An enhanced Mean Sea Surface model developed by combining SWOT KaRIn and nadir altimetry data

Charayron Rémy, Schaeffer Philippe, Ballarotta Maxime, Pujol Marie-Isabelle (CLS), Delepoulle Antoine (CLS/DATLAS), Dibarboure Gerald, Faugère Yannice (CNES)

SWOT Science Team, Arcachon, Oct. 2025

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Context

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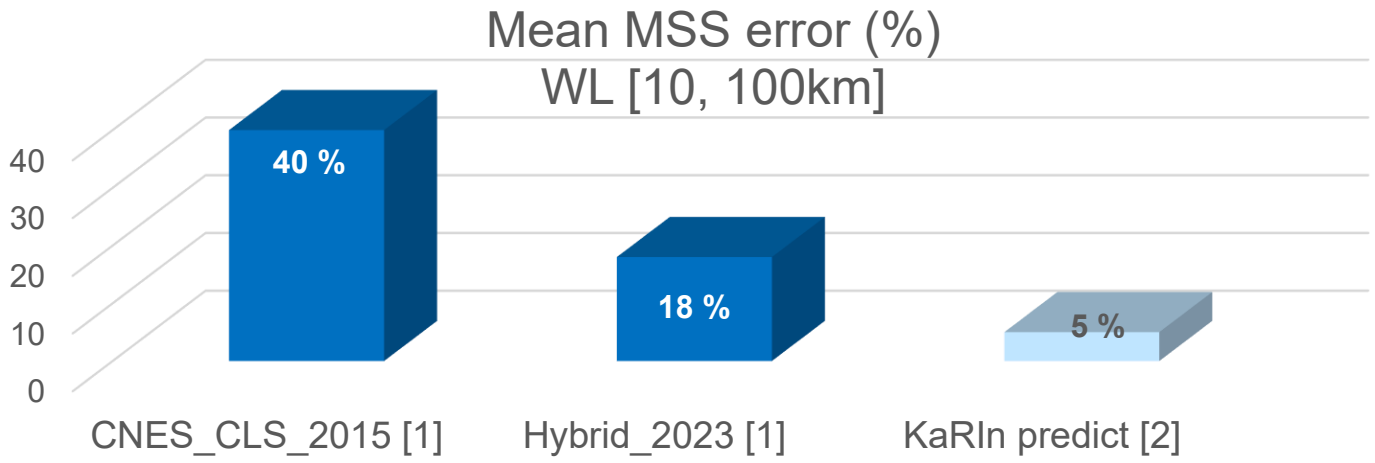
Significant improvement of the MSS estimation done in the last years :

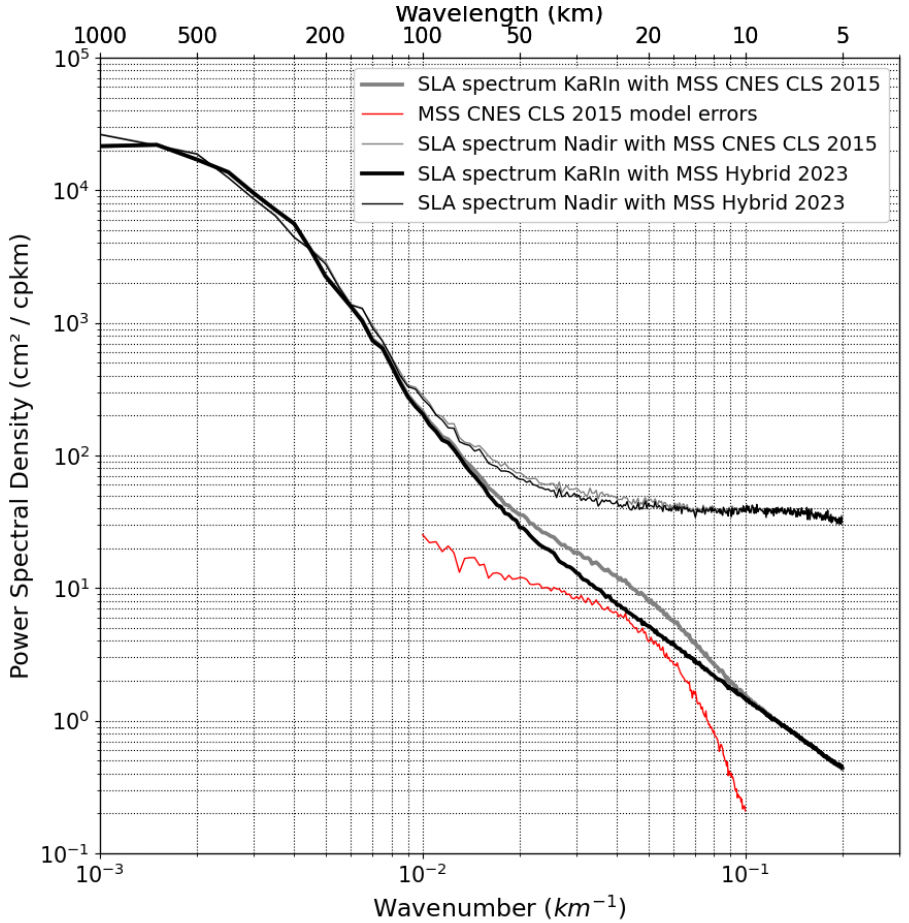


MSS errors at short wavelengths are still significant for KaRIn measurements:

- Mainly omission errors
- Create artificial hump on SSHA PSD at small mesoscale (WL [10, 100km])

Karin measurement now available for MSS estimation

- More than 30 cycles in science phase should lead to MSS error < ~5% of SSHA variance [2]



PSD of the KaRIn (thick solid line) and Nadir SSHA (thin solid line) when it is based on the CNES/CLS2015 MSS (grey); and when a more accurate MSS (here Hybrid 2023 model) is used instead (black). MSS CNES_CLS_2015 (red) estimated errors. From [1]

[1] Laloue et al, 2024. https://doi.org/10.1029/2024EA003836
[2] Dibarboure et Pujol, 2019. https://doi.org/10.1016/j.asr.2019.06.018

MSS CNES_CLS_25 Methodology

Methodology MSS CNES_CLS_25

$$\boldsymbol{CNES\_CLS\_25 = H23 + InnovComb}$$

New preliminary MSS model

MSS draft **to capture large-scale content** from H23 [1]

Combine SWOT KaRIn* mean profile (25 cycles science used) and nadir*-based MIOST[2] innovation **to improve scales from 10 to 150km**

*SSHA measurements including MSS compression correction

[1] Laloue et al, 2024. https://doi.org/10.1029/2024EA003836
[2] Ubelmann et al, 2021. https://doi.org/10.1029/2020JC016560

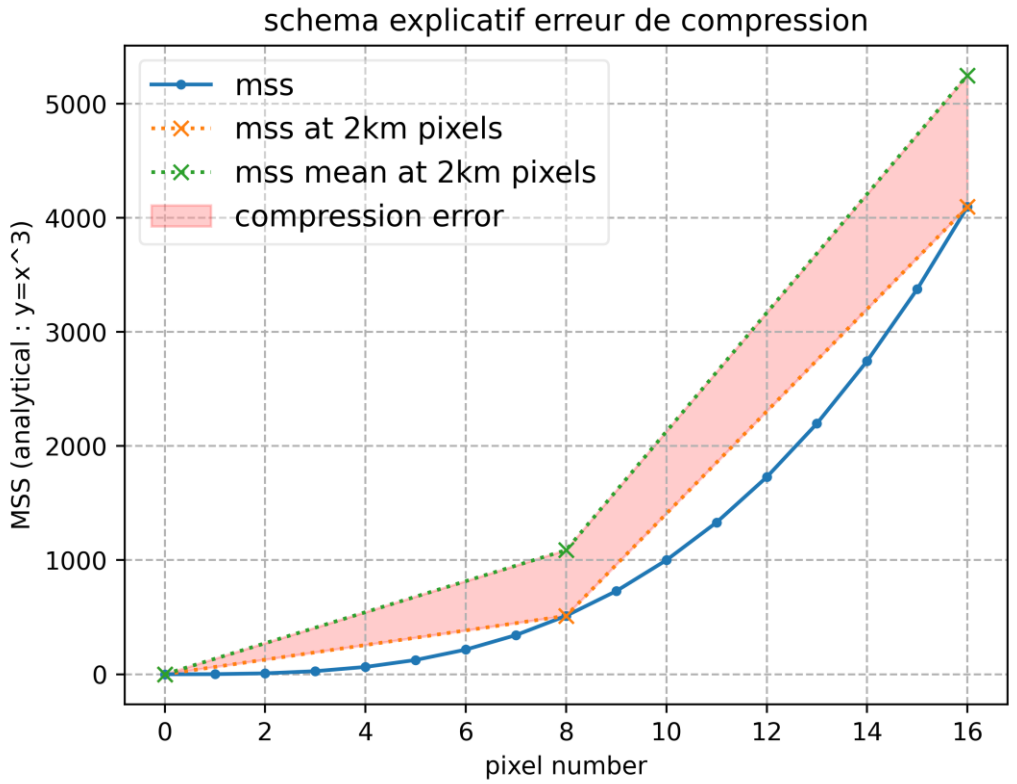
KaRIn 2km MSS compression correction

Induced by discrepancy between L2 2km compression processing and MSS content & interpolation on KaRIn 2km positions:

KaRIn SSH field 2km compressed = "compressed" SSHA + "compressed" MSS

- Discrepancy visible in area of high curvature of the MSS
- MSS resolving equivalent 2km compressed signal should be used when combining with 2km KaRIn SSH
- MSS resolving equivalent 250m signal should be used when combining with 250m KaRIn SSH

2km SSH compression processing : weighted mean of 250m SSH in 2x2km boxes

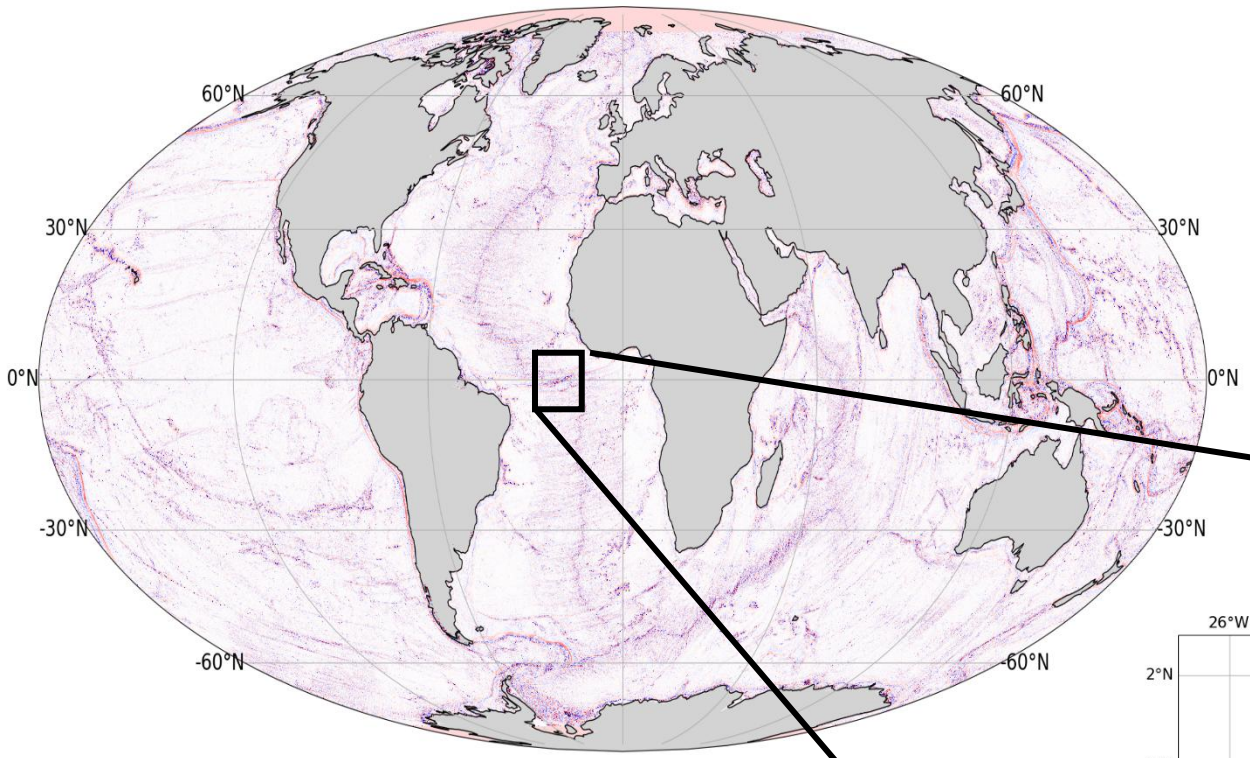


Use a unique MSS solution expected to resolves the full geodetic signal :

MSS compression correction $_{\text{for Karin 2km}}$ = MSS full resolution – Compressed MSS $_{\text{for Karin 2km}}$

MSS compression correction $_{\text{for nadir 1Hz}}$ = MSS full resolution – Compressed MSS $_{\text{for nadir 1Hz}}$

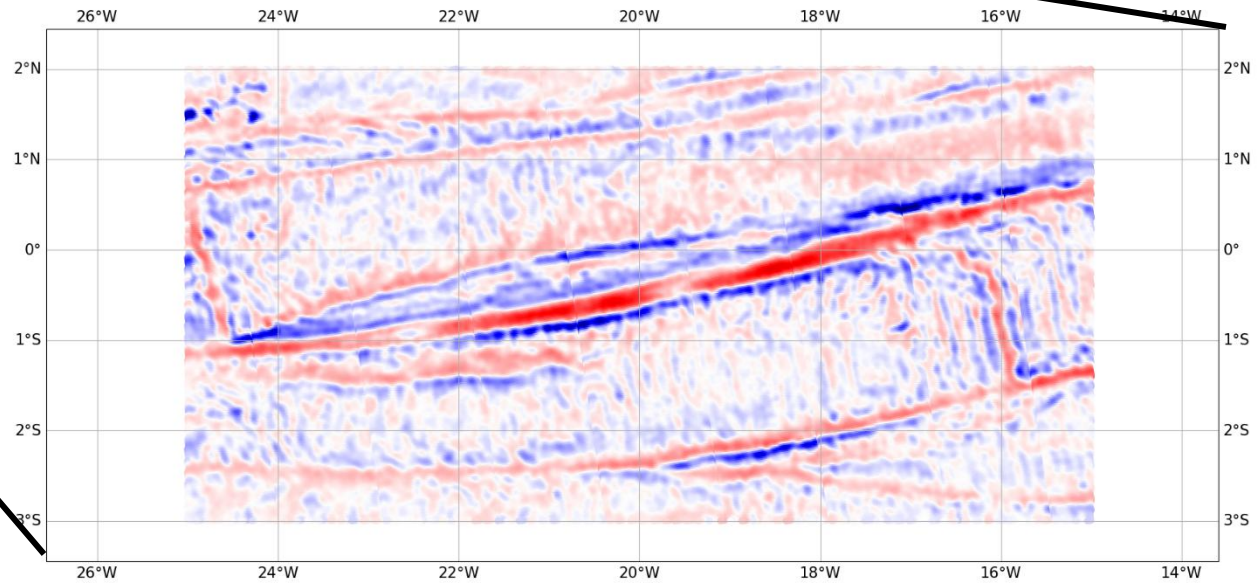
KaRIn 2km MSS compression correction



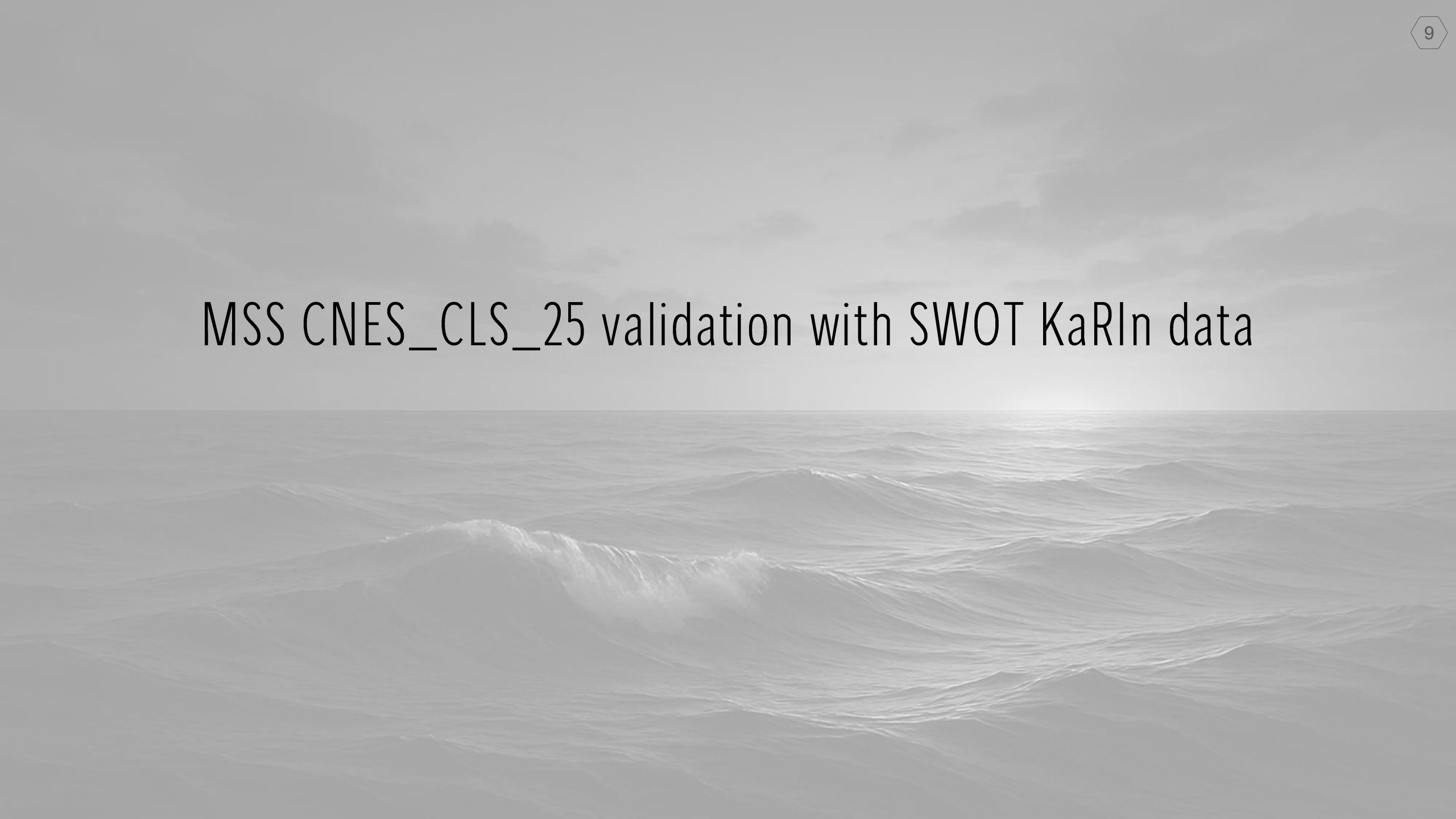
MSS compression correction

➔ Up to 1 cm for KaRin 2km;

➔ up to 4 cm for 1Hz nadir measurement



MSS CNES_CLS_25 validation with SWOT KaRIn data

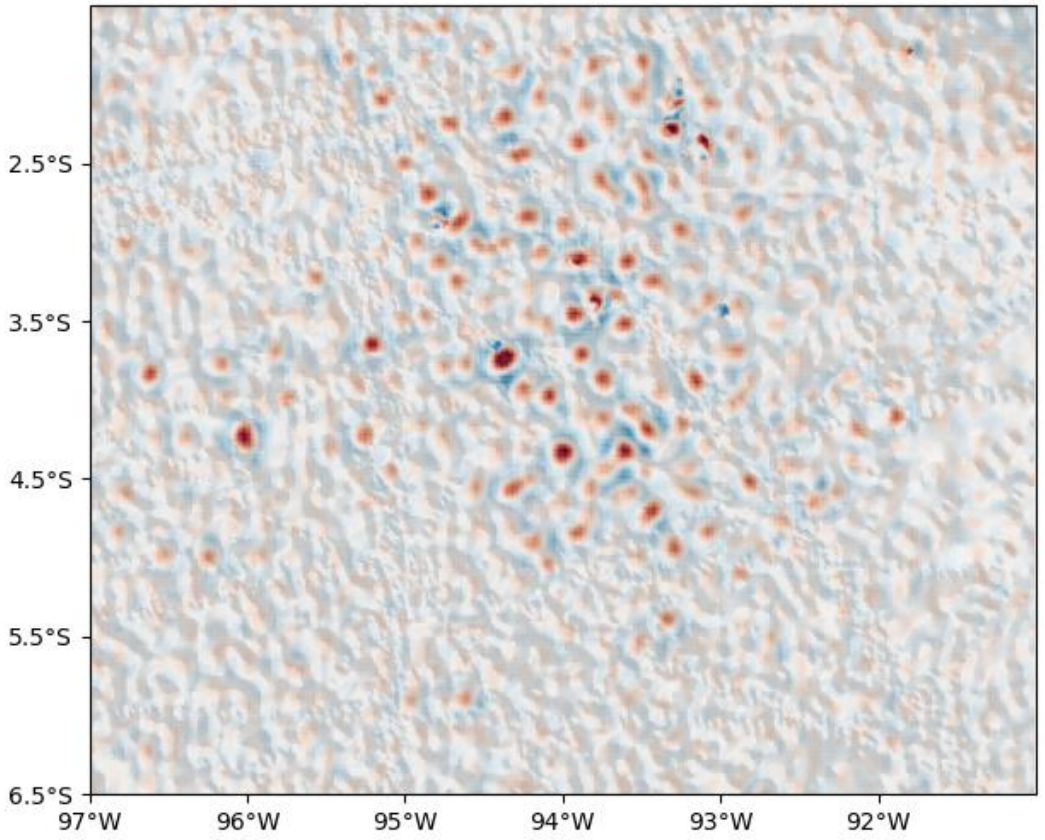


New seamounts

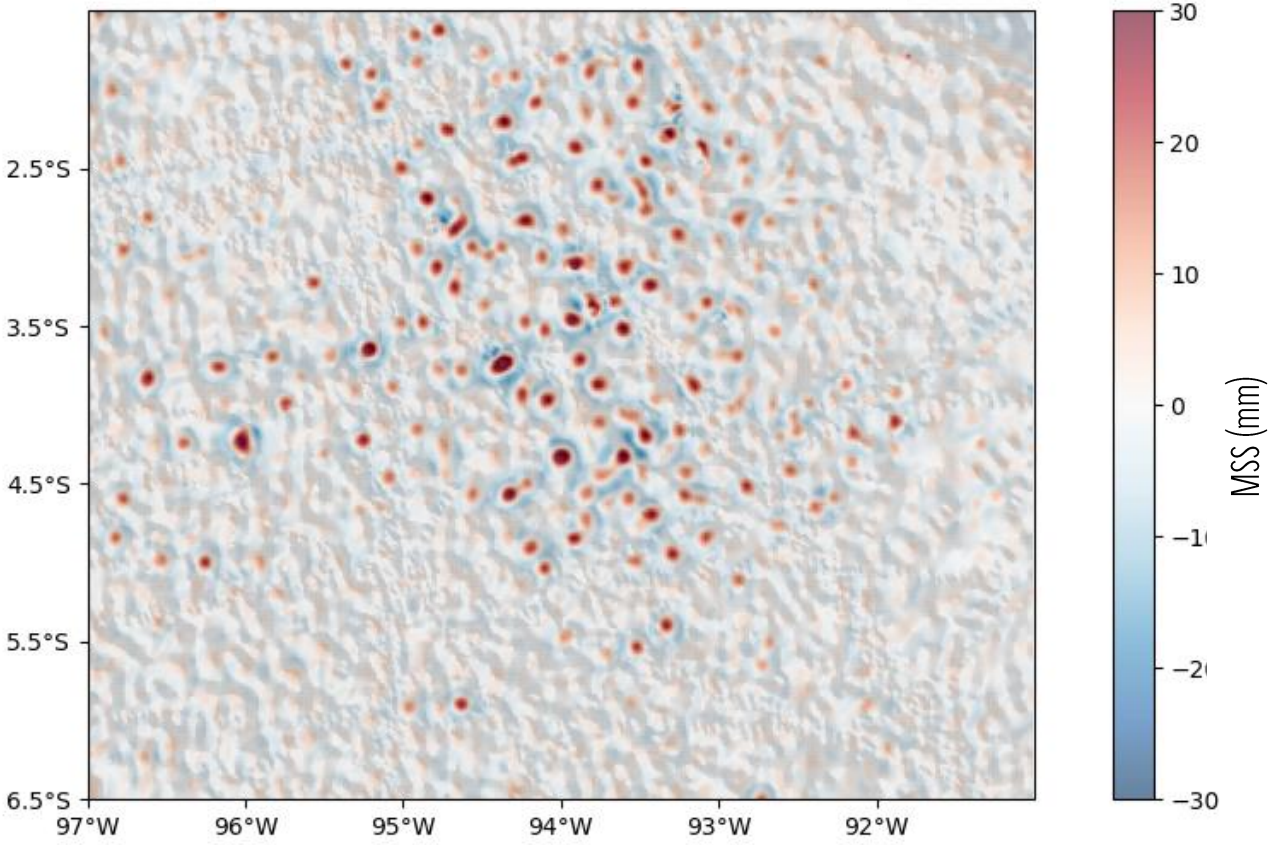
Visualisation of the short wavelengths (<20km) of the MSS

Seamounts improved in quantity and intensity in CNES_CLS_25.

MSS H23



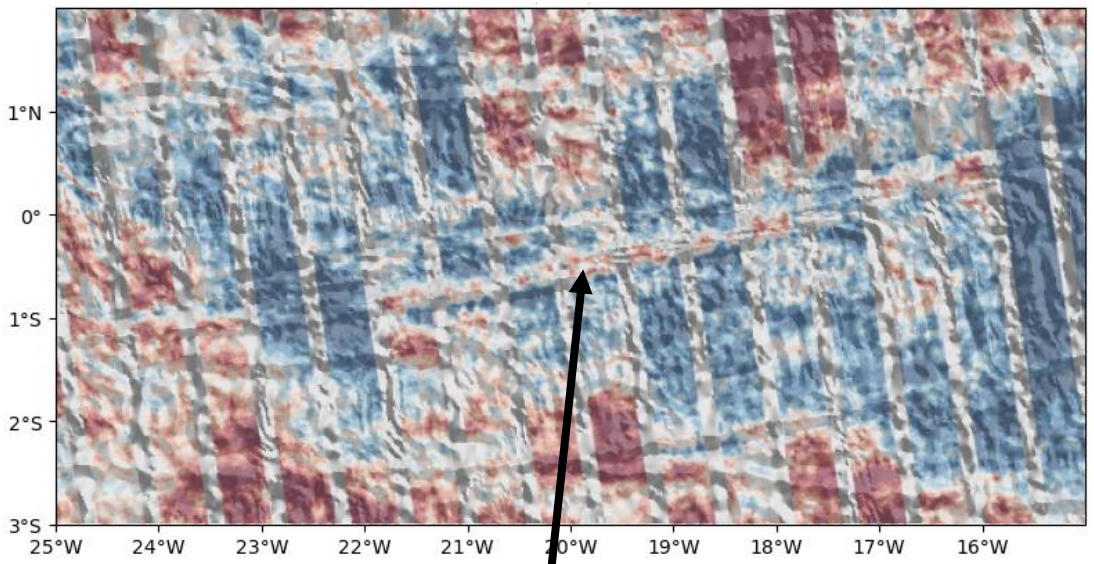
MSS CNES_CLS_25



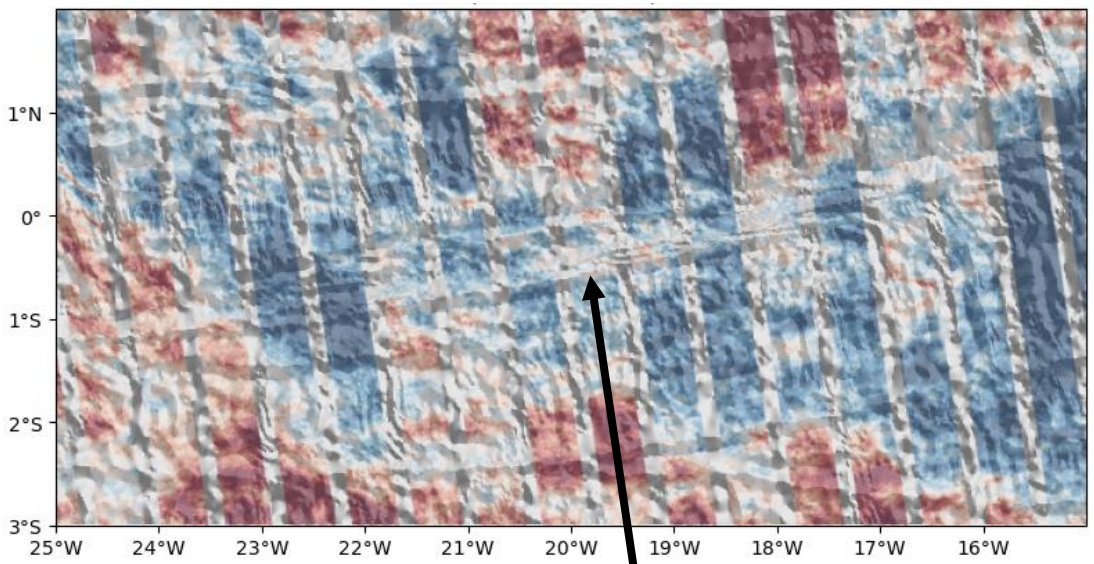
Geodesic signatures in the SWOT KaRIn SSHA removed

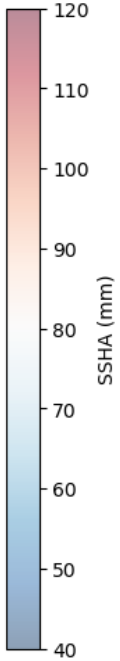
Visualisation of KaRIn SSHA superimposed with bathymetric gradients

SSHA using MSS H23



SSHA using MSS CNES_CLS_25





Geodesic structure signature in the KaRIn SSHA

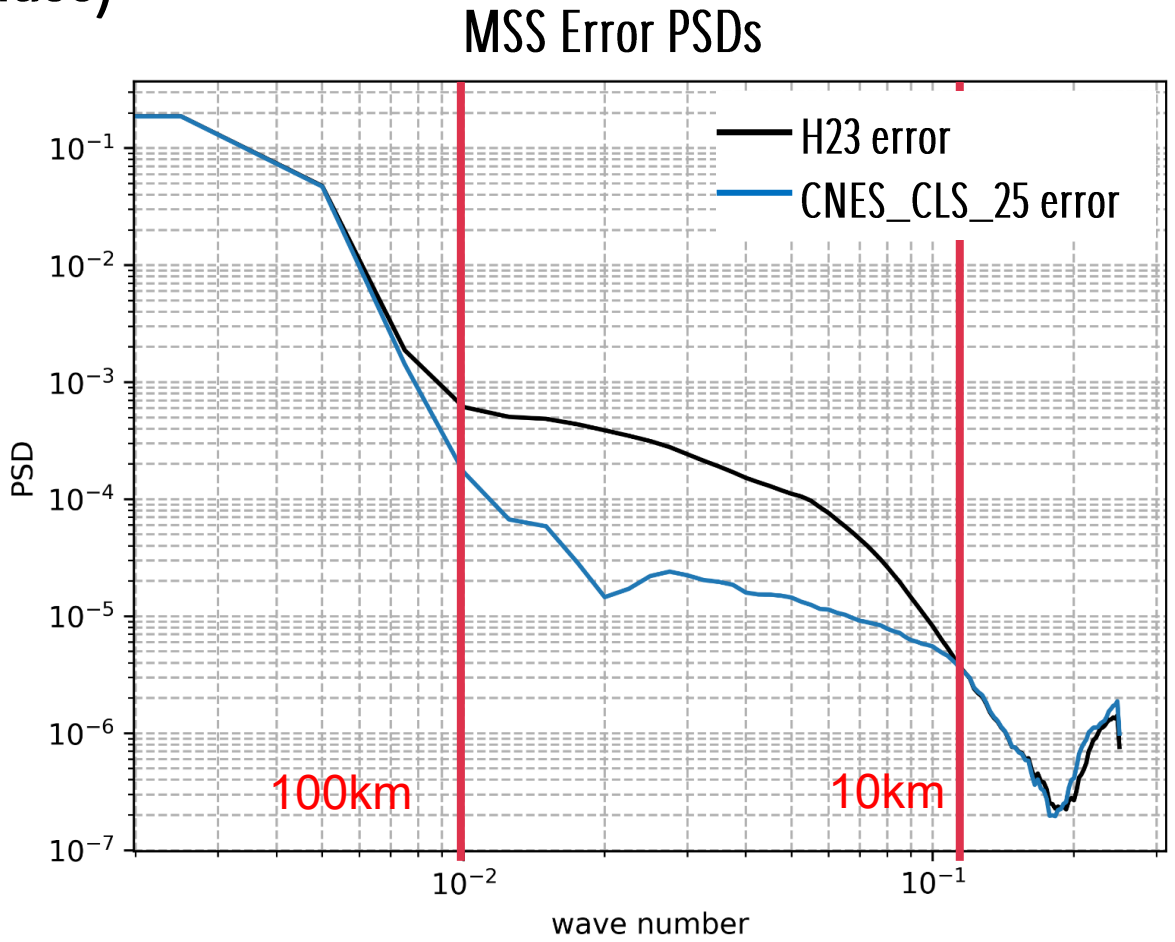
Strongly reduced geodesic structure signature in the KaRIn SSHA

Zone: Mid Atlantic transforming rift

MSS error reduction (data SWOT KaRIn calval phase)

CNES_CLS_25 error between 10 & 100km: 2,7% of SSHA variance*;

- Reduced by 81% vs H23 errors
- Ocean variability commission errors ≈75% of mss error
- Imperfect content at WL <10km : residual H23 MSS errors and no geodetic signal



MSS	MSS error PSD in cm² & % of SSHA PSD (integration on [10km; 100km])
H23	0,15 cm² ; 18% [1]
CNES_CLS_25	0,027 cm² ; 2,7%

*Data SWOT KaRIn calval L3 2km v2.0.1, all cycles used, Δ_{cycle}=66, pixels 6 to 28 and 40 to 62, MSS error methodology from [2]

[1] Laloue et al, 2024. https://doi.org/10.1029/2024EA003836
[2] Dibarboure et Pujol, 2019. https://doi.org/10.1016/j.asr.2019.06.018

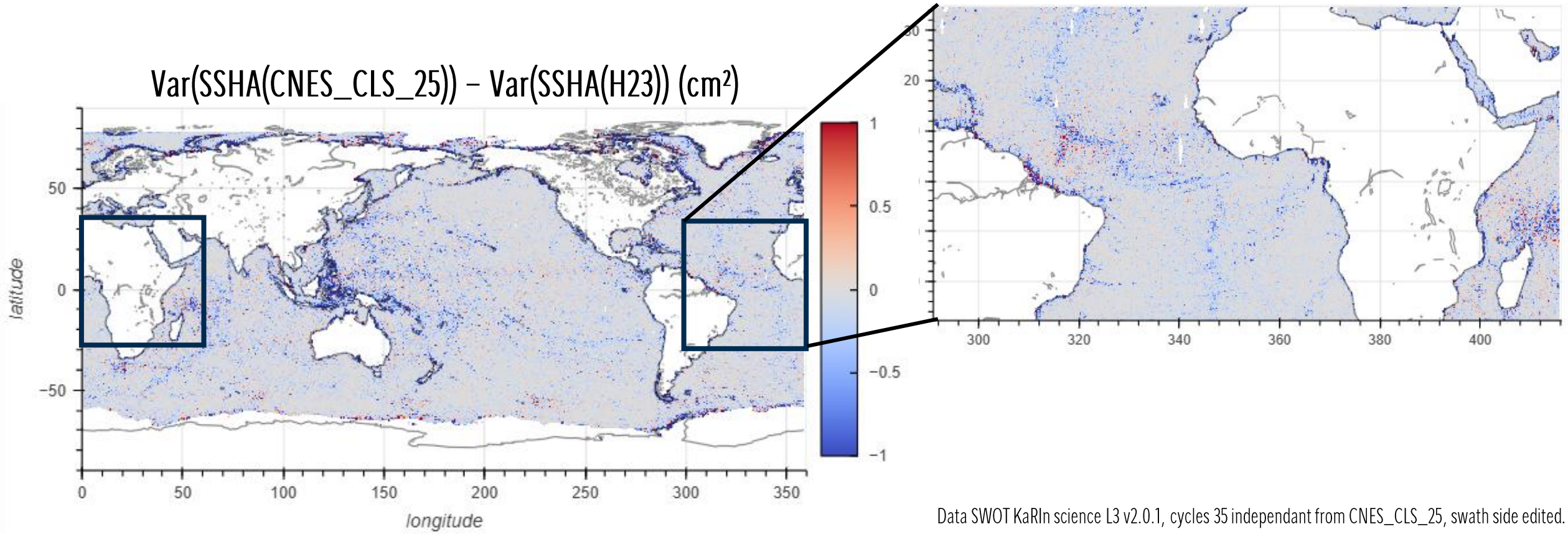
SSHA SWOT KaRIn science variance reduction

CNES_CLS_25 error reduction leads to SSHA variability reduction:

- Mainly visible along geodetic structures
- Mean reduction at λ in [10, 100km]: -11%
- Maximal reduction near λ=20km: -20%

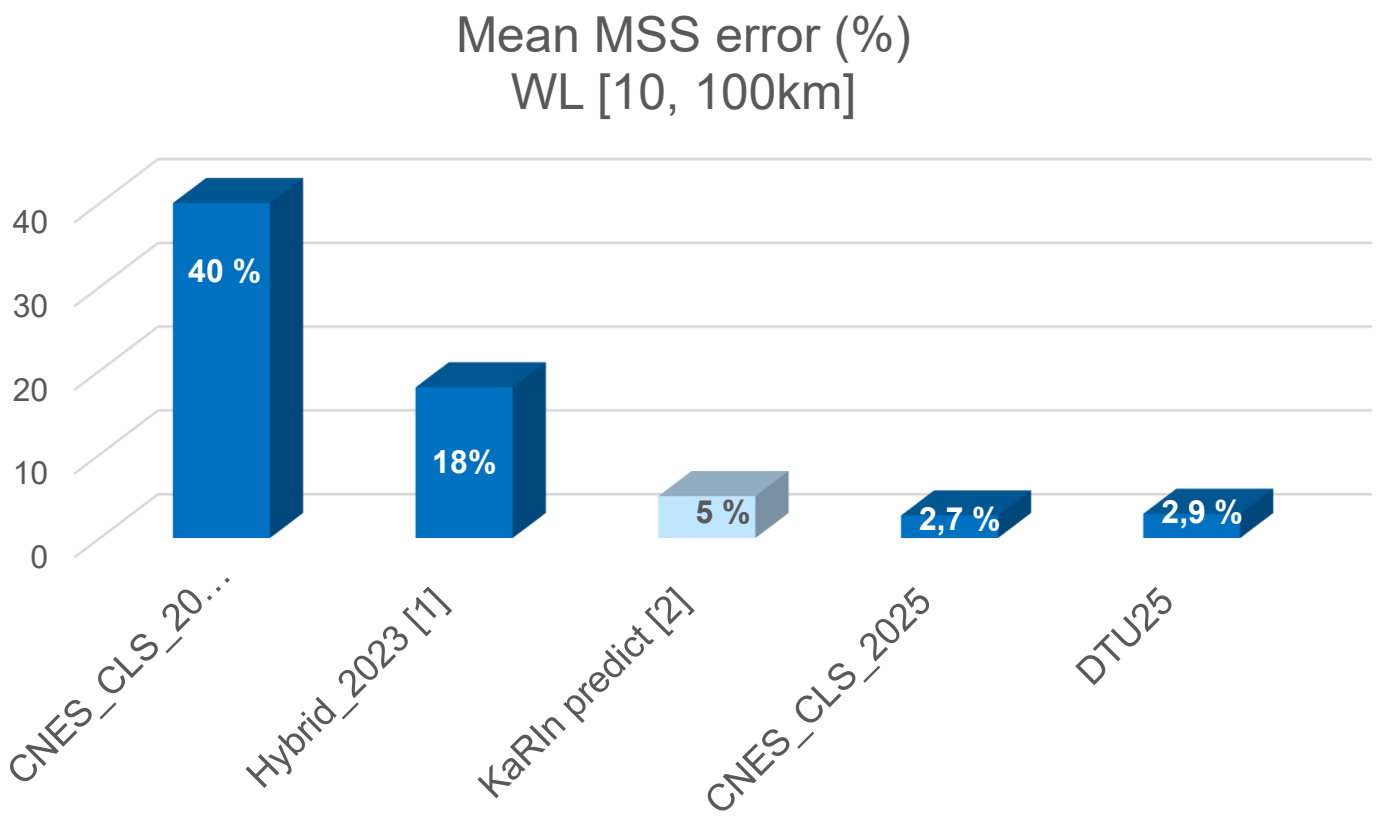
Small spots of SSHA variance increase : signature of commission errors (e.g. internal tides)

Var(SSHA(CNES_CLS_25)) – Var(SSHA(H23)) (cm²)



Data SWOT KaRIn science L3 v2.0.1, cycles 35 independant from CNES_CLS_25, swath side edited.

MSS error reduction



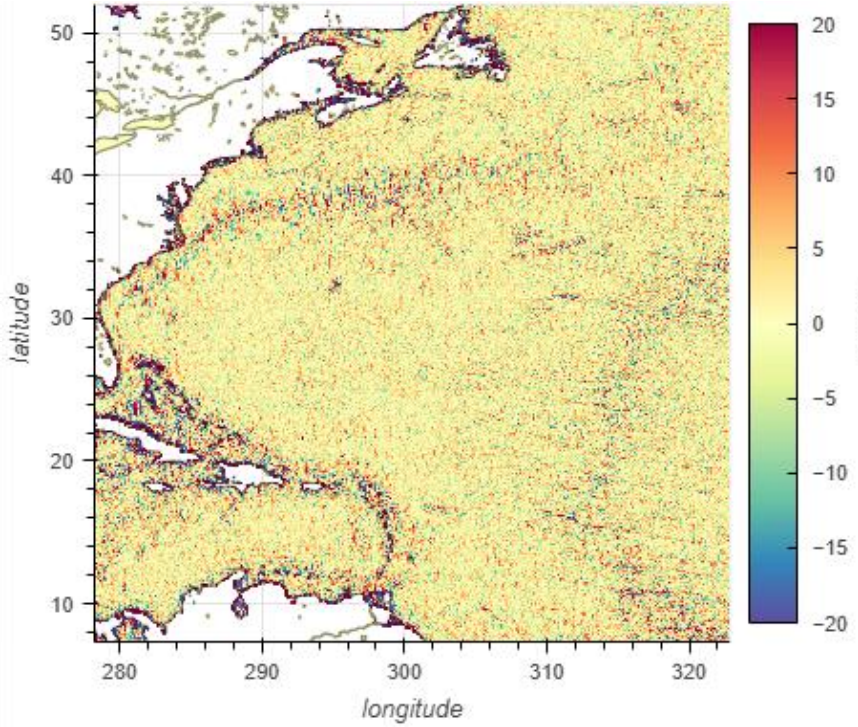
- **New generation of MSSs with relativelly low error budget** (& lower than expected)

→ The MSS is probably no longer the primary source of error for KaRIn at small scales

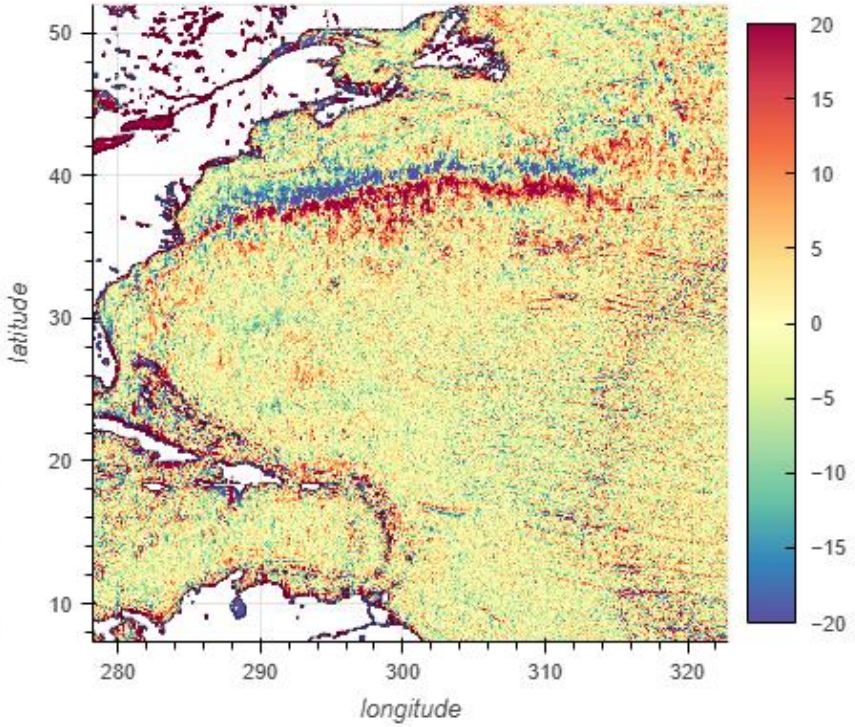
- **Nearly the same performances between CNES_CLS_25 & DTU25 MSSs.** Each one has its own strengths and weaknesses

Comparison CNES_CLS_25 & DTU25: interannual content

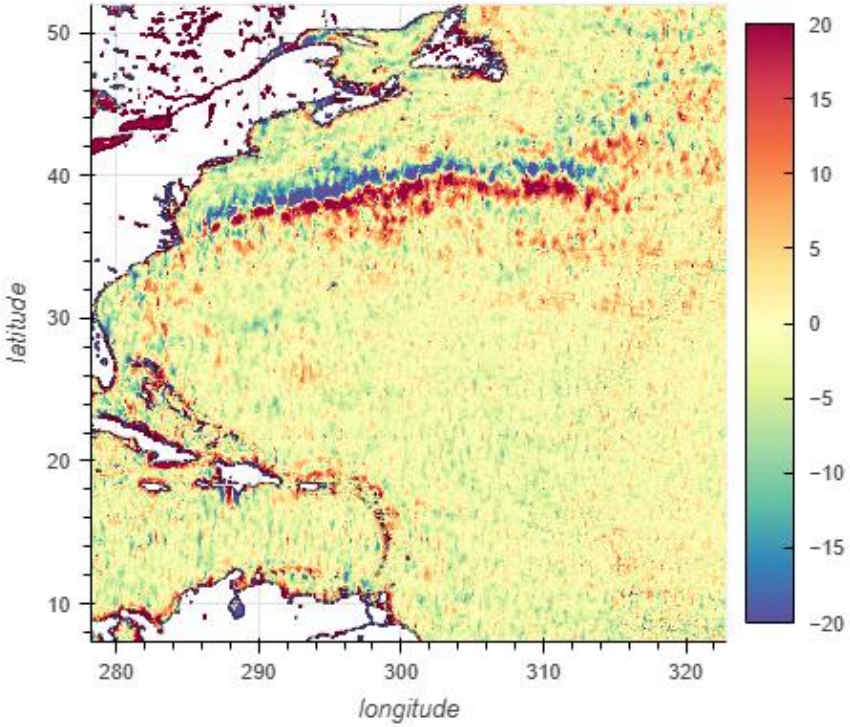
CNES_CLS_25 – H23 (mm)



DTU25 – H23 (mm)



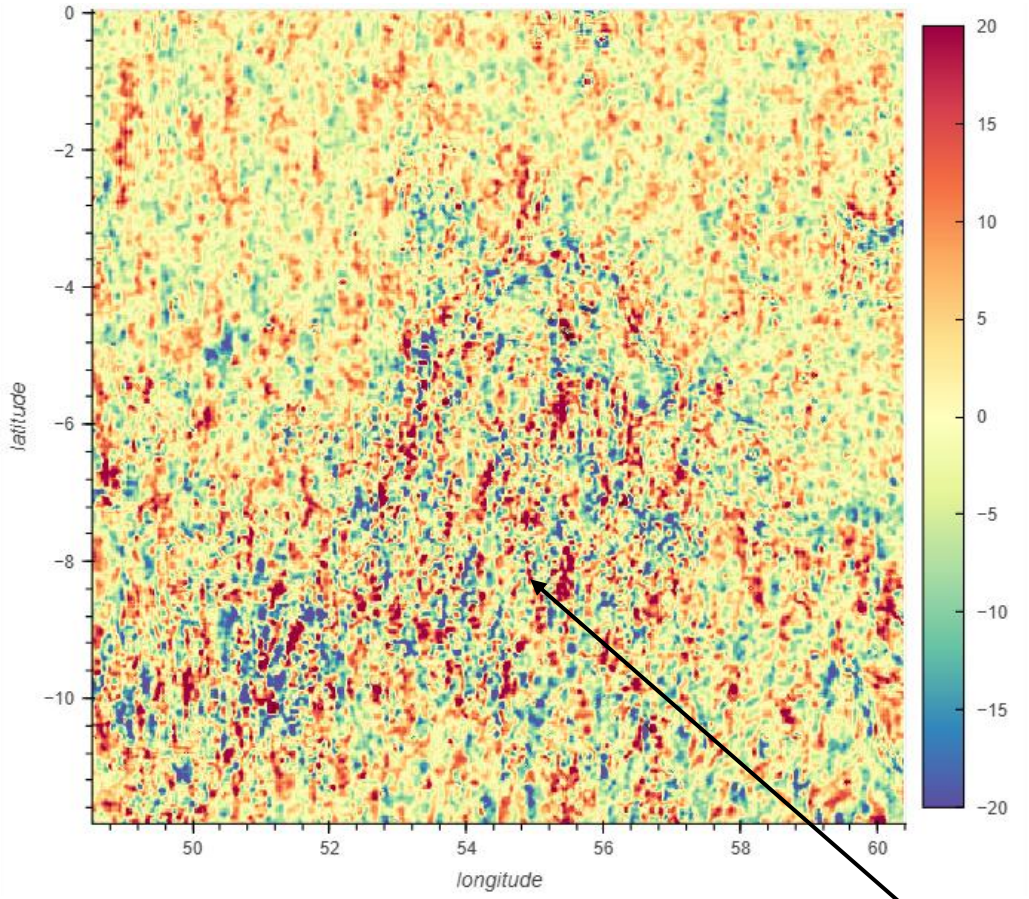
DTU25 – CNES_CLS_25 (mm)



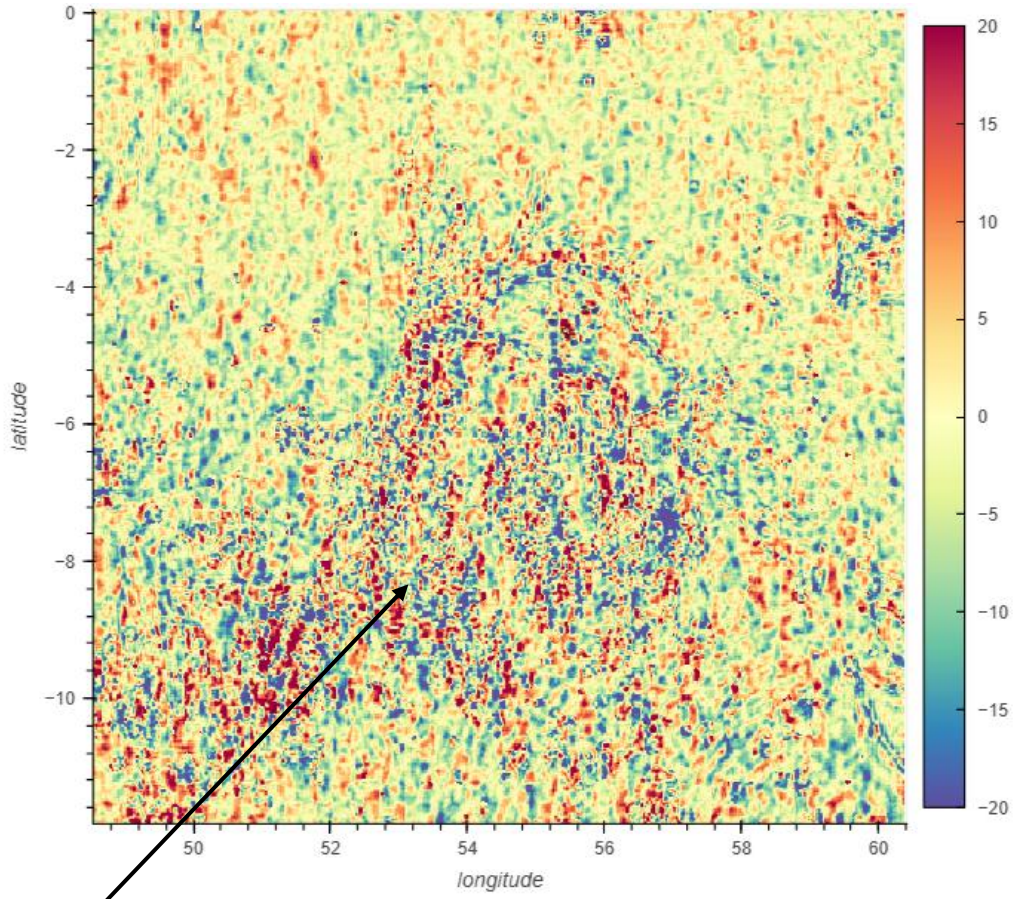
Different mean dynamic content in CNES_CLS & DTU MSSs

Comparison CNES_CLS_25 & DTU25: internal tides (commission error)

CNES_CLS_25 - H23(mm)



DTU25 – H23 (mm)



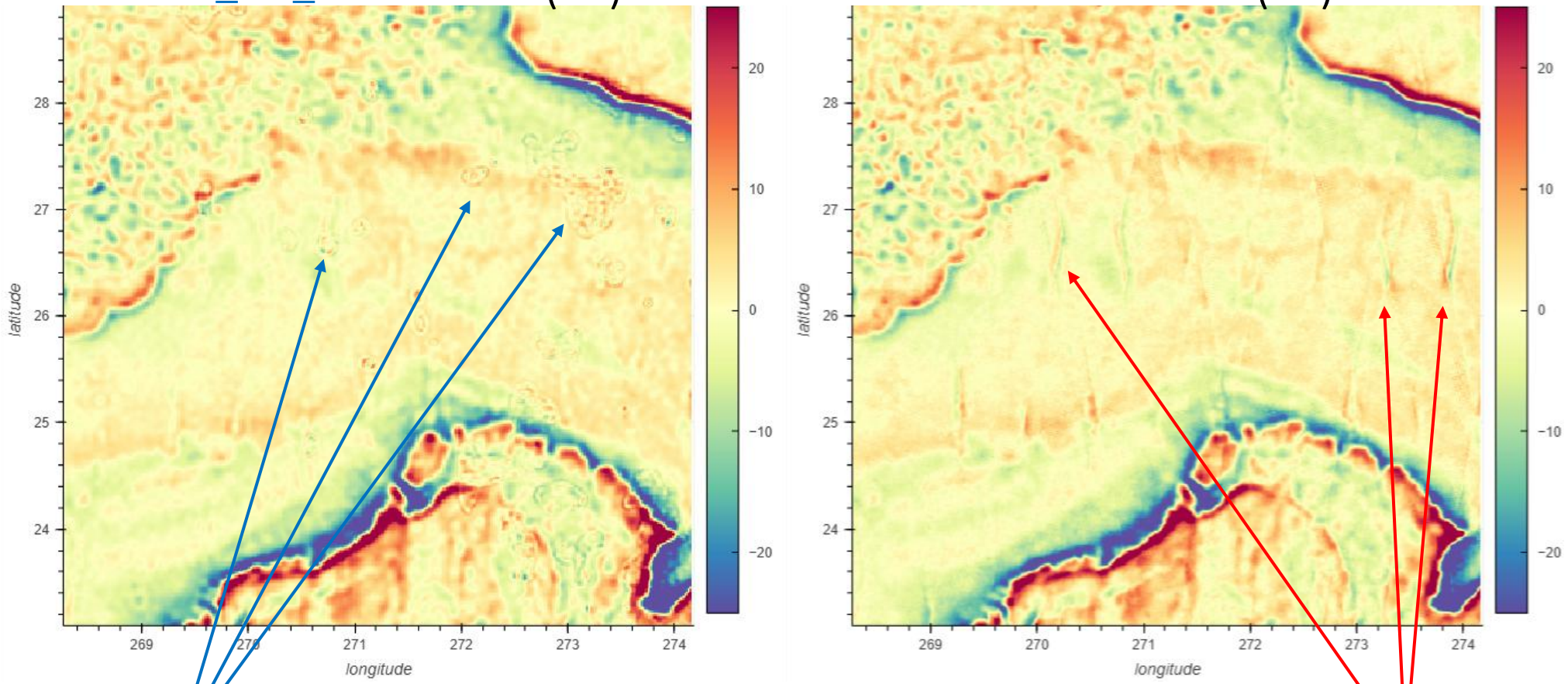
Internal tides residues

Zone: Madagascar North-East

Comparison CNES_CLS_25 & DTU25: artefacts (commission error)

CNES_CLS_25 v2 λ<20km (mm)

DTU25 λ<20km (mm)

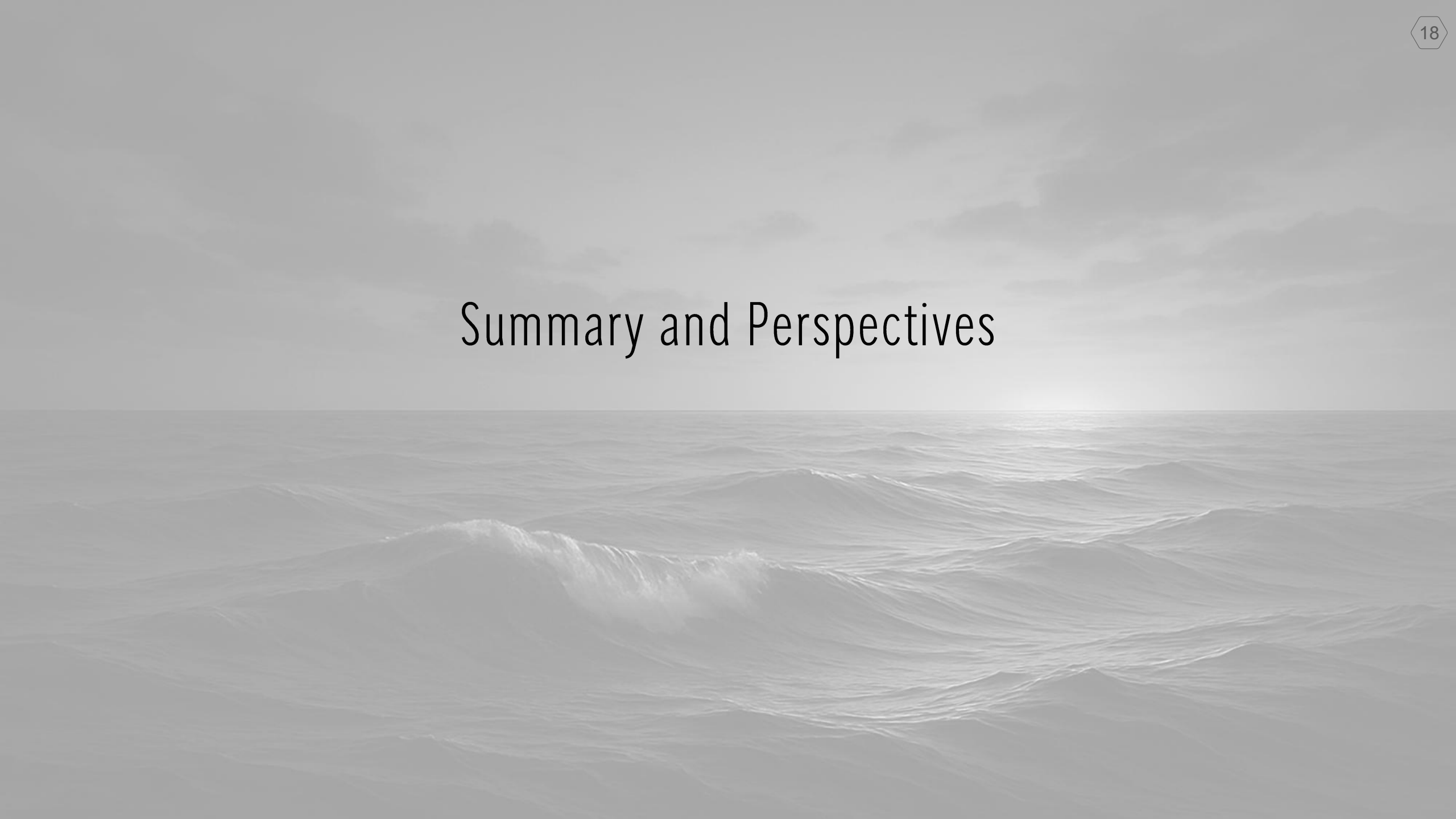


H23 Hybridation artefacts residues

KaRIn tracks artefacts

Zone: Gulf of Mexico/America

Summary and Perspectives



Summary

Conclusions:

- Significant contribution of KaRIn measurements for MSS error reduction at short WL : the error of the **new generation of MSSs is < 3% of 2km SSHA variance at WL [10, 100km] in open ocean, i.e. error reduced by ~80% vs H23 MSS**.
  - Mainly explained by reduction of the omission errors : new geodetic structures introduced or better observed in the MSS thanks to KaRIn measurements
  - Commission error still present : represents ≈75% of the MSS errors
- **CNES_CLS_25 ≈ DTU25 MSS in term of performances in open ocean (WL [10, 100km])**. Each one has its strengths and weaknesses
- **CNES_CLS_25** includes a compression correction in the processing allowing to retrieve the full MSS signal from KaRIn 2km & nadir 1hz measurements:
  - This MSS **must not be interpolated directly on 2km KaRIn or 1Hz nadir measurements, but must be « compressed »**
  - This MSS can be directly interpolated on KaRIn 250m & HR measurements

Data availability and perspectives

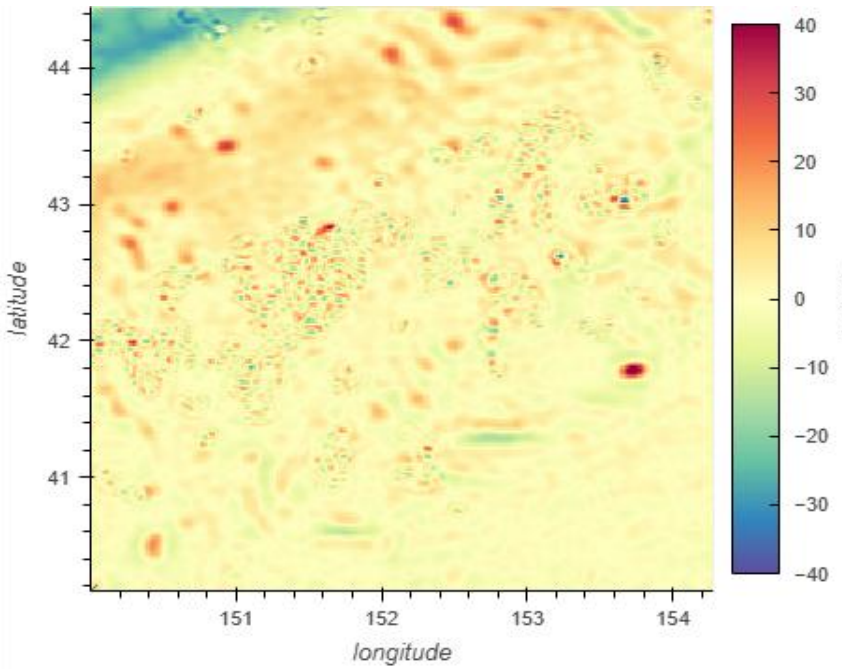
Nov 2025: CNES_CLS_25 beta version available in SWOT KaRIn L3 2km v3 products (including compression correction)

Dec 2025: MSS CNES_CLS_25 final version available on AVISO+

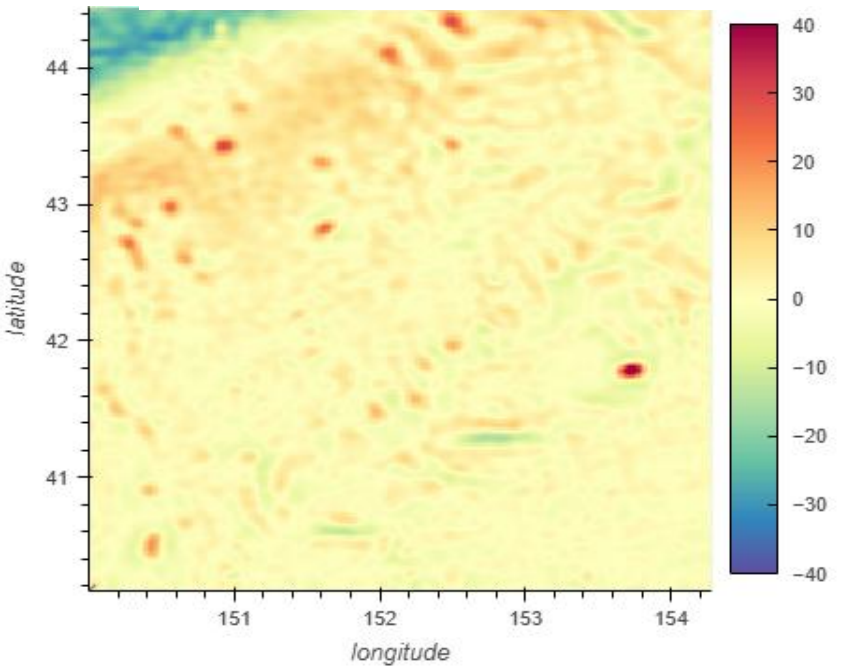
- More KaRIn cycles used (31 , as for DTU25)
- Reduced residual H23 hybridation arctefacts

Short WL (< 20km) of the MSS (units: mm)

MSS CNES_CLS_25 beta



MSS CNES_CLS_25 final




Thank you for your attention !
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datlas