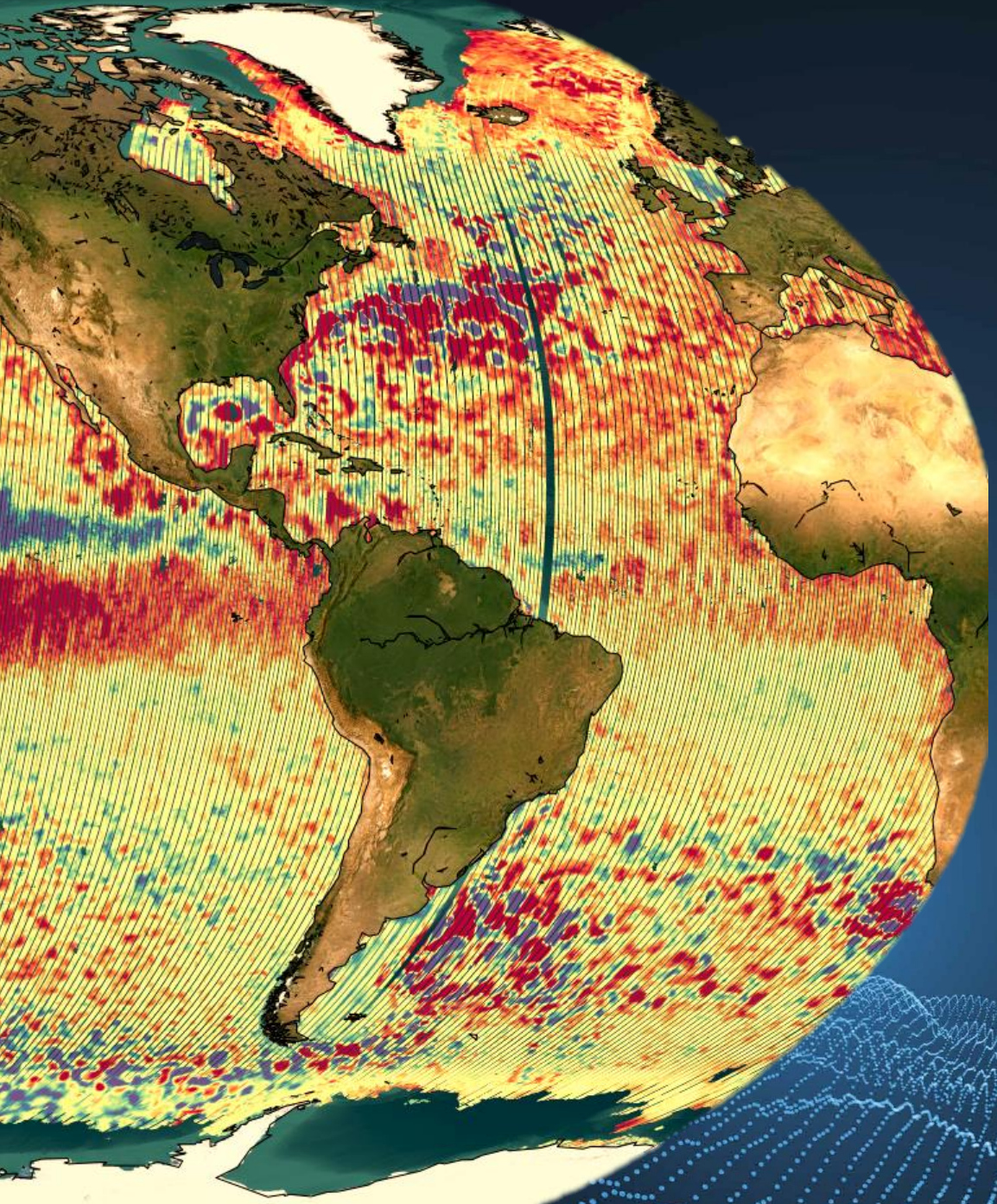


SWOT ST DESMOS PROJECT with
contributions from other SWOT ST Projects

SWOT Level-3 version 2.0

planned changes, rationale,
expected improvements
and known issues

Updated version 2025/01/15

Overview

- v1.0 of the SWOT Level-3 was released in Spring 2024
  - Multiple variants: 250-m & 2-km, near real time & complete reprocessing
  - NRT production has been temporarily paused during the Level-2 upgrade from PIC0 to PIC2/PID0

- v2.0 is being finalized for a tentative release in Jan2025 (2-km) and Fev2025 (250-m)
  - Complete reprocessing of the Science & CalVal phases
  - Upgrade of the NRT processor
  - Daily v2 production for 2-km, quarterly for the 250-m
  - v1.0 NRT will be discontinued when v2.0 starts

Your timely guidance would really help

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

- This slide package gives an overview of the main upgrades of v2.0
  - To give your some prep time if they affect your research work
  - To give you a chance to react before v2.0 is massively reprocessed
  - To try and squeeze in (or revert) some changes based your feedback
  - More ambitious requests will be considered for v3.0 (tentatively end Spring25)

v2.0 changes in a nutshell

Geophysical standards

- ~~Mean Sea Surface model 2024 (CNES/CLS, blends KaRIn & nadir altimetry~~) → item delayed until v3.0 (expected in Spring 2024) because MSS model is still being validated
- Internal tides blend solution between HRET14 & HRET8.1 model, courtesy of Ed. Zaron (replaces HRET8.1)
- Quick fix of the SSB/SSHA offset in polar transitions (known L2 issue)
- Added 5 cm offset on MDT and ADT to be consistent with other L3 products (CMEMS/DUACS)

L3 algorithms

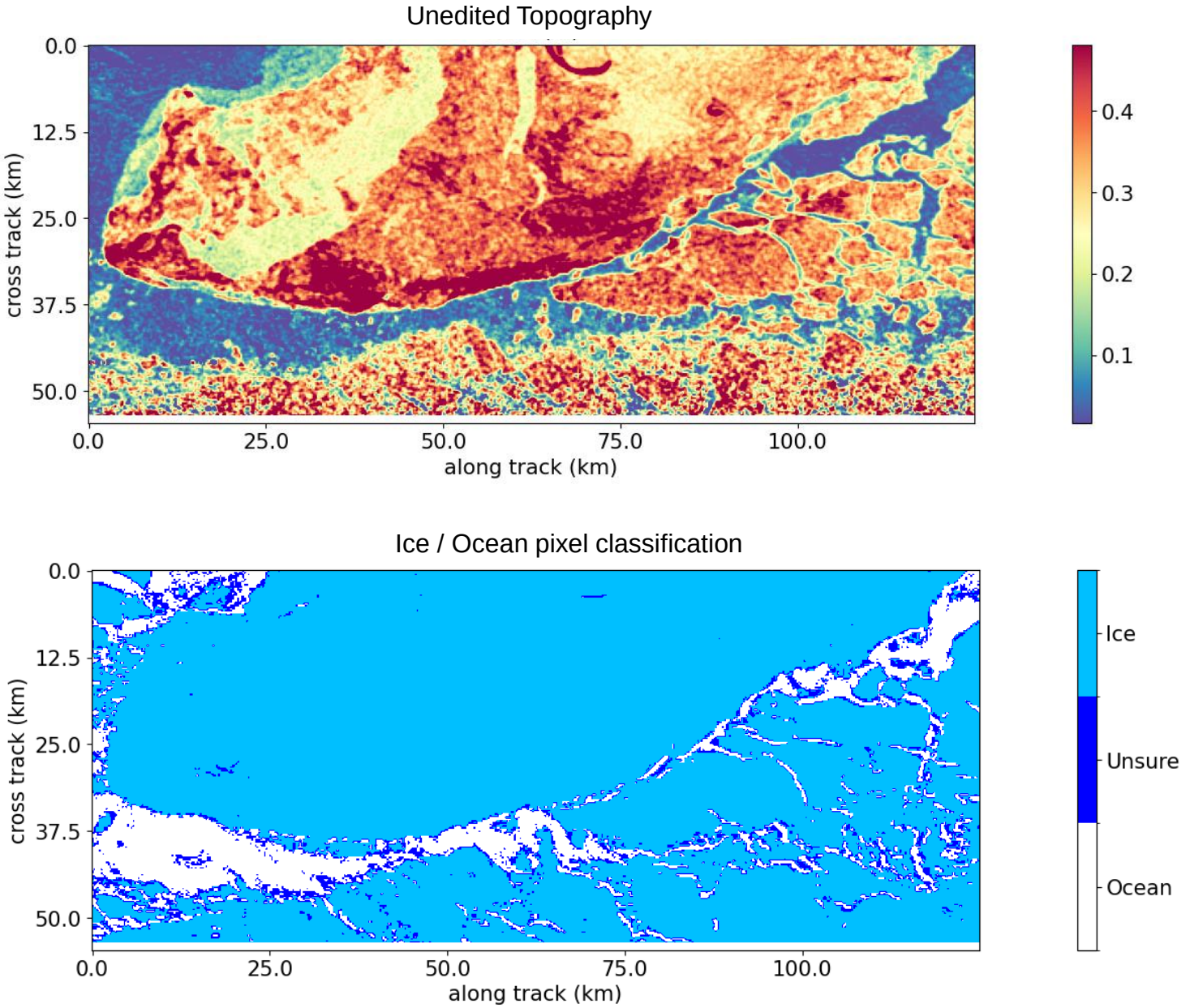
- Coverage improved: eclipse data gaps retrieved with good quality
- Coverage improved: polar/coastal regions (more precise flagging)
- Richer yet simple quality flag: more granularity, esp. coastal & polar
- Cross-calibration improved: coastal & polar seas
- Coastline & distance to coast improved: new L3 land mask, manually retrieved 40+ estuaries
- [250m only] Added surface classification (ice/leads) in editing flag
- [250m only] Retrieved SSHA in sea-ice leads
- [250m only] Improved denoising (tbc)

Product format

- Added new variables (unfiltered geostrophic velocities, internal tide model, cross-track distance)
- Changed variables names & attributes

Flagging changes: sea-ice leads and polar ocean (250-m resolution only)

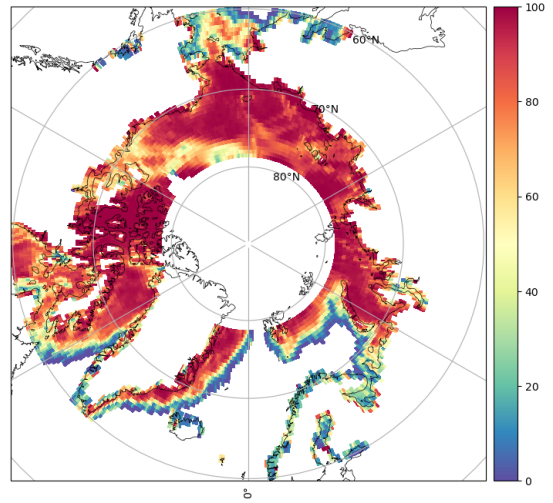
- First cut of polar pixel classification algorithms: v2.0 adds new editing flag values
- The classification methodology is being developed as a collaboration between CLS, CNES, LEGOS, and ESA
- Editing flag
  - ocean is flagged as 0
  - sea-ice is flagged as 20
  - undermined as 19
- Rationale: to retrieve as much ocean coverage as possible in polar regions (the L3 is primarily an ocean product although we try to help glaciology research as well)



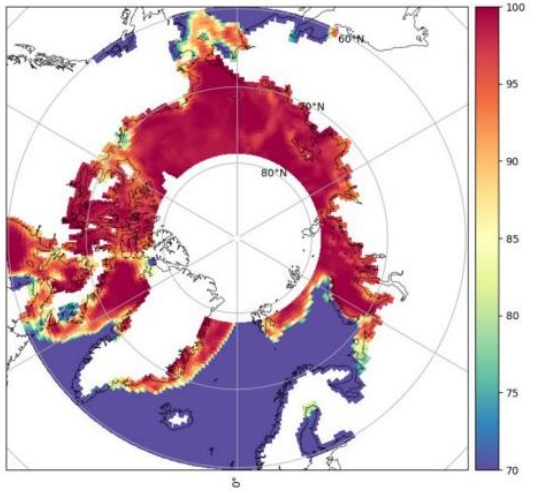
Flagging changes: sea-ice leads and polar ocean (250-m resolution only)

- In the example below the classification is self-consistent (despite time lag and different view angles)
- Limitation: work in progress (known failures for some specific SWOT passes)
- Way forward: integrate more research-grade classification flags developed by the polar community
- Please contact us if you want your classification to be added to the next L3 release

Ice concentration from SWOT L3 (%)



Ice concentration from OSISAF (%)



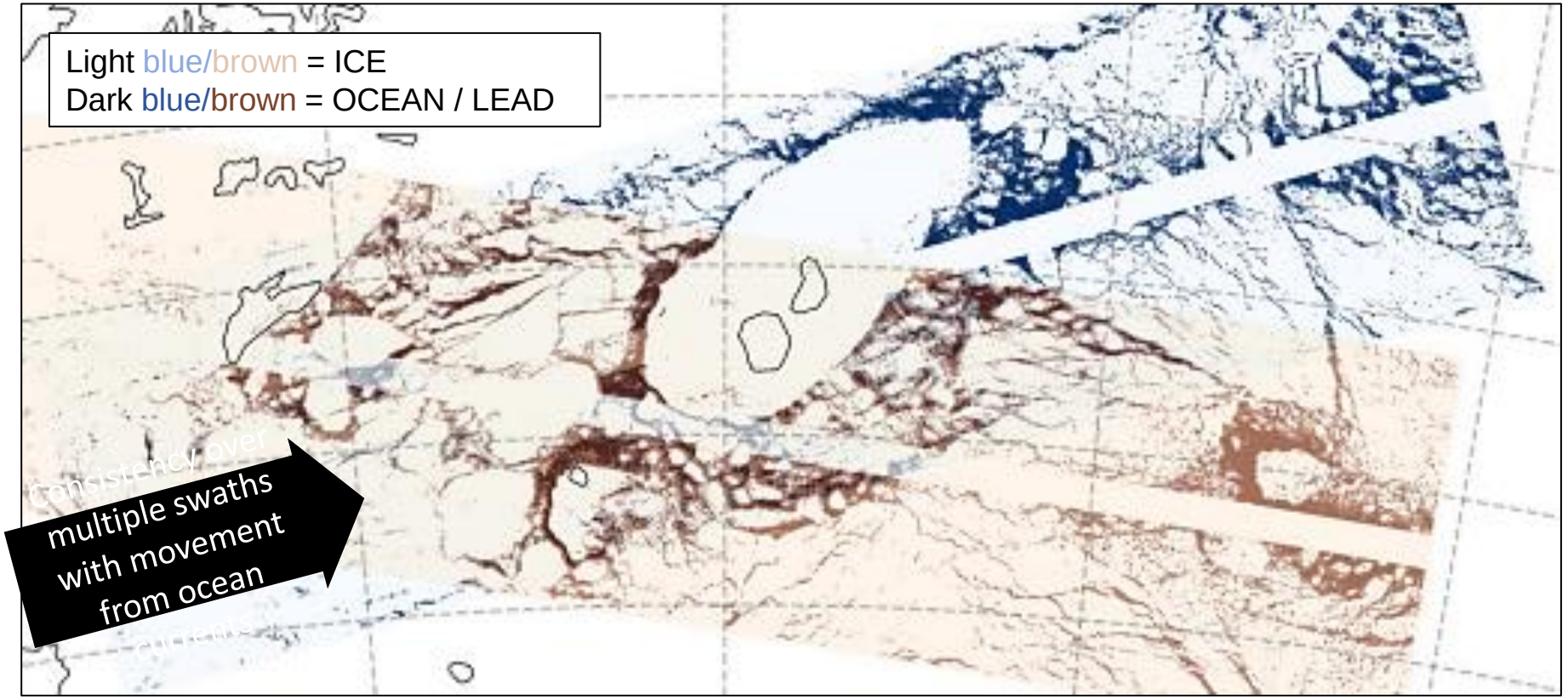
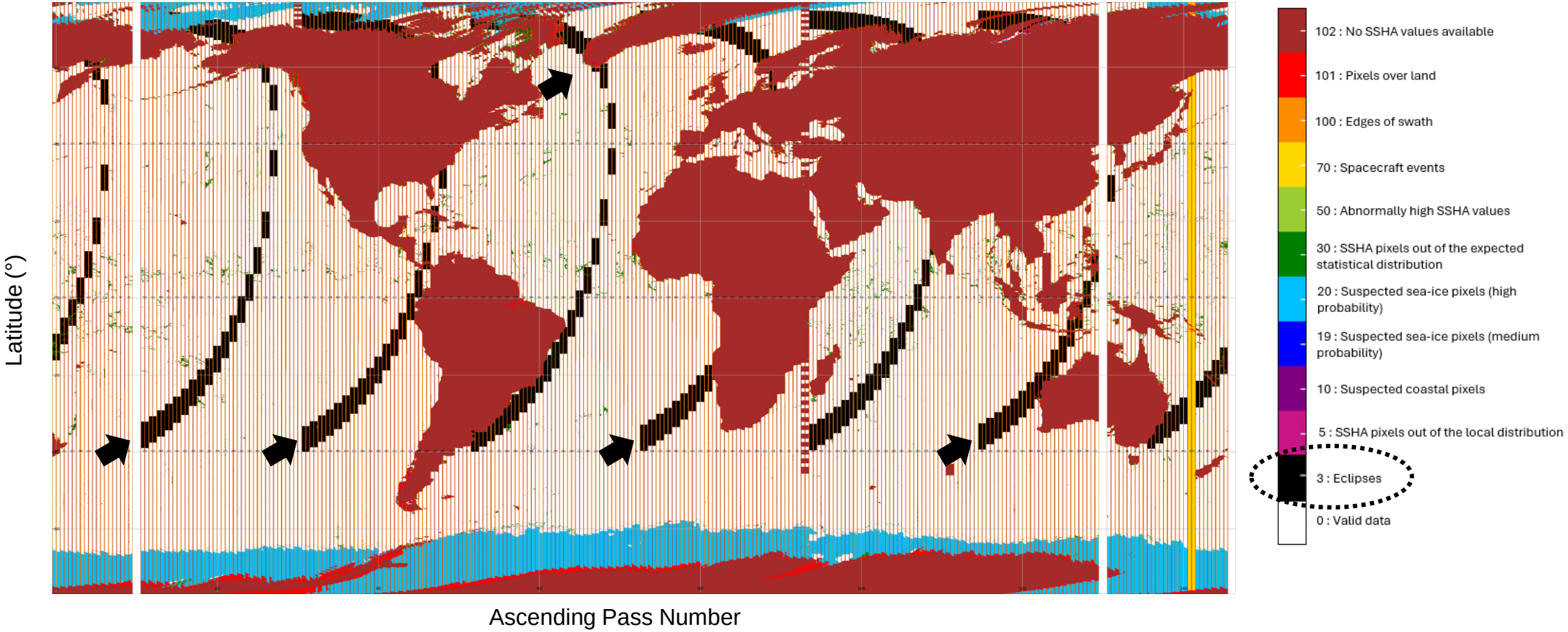


figure courtesy of LEGOS

Eclipse transitions

- Eclipse transition segments are isolated from other SWOT mission events (e.g. maneuvers) & flagged with a specific value
- Rationale: performance analyses from the L2 Project CalVal and L3 teams did not observe any degradation for these segments
- Change: in the L3 basic product, the SSHA is now provided during eclipse transitions ▶coverage improved by 4%
- Change: in the L3 expert & unsmoothed products, the segments are flagged a #3 (i.e. likely to be normal quality) ▶your choice

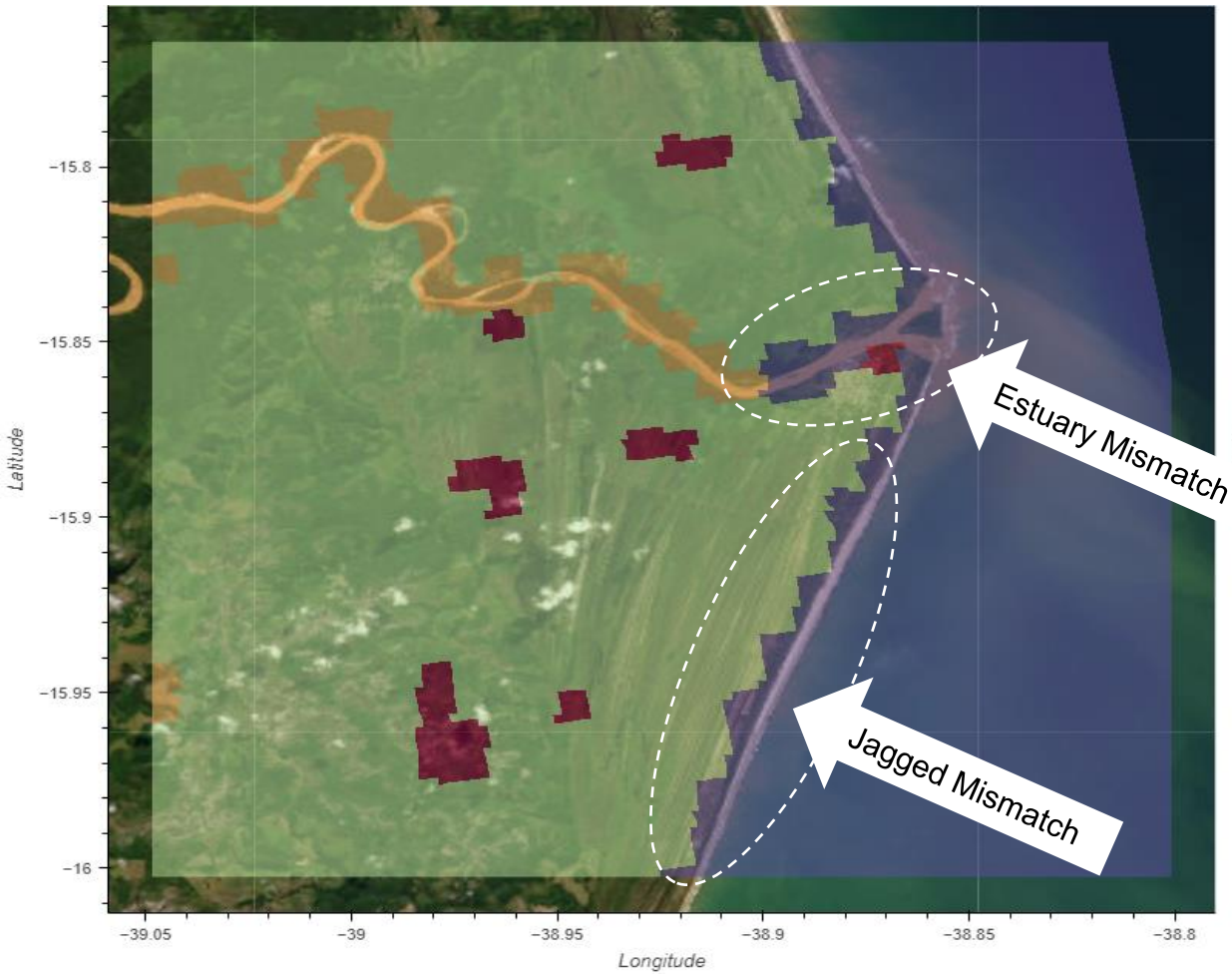


Land-sea mask / Surface type

- 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
  - v1.0 used a first cut of the land mask: it fixed most of the known L2 issues, albeit with some failures in estuaries
  - v2.0 now uses a revised mask with manual processing of ~40 estuaries to retrieve them
- Rationale: this mask was primarily developed to better classify land from the coastal ocean (which in turn affect ocean calibration)

New coastline mask (250m product overlay on ESRI optical imagery)

mask inherited from L2 Product on top of ESRI image



mask from L3 product on top of ESRI image

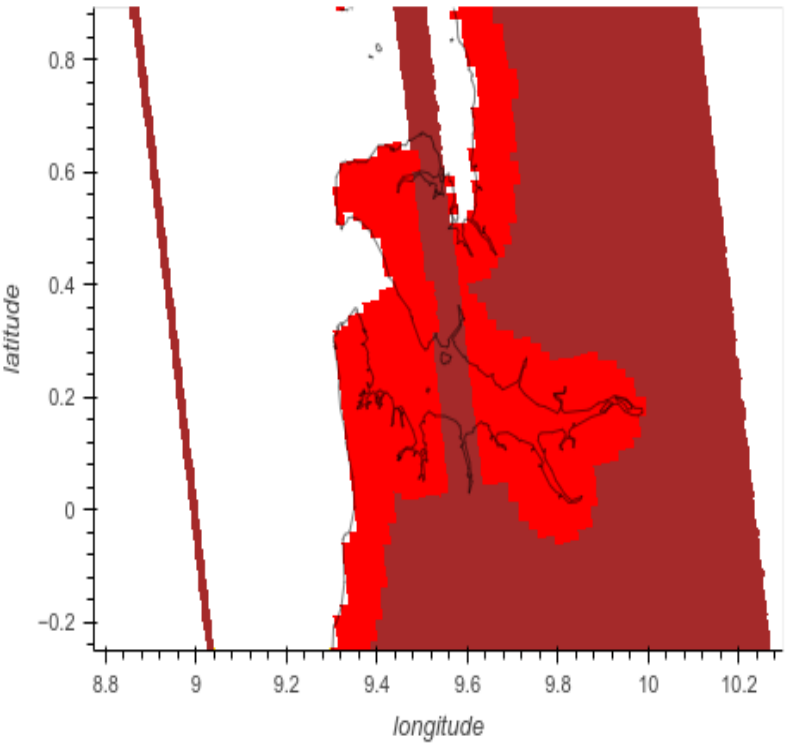
- Surface type: yellow to red is not ocean (i.e. rejected for L3) ▶ Also affects distance to coast, editing flags, etc…
- In this example, many pixels were incorrectly classified, resulting in incorrect ocean flagging and suboptimal ocean calibration

Flagging changes: estuaries

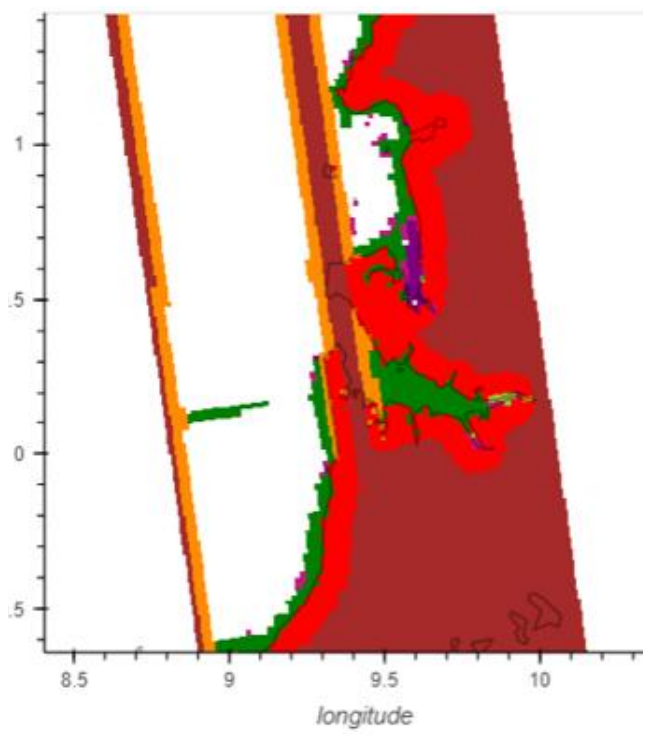
- In L3 v1.0, some estuaries were edited out by our land-sea flag (flag #101) because of the way OSM handles ocean & estuaries
- Our v2.0 mask is now manually updated in 43 major estuaries of interest for the SWOT ST & OSTST
- To make sure your estuary of interest is in the list, please contact us
- Known limitations: estuaries with no SSHA in the L2 cannot be retrieved in the L3 (known PIC/PGC issue, not related to land mask)

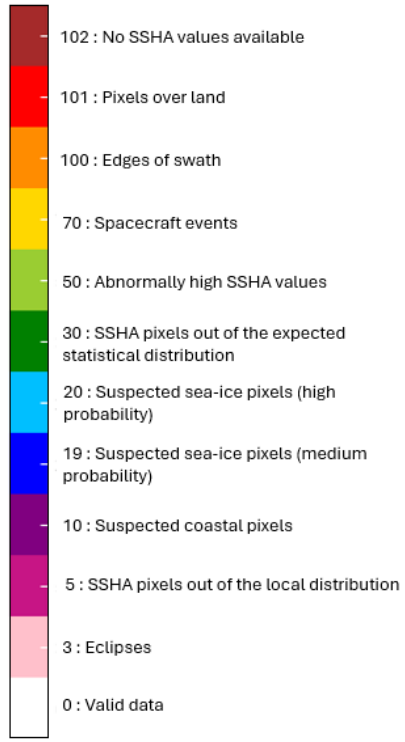
Example of Gabon estuary

BEFORE: flag v1.0.2

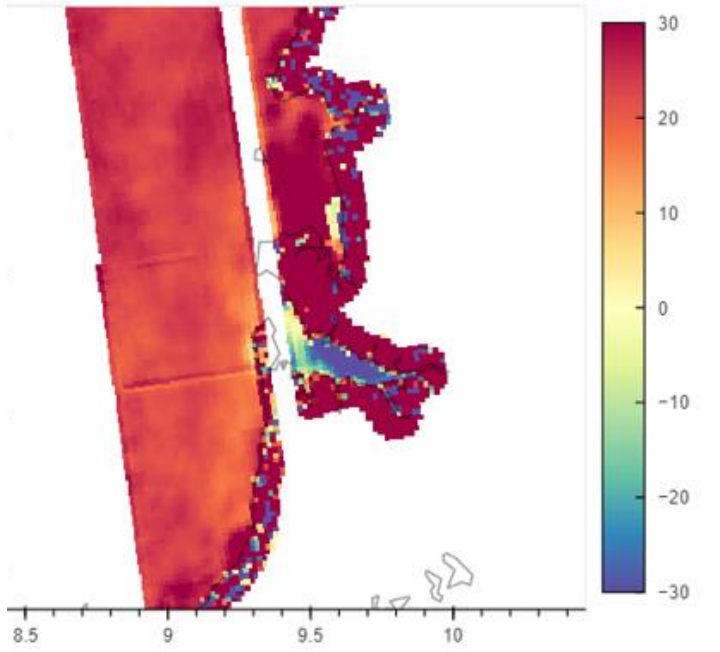


AFTER: flag v2.0





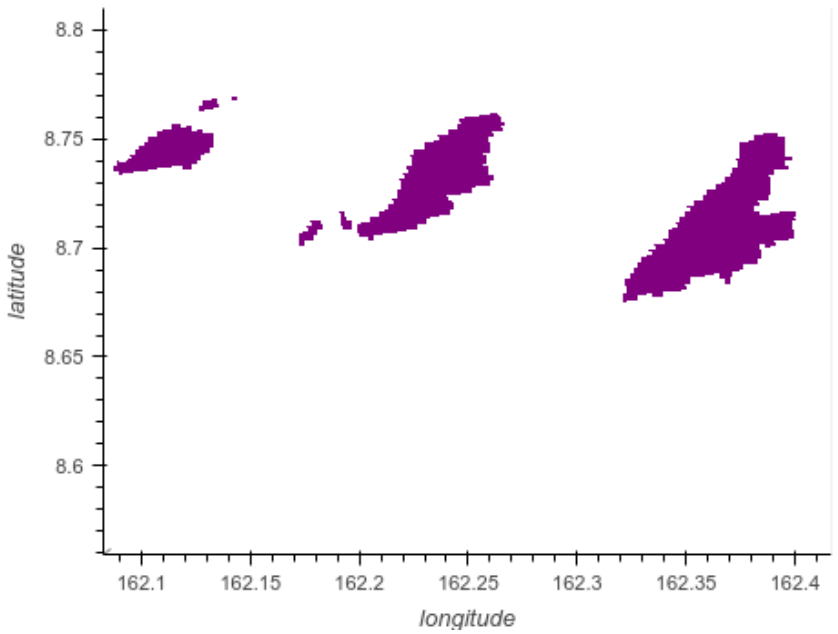
SSHA without flagging



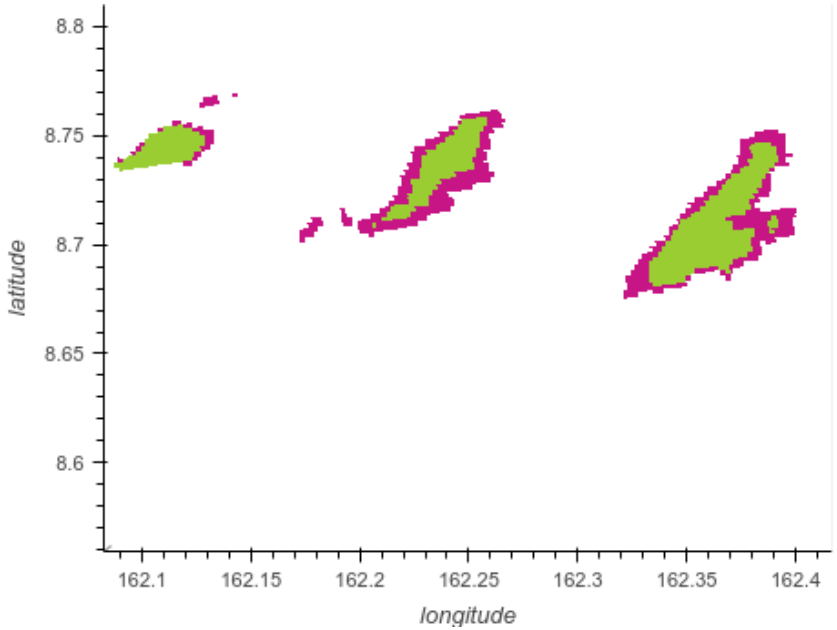
Flagging changes: coastal margins, rain cells, calibration…

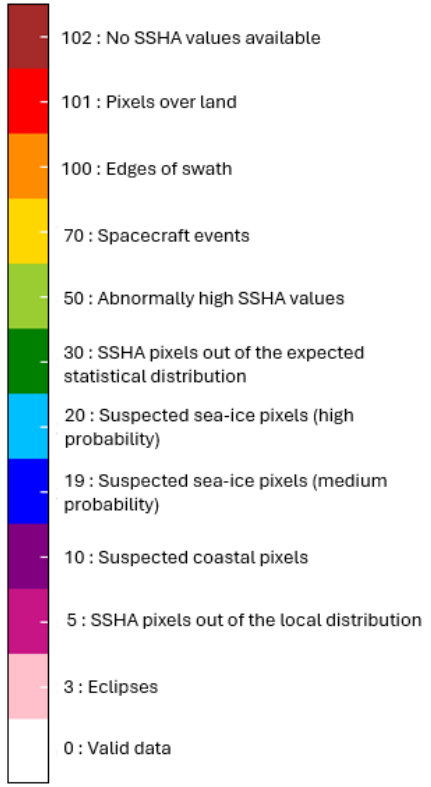
- The L2 rain flag rejects a large amount of good KaRIn data ▶ The L3 uses a local statistical analysis instead (first cut in v1)
- The L3 algorithm is revisited in v2 to reduce the occurrence of ambiguous rejection criteria (e.g. rain vs coast)
- The revised flagging is also better integrated with L3 calibration (iterative)
- Way forward: actual L3 rain flags are currently being developed for 2025 (courtesy of Fluctus, derived from DOI:10.3390/rs13234861)
- Please contact us if you want your flag algorithm to be added to the next L3 release

BEFORE: v1 flags rain cells as possible islands



AFTER: v2 flags rain cells as statistical outliers with more control over ambiguous edges of the rain cells



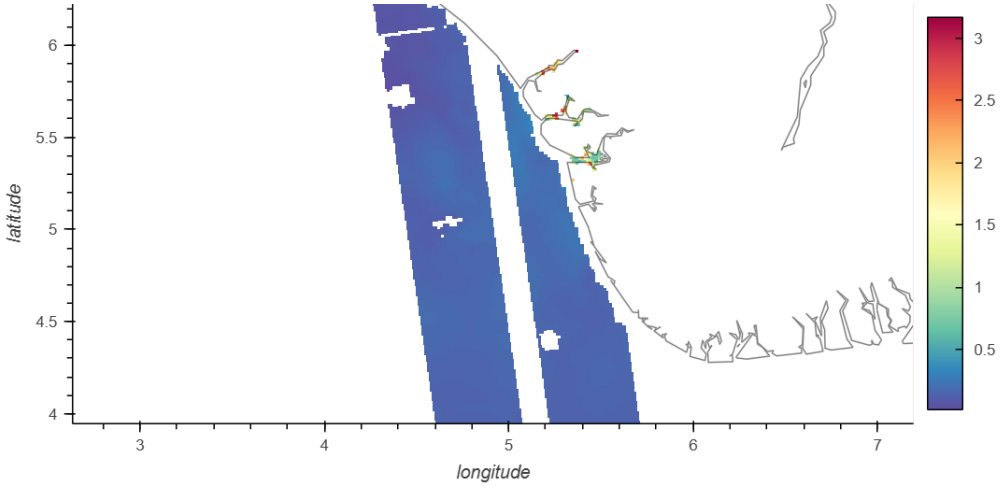


Flagging changes: remaining limitations

- The L3 flag may be too permissive in some estuaries
- The L3 flag may be too restrictive in some extreme events (e.g. Hurricane Milton) → user can tune the data selection using different values of the L3 quality flag
- Please give feedback on flag quality

Estuaries along Nigeria coast

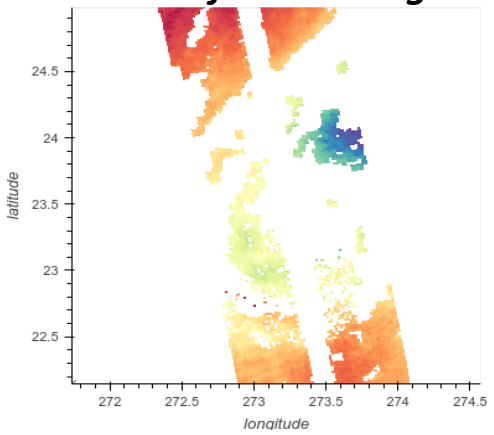
SSHA edited from v2.0 2km product (m); Cycle #24, pass #376



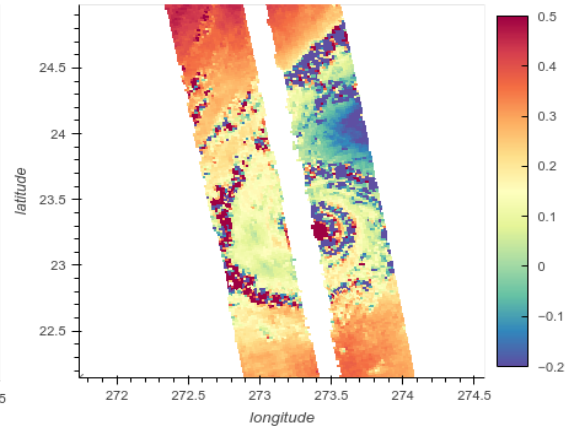
Hurricane Milton

SSHa from v2.0 2 km product (m); Cycle #22, pass #216

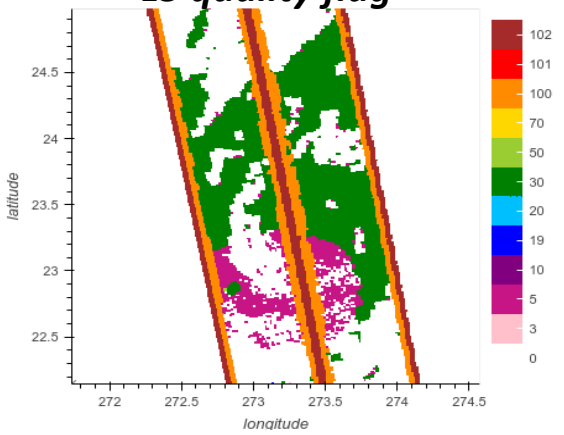
Default editing



Tuned editing



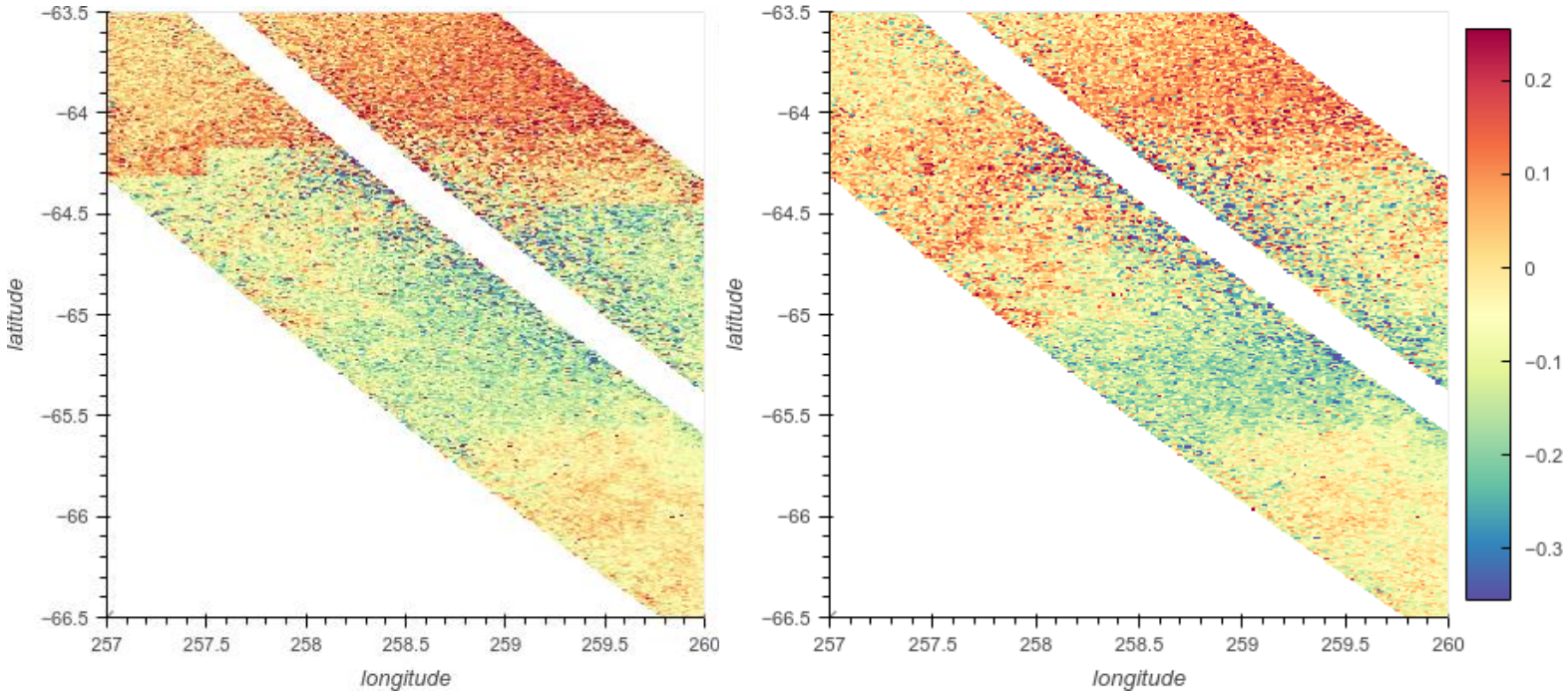
L3 quality flag



Sea State Bias (model-based)

- In polar regions, the SSB_2 correction of the L2 PIC/PGC products have a known offset (10+ cm) caused by the limit of MFWAM wave model definition
- Change: in L3 v2, the SSB_2 correction is now extrapolated towards 0 in polar areas in order to remove the SSH discontinuities that may limit polar studies
- Rationale: in sea-ice leads, SSB is assumed to be close to zero (small waves), so we enforce continuous transition from open ocean to sea-ice leads
- Limitation: this extrapolation does not yield a correct/geophysical SSB correction in MIZ
  The quick fix intends to remove only the SSB_2 offset in a gradual way, but the SSHA remains biased (no wave height available in these regions = SSHA bias)
- Way forward for future releases: switch to SSB_1 based on Nadir/KaRIn-based waves (ongoing work)

BEFORE
SSHa_unedited from v1.0.2;
250-m product (m)

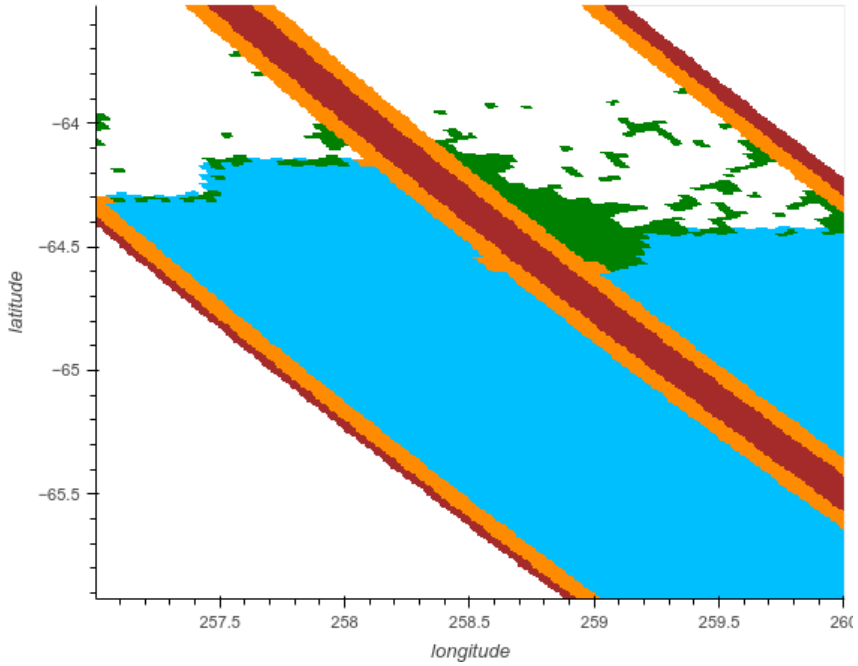


AFTER
SSHa_unedited from v2.0;
250m product (m)

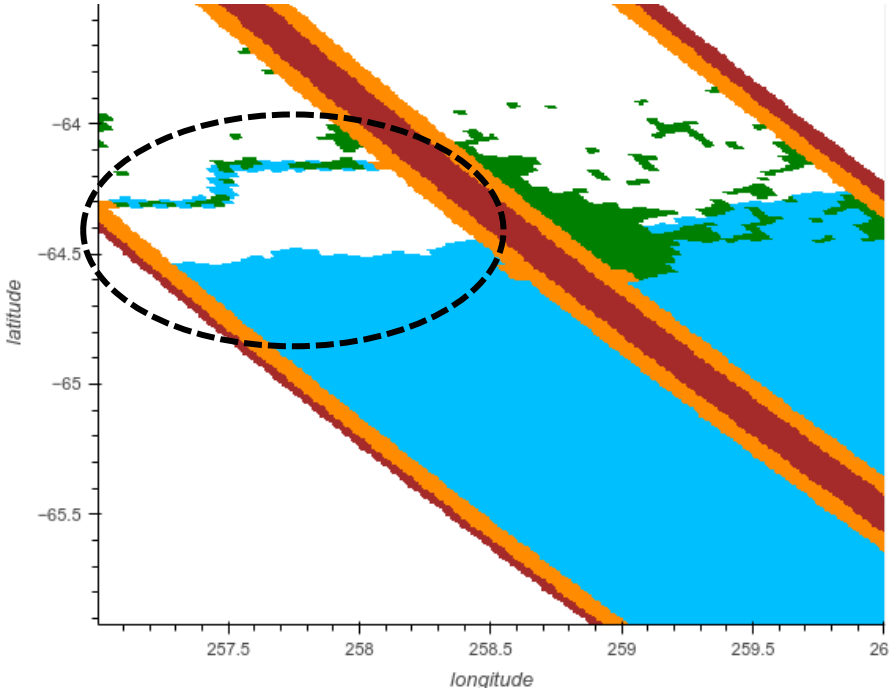
Editing changes: marginal ice zones (2-km resolution only)

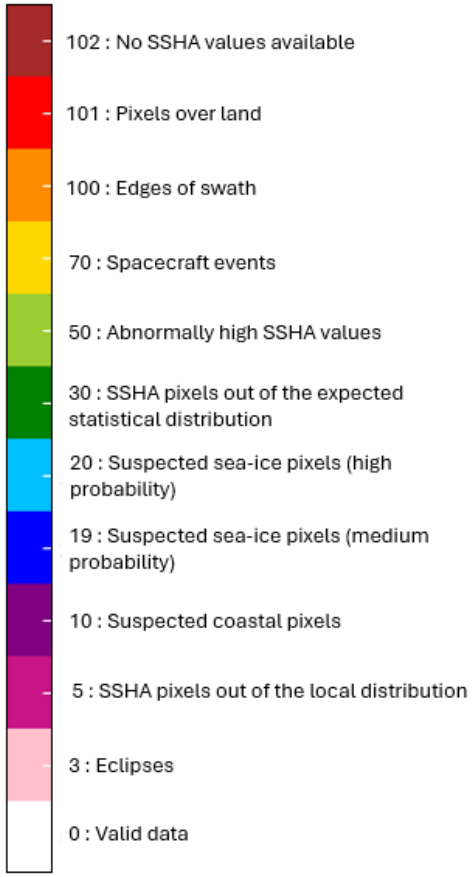
- Due to the changes in L3 SSB offset (previous slide), the editing of polar regions can be less aggressive in v2 than in v1 ▶ coverage improved in MIZ
- Only pixels with an ice concentration higher than 60% and those on the edge of the polar ocean are flagged as #20
- Below is an example of quality flag polar area (only flags higher than #20 are applied)

BEFORE: L3 v1 @ 2-km



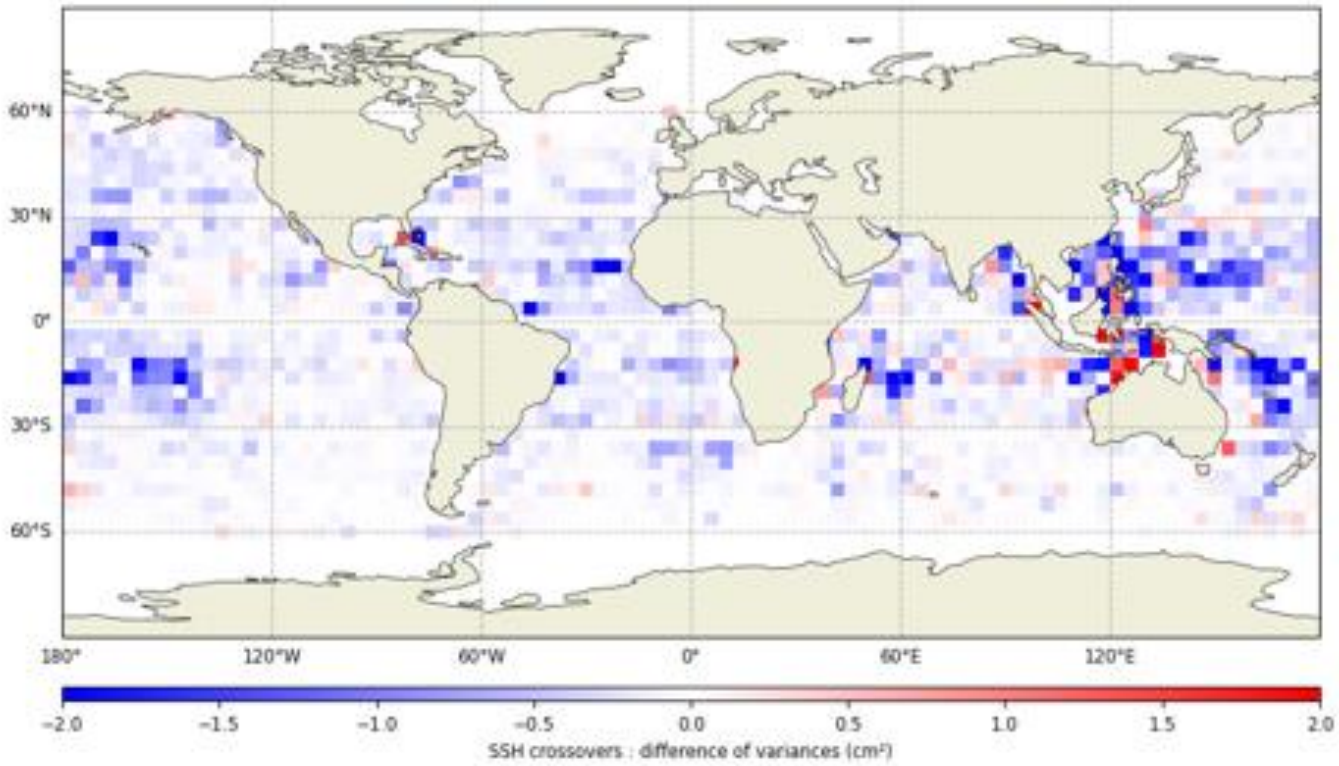
AFTER: L3 v2 @ 2-km





Internal tide model HRET (courtesy of Edward Zaron)

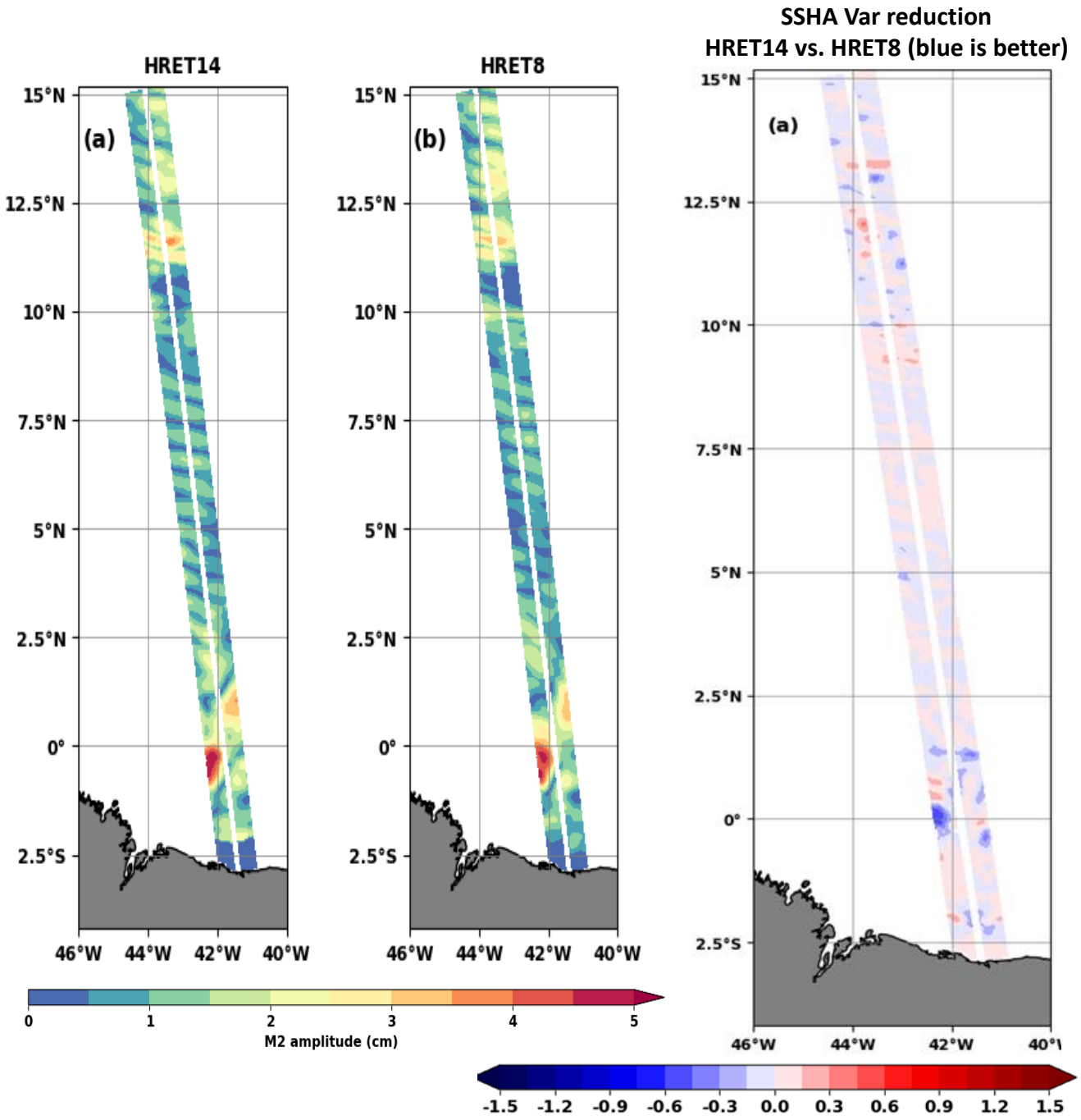
- Before (L2 and L3 v1.0): SSHA was based on HRET8.1 with 4 tidal frequencies (M2, K1, S2, O1) from Zaron et al. (2019)
- Now: SSHA based on a blend solution between HRET8.1 & HRET14 model with 5 tidal frequencies (M2, K1, S2, O1, N2) from Zaron et al. (2024)
- Rationale: bland HRET solution is slightly more accurate than HRET 8.1 over most of the open ocean (3 mm RMS, locally 1 cm)
- Added: the internal model "correction" is applied to the SSHA and provided separately so you can uncorrect/replace it
- Known limitation: the gain is not geographically homogeneous (also mission dependent)
- Way forward: use next HRET release (2025 tbc) and research-grade models (static & dynamic)
- Please contact us if you want your IT model to be added to the next L3 release



SSHA variance difference for HRET14 vs HRET8 here measured with Sentinel-3 (cm^2)

Example: HRET14 vs HRET8

- M2, S2, K1, O1 are used for HRET8 (+N2 for HRET14)
- Variance reduced with respect to HRET8
  - 3 mm RMS (global avg)
  - locally up to 1 cm RMS
- Consistent numbers found with $SWOT_{nadir}$, $SWOT_{karin}$, Jason-3, Sentinel-3 and 6 missions
- Known limitation: HRET14 is based on nadir altimetry and it does not correct for higher modes of IT, non linear waves, solitons, and non-stationary tides



Mean Dynamic Topography

- Mean Dynamic Topography model used: Hybrid CNES/CLS/CMEMS 2022 (DOI: 10.24400/527896/a01-2024.010)
  - CNES_CLS_2022 (Global ocean, DOI:10.24400/527896/a01-2023.003)
  - CMEMS_2020 (Europe region patch, DOI:10.48670/moi-00151)
- Change: apply a -5cm offset on MDT model as well as on Absolute Dynamic Topography (SSHA is unchanged)
- Rationale: fix known discrepancy between SWOT and other L3 products from CMEMS & DUACS
- Note: this historical offset originates in the (arbitrary) reference period used [1993, 1997] vs. [1993, 2012]

L3 Calibration

3 changes are implemented in the v2.0 calibration

- Data in eclipse transition segments are now used in the calibration algorithm
- Better integration with coastal/polar flagging makes it possible to maximize coverage and to remove bad pixels from calibration
- The number of degrees of freedom has been reduced (see below)
- NB: The L3 pseudo phase screen correction is not changed w.r.t L3 v1

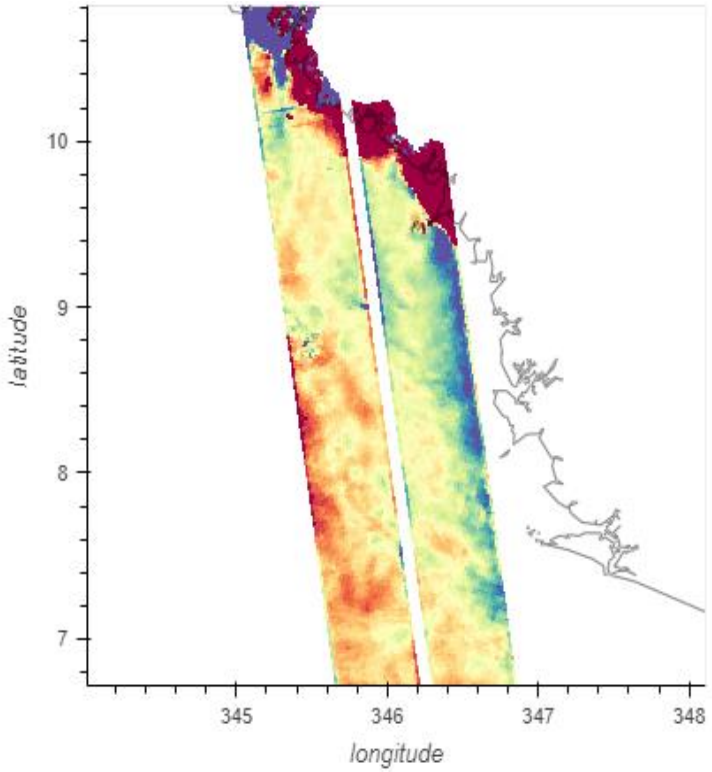
Core calibration upgrade

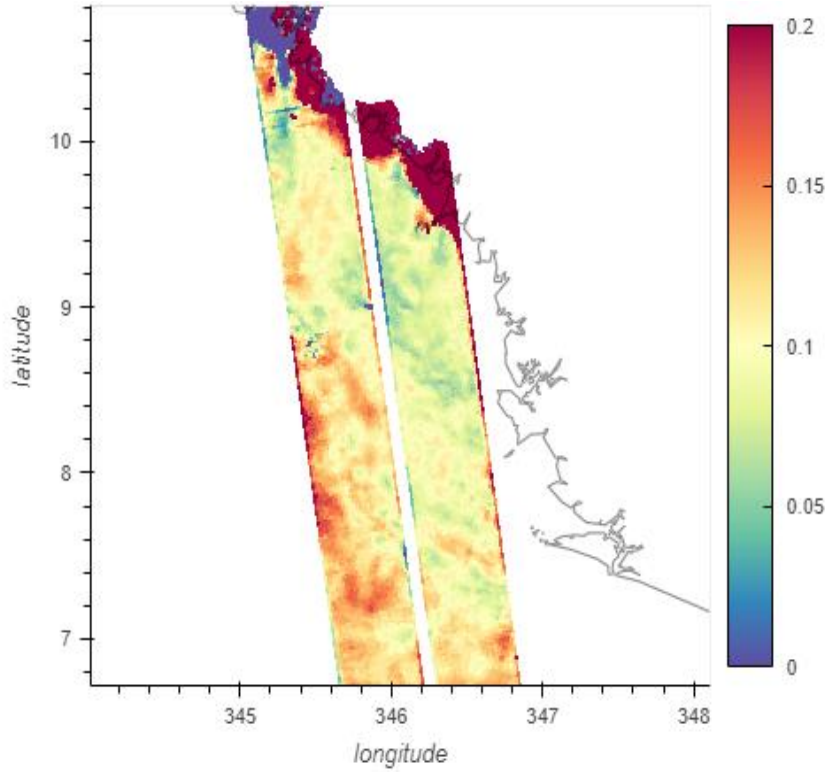
- Rationale: algorithm change derived from the observations of Ubelmann et al. (2024) and Peral et al. (2024)
- We now have a more sophisticated handling of the bias/linear/quadratic terms and the orbital harmonics VS broadband interpolators
  - Fewer degrees of freedom (we try to calibrate only what is absolutely needed) ▶We ignore uncalibrated error sources when calibration is not possible / desirable
  - The ocean no longer leaks into the unneeded parameters (see Dibarboure et al., 2022)
  - This results in better correction for the semi-enclosed / coastal / polar seas and Hydrology (1-day phase calibration is based on L3 algorithms)
- Limitation: calibration v1 was absorbing other geophysical error residuals (see SWOTST 2024 Talk) and not just KaRIn systematic errors.
  By focusing v2 on KaRIn systematic errors, you might observe more tides/DAC/SSB/WTC residuals in SSHA ▶ We need your expert feedback

Calibration changes : improvement of coastal editing before calibration

- In the example below, v1 has a residual tilt (negative on the Eastern swath)
- It is primarily caused by incorrect flagging and spurious pixels (dark red) that confused the calibration algorithm
- The new editing and more robust calibration remove the coastal tilt ▶ General behavior expected in coastal / semi-enclosed / polar seas
- NB: in this example the v2 editing also better removes spurious pixels (not shown)

BEFORE: Unedited & Calibrated SSHA v1 (m)





AFTER: Unedited & Calibrated SSHA v2 (m)

L3 Denoising and SSH derivatives

No change on 2-km and 250m denoising for v2

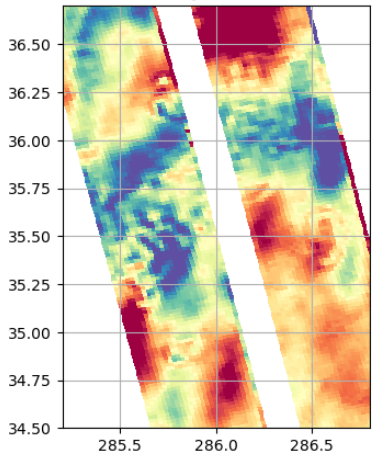
- Still provided in the product (albeit renamed as ‘filtered’) ▶Dibarboure et al (2024) have shown that is an overall positive algorithm to include despite the lack of quantitative demonstration (no ground truth) and suspicious features discussed at the SWOT ST meeting
- New developments have been put on hold until the community can find a compelling way to perform quantitative validation

Know limitations :

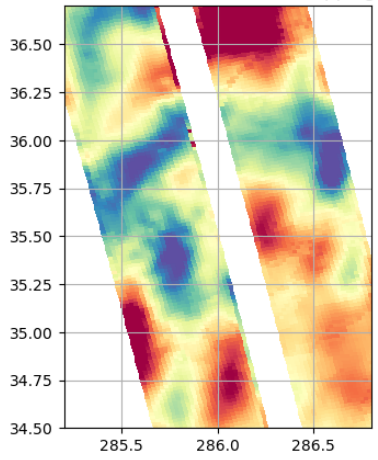
- Denoising processing may absorb other signal than uncorrelated noises. Residual small scale waves and part of the MSS errors can be observed in the removed signal (see example).
- Users that are interested in wave signal or that would like to combine ssha with another MSS filed than the one used in the L3 processing should work on ssha before denoising

Mean content of the SSHA during the CalVal phase (mm)

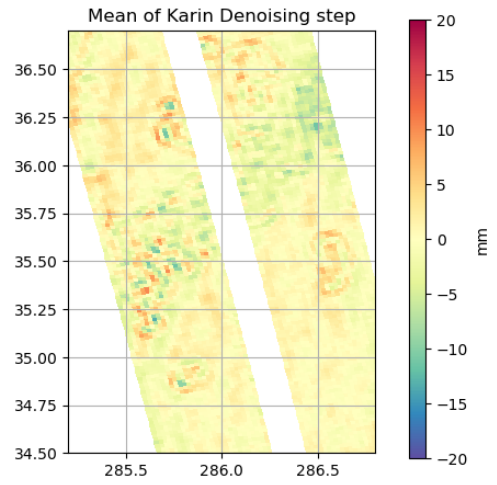
Before denoising



After denoising



Mean content of the noise removed (mm)



Small scales mean structures observed in the noise content mainly correspond to MSS errors

L3 Denoising and SSH derivatives

Unfiltered “geostrophic velocities” are now added in L3 as new parameters (raw quantity, should be smoothed or post-processed)

(Reminder) Denoising cannot address two major challenges related to SSH derivatives

- The SSH measured by KaRIn is not just from mesoscale but also a synoptic view of unbalanced motions and barotropic residuals
- Geostrophy might simply no longer be relevant for the smallest scales observed by KaRIn

Way forward: set up working group on velocities, denoising and its validation, define quantitative metrics, integrate in an open data challenge

L3 Format

Variable name changes (same content)

- ***SSHA*** renamed ***SSHA_UNFILTERED*** for clarity (no denoising applied, SSHA was short but ambiguous)
- ***SSHA_NOISELESS*** renamed ***SSHA_FILTERED*** for clarity (not enough validation to justify the original name)
- ***UGSOA*** renamed ***UGSOA_FILTERED*** for clarity (denoising applied before derivatives)
- ***VGSOA*** renamed ***VGSOA_FILTERED*** for clarity (denoising applied before derivatives)

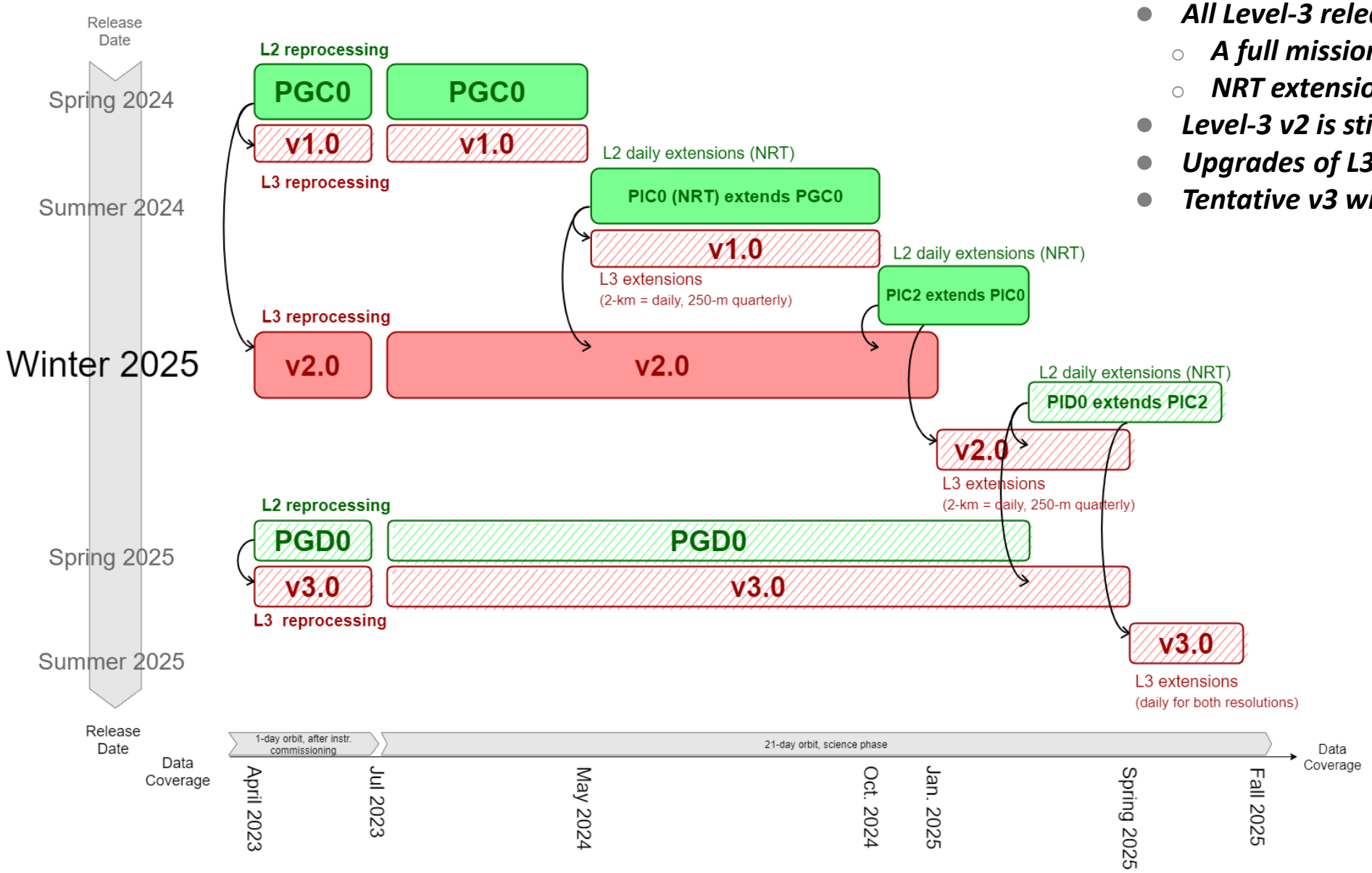
New variables added

- ***INTERNAL-TIDE*** now contains the internal tide solution applied to all SSHA variants
- ***UGSOA_UNFILTERED*** and ***VGSOA_UNFILTERED*** now contains the geostrophic velocities anomalies (zonal and meridian components) derived from the ***SSHA_UNFILTERED*** parameter (no denoising) ▶very noisy so smoothing by the user is mandatory
- ***CROSS_TRACK_DISTANCE*** now added in the unsmoothed product to complement PIC/PGC Level-2 content and for anyone who wants to compute/apply their own calibration

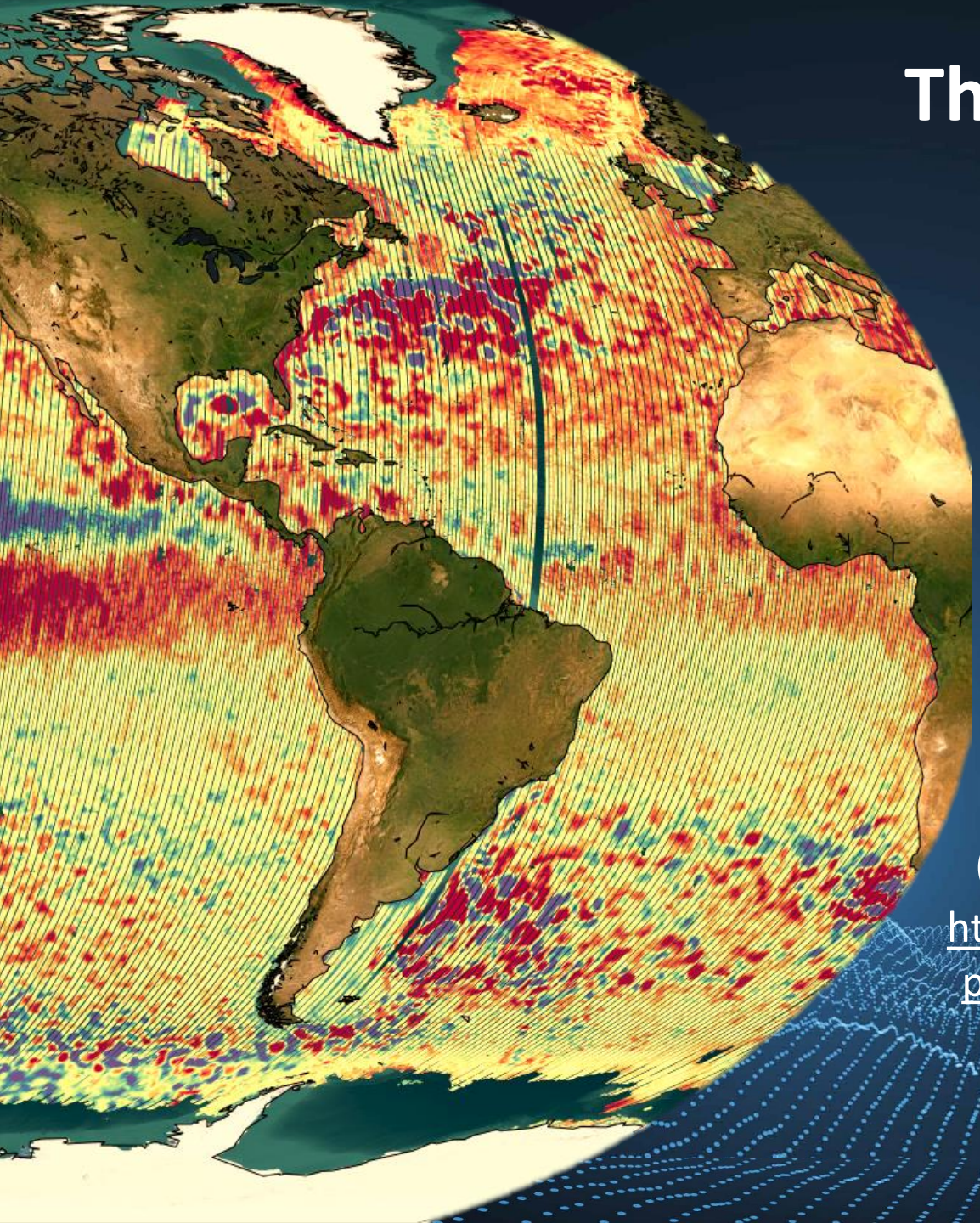
Many attributes updated for clarity (e.g. references) based on the AVISO helpdesk feedback (recurring questions about v1)

Some netcdf variables keep the same name with a different content (the change is described in the attributes, e.g. MSS or editing flag)

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 v2 is still based on L2 baseline C*
- *Upgrades of L3 algs. summarized in these slides*
- *Tentative v3 will be based on L2 baseline D reproc.*



Thank you for your attention!

Data Access

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

Reference Paper

(accepted, EGU Ocean Science)

https://egusphere.copernicus.org/preprints/2024/egusphere-2024-1501/