Reconstruction, mapping, inversion, assimilation

10 min: Is SWOT meeting requirements? The assimilation/inversion perspective

20 min: Lightning talks: 1 slide, 1 minute each

15 min: Challenges ahead, discussion and future working group plans (discussion)

Moderators: Sarah Gille, Shane Keating, Emmanuel Cosme

SWOT-ST meeting, Chapel Hill, June 2024

Is SWOT meeting requirements? The assimilation/inversion perspective

0. Context of this summary presentation

- Poll
- Discussions
- Gather messages and illustrations
- Visit of posters

Is SWOT meeting requirements and pre-launch expectations? If not, why not? ⇒ 13 yes, 2 don’t know

Is SWOT meeting requirements? The assimilation/inversion perspective

3 key messages:

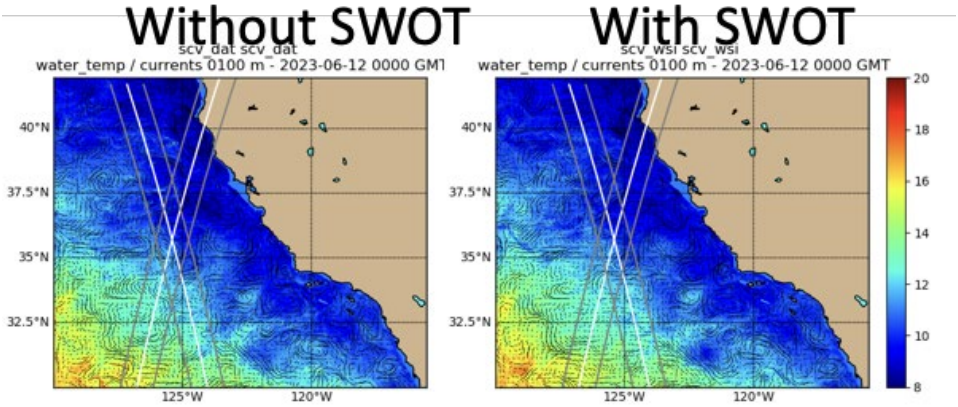
1. First steps in SWOT assimilation reveal positive impacts

2. Dealing with errors remains a hot topic

3. SWOT is challenging our inversion/assimilation systems

1. First steps in SWOT assimilation reveal positive impacts

With OGCM-based assimilation



NCOM, NRL (Jacobs et al)

Model error relative to the non assimilated Saral/Altika data

	Open Ocean		Coastal region	
	Analysis	Forecast	Analysis	Forecast
Low variability	15.1%	12.9%	13.4%	10.5%
High variability	14.5%	10.6%	14.0%	10.8%

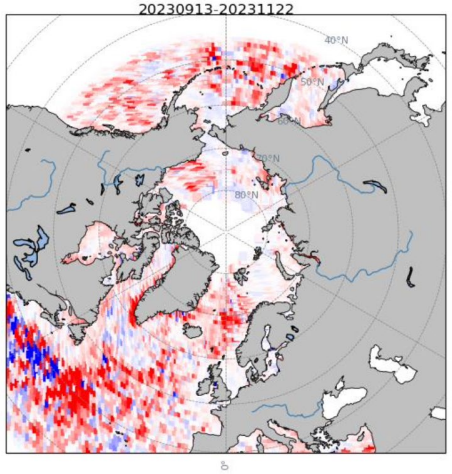
Improvement with SWOT

NEMO, Mercator (Le Traon et al)

1. First steps in SWOT assimilation reveal positive impacts

With OGCM-based assimilation

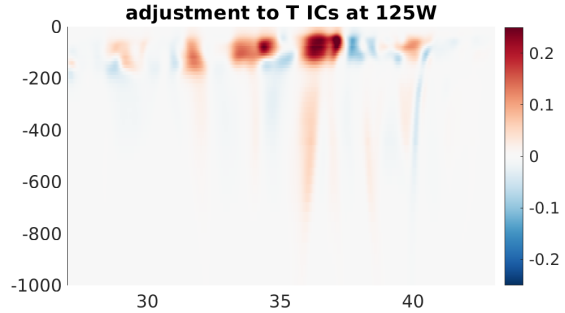
RMS difference compared to all SLA observations

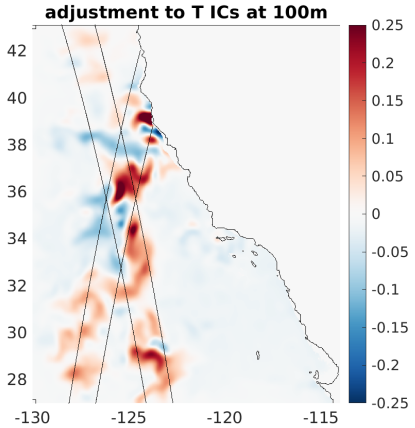


NO SWOT

SWOT

NEMO, Env. Canada (Smith et al)





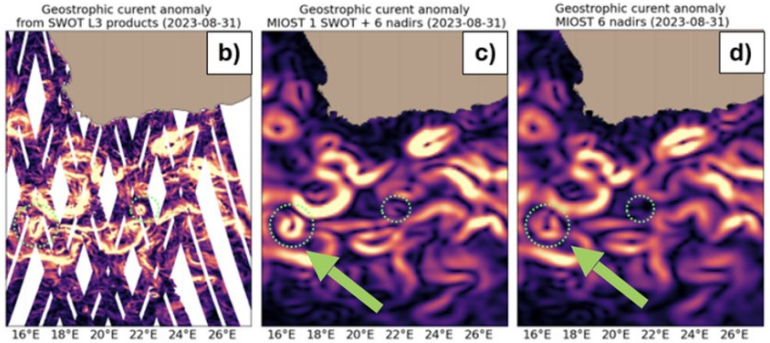
4dVar MITgcm: SWOT assimilation in the California Current modifies subsurface temperature initial conditions

SIO (Gille et al)

1. First steps in SWOT assimilation reveal positive impacts

And with SSH-focused reconstruction

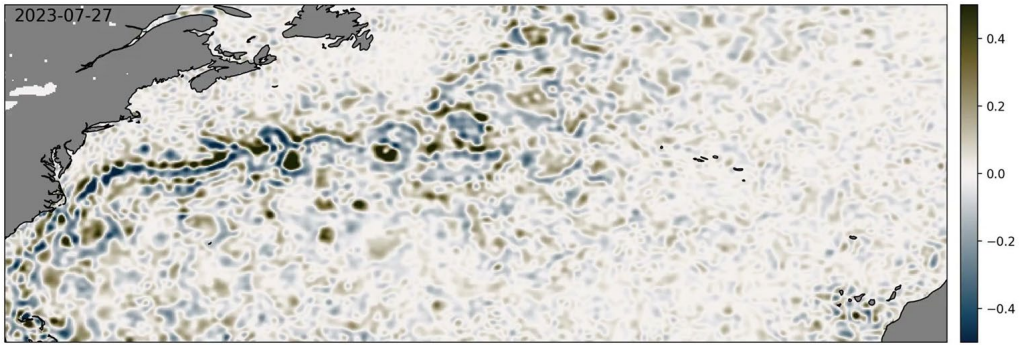
Wide swath altimetry enables better positioning of oceanic structures



MIOST, CLS (Ballarotta et al, presentation on Friday)

4DVar-QG

DUACS



4DVar, QG model (Le Guillou et al)

2. Dealing with errors remains a hot topic

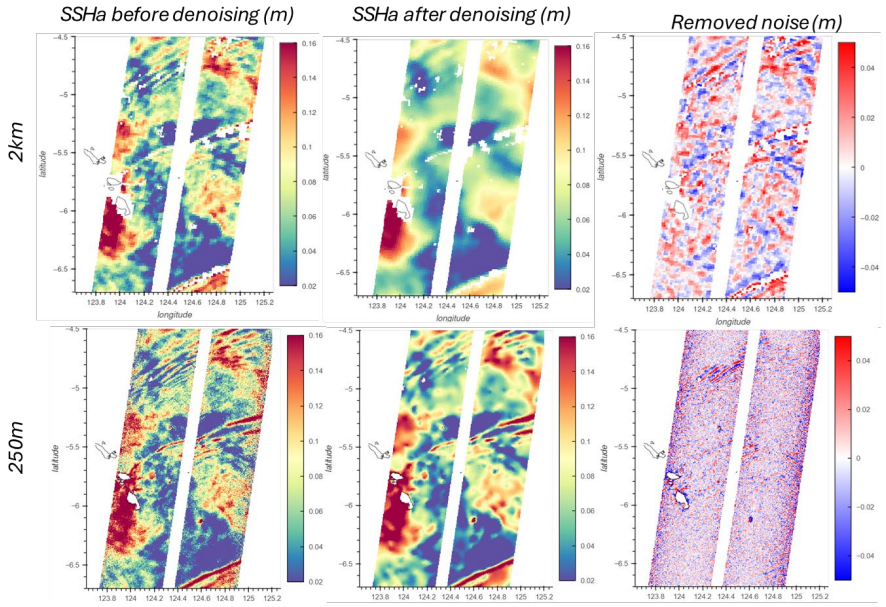
Error removal is a topic in inversion/assimilation because

- assimilation methods are filters for white noise,
- some advanced methods require the computation of observation derivatives,
- ignored spatial correlations in errors can be extremely detrimental to inversion/assimilation.
- Note: SWOT exhibits small white noise but significant red spectrum that could be signal or noise

2. Dealing with errors remains a hot topic

- UNets trained on simulated data (eNATL60) and applied on real data
- Difficulties to remove the correlated noise visible on the 2km data. Small structures (small eddies, internal waves...) are removed.
- In the 250m product, small structures are better preserved, though not perfectly.

U-Nets (Treboutte et al)



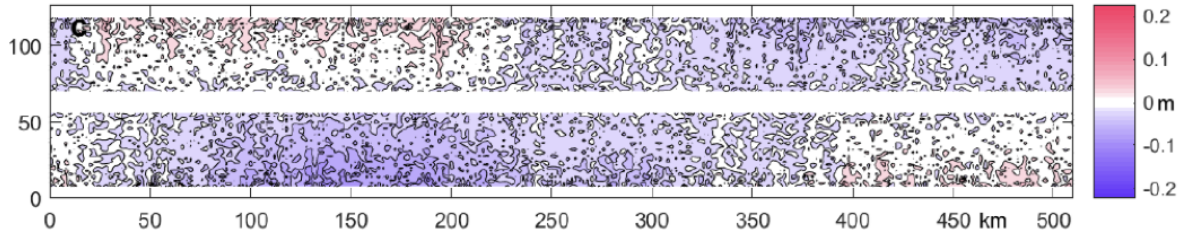
2. Dealing with errors remains a hot topic

Concerns about how to account for correlated SWOT errors is increasing. Why?

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}^b)^T \mathbf{P}^{f\,-1} (\mathbf{x} - \mathbf{x}^b) + (\mathbf{y} - \mathbf{H}\mathbf{x})^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}\mathbf{x})$$

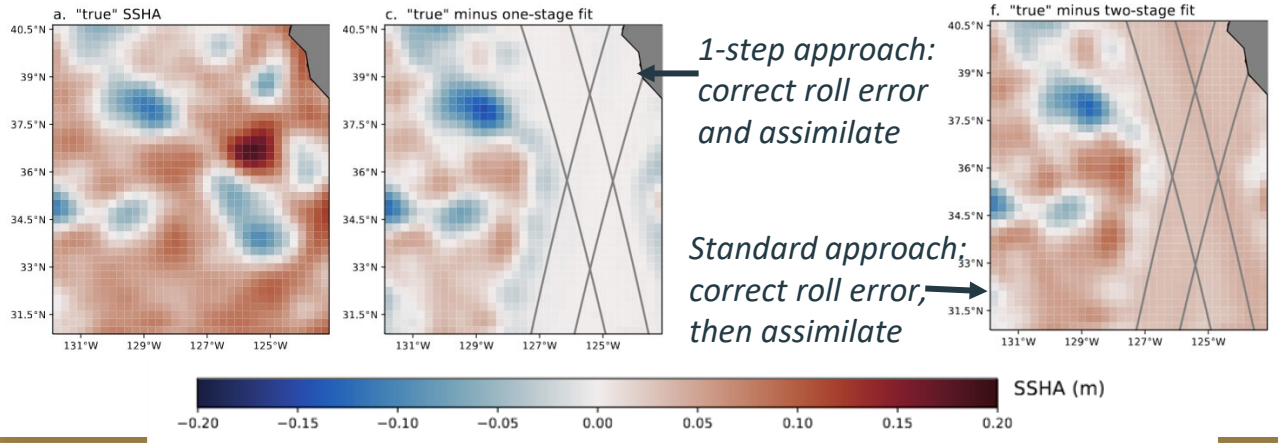
2. Dealing with errors remains a hot topic

Concerns about how to account for correlated SWOT errors is increasing. Why?



Illustrating error correlations.

(Yaremchuk, Jacobs et al)



1-step approach: correct roll error and assimilate

Standard approach: correct roll error, then assimilate

Correlated error can project onto signal (e.g. westward propagating Rossby waves), so the two should be solved for simultaneously,

(Gao, Gille et al)

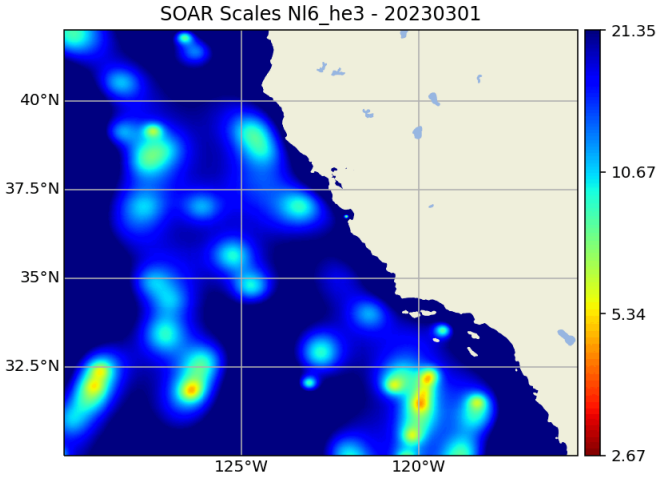
3. SWOT is challenging our inversion/assimilation systems

3.1 Inconsistency of space/time resolution

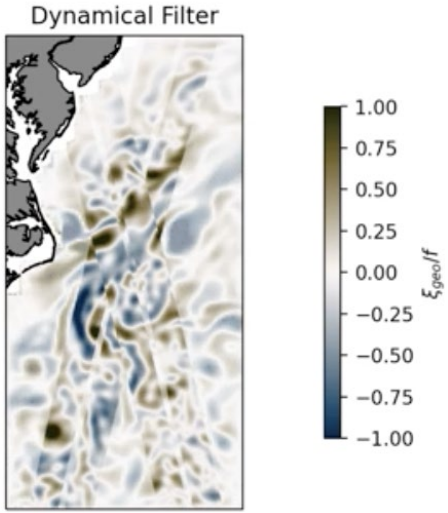
3. SWOT is challenging our inversion/assimilation systems

3.1 Inconsistency of space/time resolution

- Reconstruction errors can be heterogeneous in scales.



(Jacobs et al)



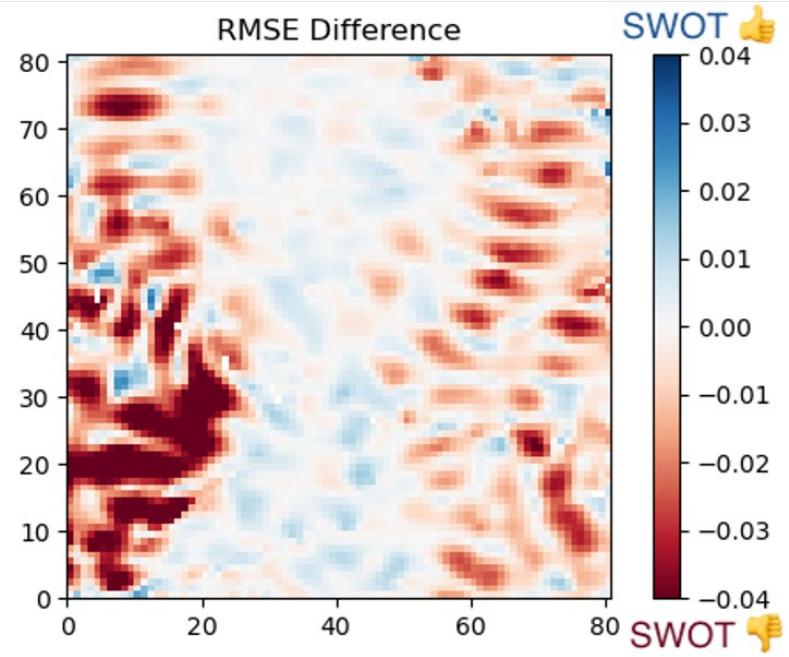
(Le Guillou et al)

3. SWOT is challenging our inversion/assimilation systems

3.1 Inconsistency of space/time resolution

- With some standard DA schemes, SWOT can overwhelm nadir data and minimize their impact in the estimation process. SWOT brings new questions for the design of DA systems.

(Bellemin-Laponnaz, Cosme et al)

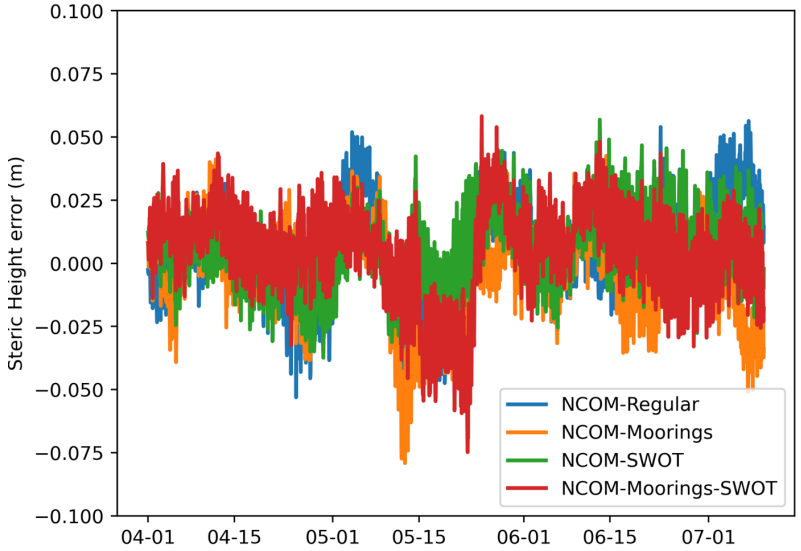


3. SWOT is challenging our inversion/assimilation systems

3.2 Multi-observation assimilation dynamics

Combining SWOT and mooring assimilation may not be better than SWOT alone due limitations in other components (background).

Time-averaged steric height RMSE	
NCOM-Regular	2.21 cm
NCOM-Moorings	2.07 cm
NCOM-SWOT	2.09 cm
NCOM-Moorings-SWOT	2.13 cm



(Jacobs et al)

3. SWOT is challenging our inversion/assimilation systems

3.3 Eddy-wave separation

- A major unresolved problem in the DA community so far

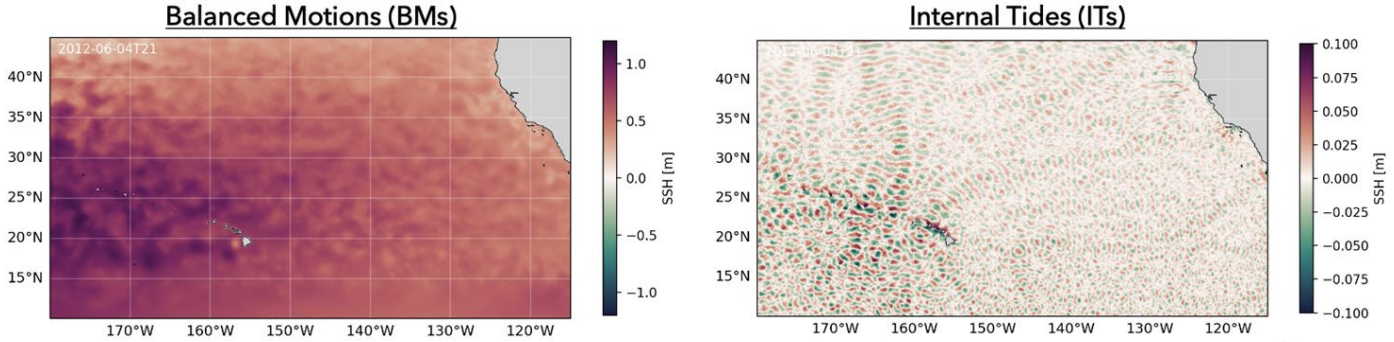


Fig1 : BMs and ITs can be separated from MITgcm SSH hourly outputs using successive filtering.

Lightning talks

1. D’Addezio/Iversen/Jacobs: SWOT advancement and challenges
2. Laura Gomez/Baptiste Mourre
3. Eugenio Cutolo
4. Gille: 4dVar in CCS
5. Shafer Smith
6. Shane Keating
7. Cosme: Assimilation of SWOT to map geostrophic and internal tide currents
8. Jinbo Wang

SWOT Assimilation

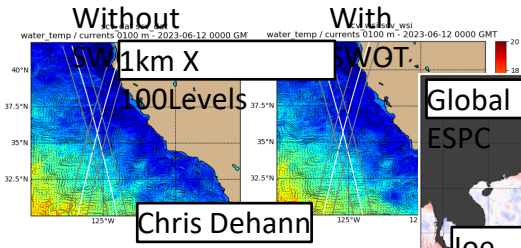
SWOT assimilations have been conducted using nadir altimeter data, nadir + moorings, nadir + SWOT

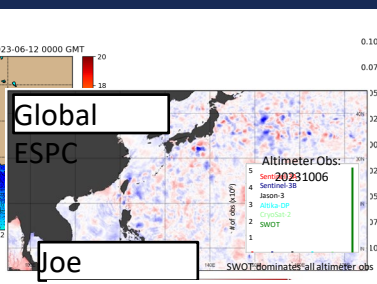
Summary conclusion: **SWOT adds skill above nadir data**

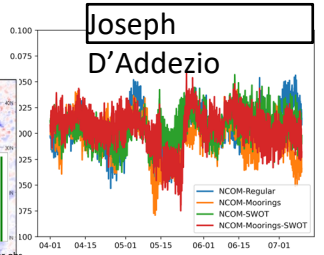
Challenge: **Realizing full SWOT resolution value**

Obstacles:

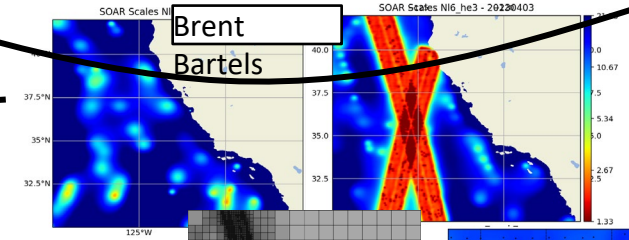
- Resolved horizontal scales change daily
- Super-obbing / thinning
- Correlated systematic errors
- Relations between TSUV appropriate to small scale physics
- …

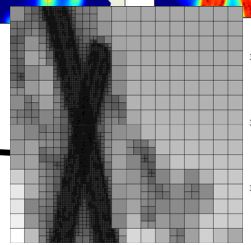


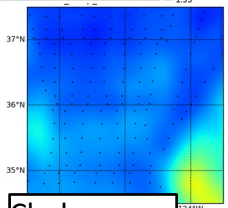


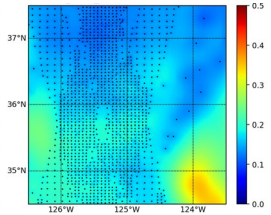


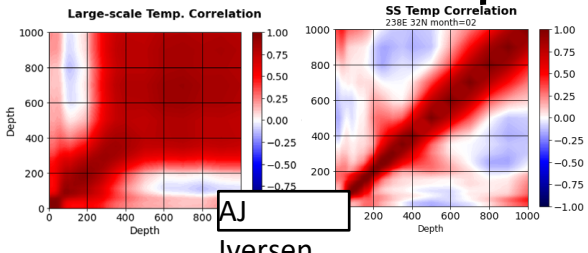
10% SSH variance reduction

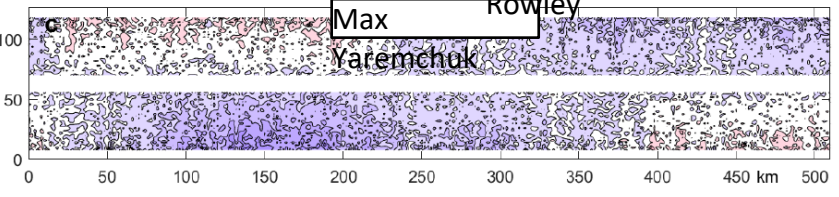






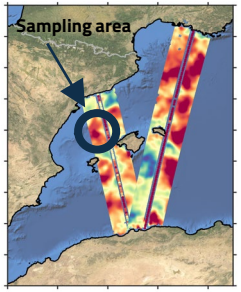






FaSt-SWOT project

Ananda Pascual, Baptiste Mourre, Laura Gómez-Navarro, Elisabet Verger-Miralles, Bàrbara Barceló-Llull, Benjamín Casas, Vincent Combes, Eugenio Cutolo, Lara Díaz-Barroso, Emma Reyes, Daniel R. Tarry, Máximo Garcia-Jove, Nikolaos Zarokanellos et al.

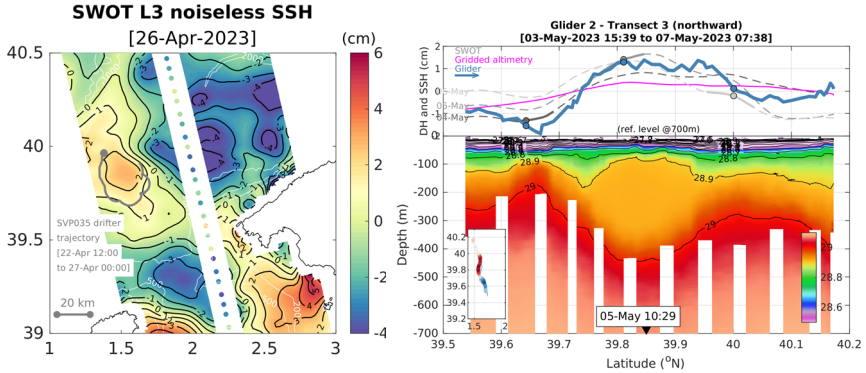


SWOT fast-sampling phase
Western Mediterranean

2 legs:
25-28 April & 7-10 May 2023

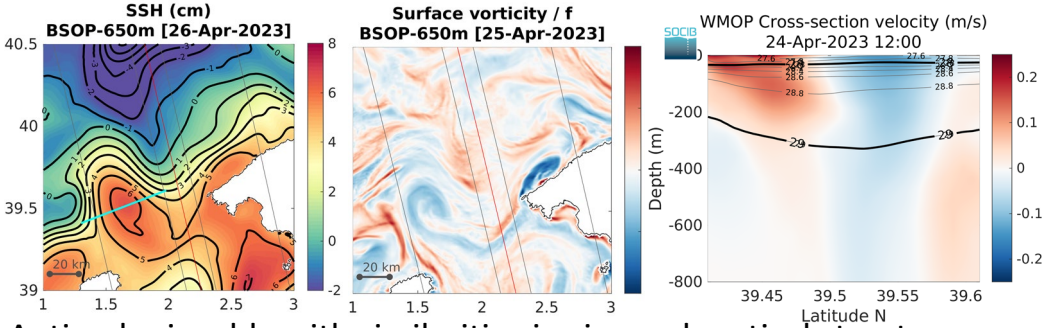
In-situ campaigns

~25km-diameter anticyclonic eddy observed with gliders, CTDs, ship-ADCP, drifters … and SWOT!



High-res. modelling and data assimilation

1) WMOP operational predictions (2km res.) including daily data assimilation (SLA, SST, Argo T/S, HFR; EnOI-type)
2) BSOP (650m res.) free-run nested in WMOP over the study area



Anticyclonic eddy with similarities in size and vertical structure present in the simulations, with a ~25km offset in space.

Future plans:

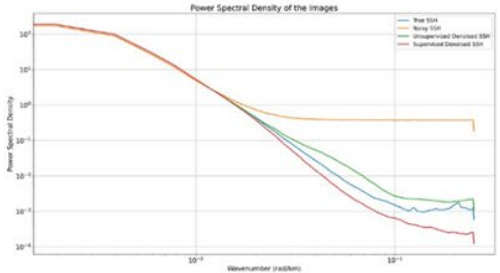
- use in-situ observations to understand and characterize SWOT and model uncertainties
- evaluate the impact of SWOT observations on the model representation of small-scale features after data assimilation
- compare to alternative reconstruction methods, including contribution of machine learning algorithms

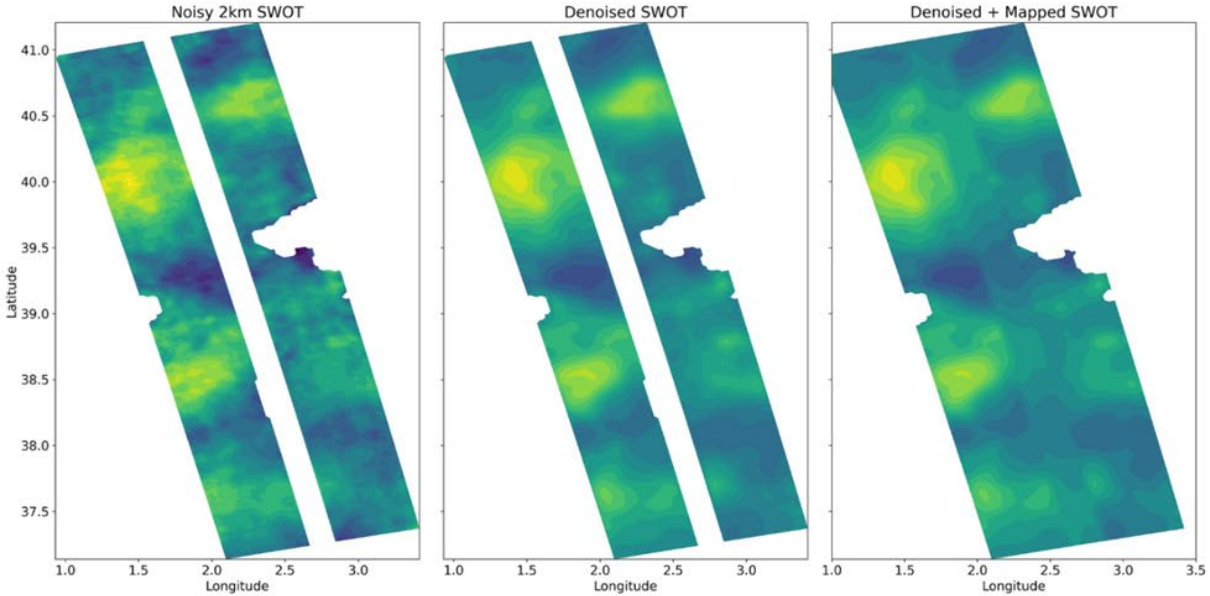
Physically Coherent SWOT Denoising and Mapping:

Deep learning advances toward the Ocean Digital Twin

Can an artificial intelligence learn how the ocean works?

Yes, if another AI is the teacher!





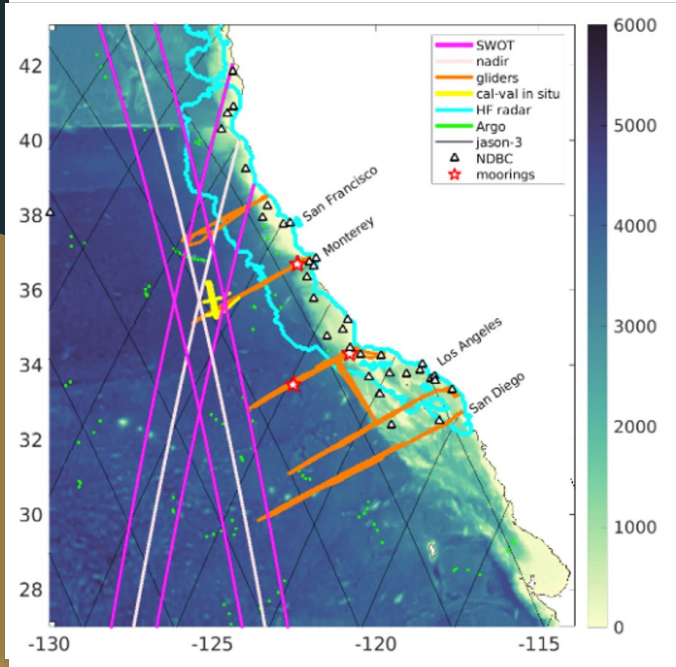
Train with snapshots from QG model, process study model and OGCM

Going global (with 250m?) same model can easily integrate: SST, Nadir, KaRIn!!!

By Eugenio Cutolo

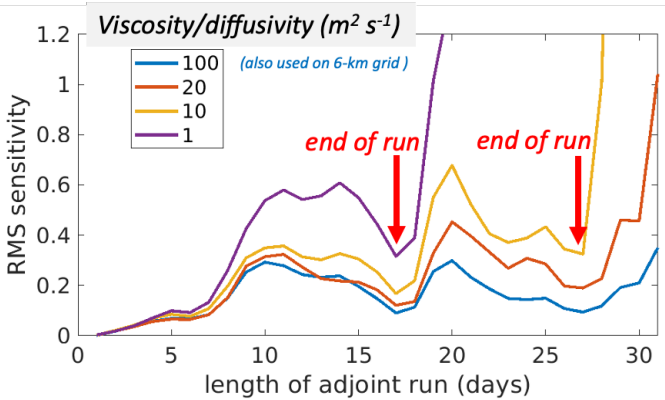
Gille, Verdy, Mazloff, Cornuelle, Gopalakrishnan

Assimilation of SWOT 1-day repeat data in the California Current System



Goals:

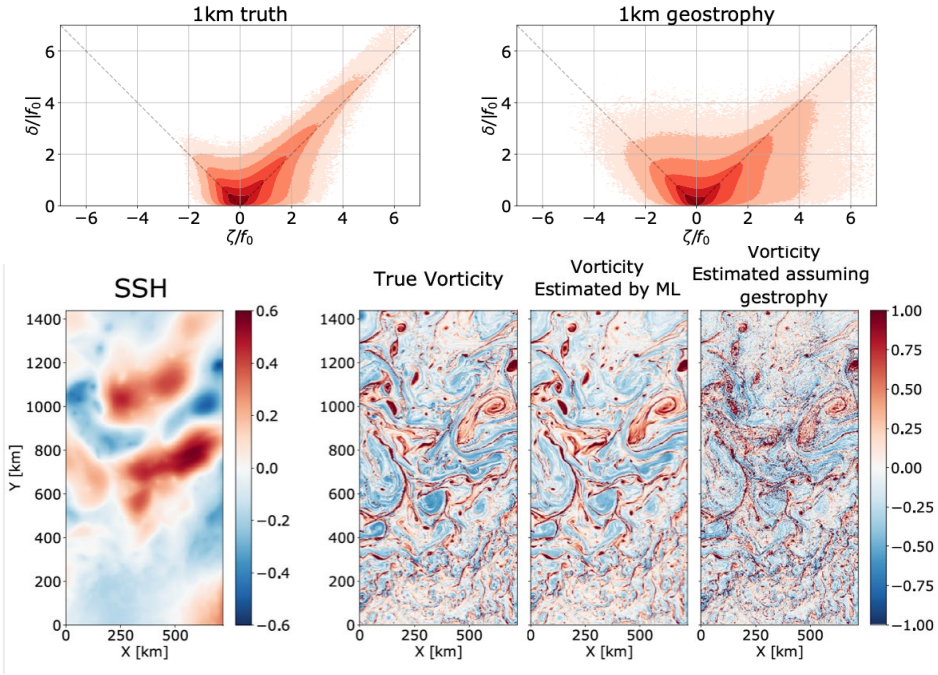
- Optimize state in-swath and out-of-swath, while maintaining consistent dynamics → 4dVar
- Resolve small-scale processes → high resolution & lower viscosity



UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

SSH → wave-filtered non-geostrophic U*

S Smith, D Balwada, S Jones, R Du, T Susskind + PDOC (hiring)

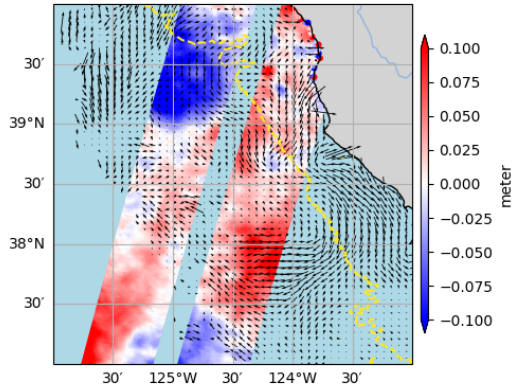


ML vorticity predictions beat geostrophy

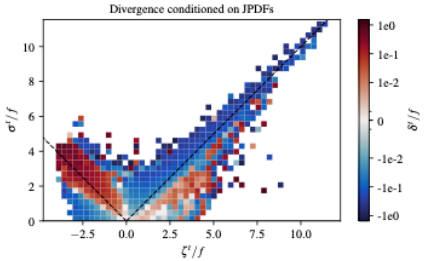
Xiao, Balwada, Jones, Herrero-Gonzalez, Smith, Abernathey, 2023: Reconstruction of surface kinematics from sea surface height using neural networks. *JAMES*, DOI: 10.1029/2023MS003709

Plans

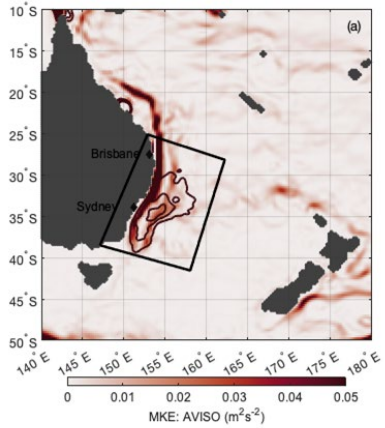
- Use coastal HRF near 1-day repeat SWOT — validate ML **U***

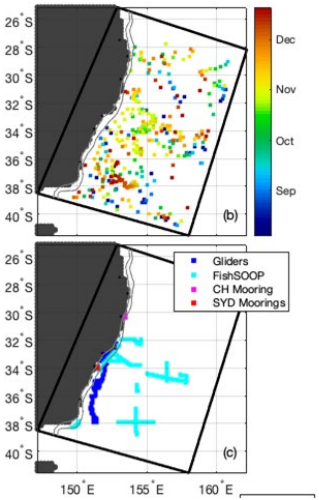


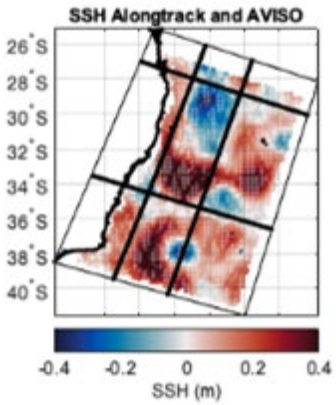
- ML applied to LLC4320 regions w/ SWOT simulator
- Global JPDF analysis on LLC4320
- QG+1 reconstruction of U* from SWOT SSH

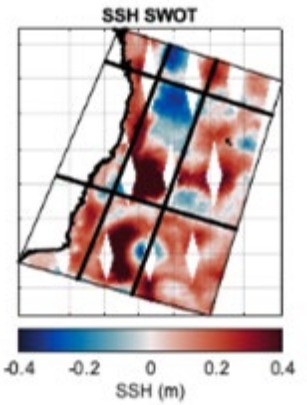


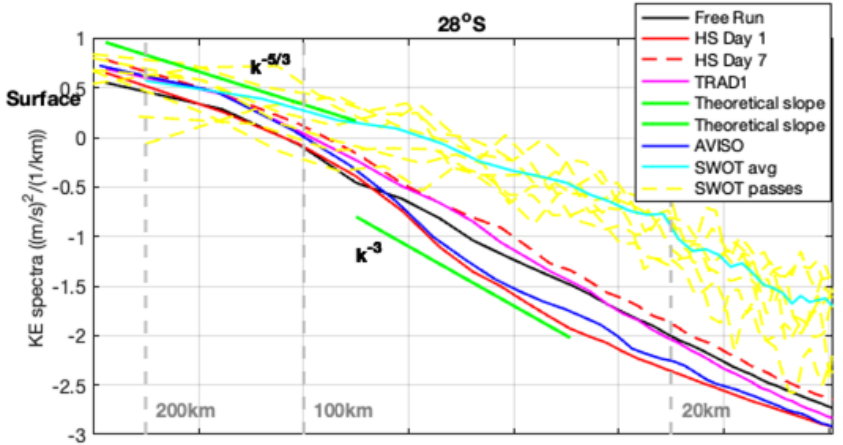
4DVar-ROMS assimilation of SWOT in Tasman Sea

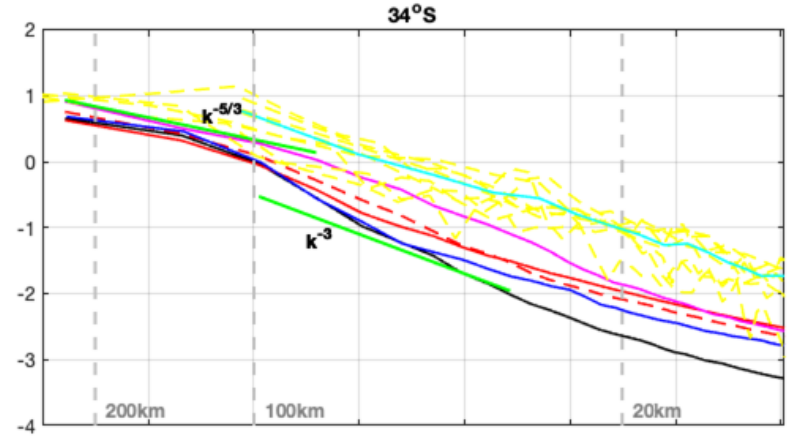






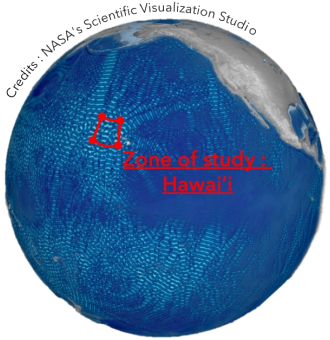


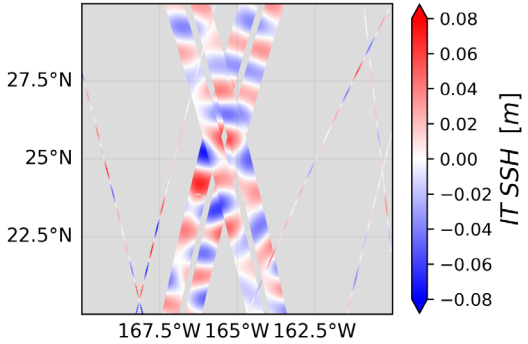




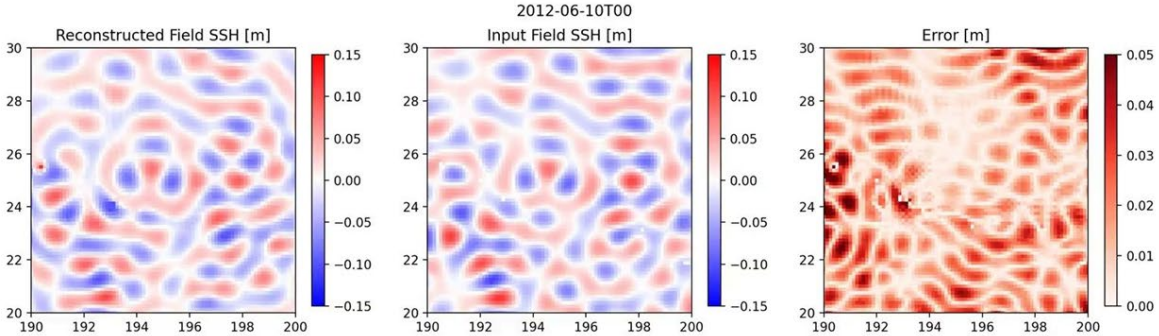
SWOT SSH mapping : Towards separation of geostrophic and internal tide currents

Valentin BELLEMIN-LAPONNAZ , Emmanuel COSME, Florian LE GUILLOU, Clément UBELMANN, Eric BLAYO



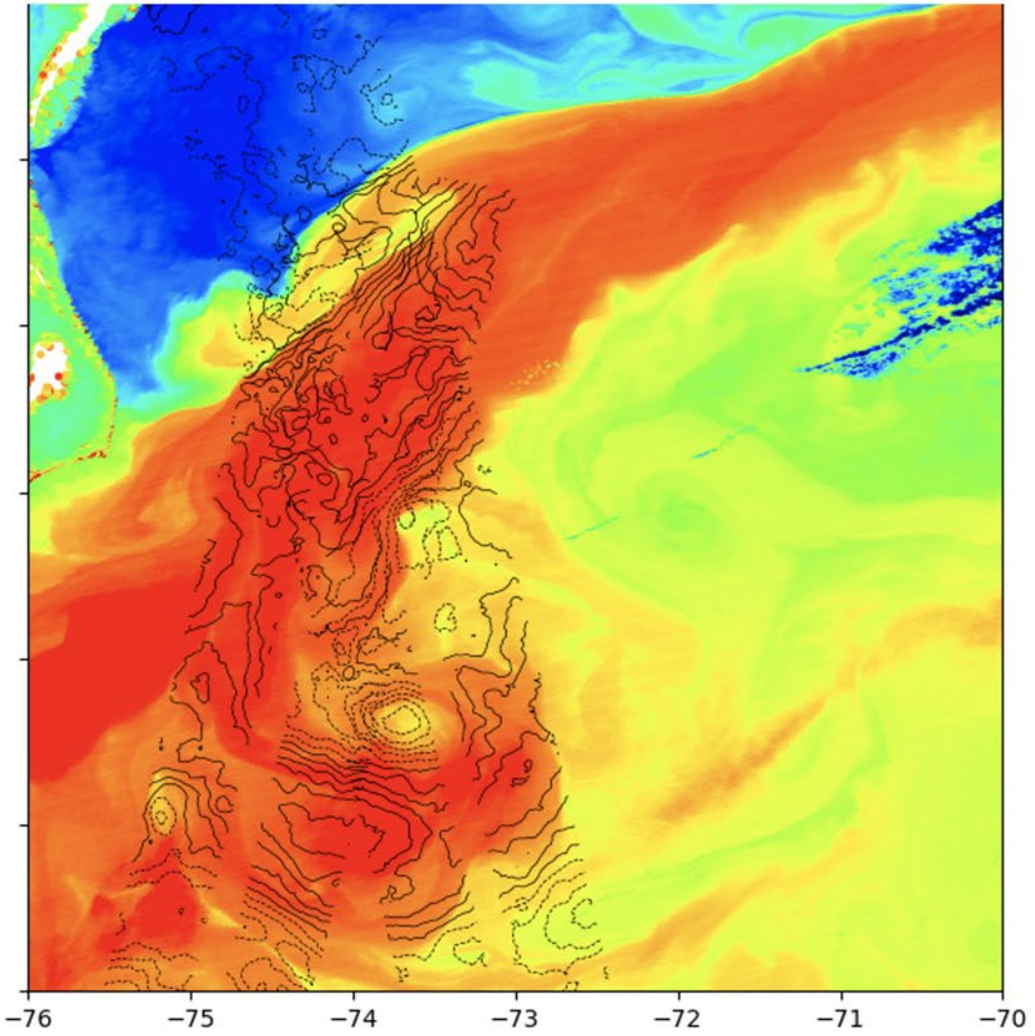


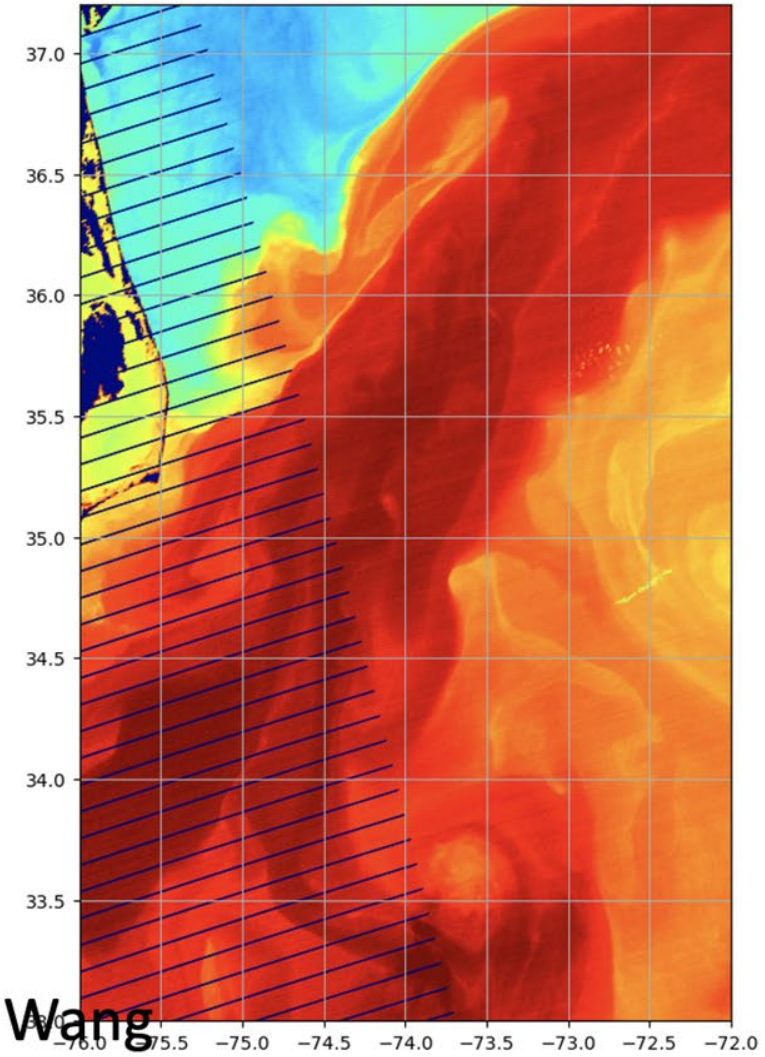
- 1-day orbit tracks simulated from MITgcm
- only mode 1 of internal tide
- 4DVar assimilation with shallow-water model
- next step: combine with QG model for balanced motions



- Structures of SSHA from SWOT match SSTA at small scales.
- Taking advantage of this correlation potentially solve the large temporal gaps in SWOT as well as separating eddies and waves.

Jinbo Wang

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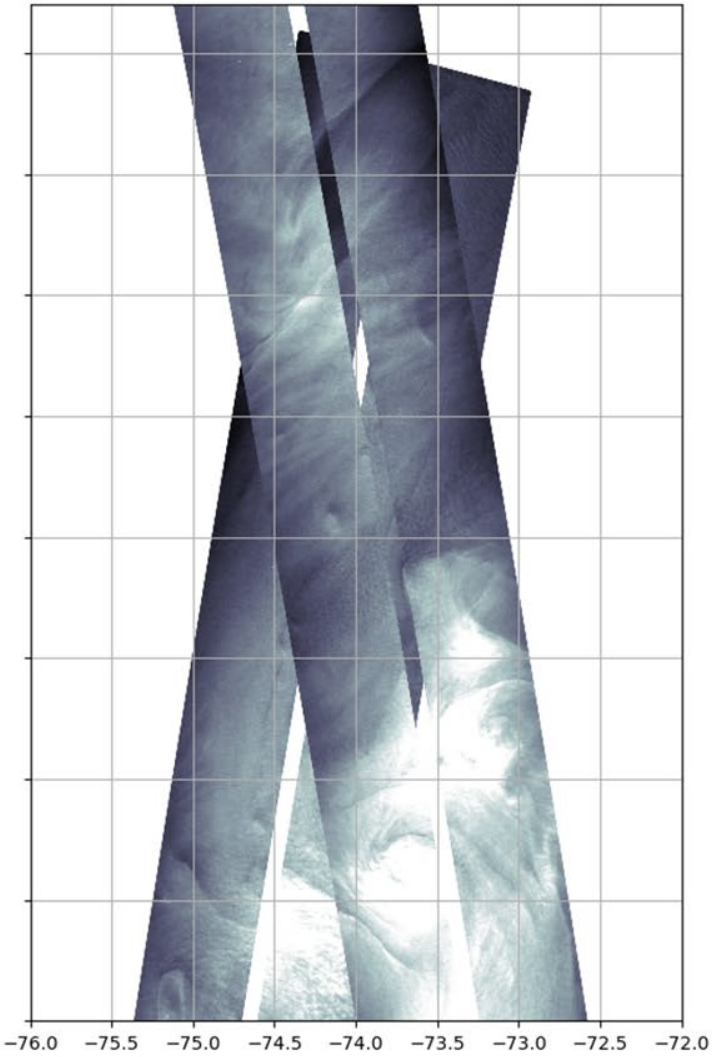
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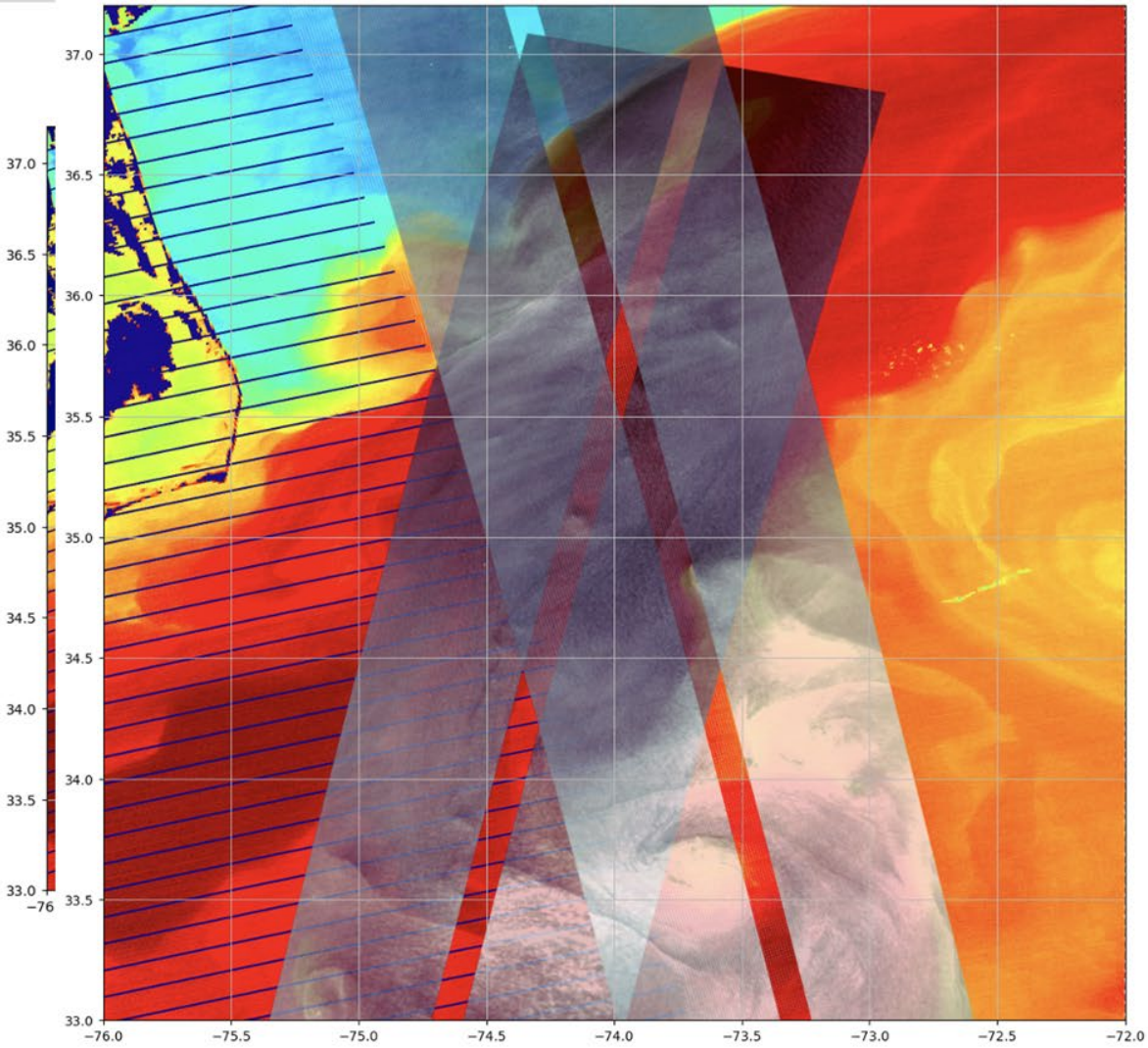
- Different sensors can observe the same feature. Taking advantage of this correspondence may increase the self-sufficiency of solving the eddy-wave balance based solely on SWOT data.



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Discussion

Discussion

- With the SWOT-ST renewal, are there any young members willing to take over some of us to lead the WG?
- How to handle correlated errors that possibly project on physical signals?
- A 250-m global product in 4 years? Can we formulate a 4-year goal collectively?
- A formal connection to the regional validation WG? HR modeling WG?
- Find a common goal. A synthesis paper? Design a data challenge focused on the CCS?

To remain connected, contact us to join the inversion/assimilation mailing list!