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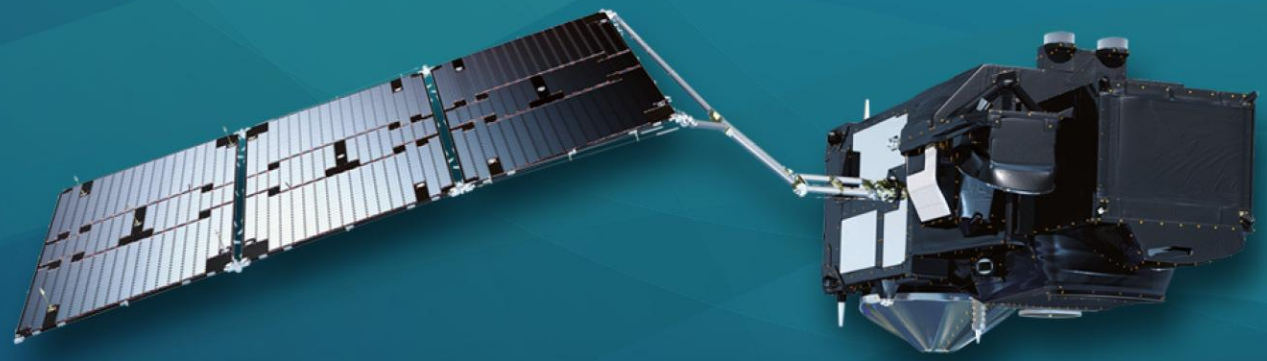


9th Sentinel-3 Validation Team meeting 2026

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

Sentinel-3 AMPLI for Ice Sheet Topography Monitoring:
Recent Results and Perspectives

J.Aublanc (CLS)
C.Yanez, F.Boy (CNES)
G.Moholdt (NPI)
S.K.Rose, S.B.Simonsen (DTU)
A.DiBella, M.Restano, F.Catapano, P.Féménias (ESA/ESRIN), F.Borde (ESA/ESTEC)

Introduction

- **Sentinel-3A** (launched in Feb 2016) and **Sentinel-3B** (launched in Apr 2018) are currently monitoring the polar ice sheets up to ± 81.5°. The constellation is planned to operate until **2035** (at least).

- **Monitoring the evolution of the ice sheets in Antarctica and Greenland is critical** because they store the vast majority of the Earth's freshwater and are major contributors to global sea-level rise (~30% contribution, according to IPCC AR6).

This talks gives an overview of recent advances in altimetry data processing with Sentinel-3 AMPLI, unlocking the potential of the mission for polar ice sheet monitoring

2016-2026

Happy birthday Sentinel-3A !

The AMPLI software: overview

- Relocation (or slope-induced) error recognised to be by far the main contributor to the error budget over the polar ice sheet **margins**

- AMPLI was developed to address this issue. The relocation at POCA is performed by means of a facet-based numerical simulation, using 10 meters HR-DEMs (REMA, ArcticDEM)

- The complete processing chain, named the "**Altimeter data Modelling and Processing for Land Ice**" (AMPLI), provides topography estimations posted at ~330 m along the satellite track.

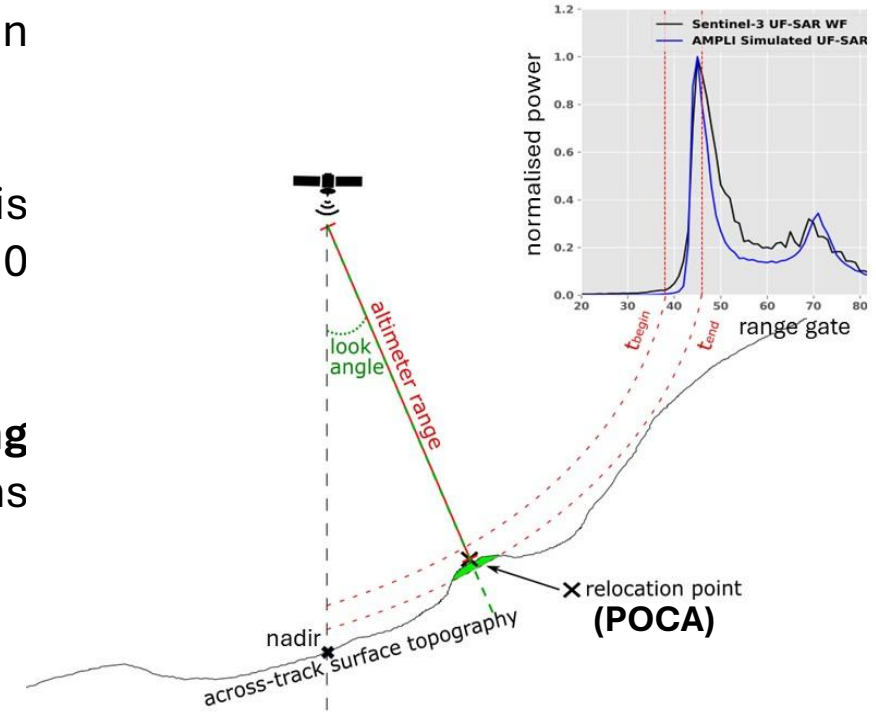
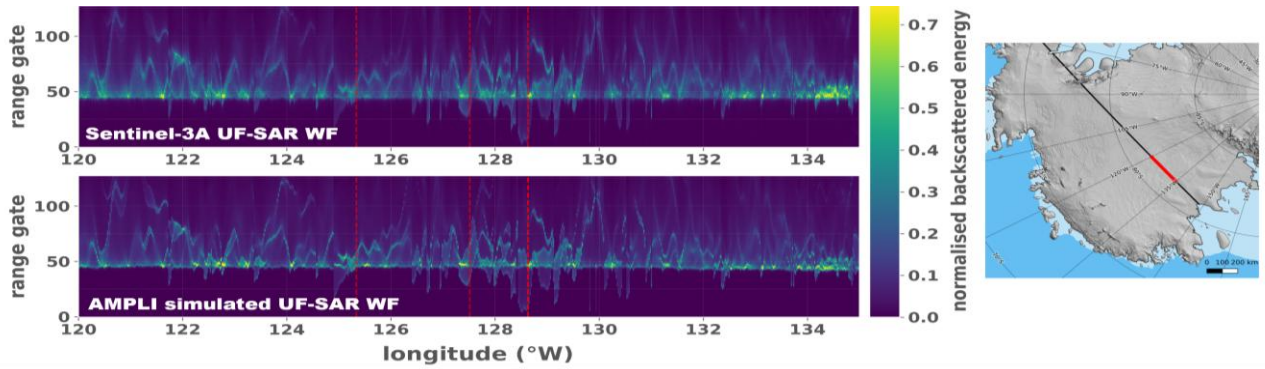


Illustration of AMPLI numerical simulation (bottom radargram)



AMPLI described in a publication:

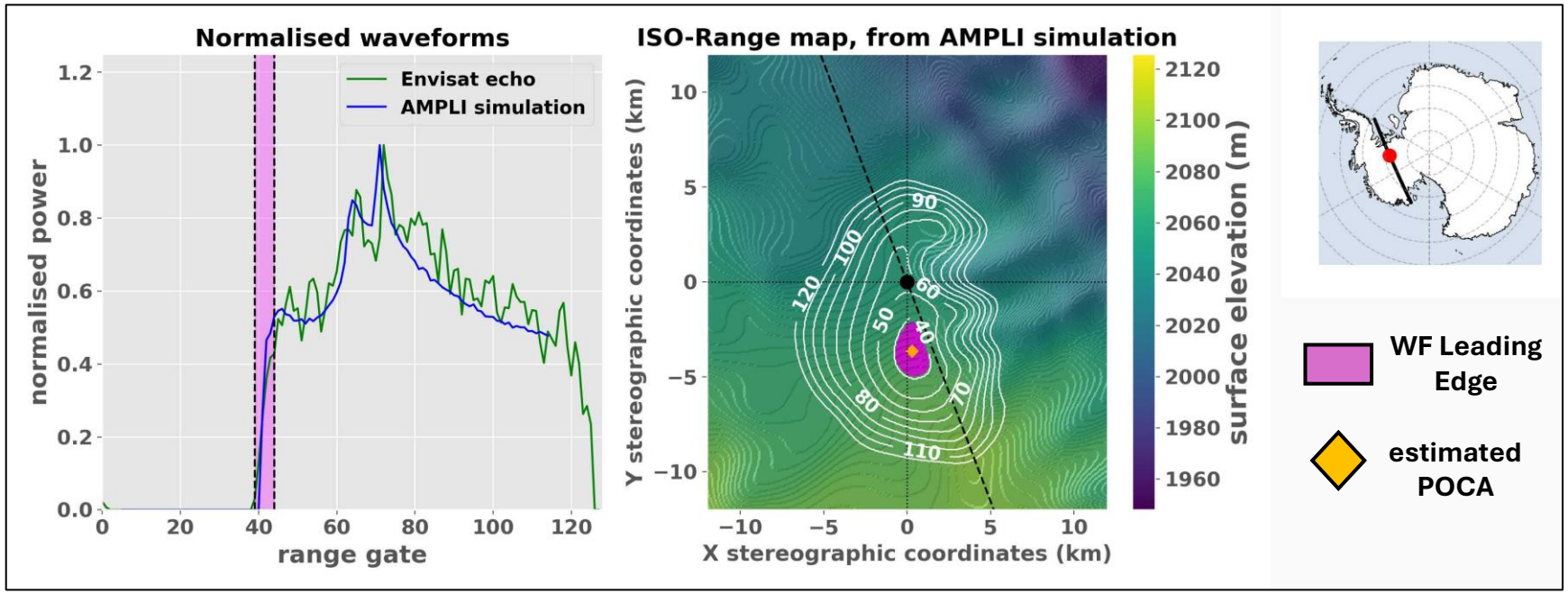
"A facet-based numerical model to retrieve ice sheet topography from Sentinel-3 altimetry"
(Aublanc et al., 2025)
https://tc.copernicus.org/articles/19/1937/2025/

The AMPLI software: description

Illustration in LRM altimetry with Envisat mission (ESA FDR4ALT)

Among other information, the facet-based numerical model generates:
(1) a simulated radar waveform (blue curve in left panel)
(2) an " iso-range map" i.e. the surface sampled by each WF sample (white contours in the middle panel)

=> enabling the estimation of the radar impact point on the ground (i.e. POCA in general)



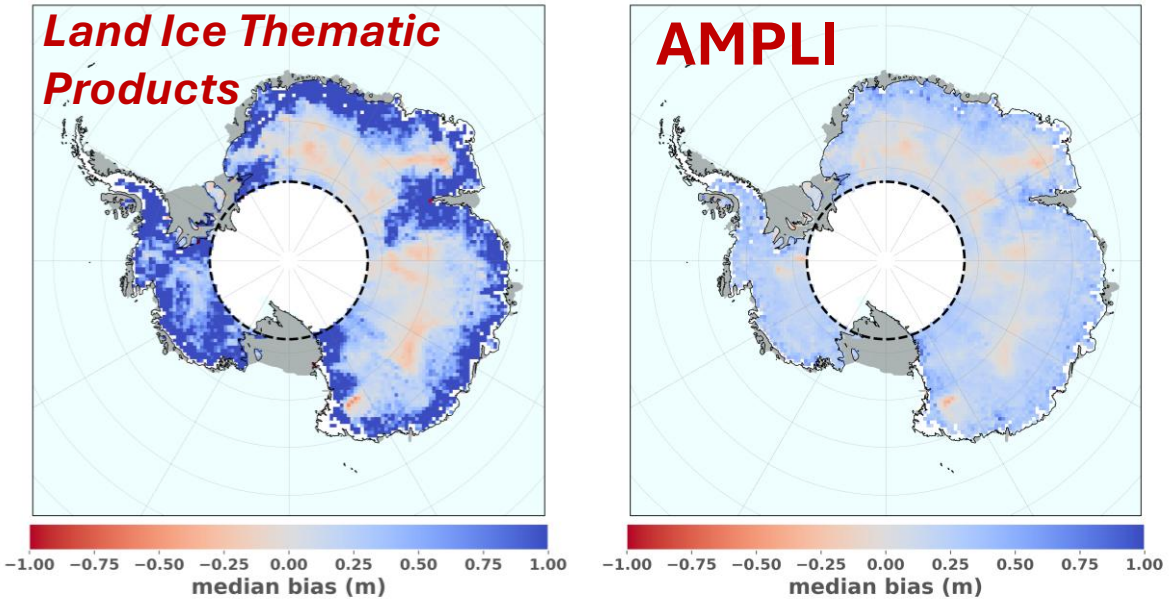
Note: *In SAR mode, the numerical modelling, the geometry, the clustering operations … are different, but the general approach remains the same*

Sentinel-3 AMPLI: key results

Results published in "The Cryosphere" - Figure 6 - https://tc.copernicus.org/articles/19/1937/2025/

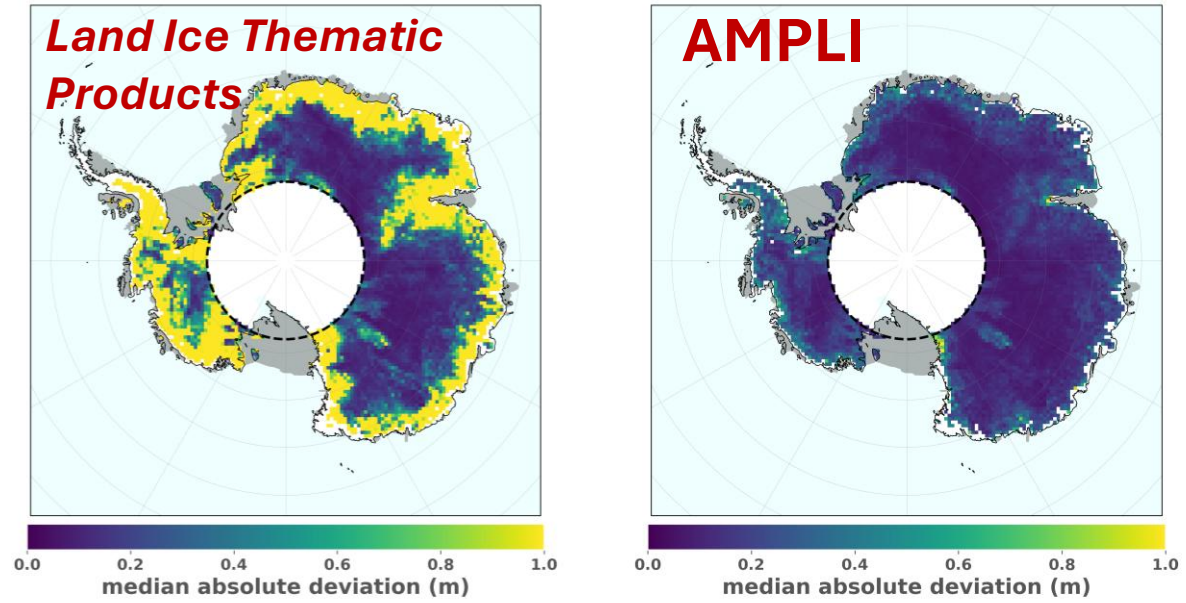
1 Along-track topography: accuracy improvement

Median bias between Sentinel-3 and ICESat-2 ATL06, at co-located points



2 Along-track topography: precision improvement

Median Absolute Deviation between Sentinel-3 and ICESat-2 ATL06, at co-located points



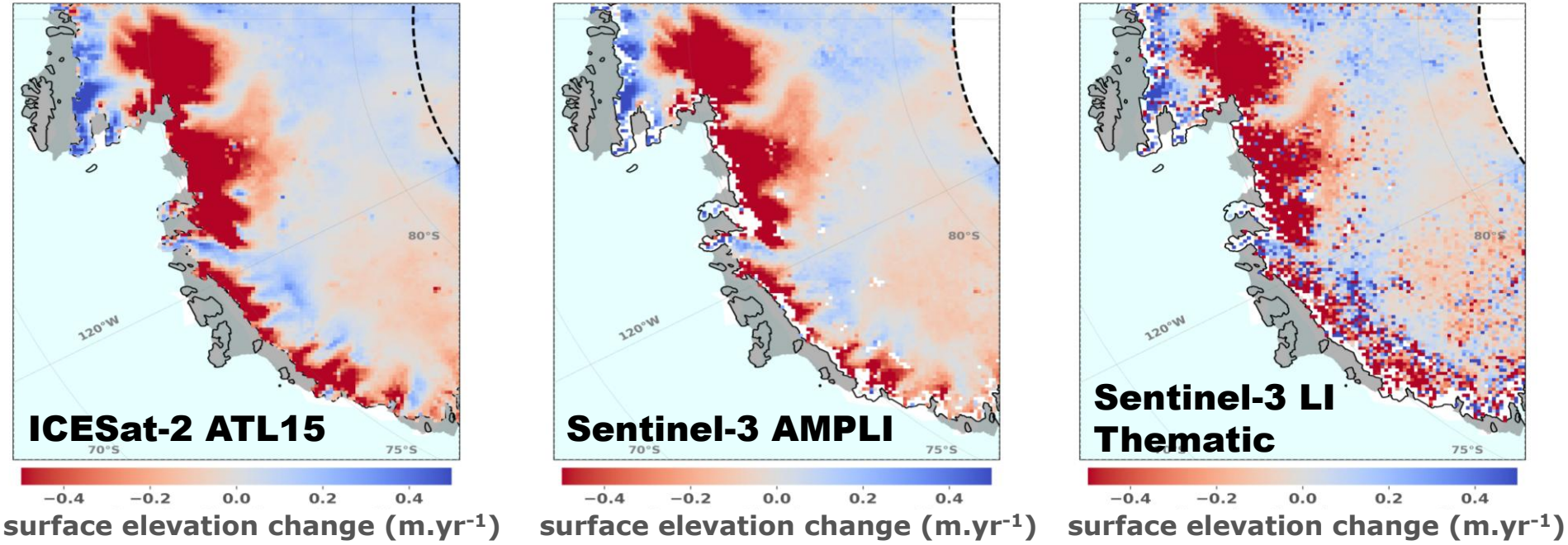
Sentinel-3 AMPLI: key results

Results published in "The Cryosphere" - Figure 7 - https://tc.copernicus.org/articles/19/1937/2025/

3 Surface Elevation Change

Calculated with L2 along-track topography from AMPLI and ground segment processing ("Sentinel-3 LI Thematic")

2019-2022 Surface Elevation Change in West Antarctica



Sentinel-3 AMPLI Products availability

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Sentinel-3 AMPLI « Demonstration » Products are openly available on ESA CDSE

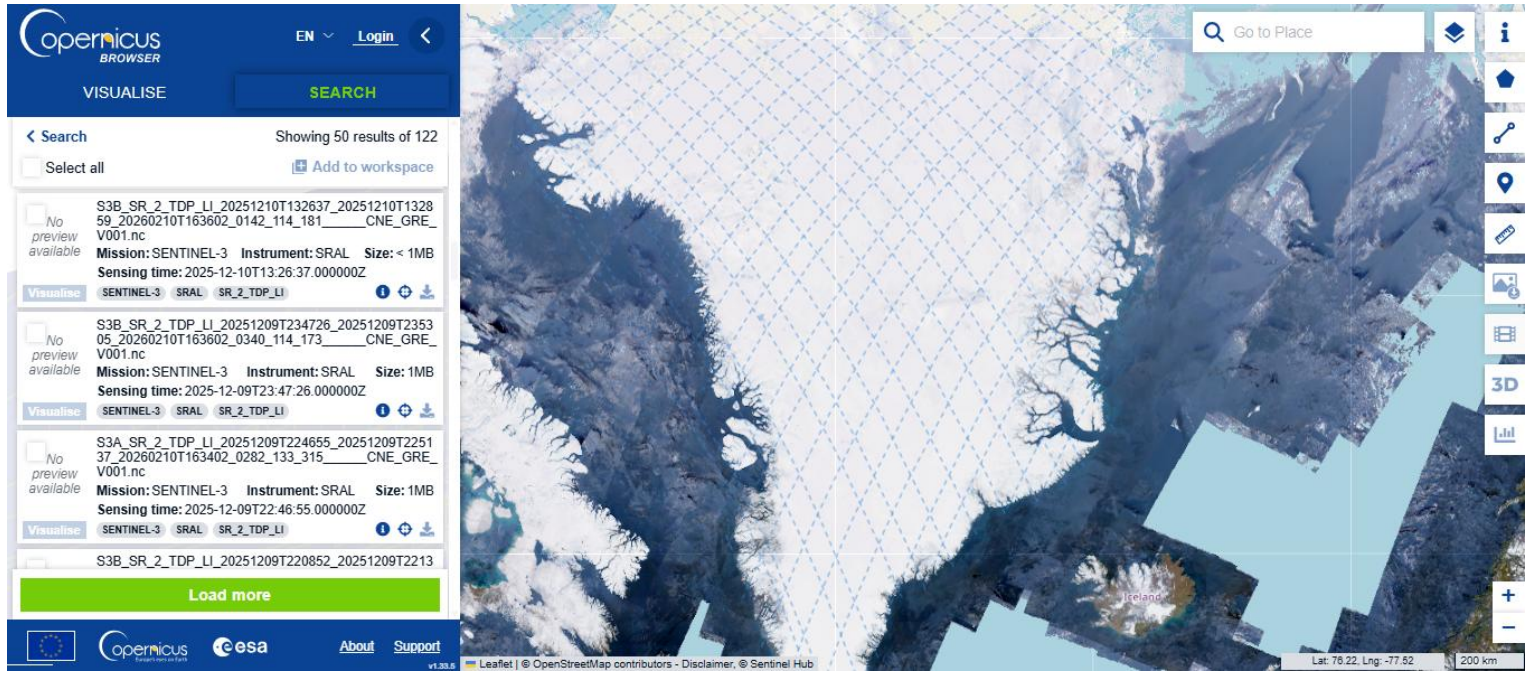
The data set spans the entire Sentinel-3A and Sentinel-3B missions and is currently updated every 3 months by the S3MPC.

Link to ESA "Copernicus Data Space Ecosystem" (CDSE)

https://dataspace.copernicus.eu/

Link to AMPLI « Product Handbook »

https://sentiwiki.copernicus.eu/web/document-library#DocumentLibrary-TechnicalDocumentLibrary-S3-SRAL-TD

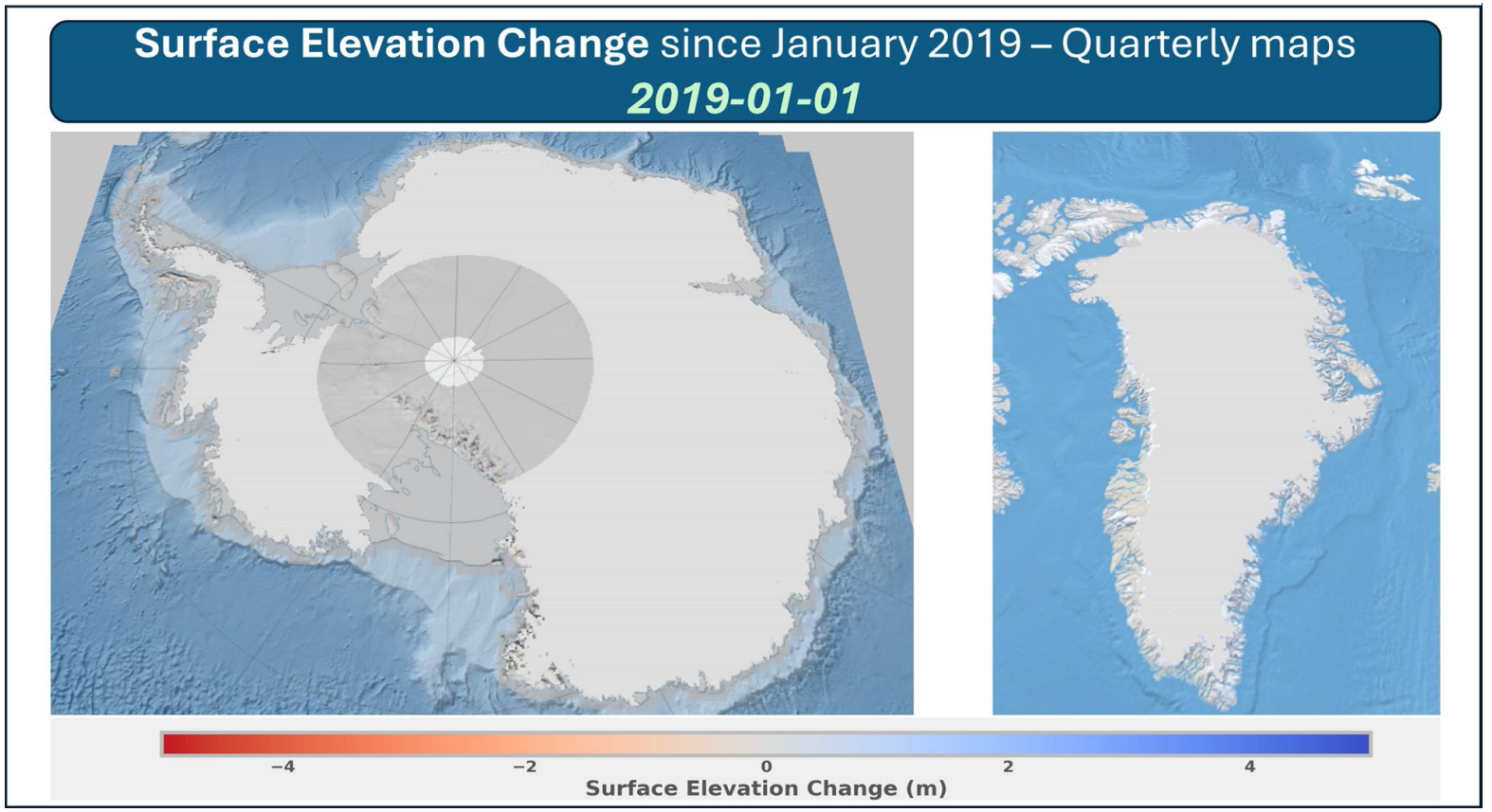


2019-2024 Surface Elevation Change

Results Update:

2019-2024 Surface Elevation Change (SEC) over the Antarctic and Greenland ice sheets

- **Surface Elevation Change** was calculated using the Sentinel-3A and Sentinel-3B topography measurements recorded in the level-2 AMPLI Products following the methodology described in Aublanc et al. (2025).
- **Quarterly maps of Surface Elevation Change were produced**, 10 km pixel size, to match ICESat-2 ATL15 spatio-temporal resolution.

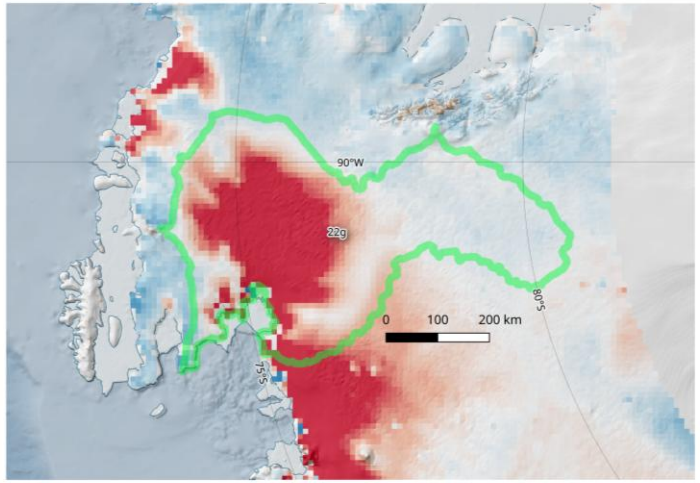


2019-2024 Surface Elevation Change

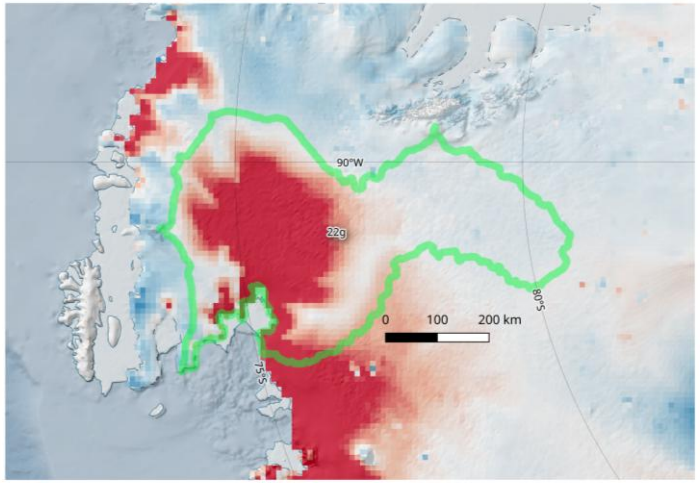
Pine Island
West Antarctica

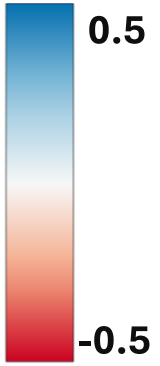
- Important ice melting in the region (reaching 4 m/yr on some areas close to the coastline)
- Close agreement between S3 AMPLI and ICESat-2 on common grid points
- Few pixels missing close to the coastline with S3 AMPLI (closed-Loop tracking failures + processing failures)

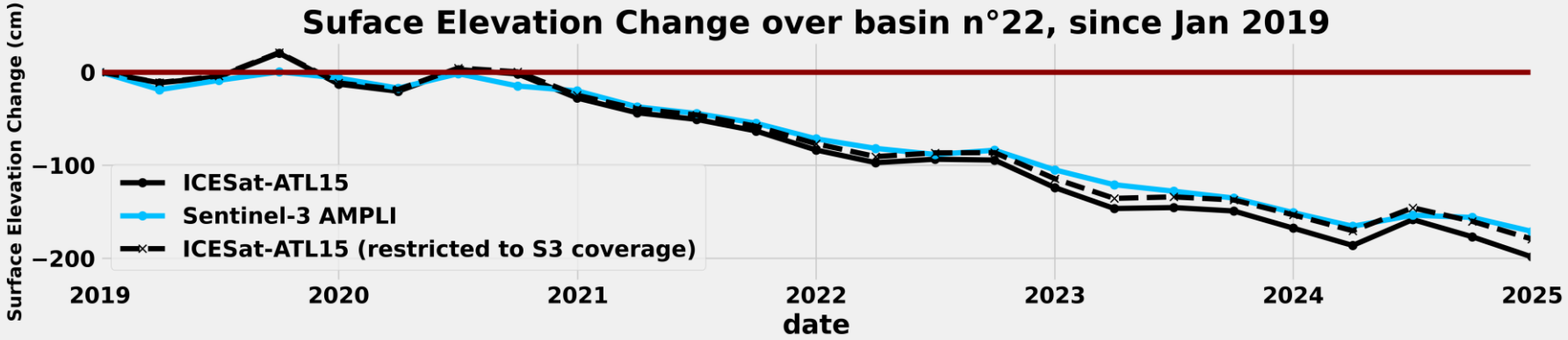
Sentinel-3 AMPLI *- 10 km grid*



ICESat-2 ATL15 *- 10 km grid*





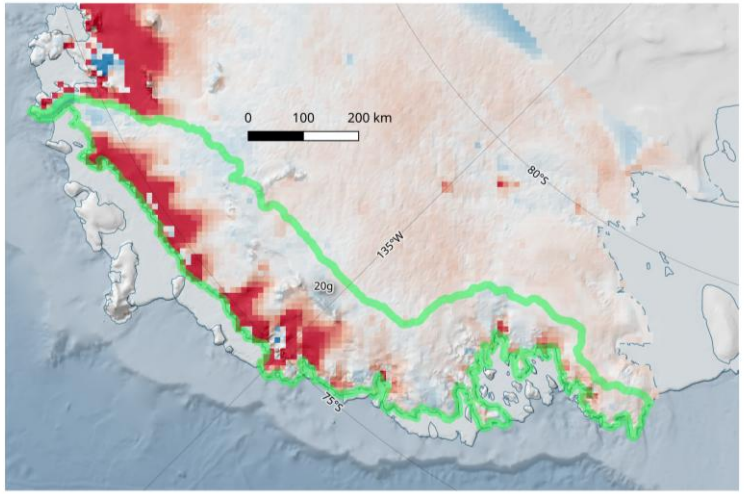


2019-2024 Surface Elevation Change

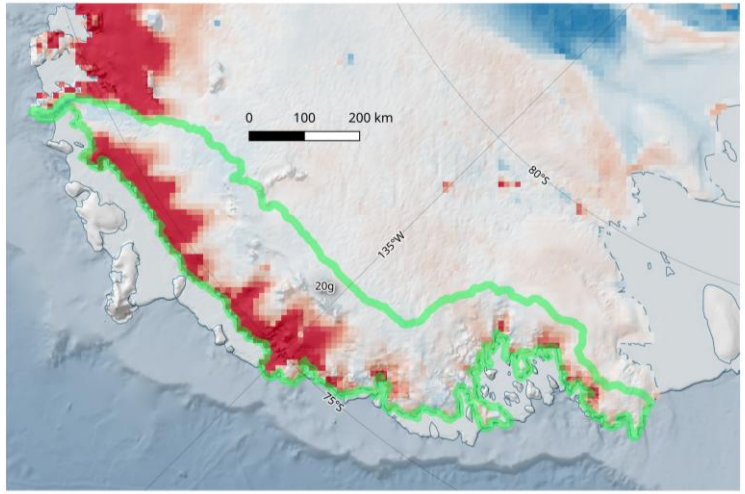
Getz
West Antarctica

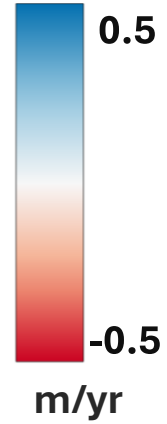
- Again, close agreement between S3 AMPLI and ICESat-2 on common grid points
- More missing pixels in S3 AMPLI grid close to the coastline
- Errors also in few pixels S3 grid, to be investigated and solved. Performance remains far superior to the Land Ice Thematic product (not shown here).

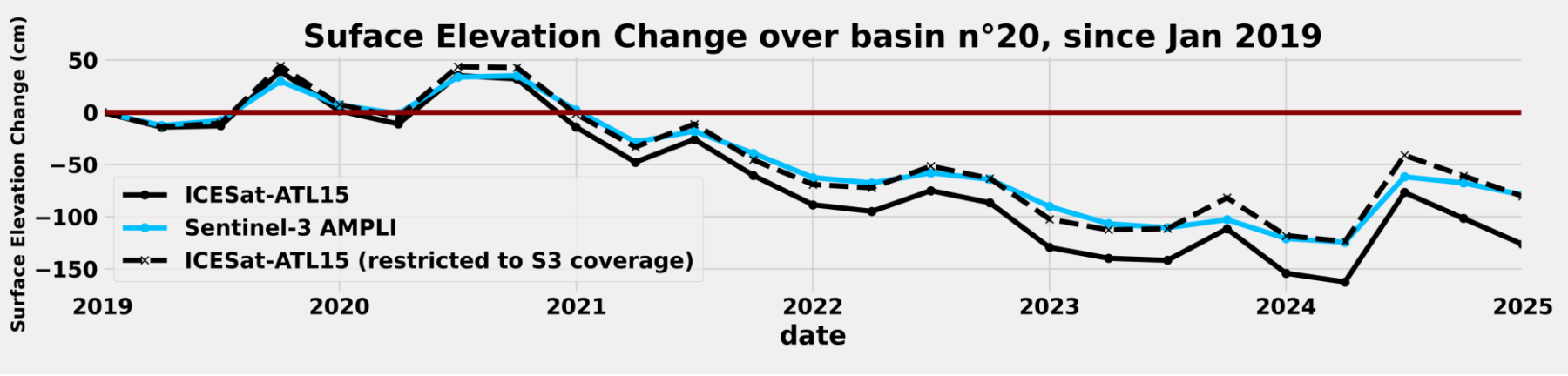
Sentinel-3 AMPLI *- 10 km grid*



ICESat-2 ATL15 *- 10 km grid*







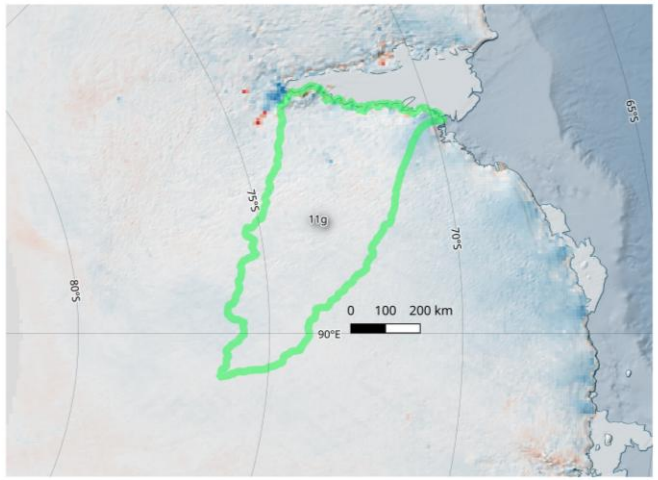
2019-2024 Surface Elevation Change

Basin ID n°11
East Antarctica

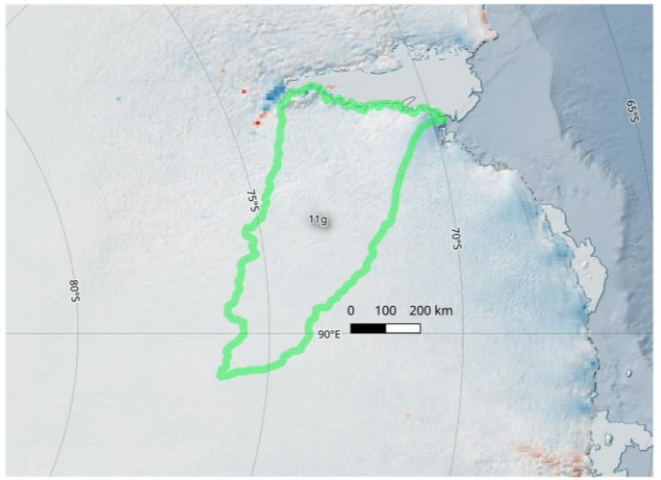
- Stable area, with less than 20 cm of elevation change since 2019
- AMPLI oscillations most likely induced by "snow volume scattering" effect,

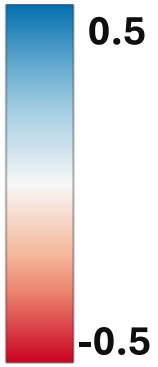
  => *see next slide site n°2 "Taishan"*

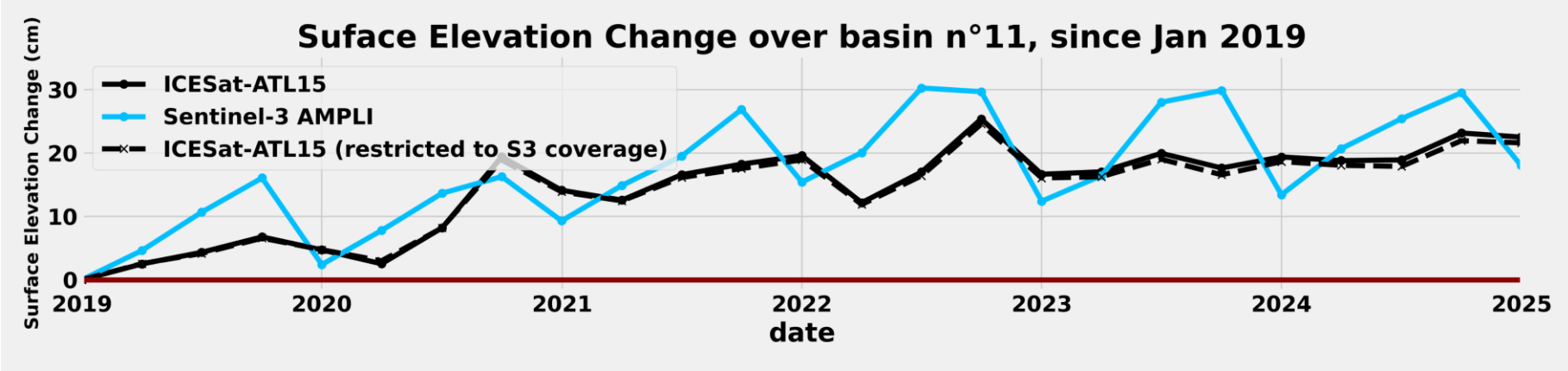
Sentinel-3 AMPLI *- 10 km grid*



ICESat-2 ATL15 *- 10 km grid*





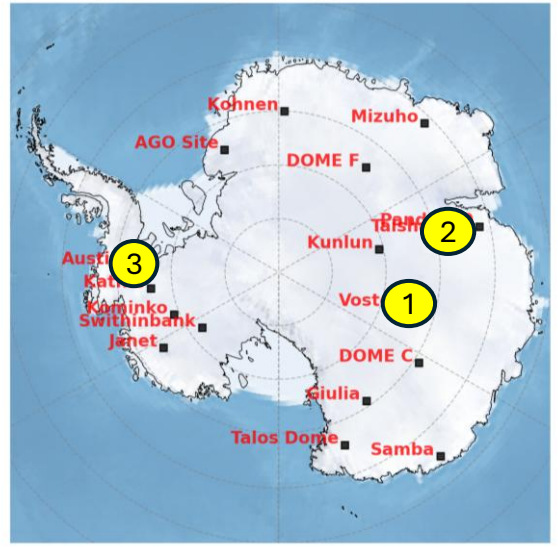


On-going studies and perspectives

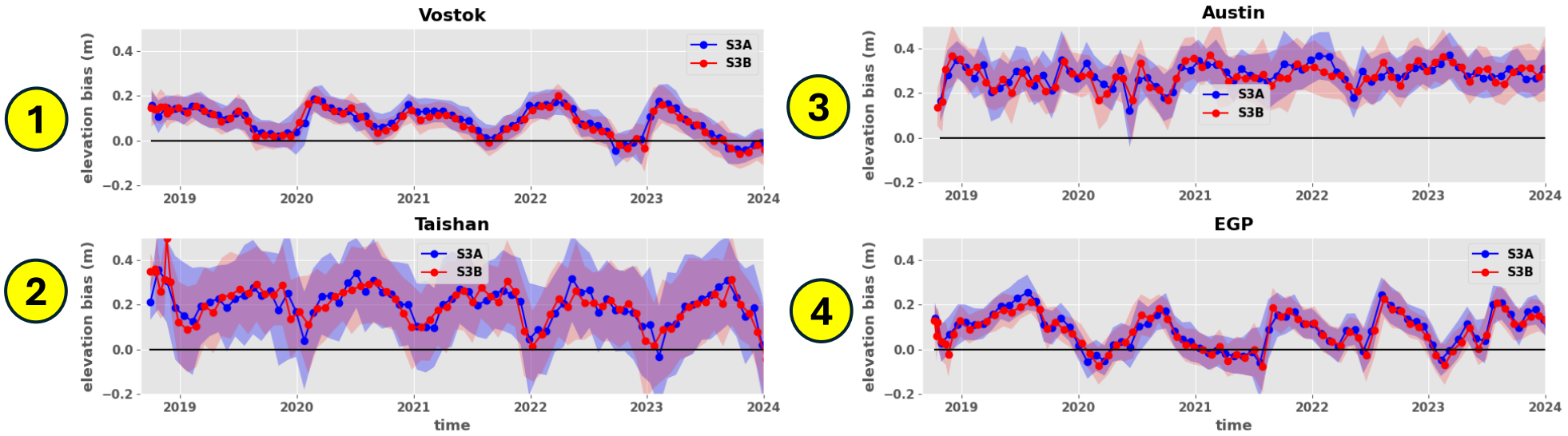
On-going studies: Snow Volume Scattering correction

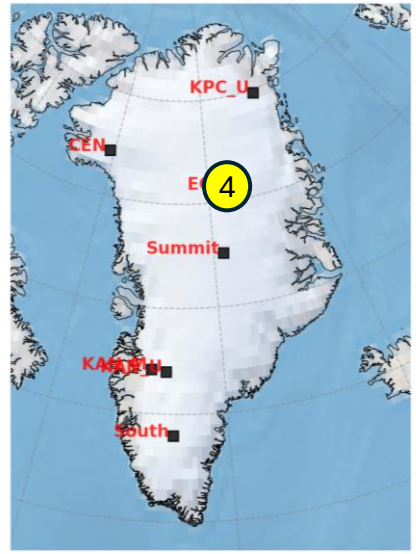
Problematic: Since the Ku-band radarwave penetrates into the snowpack, this impacts the shape of the radar waveform, inducing a bias in the surface topography estimated from retracking.

2025 study: Sentinel-3A/B accuracy was assessed over 25 sites (17 Antarctica + 8 Greenland) during 2019-2024, using co-located measurements with ICESat-2 ATL06.



Median bias between Sentinel-3 and ICESat-2 ATL06 (S3A in blue / S3B in red)





On-going studies and perspectives

Snow Volume Scattering correction study: First Conclusions

- **Snow volume scattering generates an "artificial" temporal fluctuation in the estimated topography**
  - A seasonal signal of **~15-20 cm in amplitude** is generally observed in the **East Antarctic Ice Sheet Interior**
  - **Apart from that, there are no general rules**. Time series are always different across the sites. On some sites there is almost no temporal variations. On other sites, more sporadic and irregular fluctuations over time may occur, but generally limited to 20–30 cm maximum.
  - **In South Greenland stronger variations are seen**, sometimes greater than 50 cm. To be understood.
- **The results are very dependant in the choice of retracking threshold (50% for AMPLI).** With an 80% threshold (ESA Land Ice Thematic Product), the amplitude of the temporal variations can increase by a factor of two, and more (back-up slides).
- A sensitivity analysis shows that the WF **"Leading Edge Width"** and **"Sigma-0"** are two altimetry parameters the most correlated with these temporal topography fluctuations (among those tested)
- **Impact of melt events in Greenland** remains to be analysed in detail. Preliminary results indicate an impact on the relocation that AMPLI can take into account compared to current ground segment processing.

On-going studies and perspectives

On-going studies: Uncertainty calculation

- The baseline approach developed for **CryoTempo project** was reused:

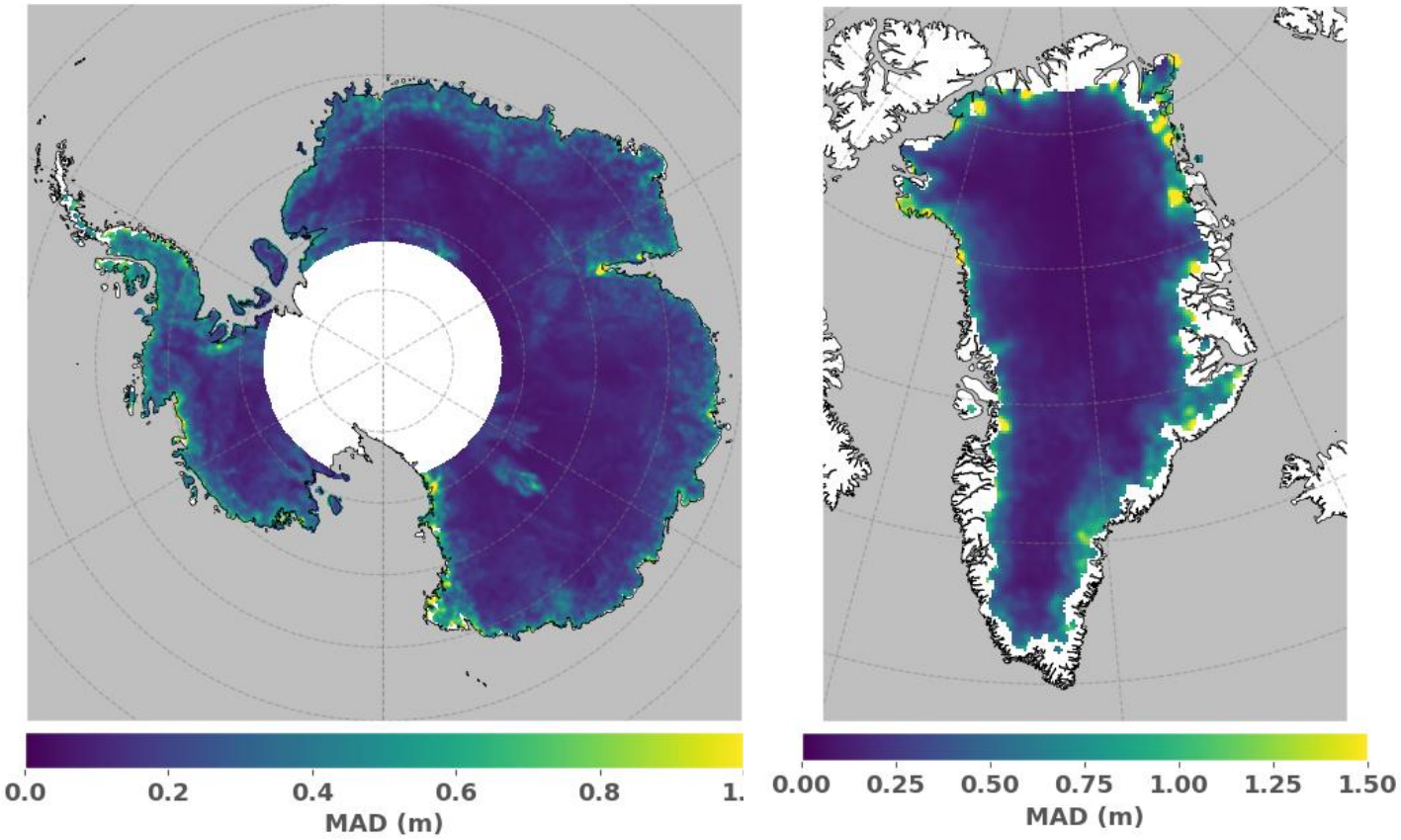
Uncertainty = MAD of S3 elevations, using ICESat-2 ATL06 as reference

- The uncertainty will be read in the "spatial LUTs", generated with 2 years of Sentinel-3 / ICESat-2 co-located points

- The approach could be further improved by accounting for time-varying and/or real-time error components (e.g. snow melting events, see back-up slide).

- To be deployed for a next AMPLI version (2027?)

Median Absolute Deviation (MAD) between S3 AMPLI and ICESat-2 ATL15



Sentinel-3 AMPLI in St3TART project

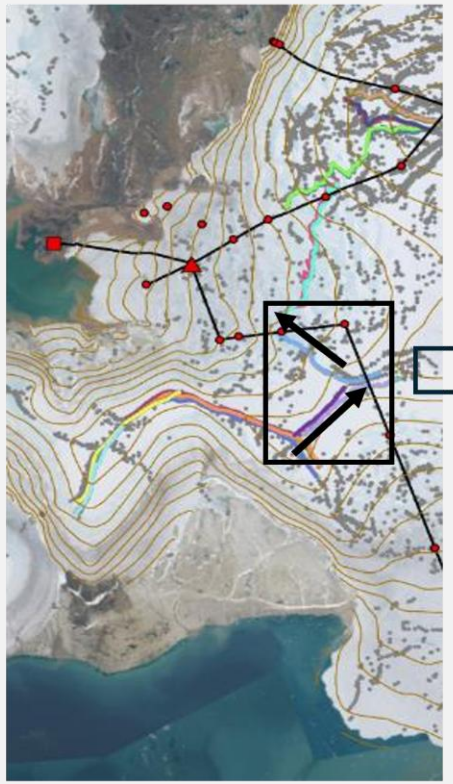
Sentinel-3 AMPLI Products were generated over Svalbard (2016-2025 time series), with in-situ validation performed by NPI (G.Moholdt). Promising resuls in the ice cap interior (decimetre level bias).

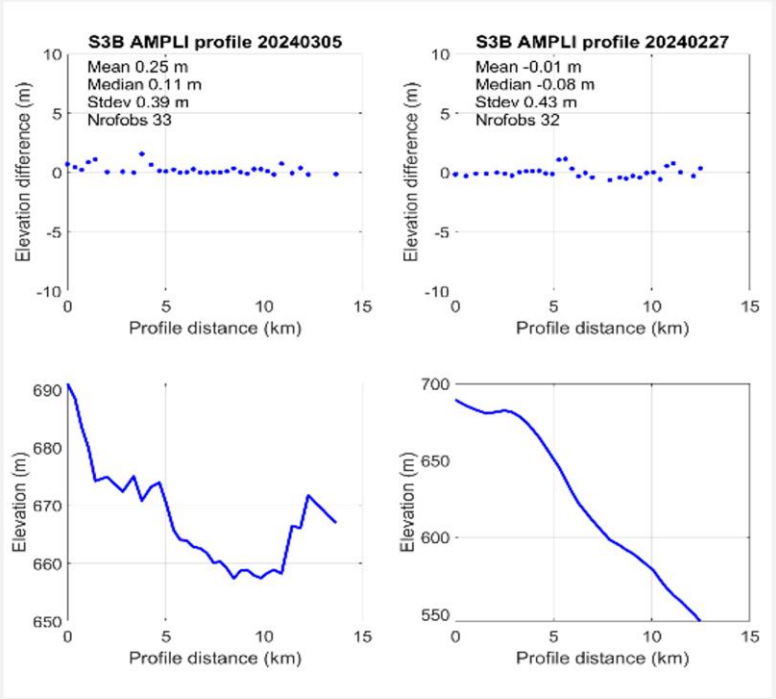
AMPLI can *"capture elevation changes from both winter snow accumulation and summer melting, with residual volume backscatter impacts around the onset of melting (when snow gets wet/refreeze)"*

Credits:
G.Moholdt (NPI)

St3TART Project

- **Austfonna ice cap**
  - Annual monitoring of glacier mass balance
  - St3TART field campaigns **2024**, 2026, 2028
  - April 2024 campaign
    - Direct GNSS repeats of selected S3 POCA-tracks
    - S3 AMPLI processing by CLS/J. Aublanc
    - 9 tracks done with GNSS within 3 months of S3
    - >500 km GNSS profiles
    - Published on Data Hub





Example of snowmobile GNSS repeat of 2 selected POCA tracks (AMPLI, J. Aublanc) across the ice cap divide. The tracks were surveyed on 6 May 2024, about 2 months after S3 overpasses.

Conclusions…

Take away messages

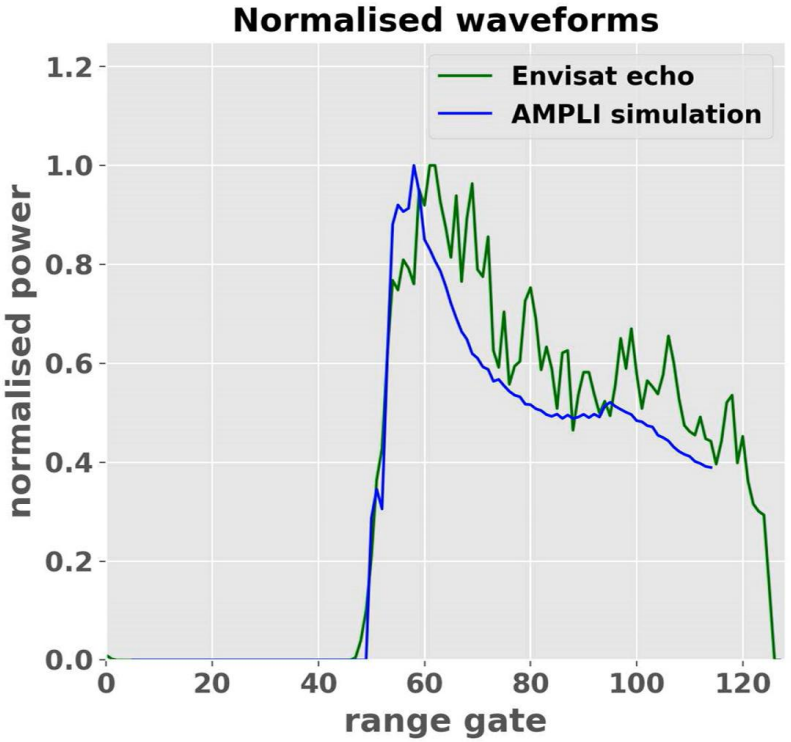
- **Sentinel-3 AMPLI is a level-2 processing chain,** estimating the ice sheet topography along the track, with an innovative approach to estimate the radar impact point on the ground (i.e. POCA location)
- **Outperforms the standard L2 processing** (BC-005 Land Ice Thematic), in both accuracy and precision
- Results with AMPLI highlight **the potential of Sentinel-3 for ice sheet monitoring** (close to ICESat-2)
- **AMPLI Products are openly available in ESA CDSE**, the data set is complemented every 3 months

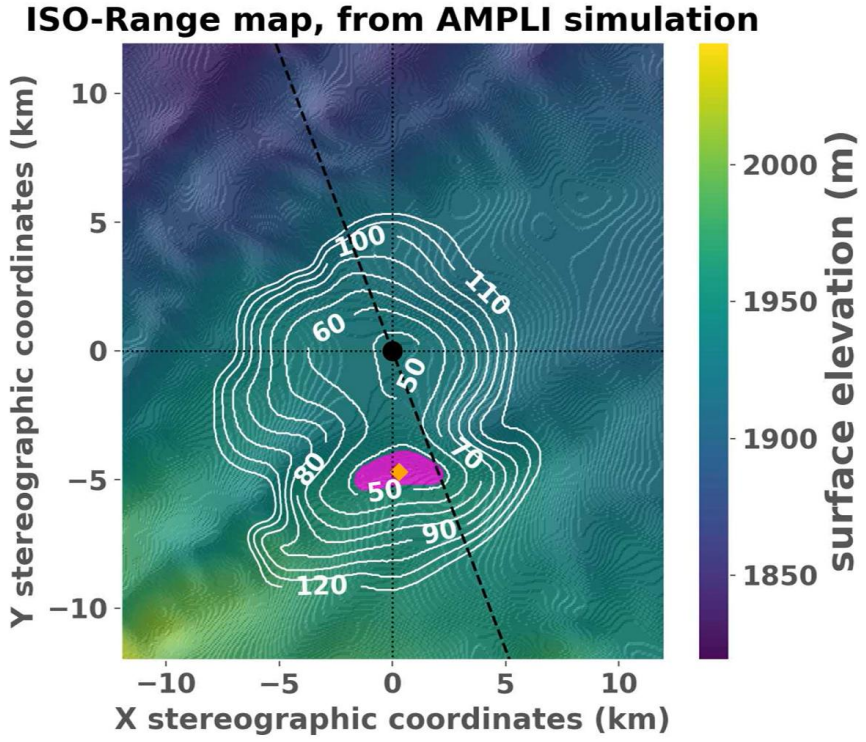
Perspectives / Priorities for processing improvement

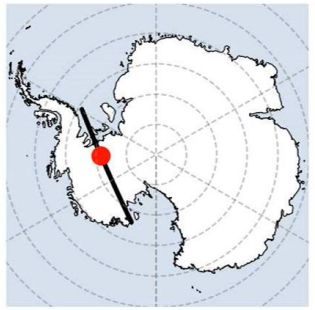
- **Adjust the processing to better monitor imbalance areas,** adapting the work performed within ESA FDR4ALT project *(where static DEM used for relocation is deviating from the ground truth)*
- **Dedicated CalVal over the ice margins,** to detect and understand the remaining simulation/relocation anomalies and improve the processing
- **Snow Volume scattering correction =>** on-going work
- Investigate potential of **Neural Network-based** processing … Analyse impact of snow melting … Processing over **ice caps …**

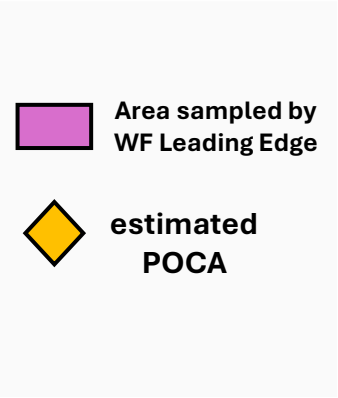
Conclusions…

Promising results in the ESA FDR4ALT Project, **in which AMPLI is being adapted to LRM altimetry (AltiKa, Envisat, ERS).** Important work for reconstructing reliable time series, in order to better understand/quantify the recent evolution of the polar ice sheets.









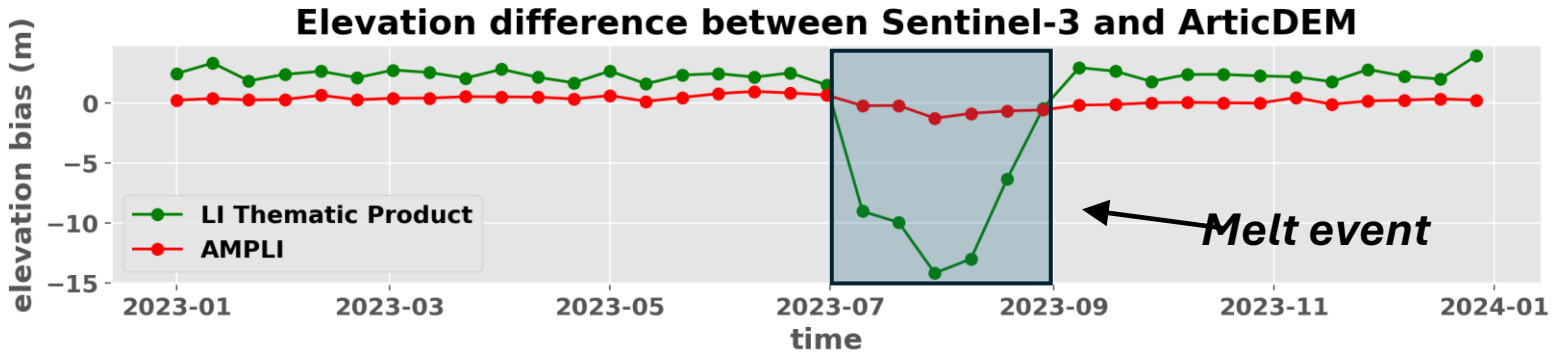
BACK UP

Quick analysis of AMPLI elevations during Greenland melt events

The top figure shows the surface elevation bias between Sentinel-3 and ArcticDEM v4.1 in the south site (blue circle in the right map), reproducing the analysis and results from DTU (S.K.Rose), with the addition of AMPLI elevations.

Location of south site highlighted in blue

LI Thematic Products underestimate the topography by 10-15 meters… **and AMPLI is almost not affected**



Assumption: Melt events generate a variation of backscatter properties in the footprint (emergence of melt ponds?), which change the position of the impact point on the ground.

- ❖ AMPLI has been designed to handle such situations (by relocating the measurement using numerical simulations)
- ❖ While the ground segment processing performs the relocation based solely on DEM information