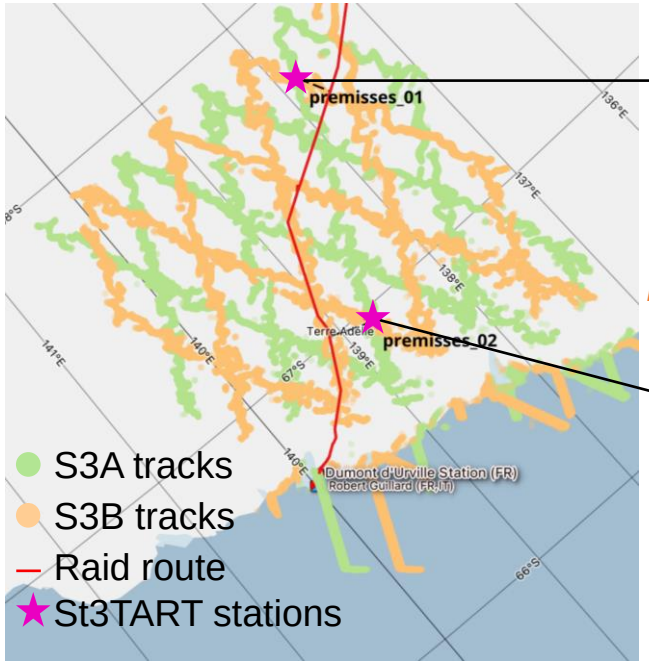

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See Reboud et al., poster for more details on land ice validation methodologies

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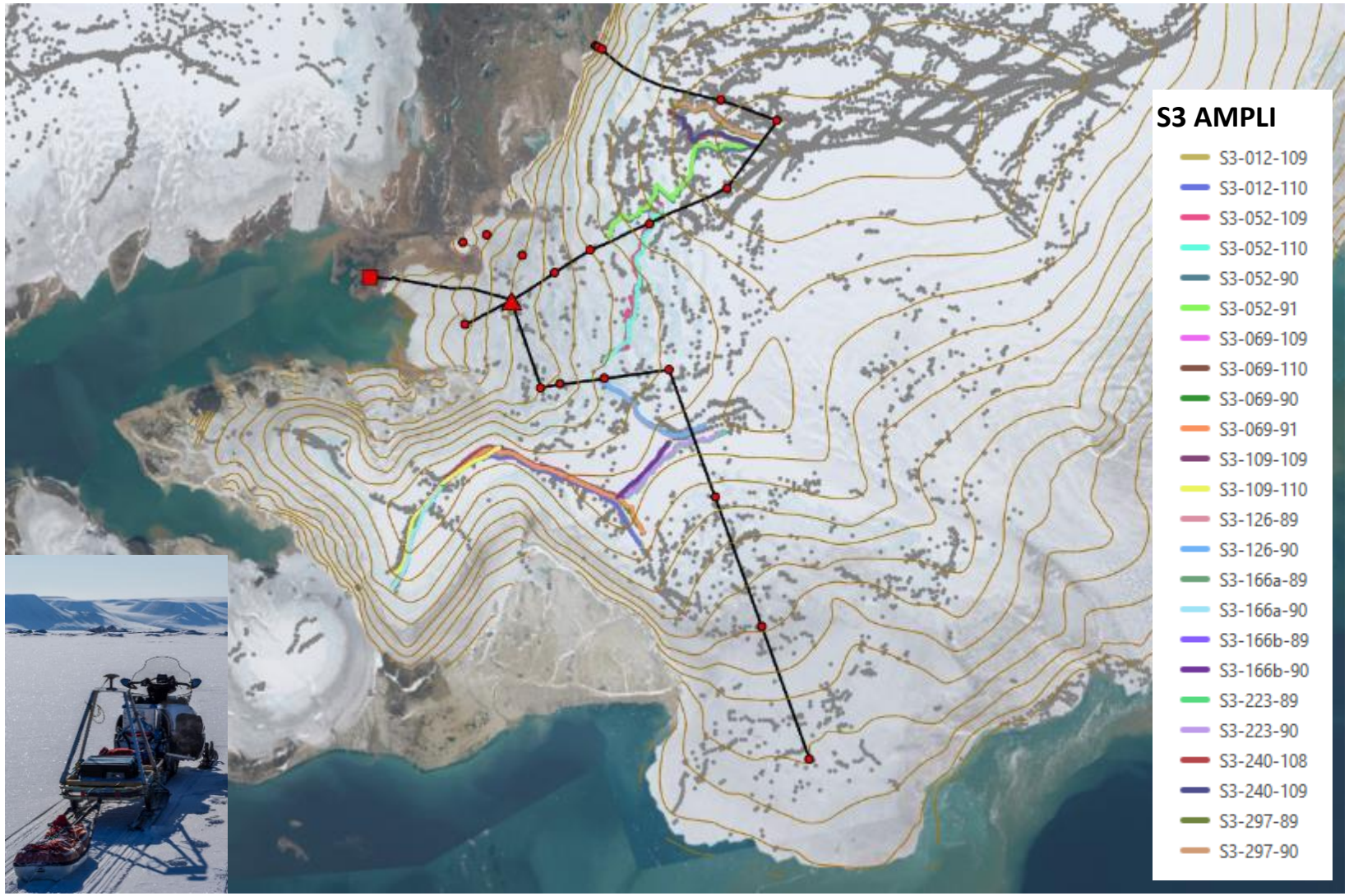
Svalbard field campaigns: Austfonna ice cap

- Annual monitoring of glacier mass balance
- St3TART field campaigns 2024, **2026**, 2028
- April 2026 campaign:
  - Focus on GNSS/GPR grids in areas where POCA data tend to repeat (AMPLI).
  - Capture the cross-track spread of repeat cycles.
  - Coordinate survey with tentative airborne surveys (AWI + CRISTALair).



Summary

- **Inland waters**
  - Operational provision of FRM over rivers and lakes.
- **Sea ice**
  - FRM computation is ongoing for the 2025 campaigns.
  - New campaign in Arctic performed in April 2026.
- **Land ice**
  - Successful insallation of 2 stations in Antarctica.
  - Data processing is starting.
  - 2027 campaign is planned, pending for IPEV confirmation.

- Work on the uncertainty characterisation is ongoing for the three domains.

Uncertainty assessment

Inland waters

- The FRM equation on most complex super site is :

$$FRM(t) = WSH_{IS}(t + \delta_t) + 2\,WSH_{MS}$$

Micro-station **instrumental uncertainty**

Does the **time lag estimation** used to schedule micro-station measurement date **generates errors on FRM computation** ?

- Assessment of **LiDAR uncertainty** → Computed from the σ of the raw **LiDAR beams** values → **1.2 cm**
- Assessment of **GNSS uncertainty** → Computed from the Kalman filter residuals (SDU) → **0.6 cm**
- **Final computation** →

$$\Sigma_{MS} = \sqrt{\Sigma^2_{GNSS} + \Sigma^2_{LiDAR}} = \textbf{1.3 cm}$$

Sea Ice

- Uncertainty tree diagrams for every instrument
- Next step: quantification of uncertainties with summary in effects tables.

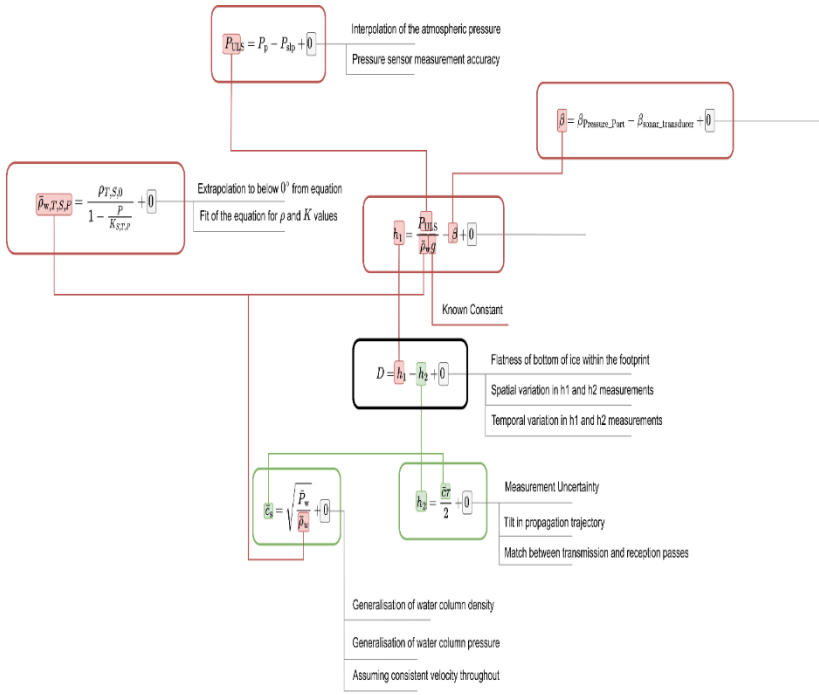


Figure: ULS FRM uncertainty tree diagram (first draft)

Land ice

- Assessment of **the snowVUE uncertainty** → test of the impact of:
  - temperature,
  - snow penetration,
  - surface slope,
  - surface roughness.

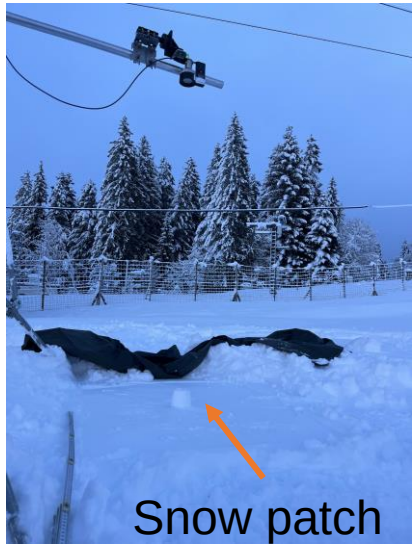
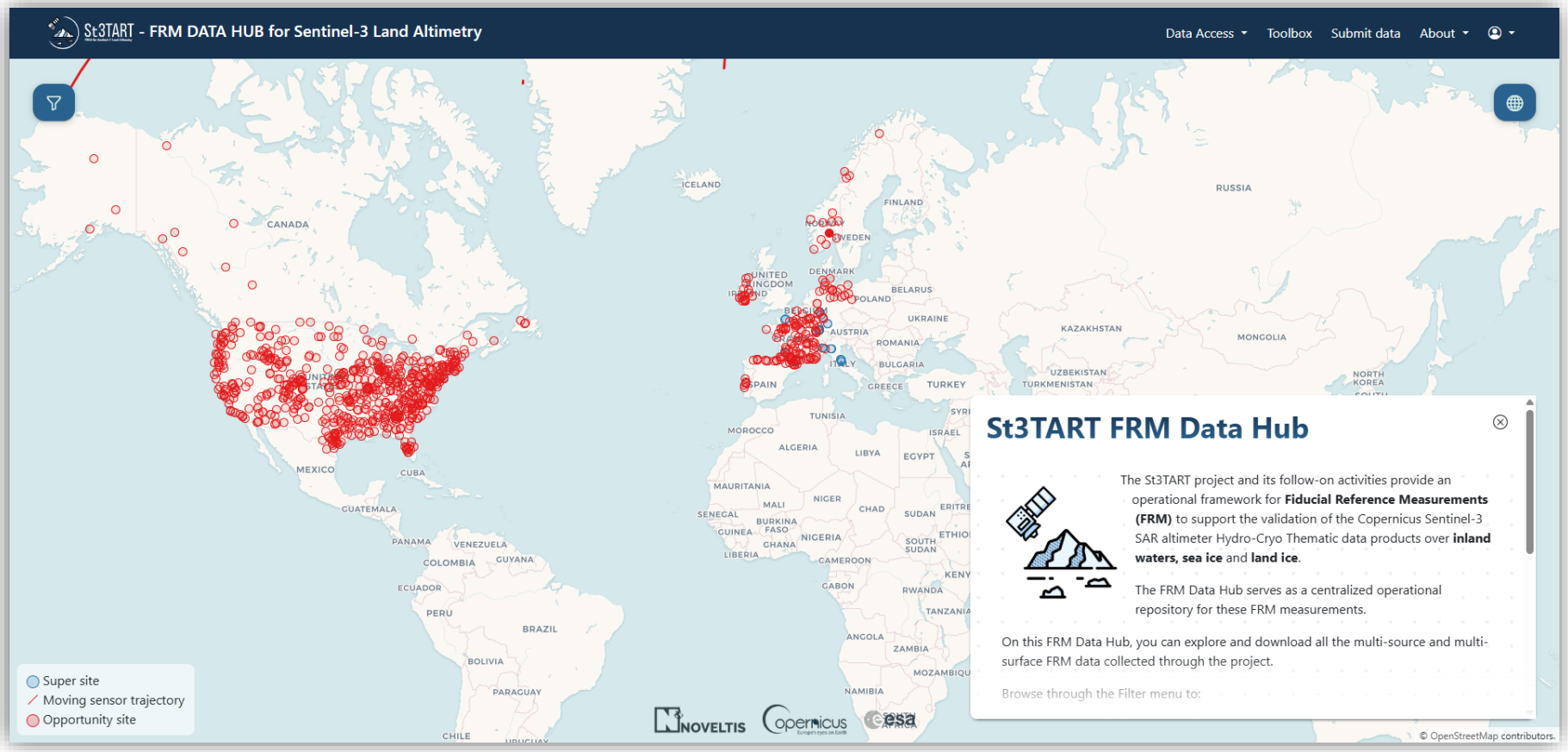


Figure: example of test conducted with the snowVUE

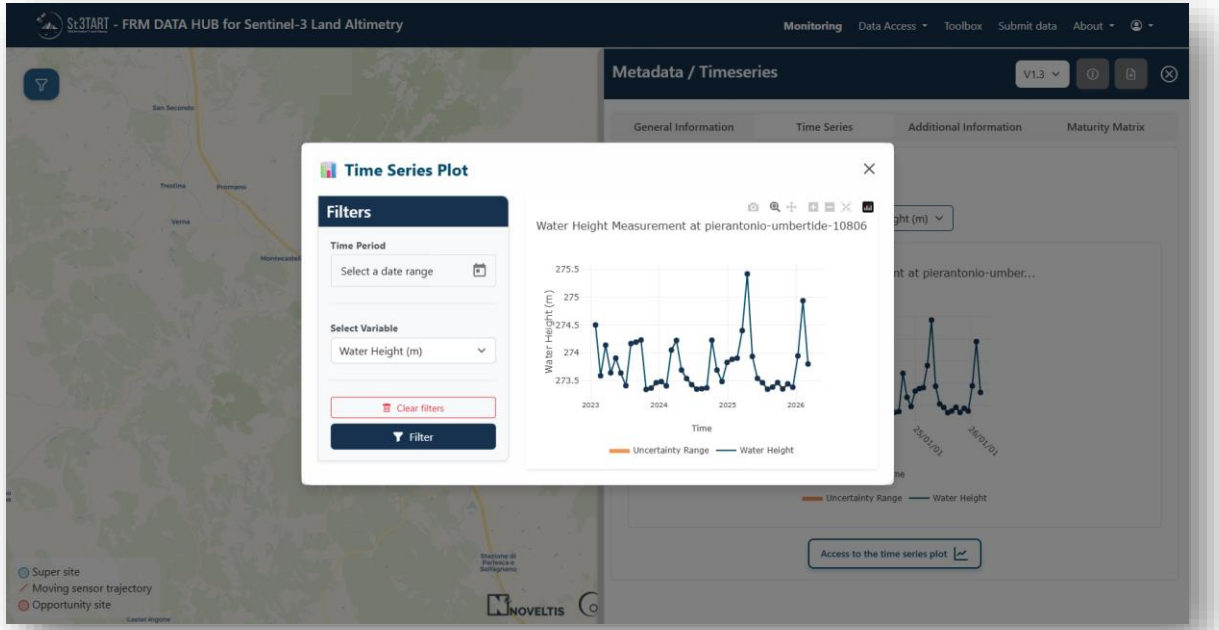
Central repository for FRM measurements

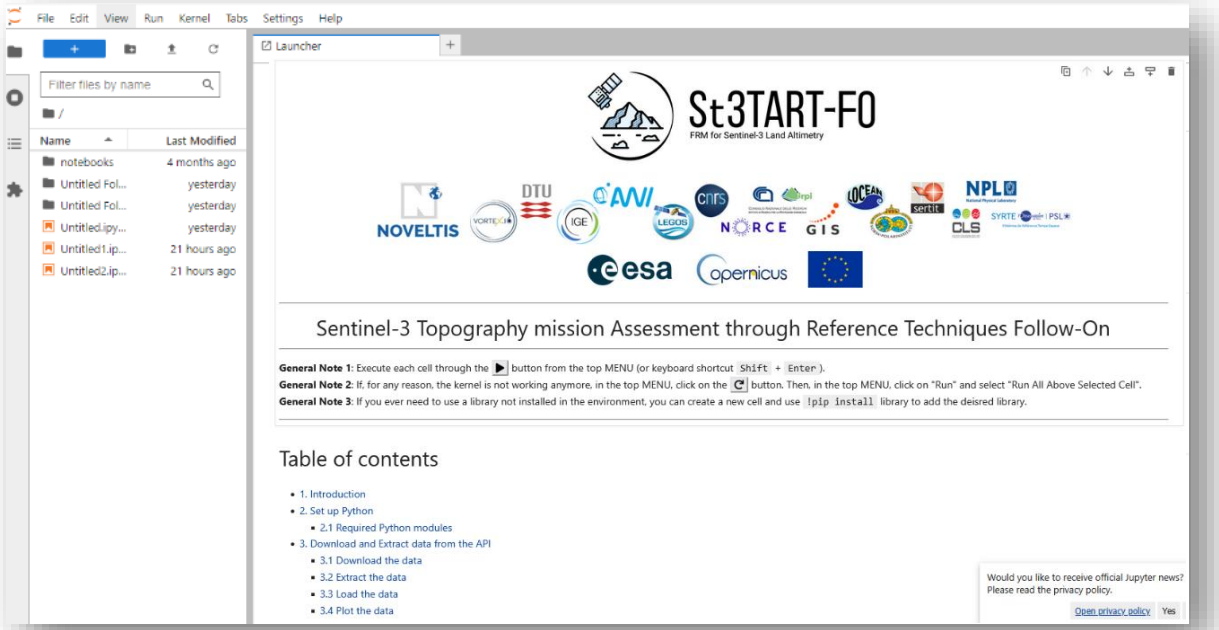


- Aim: to **federate** the **Cal/Val community**
- **Free** and **openly** accessible from mid **S1 2025**
- **Unified** data **format**: **NetCDF** with specific attributes
- Data downloadable from **API**

https://frm-datahub.noveltis.fr/

Advanced features





Visualisation & Download

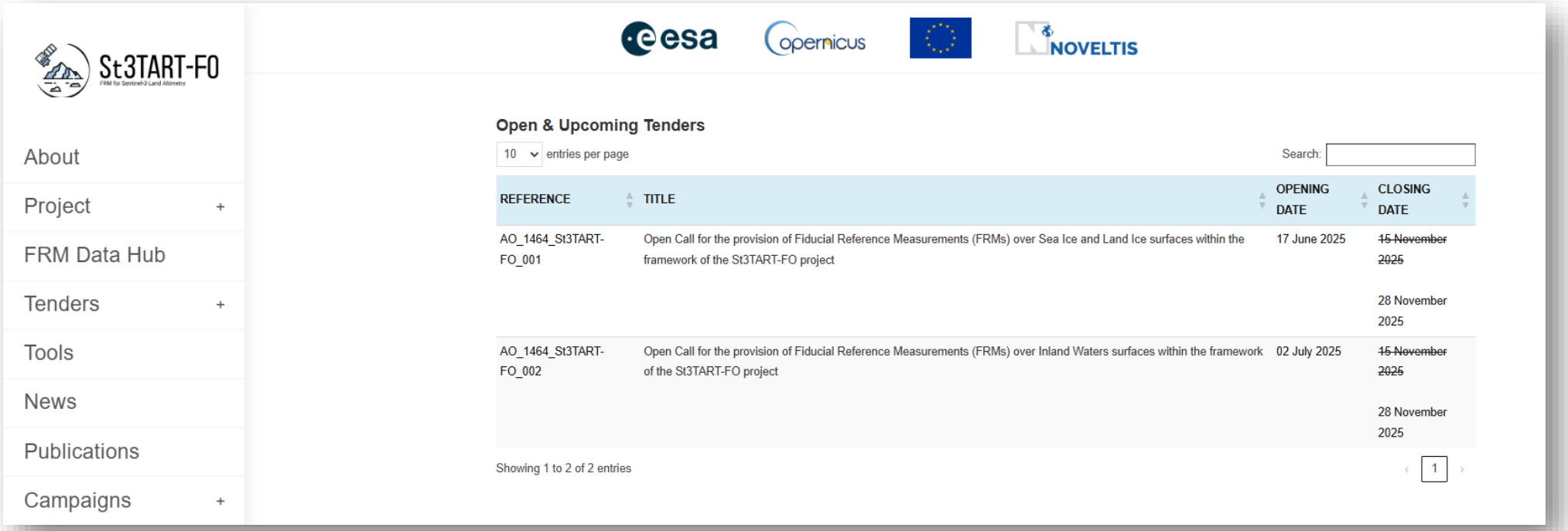
- Interactive time series plots
- Maturity matrix display
- Metadata

Jupyter Hub

- Working area hosting data analysis scripts (open source)
- Jupyter Notebooks with examples of FRM computations

FRM Collaborative Campaigns

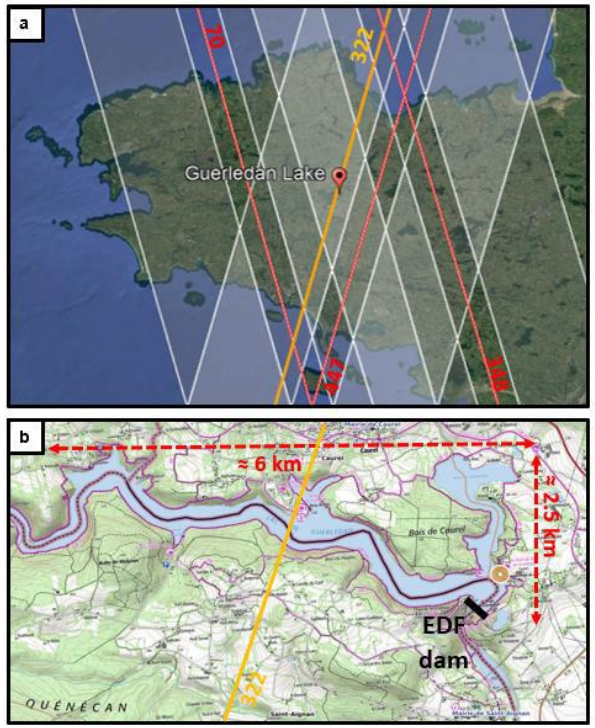
- Connect with external partners for additional field campaigns and leverage diverse expertise and resources: **inland waters**, **sea ice**, and **land ice**.
- Execution of activities submitted and approved with ESA through **Announcement of Opportunities** (AOs)
- **Dedicated budget available for the AOs**



FRM Collaborative Campaigns

For **inland waters**:

- 1 additional supersite over the Guerlédan Lake + multi-sensor field campaigns.
- 17 super sites measured using GNSS-IR sensors in West Africa, Australia, and the Philippines.



Guerlédan Lake, France

GNSS station over Sanaga River, Cameroon

FRM Collaborative Campaigns

For **sea ice**, and **land ice**:

- Multi-sensor campaigns in Svalbard in 2026 and 2027.
- Drone measurements canceled due to poor ice conditions.

Year	Thematic surface	Activity	Sensors	Measurands	Partner
2026	SI	Drone	Snow radar	snow depth	NORCE
			Lidar	Total freeboard	iTechDrone
					University of Würtzburg
			Safety, logistics & scientific support		UNIS
	SI	In support of Ice-T buoy	Test of miniature radars in Svalbard	Snow depth	LOCEAN UNIS
	SI	Airborne	EM-bird Snow radar Laser scanner	Total thickness Snow depth Total freeboard	AWI
	LI		Laser scanner Snow radar Camera	Surface elevation	
	LI	In-situ survey during airborne campaign	Surface GNSS Snow radar	Surface elevation Snow depth	NPI
2027	SI	Drone	Snow radar	Snow depth	NORCE
			Safety, logistics & scientific support		UNIS
	SI	Mooring turnaround	Support for mooring turnaround		LOCEAN

- **Longyearbyen, Svalbard**

- September 21-25, 2026.

- To bring together experts from **CRISTAL IN-PROVA** and **St3TART-FO** ESA funded projects, alongside representatives from Copernicus Services, Copernicus In-Situ, EEA, and MAG/QWG/S3VT.

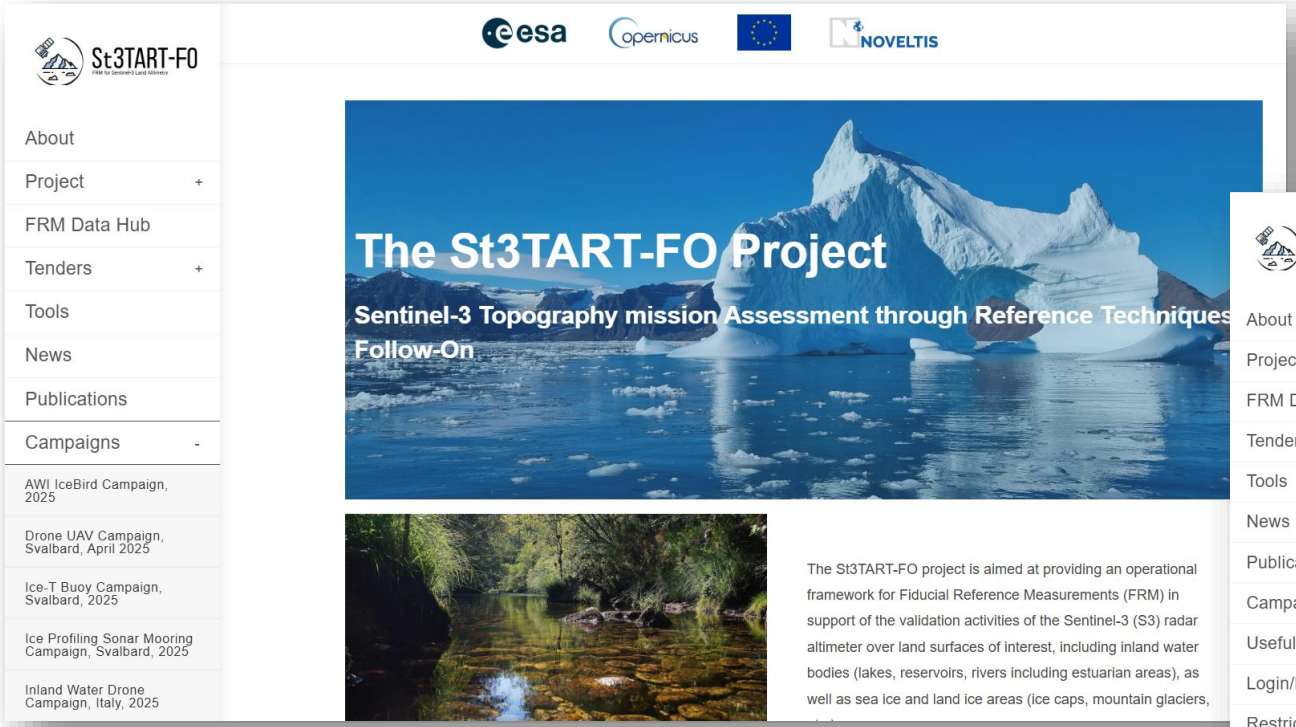
- To foster discussions on fiducial reference measurements and Cal/Val strategies for the cryosphere and hydrology.

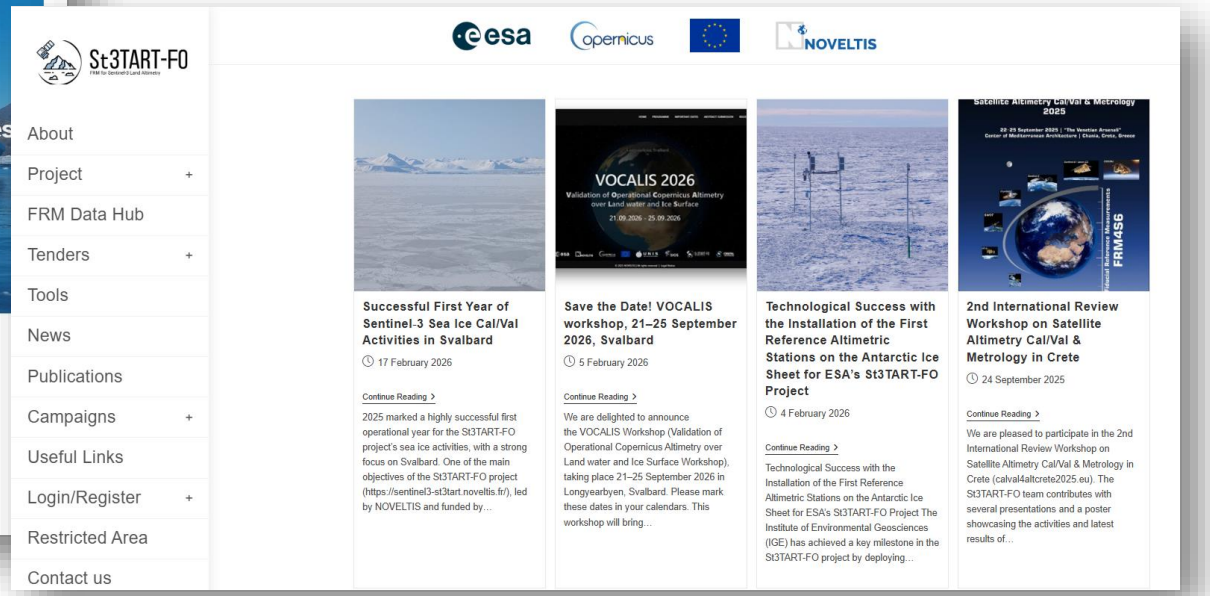
https://vocalis2026-workshop.noveltis.fr

For more information about St3TART-FO…

- Please visit our **project website**: **https://sentinel3-st3tart.noveltis.fr/**

St3TART-FO website





Thank you on behalf of the St3TART-FO team!

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