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Updated: 2026/08/24

SWOT Level-3 ocean topography version 3.0 unsmoothed

changes, rationale, expected improvements, and known issues

SWOT Science Team DESMOS PROJECT
with contributions from the
SWOT Science Team community

CLS cnes datlas

Products evolution overview

- Previous release : v2.0.1 Basic/Expert & Unsmoothed released in March 2025
  - Complete reprocessing of the Science phase & CalVal phase

Not discussed in this package
- L3 wind & wave v3 reprocessing (2026Q4)
- L3 coastal experiments (2026Q4)

- Latest release @ 2-km: v3.0 in November 2025
  - Upgraded Basic & Expert product variants: Complete reprocessing of the Science & CalVal phases with new algorithms
  - New "technical" product variant: additional expert parameters requested by the Science Team and OSTST community

- **New release @ 250-m: v3.0 in August 2026**
  - Full mission reprocessing with v3.0 algorithms
  - Consistent with L3 Expert 2-km
  - Plus new additional variables specific to the 250-m resolution

- Reminder: this is a collaborative product made by and for the Science Team. ***YOUR*** feedback (positive or negative), your inputs and needs are most needed to guide the definition of the next release (v4, tentatively Spring 2027)

If you need help with the L3, feel free to contact the AVISO helpdesk: aviso-swot@altimetry.fr

L3 Unsmoothed v3.0 changes in a nutshell

New additional variables

- Rain rate @ 250-m pixel
- DTU Mean Sea Surface
- Sea-ice segmentation
- Low-frequency calibration

Geophysical standards

- Default MSS model change: new CNES_CLS_2025 model using KaRIn measurements (will replace the Hybrid_2023 model)
- Ocean tide FES_2022 solution extrapolated in complex coastal areas (to avoid default values)

L3 algorithms

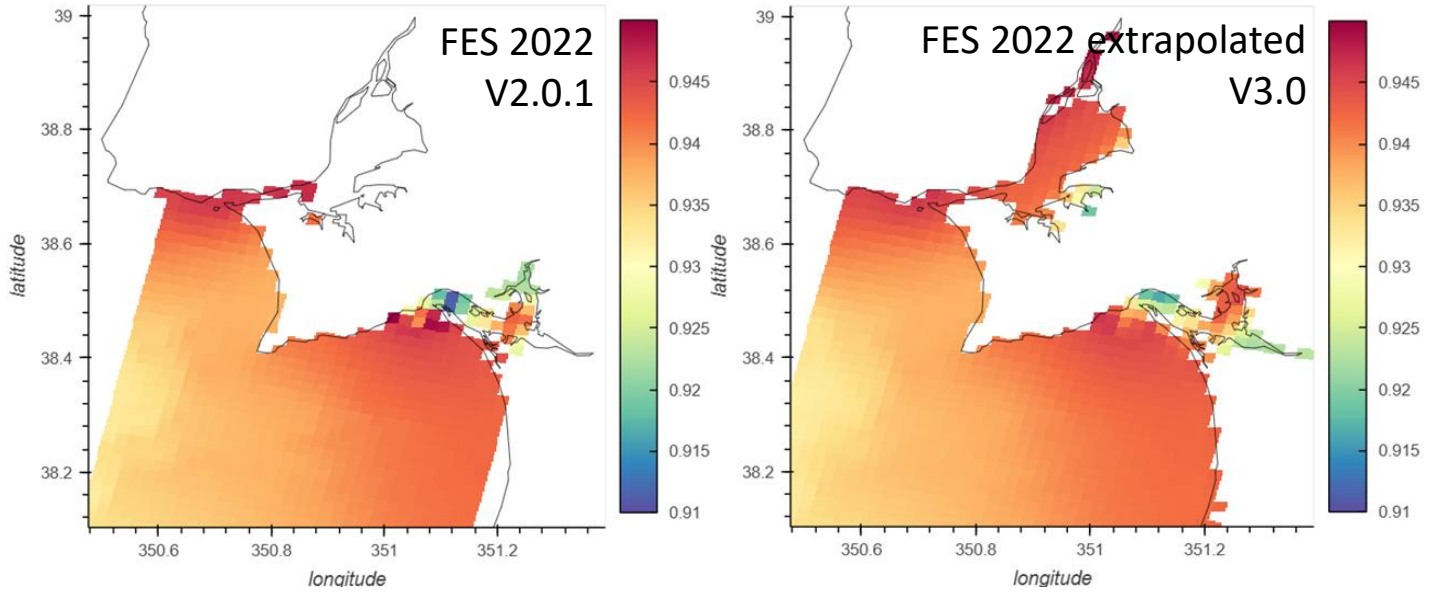
- Coastline improved : new L3 land mask, more precise, with many estuaries now better retrieved at 250-m resolution
- Data selection quality flag granularity improved for rain cells
- Data selection quality flag improved for sea-ice leads
- Upgrade of the cross-calibration (coastal+polar improvements)
- Upgrade of the denoising with correction of geographically bias artefacts

Note: most evolutions are coherent with v3.0 Basic/Expert/Technical products.

Geophysical standards : FES 2022 solution extrapolated in complex coastal areas

- **OLD** : The L3 v2.0.1 product uses an ocean tide solution from the FES2022 harmonic atlas on an unstructured native grid. Like other tides models, this solution is not defined everywhere, especially over complex coastlines
- **NEW** : The L3 v3.0 switches to the extrapolated structured FES2022 atlas when the native version is not available.
  The extrapolation is very local.

- **Rationale**: avoid defaulted SSH pixels (NaN) caused by the tides correction by providing an extrapolated value in a limited area (suboptimal quality but valid)
- **Limitations**: some discontinuities in the tide correction and SSH might be observed at the transition between the two FES models



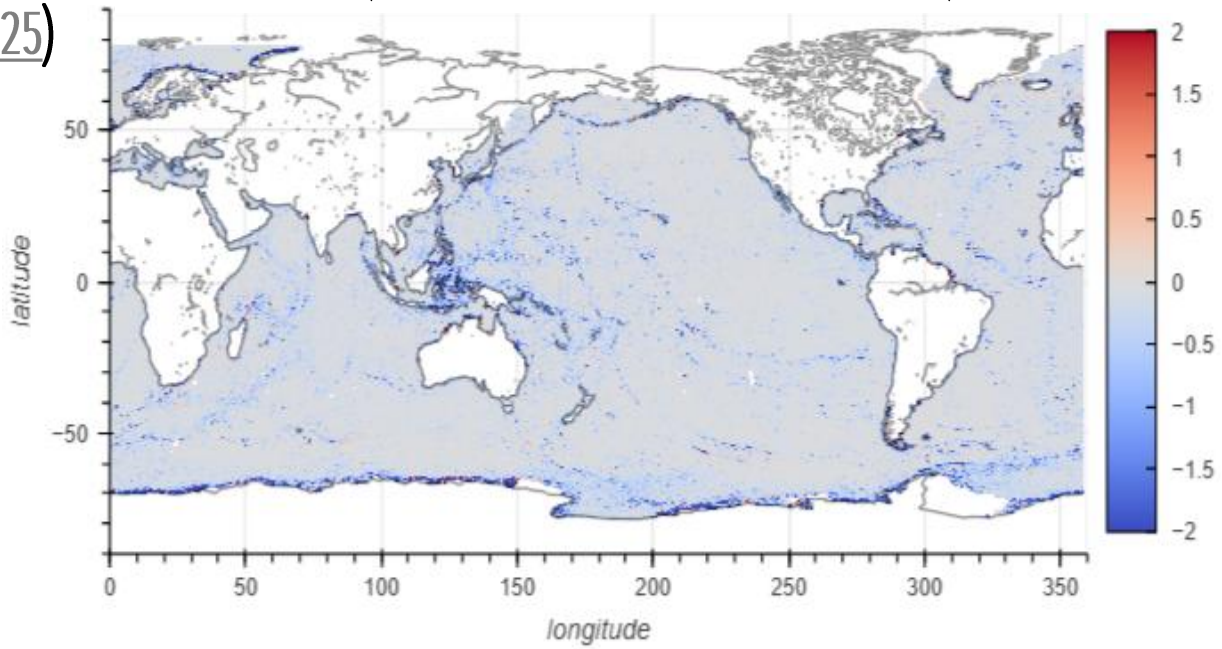
Example of the impact of the extrapolation of FES 2022. Case of an esturary in Spain – Only land sea mask data selection applied

Geophysical standards : MSS Model Upgrade (CLS/CNES 2025)

The L3 v3 uses the new CNES/CLS 2025 model (Charayron et al 2025)

- Replaces MSS Hybrid 2023 (SIO_2022/CNES_CLS_2022/DTU21) used in v2.0
- Blends 30 years of altimetry with 25 cycles (~1,5 year) of SWOT/KaRIn science orbit
- Better separation of mesoscale from the MSS with CMEMS DT2024 multi-mission maps
- Better separation of small mesoscale using MIOST-IT algorithm (doi:10.5194/os-2021-80)
- Better scales < 100 km using SWOT/KaRIn (also shown by Yu et al., 2024)

Short-wavelengths MSS error difference from MSS H2023 to 2025
(blue means 2025 model is better, λ 15-125km, unit: cm²)



Rationale for using this beta MSS model

- Significant reduction of geoid features affecting KaRIn SSHA
- SSHA variance reduction (w. independent data): 10% for 10-125 km (global average) ; up to 20% around 20-30km
- SSHA variance is reduced only over geodetic features (not mesoscale, not internal tides)
- MSS error at short wavelengths reduced by more than 1 cm² in rugged bathymetry regions (i.e. substantial for small/sub mesoscale) (see Fig.)
- Metrics confirmed with independent data: nadir altimeters and SWOT 1-day phase

Work in progress

- Limitation: coastal KaRIn data is mixed bag of good & bad (subpar geophysical corrections) hence a conservative approach for this release; no optimization in polar ice-covered areas

Charayron R. et al. The new CNES CLS 2025 MSS model leveraging SWOT KaRIn data. SWOT-ST 2025. MSS_2025_presentation_SWOT-ST25pdf

Geophysical standards : additional MSS model

- MSS DTU25 model (Nielsson et al, 2025) added as a new parameter
- This MSS is not used for the default SSHA, but users can change the MSS reference combining the variables available in L3 product as follow:

SSHA filtered using MSS DTU = ssha_filtered + mss – mss_dtu
(ssha_unfiltered and ssh_unedited can be updated in the same way)

Rationale for adding this model

- Alternative MSS models were requested by expert users (for evaluation or replacement)
- Over the global ocean, the DTU model was shown to have the same performances than our default MSS model CNES_CLS_2025 (Charayron et al, 2026)
- DTU leverages the KaRIn 250-m resolution in some key coastal areas to enhance the resolution of their MSS model (right figure) at the cost of a slightly worse performance in other regions

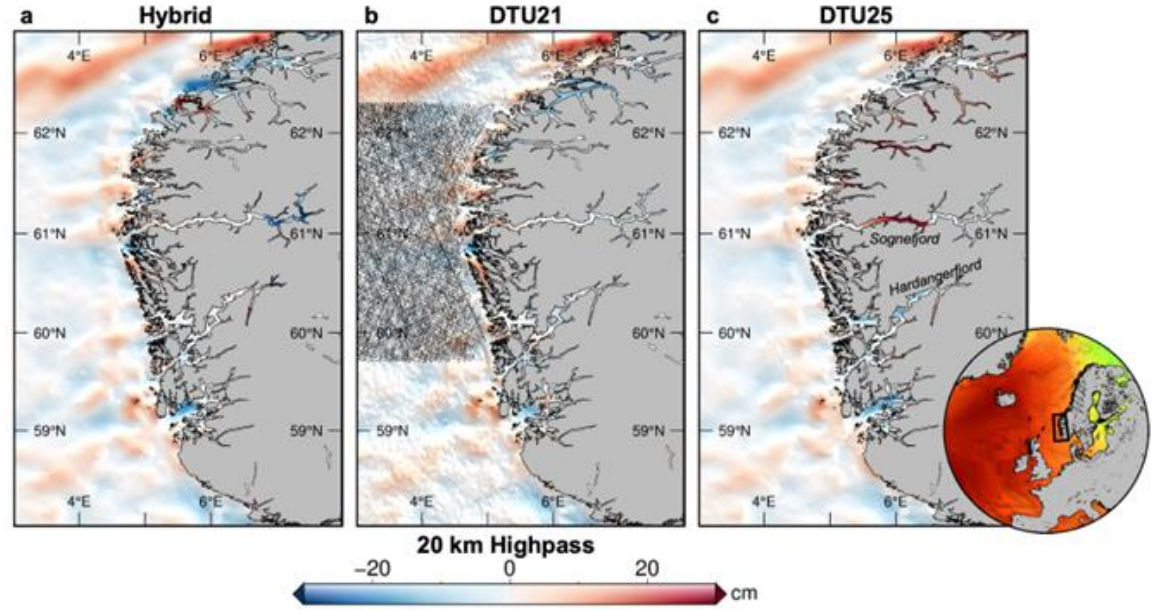


Figure 12. The western coast of Norway highpass filtered at 20 km with the HybridMSS, DTU21MSS and DTU25MSS in **(a)**, **(b)**, and **(c)** respectively. Black points in **(b)** indicate where nadir altimetry observations are located (between 59.7–62.3° N) in the creation of the DTU21MSS. *(From Nielsson et al, 2025)*

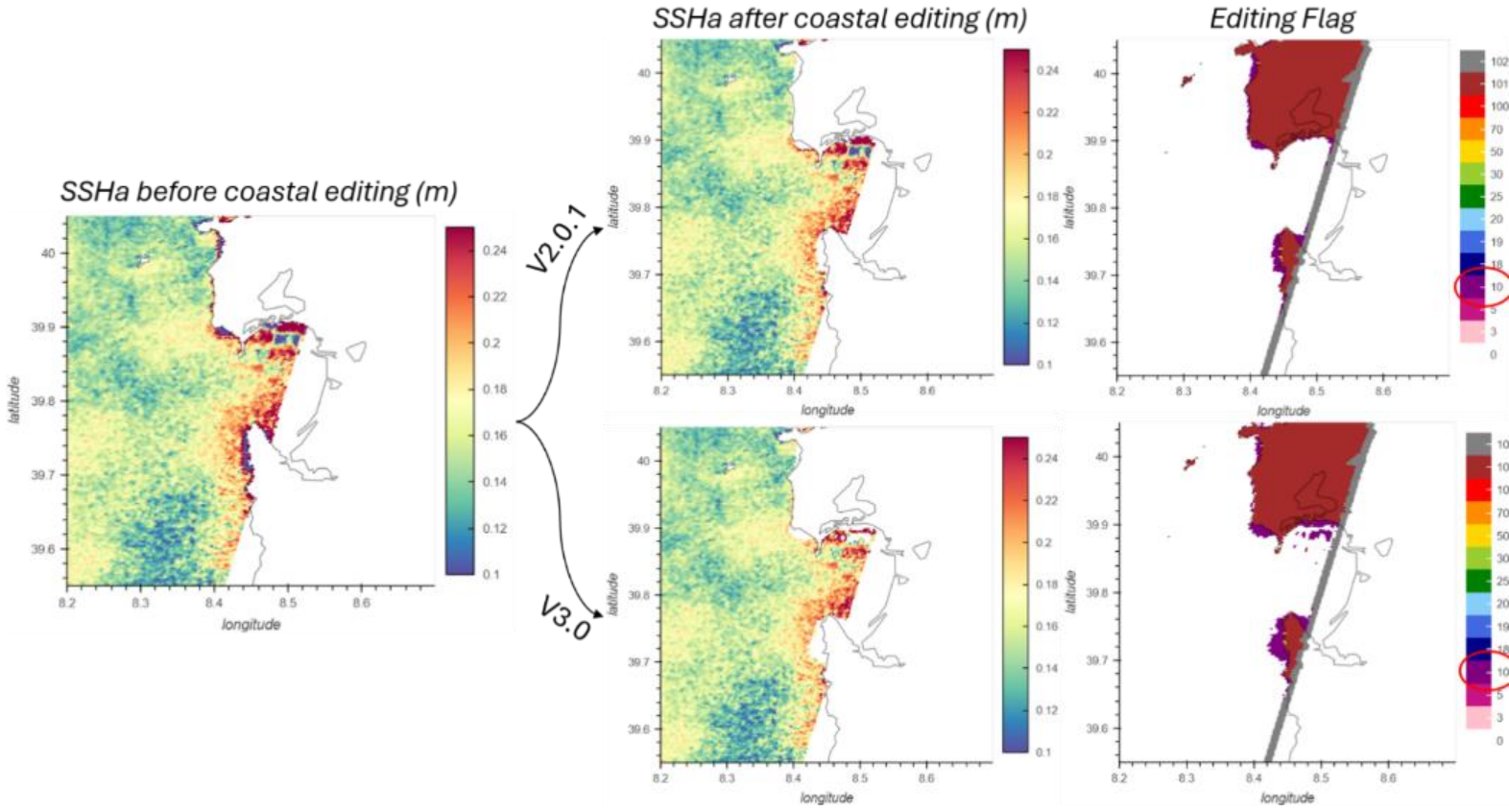
Data selection improved: Land-sea mask / Surface type

- The surface type mask is used to derive quantities related to the coastal domain (e.g. distance to coast, editing flags)
- The mask provided in the L2 product is sometimes incorrect (known limitation, regionally dependent)
  - It can be misplaced by a few kilometers with respect to the "true" shoreline (as per optical imagery or SWOT sigma0)
  - Its resolution is sometimes insufficient to resolve complex shorelines
  - It can be off in some estuaries
- The L3 product contains a new custom land mask derived from Open Street Map (OSM) contours with some adaptations
  - OLD v1: first cut of the land mask: it fixed most of the known L2 issues, albeit with some failures in estuaries
  - OLD v2: revised mask with manual processing of ~40 estuaries to retrieve them
  - NEW v3: fully updated land mask with a better retrieval of most of the estuaries (contact us if yours is not !)
- **Rationale:** this mask was primarily developed to better classify land from the coastal ocean (which in turn affect ocean calibration)

Data selection : coastal flag improved (250m)

- OLD : in L3 v2.0.1, some artefacts closed to the coast are not flagged.
- NEW : L3 v3.0 solution detects and flags these artefacts with the coastal flag (flag #10)

Flag	Description
102	No SSHa values available
101	Pixels over land
100	Edges of swath. Only values between 10 and 60 km to the nadir are considered as valid data
70	Pixels impacted by spacecraft events
50	Abnormally high SSHa values
30	SSHa pixels out of the expected statistical distribution
25	Rain cells
20	Sea-ice pixels
19	Unsure sea-ice pixels in polar areas (only for the unsmoothed product)
18	Unsure ocean pixels in polar ares (only for the unsmoothed product)
10	Suspected coastal pixels
5	SSHa pixels out of the local distribution
3	Eclipses
0	Valid data



Example of the coastal editing in L3 V2.0 and in L3 V3.0 (only flags > 10 are applied)

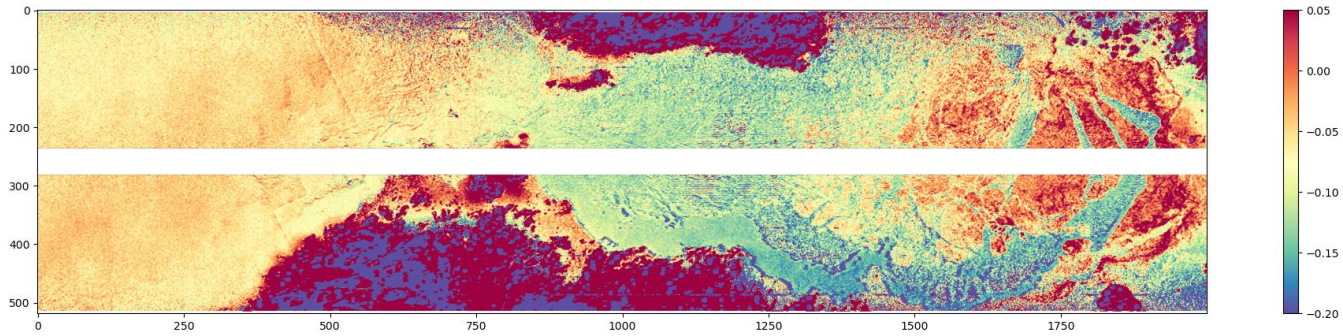
Data selection : Polar selection improved

- OLD: L3 v2.0 detection sea-ice pixel with the sea-ice clustering provided by the LEGOS only where the ice concentration (OSISAF) is higher than 50%.

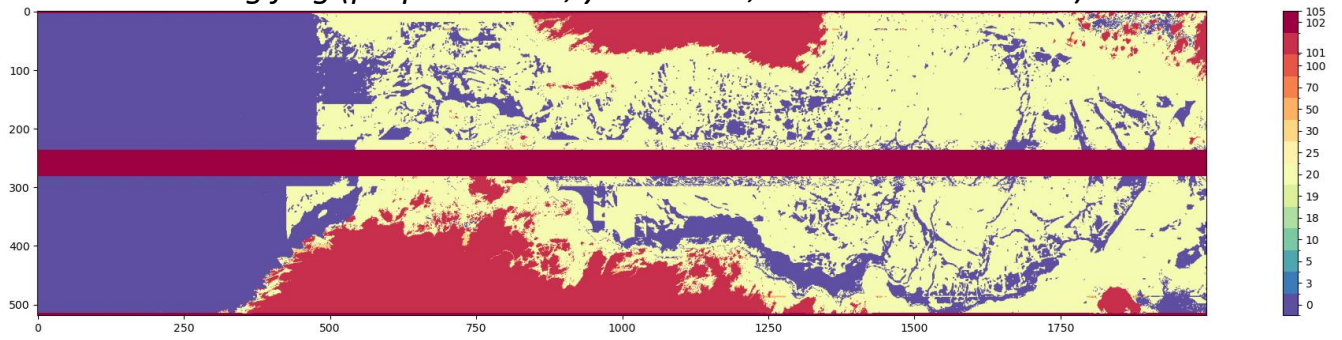
- NEW : L3 v3.0 has a new sea-ice detection. It is based on the sea ice probability provided by a combination of two different segmentation algorithms : the MRF method by default and the XGBoost method otherwise

- The new individual "sea-ice flags" themselves are also provided in dedicated variables : **sea_ice_probability_mrf**, **sea_ice_probability_xgboost**.
- The segmentation algorithm from LEGOS is also available separately (**sea_ice_clustering_legos**)

SSHa (m)



Editing flag (purple : ocean, yellow : ice, red : no data or land)



Example of sea ice editing (Cycle 13 Pass 1 in Arctic).

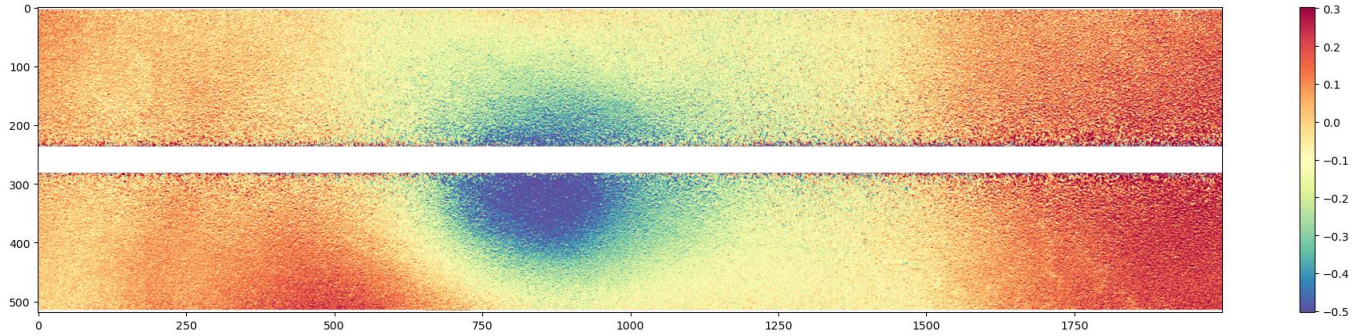
Data selection : Polar selection improved

Known limitations

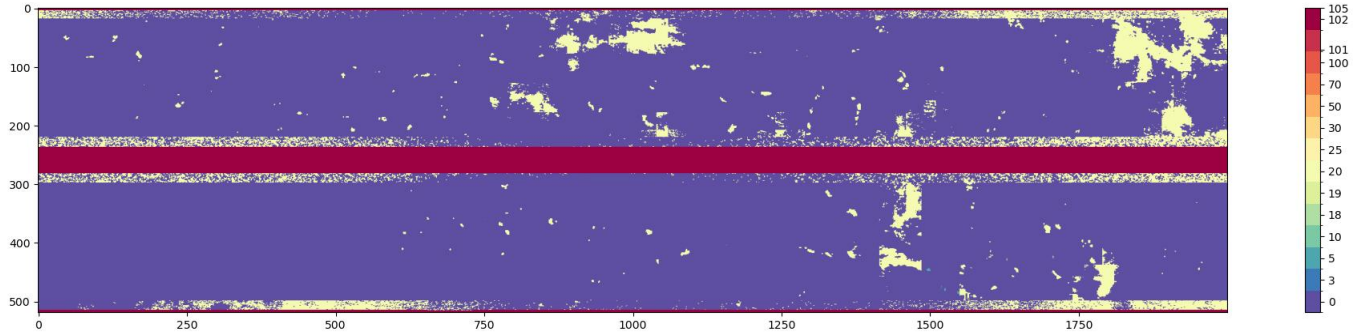
- Rain cells and noise can be incorrectly flagged as sea-ice if they are located above 50°N/S. This is caused by the drop in radar backscatter that could be from rain or ice.

- In high waves regions/events, the higher radar noise in the swath edges is periodically flagged as sea-ice because the XGBoost algorithm is sensitive to random noise. Some discontinuities can be visible between the two methods.

SSHa (m)



Editing flag (purple : ocean, yellow : ice, red : no data or land)



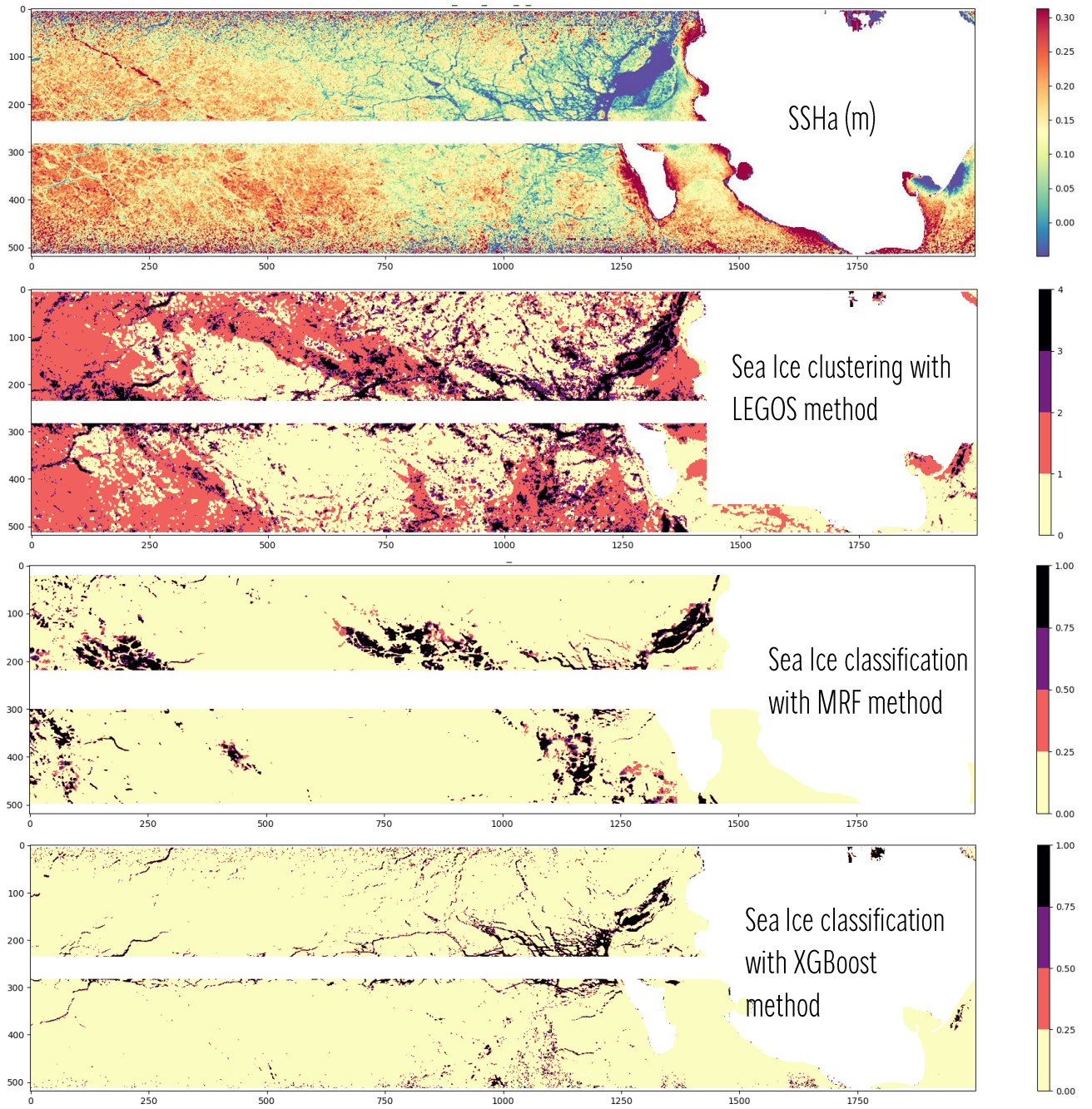
Example of limitation of the sea ice ediiting (Cycle 34 Pass 567 ~ -50° of latitude)

250m additional variables : Sea/ice surface probability

- 2 sea ice probabilities and 1 sea ice clustering are available in the Unsmoothed product. Each of them is a work in progress with their own strengths and weaknesses

  - **LEGOS clustering in its beta version**: lot of unsure data, limited spatial coverage (for more information see Jestin et al, 2026)
  - **MRF algorithm**: derived from SWOT hydrology water detection, gives probability, may detect fake leads, robust to the season, from CNES
  - **XGBoost method**: gives probability, sensitive to noise and to rain cells, robust to the season, from CLS.

- The ice concentration is available for MRF and XGBoost methods
- Classification recommended for MRF and XGBoost methods
  - Between 0 and 0.25 : ice
  - Between 0.25 and 0.5 : unsure ice
  - Between 0.5 and 0.75 : unsure ocean
  - Between 0.75 and 1 : ocean



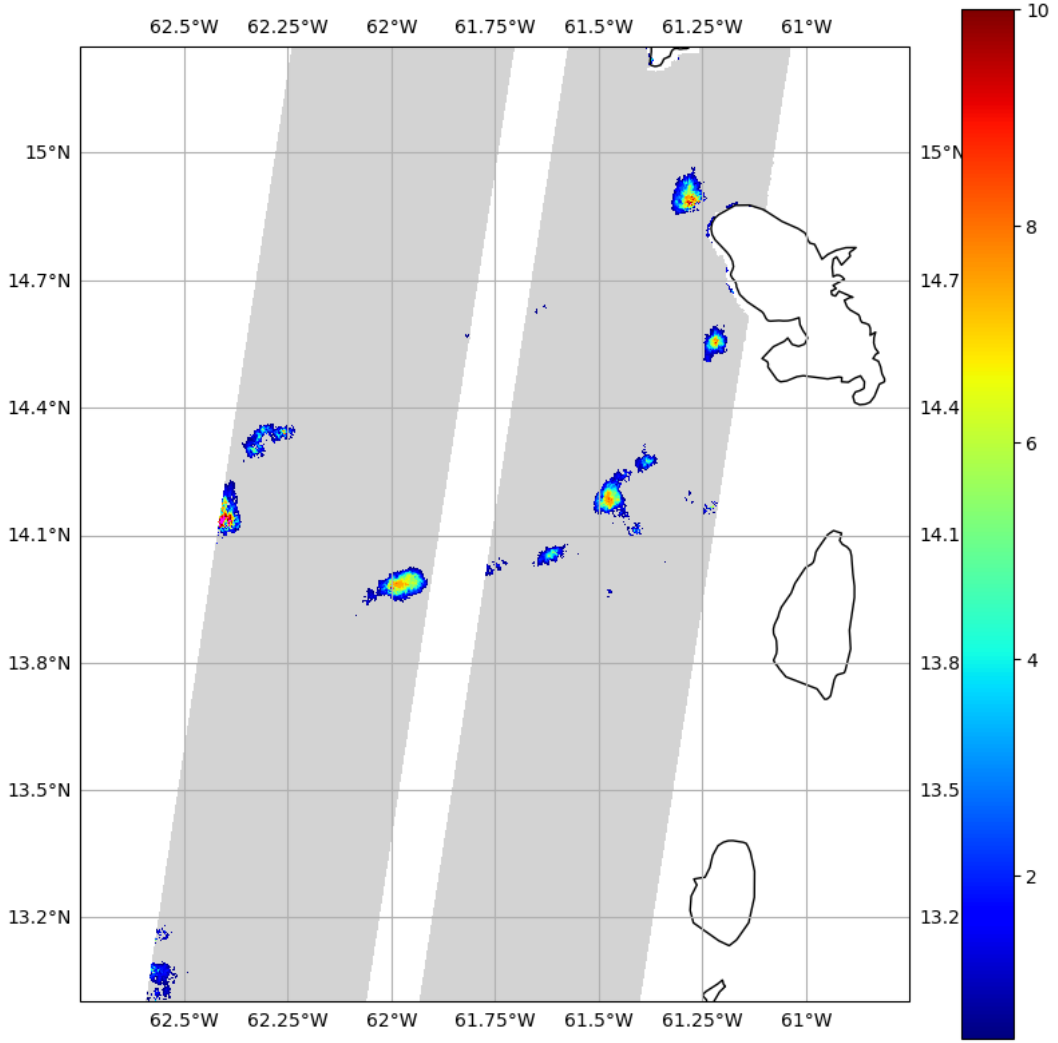
Example of the new sea ice classifications (250m product)

250m additional variable : precipitation rate

- Available in the "**rain_rate_cnn"** parameter
- Adapted from the work of Colin et al. (2025) on Sentinel-1 : based on a combination of 5 convolutional neural networks, trained using Nexrad ground radar match-ups as reference
- Fixes anomalies reported in precipitation rate of the 2km expert products
- NB : the precipitation rate is not included in the editing flag unlike the L3 V3 2km. Thus, the flag #25 doesn't exist in this version.

Known limitations

- The maximum rain rate generated by the product is approximately 100 mm/h
- Rain cells are well localized, but their intensity must be validated
- An uncertainty of the rain rate is provided in the product but the uncertainty concerns describes the location rather than the intensity
- There are frequent over-detection of rain in the coastline (confusion between radar backscatter drops from both sources)



Example of precipitation rate in L3 V3.0 (Cycle 9 P145)

L3 Calibration: evolutions & additional variables

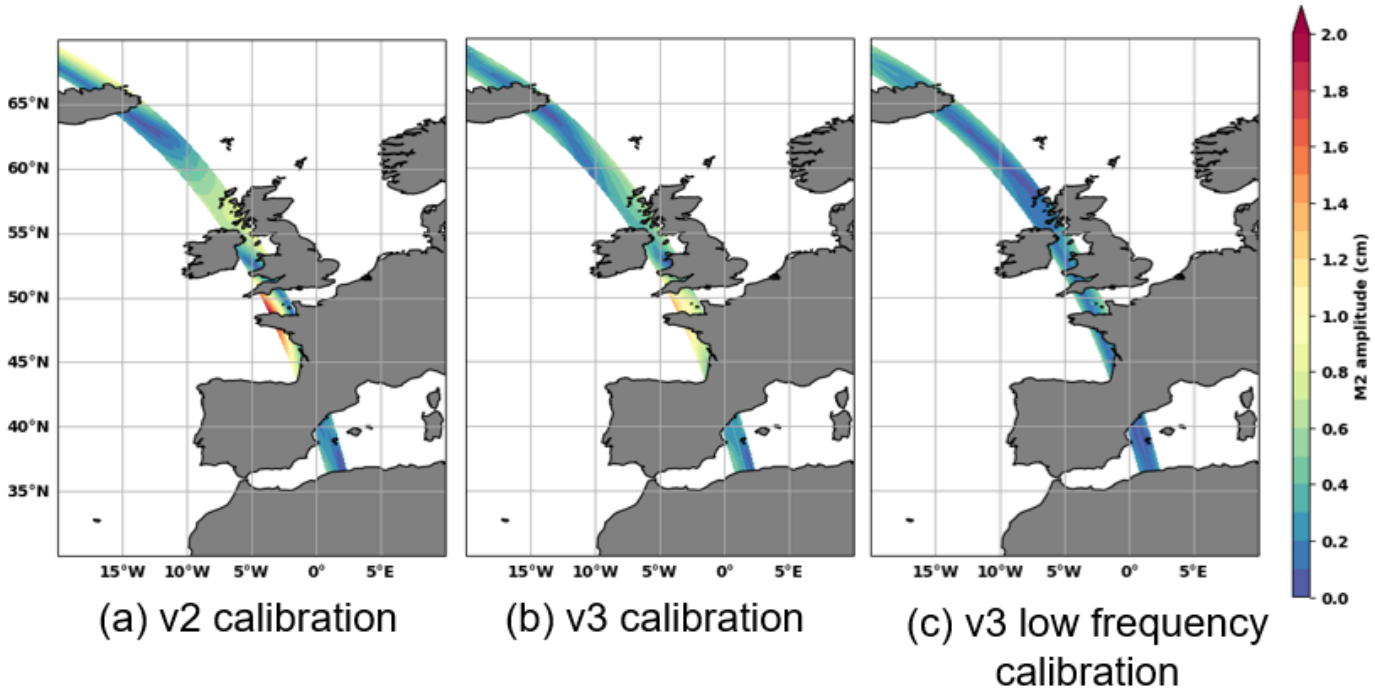
Upgrades to the v3.0 calibration: 250m calibration solution is deduced from 2-km solution and benefit from the same upgrades than for v3 2km version (see slides in annex).

Rationale

- The L3 calibration correction might absorb geophysical correction residuals (e.g. SSB, ocean tide; see SWOTST 2024 Talk) and not just KaRIn errors. This is beneficial for most users, but terrible for some experts (e.g. assimilation in tides models, SSB studies…)
- The low frequency component of the calibration is not prone to ocean leakage. It is a good alternative for anyone who wants to be sure the L3 calibration does not affect their signals of interest
- Available in the "calibration_low_frequency" variable

Known limits

- This calibration reduces the satellite's systematic errors. But it is much less effective than the full correction (SWOTST 2025 poster)



Example of different calibration solutions

L3 Denoising AI filter

Optimized denoising for v3

- Improved U-Net with slower learning process and more realistic training datasets, plus extensive validation (Meis et al. 2026, submitted)

Rationale

- The primary objective of denoising is to reduce measurement random noise (not geographically correlated errors of geophysical sources), while preserving as much signal as possible (including balanced and unbalanced motion) observed with SWOT-KaRIn
- Dibarboure et al. (2024) have shown that the v2.0 algorithm is generally beneficial to reduce L2 KaRIn noise
- The SWOT ST community has reported suspicious features as well as occasional artifacts, that should be fixed in v3.0

Known limitations

- The UNet is trained on ocean models: despite our extensive validation, smaller ocean features *might be distorted* by the AI filter

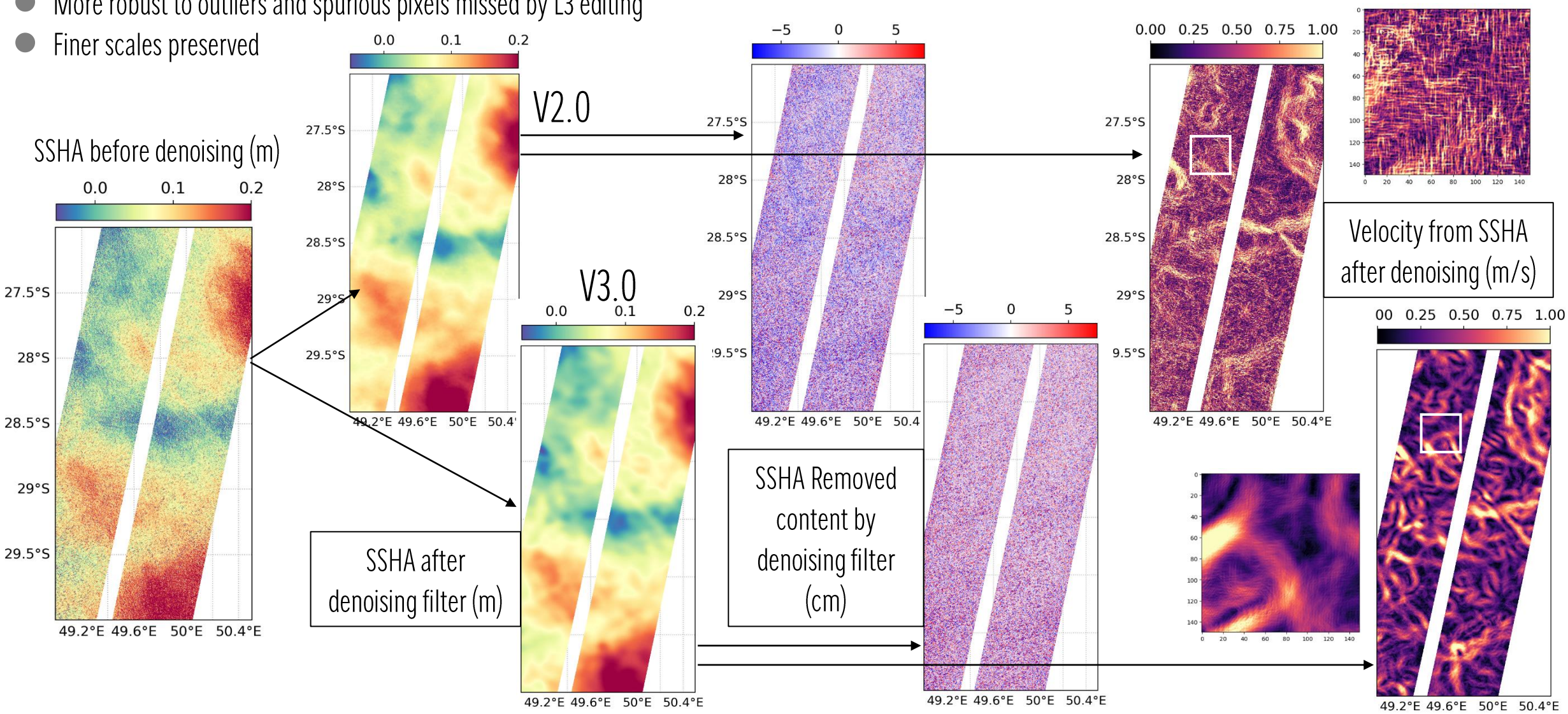
SWOT-ST Meeting Recommendations (Oct 2025)

- Provide an alternative based on a conventional low-pass filter in addition to the AI filter
- This could be implemented in the next L3 release (v4 in 2026) ▶ your inputs are needed: kernel TBD, cutoff TBD, static or adaptive ?

L3 Denoising 250-m

Benefits:

- Removes regional biases and other artifacts that can be observed in v2 (e.g. sea-wave correlated biases, gridded artifacts in velocity and relative vorticity)
- More robust to outliers and spurious pixels missed by L3 editing
- Finer scales preserved



L3 additional variables overview

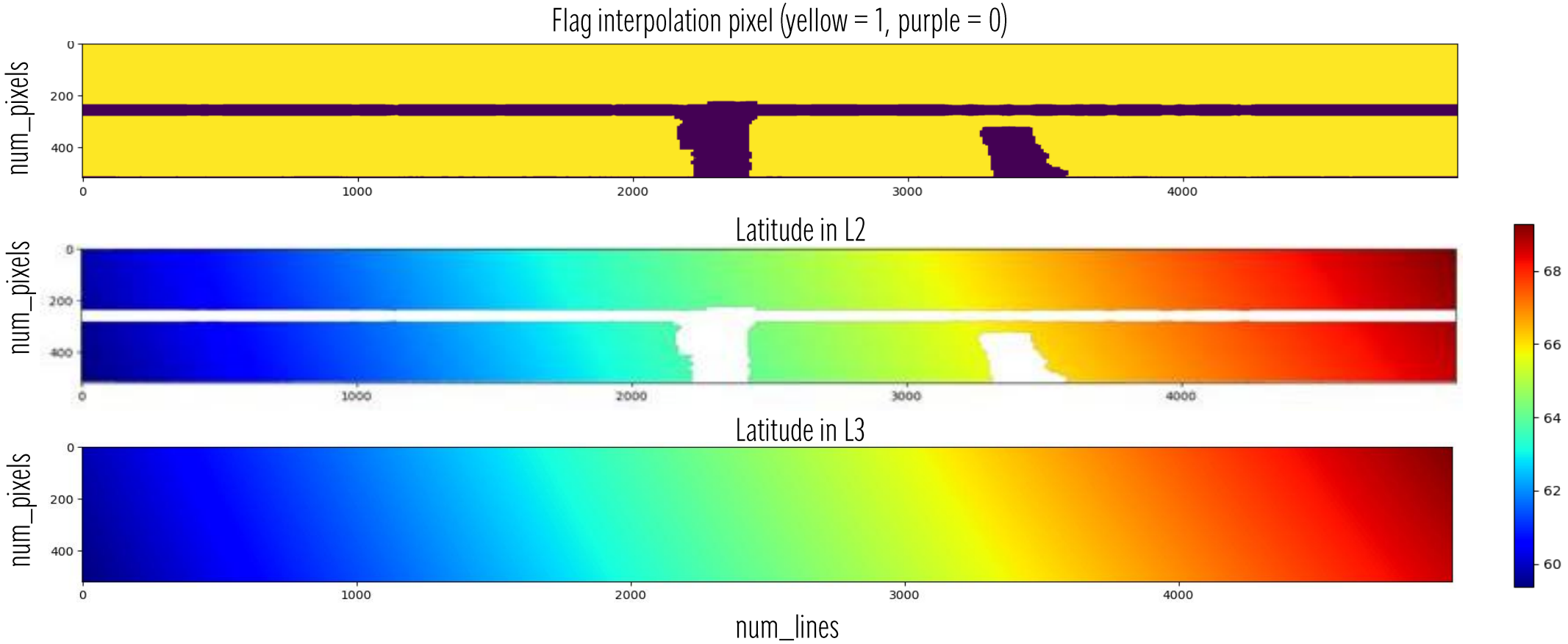
Additional variables added in the unsmoothed product requested by experts from the SWOT community

- Additional or alternative parameters of interest for processing experts: precipitation rate, sea-ice detection flags, low-frequency calibration, MSS …

variable	Description
mss_dtu	mean sea surface height above the reference ellipsoid from DTU2025 solution (Nilsson et al. 2025)
calibration_low_frequency	Low frequency components of the calibration correction
rain_rate_cnn	Precipitation rate based on convolutional neural network
sea_ice_probability_mrf	Sea/ice surface probability based on Markov Random Field (MRF) method (unsupervised model) using sigma0 characteristics.
sea_ice_probability_xgboost	Sea/ice surface probability based on XGBoost method (supervised model) using on sigma0, SSHa and coherence characteristics.
sea_ice_clustering_legos	Sea/ice flag segmentation based on different k-means clusterings method using on sigma0 and SSHa characteristics. (Bata version from Jestin et al. 2026)
flag_interpolation_pixel	Flag indicating pixel positions that are reconstructed by linear interpolation (position set to DV in L2 product)

L3 additional variable: Flag interpolation pixel

In L2, longitudes and latitudes may be missing, particularly on land, at the poles and at the nadir. The "flag_interpolation_pixel" variable indicates the lon/lat positions that are not defined in L2 product and "reconstructed" for L3 production. The positions are reconstructed by basic linear interpolation using neighboring available points.



Example of the application of the flag interpolation pixel (C1 P149)

What's next ?

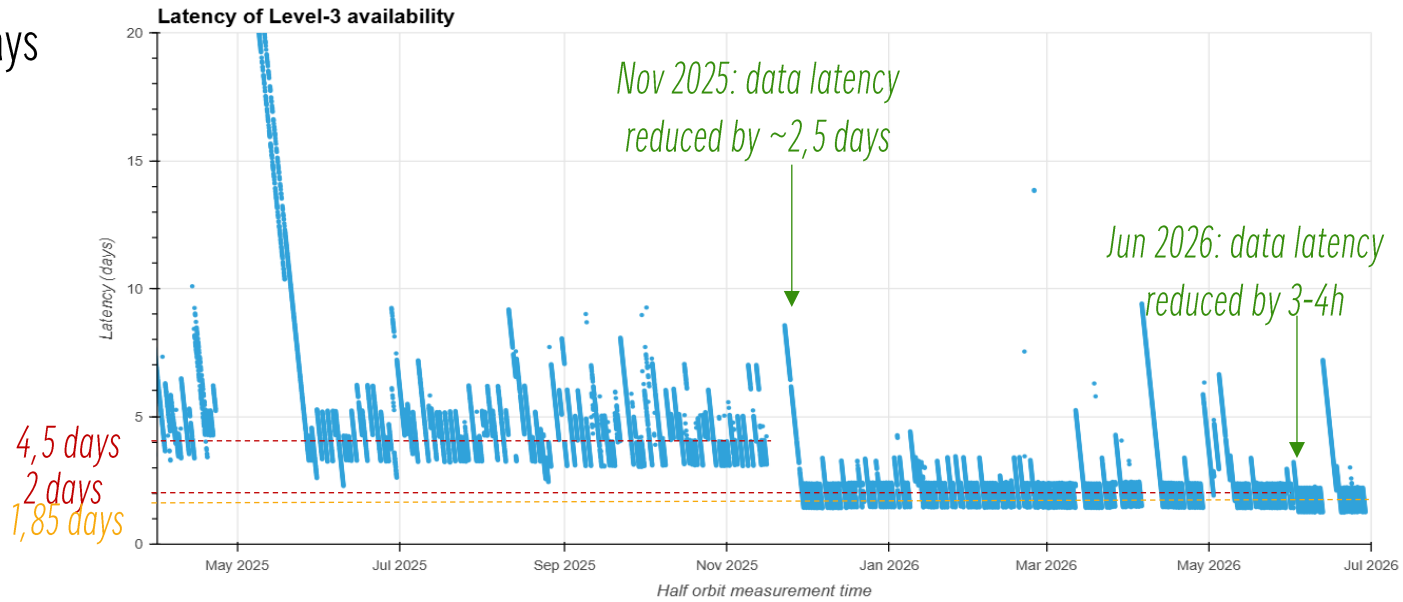
L3 products latency and routine productions

Weekly extension of the L3 Unsmoothed product

- Weekly production now possible after v3 system developements, daily extension is our final objective
- Target latency : 21 days (to optimal calibration time windows, without the daily micro-reprocessing like in the L3 Expert product)
- ETA on AVISO: September 2026

Latency improved for the L3 expert (2km) product

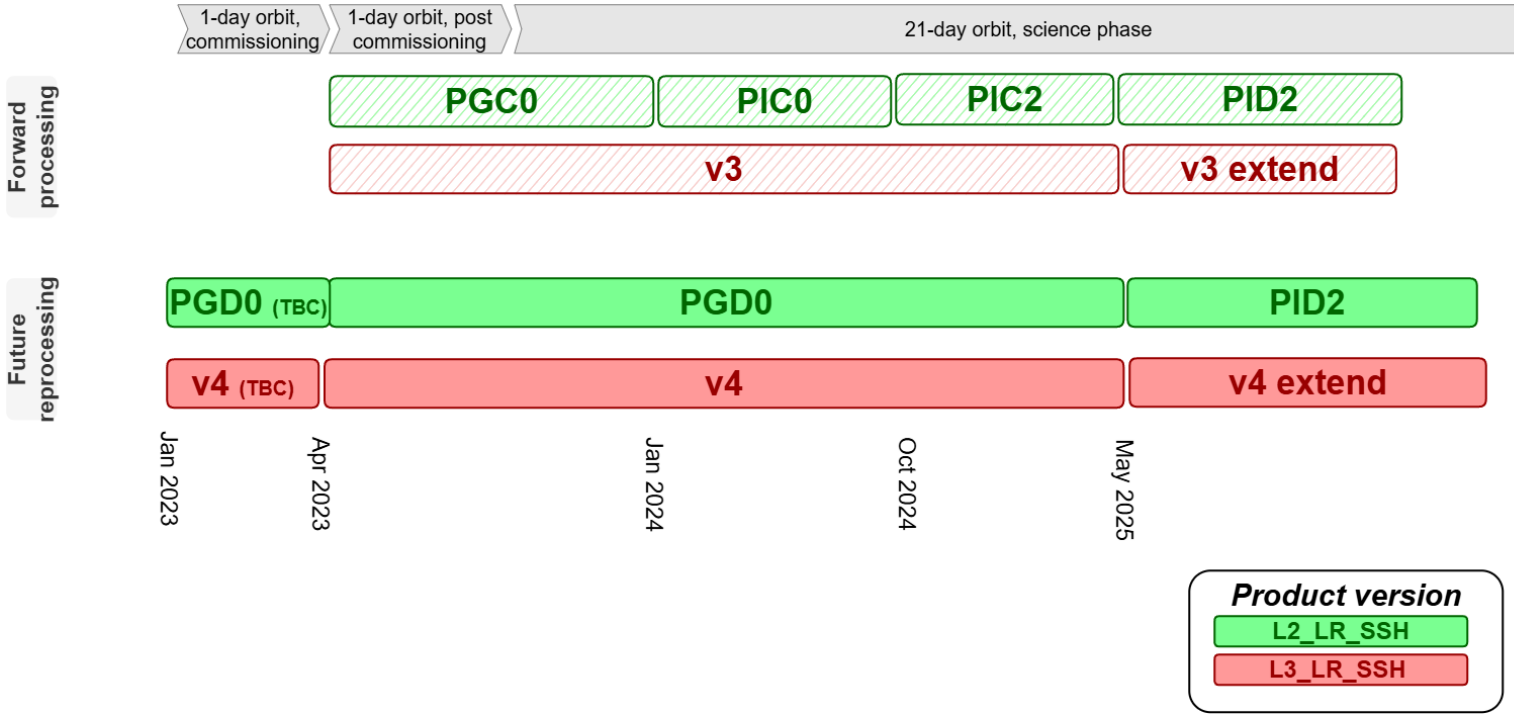
- Significant improvement since November 2025
- Old L3 latency was 4 to 4.5 days → New latency is <2 days
- Minor improvements in June 2026 : 4 hours gained with better workflow synchronization
- Delivered on a best effort basis: hiccups may occur™



Sea level L3 reprocessing v4.0

Tentative 2027 reprocessing strategy

- Include commissioning phase data (TBC)
- L3 2-km & 250-m & Wind/Wave variants
- Based on L2 baseline D from the SWOT Project



Expected evolutions in L3 processing

- Research-grade demonstration of better L2 algorithms and models: MSS, tides, MDT, radiometer WTC, SSB…
- Improved L3 algorithms: calibration, flagging (coast, polar),
- Alternative ssha filtering: not AI-based, based on recommendations from by SWOT-ST,
- Improvement of swell spectra flagging and clustering
- And more…

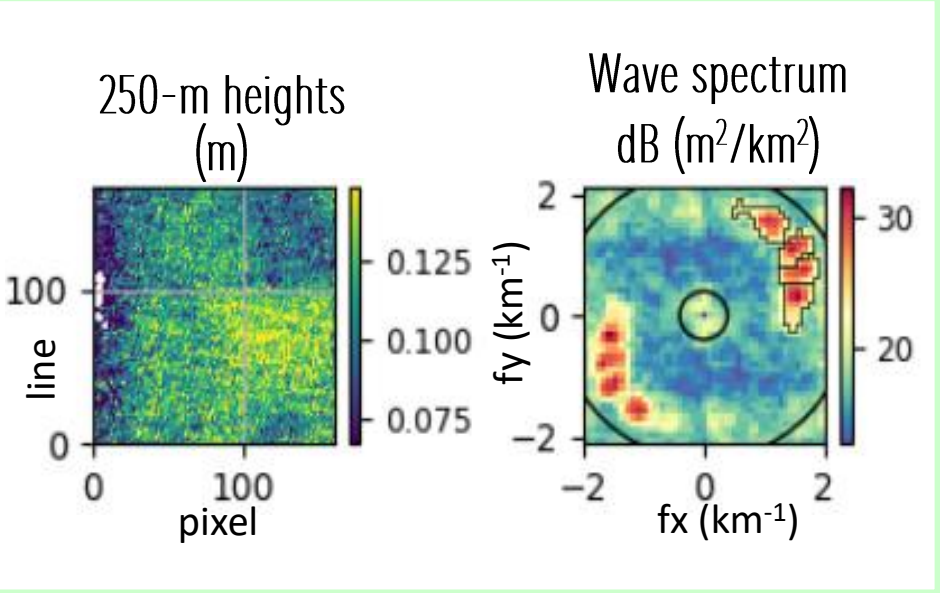
If you have any needs, requirements, or suggestions that could improve the v4.0 release, **NOW** would the best time to contribute. Our deadline for v4 algorithm baseline freeze is **Dec 2026**

Wind Wave L3 KaRIn product

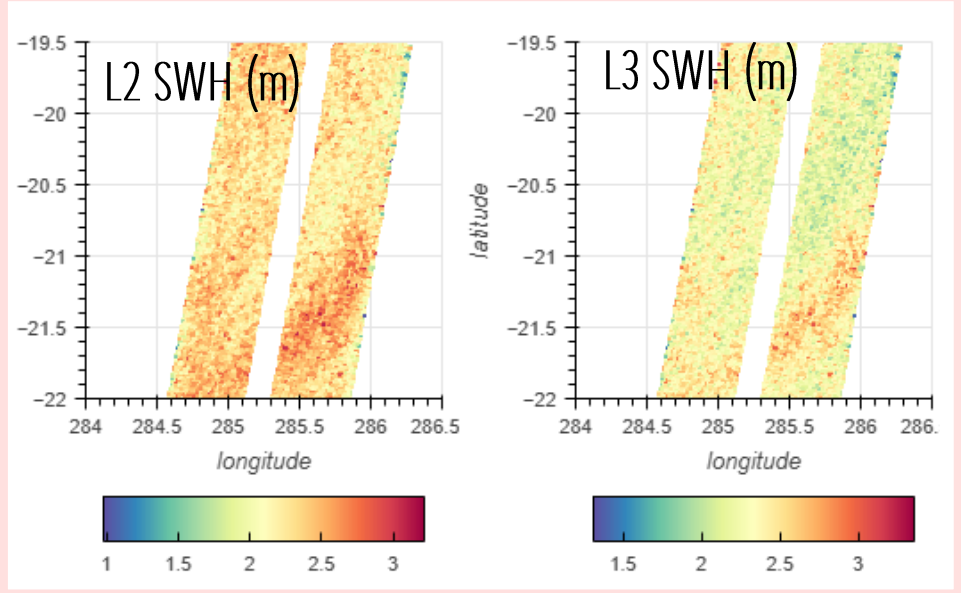
One L3 product for sea-state information: **the L3 LR Wind and Wave product**

- 2D wave height spectra obtained from 250-m KaRIn heights, thus representing swell energy for wavelengths > 500 m, corrected for KaRIn transfer functions
- New version v3.0 expected in 2026Q4 with 2 important features (full mission reprocessing is ongoing)

multiple swell partitions in the same spectrum, with derived parameters (SWH, wavelength, direction, peakedness)



2D swath SWH from L2 2km products **recalibrated for large scale systematic errors**

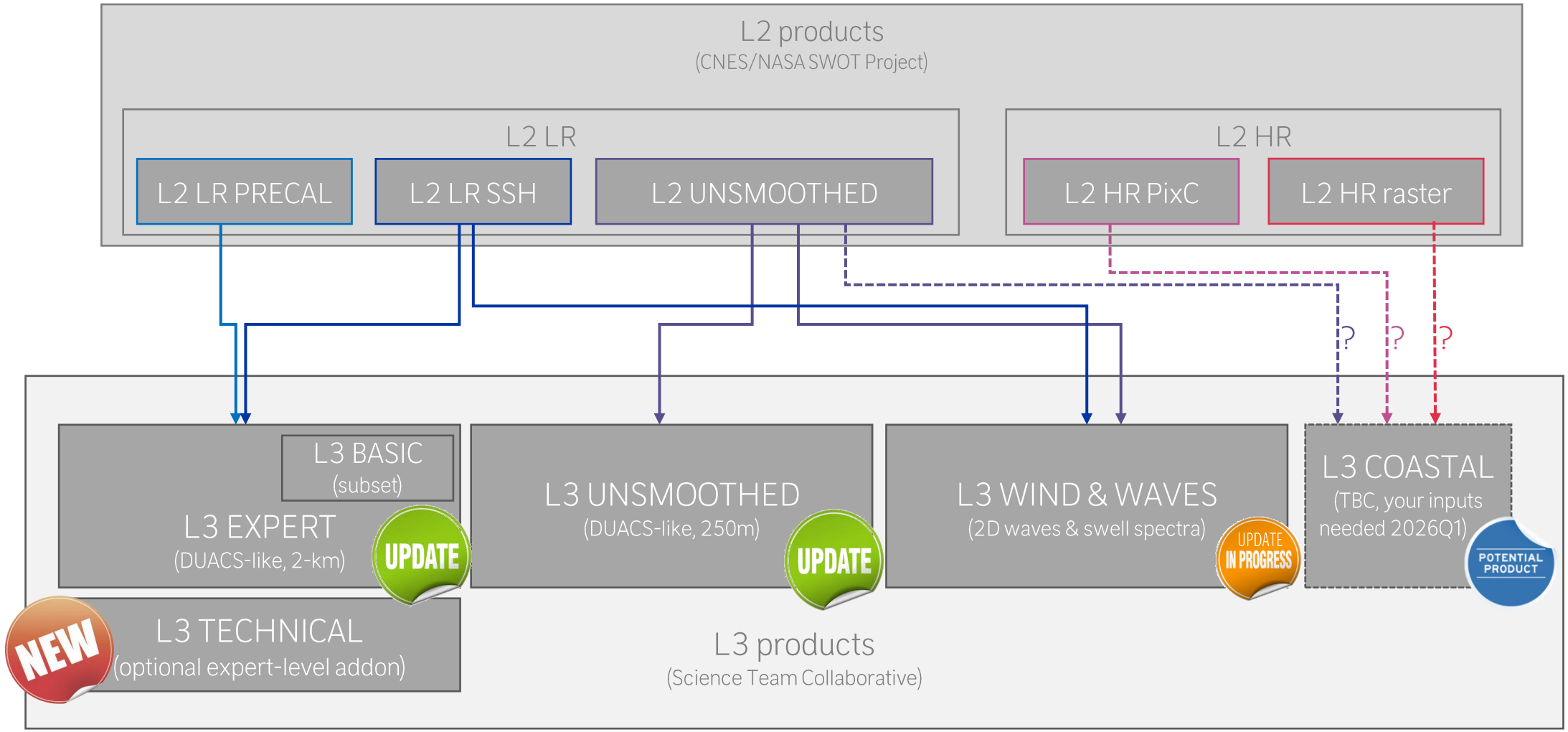


See OSTST26 poster *"Advances in SWOT KaRIn Level-3 Wind–Wave Processing: Multi-Swell Spectrum Retrievals and Swath SWH"*

L3 Wind Wave product access

L3 KaRIn products general information

Level-3 products family picture and upstream dependencies



L3 product manuals

Contains: L3 product content, known limitations, examples, additional information…

Your feedback is very welcome: if the document is incomplete or incorrect or confusing, let us know !

AVISO helpdesk for SWOT

aviso-swot@altimetry.fr

Handbook for the L3 expert & basic & unsmoothed sea level products

https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/handbook_duacs_SWOT_L3.pdf

Handbook for the L3 wind & waves

https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_SWOT_L3_LR_WIND_WAVE.pdf

Thank you for your attention !

L3 paper

https://doi.org/10.5194/os-21-283-2025

L3 product access

https://doi.org/10.24400/527896/A01-2023.018

L4 paper

https://doi.org/10.5194/os-21-63-2025

L4 product access

https://doi.org/10.24400/527896/A01-2024.007

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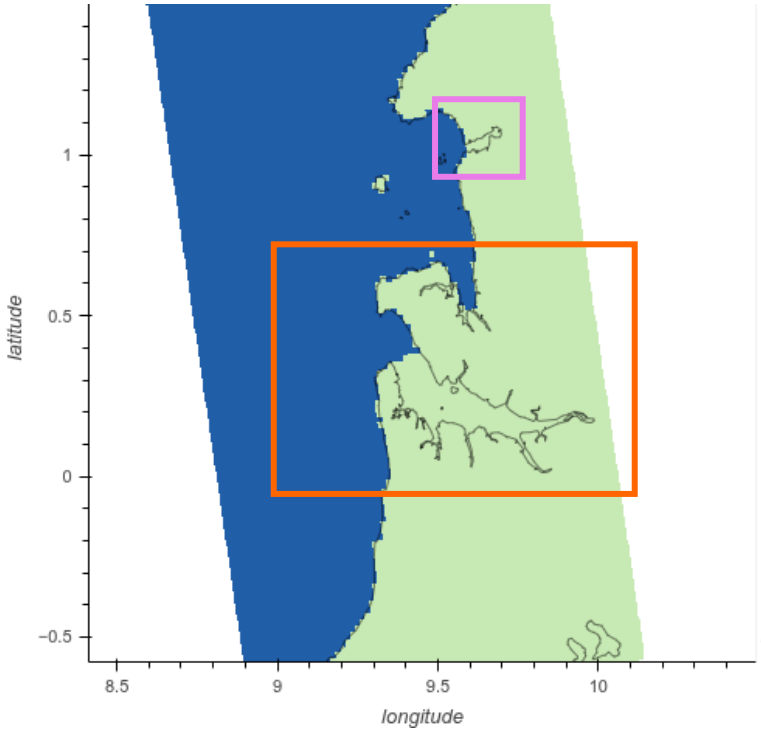
Appendix: reminders about common evolutions with 2km product v3.0

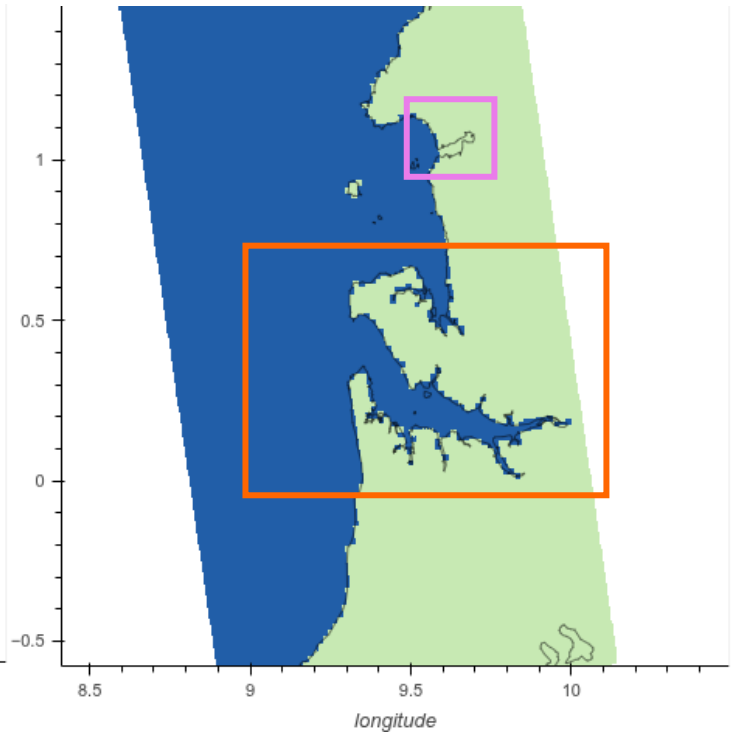
New coastline mask (example 2km product)

V1.0.2



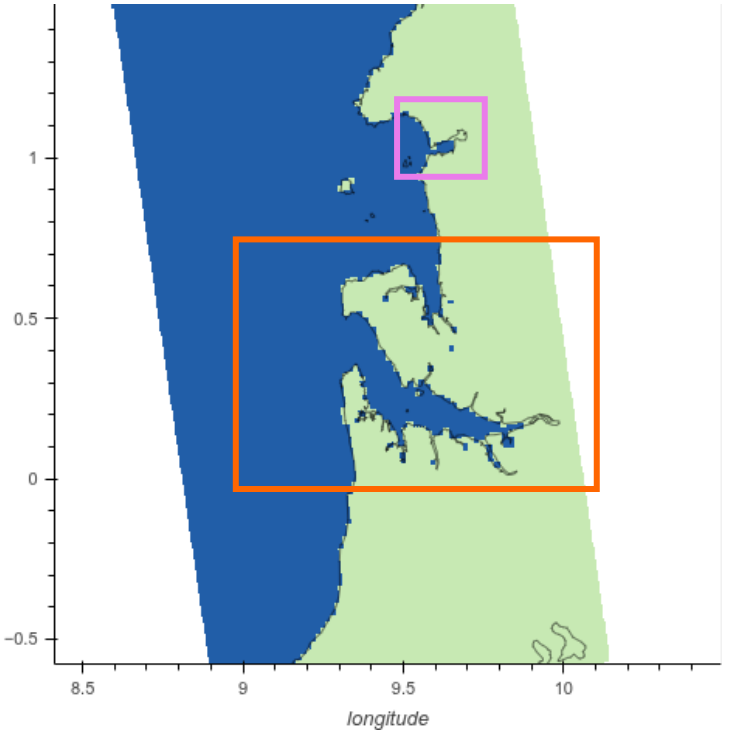
- Failure in estuaries

V2.0

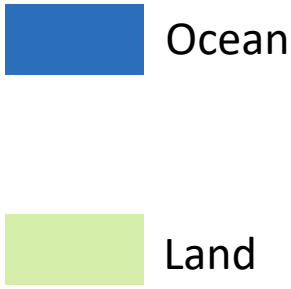


- Manual processing of the orange area with the L2 mask (degraded resolution in the manual processed areas)
- Limited number of manual processed estuaries : in the pink area, an estuary is not retrieved for example

V3.0



- Systematic retrieving : more estuaries are retrieved such as the pink one
- Open Street Map contours in estuary areas : better resolution in the orange area



L3 Calibration

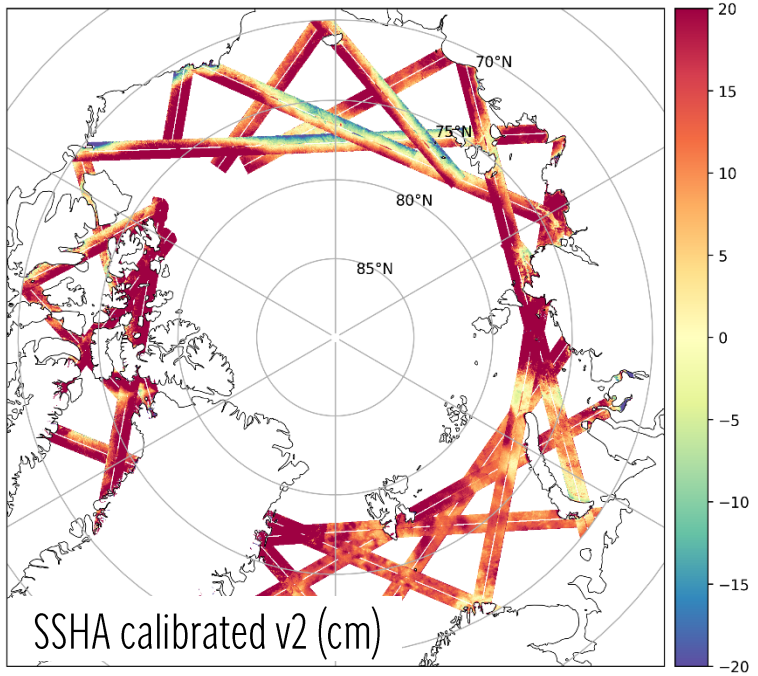
Upgrades to the v3.0 calibration

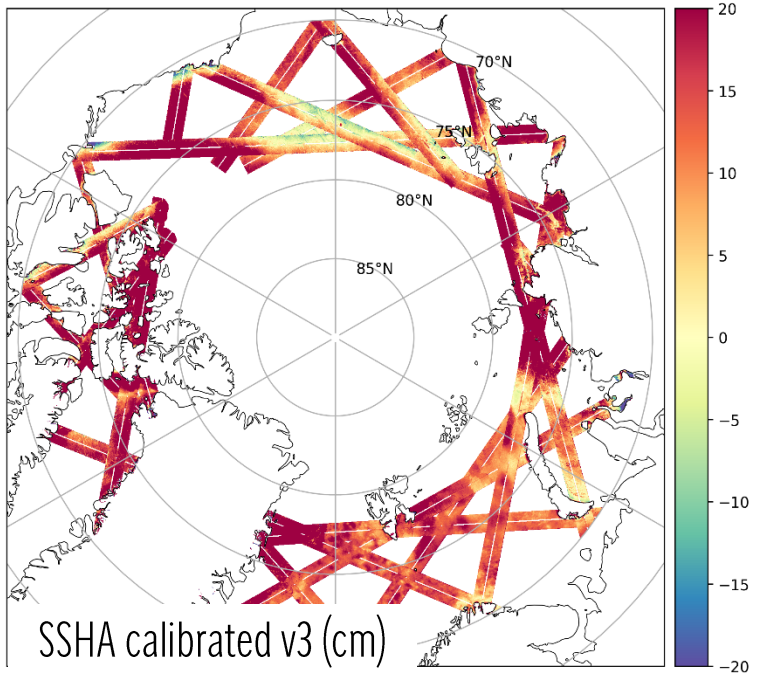
- Better estimation of the calibration depending on the beta angle
- Better interpolation of the calibration solution in areas where direct estimation is not possible: significant improvement in polar ocean and near land areas where measurement available cannot be used for calibration
- L3 pseudo phase screen correction updated for PID changes (both for 2km and 250m specifically)
- Use nadir CMEMS MY DT-2024 products when available, NRT otherwise

Rationale

- Algorithm change derived from the observations of Ubelmann et al. (2024)
- Better interpolation of the non predictable terms: Gyro and Long-wavelengths KaRIn error now interpolated with OI rather than polynomial estimation (Q & R components)

Ongoing work : the predictable part of the uncalibrated errors is understood from Ubelmann et al. (submitted): The L3 calibration will be upgraded in v4 (2027)





Example of residual calibration errors clearly visible in V2; significantly reduced in V3

L3 Calibration

Expected benefits: better correction for the semi-enclosed / coastal / polar seas
and even Hydrology (for the 1-day CalVal phase, the L2 products are based on our L3 calibration)

Known Limitations:

- SSHA bias inherited from CMEMS L3 nadir differences between MY & NRT series → L3 v3 KaRIn products are distributed in two separate directories (one for each time span):
  - **reproc**: L3 KaRIn products based on CMEMS L3 DT
  - **forward**: L3 KaRIn products based on CMEMS L3 NRT
- Calibration might still absorb other geophysical correction residuals (SWOTST 2024 Talk) and not just KaRIn errors

NEW : Alternative L3 calibration also accessible in the new technical product : less efficient but zero ocean leakage
(see also the SWOTST 2025 meeting poster here: #ST2025OS1_18)

Example of signature of uncorrected satellite roll angle in SSHA now removed by calibration v3.0