Opportunities and Challenges for new ocean current observations with the SWOT Mission
Surface Water and Ocean Topography (SWOT)

Rosemary Morrow, SWOT CNES Ocean Lead

SWOT:

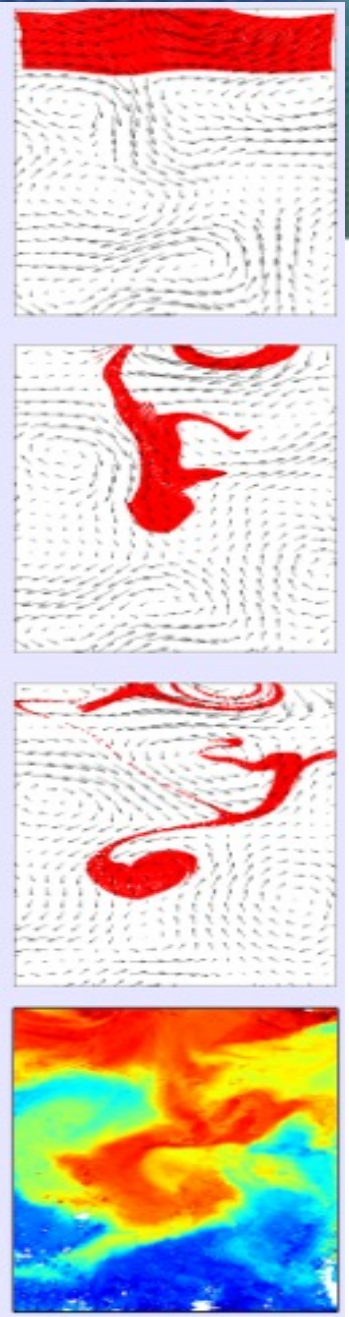
1st global wide-swath altimetry mission using SAR-Interferometry

3 science communities: Hydrology, oceanography & coastal

Launch : Early Dec 2022 !

ESA World Ocean Circulation meeting, 12/10/2022

Today's Mapped altimetric geostrophic currents > 100 km & horizontal advection



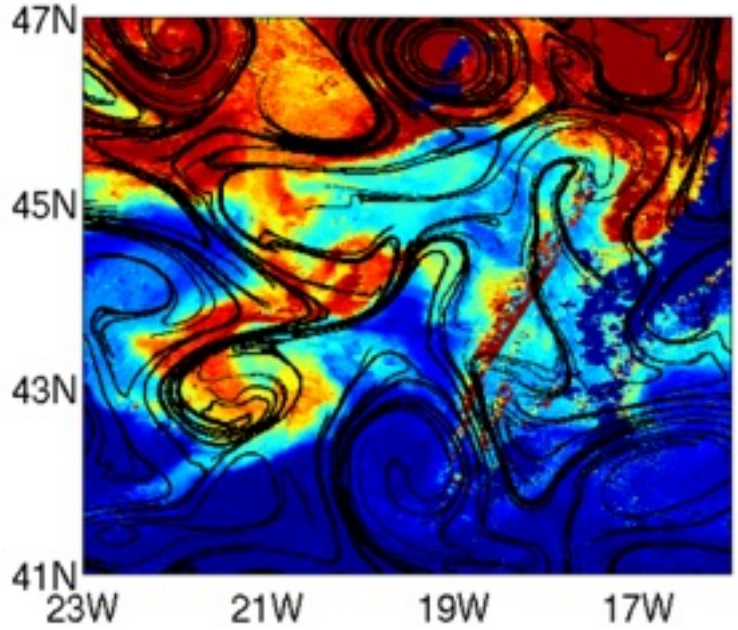
Day 0

Day 10

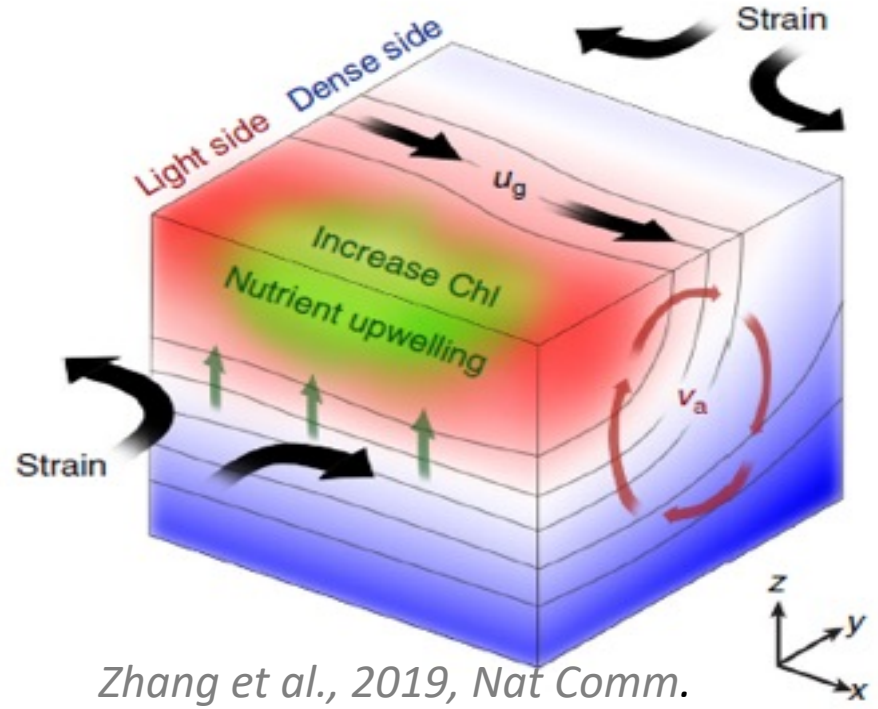
Day 15

Chlorophyll Day 15

- horizontal stirring structures the surface tracer fields (SST, SSS, ChlA, pollutants, …)
- Lagrangian particle tracking & statistics, eg Lyapunov Exposants (FSLE, FTLE, …)
- Strain/deformation driving vertical transfers
- Dispersion & diffusion



Credits : F. d'Ovidio



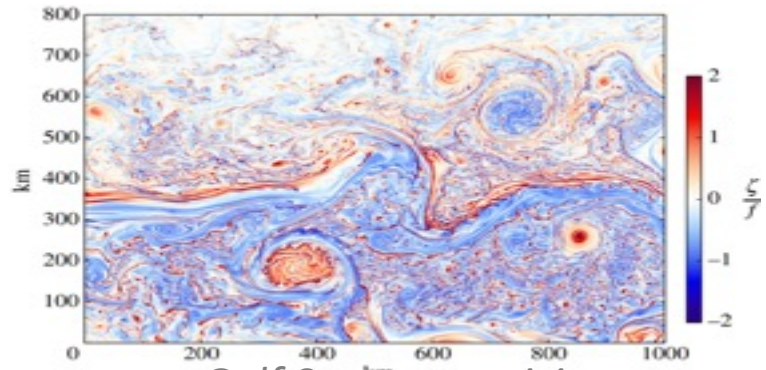
Zhang et al., 2019, Nat Comm.

Missing Today => Smaller scales

- Smaller mesoscales (open ocean, regional seas, coastal, high latitudes, …)
- Meso & Submesoscale interactions driving vertical velocities

SWOT Ocean Opportunities

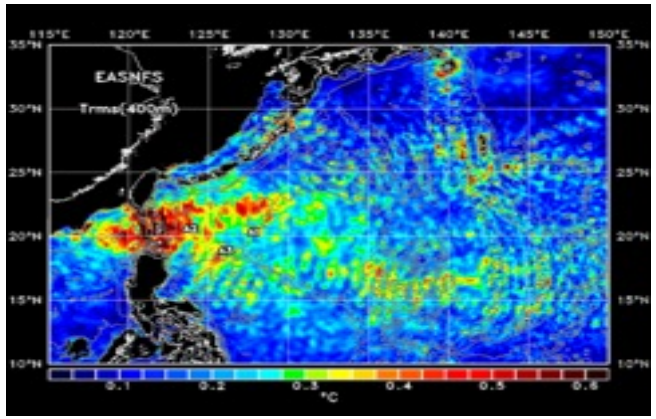
Today altimetric 2D sea surface height maps resolve ocean scales of 150-200 km
=> SWOT aims to observe **2D ocean dynamics at 15-40 km effective resolution**



Gulf Stream vorticity

Opportunities :

- Improved 2D observation of horizontal **ocean currents & energy cascade** down to finer scales
- Finer horizontal currents to derive **vertical velocities** : study the ocean's capacity to stock heat, carbon and nutrients
- Extending 2D SSH/currents into **coastal/estuary regions & high-latitudes to 78°**
- Orbit designed to resolve **tides, internal tides** & improve **marine gravity fields**
- Observe the dynamical **interaction between ocean eddies / jets and internal tides** => important for dissipation & mixing



SSH of Internal Tides

SWOT -2D SAR-Interferometry data products

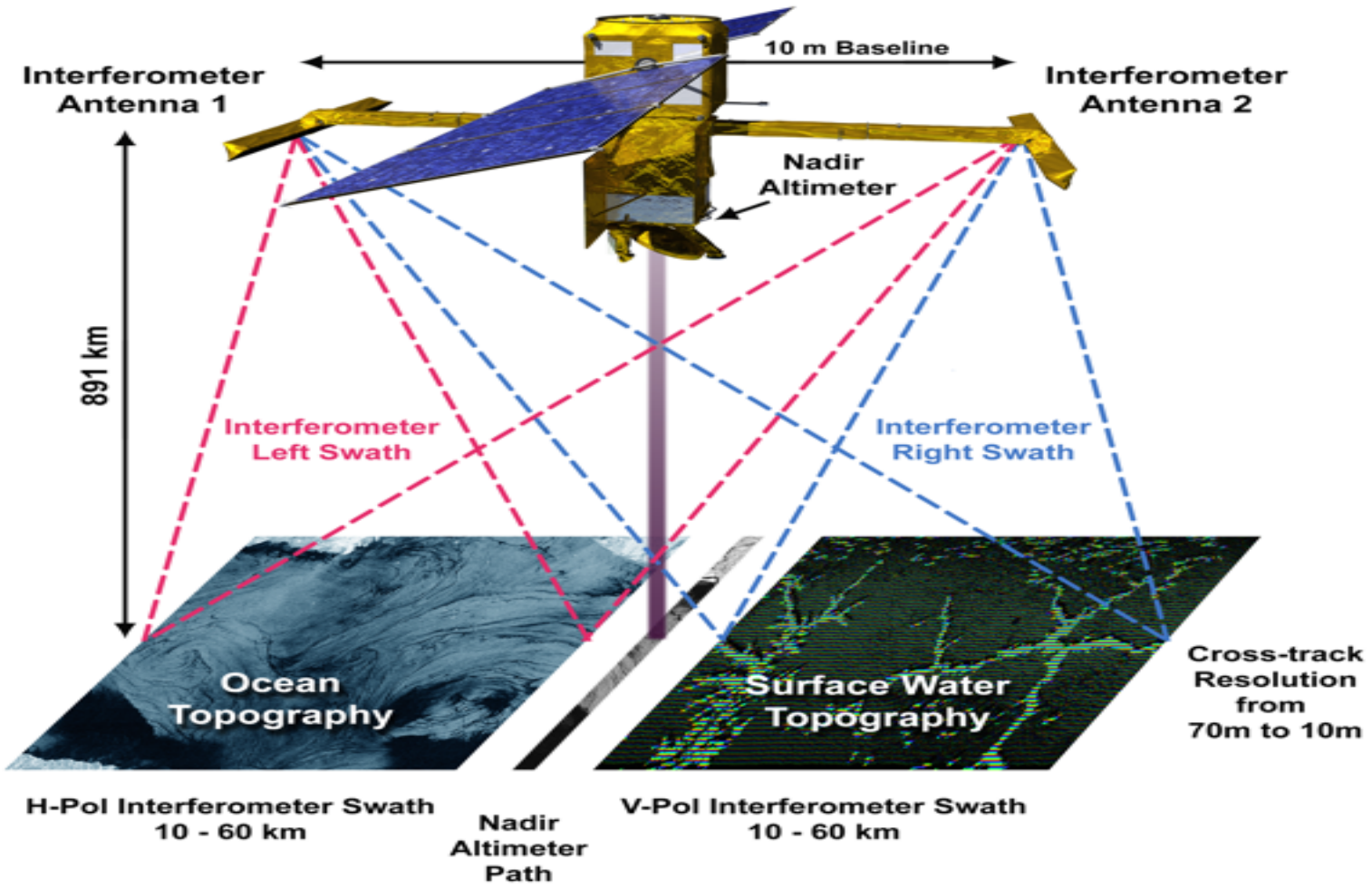


Image Credit : K. Wiedman

Over Land : Full resolution within land mask

Resolve Rivers > 100 m, Lakes > 250m^2

Higher noise

Over Oceans : Onboard Processor performs initial SAR-Interferometry processing reduces data download volume

Basic SSH product
(**2 km** resolution/posting)
(0.6 GB/day) **σ = 1.37 cm**

High resolution product: SSH & SAR images (**250m** posting / 500m res)
(37 GB/day) **σ = 5.48 cm**

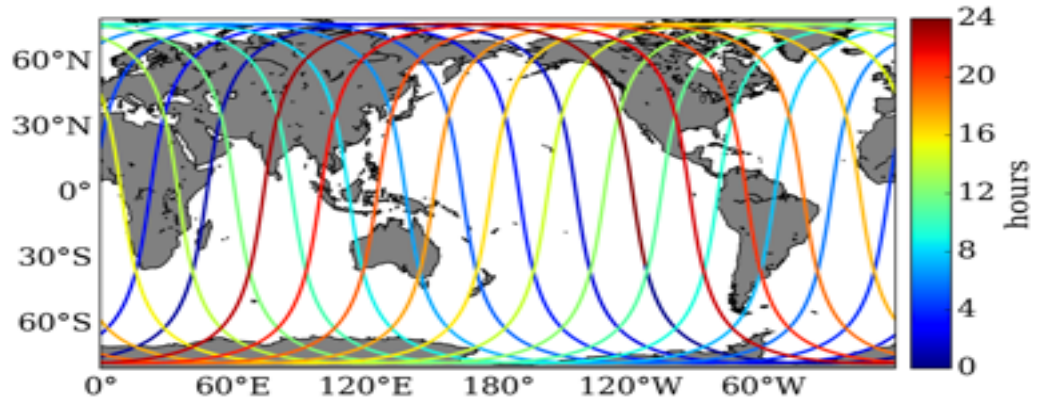
SWOT orbits & land mask

First 6 months : 1-day orbit :

1st 3 months – instrument checkout

2nd 3 months – Mar-May 2023 – Validation

- Ideal for ocean studies of rapidly evolving small mesoscales and submesoscales



3-years in 21-day repeat orbit

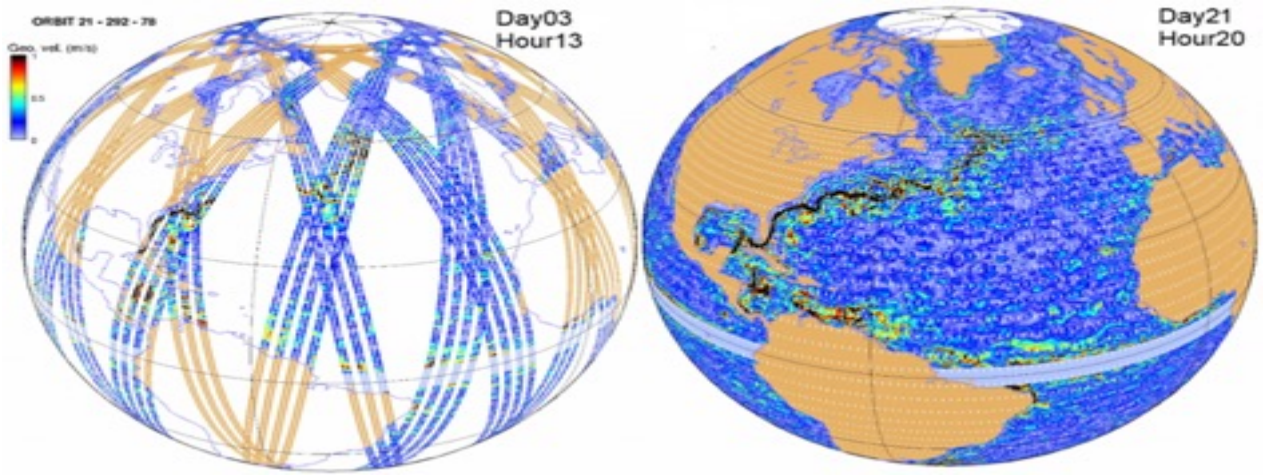
Nominally : 2023 to 2025

Full global coverage

1-day and 10-day sub-cycles for better mesoscale coverage

After 3 days

After 21 days



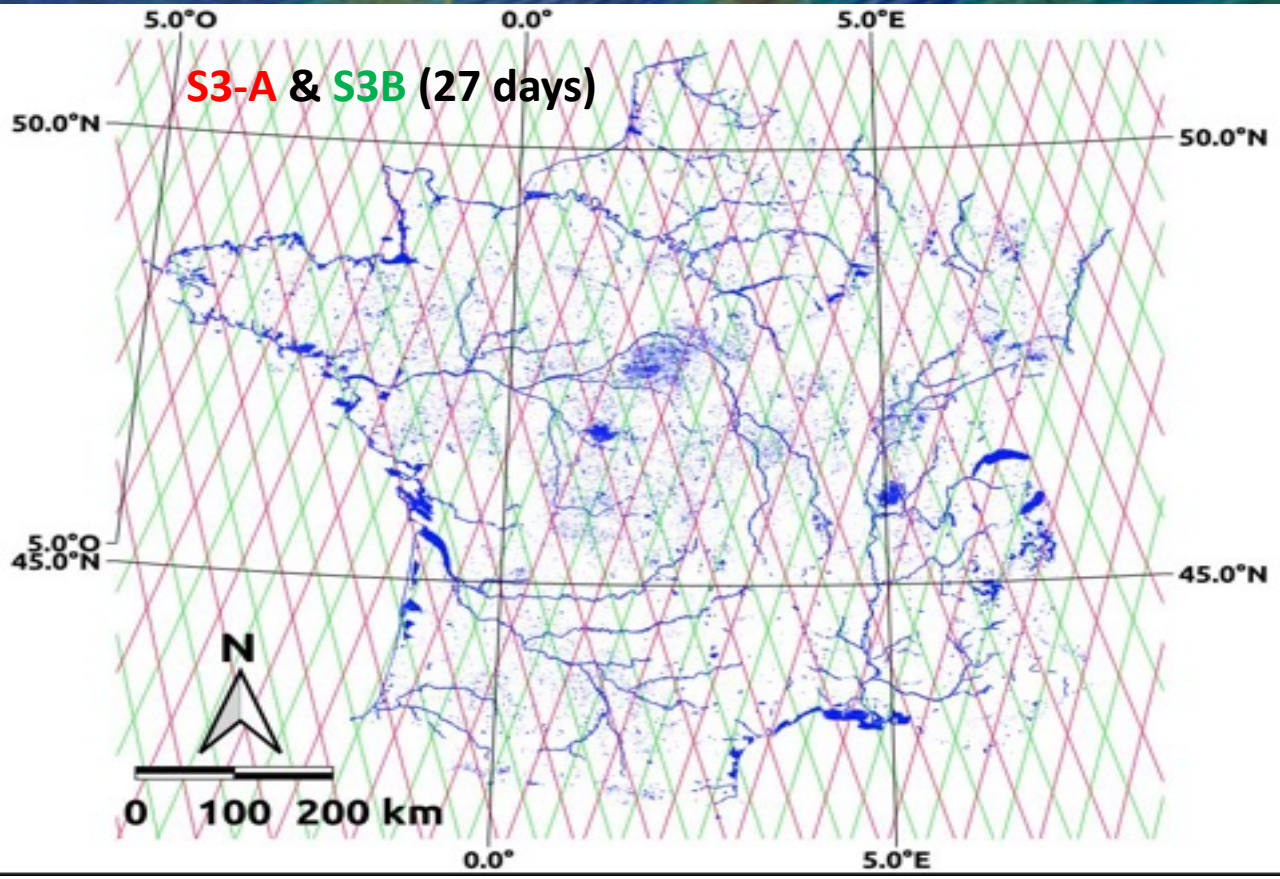
Orbit kmz files available on AVISO+ SWOT orbits

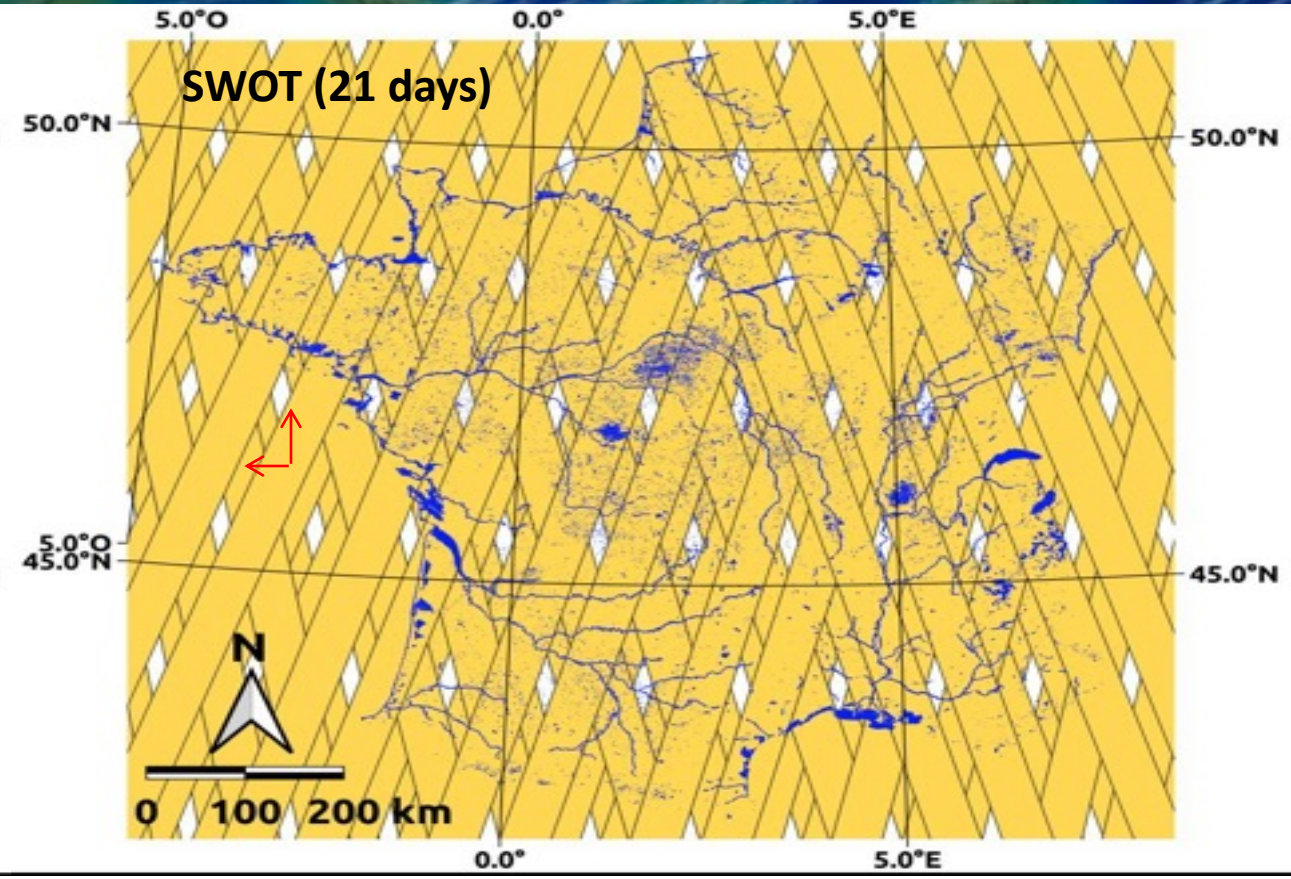
Land Mask

High-resolution data downloaded over land & 3km from coastlines

Low-resolution (2 km & 250m data) from onboard processor : global

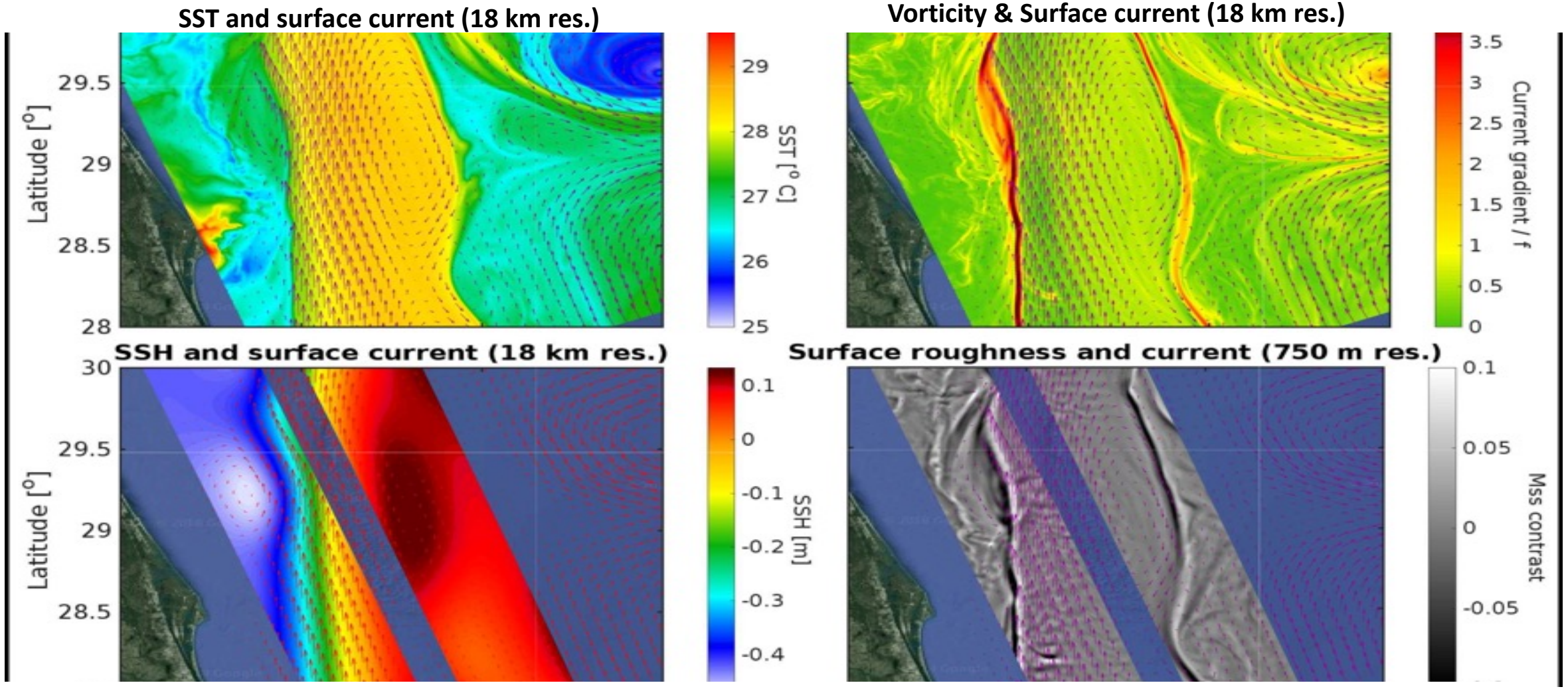
Comparison S3-1D vs SWOT-2D spatial coverage





- Global coverage only possible with wide swath altimetry -> many new coastal and hydrology zones will be seen
- A joint 2D observation of height & slopes for u_g, v_g currents < 150 km

SAR-Interferometry : Colocated all-weather SSH and SAR imagery for ocean front detection



SWOT SAR images at 250 m res. *credits Ifremer*

Upper panel : modelled surface currents, SST & vorticity across the Gulf Stream

Lower panel : simulated SWOT swath of SSH, geostrophic currents and SAR surface roughness

New SSH signals from 15-150 km

Deriving ocean geostrophic currents
Ocean tidal & internal tidal currents

Geostrophic currents & vorticity

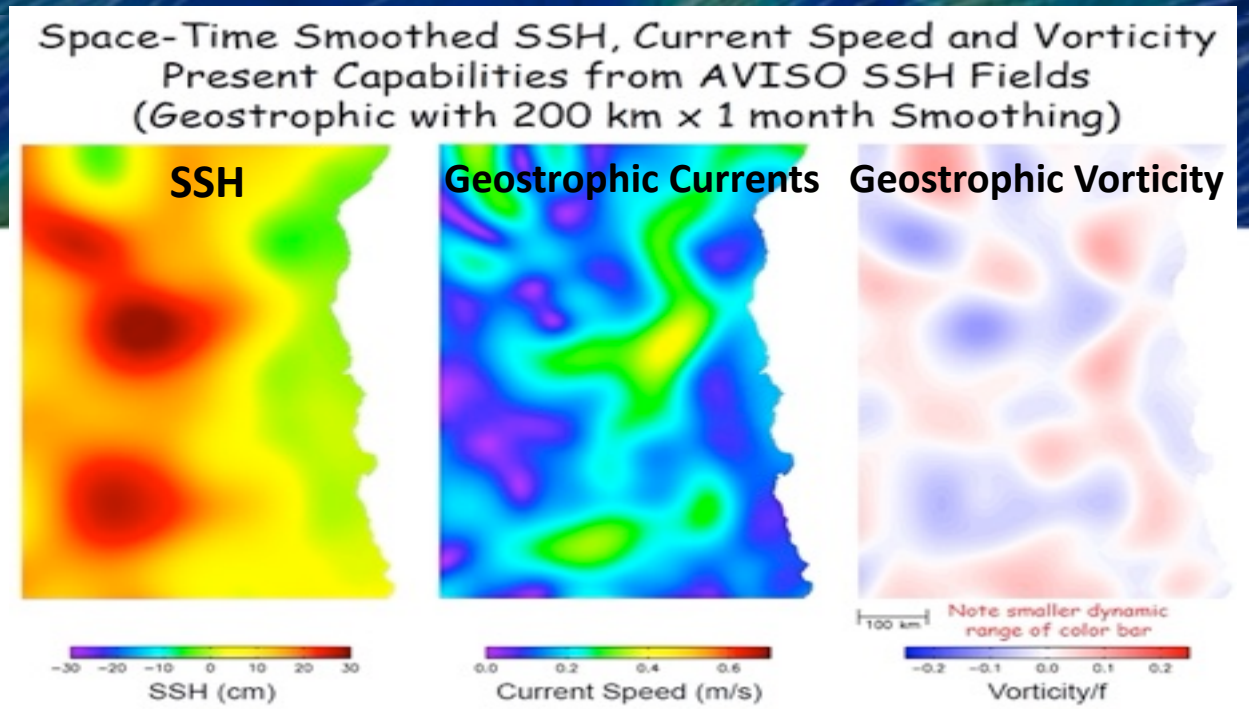
why horizontal SSH resolution is important

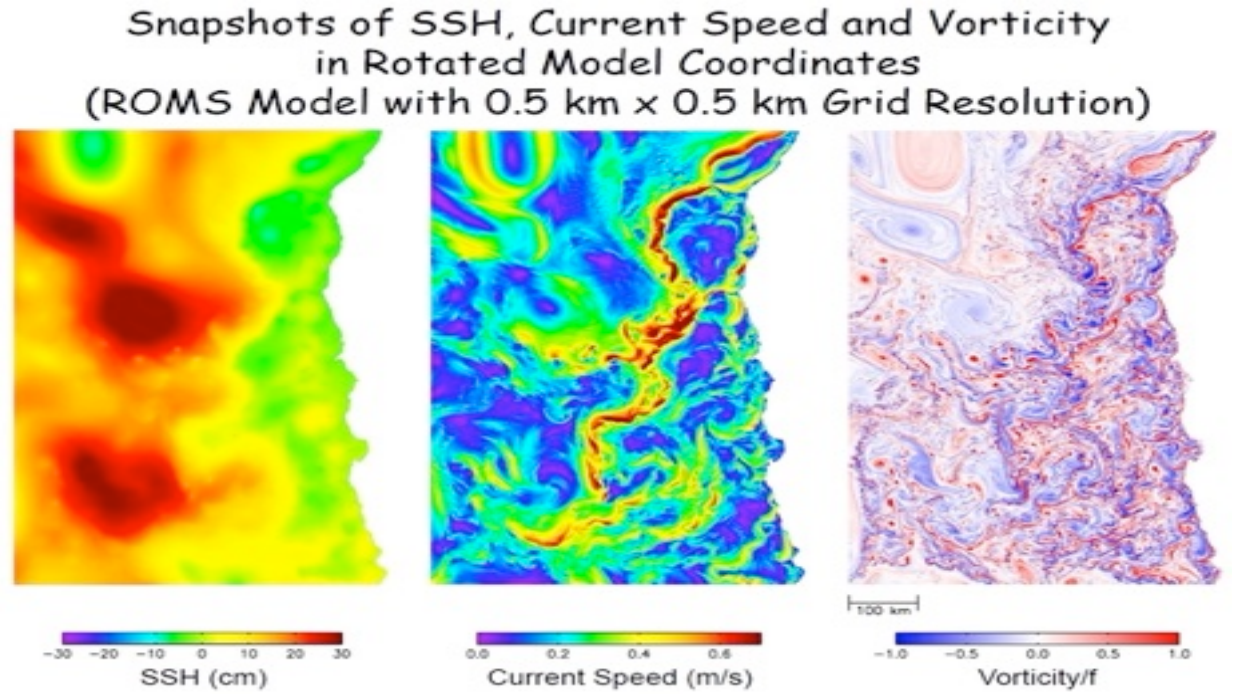
Today's 2D Mapping of AVISO-like observations smooth SSH & derived currents, vorticity

Mapping of SWOT-like observations of SSH, currents, vorticity

⇒ More anisotropic

⇒ Sharper gradients in currents & vorticity





Chelton et al, PO, 2019

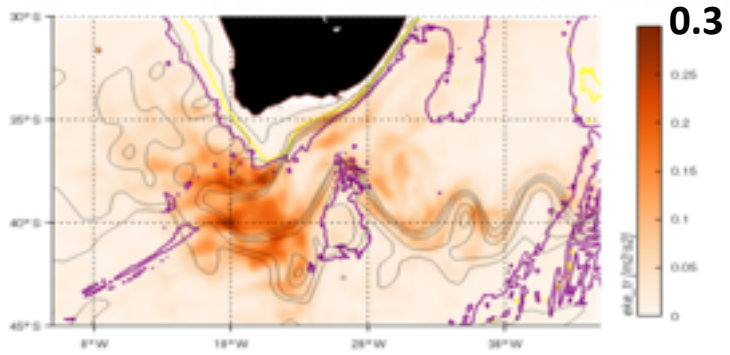
Eddy diagnostics (u_g, v_g), MITgcm model 1/20°

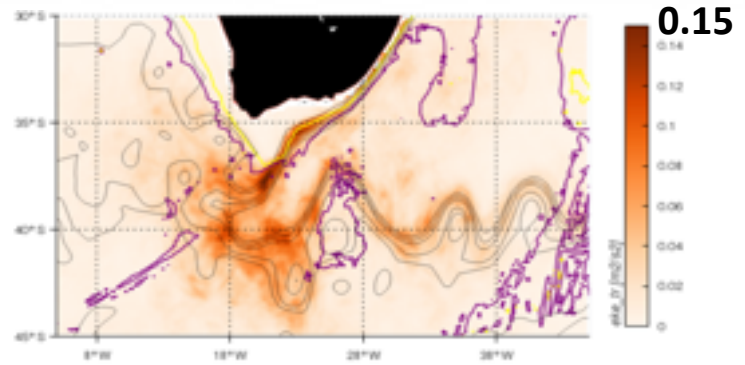
Today's scales > 150 km

New scales from SWOT < 150 km

EKE: Similar amplitude, different distribution

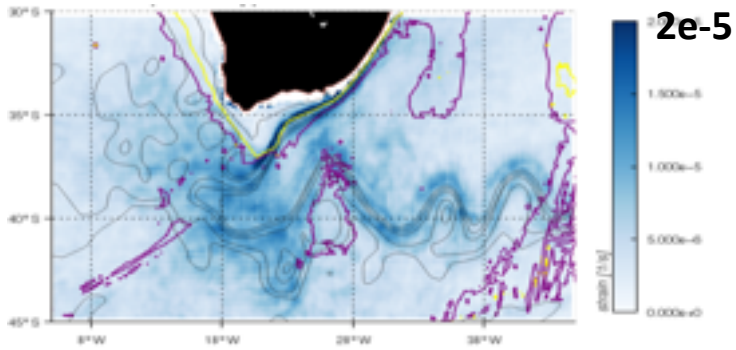
$$EKE = \frac{1}{2}\left(u'^2 + v'^2\right)$$

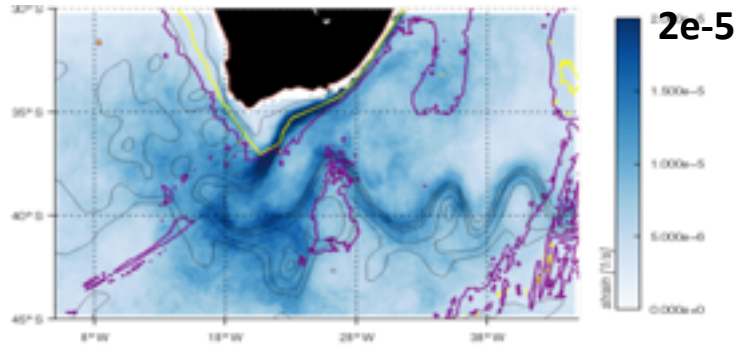




Strain: Fine scales 3x more energetic in boundary currents & meandering fronts

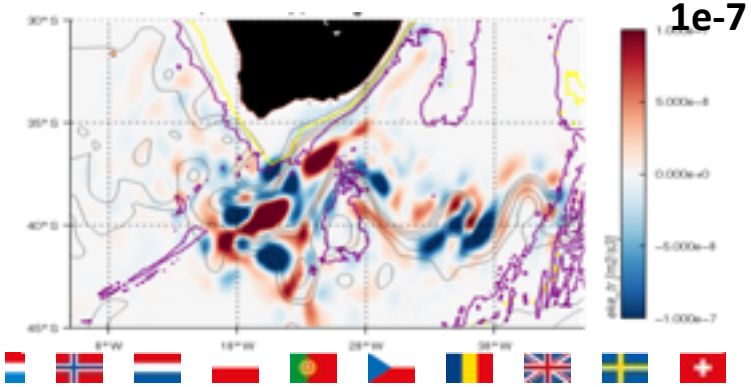
$$S_g = \sqrt{\left(\frac{\partial u_g}{\partial x} - \frac{\partial v_g}{\partial y}\right)^2 + \left(\frac{\partial v_g}{\partial x} + \frac{\partial u_g}{\partial y}\right)^2}$$

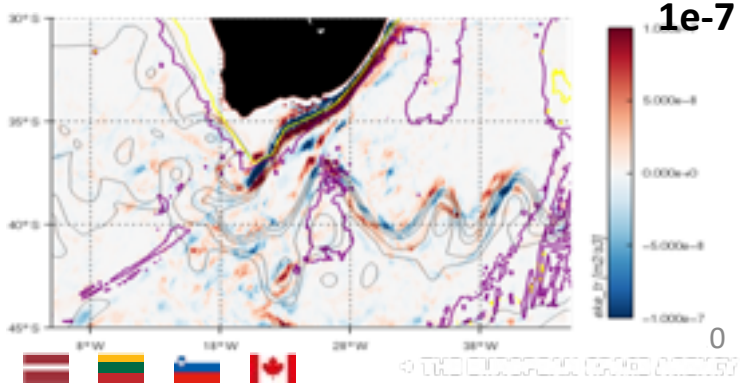




BT EKE transfer: Finer-scale energy transfer mainly in boundary currents

$$EKE_{tr} = \overline{u'u'}\frac{\partial \bar{u}}{\partial x} + \overline{v'u'}\frac{\partial \bar{v}}{\partial x} + \overline{u'v'}\frac{\partial \bar{u}}{\partial y} + \overline{v'v'}\frac{\partial \bar{v}}{\partial y}$$





Are these model estimates correct? Need finer-scale observations of geostrophic currents

Opportunity & Challenge : Global Barotropic Tides & tidal currents

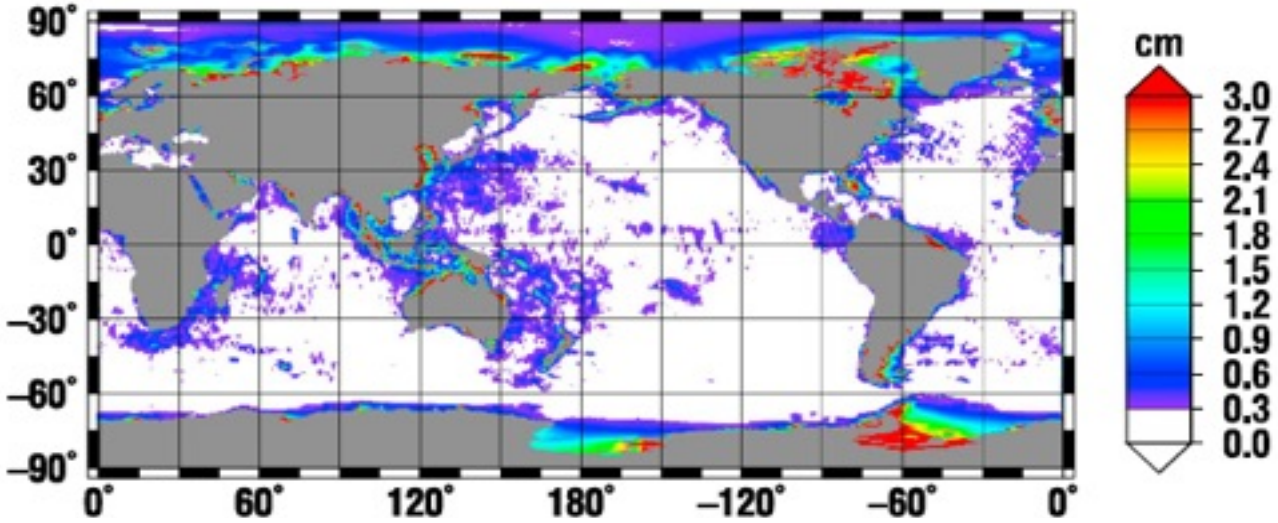
High-frequency barotropic tides are removed from all altimetry missions before calculating geostrophic currents

SWOT **orbit chosen to resolve tides** to 78° latitude

– 3 years of SWOT data will provide finer-scale 2D tides (2km or 500 m grid)

-> Barotropic tides improved in coastal and high-latitude regions

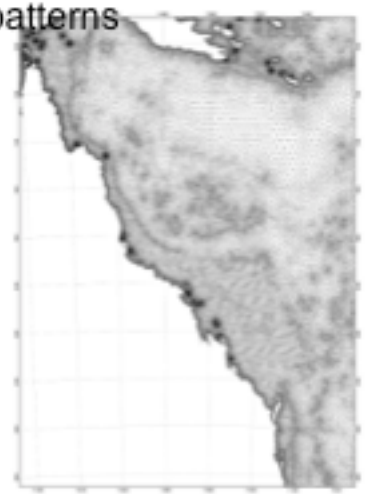
Errors in Today's Barotropic Tide models



St. Dev of 7 global tide models, M2

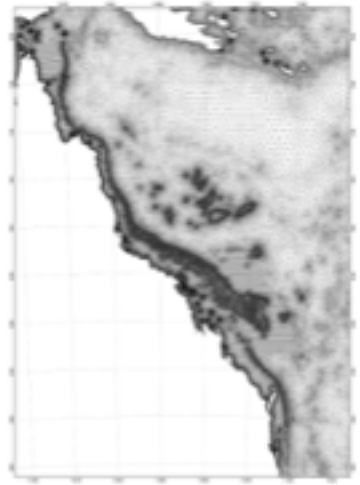
Stammer et al., 2014

Example on the Great Barrier Reef : initial FES2022 mesh, and then refined on the reef patterns

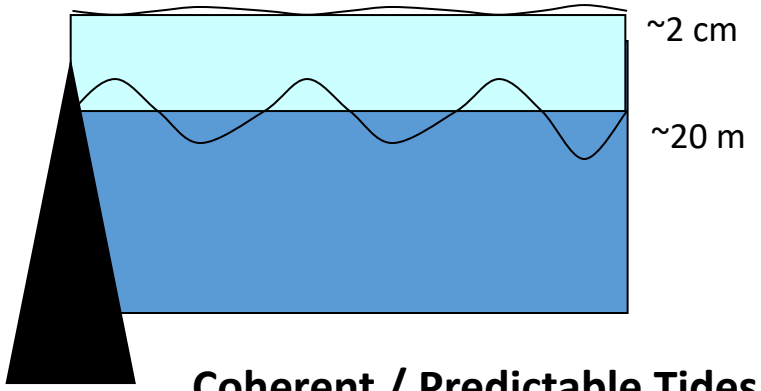


Pre-launch :

Improvements in FES2022 barotropic tide model (bathymetry, 8x more mesh grid, …)

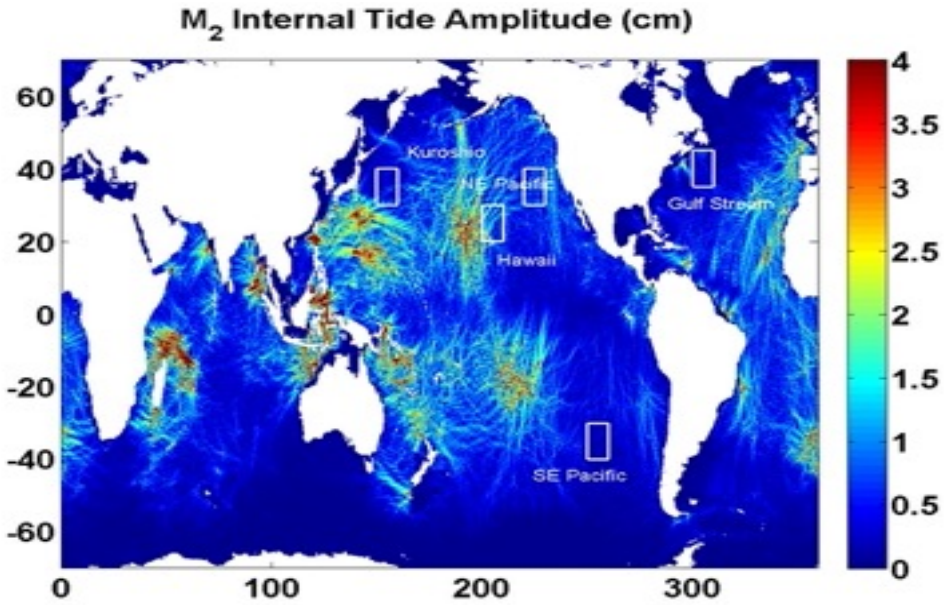


Opportunity & Challenge : Non-linear interactions between Internal tides and mesoscale turbulence



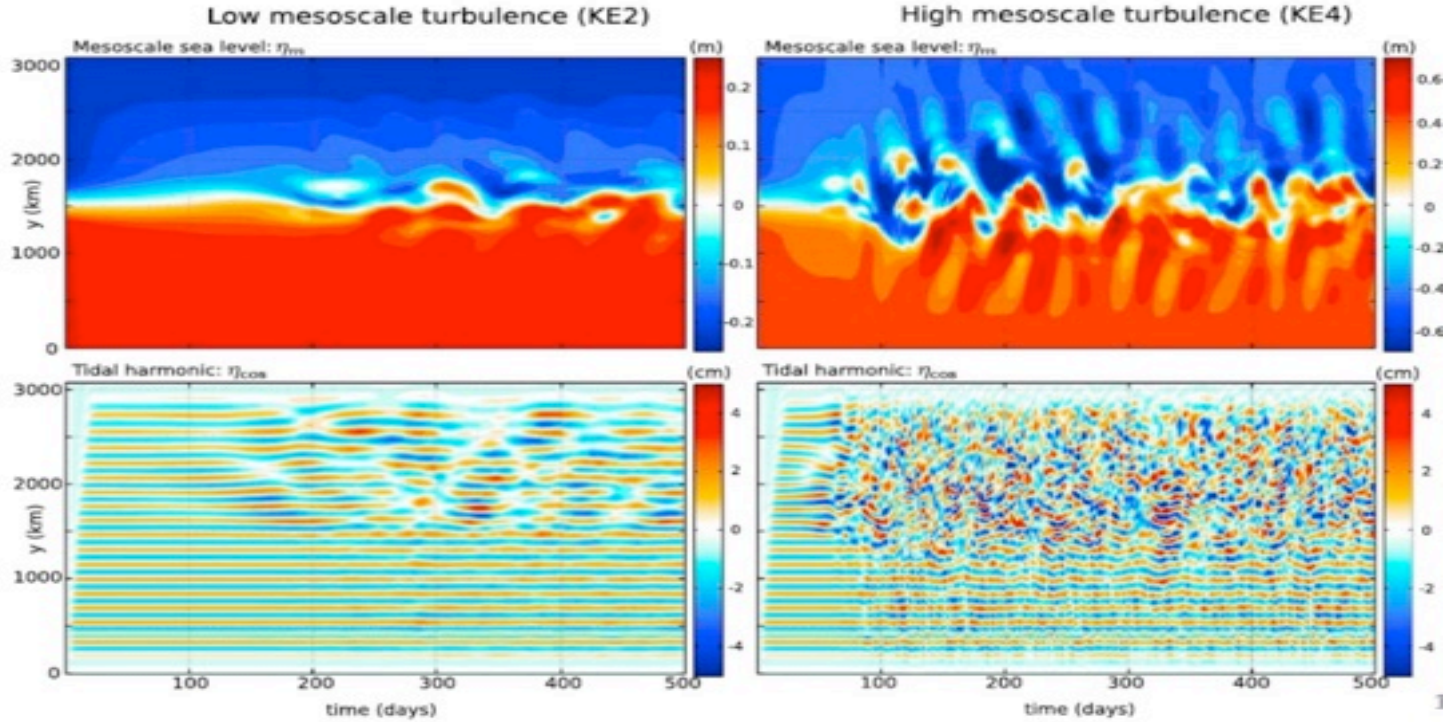
- Coherent tides, can be predicted and removed from altimetric SSH & other data,
  - incoherent tides, non-predictable -> instabilities, mixing, dissipation

Coherent / Predictable Tides



Model : HYCOM 1/12° *Arbic et al., 2012*

Ponte and Klein (2015) idealized experiments on internal tide incoherence



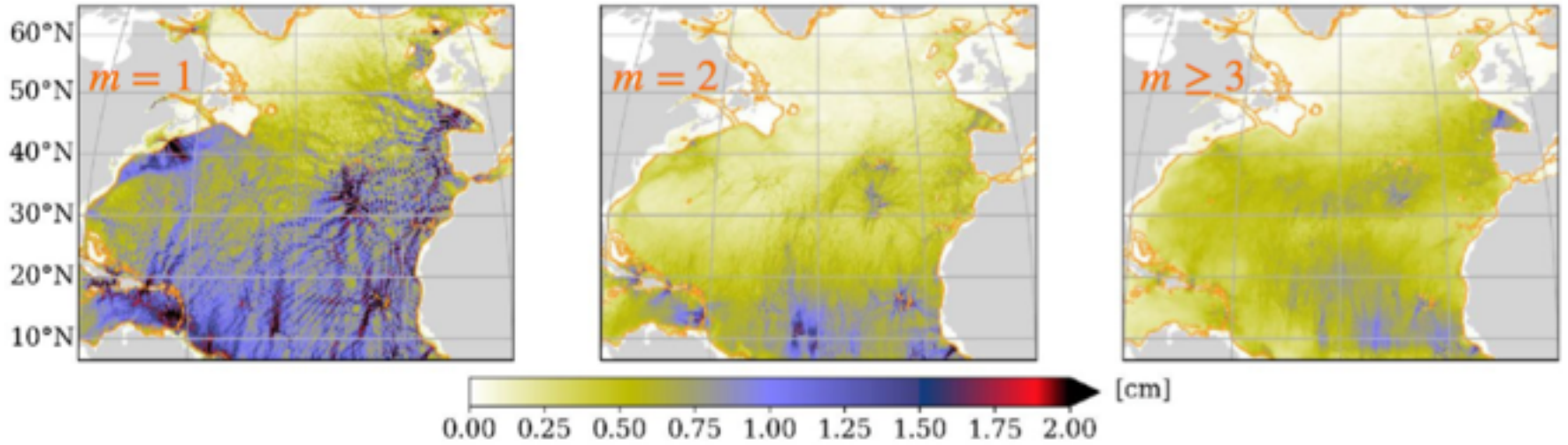
Ponte & Klein, 2015

Incoherent tidal currents (modelled eNATL60)

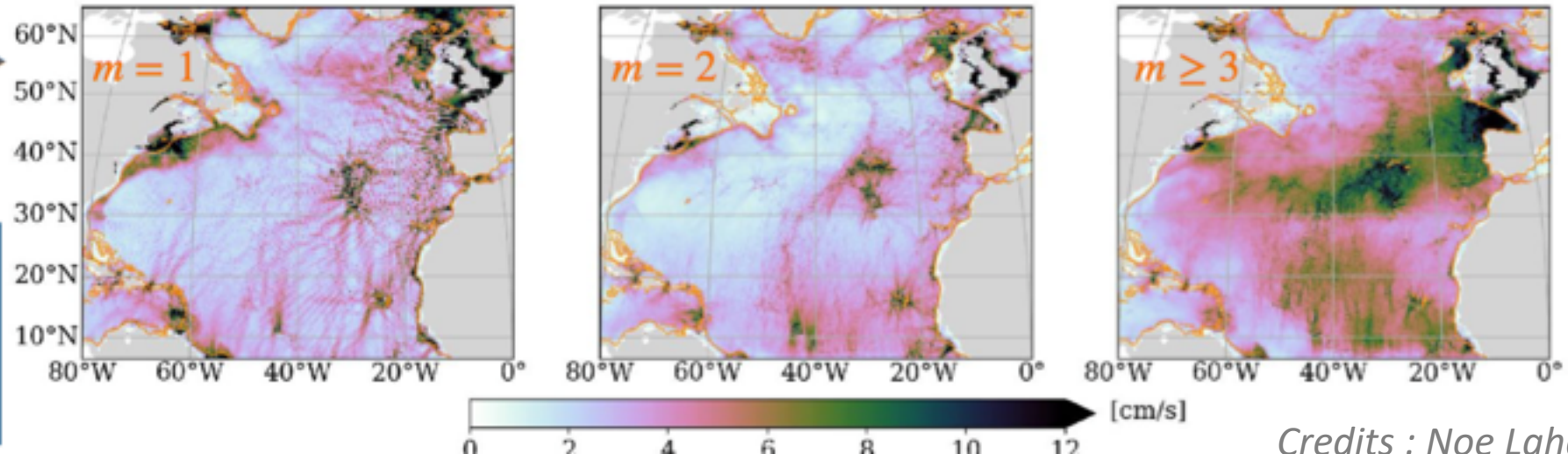
Need more observations to verify

Surface signature per vertical mode

$$\sqrt{\langle \tilde{\eta}^2 \rangle_t} \longrightarrow$$



$$\sqrt{\langle \tilde{u}^2 + v^2 \rangle_t} \longrightarrow$$

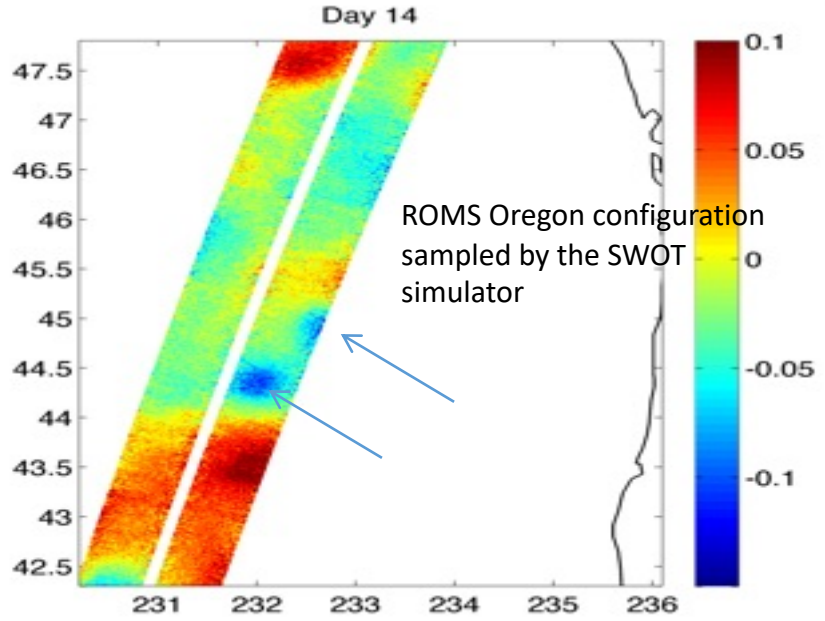


N.B.: Smaller scales in surface currents compared to SLA

Credits : Noe Lahaye

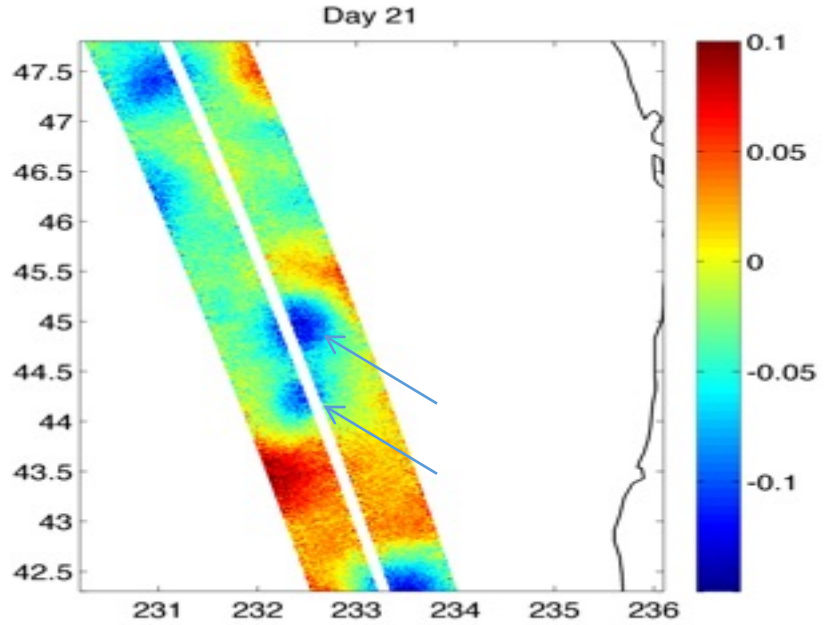
Challenge : 2D Mapping of SSH & currents

How to maintain the high spatial resolution but lower temporal sampling?



ROMS Oregon configuration sampled by the SWOT simulator

Day 17 mapping ?



New solutions needed to maintain fine-scales in observation gaps :

- Combine SWOT & multi-satellite nadir altimetry; synergy with other observations (SST, SSS, drifters, …)
- Dynamical interpolation with simple models; Simple models & stochastic processes;

New solutions needed to deal with mesoscale & internal tides with similar space scales in 2D altimétric « snapshots »

- Simple QG & SW models, AI & full assimilation techniques

Example 2D mapping : Using simple models to solve for balanced & wave dynamics

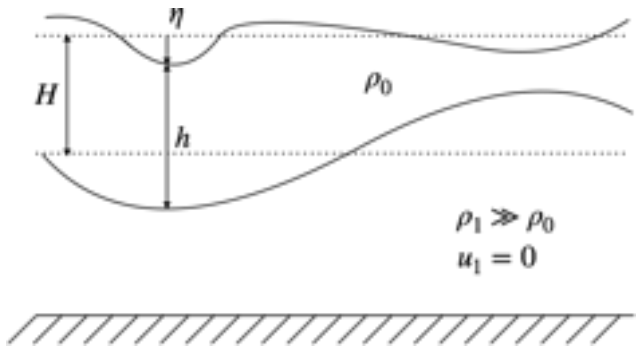
Le Guillou et al., 2022

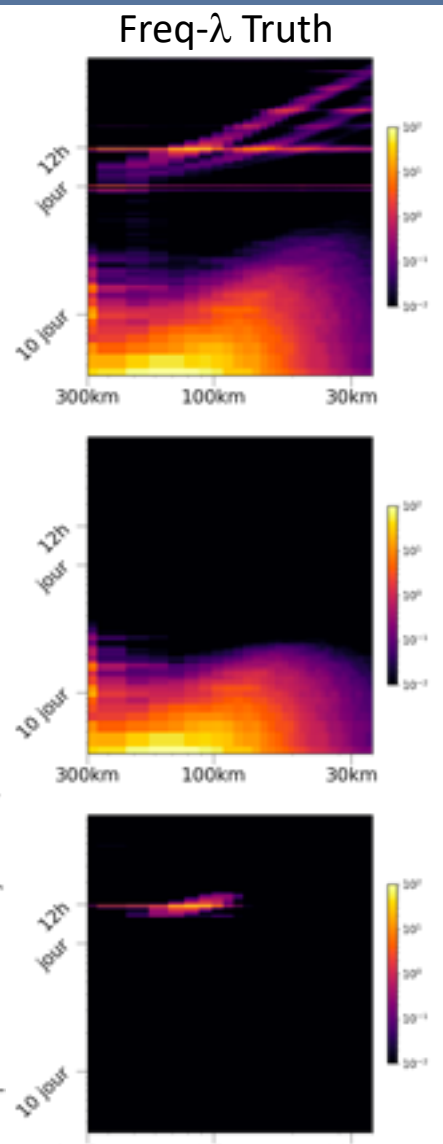
Solving the shallow water momentum equations (Remove the BT tide)

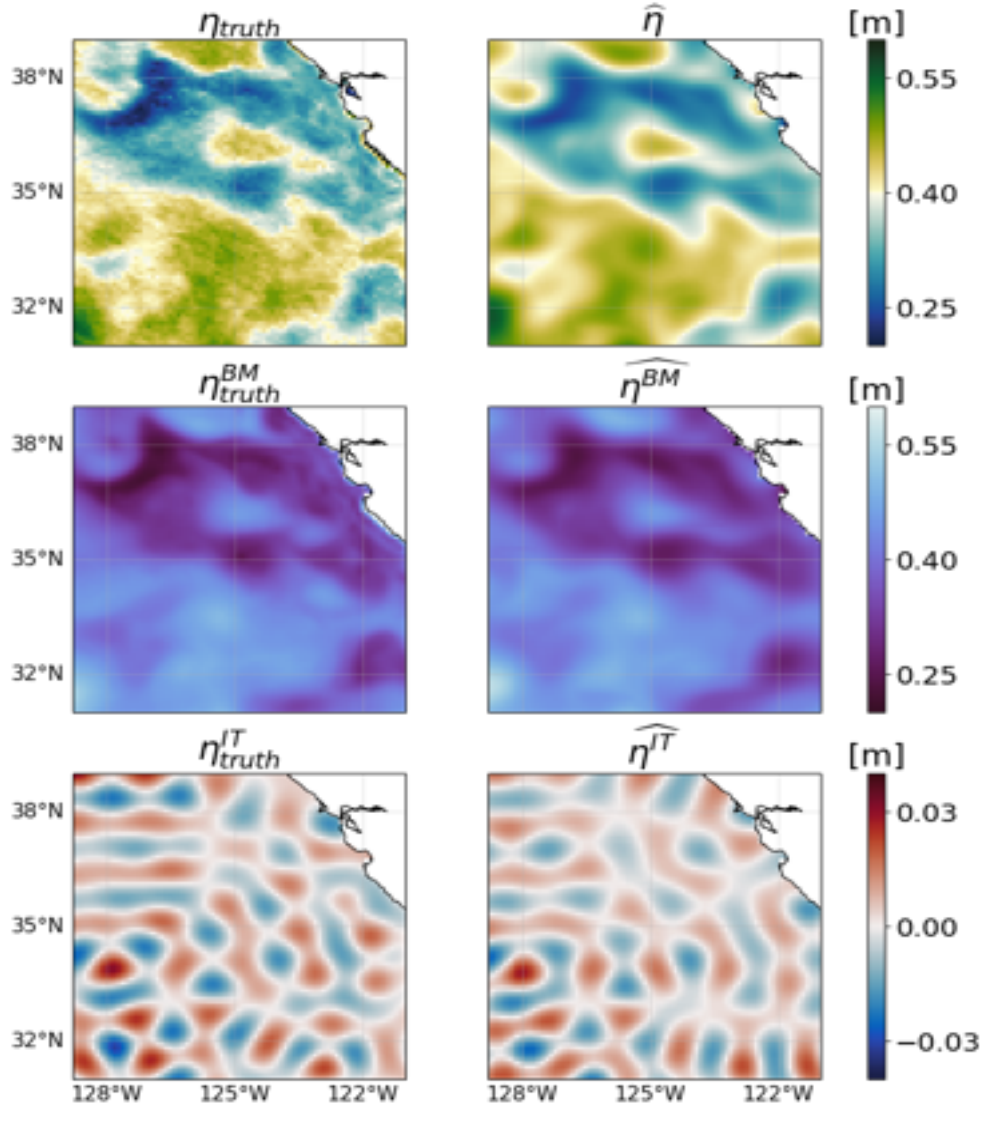
QG dynamics for the balanced flow

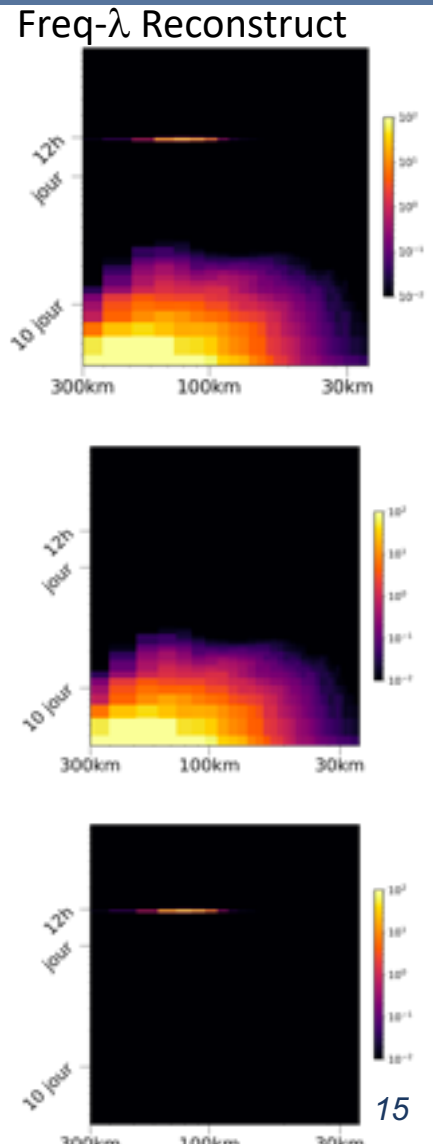
Linear SW wave model for the internal tides

Data assimilation with reduced bases





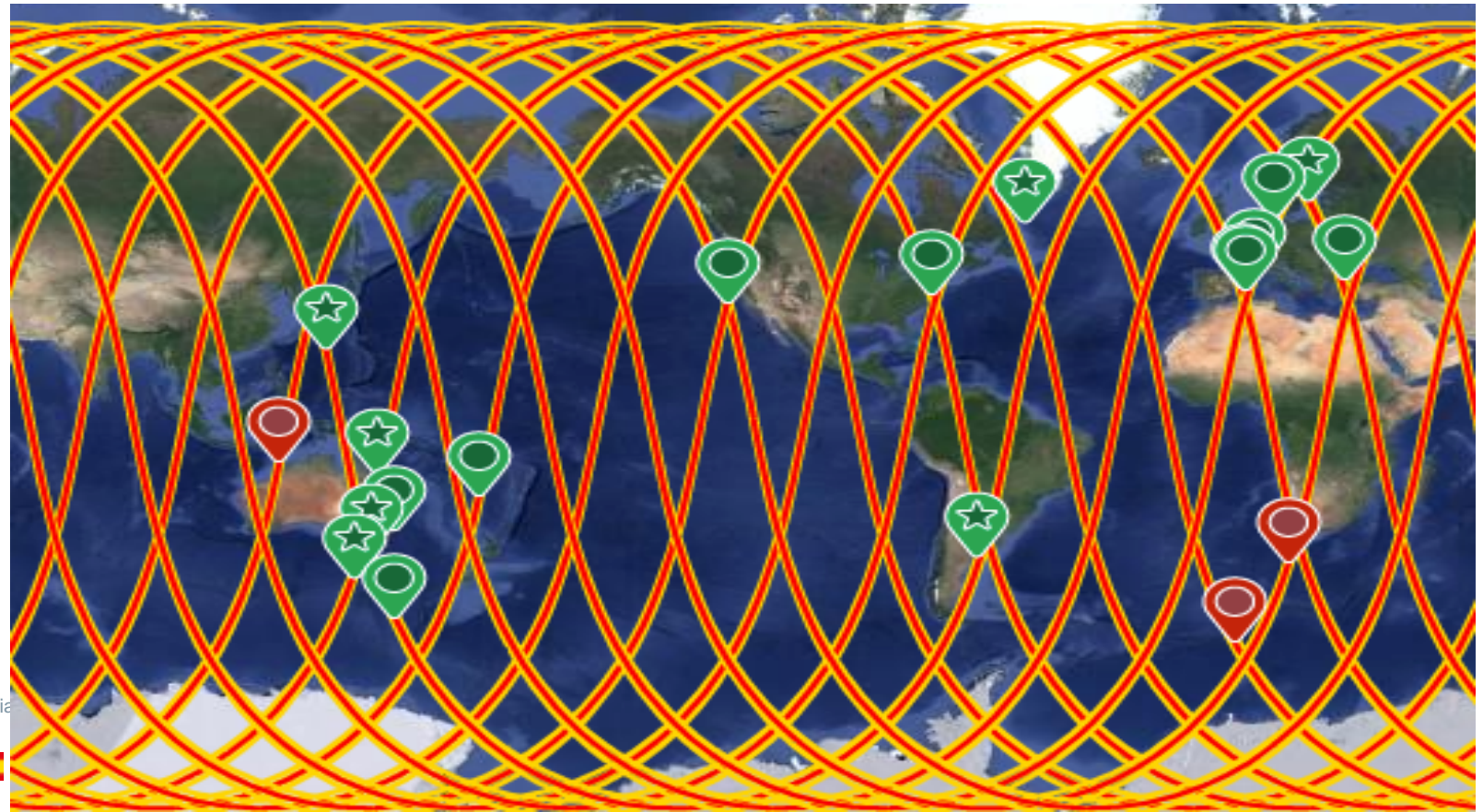




SWOT In-situ Validation « Adopt a Crossover »

https://www.swot-adac.org/

- CLIVAR endorsed project for an international multi-site in-situ deployment under SWOT swaths and crossovers in 2023
- Development of SWOT-supported in situ campaigns for fine-scale dynamics in different regions and seasons
- **In-situ data sets for validation of ocean models & inversion/assimilation techniques & other satellite products (Data Challenges)**
- *Partners : US, France, UK, Canada, Australia, S Africa, Norway, Turkey, China, Argentina…*



See Lehain & Farrar talk later today!

SWOT Ocean Final remarks

- **SWOT will give us unprecedented 2D SSH observations of small mesoscales, and derived balanced currents. Larger mesoscales are deep reaching, depth of smaller scales may be varied, both may be offset/decoupled from total surface currents.**

- **SWOT observes colocated 2D SSH and SAR images** … we need innovative ways to combine this information + multi-satellite & in-situ data (drifters, gliders..) –> links with WOC initiatives

- SWOT will provide unique 2D observations of the **interactions between balanced flow and internal tides**

- **Mapping the fine-scale SWOT SSH swath data onto regular 2D /3D fields presents many challenges,** explored using interpolation techniques, different vertical projection schemes, full assimilation techniques, and synergy with multiple satellite & in-situ data sets –> links with WOC initiatives

- **Unique AdAC in-situ data sets for validation of** high-resolution ocean models and reconstruction techniques & other surface current products

SWOT Time Line

Early Dec 2022 : SWOT Launch into 1-day orbit for 6 months
Dec 22 – Feb 23 : Instrument Checkout
Mar 23-May 23 : Science CalVal : 1-day

Jun 23 : SWOT moved to 21-day nominal orbit for 3 years
Sep 23 : 1st "pre-validated" swath data available for science validation
2024 : Validated swath data available
2024+ : first gridded DUACS maps with SWOT

Info : SWOT Mission, orbits, data products, Science Team : http://swot.jpl.nasa.gov & www.aviso.altimetry.fr => swot

SWOT Ocean Simulator (orbits & errors) :
https://github.com/SWOTsimulator

Thank you

2D kinetic energy fluxes : Balanced vs unbalanced

Modelled Time-averaged (2005-2009) cross-scale **surface kinetic energy flux** estimated from total currents (left), rotational (balanced) currents (middle) and the interaction of balanced and unbalanced flow (right). At **diameters, L** of 9, 22, 61, and 105 km.

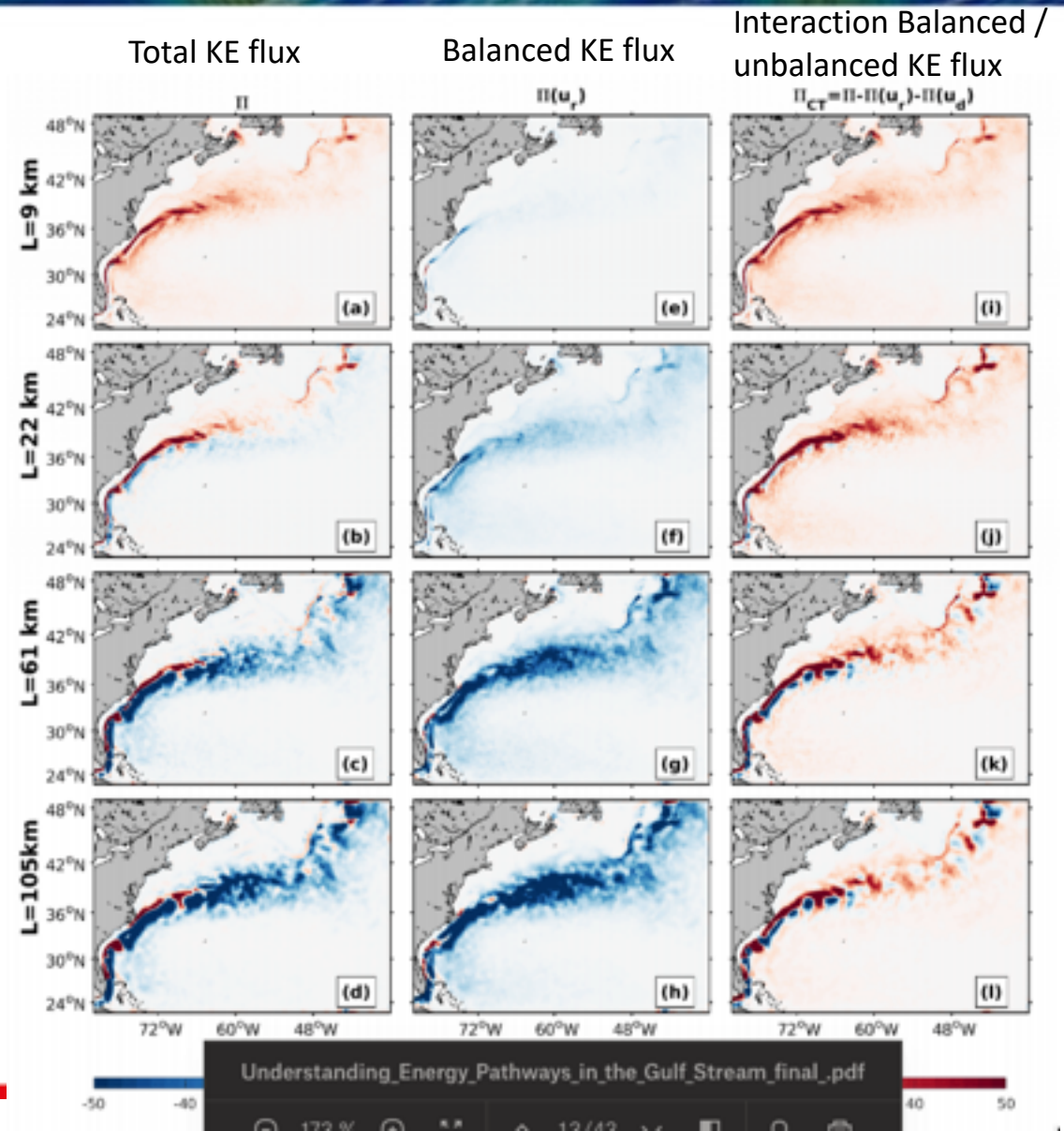
Balanced flow dominates the inverse cascade (in blue) down to scales of 22 km

Unbalanced (divergent) component is an order of magnitude smaller (not shown)

Direct cascade (in red) is due to cross-scale KE flux from the **interaction of balanced and un-balanced flow**.

SWOT will give us a better observation of the balanced 2D KE energy fluxes : Direct cascade to smaller scales needs consistent observations of balanced & ageostrophic interactions.

Contreras et al., 2022 (in review)



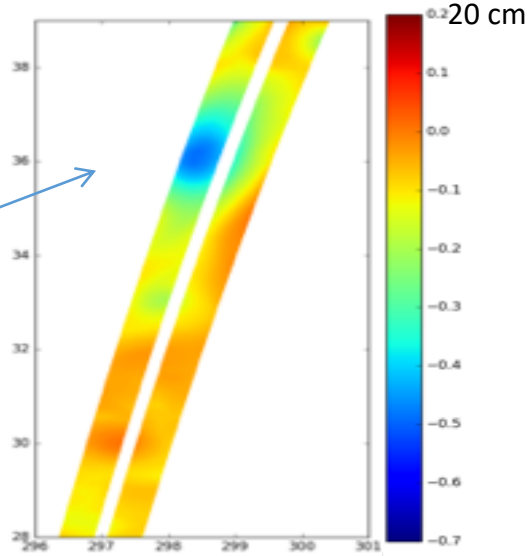
Challenge : Removing Systematic & random SWOT errors

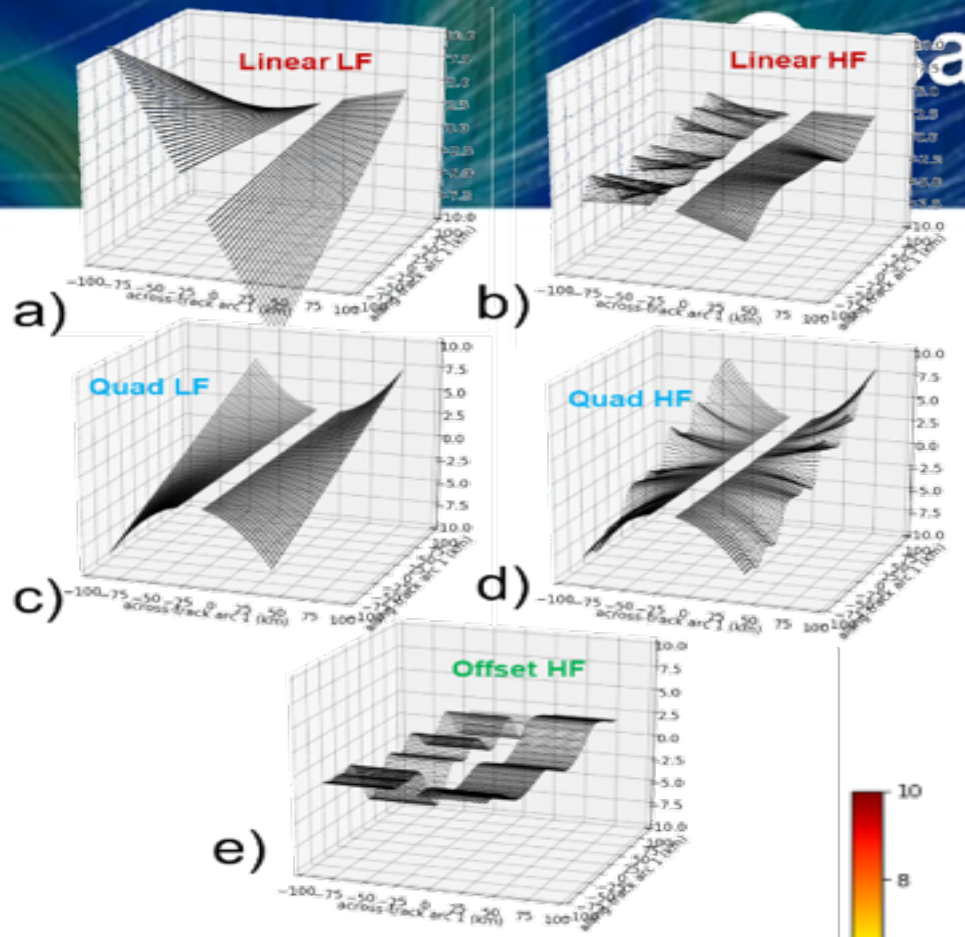
Interferometry depends on a good estimate of

a) Platform Roll
b) phase errors
c), d) baseline dilation
e) Timing Errors

These errors can reach 20 cm !

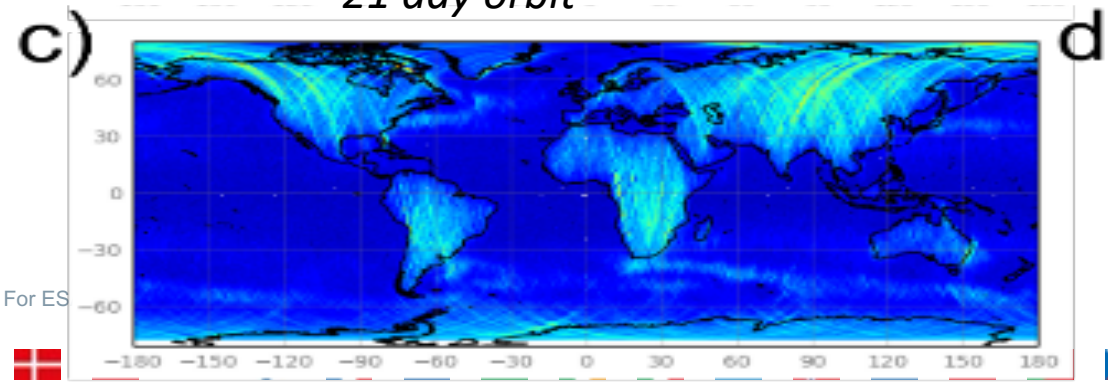
True Ocean SSH



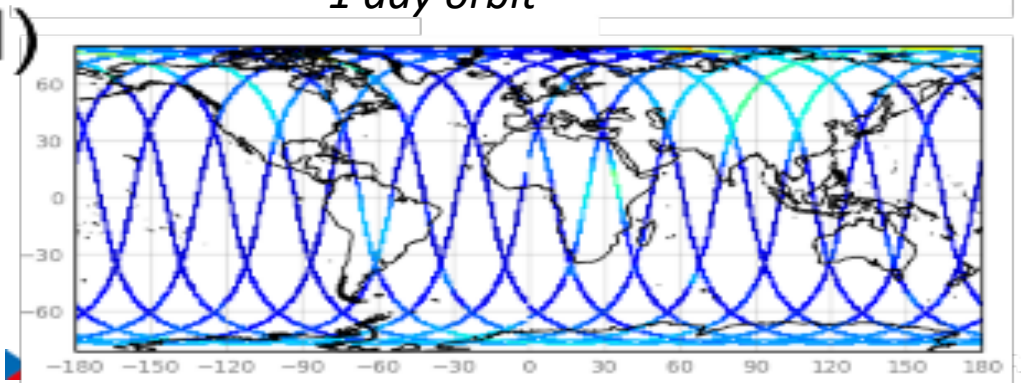


Residual errors after **crossover calibration** *(Dibarboure et al., 2022):*

21 day orbit



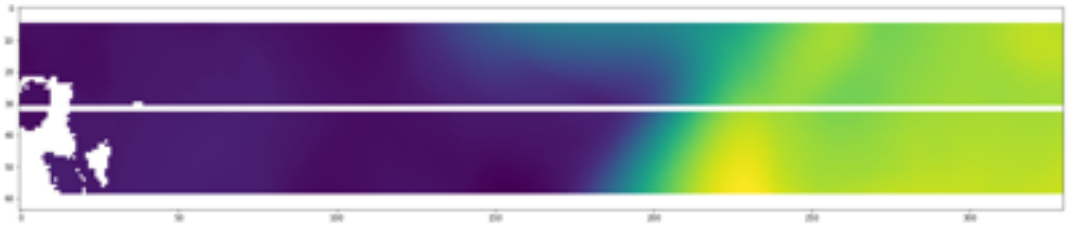
1 day orbit



Challenge : random noise increases with sea-state, impacts on SSH gradients (currents & vorticity)

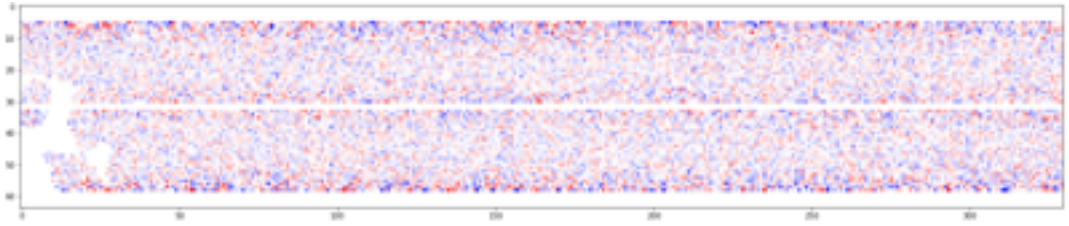
- **Swath example**: Neural network filtering of random noise

1. True SSH SSH

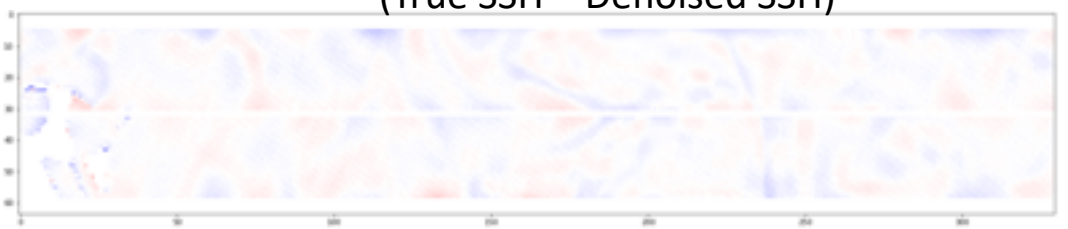


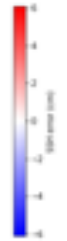
3. Denoised SSH

2. Random SWOT Noise

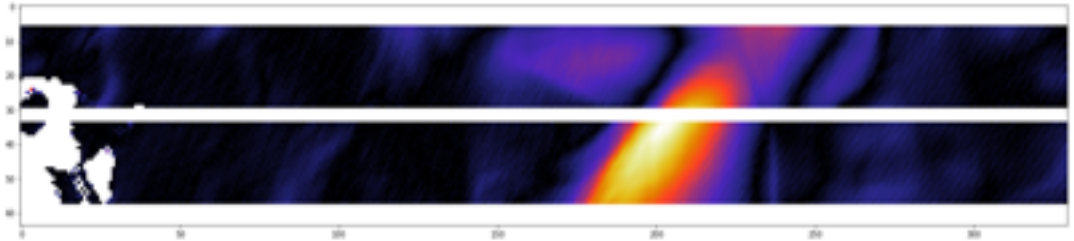


4. Errors made by the model
(True SSH – Denoised SSH)

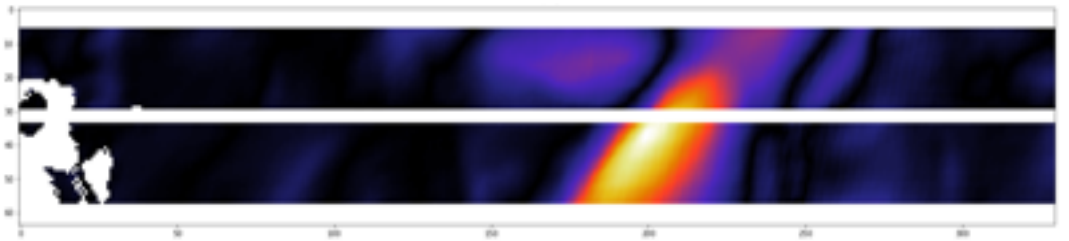


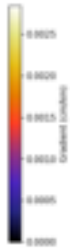


5. First derivative of the True SSH



6. First derivative of the Denoised SSH





CLS, Datlas

→ Noise is correctly removed : the error made by the U-Net is around 1 cm

→ No artifacts near the coastline

→ The first derivative is correctly restored

SWOT studies on noise reduction from IGE, CLS, Datlas, IMFT-Atlantique, …