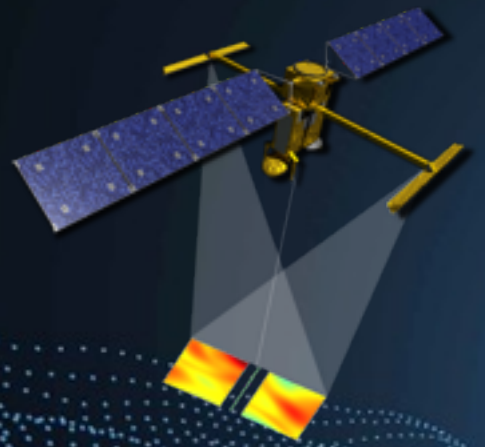
Present and future altimeter capability



Yannice Faugère (CLS) and Gerald Dibarboure (CNES)

With inputs from:

I Pujol, M Ballarotta, P Veillard, P Prandi, C Pegliasco, A Delepoulle, S Mulet, S Jousset, P Schaeffer, A Treboutte, M Ghantous (CLS)

C Ubelmann & S Metref (Datlas), R Morrow & F Lyard (Legos), M Cancet (Noveltis),

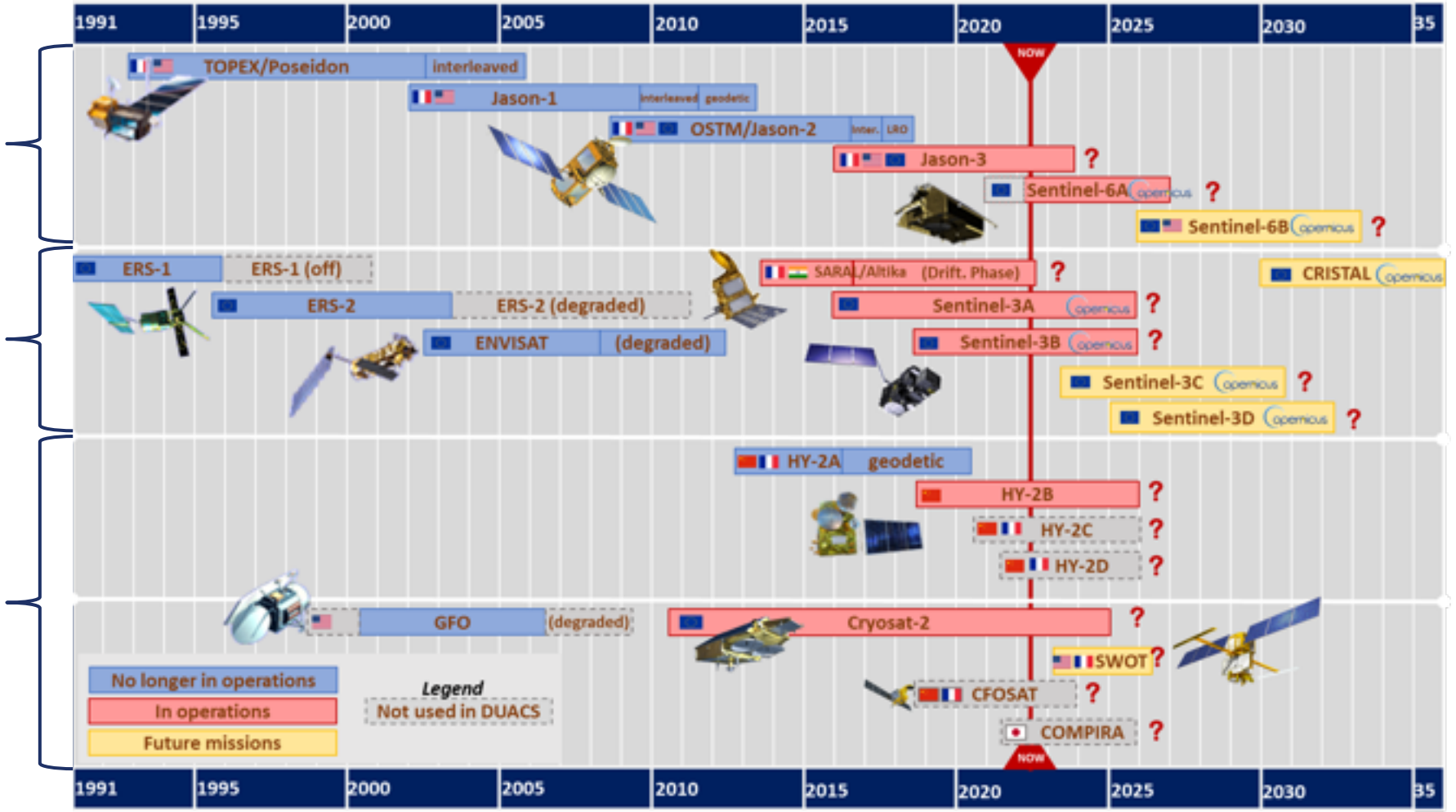
R Fablet & M Beauchamp (IMT), V Bellemin (IGE), M Auger (LOCEAN)

DUACS

WOC User Consultation Meeting 2022 |10-12 Octobre | ESA-ESRIN | Frascati (Rome), Italy

Context: Altimetric constellation

- Reference altimeter (for climate) **Topex/Poseidon, Jason** series and now Sentinel-6 to retrieve large climate scales.
- **Coverage altimeters (ERS1/2, Envisat, Sentinel3A/B),** are needed to retrieve the mesoscale signals.
- Same for **collaborative missions (GFO, SARAL, HY2B)** and **opportunity missions (Cryosat-2, CFOSAT)**



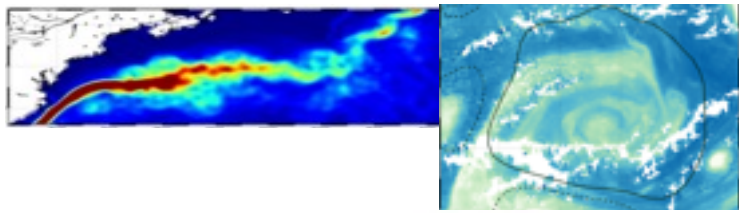
Altimetry products built from 15 missions ingested over the past 27 years (100+ years cumulated data)

Context:

- Operational production of derived altimetry observation fields in the **Marine Copernicus Service => ingested in 23 Observed products (and all the Model product)**
  - Surface topography and associated geostrophic Current in SL-TAC
  - Total current (including Eckman) and 3D state of the ocean in MultiOps
  - SWH products

Geostrophic current from:		=> All the same, produced since 1998 by **DUACS system**, distributed on Aviso up to 2015, distributed in Marine Copernicys Service since then, available in the **Sea Level product**, and used in the surface current product (**Copernicus-Globcurrent**)
CMEMS	Globcurrent	
DUACS/aviso	Surcouf	

- R&D activities, demonstration product **supported by CNES**
  - New altimetry processing
  - New geophysical correction
  - New mapping algorithms, derived products

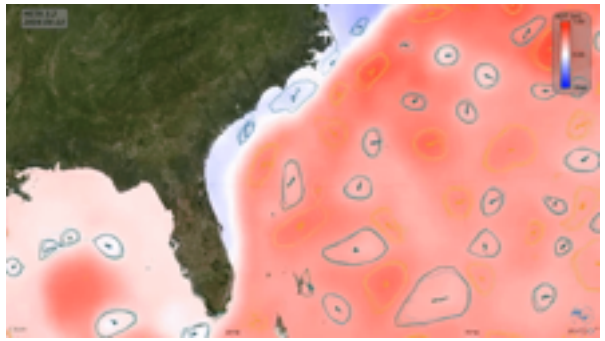


Outline: Capability of altimetry (focus on derived current):

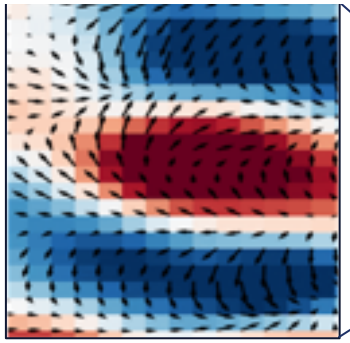
=>Today / Next months / Next years

Today: Marine Corpernicus – latest upgrades

- Full reprocessing in 2021 leads to a better description of the mesoscale (DT2021) =>10% Improvement of gridded Sea Level at Global scale relative to DT2018
- Regional distribution of this improvement =>up to 20% Improvement on geostrophic currents at mesoscales by comparison to drifting buoys



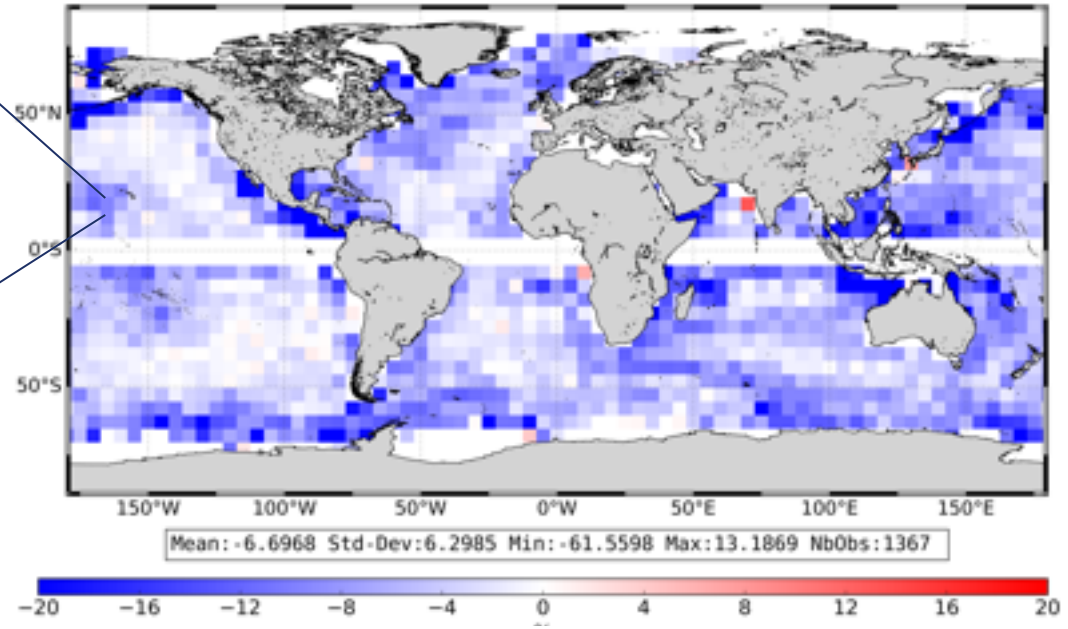
MIOST Coherent Internal Tide (2021) Hawai area



30cm.s-1

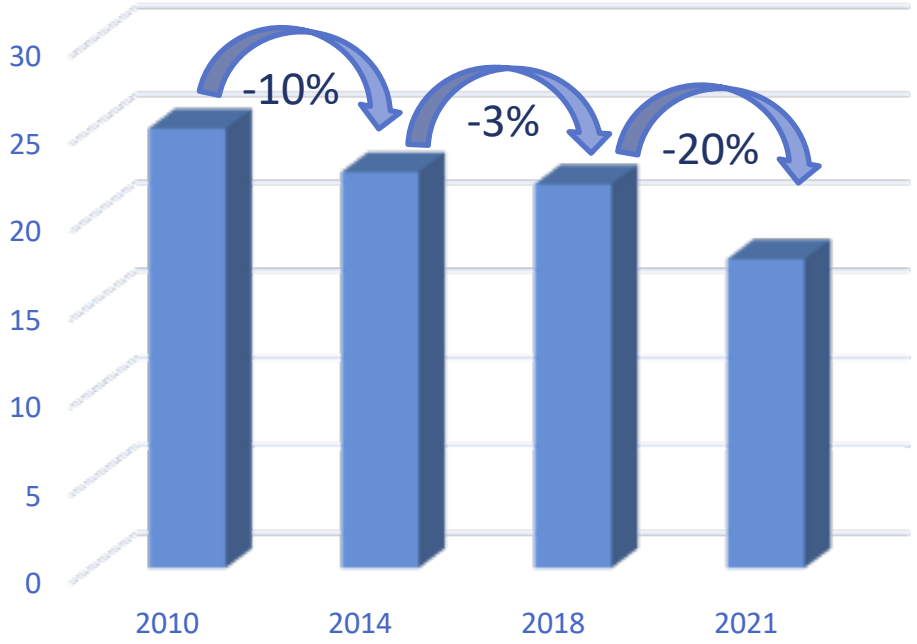
-30cm.s-1

Error reduction using independent drifting buoys corrected from NIO & Eckman (2015-2020)



Error estimation (cm2)

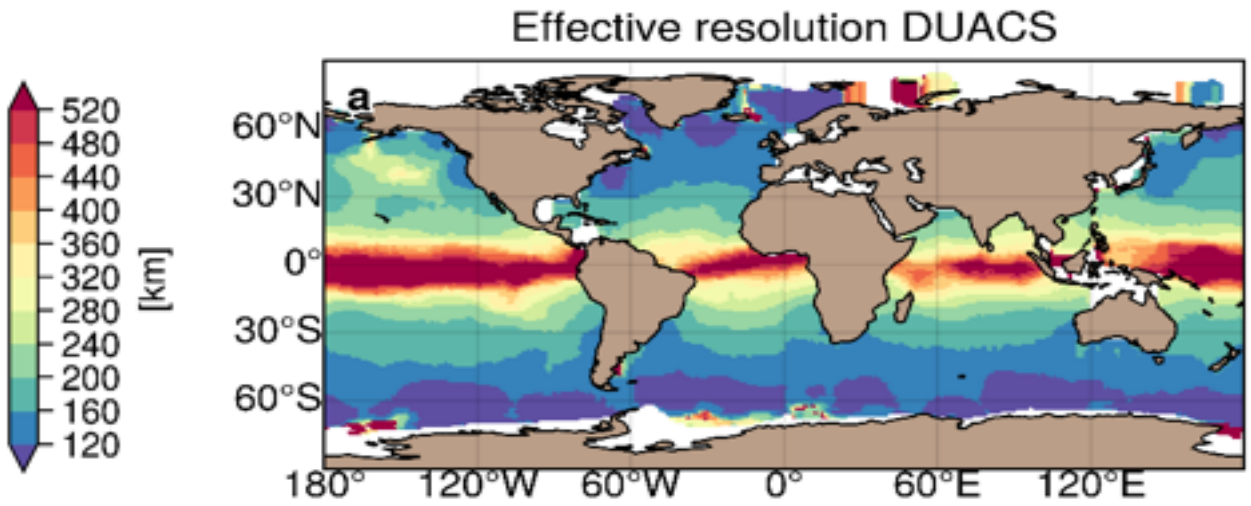
Open ocean/variance > 200 cm² / wavelength 65-500km



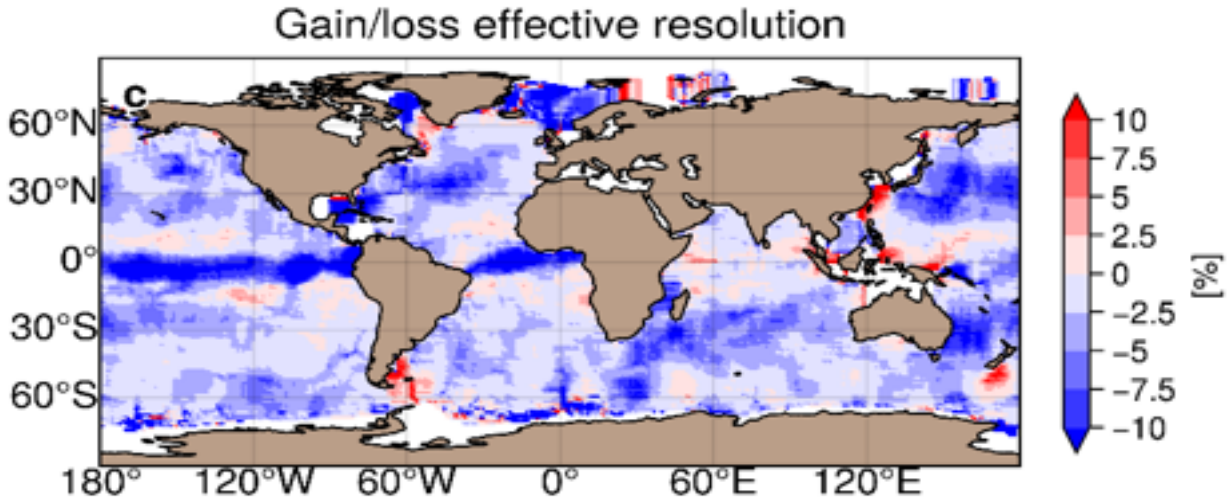
Today: L4 demo products

New MIOST & multivariate mapping approach developed to improve the mapping performance:

- Multiscale: decomposition of the observed signal into different physical contributions.
- multivariate: able to exploit the geostrophic signature resulting from the synergy of altimetry and drifter observations.
- OSE studies showed the interest of SWOT : improvement of the MIOST maps compared to DUACS OI map (CMEMS)



Ballarotta et al 2019

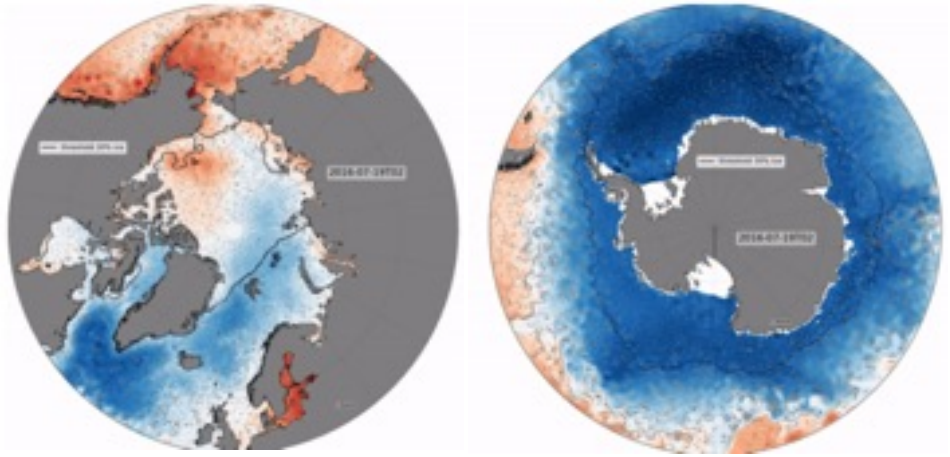


blue : MIOST have a better resolution

- 4 year MIOST demo product available, ESSD Paper from Ballarotta et al (see Pre-Print)

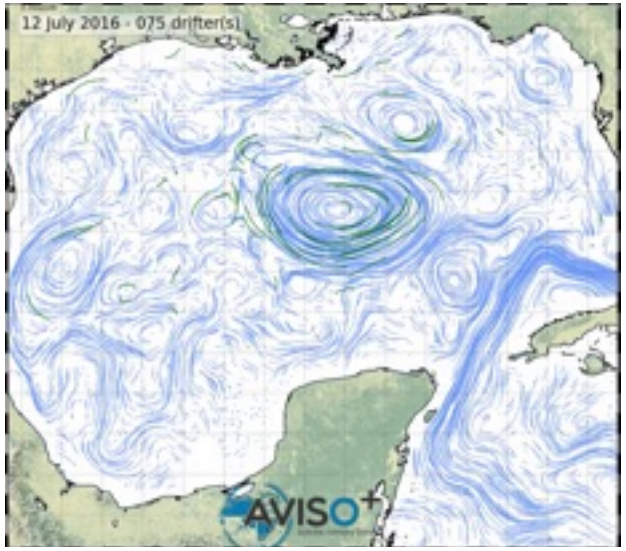
Polar demo product

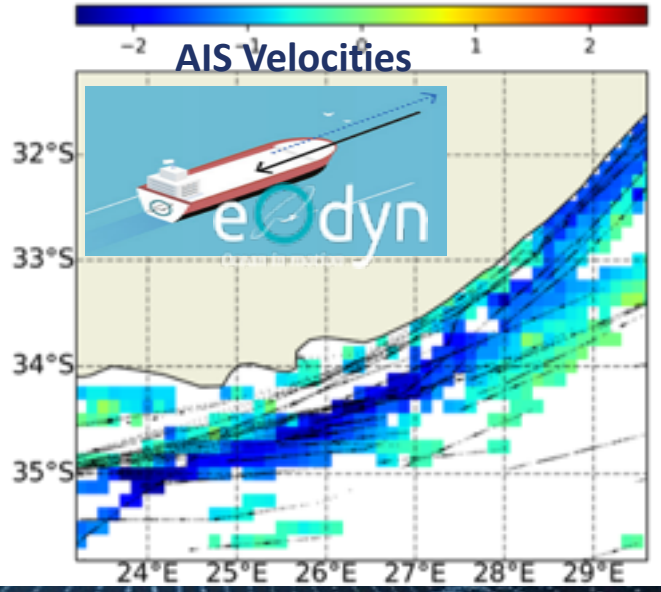
- Satellite echoes from AltiKa, Sentinel-3A and Cryosat-2 are processed within the leads and combined to obtain multimission **Sea Level and geostrophic currents over the sea ice covered areas in Arctic and Antarctic**
- **Along-tracks and maps** covering the whole high latitudes were produced for **2013-2020 and validated**

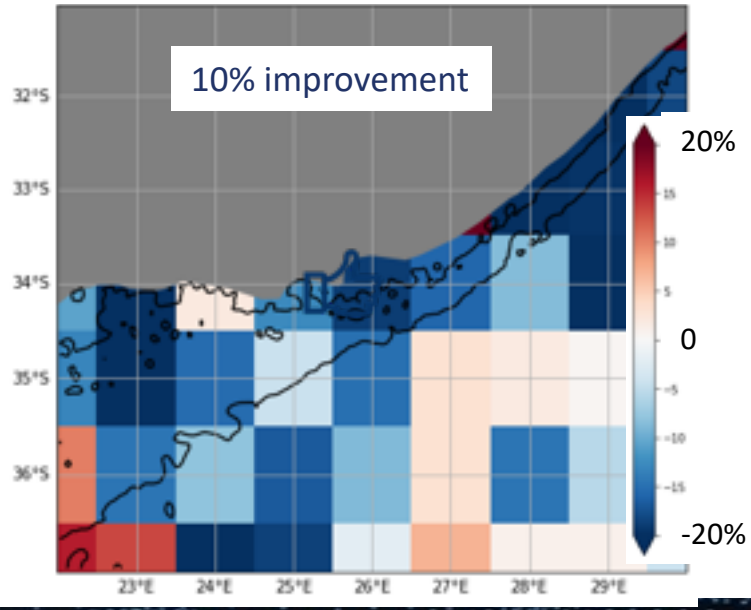


Multivariate demo products

- Combination of Altimetry/drifters/AIS
- Simultaneous estimation of H/U/V
- Improvement of geostrophy (potentially ageostrophy also)







Today:

Experimental high resolution along-track L3 product for Sea level & currents

➔ **Samples already available**

➔ **OP production in CMEMS from 29th November 2022 :**

- S3A/B SAR
- S6A SAR
- J3 LRM

H2B/C expected in 2023

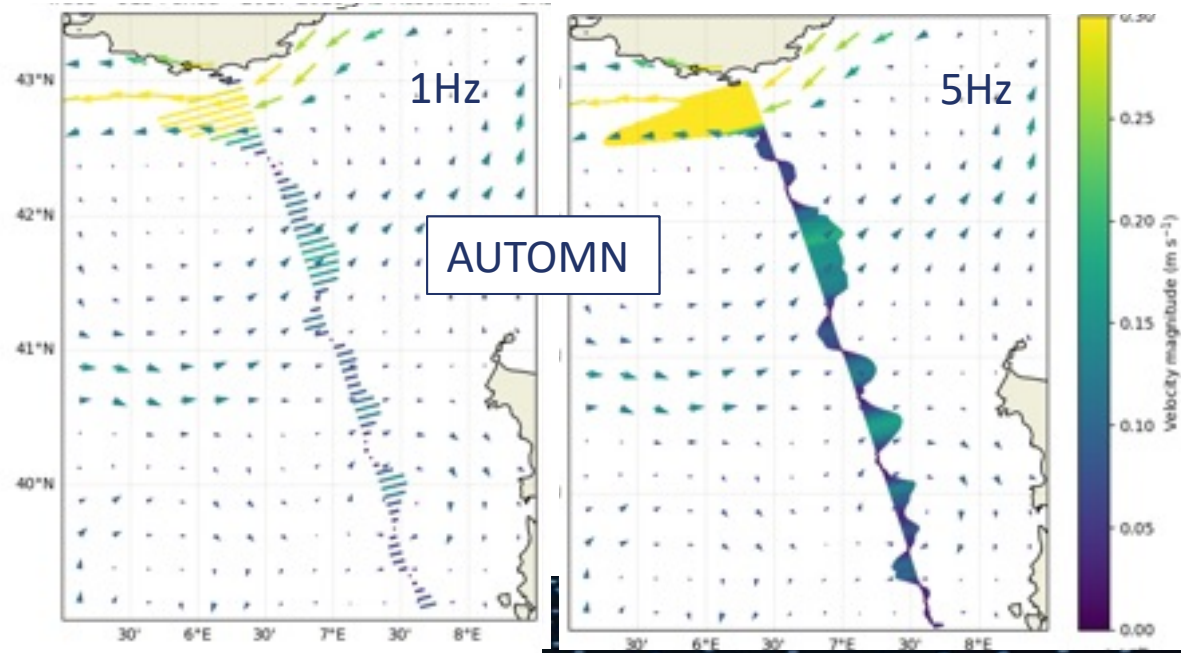
➔ **Reprocessed time series TBD**

- Use 20Hz upstream+Innovative processing :
  - **SAR** measurement (C2, S3A) processed with **LR-RMC** technique (S3A; Moreau et al, 2021)
  - LRM processed with **adaptive technique** (J3, Thibaut et al, 2017) and including noise reduction correction (J3, Tran et al, 2021)
  - Up-to-date corrections and L3 processing standards

- 5Hz (~1 km) L3 samples product delivered for the North Atlantic area:
  - available on AVISO (doi:10.24400/527896/a01-2021.003) & CMEMS (doi:10.48670/moi-00137)
- Different variables available, including geostrophic current in X-track direction.

- Improved restitution of the signal compared to the conventional 1Hz product :
  - **Resolve shorter wavelength** : 35 km (S3A) to 55 km (J3) (~65km for 1Hz)
  - **Optimize data availability in coastal areas** : up to ~5km (~10km for 1Hz)
  - **Improve the consistency with independent TG** signal : variance of the SLA differences reduced by 5% (S3A) to 17% (J3) compared to 1Hz
  - **Improve the restitution of the coastal currents** : Intensity, Location and seasonal variability improved

S3A geostrophic current, 2017-2018 seasonal mean
Pass 513, near Porquerolle Island (Med Sea),

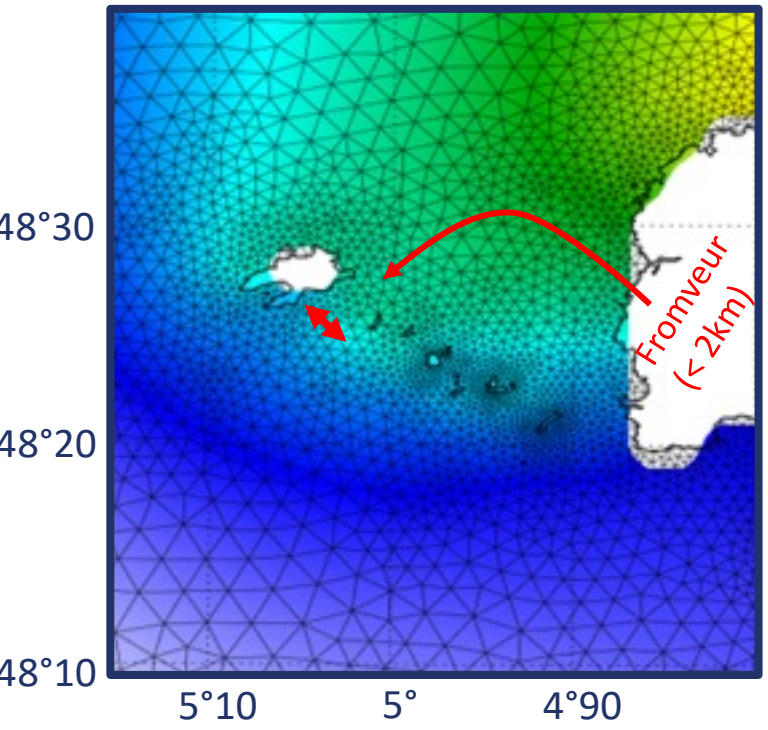


Ref: Pujol et al., 2022. Refining the resolution of DUACS along track (level 3) altimeter Sea Level products. ESSD, in review

Coming weeks: New Ocean Tide model

Fes2022 barotropic tide

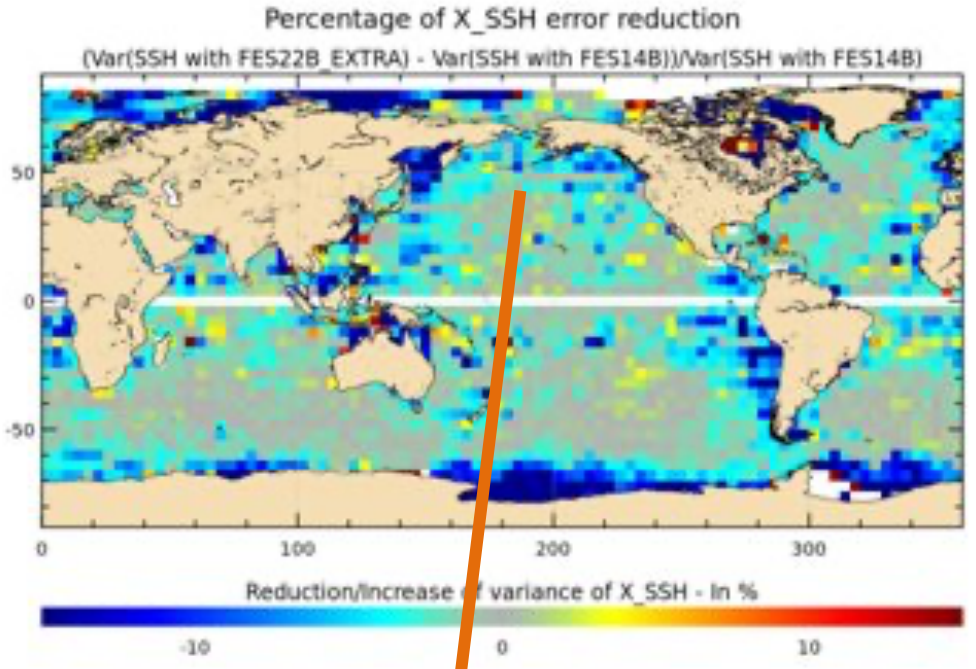
- Improved bathymetry partly through the use of regional bathymetry
- New high resolution mesh: 8 times more elements than on the FES14B grid
- Assimilation of new databases: TG, extension of the altimeter period, etc.
- Improved polar coverage and accuracy



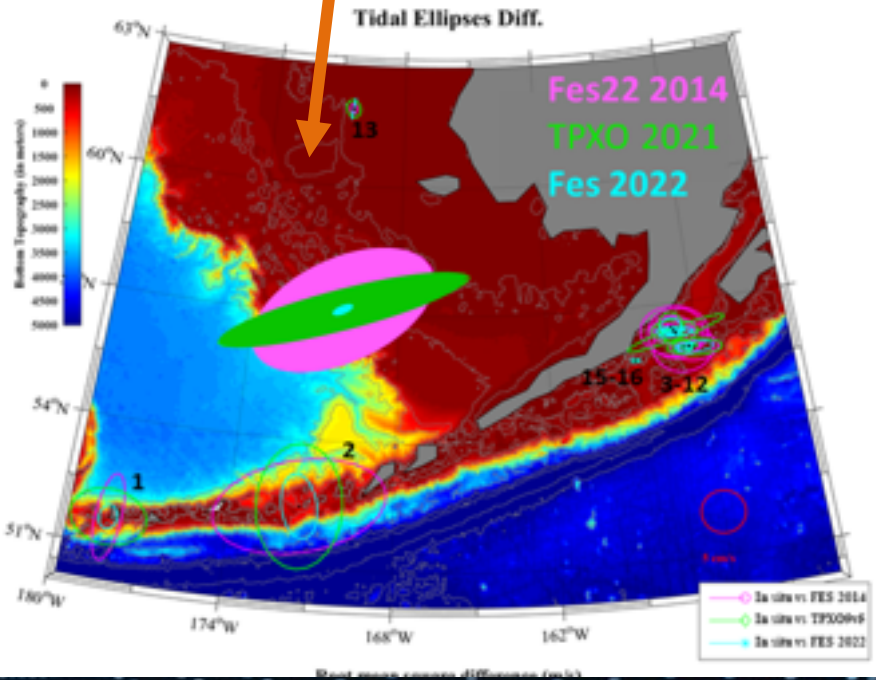
Algo Performance:

- Great improvements: >10% of error reduction on Topography for low bathymetry areas and polar regions
- Very good consistency of FES22 currents with in situ measurements

On Aviso Nov 2023



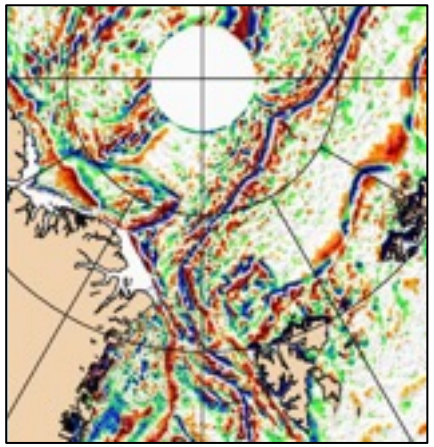
Currents assessment in Aleoutian islands

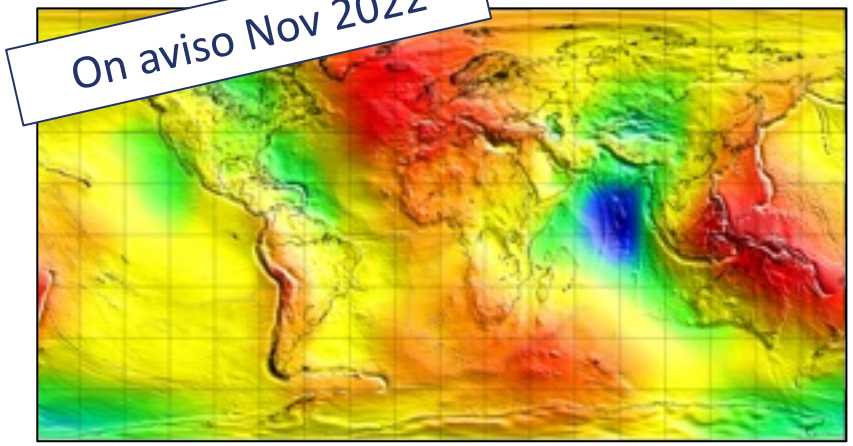


Coming weeks: New MSS/MDT fields

- Mean Sea Surface and Mean Dynamic Topgraphy are crucial for High Resolution applications

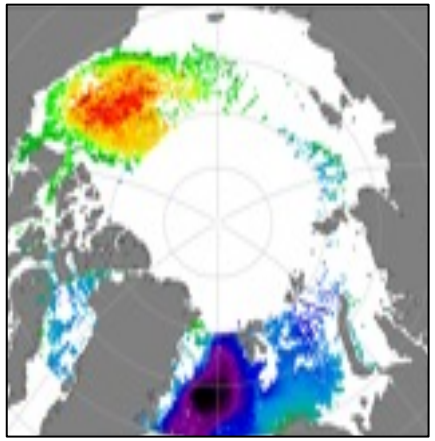
MSS CNES-CLS22
Repeat mission 1Hz + non repeat misision Cryosat-2 & Altika) at Full Res Altimetry measurement 6 billions altimetry measurements used (x300 compared with version!)
Coastal processing & slope correction (Sandwelland Smith, 2014)
New correlation scales
Ingestion of Arctic leads measurement in sea ice covered areas

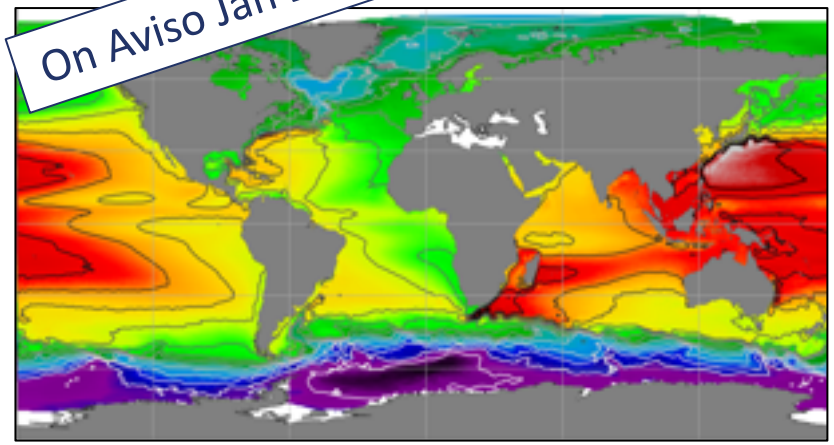




Strong improvement at small scales and in Arctic

MDT CNES-CLS22
input MSS: MSS CNES-CLS22
Geoid GOCO06S (GOCE data fully reprocessed)
First guess Optimal filter (Rio et al, 2011) + lagrangian filter along the coast to avoid streamline going into land
Surface drifters and T/S profiles + and 1993-07/2021 + update of the processing
New In situ data in Arctic regions

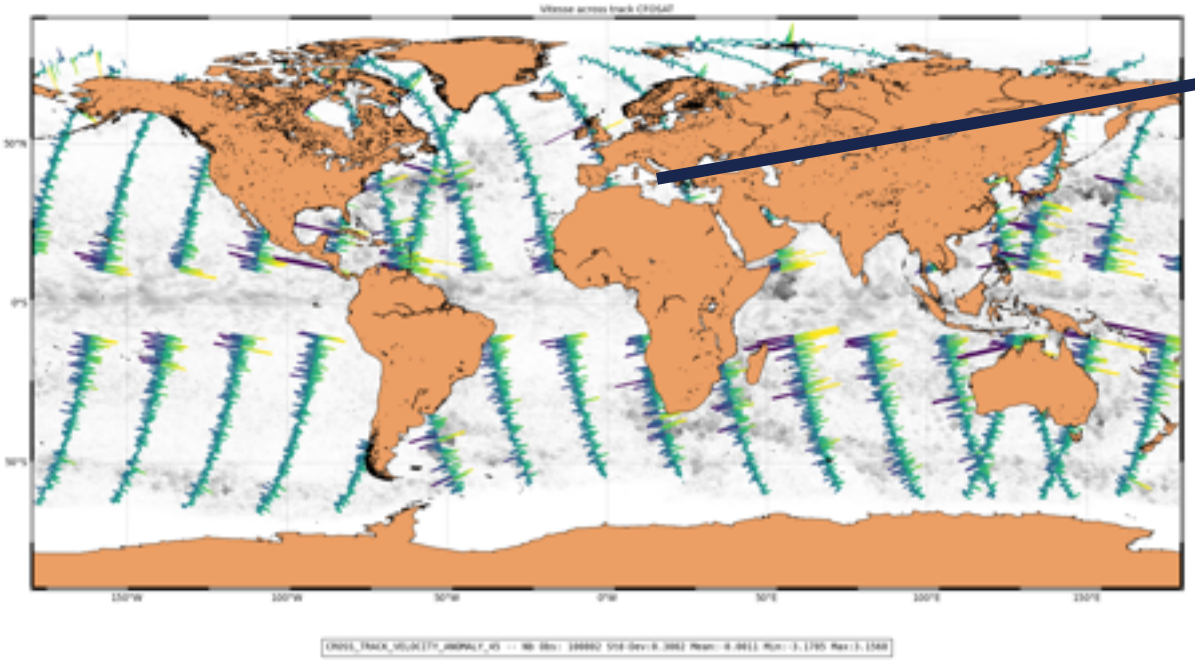




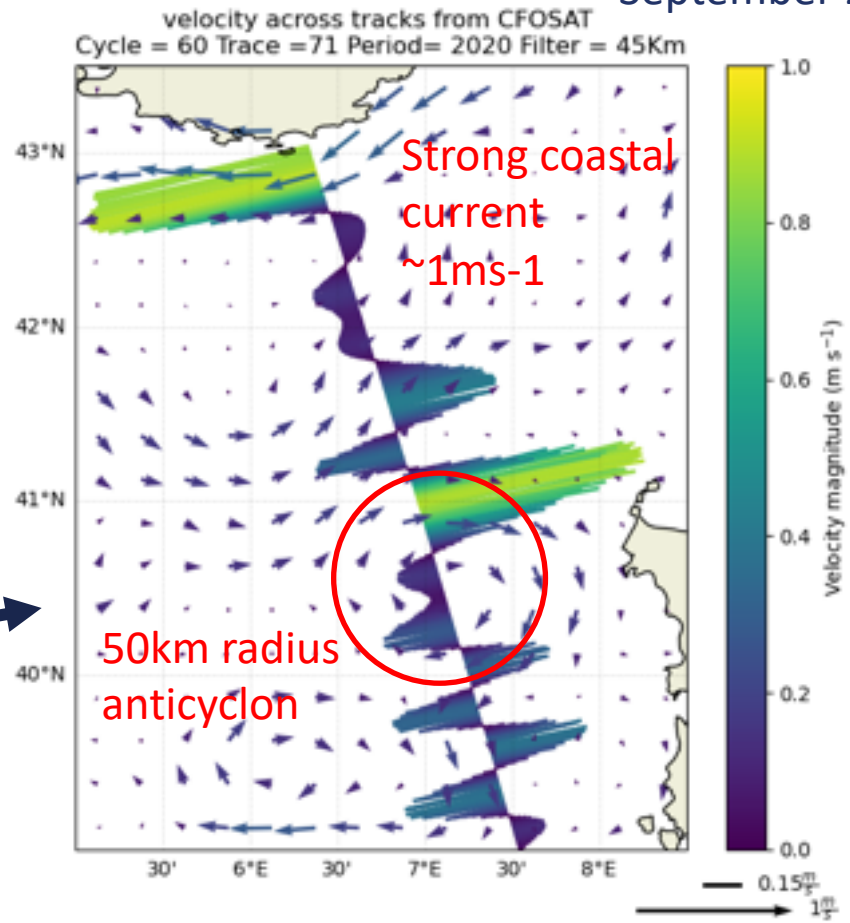
Coming weeks: CFOsat geostrophic currents

CFOsat altimeter system capability

- Poor performances at large scales due to Orbit quality =>DUACS multimission used instead (>1000km wavelength)
- Good performances at mesoscales.
- With appropriate filtering (~50km), CFOsat can provide an interesting set of across-track Geostrophic Currents
- Example shows 1 day of coverage at 5Hz

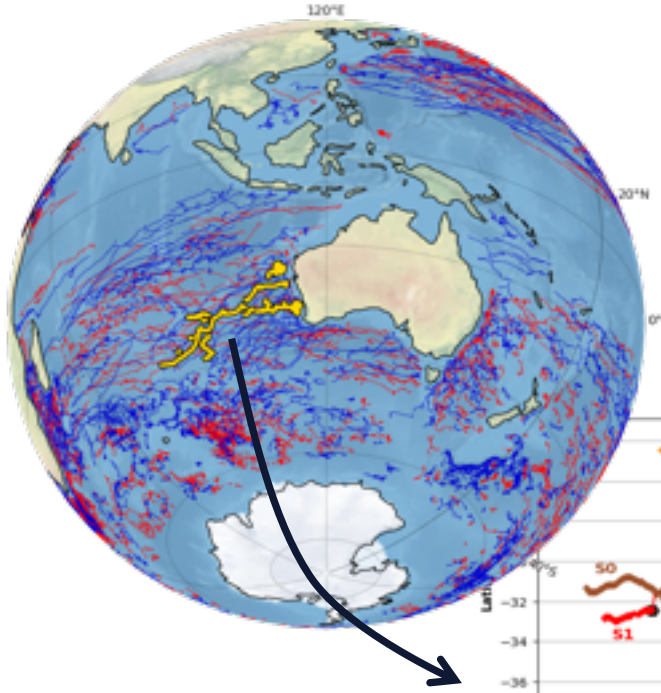


September 2020

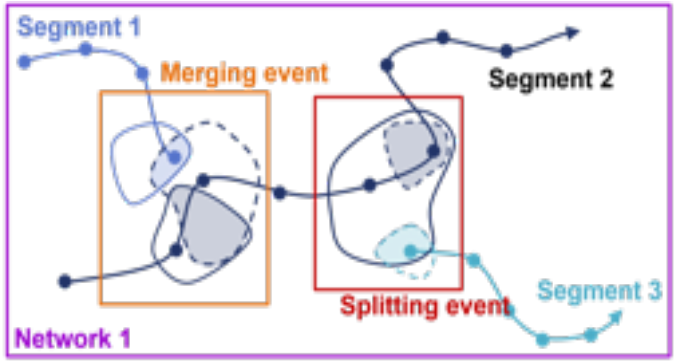


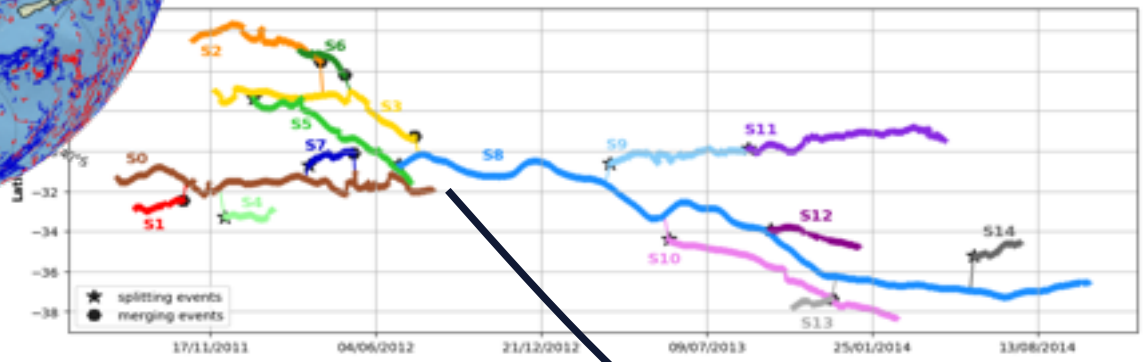
- More dynamic in across track direction compared to gridded maps
- Interest of using perfectly collocated SWIM SWH spectra and across track current
- Demo product over 1 year (2021) available early 2023

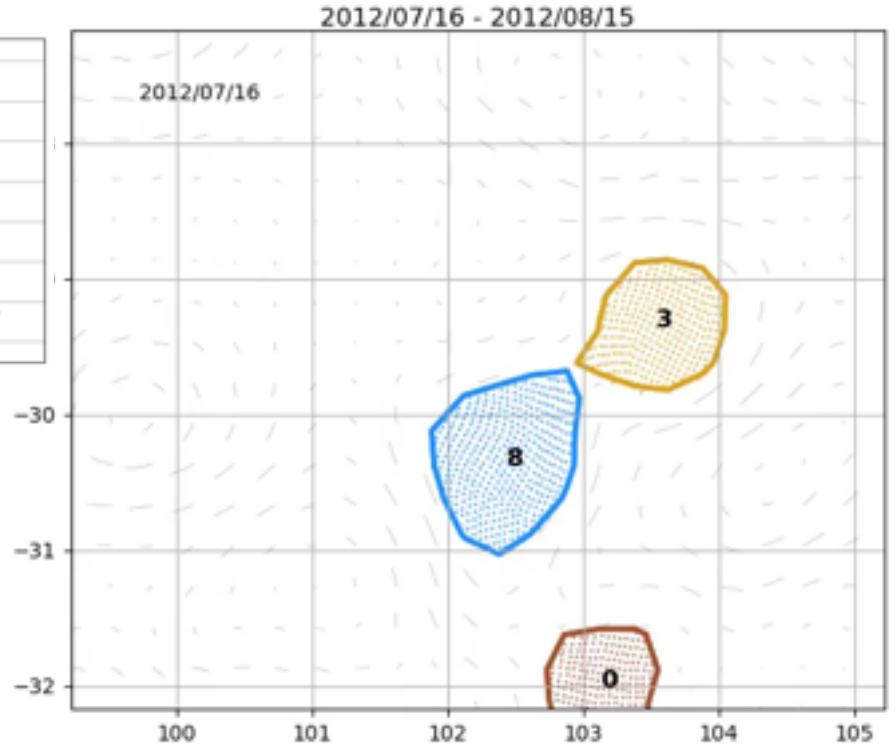
Coming weeks: New eddy network



- Managing interactions between mesoscale eddies (e.g. merging and splitting events) is necessary to properly understand the dynamics of these structures.
- The daily detected eddies are gathered in networks, where segments are linked by interactions identified by an Eulerian method
- Assessment







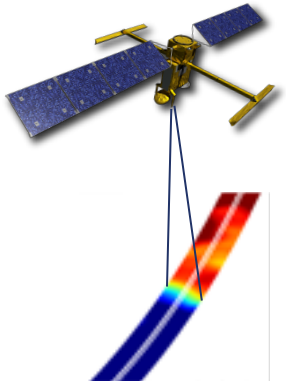
30-year atlas META3.2 (w/o interaction) available

30-year atlas META4 (with interaction) available end 2022 on Aviso (30M obs, 20K interactions)

[Open source code](#)

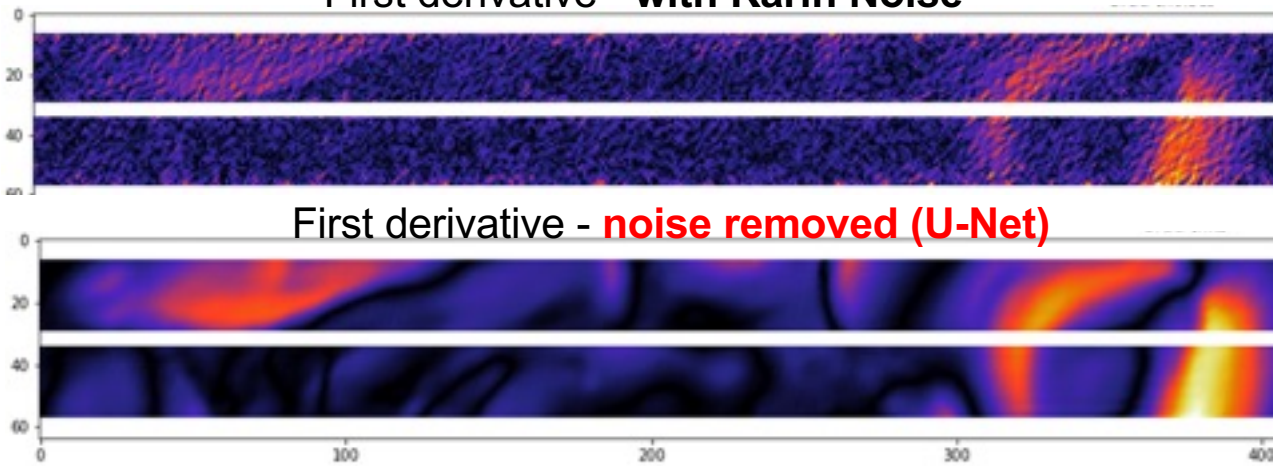
The particles injected in S3 before the merging and advected forward in time wrap around the core of S8 and stay stable in time.

Coming Years: Swath altimetry

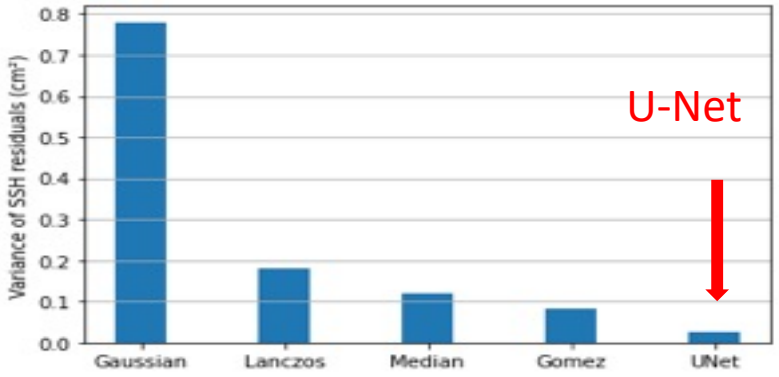


SWOT launch december 2022!!

Access to 2D fields:
=>need 2D Multimision Xcal, 2D Editing procedure , 2D Filtering, 2D longwave length homogeneisation, subsampling, …

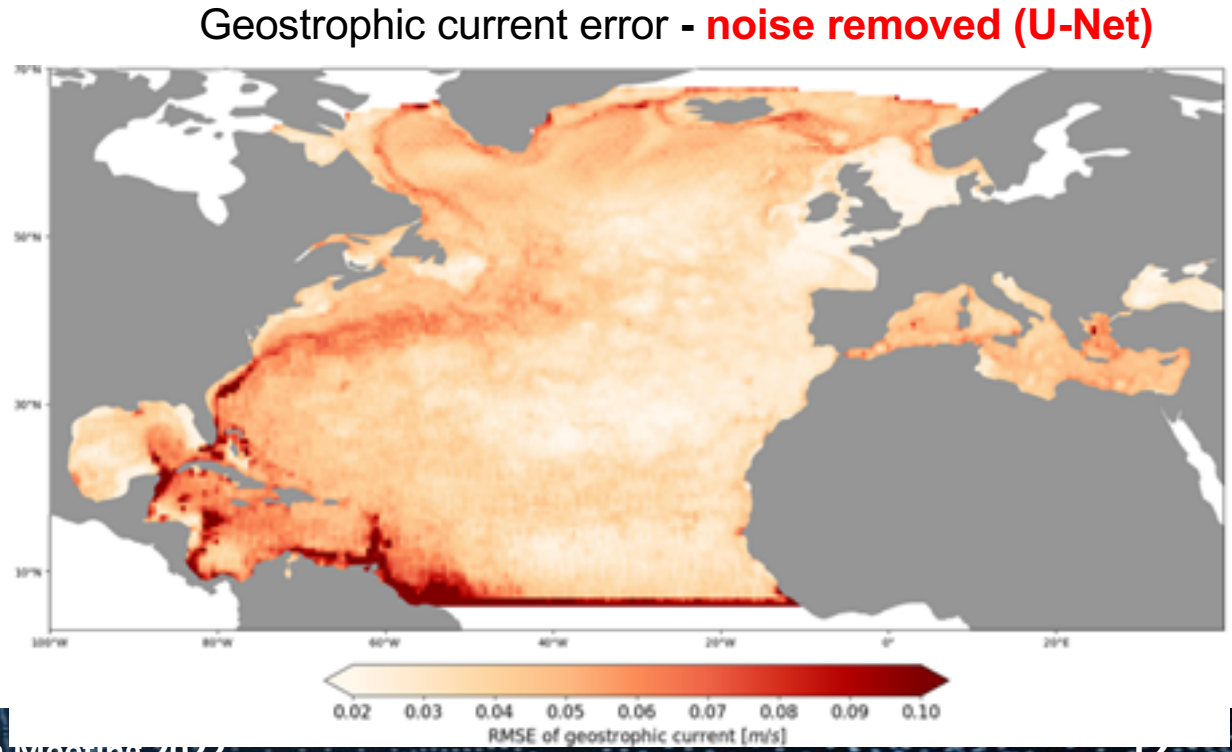


→ Exemple : use of a IA-based (U-Net) method to mitigate the Karin noise, better results than classical filters (Gaussian, Lanczos, Median filters) =>**10km resolution capability** based on current simulated error scenario



Set up of a datachallenge:

https://github.com/ocean-data-challenges

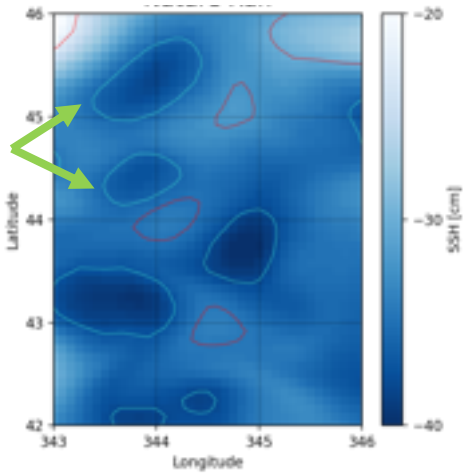


Coming Years: Optimized gridded products

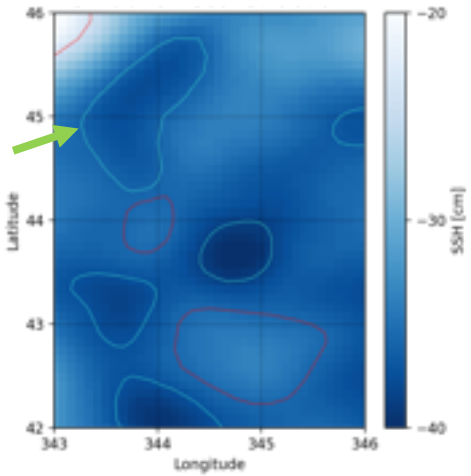
Mapping OSSE experiments

V. Bellemin-Laponnaz et al,
Paper in prep.

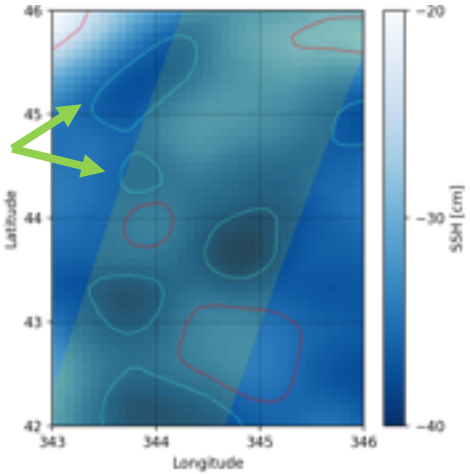
Truth (GLORYS12)



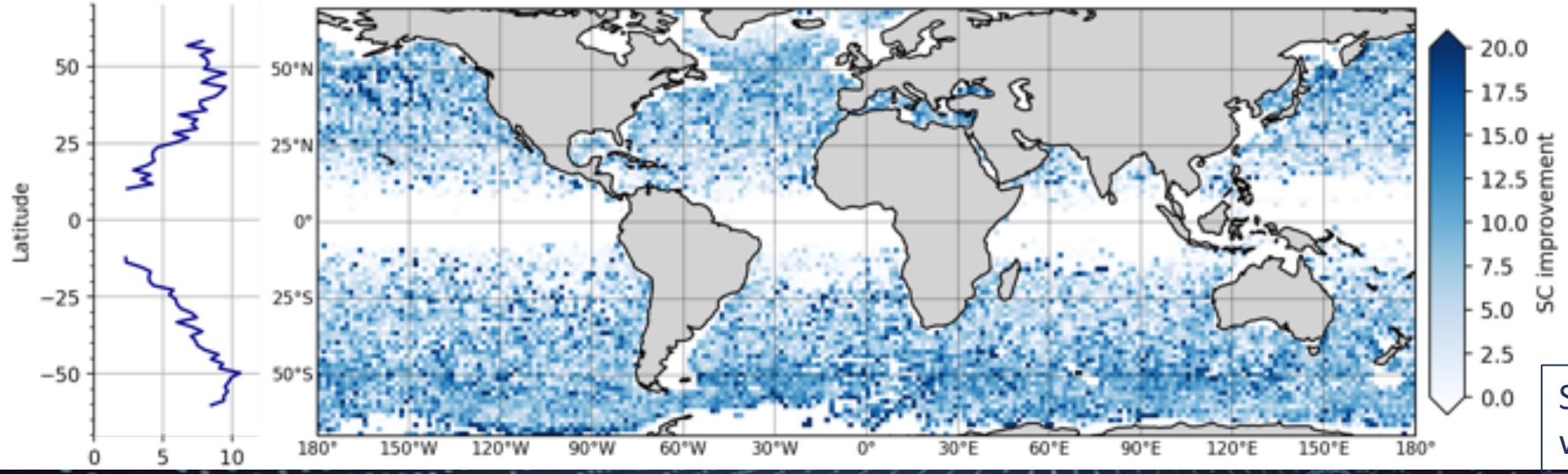
3 Nadirs reconstruction



3 Nadirs + SWOT reconstruction



SC improvement when SWOT is added to a 3 Nadirs constellation (eddy with radius <50km)

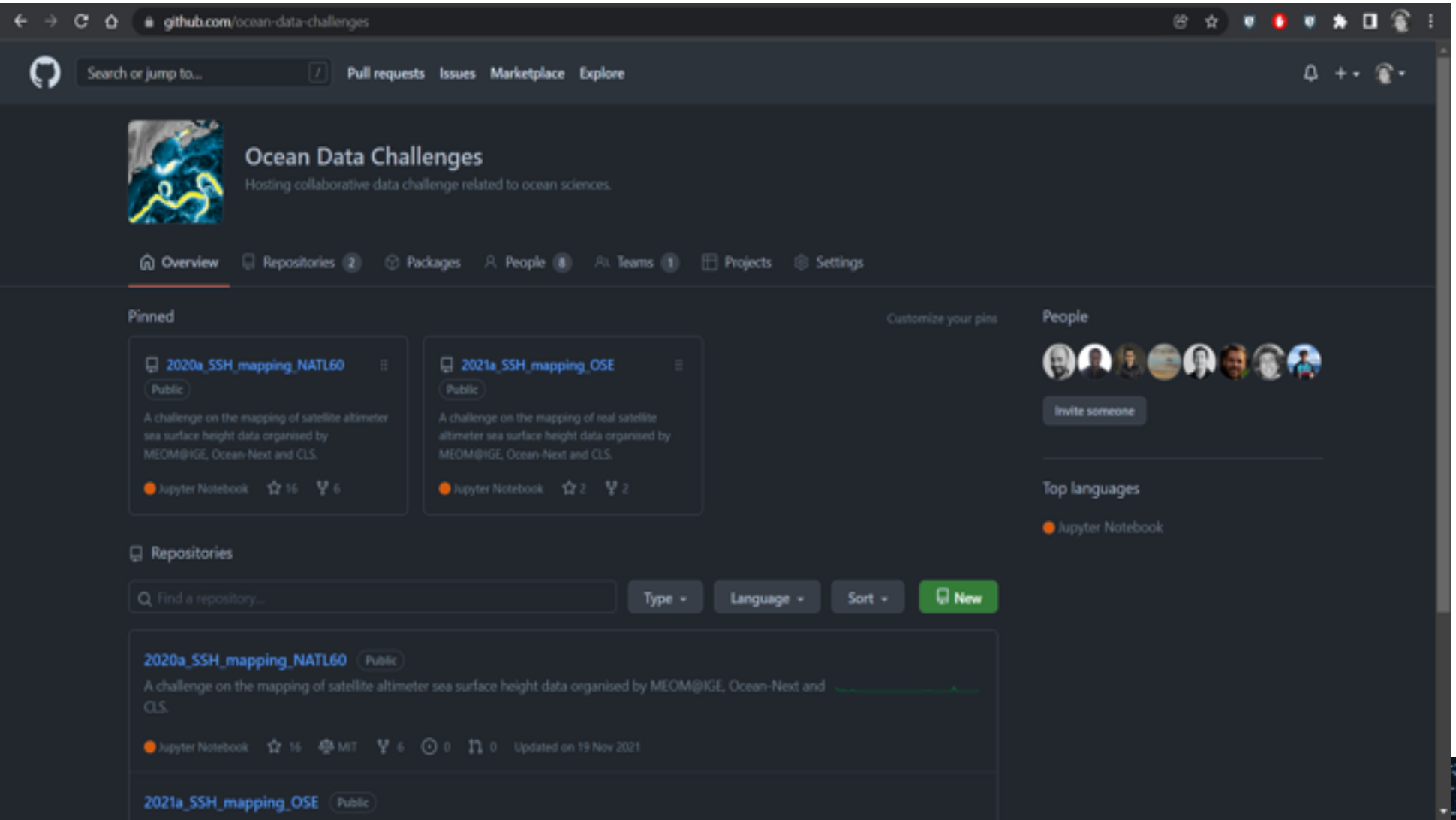


☞ **Improvement in eddy detection accuracy (SC)**
btw. 5 to 10 %
☞ Higher at high latitudes

SC : Percentage of the eddy surface well mapped by satellite reconstruction

Coming Years: Optimized gridded products

- Interest of « datachallenges » to intercompare the methods on a fair basis (same input, same diagnostics, …)
- Exemple of the BOOST-SWOT datachallenge (ANR project with MEOM-IGE, Ocean Next, IMT-Atlantique, CLS)



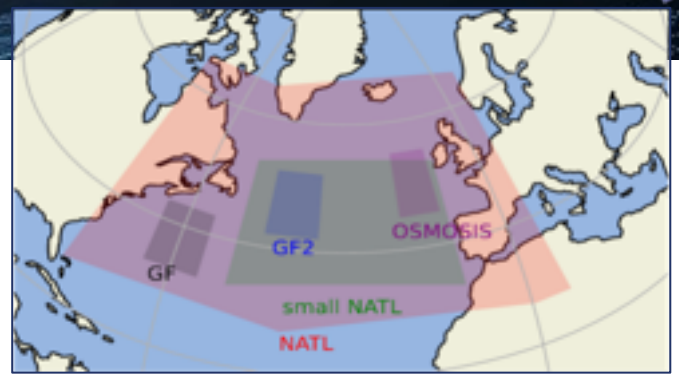
More info on https://www.aviso.altimetry.fr/en/data/products/ocean-data-challenges.html

Follow up in a Copernicus Marine Service Evolution project

Coming Years: Optimized gridded products

- Datachallenge over the GulfStream region (GF)

Method	μ(RMSE)	σ(RMSE)	λx (degree)	λt (days)
duacs 4 nadirs	0.92	0.01	1.42	12.0
bfn 4 nadirs	0.92	0.02	1.23	10.6
dymost 4 nadirs	0.91	0.01	1.36	11.79
miost 4 nadirs	0.93	0.01	1.35	10.19
4DVarNet 4 nadirs	**0.94**	**0.01**	**0.83**	**8.01**
duacs 1 swot + 4 nadirs	0.92	0.02	1.22	11.15
bfn 1 swot + 4 nadirs	0.93	0.02	0.8	10.09
dymost 1 swot + 4 nadirs	0.93	0.02	1.2	10.07
miost 1 swot + 4 nadirs	0.94	0.01	1.18	10.14
4DVarNet 1 swot + 4 nadirs	**0.95**	**0.01**	**0.62**	**5.29**



Best results for the AI based 4DVarNet algo (R. Fablet) trained on Natl60

- AI method 4DVarNet have very good mapping performances in OSSE: **50% improvement vs OI DUACS (space and time)** in a « swot + 4 nadirs » configuration
- Application on **real data (OSE) is also positive: 30% improvement (space)** resolution vs OI DUACS in a « 4 nadirs » configuration => also demonstrates the quality of eNatl60 fields
- **Adding SST information to the SSH** still improves the metrics: **up to 50% improvement in OSSE (time), 10% in OSE (space)**
- **4VarNet is promising to optimize the use SWOT data in the gridded Sea Level products**

Fablet et al. Learning Variational Data Assimilation Models and Solvers. JAMES, 2021.
https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021MS002572
M Beauchamp et al, Intercomparison of data-driven and learning-based interpolations of along-track nadir and wide-swath swot altimetry observations. Remote Sensing

Next step planning

- SWOT demo products target - **Fall 2023**
  - SWOT 21-day : demo products after release of prevalidated products by CNES
  - SWOT-1 day: after reprocessing by JPL
- Preoperational Products (on the fly) - **end 2023**
- SWOT operational in Copernicus Marine service - **2024+**

We welcome any contribution for L3/L4 processing for intercomparison and possible integration

More info:

CNES/Aviso Catalogue	Marine Service Catalogue	contact: yfaugere@groupcls.com

Thank You !