DUACS

Updated: 2025/11/25

SWOT Level-3 ocean topography version 3.0

planned changes, rationale, expected improvements and known issues

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

CLS cnes datlas

Overview

- Previous release : v2.0.1 Basic/Expert & Unsmoothed released in March 2025
  - Complete reprocessing of the Science phase & CalVal phase
  - Daily v2 production for 2-km, every 3 – 6 months for the 250-m
  - v1.0 NRT was discontinued when v2.0 started

Not addressed in this package

- Upcoming 250-m reprocessing (2026Q1)
- L3 wind & wave v3 reprocessing (2026Q2)
- L3 coastal experiments (2026)

- Upcoming release : 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
  - NRT L3 timeliness is improved (tentatively 48h) thanks to changes in L2 Science Data System and L3 processor
  - L3 Unsmoothed (250-m) currently still in v2.0.1 (upgrade to v3.0 with specific 250-m algorithms is ongoing)

- This is a collaborative product made by and for the Science Team:
  YOUR feedback (good or bad), your inputs and needs are most welcome to guide the definition of the next release (v4 tentatively Fall 2026)

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

v3.0 changes in a nutshell

Geophysical standards

- 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

L3 algorithms

- Coastline improved : new L3 land mask, more precise, with many estuaries now correctly retrieved
- Data selection quality flag granularity improved for rain cells
- Upgrade of the cross-calibration (coastal+polar improvements)
- Upgrade of the denoising with correction of geographically bias artefacts
- Improved geostrophic currents : the 2D-spline fit methodology proposed by Tranchant (2025) will replace the stencil derivatives (those remain available in the new technical product variant)

New sub-product (separate files)

- Addition of a "technical" product variant with additional variables : alternative geophysical corrections & geostrophic currents; complementary information for some corrections (ocean tide, calibration)

L3 latency improved

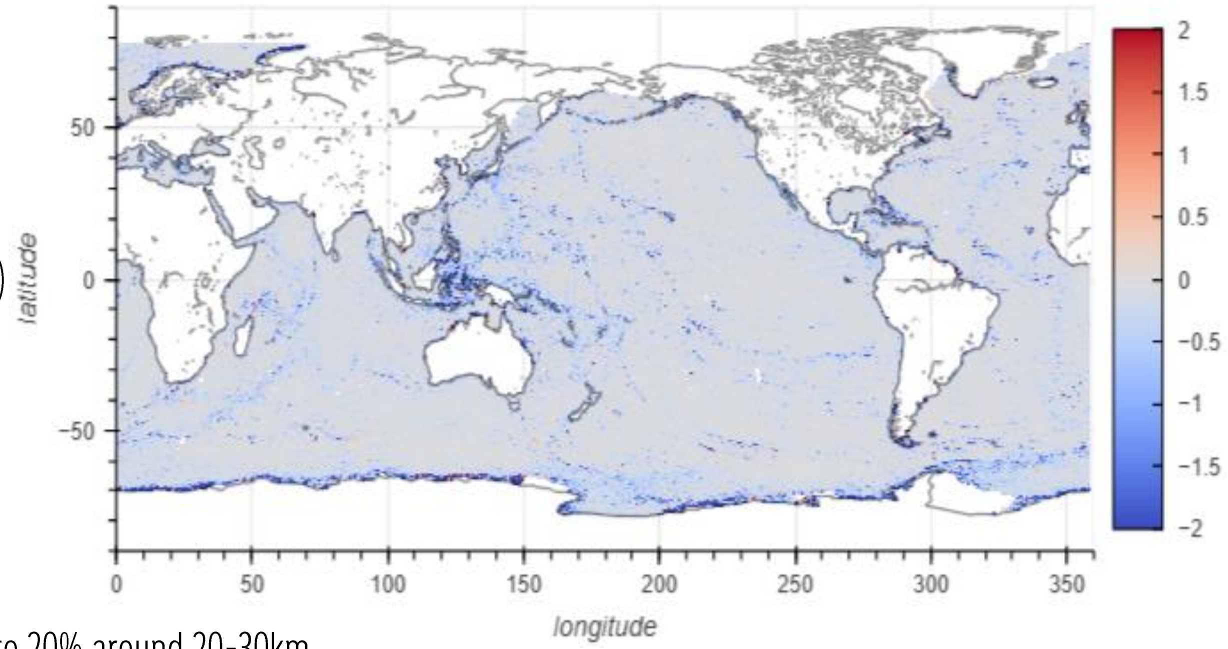
- Latency of the L3 expert product is being reduced: target data delivery is 2 days after measurement (was 4-5 days in v2)

Content update on 2km products only

No update of the 250-m L3 Unsmoothed in 2025

MSS Model Upgrade (CLS/CNES 2025)

Short-wavelengths MSS error difference from MSS H2023 to 2025
(blue means 2025 model is better, λ 15-125km, unit: cm^2)



The L3 v3 uses the new CNES/CLS 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)
- Considering "MSS compression" correction for KaRin 2km (see next slide)

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 cm^2 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
- Way forward: perform a comprehensive comparison of 2024/25 models from all MSS groups (first generation of KaRIn-based models), follow the recommendations from the SWOTST/OSTST MSS working group, develop new hybrid models if needed (e.g. blend models from DTU25 / SIO25 and CLS25)

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

KaRin 2km: solving the SSH vs. MSS resolution discrepancy

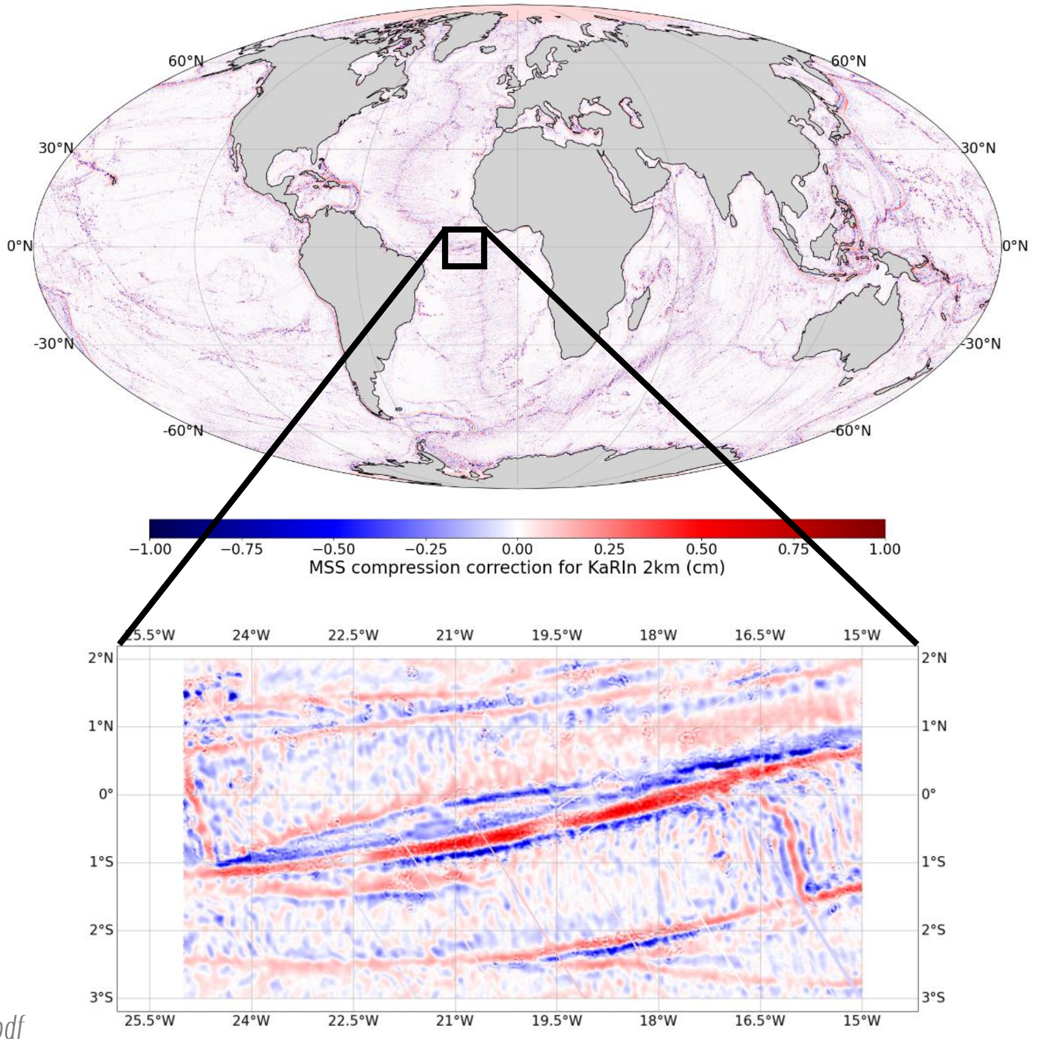
Root cause: discrepancy between L2 2km compression (averaging of 250m pixels) or nadir altimetry footprints w.r.t the higher resolution of new MSS

- MSS models resolving more than 2km should not just be interpolated when they are combined with low resolution SSH averaging/compression (because of small geoid curvature)
- Discrepancy between SSH and MSS is visible in SSHA for areas of high curvature of the MSS (if the discrepancy is not fixed)
- If the averaging process of the MSS is not consistent with the SSH averaging, the consistency can be restored with an a posteriori MSS "compression correction" (proxy of MSS averaging)

New KaRIn L3 products provide consistent SSH & MSS content as well as separate MSS model components (HR MSS model and compression proxy)

MSS compression correction

➔ Up to 1 cm for KaRin 2km; up to 4 cm for 1Hz nadir measurement

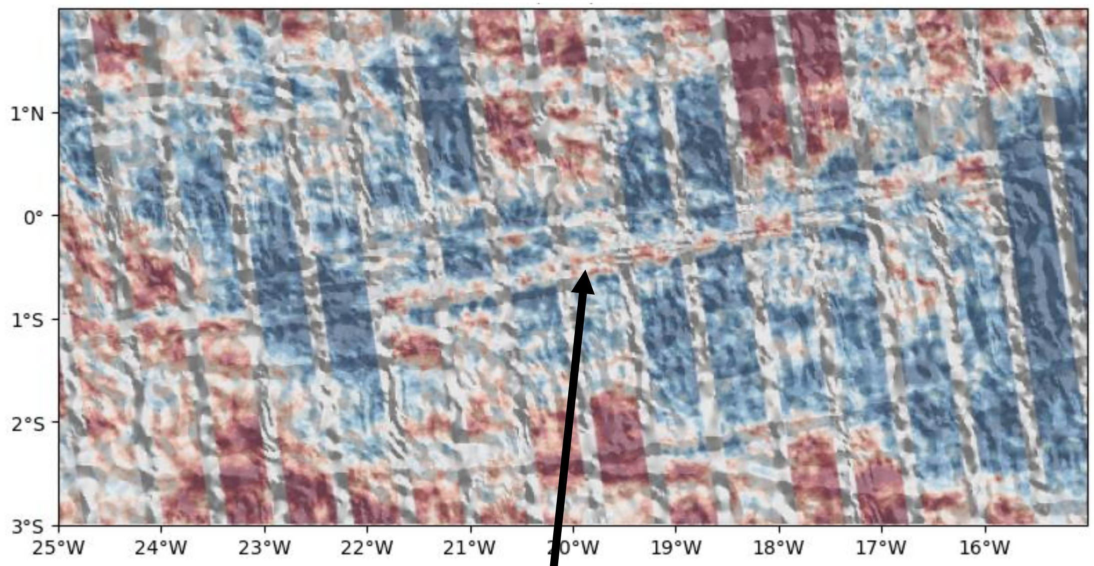


Charayron R. et al. The new CNES CLS 2025 MSS model leveraging SWOT KaRIn data. SWOT-ST 2025. MSS_2025_presentation_SWOT-ST25pdf

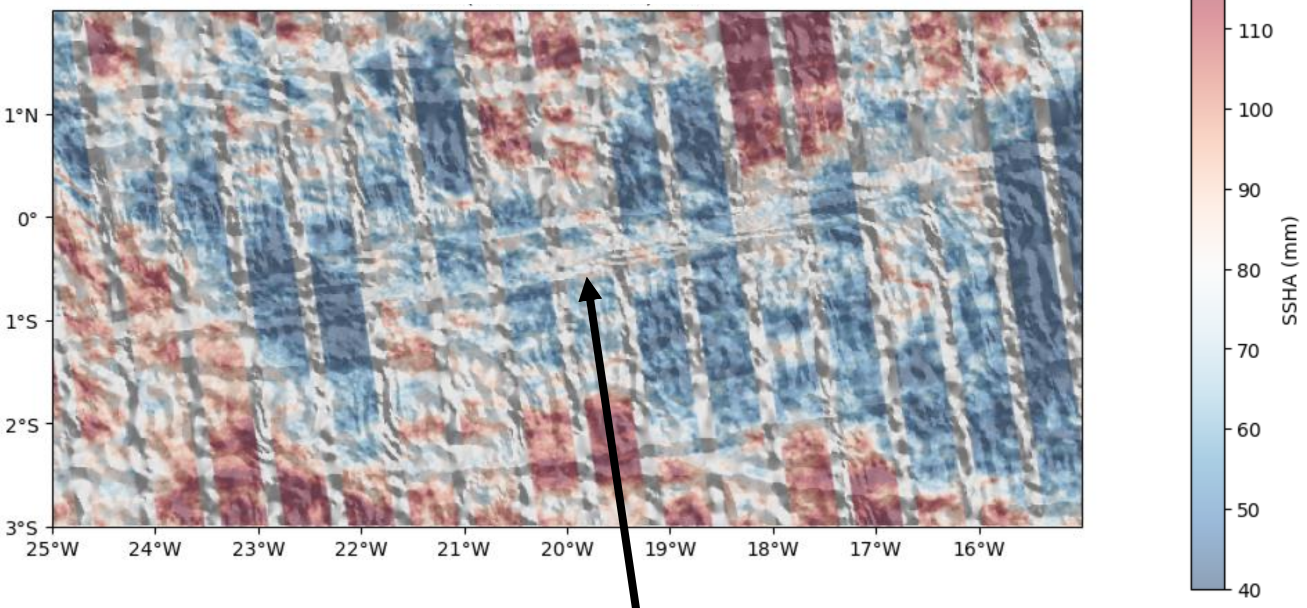
MSS Model Upgrade (CLS/CNES 2025)

KaRIn SSHA (color) superimposed with bathymetric gradients (greyscale lighting)

SSHA using MSS H23



SSHA using MSS CNES_CLS_25



Geodesic structure signature in the KaRIn SSHA (color)

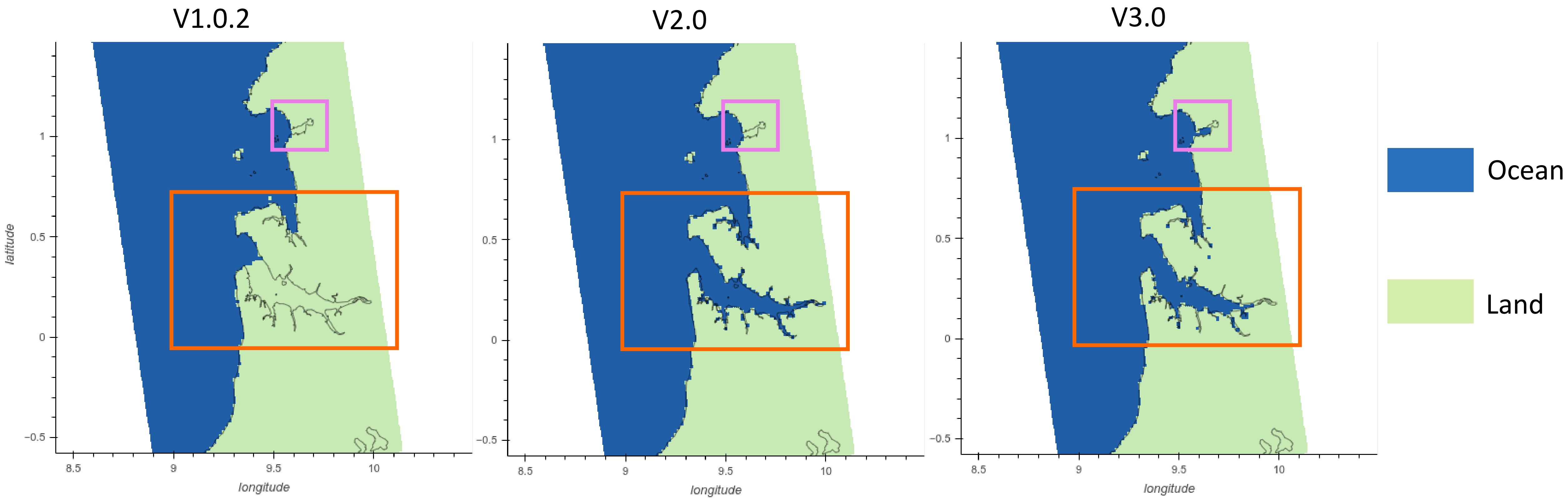
Strongly reduced geodesic structure signature in the KaRIn SSHA

Zone: Mid Atlantic transforming rift

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
- These limitations are generally acceptable for the 2-km resolution, but often not for the 250-m products
- 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)

New coastline mask (example 2km product)



- Failure in estuaries

- 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

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

FES 2022 solution extrapolated in complex coastal areas

- OLD : The L3 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

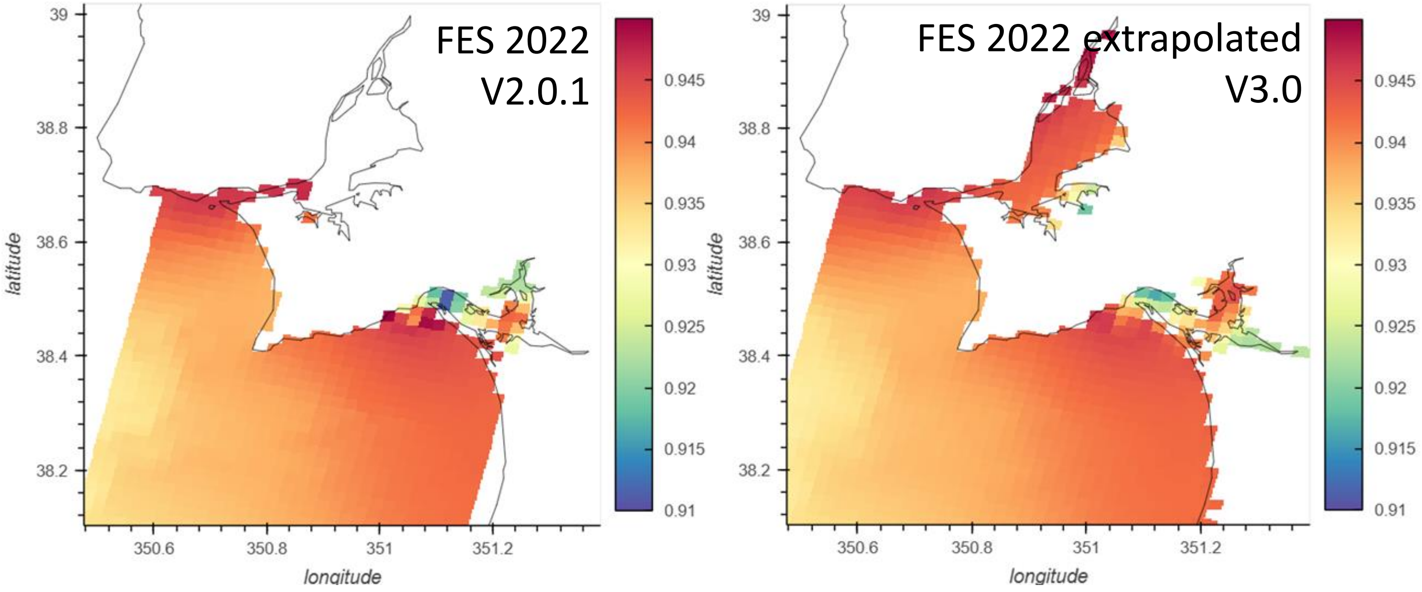
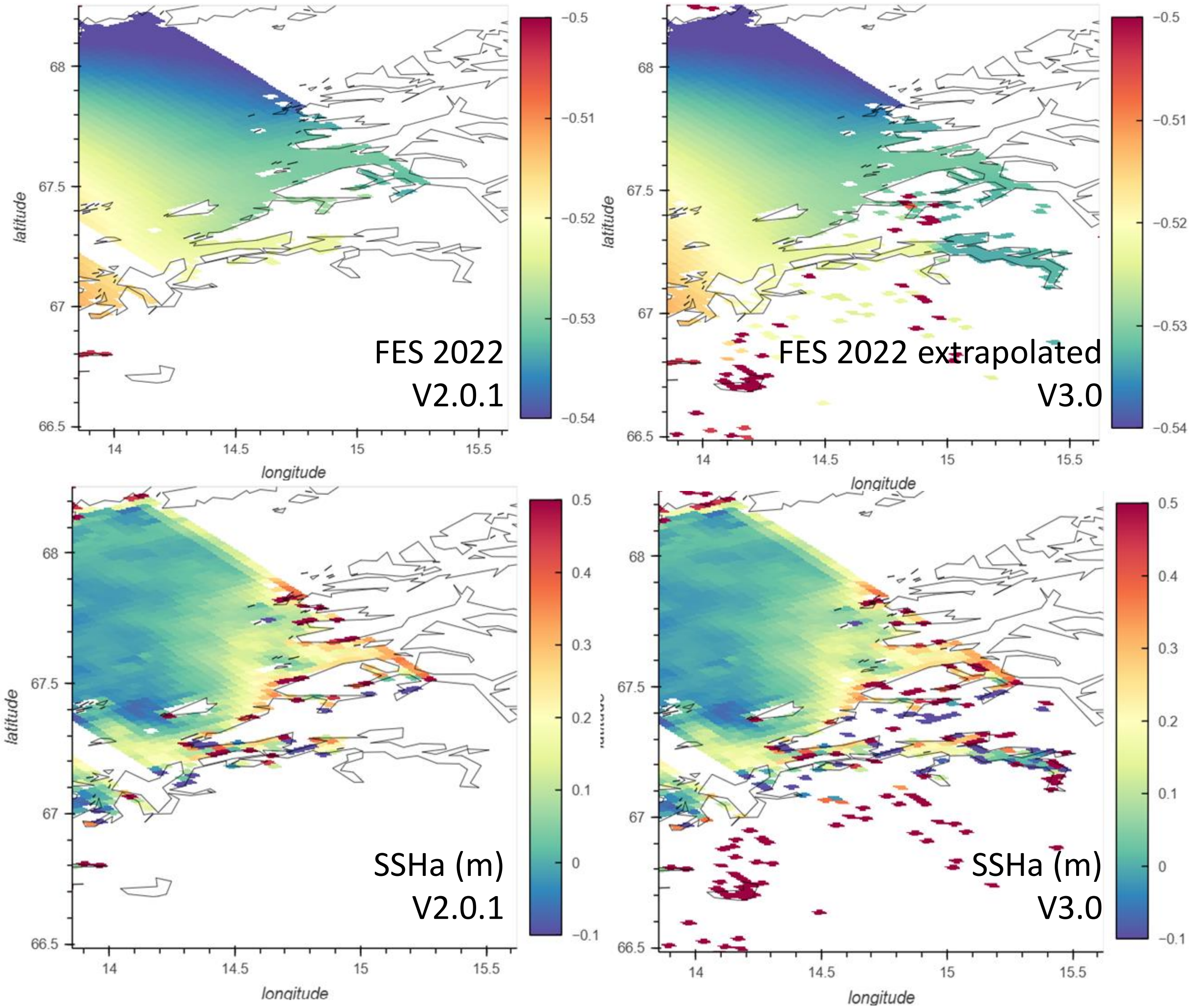


Fig.: Example of the impact of the extrapolation of FES 2022. Case of an esturary in Spain – Only land sea mask data selection applied

FES 2022 solution extrapolated in complex coastal areas

Fig.: Example of the impact of the extrapolation of FES 2022
Case of Fjord in Norway – Only land sea mask data selection applied



Data selection : flag_val granularity improved

- OLD: L3 v2.0 detection spurious pixels based on SSHA statistical analysis (the flag mixes all root causes)
- NEW : L3 v3.0 adds a rain detection flag and a precipitation rate derived from the work of FLUCTUS and CLS (Picard et al, 2025)
- The new experimental flag (value #25) can be used to isolate only the pixels affected by rain cells
- The new "rain precipitation rate" solutions themselves are also provided separately in the "L3 technical" product variant (see next slides)

Way forward: fine-tuning of the rain algorithms and thresholds, improved editing of the 250-m pixels.

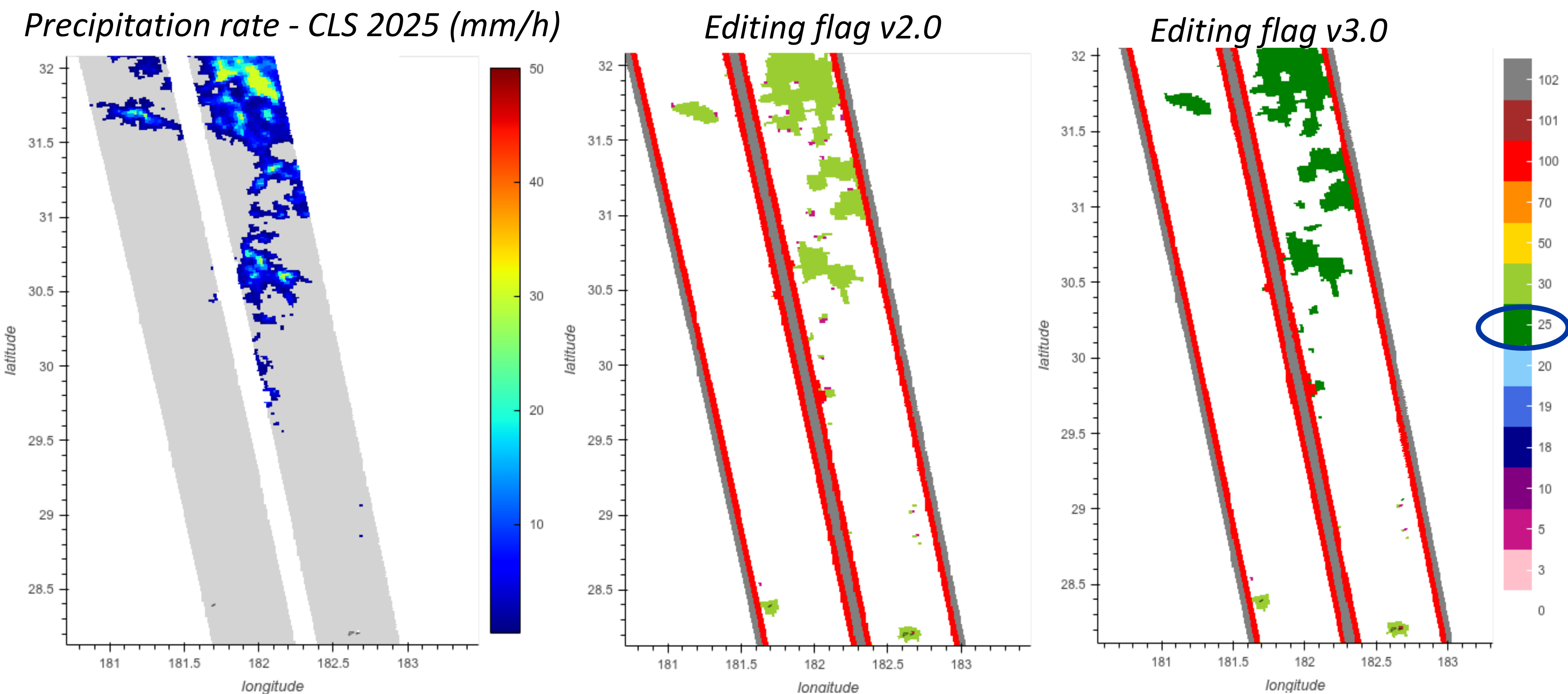


Fig.: Example of the new rain flag in the editing flag

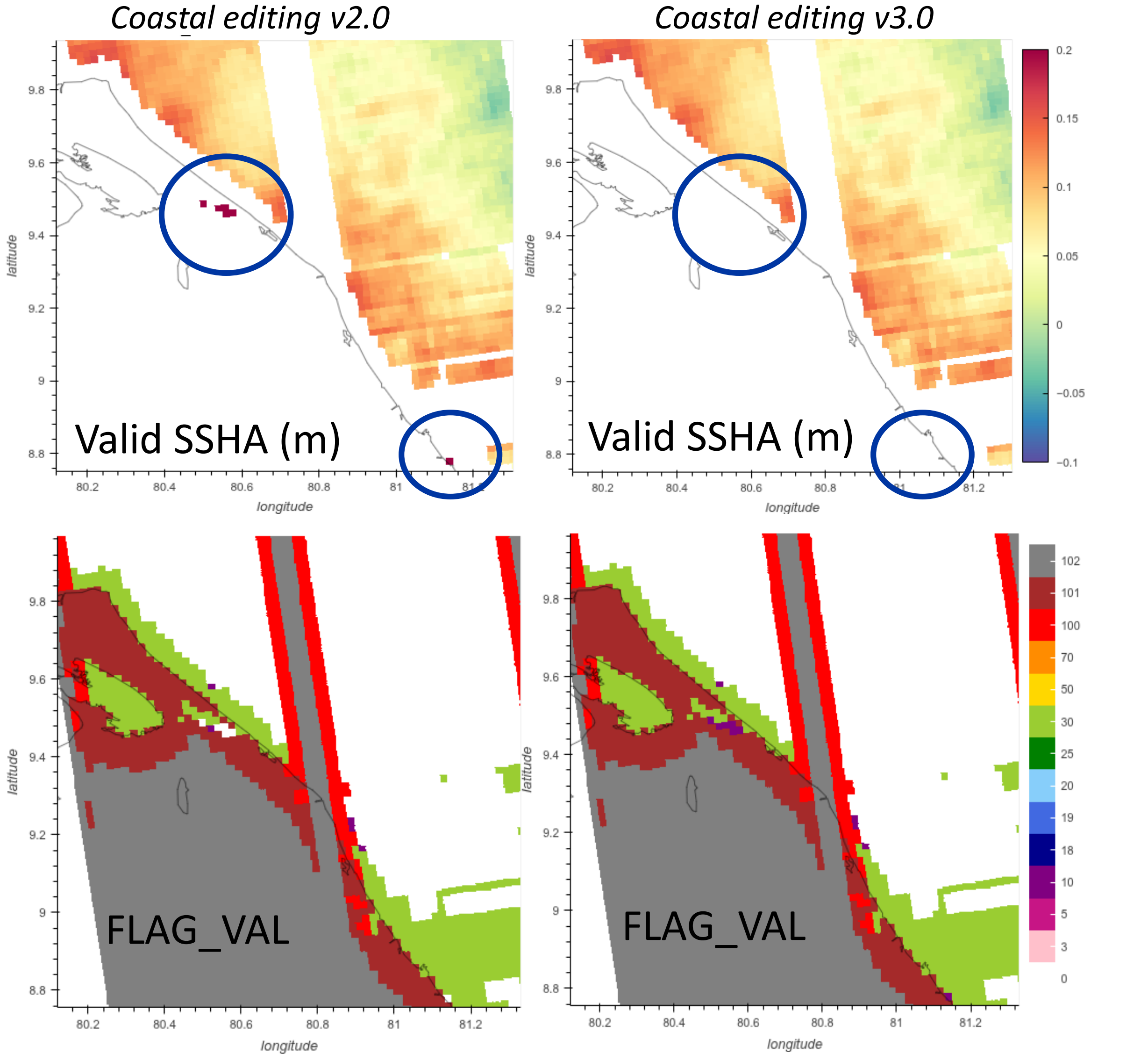
Picard, B., Colin, A., Husson, A., & Dibarboure, G. (2025). The effect rain on a Ka-band swath altimeter: lessons learned from the SWOT mission. Submitted. https://doi.org/10.31223/X5WF0Z

Data selection : coastal flag improved

- OLD : L3 v2.0, there are still few isolated pixels on land or very close to the coast that are not flagged
- NEW : L3 v3.0 solution detects and flags these pixels 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 (only flags > 5 are applied)



L3 Calibration

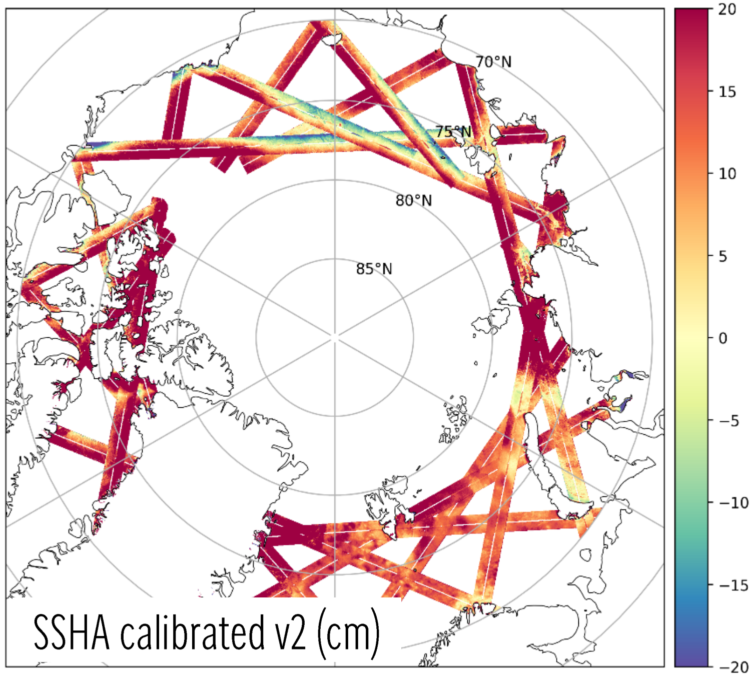
Upgrades to the v3.0 calibration

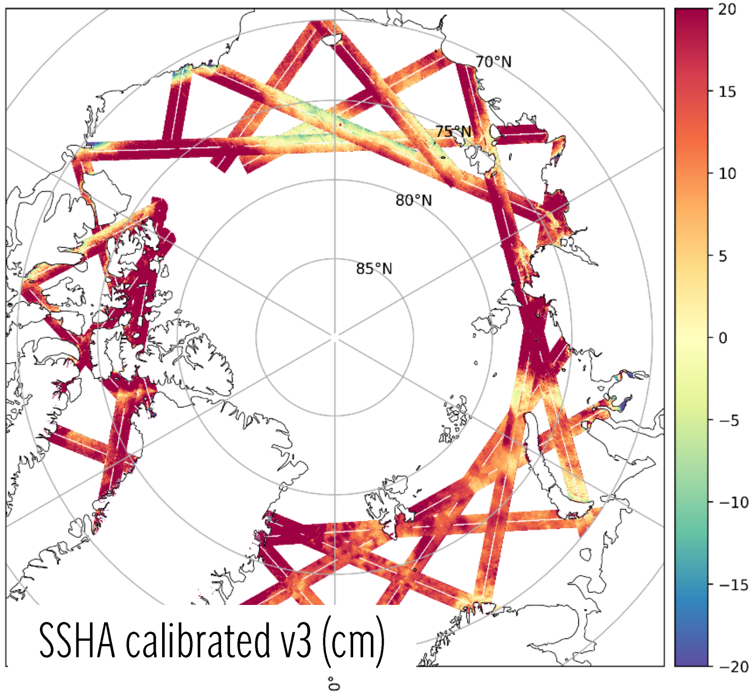
- Better estimation of the calibration depending on the beta angle
- Better interpolation of the calibration solution in areas where direct estimation is not possible: significant improvement in polar ocean and near land areas where measurement available cannot be used for calibration
- L3 pseudo phase screen correction updated for PID changes
- 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.(in prep): The L3 calibration will be upgraded in v4 (2026)





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

L3 Calibration

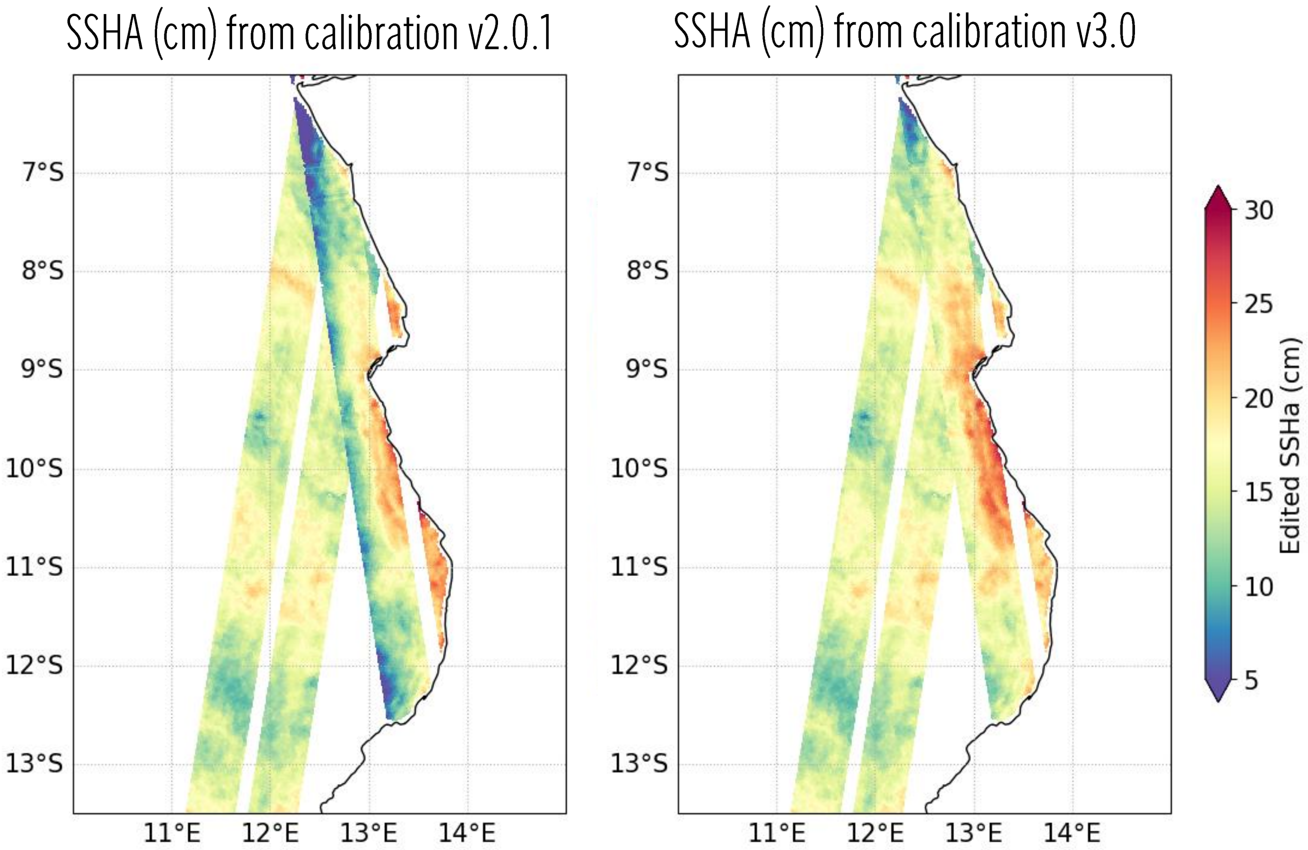
Expected benefits: better correction for the semi-enclosed / coastal / polar seas and even Hydrology (for the 1-day CalVal phase, the L2 products are based on our L3 calibration)

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



L3 Denoising AI filter (optional in both basic & expert products)

Optimized 2-km denoising for v3

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

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)

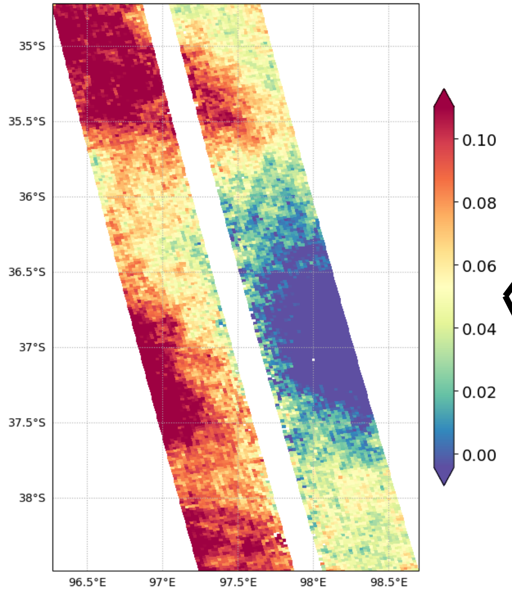
- Provide an alternative based on a conventional low-pass filter in addition to the AI filter
- This could be implemented in the next L3 release (v4 in 2026) ► your inputs are needed: kernel TBD, cutoff TBD, static or adaptive ?

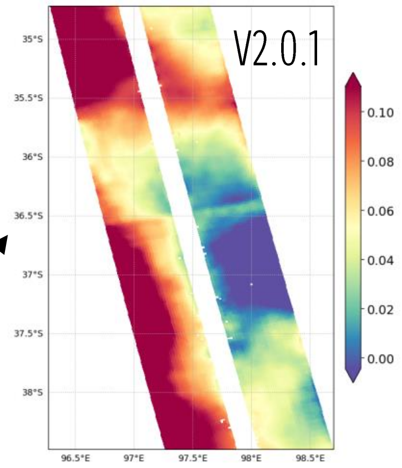
L3 Denoising

Benefits:

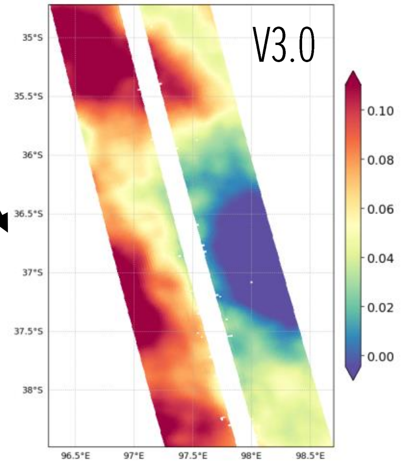
- Removes regional biases and other artifacts that can be observed in v2 (e.g. sea-wave correlated biases, local discontinuities)
- Mitigates possible absorption of some physical signal (e.g. short-wavelength tides)

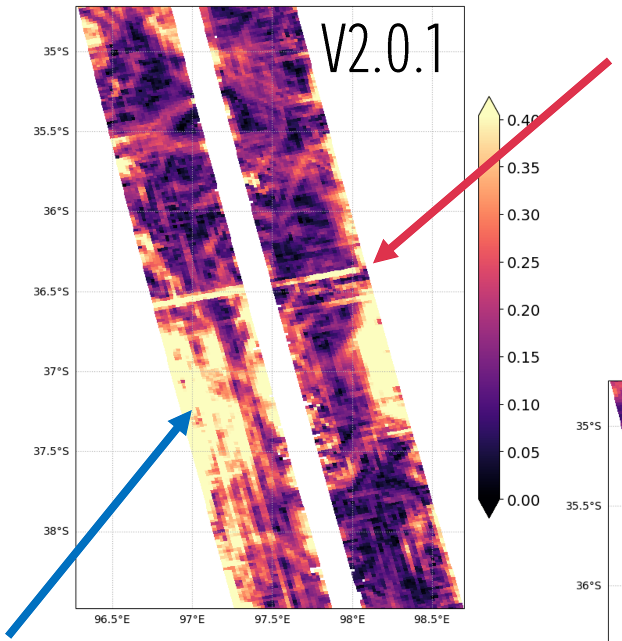
SSHA before denoising (m)



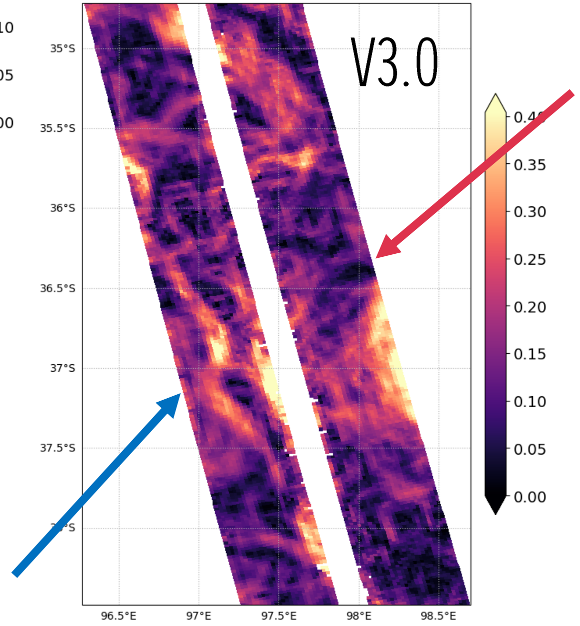


SSHA after denoising (m)





1st gradients of SSHA after denoising (m/s)

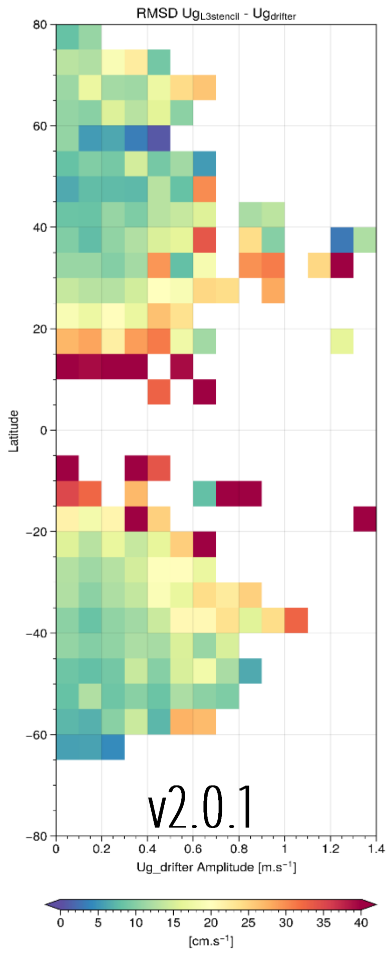


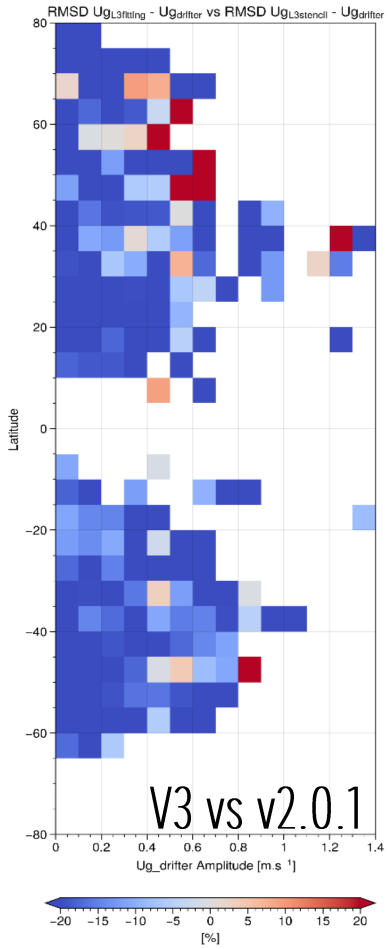
See also the SWOTST 2025 meeting poster here: #ST2025OS1_004

L3 SSHA derivatives

Optimized geostrophic current estimation for v3

- NEW : 2D spline fitting methodology from Tranchant et al. (2025) that filters some of the short wave-lengths that may include part of unbalanced motion not compatible with geostrophic approximation





- Better consistency of the KaRIn geostrophic currents estimated with independent drifter measurements : overall, the L3 fitting method reduces RMSD by 10 to 20% (Fig 2)
- OLD : Previous baseline (stencils) is still available, but now in the new technical L3 variant (next slide)

Fig 2: Intercomparison RMSD Karin velocity vs drifter velocity as a function of drifter velocity amplitude. Left: comparison between KaRIn currents available in v2.0.1 and drifters (units cm.s^{-1}); right: differences of RMSD when Karin v3 KaRIn currents are considered (units: %)

Reference: Tranchant Yann-Treden, Benoit Legresy, Annie Foppert, et al. SWOT reveals fine-scale balanced motions and dispersion properties in the Antarctic Circumpolar Current. ESS Open Archive . January 11, 2025, DOI: 10.22541/essoar.173655552.25945463/v1

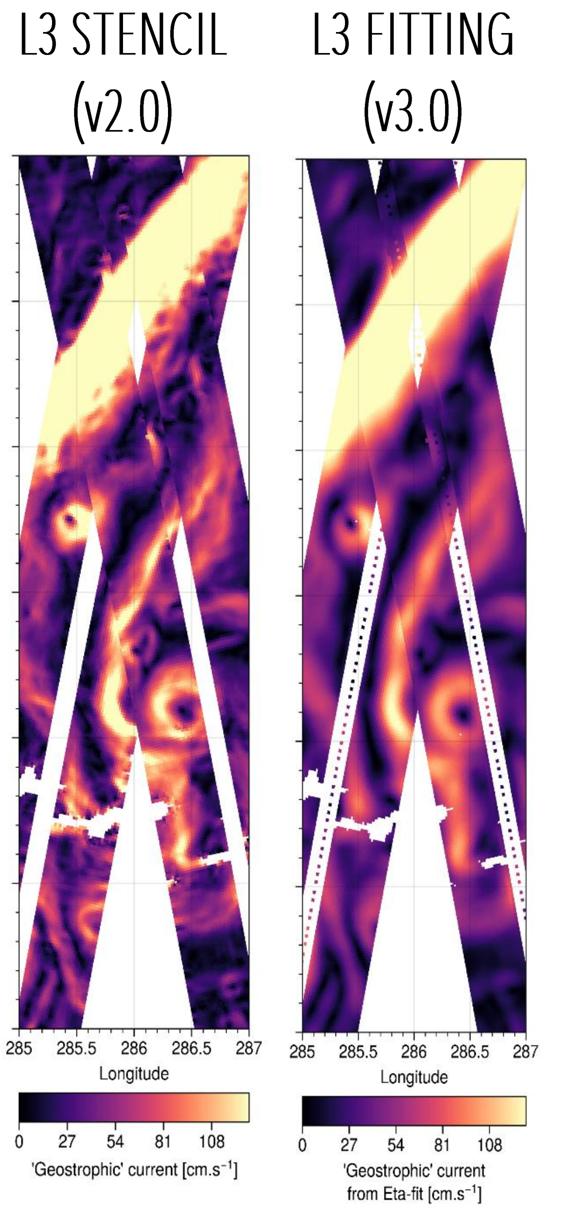


Fig 1: example of geostrophic velocity amplitude

L3 technical product content

New technical product variant (2-km only) requested by experts from the SWOT community

- Netcdf format and structure are consistent with other L3 products (can be combined with L3 and L2 variables)
- Additional or alternative parameters of interest for processing experts: tides, IT, precipitation rate, velocities, MSS compression proxy, low-frequency calibration…
- This product can be expanded upon request (new variants, new models, new algorithms, technical content…) ▶ Feel free to contact us with your suggestions !

variable	Description
loading_tide_fes	Loading tide component from FES 2022 model. Allows to retrieve the dynamical part of ocean tides : « ocean_tide » variable in the core product providing the total geocentric tide. Dyn ocean tides = « ocean_tide » from core product – « loading_tide_fes22 »
ocean_tide_got & loading_tide_got	ocean tide solution from GOT5.6 (R Ray, 2024) # ocean_tide_got56 gives the total geocentric tide (ocean+load) # loading_tide_got56 gives the loading tide component
internal_tide_zhao	Internal tide solution from (Zhao, 2025; https://doi.org/10.5194/essd-2024-611)
internal_tide_miost	Internal tide solution from MIOST-IT24 from (Tchilibou et al, 2025; https://doi.org/10.5194/egusphere-2024-3947)
rain_rate_itu	Precipitation rate from (Picard et al, 2025; https://doi.org/10.31223/X5WF0Z), based on Physically-based atmospheric attenuation model
flag_rain_itu	Rain flag deduced from thressholds applied on rain_rate_itu field (Picard et al, 2025; https://doi.org/10.31223/X5WF0Z),
rain_rate_rf	Precipitation rate from (Picard et al, 2025; https://doi.org/10.31223/X5WF0Z), based on Supervised random forest algorithm
calibration_low_frequence	Calibration : low frequence component
ugosa_filtered_stencil, vgosa_filtered_stencil	Geostrophic velocity anomalies derived from ssha_filtered: zonal and meridional component, using stencil derivate (from L3 v2.0.1 version). Note: is equivalent to velocities derived with 2D fit with reduced kernel
mss_compression_correction	MSS compression correction for KaRIn 2km product resolution (Charayron et al. 2025). This correction is applied on MSS available in the expert product (variable «mss»).

Goddard Ocean Tide 5.6 (courtesy of R.Ray, NASA/GFSC)

- New solution for the amplitudes and phases of the daily and sub-daily global ocean tides
- Based on decades of radar altimetry from multiple satellite missions : Topex/Poseidon, Jason-1, Jason-2, Jason-3, and Sentinel-6A Michael Freilich in main part of deep ocean (Lat < ±66 ∘) + Others satellites in shallow seas and in polar latitudes
- Tidal analysis of these data was done relative to a prior model, which for the most part was the Finite Element Solution FES2014 of Lyard et al. (2021), with some minor patches.
- Includes some new minor waves : 3rd degree and some wave inferred

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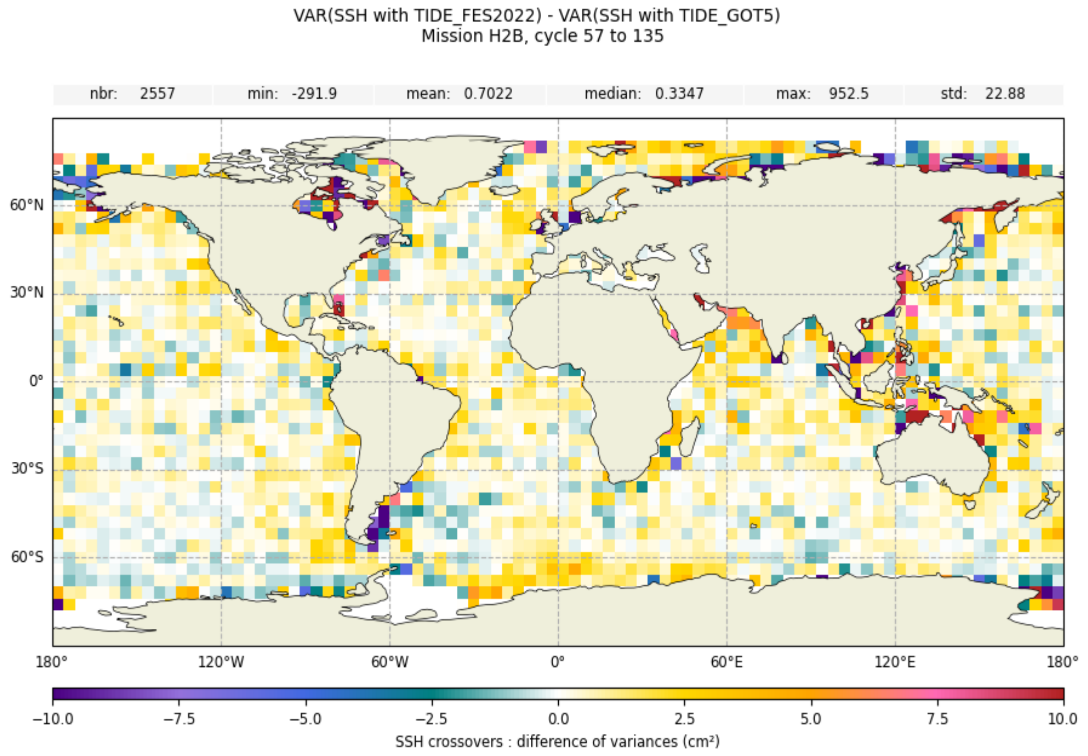


Fig : Difference of variance of SSH differences at HaiYang-2B crossover locations, when SSH is corrected from ocean tide with FES22 or with GOT5.6 model. (courtesy L. Carrere) (unit cm²)

- Slightly better performances with GOT5.6 model in the open ocean, but FES22 significantly better in key shallow seas (tough choice)
- Your feedback is needed for v4: switch baseline from FES to GOT?

Reference :Ray, R.D. (2025). "Documentation for Goddard Ocean Tide Solution GOT5: Global Tides from Multimission Satellite Altimetry", NASA TM-20250002085, Goddard Space Flight Center.

Internal tide Zhao30y (courtesy of Z.Zhao, U.Whashington)

New IT model (2025)

- Computed from 30 years of satellite sea surface height (SSH) measurements from 1993 to 2022
- New improved mapping technique considering mode 1 and mode 2 constituents
- Decomposes the internal tide field and reveals numerous long-range internal tidal beams, which contain key information on their generation, propagation & dissipation
- Atlases are available for the eight major tidal components : M2, K1, S2, O1, N2, K2, P1, Q1
- Zhao30yr induces a small local variance reduction(< 2 cm²) compared to HRET22, in tropical oceans, and worse values in some local areas (e.g. > 4cm² North-East of Madagascar)

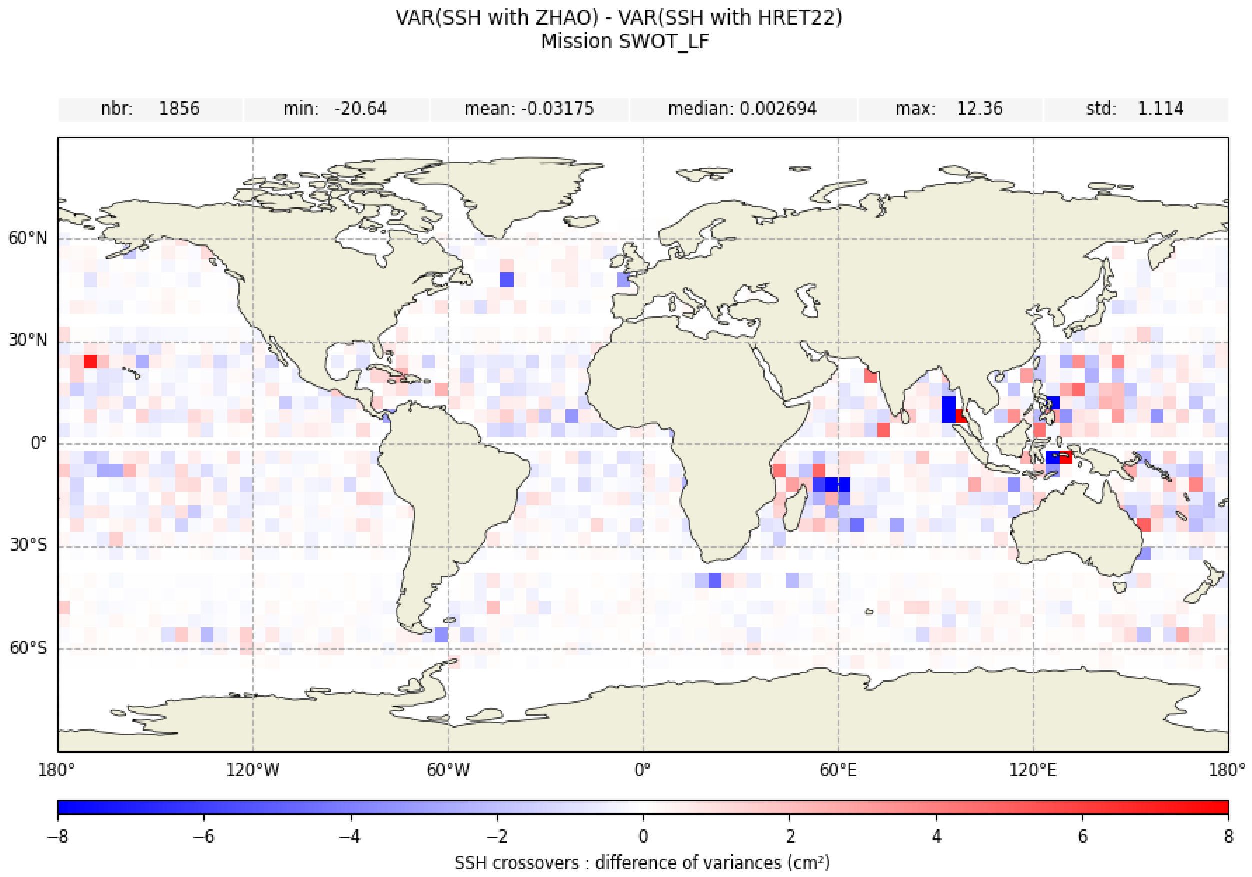


Fig : Difference of variance of SSH differences at SWOT-nadir crossover locations over the [2023, 2024] period, when SSH is corrected from internal tide with ZHAO30y or with HRET22 model. (courtesy L. Carrere) (unit cm²)

Reference : Zhao, Z.: A New-Generation Internal Tide Model Based on 30 Years of Satellite Sea Surface Height Measurements, Earth Syst. Sci. Data Discuss. [preprint], https://doi.org/10.5194/essd-2024-611, in review, 2025.

Internal tide MIOST-IT24 (Tchilibou et al, 2025)

New global atlas of the sea surface height (SSH) signature of coherent internal tides

- Derived from a single time inversion of 28-year (1993-2020) along-tracks altimetry dataset.
- Simultaneously resolves the contributions of internal tides and mesoscale eddy variability : consider mode 1 and mode 2 internal tides wavelengths
- Atlases are available for the four major tidal components M2, K1, S2, O1

▶ Performances marginally better than HRET at global scale

▶ Locally, MIOST-IT24 model contributes to reduce the variance (4cm² in Indonesian regions), at the cost of some local degradations elsewhere (tough choice)

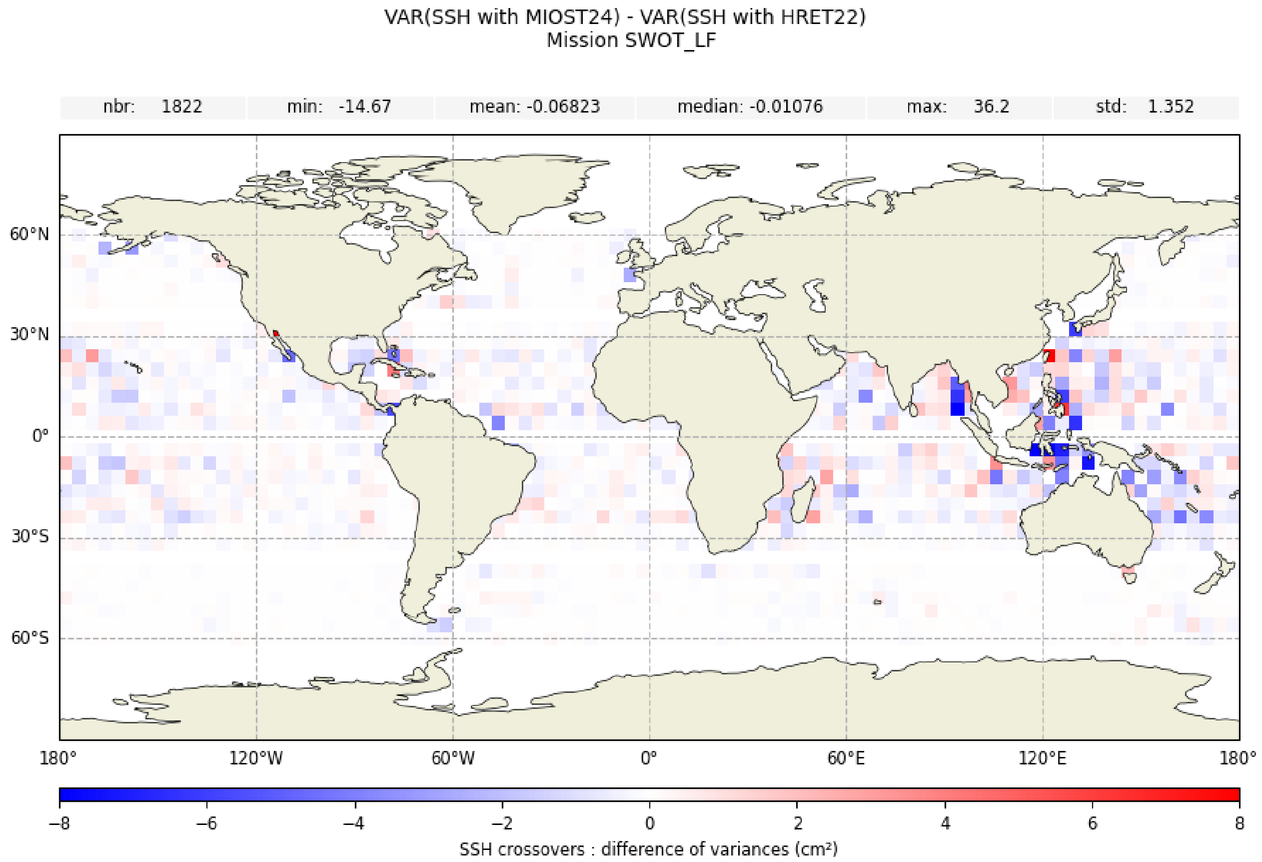


Fig : Difference of variance of SSH differences at SWOT-nadir crossover locations over the [2023, 2024] period, when SSH is corrected from internal tide with MOST-IT24 or with HRET22 model. (courtesy L. Carrere) (unit cm²)

Reference : Tchilibou, M., Barbot, S., Carrere, L., Koch-Larrouy, A., Dibarboure, G., and Ubelmann, C.: M2 Monthly and annual mode 1 and mode 2 internal tide atlases from altimetry data and MIOST: focus on the Indo-Philippine Archipelago and the region off the Amazon shelf, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3947, 2025.

Rain flagging and Precipitation rate (ITU & RF)

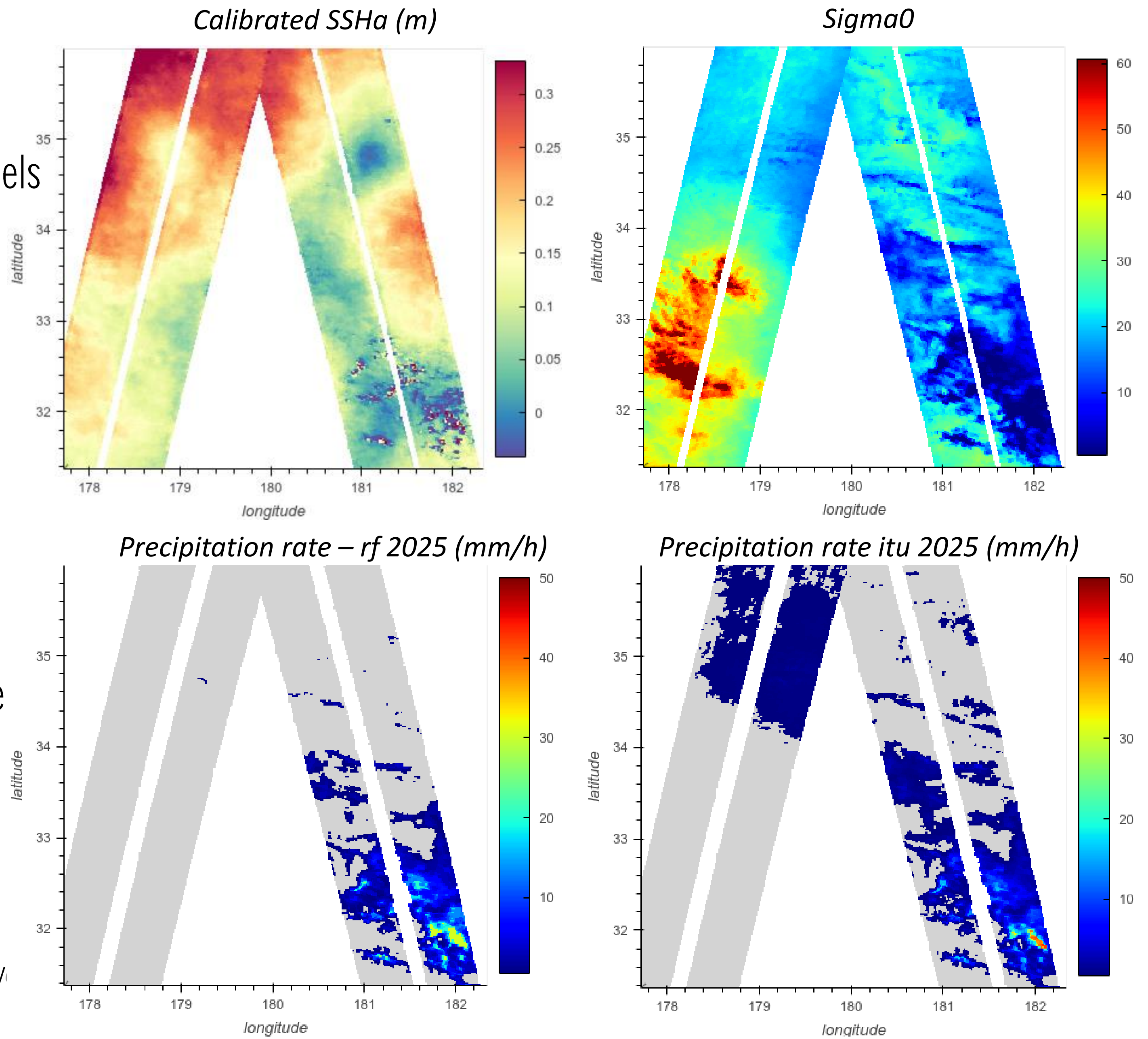
itu 2025

- Physically-based attenuation inversion using ITU-R models
- **Advantages** : robust to extreme events
- **Known limitations** : over detection (low precipitations)

rf 2025

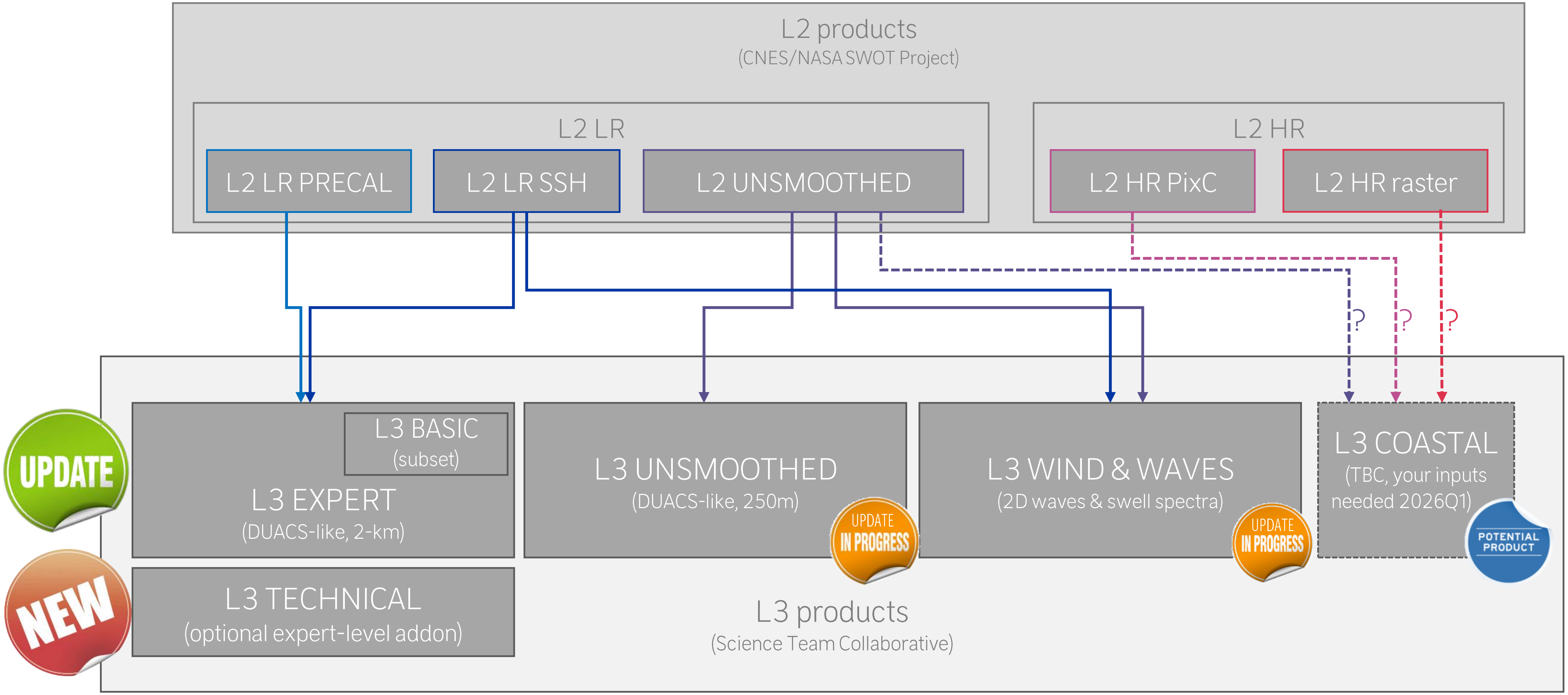
- Supervised machine learning algorithm trained on collocated NEXRAD radar data
- **Advantages** : better detection of low precipitation rate
- **Known limitations** : Some discontinuities can be visible

More details in Picard et al (2025)



Picard, B., Colin, A., Husson, A., & Dibarboure, G. (2025). The effects of rain on a Ka-band sw learned from the SWOT mission. Submitted. https://doi.org/10.31223/X5WF0Z

Level-3 products family picture and upstream dependencies



L3 product manual

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

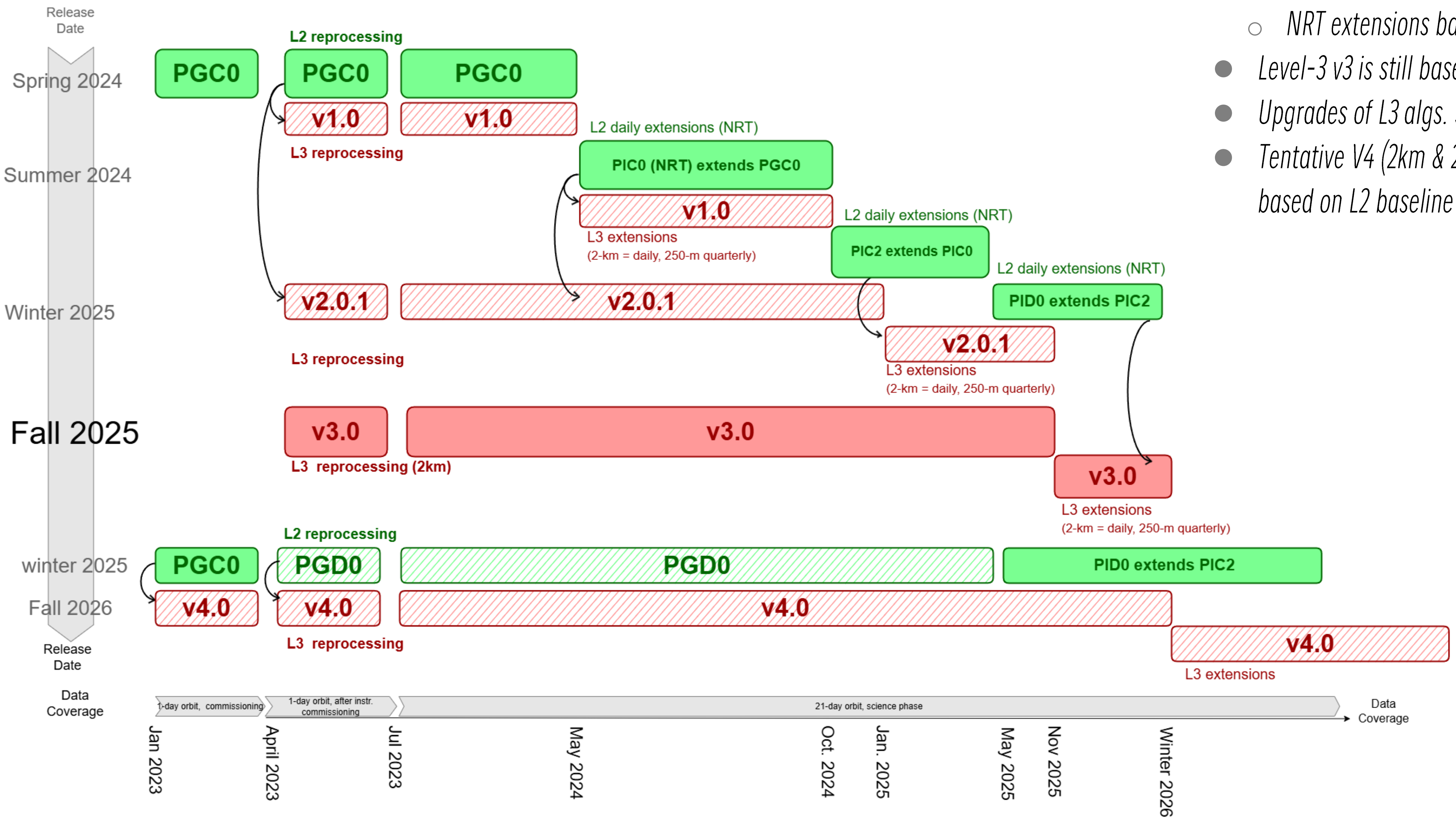
Handbook for the L3 expert & basic & unsmoothed

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

L2 & L3 versions and release dates

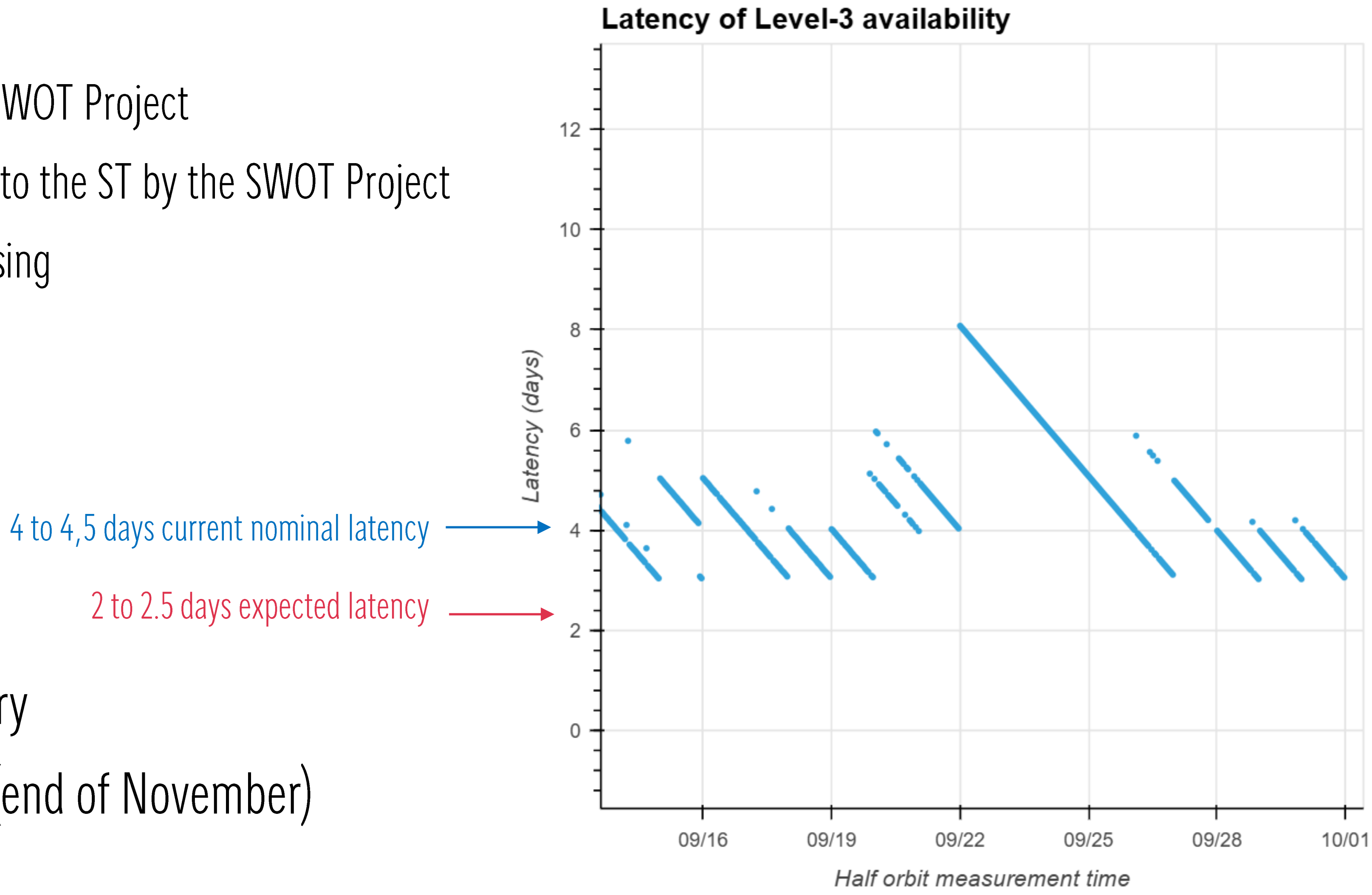


- *All Level-3 releases are composed of*
  - *A full mission reprocessing based on L2 PGxx*
  - *NRT extensions based on Level-2 PIxx*
- *Level-3 v3 is still based on L2 baseline C*
- *Upgrades of L3 algs. summarized in these slides*
- *Tentative V4 (2km & 250m) for Fall 2026 will be based on L2 baseline D reproc.*

Product latency for NRT

Latency improved for the L3 expert (2km) product

- Made possible thanks to
  - Improvement of L2 timeliness by the SWOT Project
  - Distribution of the L2 PRECAL product to the ST by the SWOT Project
  - Massive optimization of the L3 processing
- Old L3 latency : 4 to 4.5 days
- New latency (target) : 2 to 2.5 days



- Available on AVISO in NRT repository
- Tentative ETA : Thanksgiving 2025 (end of November)
- Fallback ETA : end of 2025

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

DUACS team

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