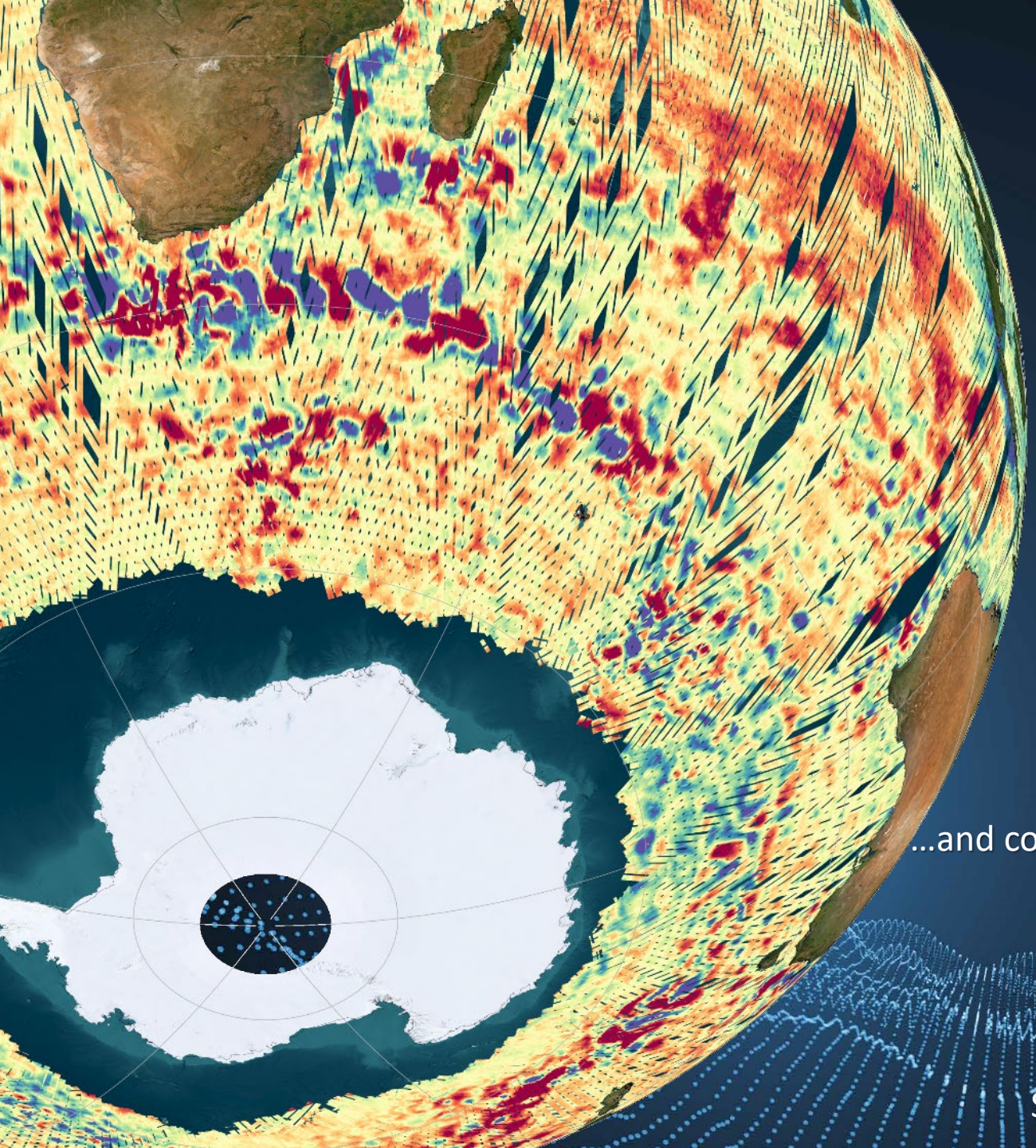


SWOT ST DESMOS PROJECT

SWOT Level-3 Overview
algorithms and examples

G.Dibarboure (CNES), C.Ubelmann (DATLAS)
Y.Faugere, A.Delepoulle, F.Briol, R.Chevrier (CLS)
C.Busche, A.Treboutte, P.Prandi (CLS)

…and insightful feedback / contributions from others
…and contributions from other ST Projects (AdAC, tides, CalVal, mss…)

SWOT Science Team Meeting, September 2023, Toulouse

The Level-3 in a nutshell

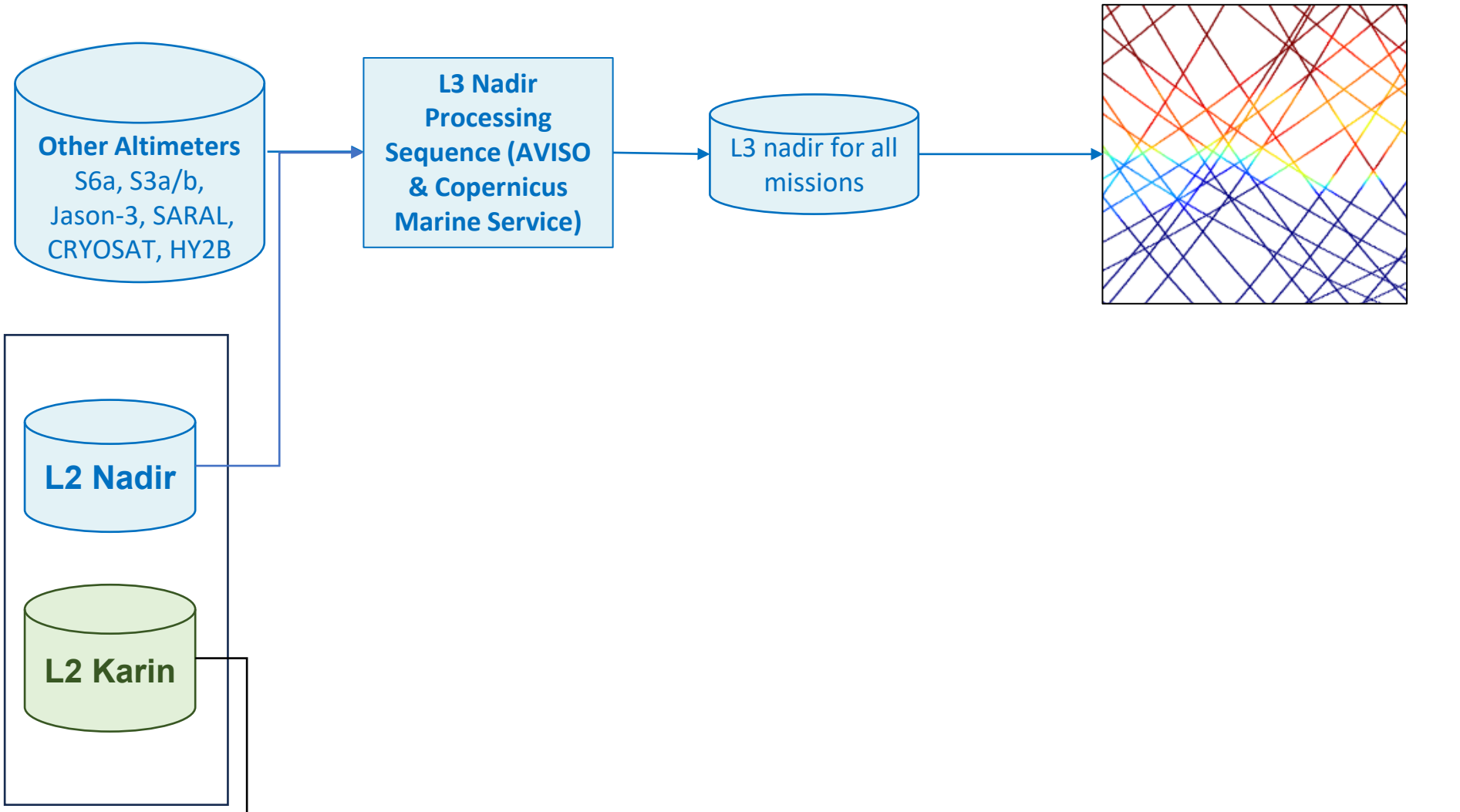
Context

- L3 is formally part of the Science Team Project DESMOS (PI: Pierre-Yves Le Traon)
- Funded by the French Early Adopter Program (i.e. PIA), not the SWOT Project
- Convergence point: Project CalVal, ST research and Operational Oceanography

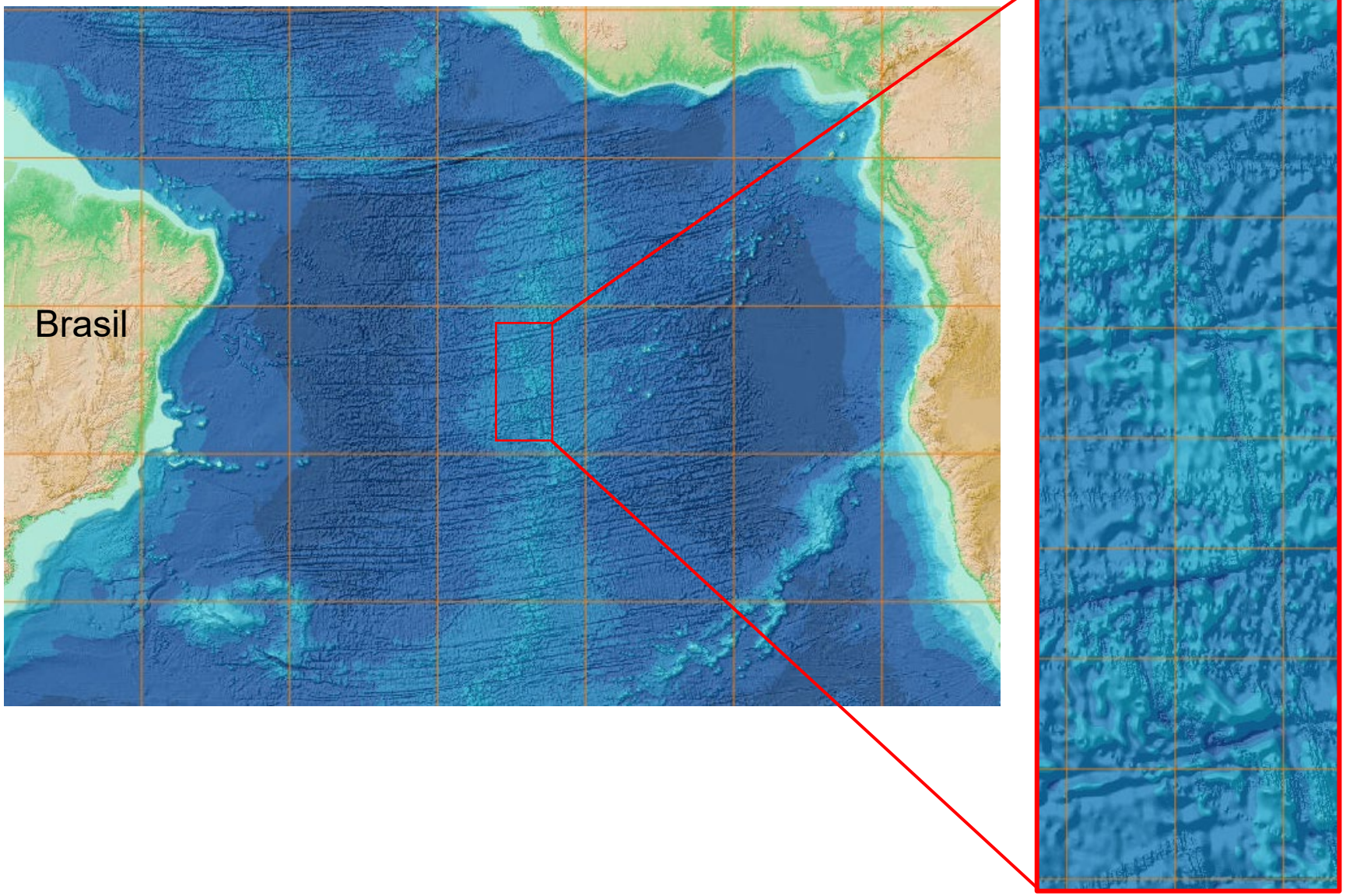
Added-value

- State of the art research-grade upgrades (incl. very recent & submitted papers)
- Multi-mission calibration (SWOT is consistent with other altimeters)
- Noise-mitigation for SSHA derivatives (experimental, AI-based)
- Pre-made sophisticated editing procedure
- KaRIN and nadir instruments blended into a single image
- Every item is optional and compatible with L2 (take what you want, ignore the rest)
- Near real time production running since last Spring

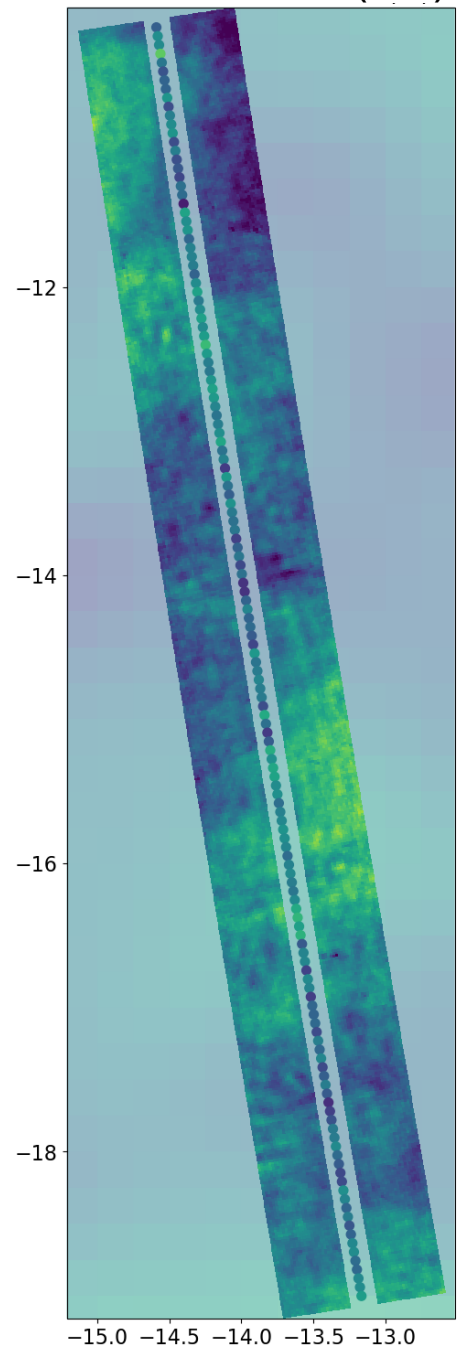
SWOT Level-3 algorithm sequence



Mid-Atlantic rift shows up as MSS error (South)

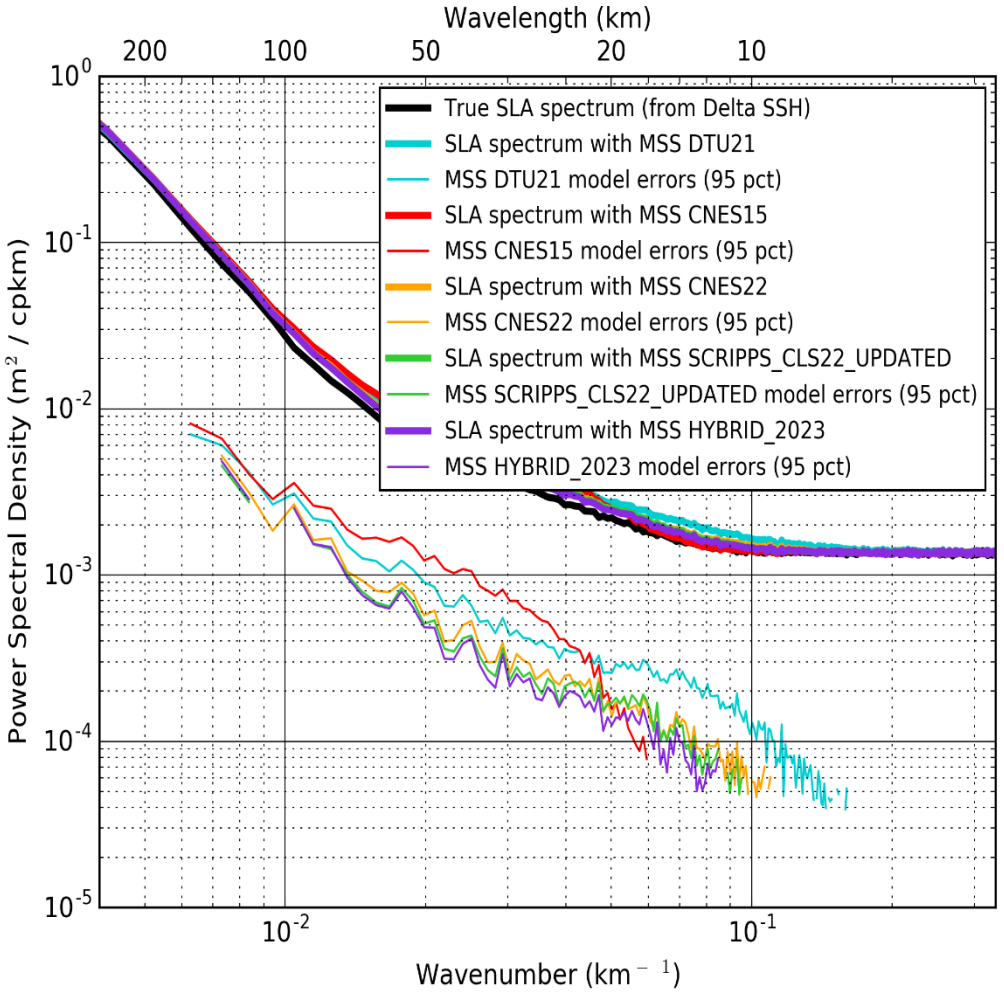


KaRIn SSHA (cm)



Why CLS/SIO/DTU hybrid $2023_{\beta 1}$ as a MSS model?

Sentinel-3A LRRMC used for validation



MSS errors from 15 to 100 km wavelengths

MSS model	Error (cm²)	Error (% of SSHA variance)
CNES&CLS v2015	0,40	34
DTU v2021	0,34	29
CNES&CLS v2022	0,23	20
SIO v2022	0,21	18
HYBRID v2023 (SIO, CNES/CLS, DTU)	0,20	17

-50%

**SSHA "noise free" variance is estimated to 1,16cm²*

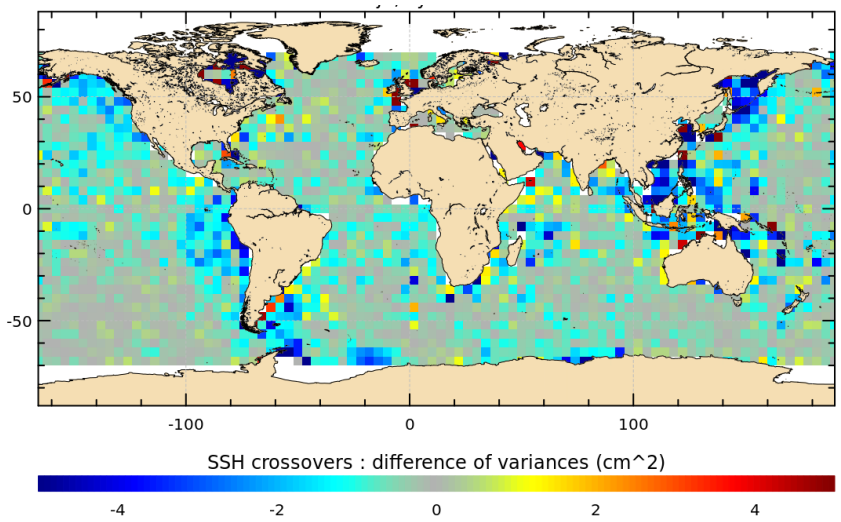
Blends the strengths of 3 modern MSS models

- CLS22 for large scale and coastal variability
- SIO22 for smaller geoid features
- DTU21 for polar regions

See Pujol et al & Schaeffer et al. presentation & poster in MSS splinter

Why FES22 as a tide model?

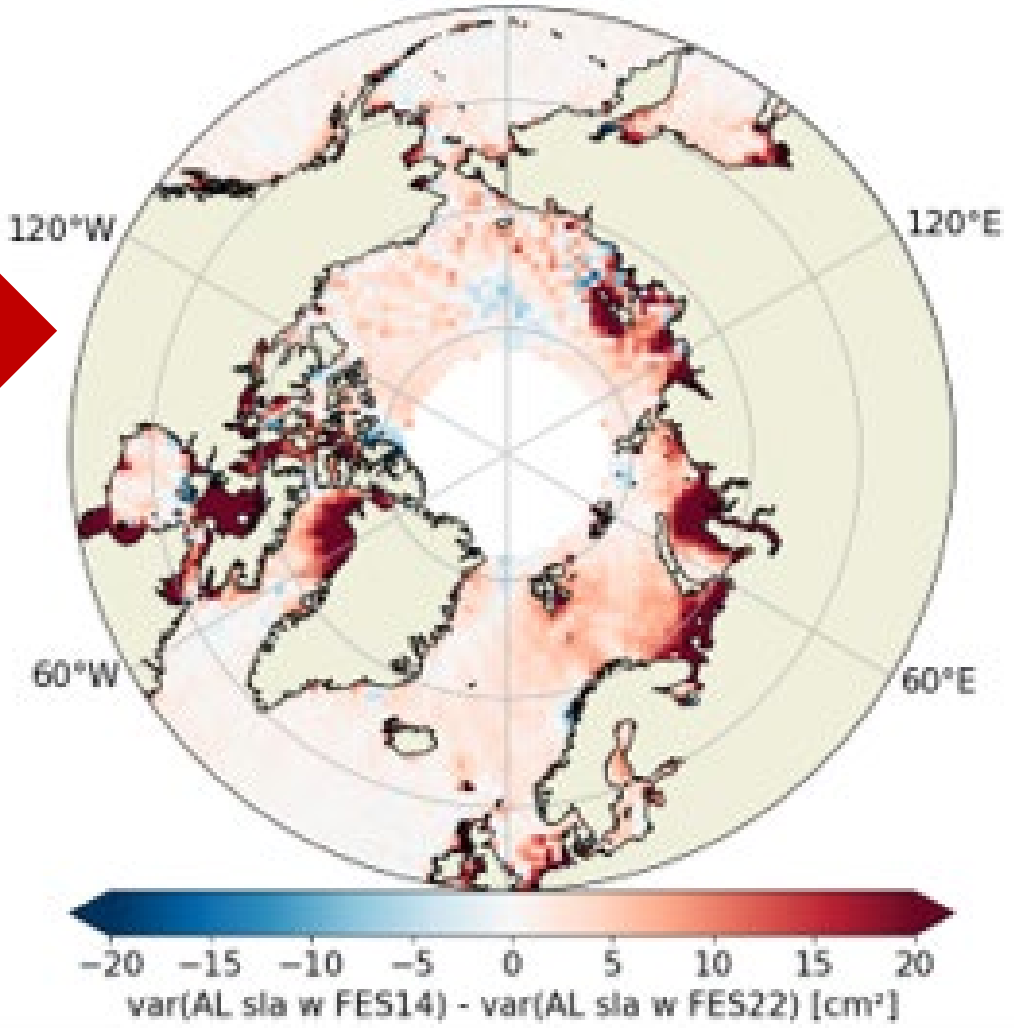
SSHA xover variance reduced from FES14B to FES 23a (measured with Sentinel-3A which is independent)

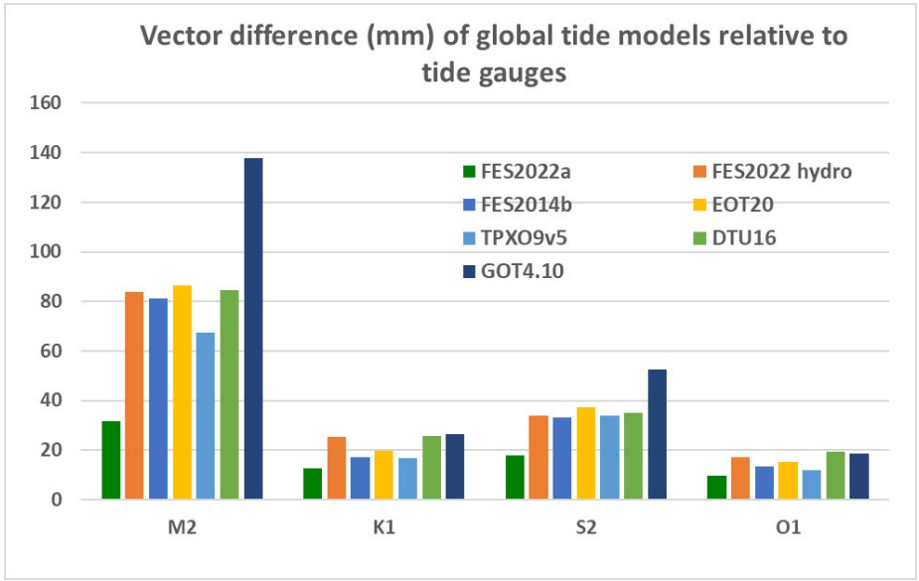


BLUE is better

RED is better

SSHA variance reduction from FES23 to FES 14a (measured with SARAL)





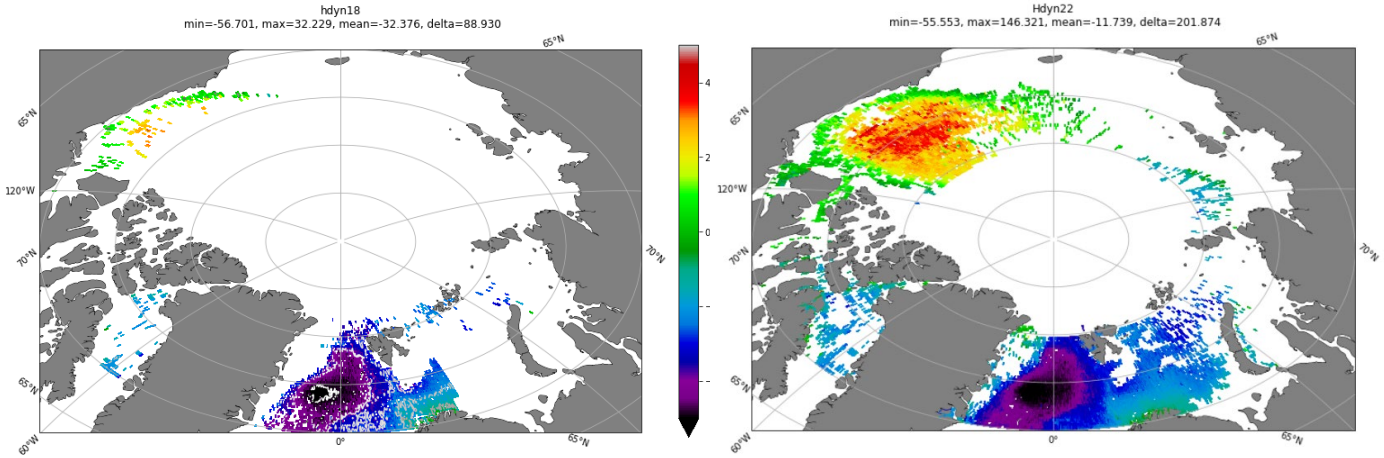
See Carrere et al (OSTST22) and Lyard et al paper (in prep)

Why CLS22 as a Mean Dynamic Topography?

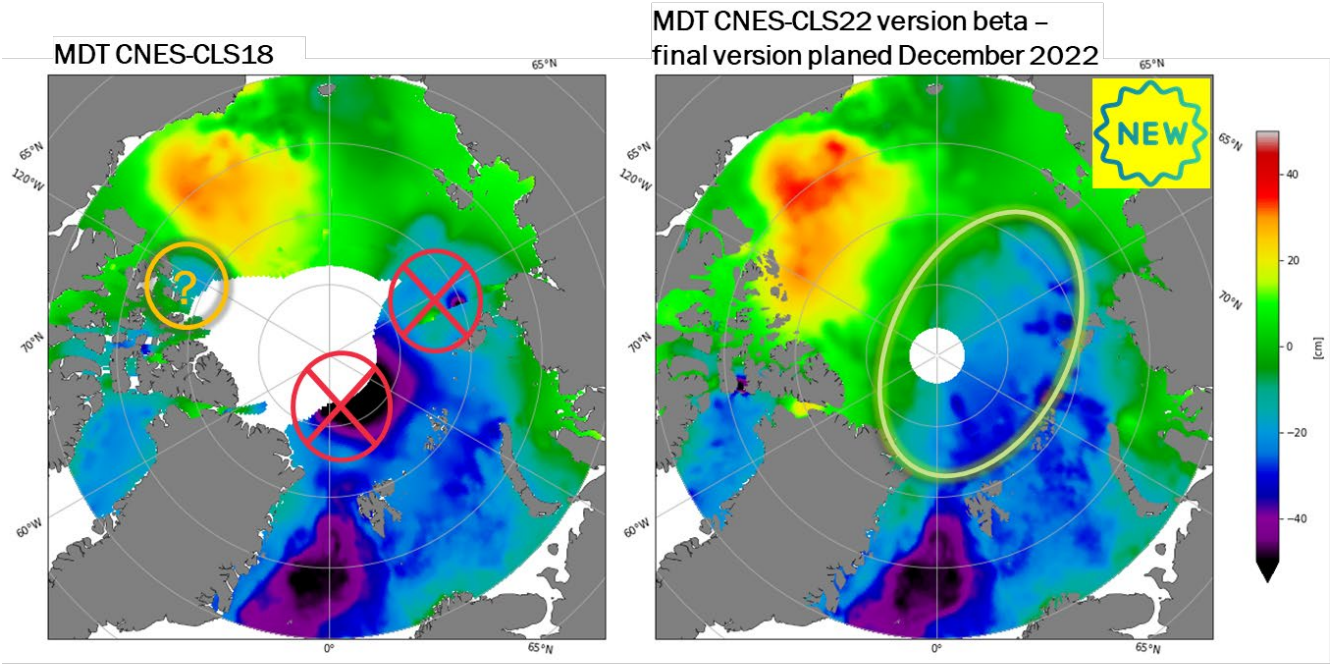
2018

2022

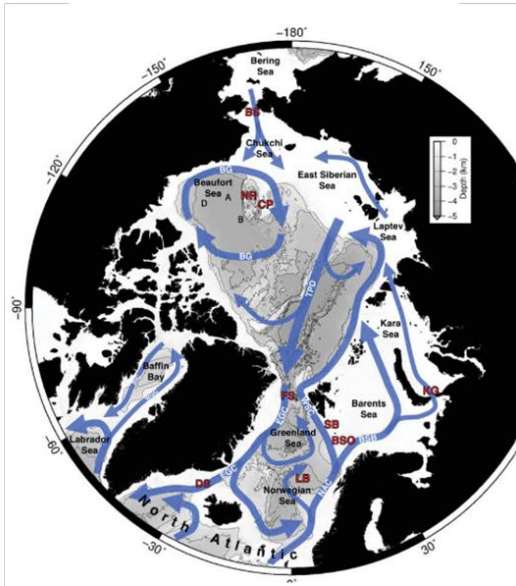
In-situ HDYN



MDT model



Arctic circulation from Armitage et al. (2017)

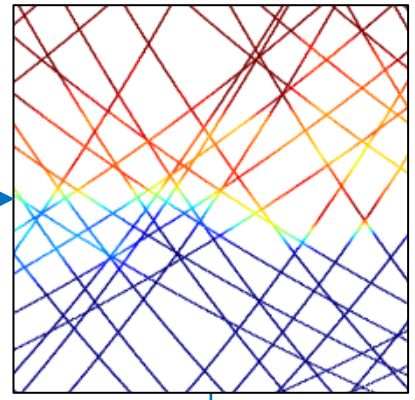


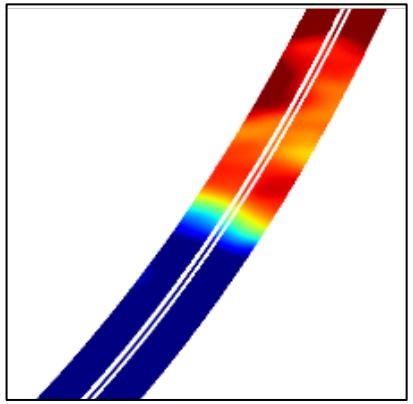
Regional improvements with v2022 model

- Much better coverage
- Known 2018 artifacts fixed
- Velocities are 10% more consistent with drifters on average (locally much more)

See Jousset et al (OSTST 2022, paper in prep)

SWOT Level-3 algorithm sequence





Other Altimeters
S6a, S3a/b, J3, Al, C2, H2b

L3 Nadir Processing Sequence (AVISO & Copernicus Marine Service)

L3 for all missions

L2 Nadir

L2 Karin

SWOT Level-2 Products

Multi-mission Calibration Layer

Noise reduction Layer

Relative Vorticity Layer

Editing Layer 1

Editing Layer 2

Geostrophic Velocities Layer

L3 Karin processing sequence

premade & ligthweight

L3 Karin basic

pick what you want

L3 Karin expert

SWOT L3 Products (nadir & karin blended)

SSB

MSS Hyb 23

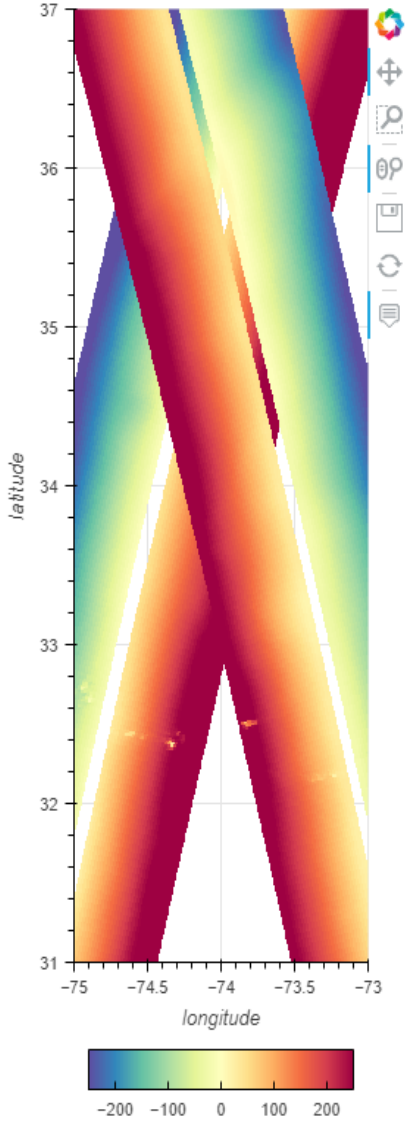
Tide FES 22

MDT CLS 22

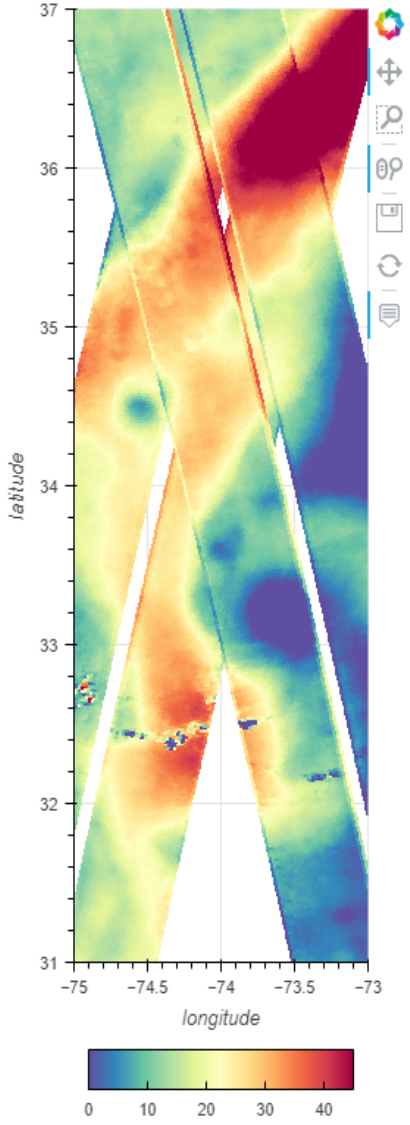
L2 Research-grade standards

End-to-end example

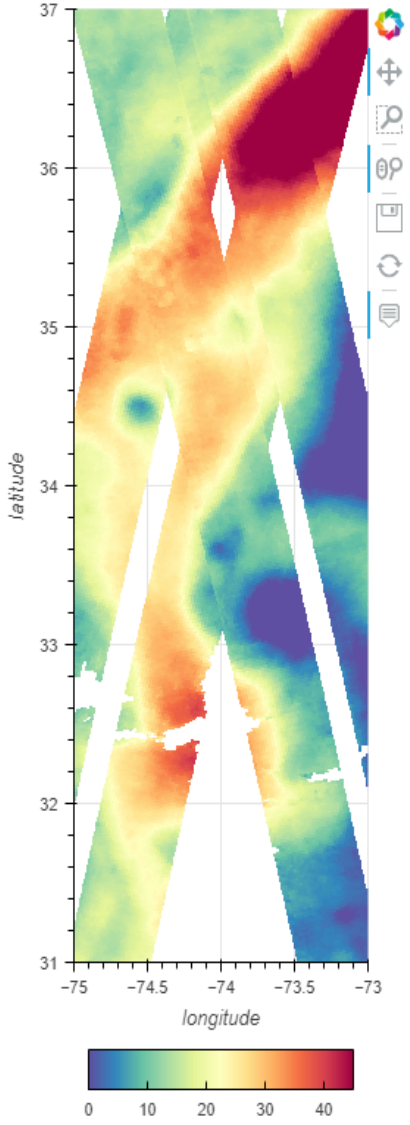
Uncalibrated L2 SSHA (cm)



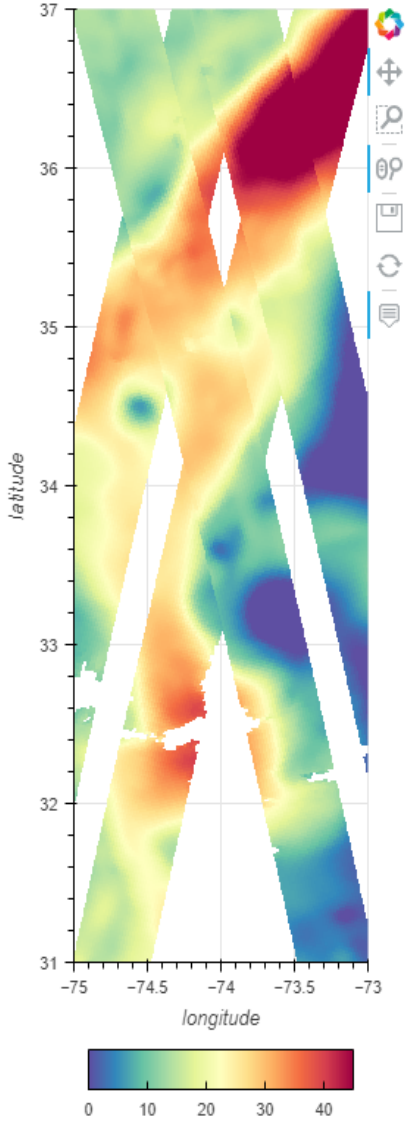
Calibrated SSHA



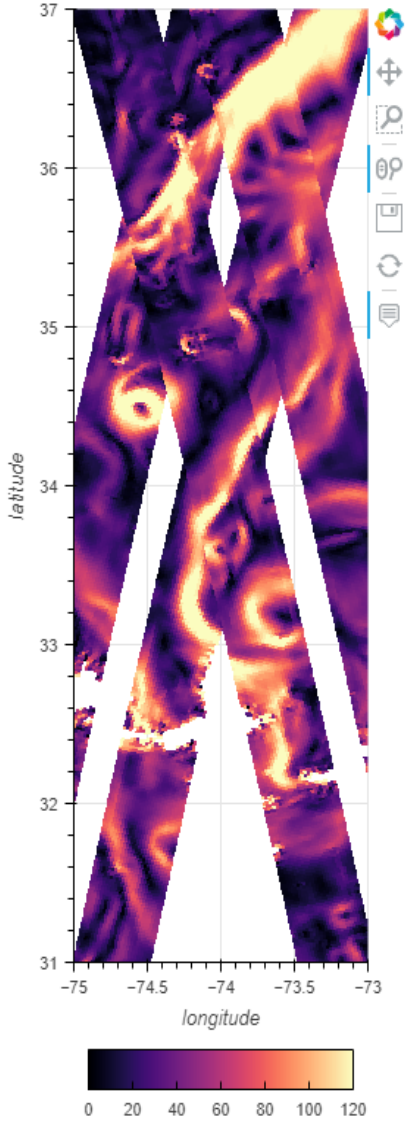
Edited SSHA



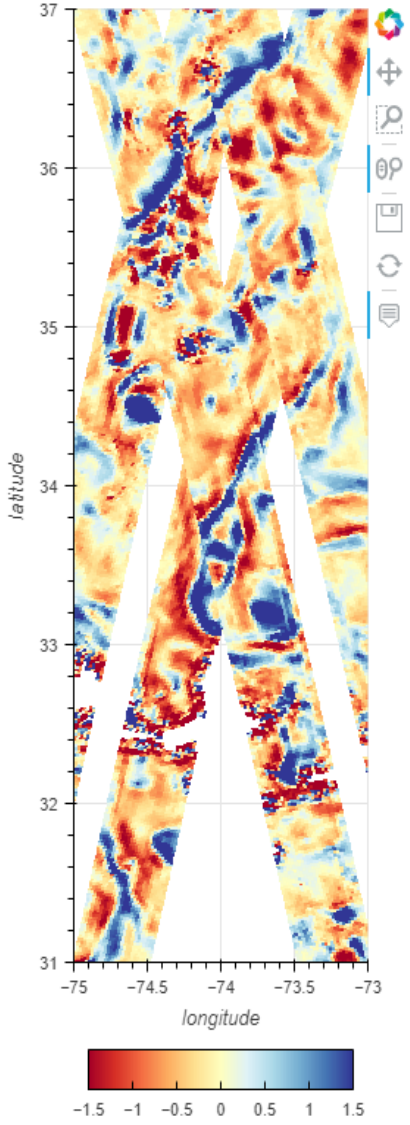
Noise-reduced SSHA



Geostrophic Velocities

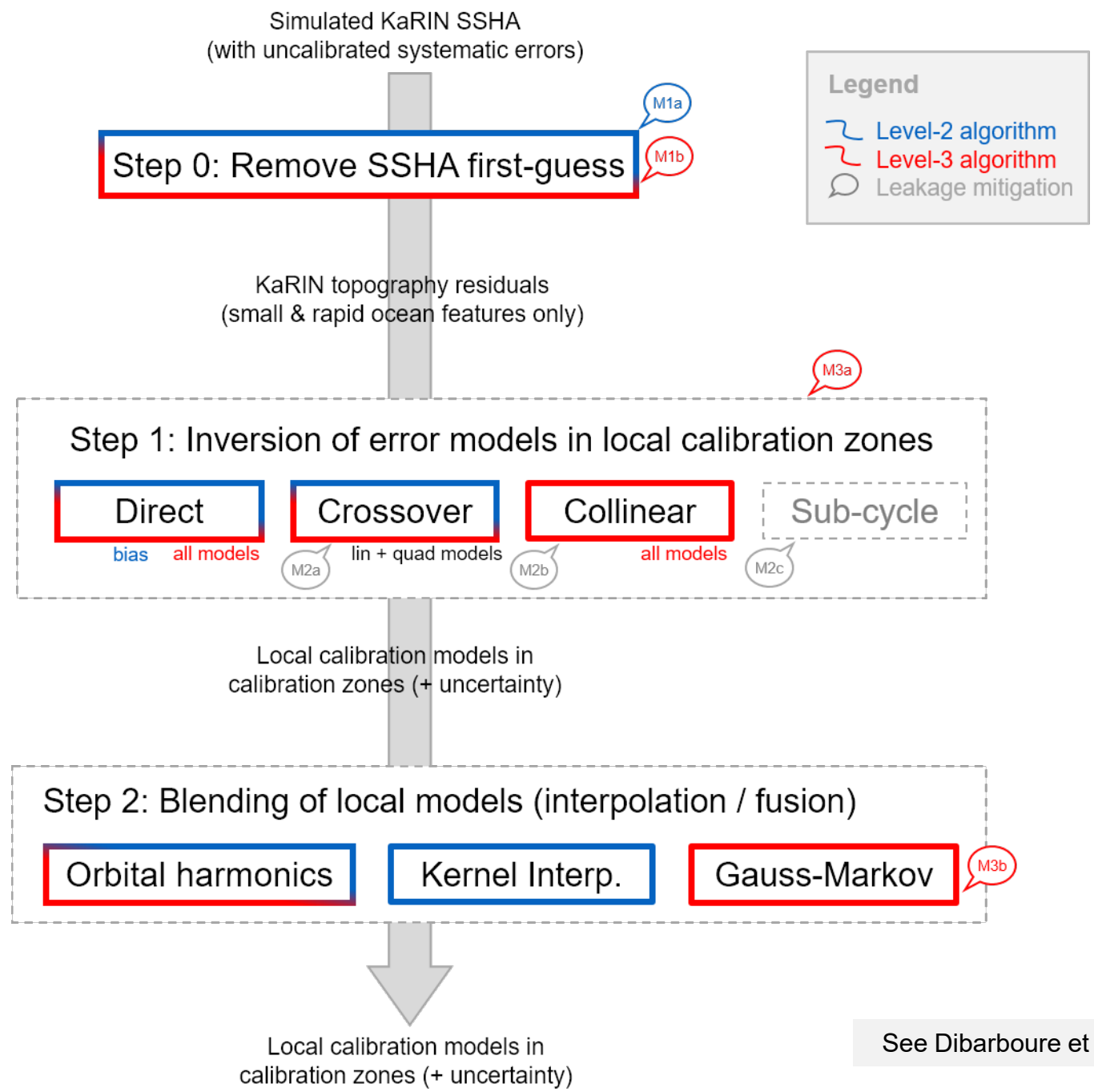


Relative Vorticity



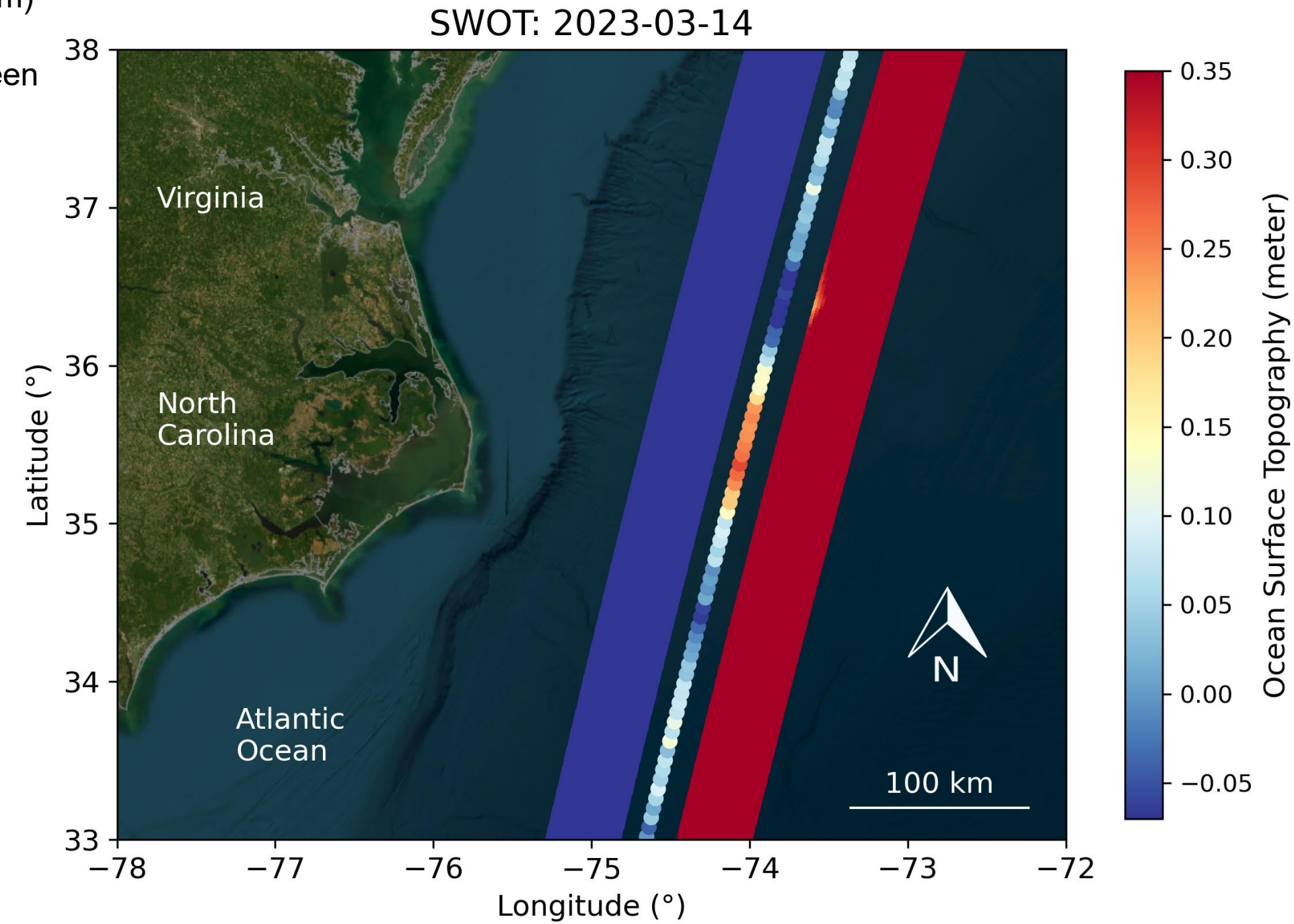
L3 data-driven calibration Layer (red items)

- Step 0 & M1b: external data from all nadir altimeters (SWOT + S6 + S3)
- Step 1: use Direct and Crossover retrieval algorithms for the 21-day orbit, and Direct + Collinear for the 1-day orbit
- Step 1: Can resolve intra-crossover variability (not just a scalar/xover)
- Step 2: use Gauss-Markov interpolator for broadband error (not a simple kernel interpolator)
- M3a & M3b: use covariance/spectra instead of least squares (measured in simulation, determined in CalVal for flight data)

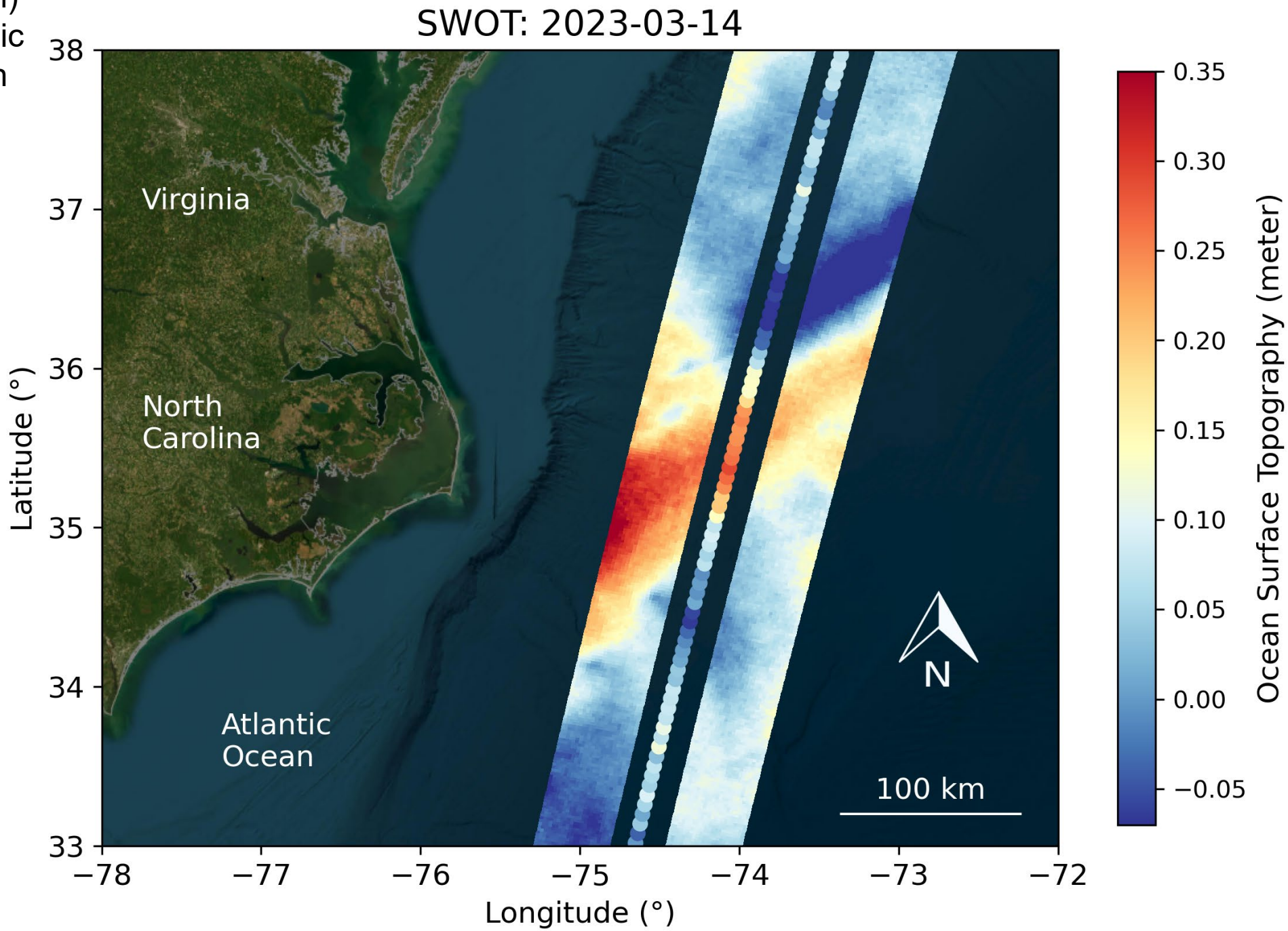


See Dibarboure et al, 2022

1st order: o(10m)
No calibration
No phase screen



3rd order: o(1cm) Static & Dynamic calibrations with phase screen



Editing Layer 2

v0.1 process

1. **Mask non-ocean data**: use of *ancillary_surface_classification_flag*

2. **Mask data with ice concentration above 30 %** : use of *ice_conc (OSI SAF)*

3. **Mask data with products quality information**
   - **combination of quality flags from** 19 bits in *ssha_karin_2_qual*
   - **threshold in KaRIn uncertainty from** *ssh_karin_uncert*

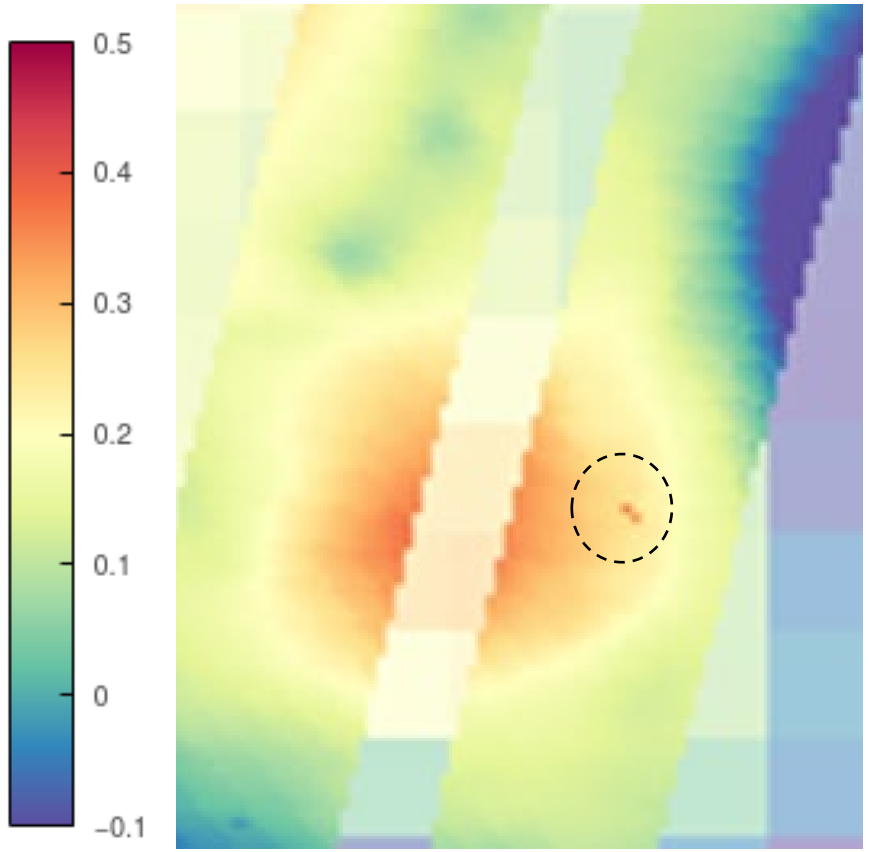
v0.2 or v1.0 additions

5. Apply Roberts filter to detect unusually sharp spikes and gradients

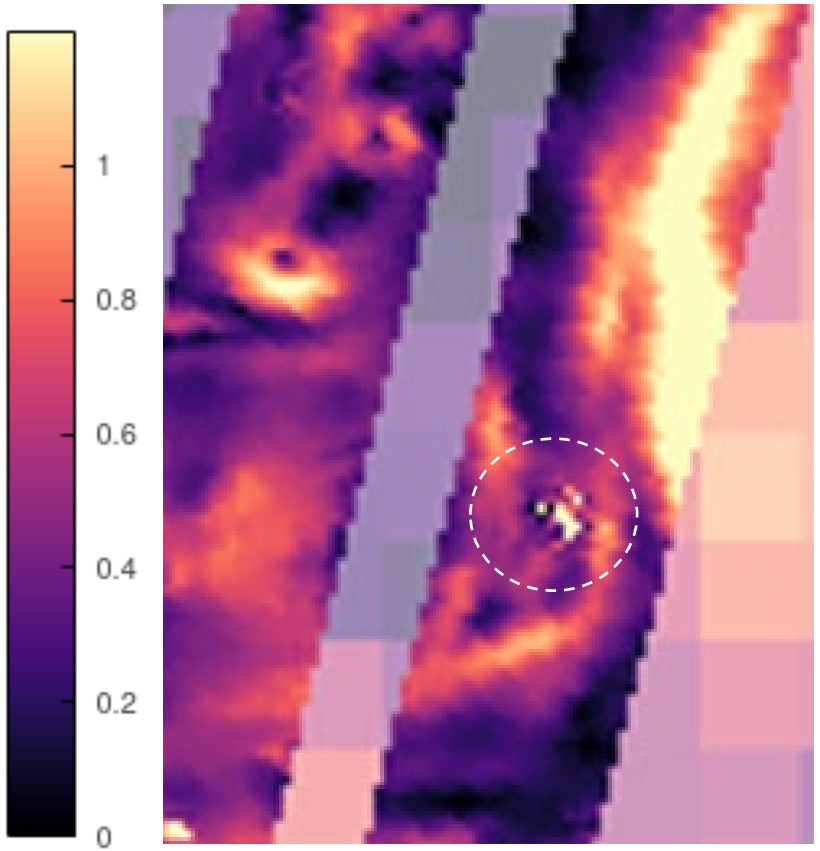
4. Take out residual spurious pixels (iterative comparison to local variability)

Known limitations of v0.1 editing

- Some leftover spurious pixels in v0.1 ⇨ More impactful on SSHA derivatives
- Editing layer is being improved for v1.0 (imagery algorithms)
- Critical and delicate ⇨ Community feedback & suggestions (or algorithm) would help



SLA (m)



Geo.Velocities (m/s)

AI-based Noise-mitigation algorithm

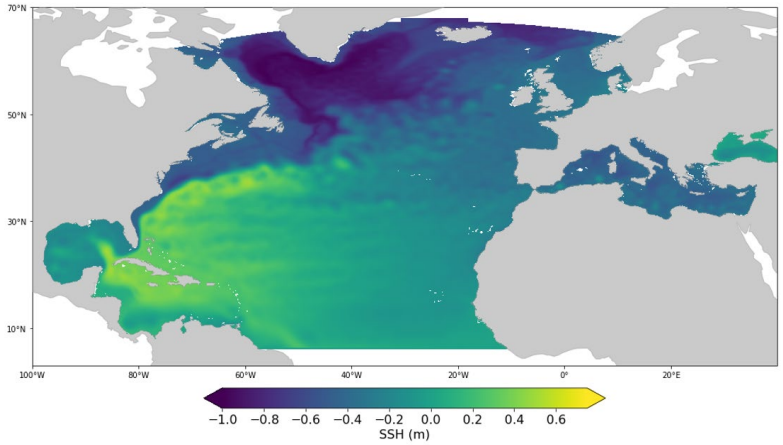
- **Simulated SWOT Data (eNATL60 model)** :
  Noisy SSH = true SSH + Karin noise modulated by waves*

- **Waves model** : global ocean reanalysis wave system of Météo-France (WAVERYS), resolution of 1/5° degree**

- **Division of the dataset** :
  - Year 2009 : training dataset
    (train : 75 %, validating : 25 %)
  - Year 2010 : dataset for the calculation of scores

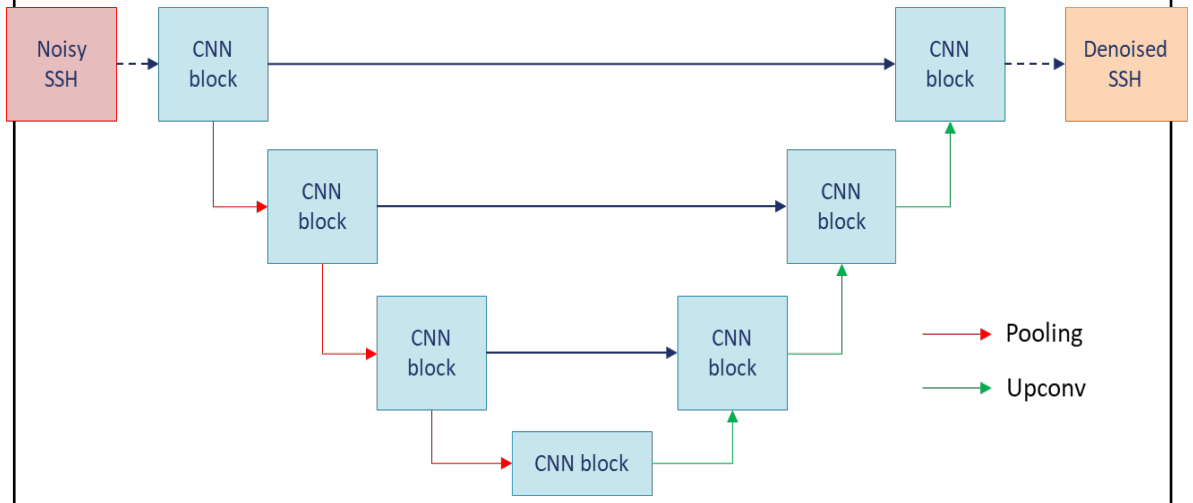
- **Data preprocessing :**
  - used of anomalies of SSH
  - used of data normalization
  - used of data augmentation : Vertical and/or Horizontal Flip

- **Division of the swaths :** 512 km along-track



Example of SSH on eNATL60 domain

- **U-Net architecture (231 000 parameters)**



Inspired by Ronneberger, O., Fischer, P., Brox, T., 2015. U-Net: Convolutional Networks for Biomedical Image Segmentation. ArXiv150504597 Cs.

* Noise level adjusted to real SWOT data
**https://catalogue.marine.copernicus.eu/documents/PUM/CMEMS-GLO-PUM-001-032.pdf

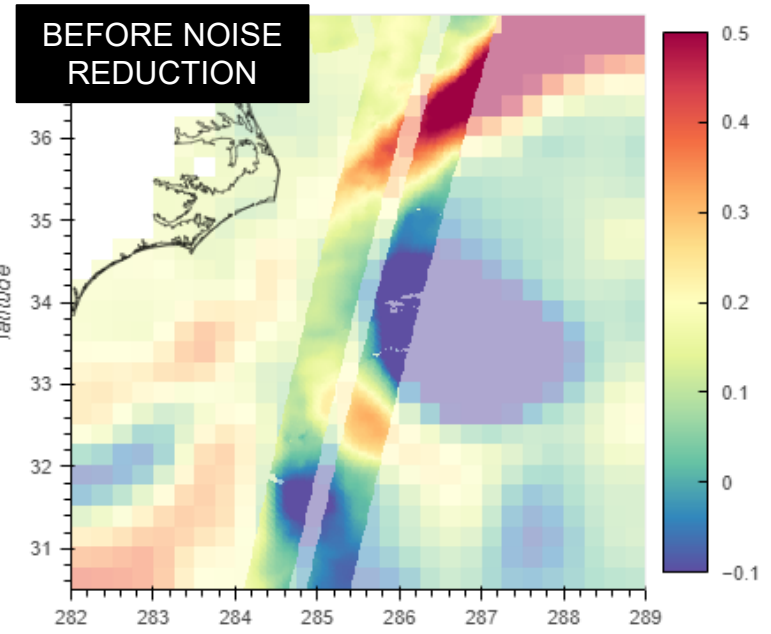
See Treboutte et al, 2023

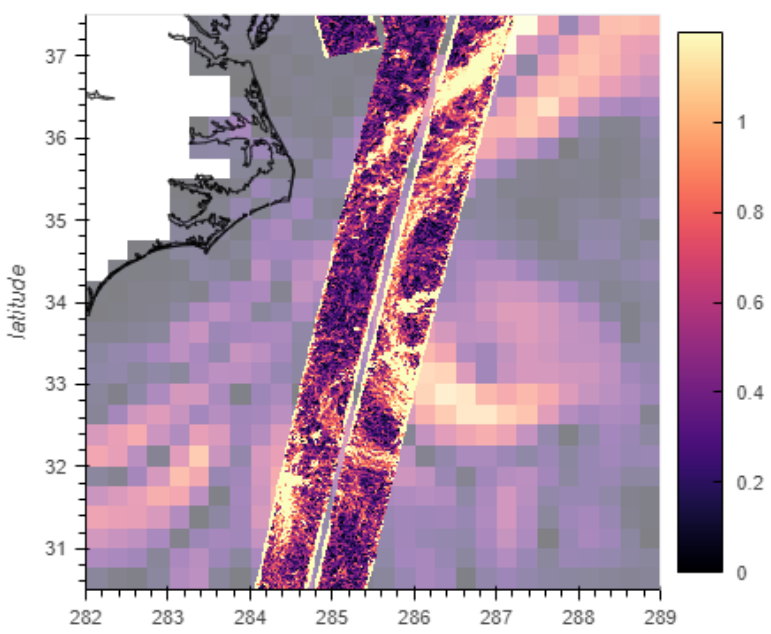
SSHA (m)

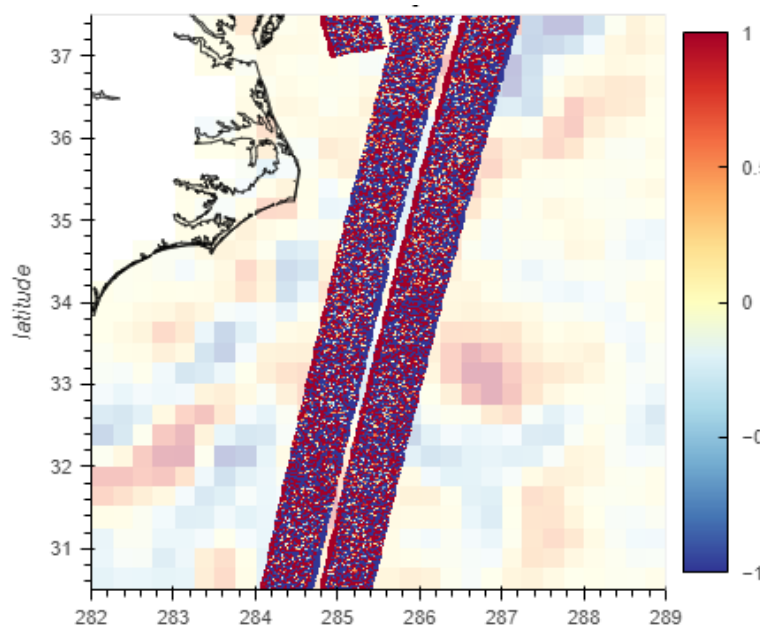
Geostrophic Velocities (m/s)

Relative Vorticity

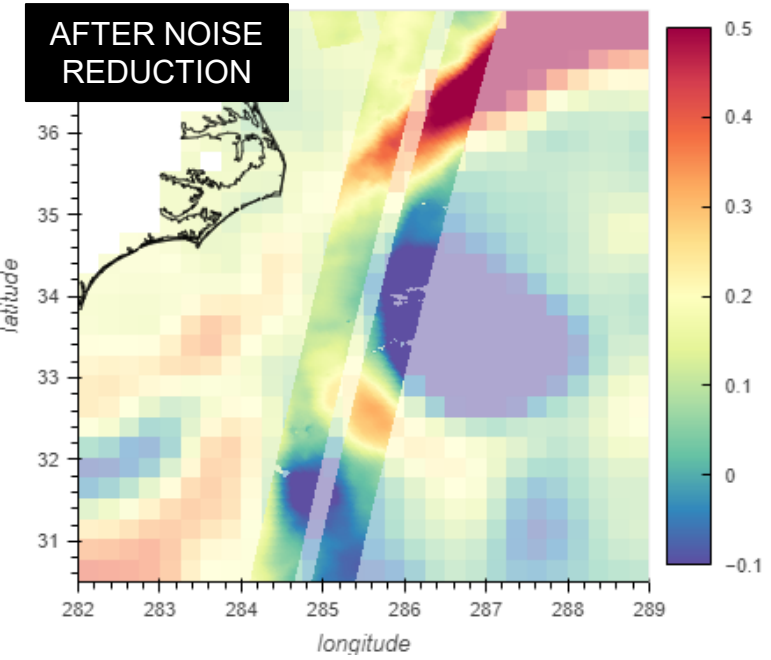
BEFORE NOISE REDUCTION

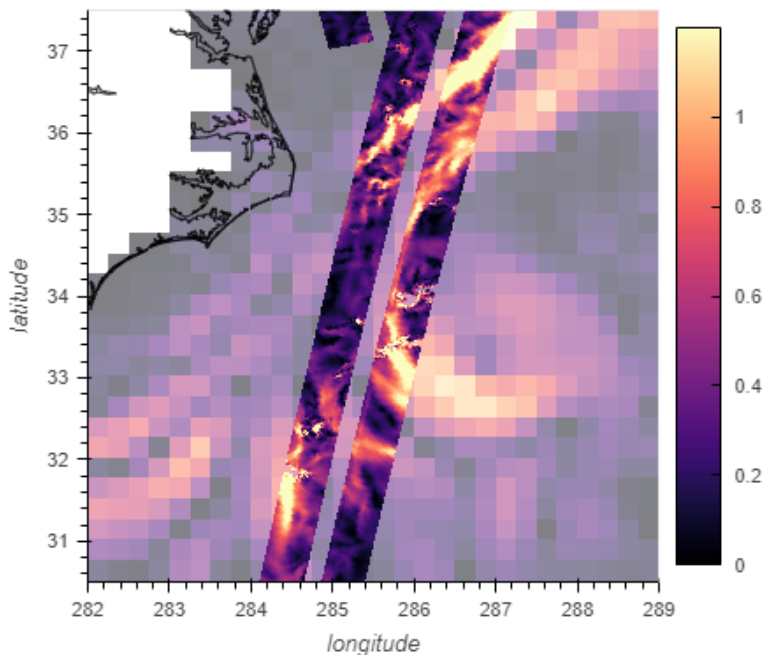


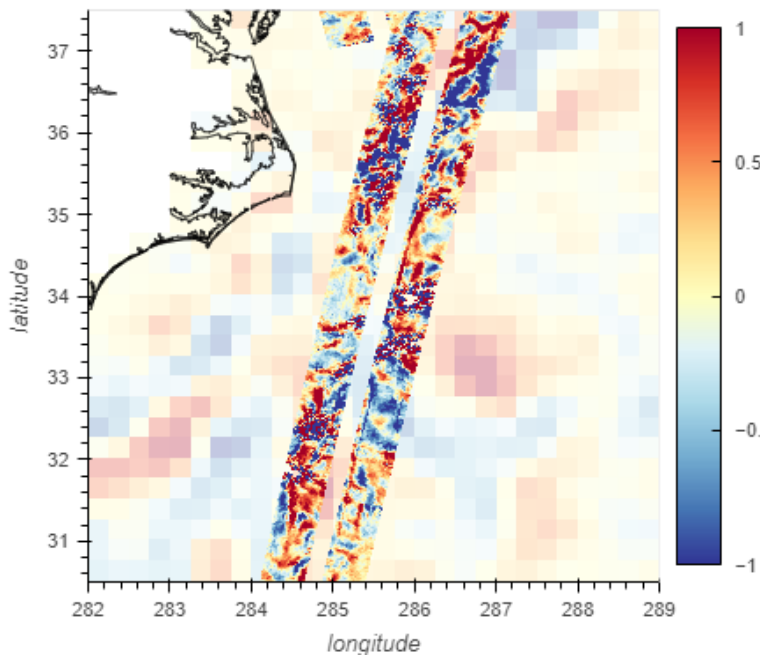




AFTER NOISE REDUCTION

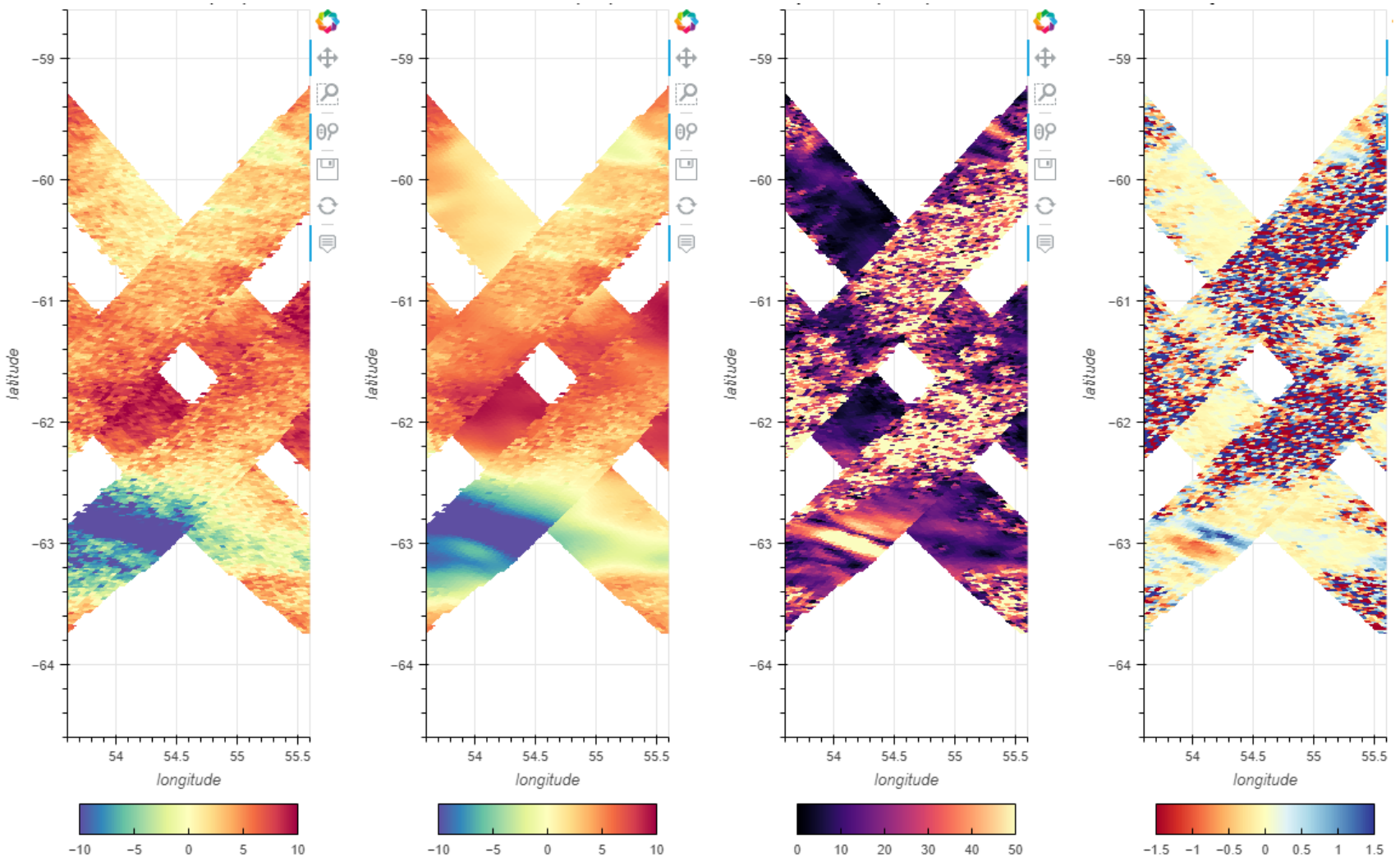






Known limitations of v0.1 noise reduction

- Flight data are very different from pre-launch simulations
- The NN misbehaves when the local SSHA properties are not in its training datasets
- The methodology will be consolidated for v1.0
- The long-term solution is to mitigate noise at full 250-m resolution and to downscale to 2-km



SSHA BEFORE

SSHA AFTER

Velocities from noise-mitigated SSHA (cm/s)

Vorticity from noise-mitigated SSHA

Choosing your SWOT Product

Why should you use Level-3 products?

- Lightweight, simple, and usable out-of-the-box
- No altimetry engineering knowledge required
- Nadir altimeter & KaRIn in one single image
- Sustainable production: NRT and reprocessing

Why should you use Level-2 products?

- L3 is not a replacement to the Level-2 (L3 has new layers, but no duplication of L2 content)
- L2 remains the go-to product for altimetry experts (engineering, algorithms, other surfaces)

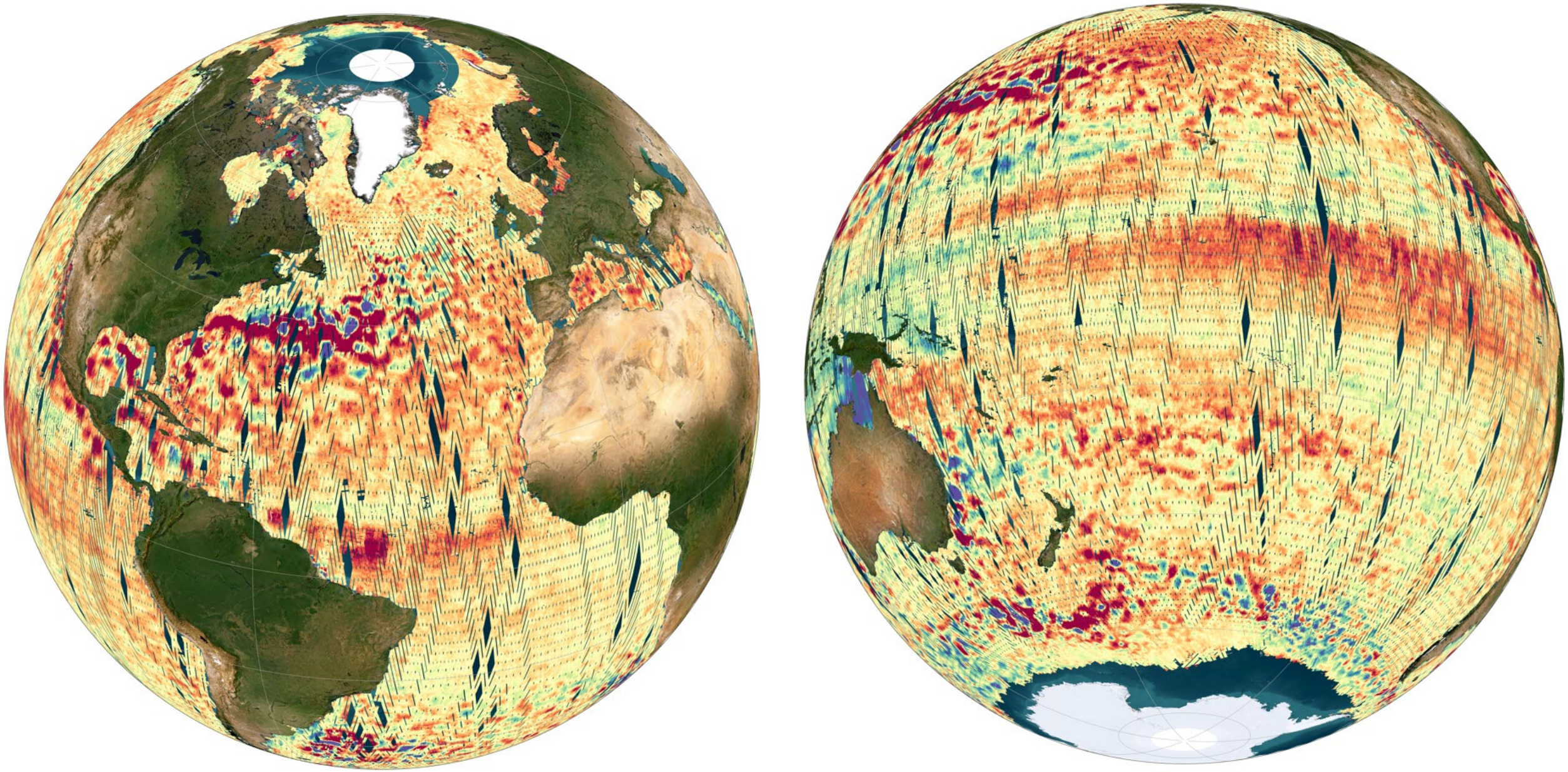
Why not use both?

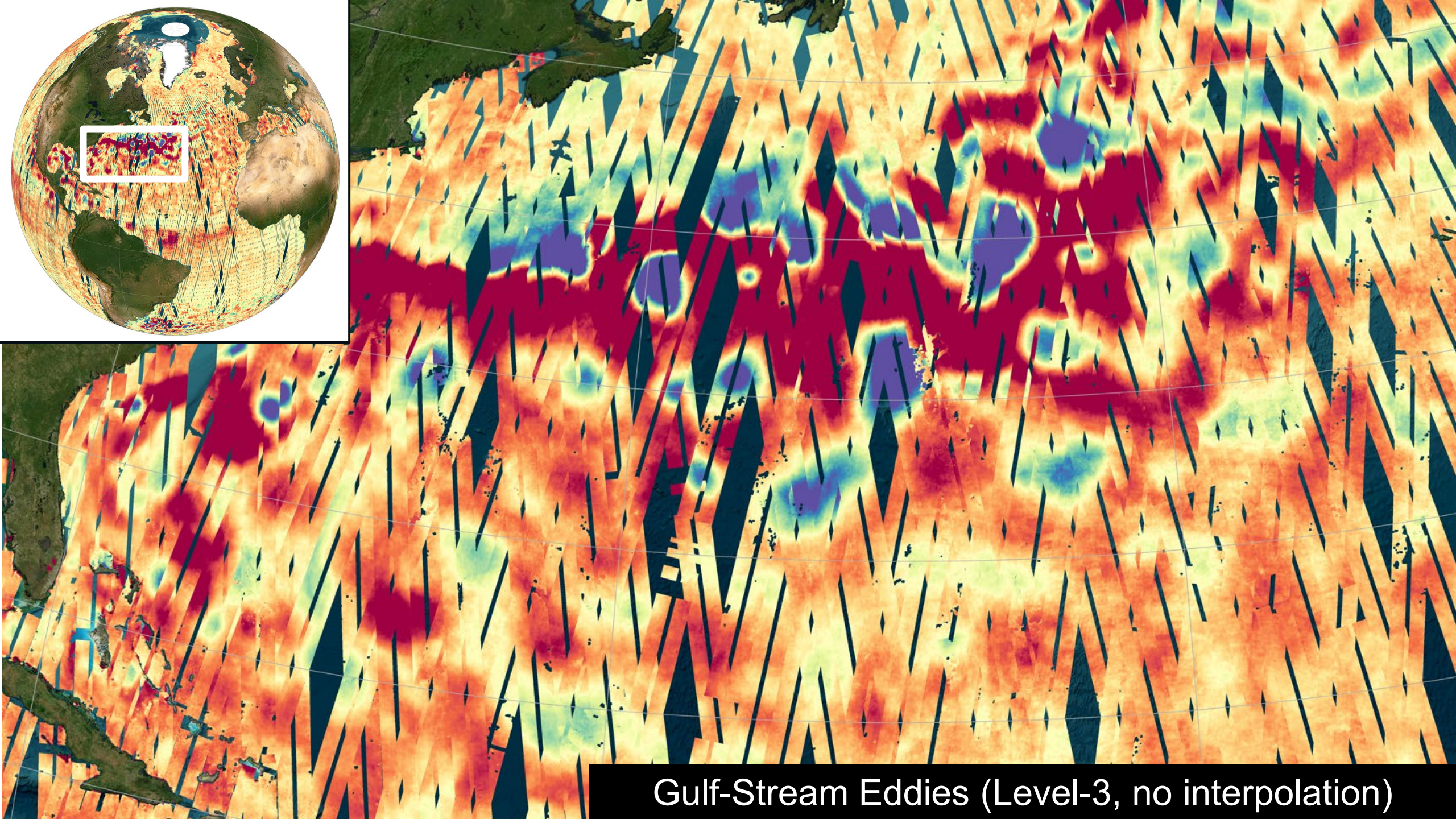
- L3 uses the same grid and pixels as the L2 ⇨ you can blend L3 layers into the L2
- Sandbox product: can integrate your research algorithms or L2 candidates or experiments
- Community-driven content: make requests & help define future L2 & L3 standards

Some convincing Level-3 examples

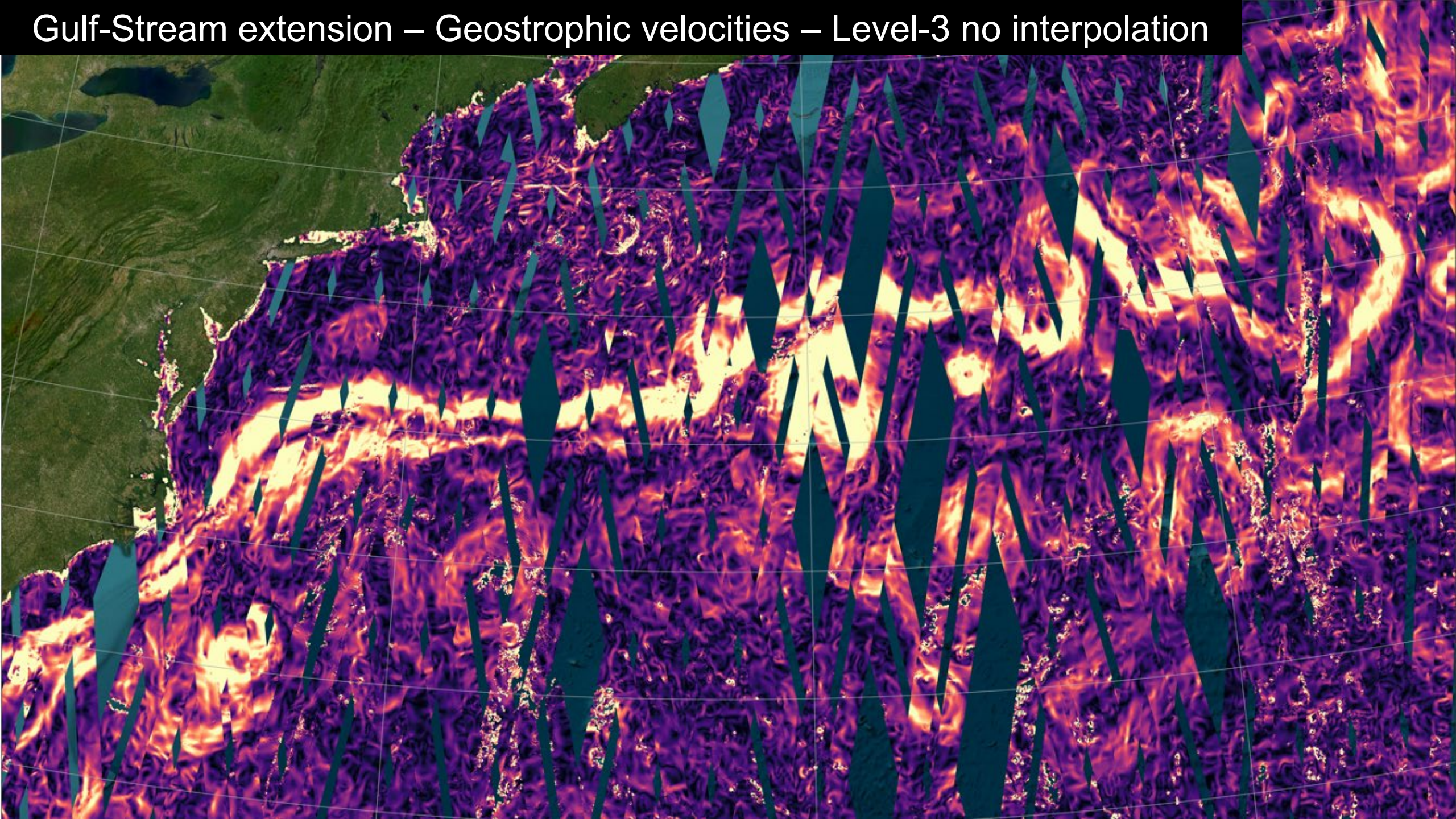
(a.k.a very encouraging after only 6 months of KaRIn data)

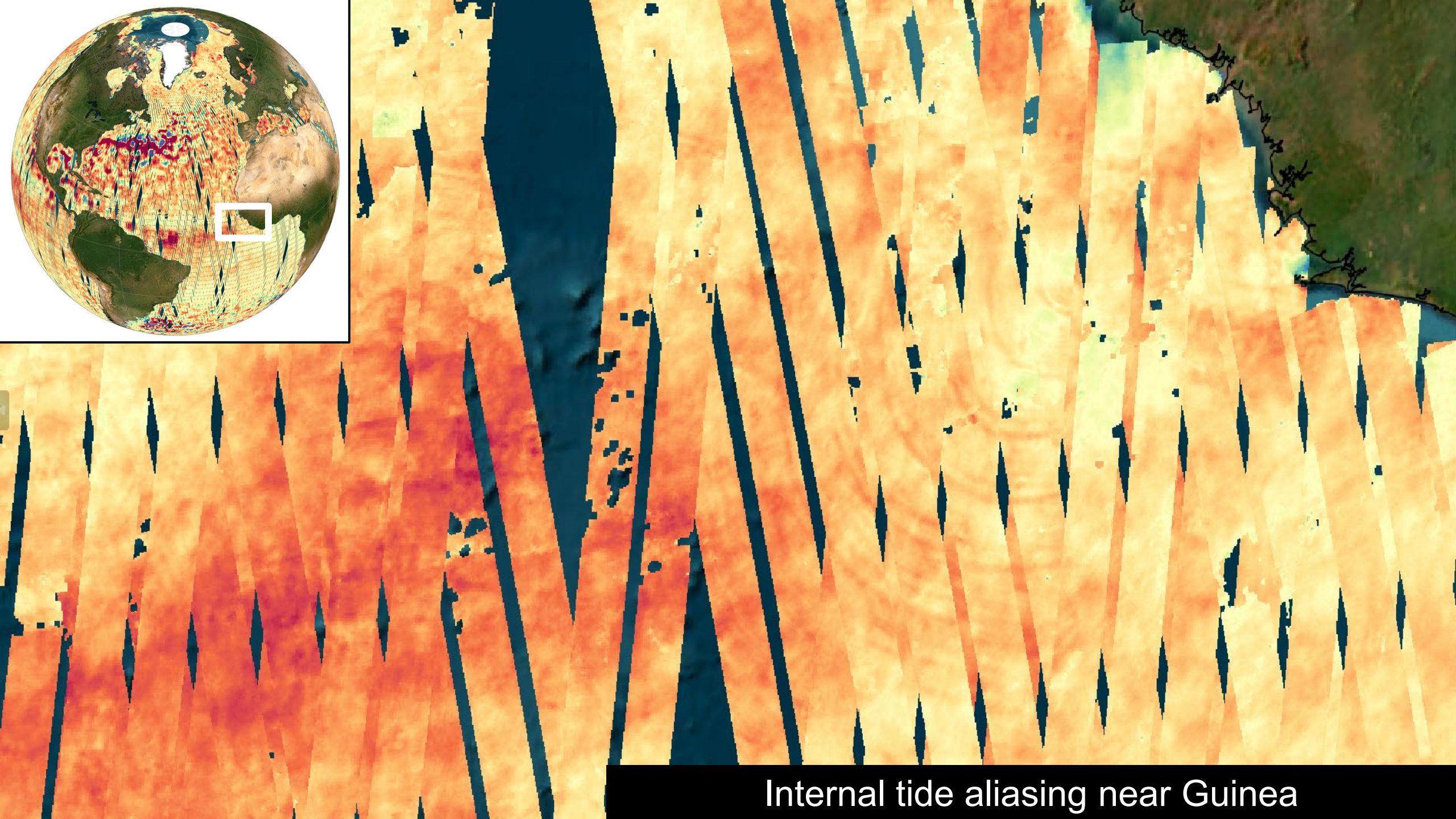
15 days of SWOT Level-3 SSHA (August 2023)



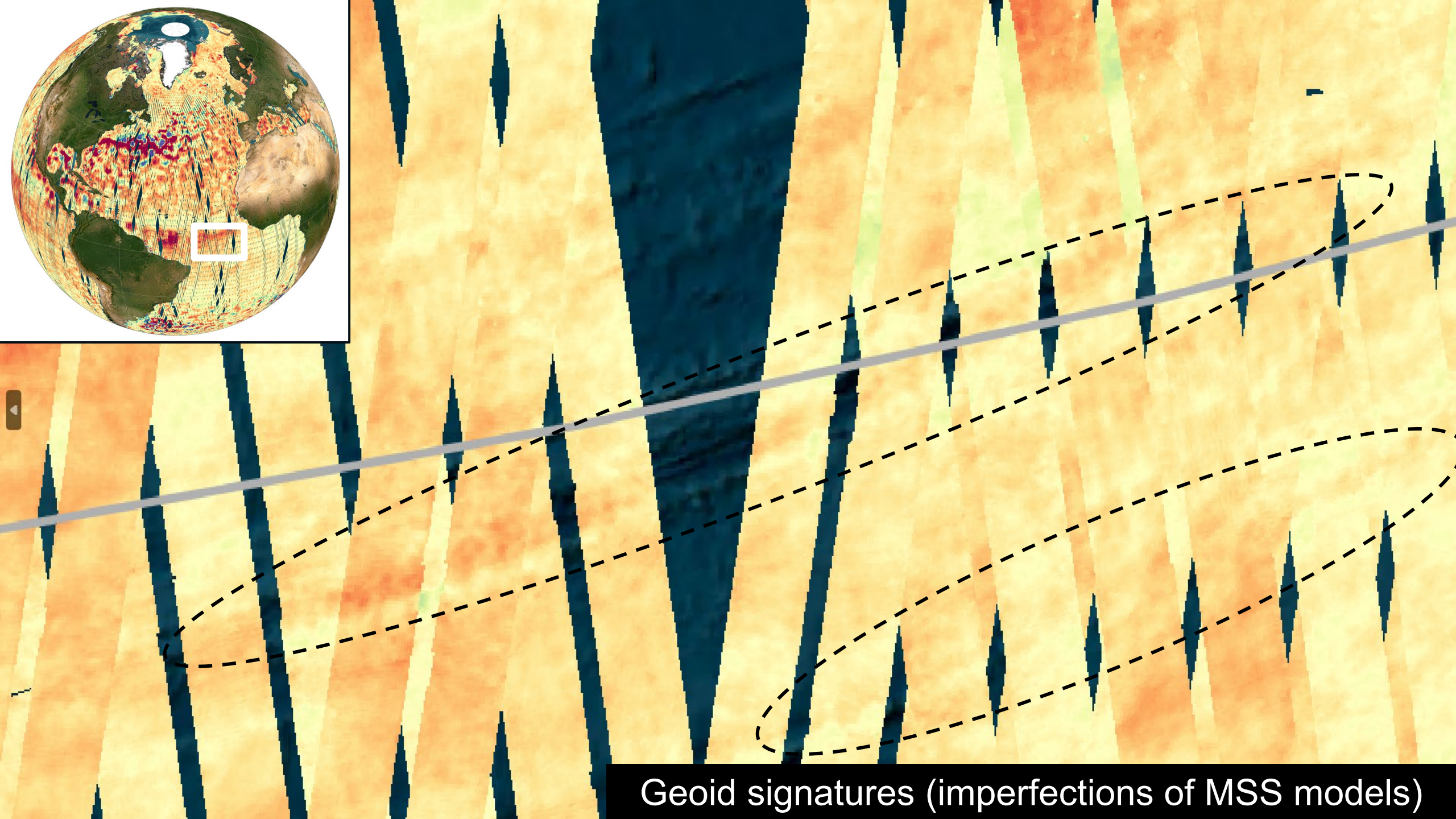


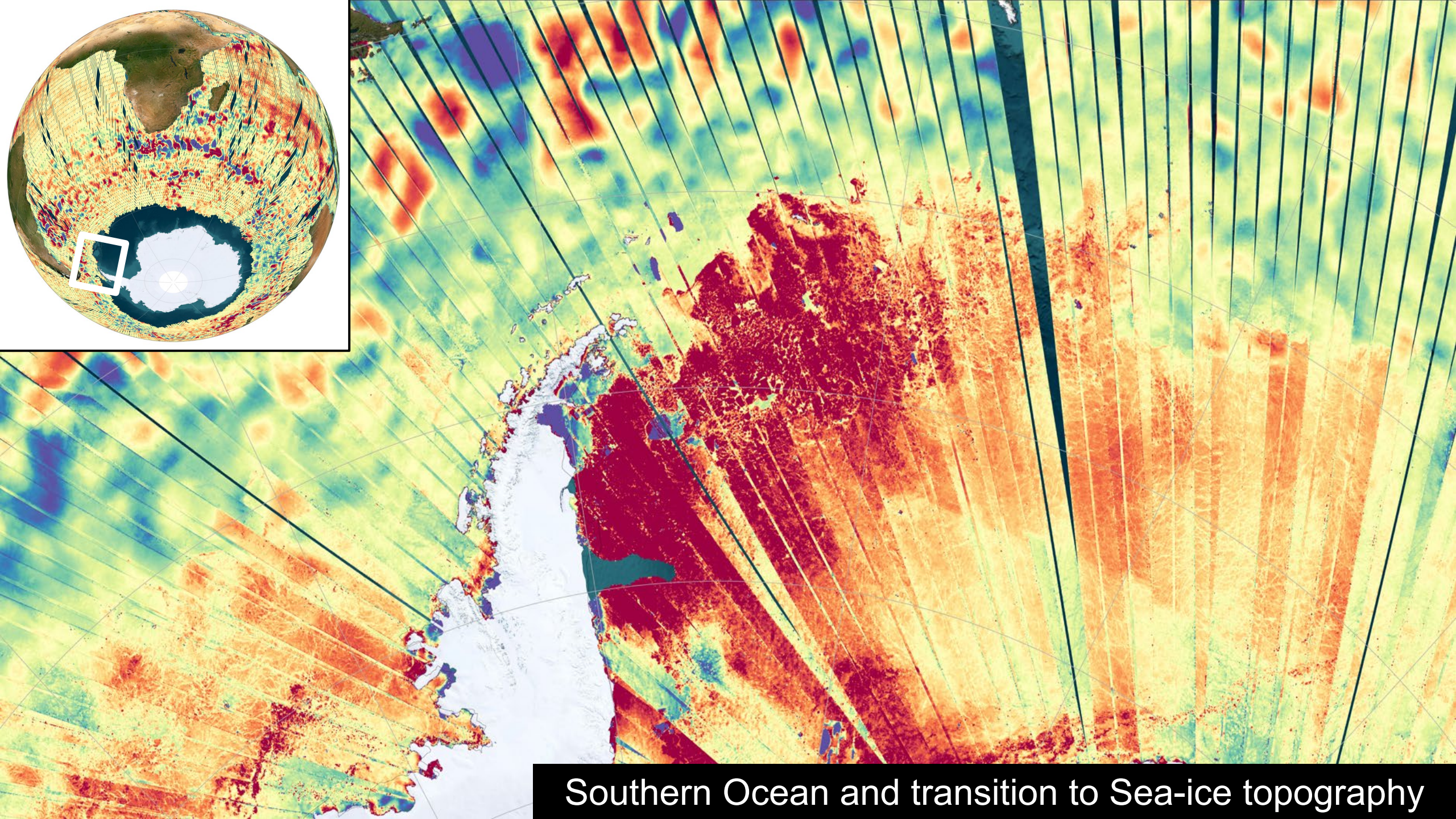
Gulf-Stream Eddies (Level-3, no interpolation)


Gulf-Stream extension – Geostrophic velocities – Level-3 no interpolation



Internal tide aliasing near Guinea


Geoid signatures (imperfections of MSS models)


Southern Ocean and transition to Sea-ice topography

Schedule & Last Comments

v0.1 (internal)

- January: prelaunch papers adjusted to SWOT flight data
- March: on-demand NRT production starts for AdAC
- April: end of KaRIn checkout ➔ global NRT production starts
- August: minor adjustments for Science orbit ➔ NRT restarts

v0.2 (first release)

- August: minor adjustments to v0.1 algorithms
- September: L3 reprocessing (from L2 pre-validated)
- September: first release on AVISO

v1.0 and beyond

- October: user feedback collection & L3 algorithm upgrades
- Oct/Nov: v1 released for NRT upgrade & reprocessing
- Quarterly updates until quality is deemed stable

Release of L3 products has the same usage restrictions as L2

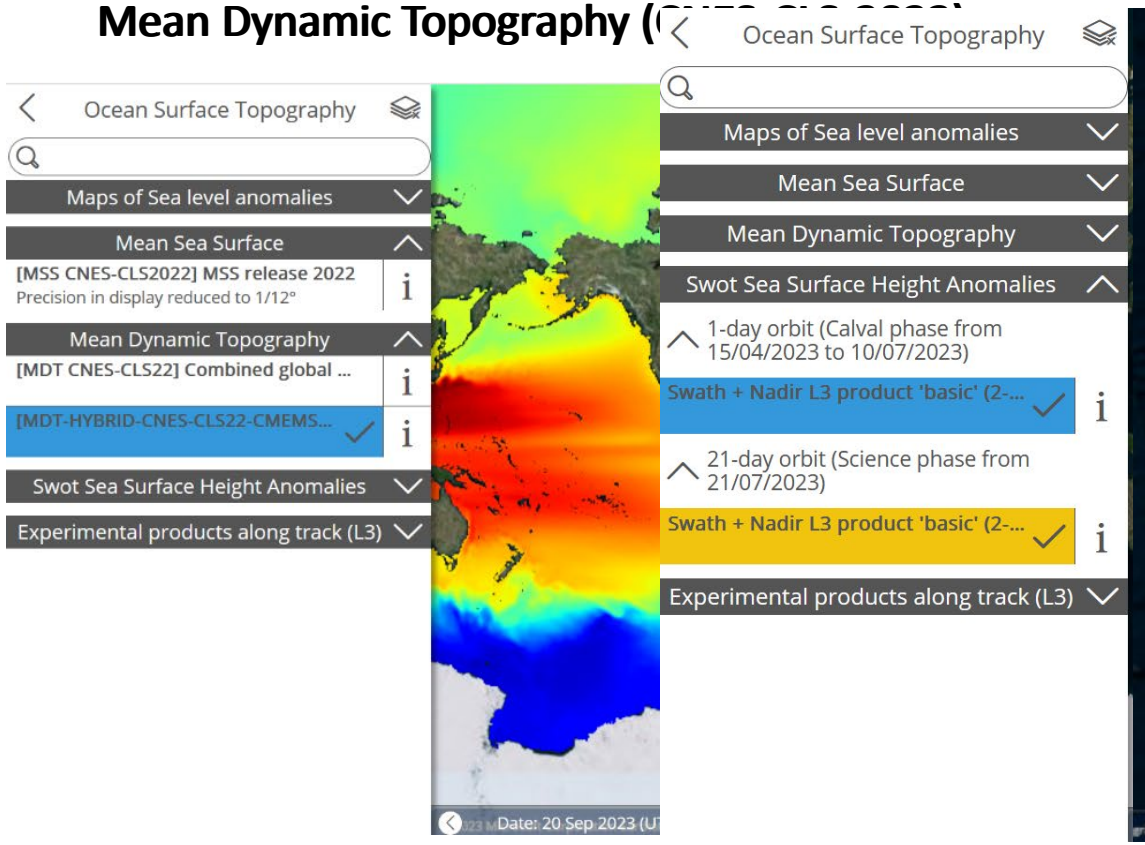
Community feedback (good or bad) is crucial to drive future work

Community product: we can integrate your algorithms and variants

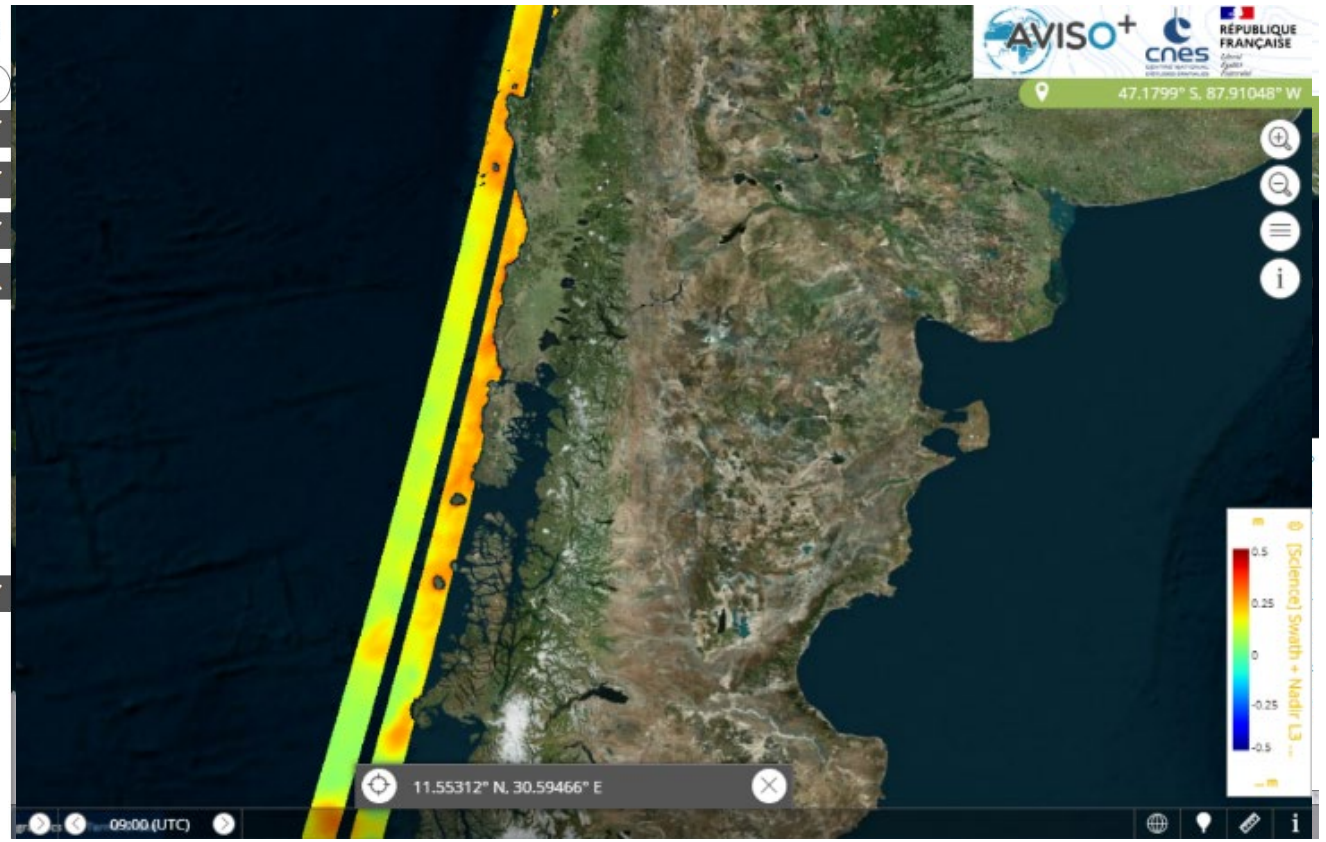
L3 Data availability on AVISO

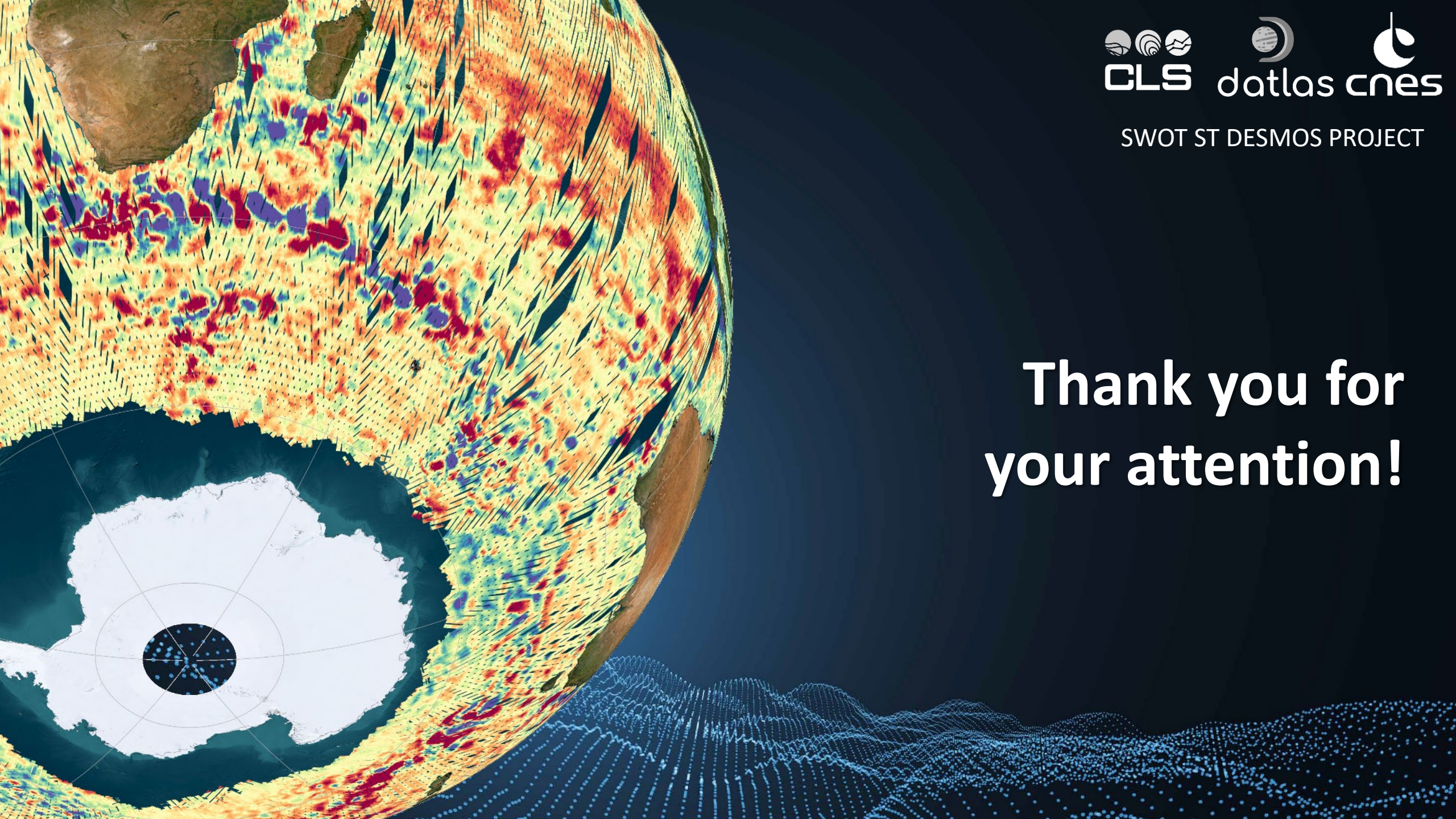
- Already available on the CNES Cloud where they are produced (incl. NRT 21-day phase)
- v0.2 available on the same FTP servers as L2 (and same vector and restrictions as the L2 products)
- Once L2 beta/pre-validated are cleared for the public, L3 will also become accessible from other AVISO vectors (OpenDAP, Thredds, etc)
- By next November: AVISO's web tool to explore SWOT L3 and other AVISO datasets

Mean Dynamic Topography (



SWOT SSHA (KaRIn + Nadir 'basic' product)





SWOT ST DESMOS PROJECT

Thank you for your attention!

References for SWOT L3 processing

An 2024 paper will describe the Level-3 algorithms and parameters in details
(after v1.0 is stable & SWOT publication embargo is lifted)

Current Level-3 algorithms are described in the following prelaunch papers:

- **Nadir L3 sequence: https://doi.org/10.3390/rs15030793**
- **Calibration of KaRIn images https://doi.org/10.3390/rs14236070**
- **Overall multi-mission strategy https://doi.org/10.5194/egusphere-egu22-7479**
- **KaRIn noise mitigation https://doi.org/10.3390/rs15082183**
- **MDT CNES/CLS v2022 https://doi.org/10.24400/527896/a03-2022.3292**
- **FES v2022 https://doi.org/10.24400/527896/a03-2022.3287**
- **Hybrid MSS CLS/Scripps/CNES v2022 https://doi.org/10.3390/rs15112910**

L3 Karin content

Information	Variable (lightweight product)
Time	time
Geolocation	latitude, longitude, i_num_line, i_num_pixel
Height	ssha, ssha_noiseless, ssha_unedited, sla_nadir, mdt
Data	sigma0
Speed	ugosa, vgosa, ugos, vgos
Flag and corrections	quality_flag, calibration, cross_track_distance
Geophysical correction	ocean_tide, dac, mss