MERCATOR OCEAN INTERNATIONAL

Impact of SWOT observations in a global high-resolution analysis and forecasting system

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Mercator Ocean international

Introduction and Objectives

- Main objectives of this study:

➢ Prepare the assimilation of SWOT in Mercator Ocean International (Copernicus Marine Service) analysis and forecasting systems.

➢ Main contribution of SWOT will be to constrain models at small scales (< 150-200 km) through data assimilation. These scales are not constrained by conventional altimeters. Most impacted fields will be surface and upper layer velocities => improved ocean currents, better positioning of fronts => impact for marine safety, pollution monitoring, ship routing, offshore industry, coastal applications.

- Use an **O**bserving **S**ystem **S**imulation **E**xperiments (OSSE)

➢ OSSE with regional Model (1/12°) and NatRun (1/36°)

➢ OSSE with regional Model (1/36°) and NatRun (NATL60, 1/60°)

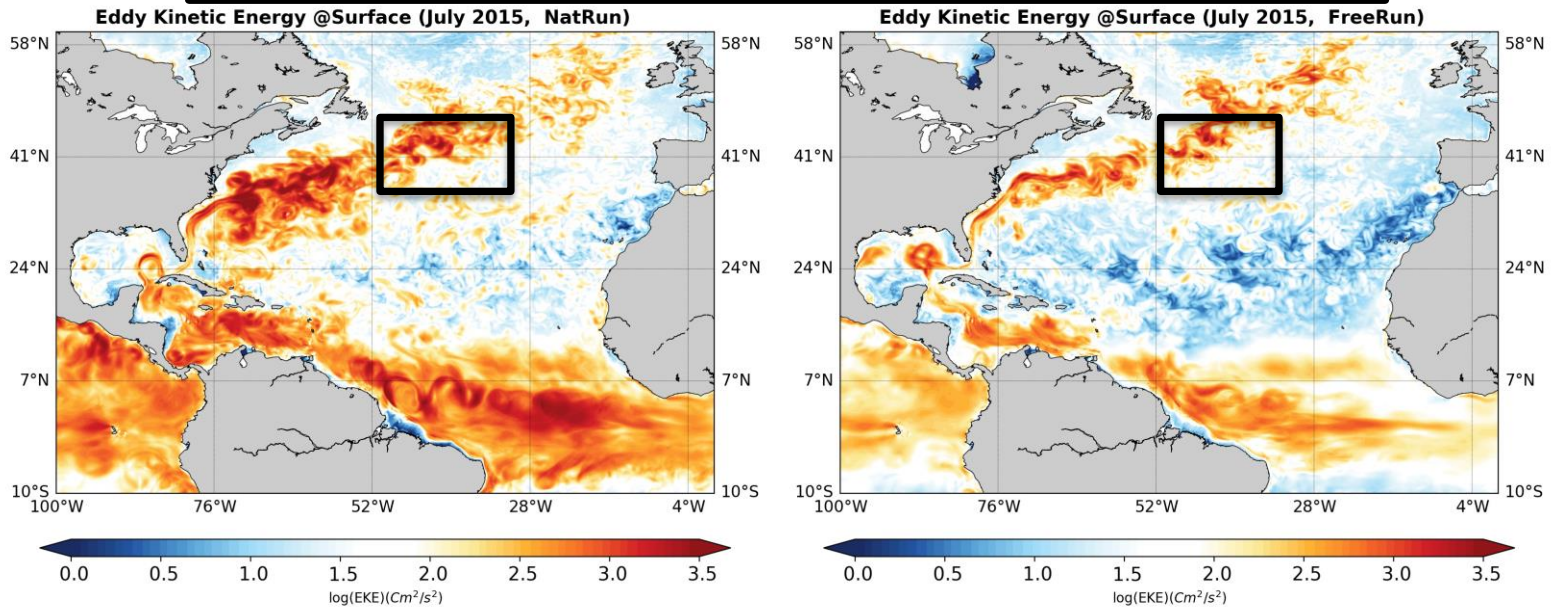
➢ OSSE global model (1/12°) : recent results (first time with the global system)

Global OSSEs Nadir vs SWOT

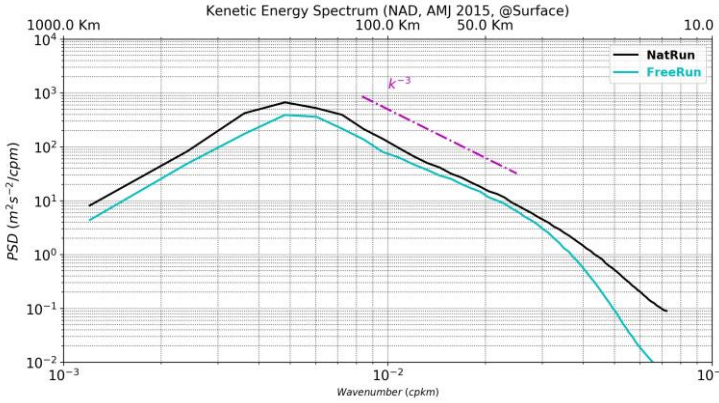
OSSE design

- OSSEs carried out over the year 2015 at Mercator-Ocean International
- 1/12º Nature Run (NR), previously assessed by Benkiran et al. (2021)
- Observations simulated from NR with realistic errors, inc. SST(L3S) , in situ T/S, SSH
- SWOT obs simulated with KaRIn(SWH=2m), 20,86 day repeat cycle. **Not yet with correlated phase/roll errors**.
- Inclination of 77.6° and Altitude of 891Km.
- OSSE experiments: 1/12º NEMO model, SAM2(SEEK), different Forcing flux, Bulk formulae, ocean stress and Atmospheric pressure.

EKE NatRun(July, 2015) EKE FreeRun (July, 2015)

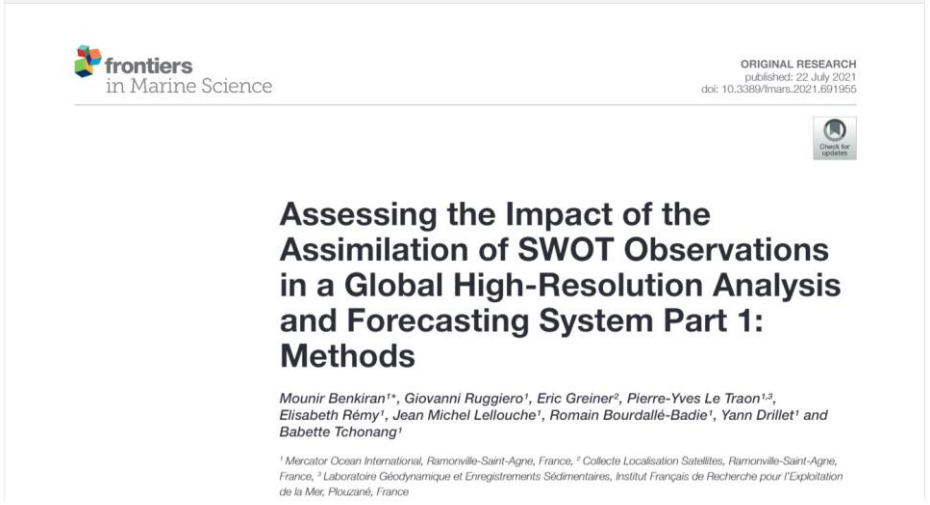


- Atlantic Mean Eddy Kinetic Energy(EKE): NatRun vs Free (Assimilated) Run: NR is more energetic in areas of high activity, western edge currents, tropical band...
- KE Spectrum: NR presents more energy at all scales compared FreeRun, It is also interesting to note that in NR the smallest scales



Impact of the future SWOT mission on the 1/12° Mercator Ocean global ocean analysis and forecasting system (Benkiran et al., 2021; Tchonang et al., 2021)

- The necessary updates to the operational forecasting system to better assimilate this new dataset
- The results of the SWOT data assimilation experiments with respect to conventional sea level data (Nadirs).
- Impact of SWOT data error on the global ocean forecasting system.



frontiers in Marine Science

ORIGINAL RESEARCH
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Assessing the Impact of the Assimilation of SWOT Observations in a Global High-Resolution Analysis and Forecasting System Part 1: Methods

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Assessing the Impact of the Assimilation of SWOT Observations in a Global High-Resolution Analysis and Forecasting System – Part 2: Results

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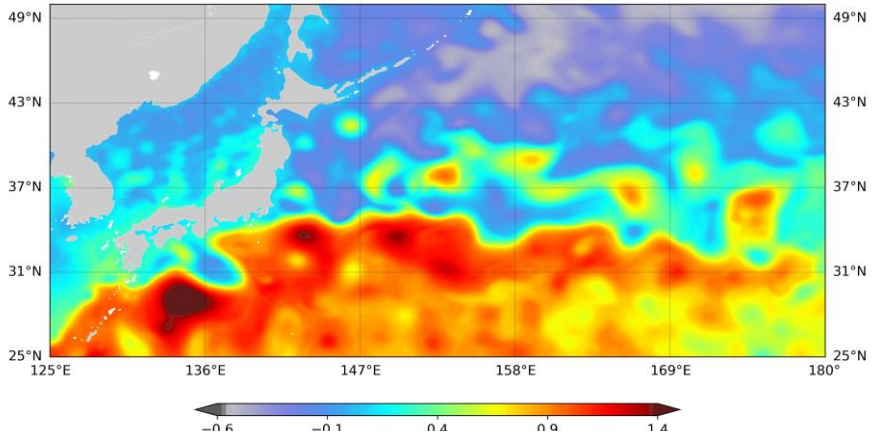
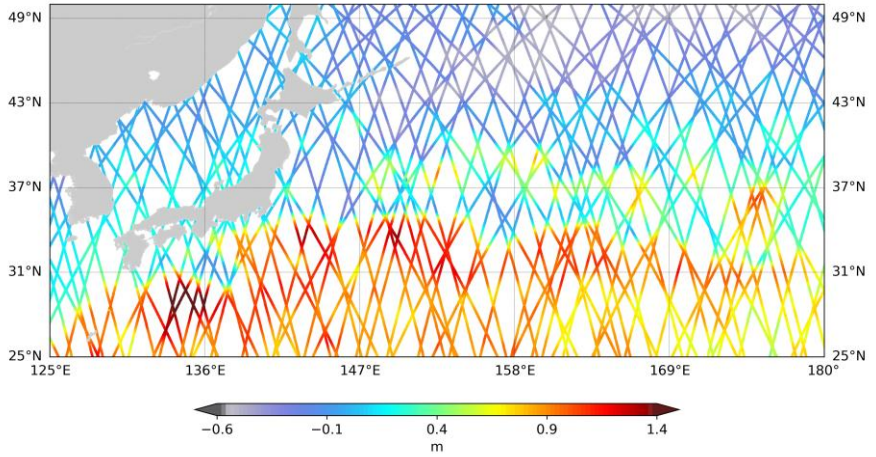
Observing System Simulation Experiments(OSSEs) global system (1/12°)

*SSH from NatRun over the **7-day** (01-08/01/2015) analysis window over the Kurushio region*

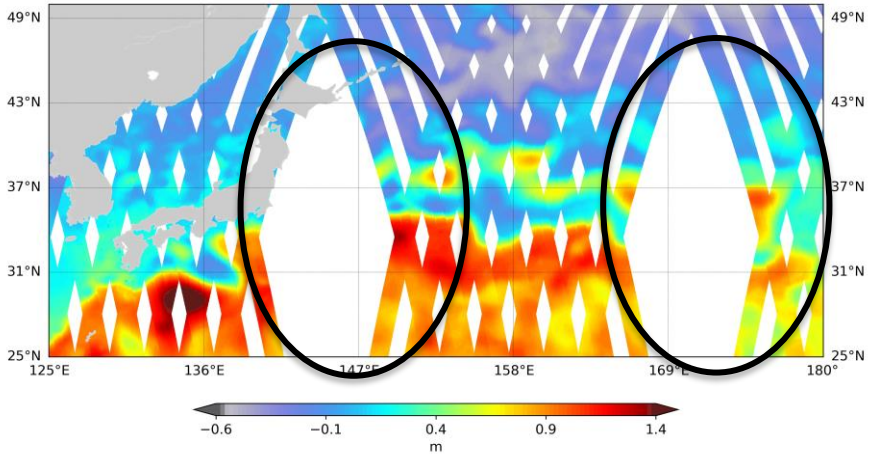
SSH NatRun Snapshot January 4, 2015



SSH : J3, S3A S3B (January 1-8, 2015)



SSH : SWOT (January 1-8, 2015)



SWOT alone:

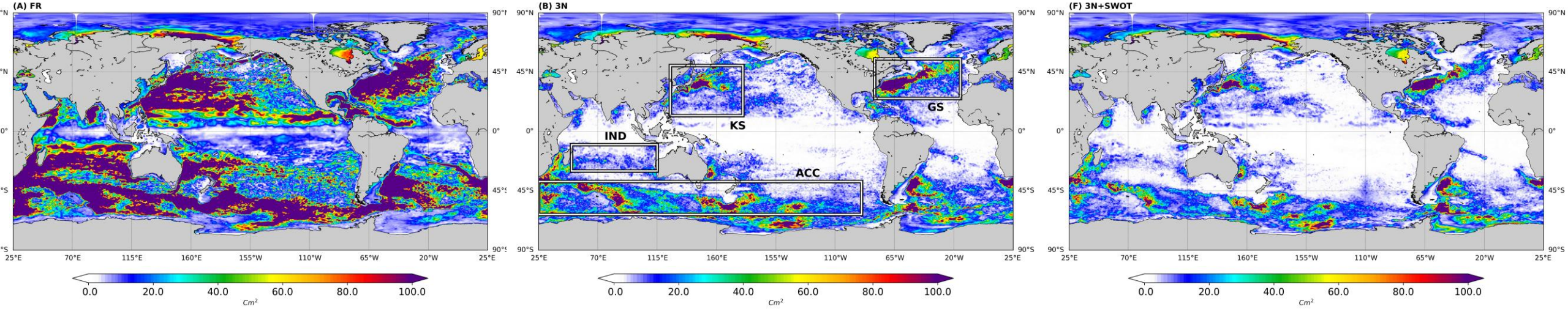
- good representation of the structures (2D)
- Non-homogeneous data coverage during an analysis cycle.

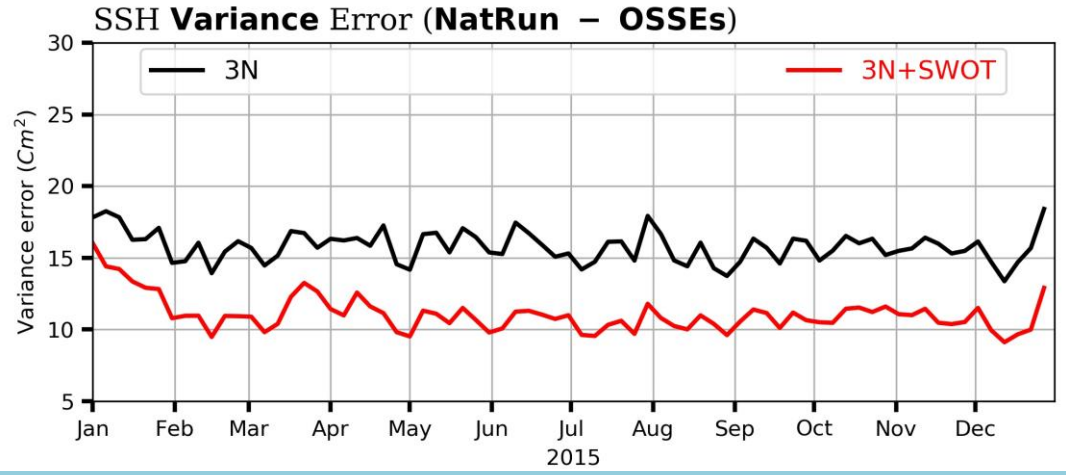
Best data coverage : SWOT + ?Nadirs

Variance of SSH Error: 3Nadirs vs SWOT (Analysis, 2015)

Error = NatRun - OSSEs

Control Run | 3Nadirs | 3Nadirs +SWOT





<u>Improvement (36%,</u> <u>average) :</u>

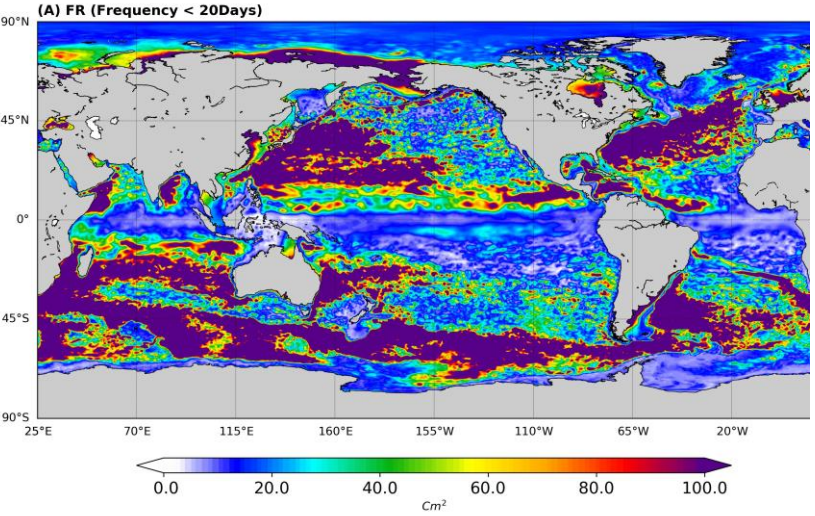
OSSE3 (3N+SWOT) = 11Cm^2 compared to **OSSE1(3N)** =15Cm^2

Adding SWOT observations to those of three nadir altimeters reduces the global error variance of the SSH in the analyses by about 36%.

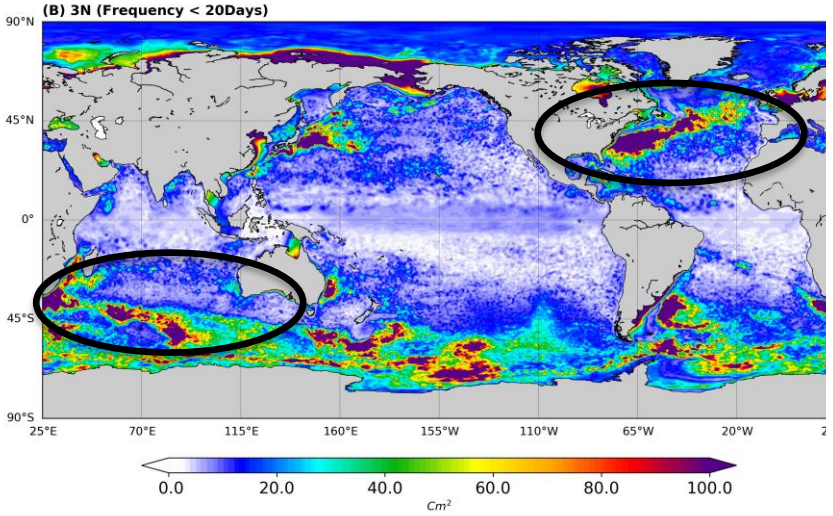
SWOT Impact on high **frequency**

Variance of SSH Error *(NR – Model Analysis; **Time scales < 20Days**, Cm², 2015).*

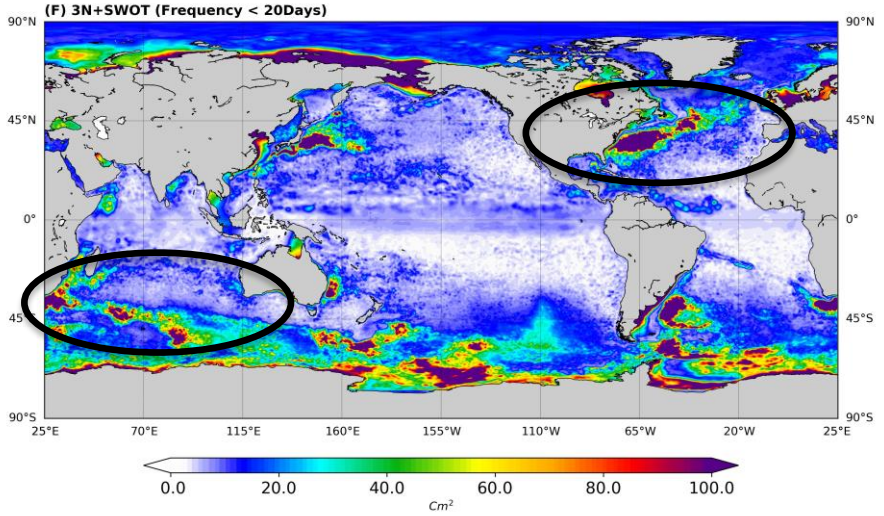
Control Run



3Nadirs



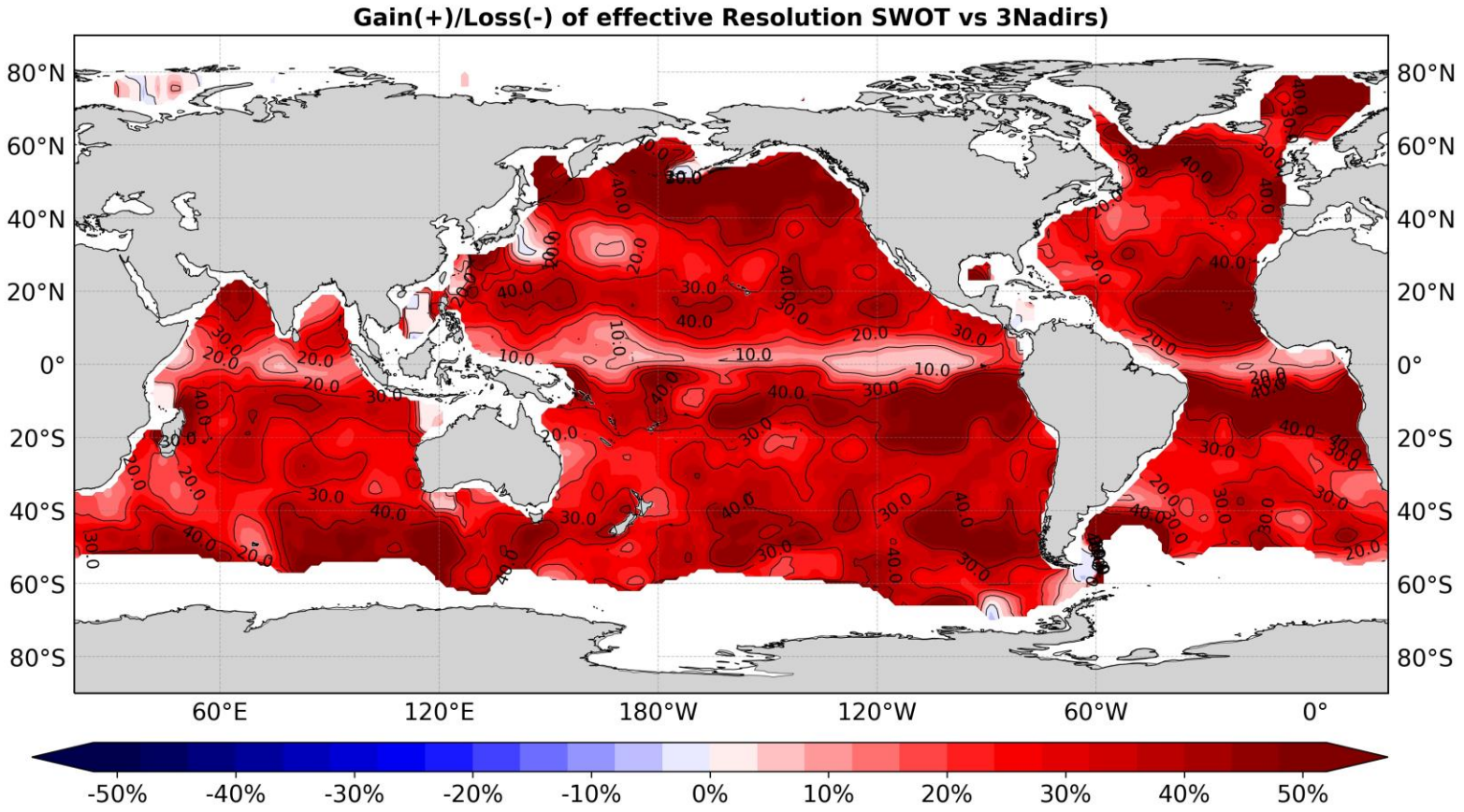
3Nadirs +SWOT

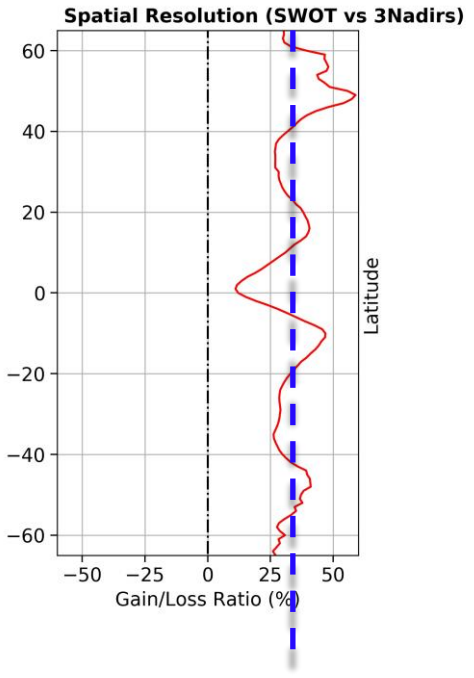


- *Best control of the high frequency by assimilation (adding) of SWOT…*
  - Much error is corrected (reduced) by adding SWOT
  - Better control of the high-resolution.

Effective resolution : SWOT vs 3Nadirs

(As proposed by Ballarotta et al 2019)





- improvement : Very different depending on the geographical area:
  - Important in high, mid latitude and WBCs…
  - Less in the tropical zone (large scales)

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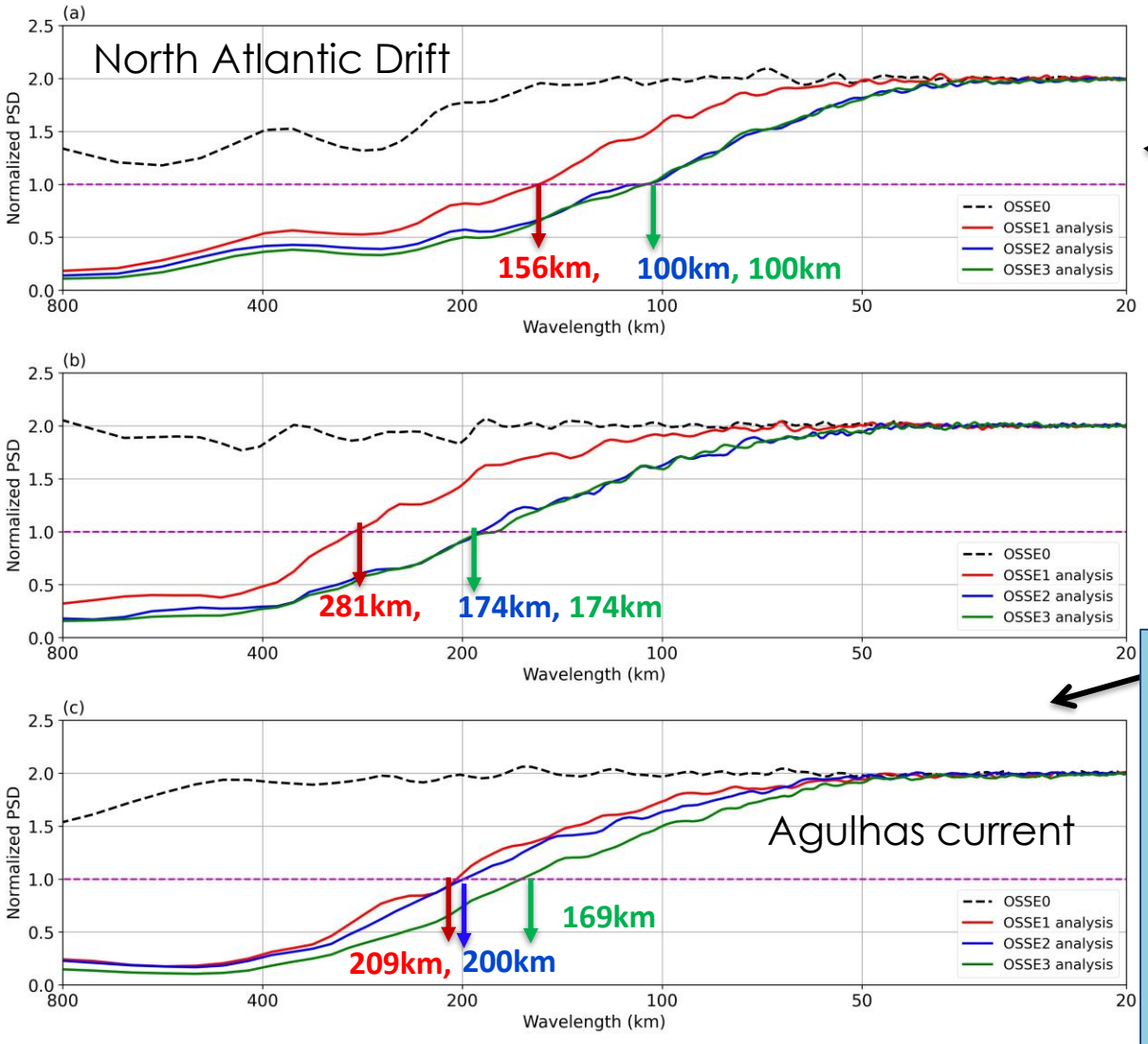
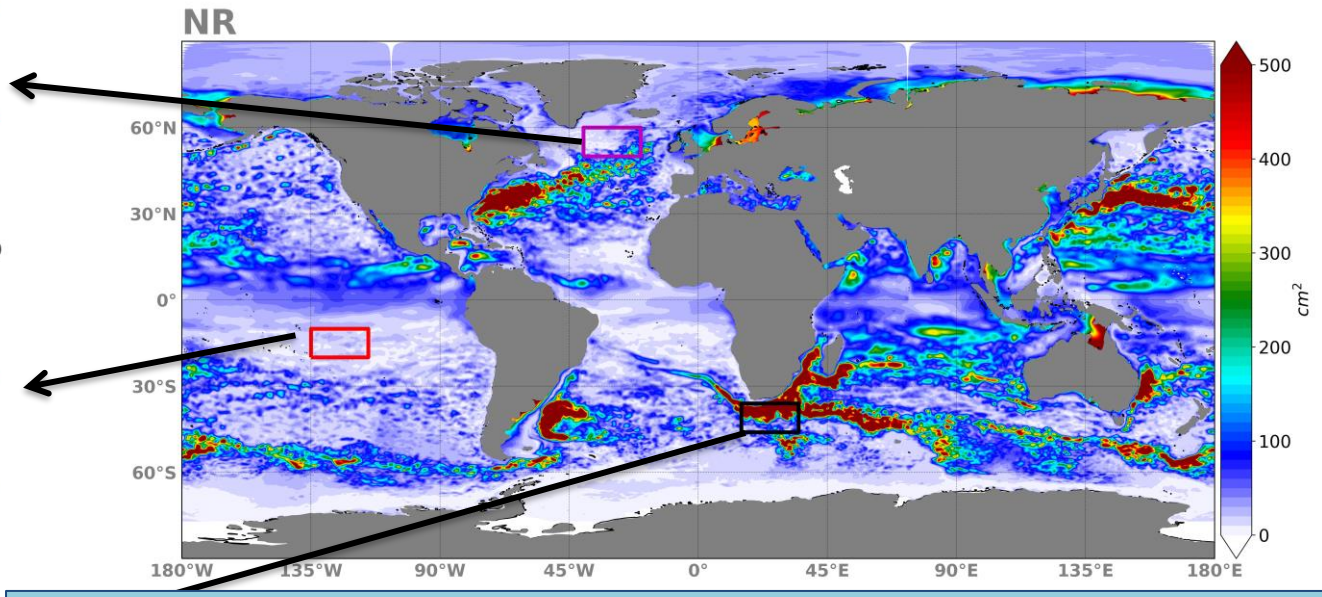
Results: spectral analysis

❖ Normalized spectra : D'Addezio et al., 2019 ➔ $\frac{\varepsilon_{OSSE_k}}{\langle \gamma_{NR}, \gamma_{OSSE_k} \rangle}$ ➔ Error spectrum (NR – OSSE)

➔ Average spectrum of NR and OSSE



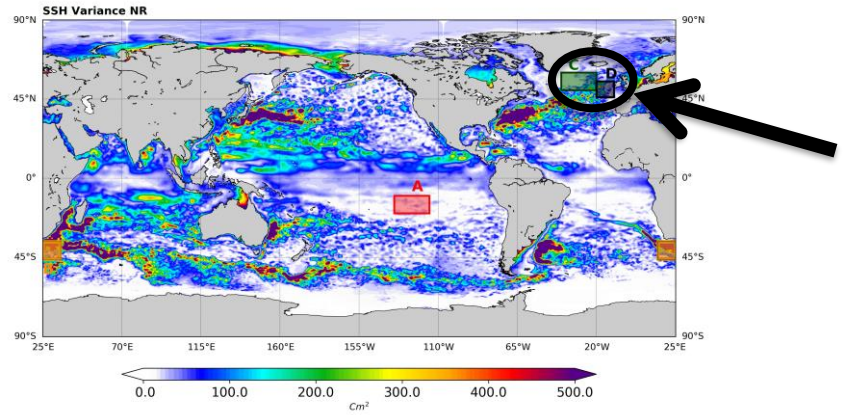


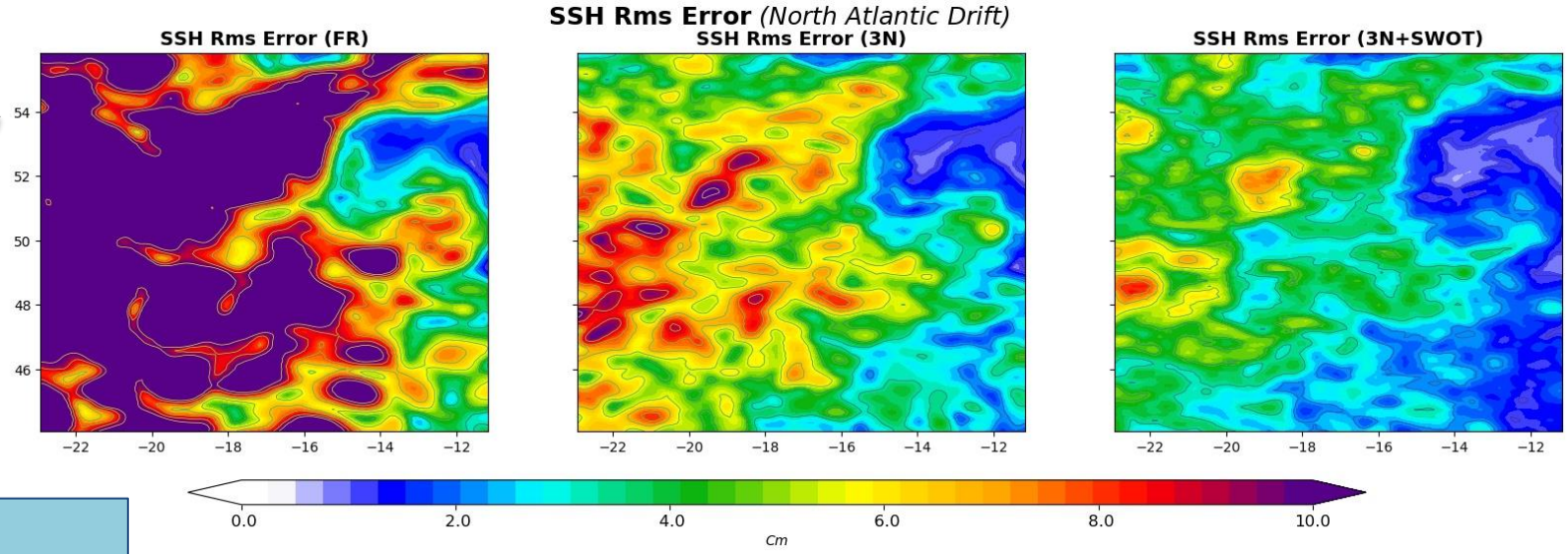
Adding SWOT (OSSE3):

- Smallest error in all 3 regions
- Crosses the normalized value of 1 at smaller wavelengths than other OSSEs
- 200 km - 50 km ➔ improvement of more than 40% compared to the OSSE1 (3Nadirs)
- Agulhas current (Swot alone): data coverage during an analysis cycle

OSSE1: 3Nadirs. OSSE2: SWOT OSSE3: SWOT + 3Nadirs

Spectral analysis : SSH(**Forecast**) Corehence (North Atlantic Drift)



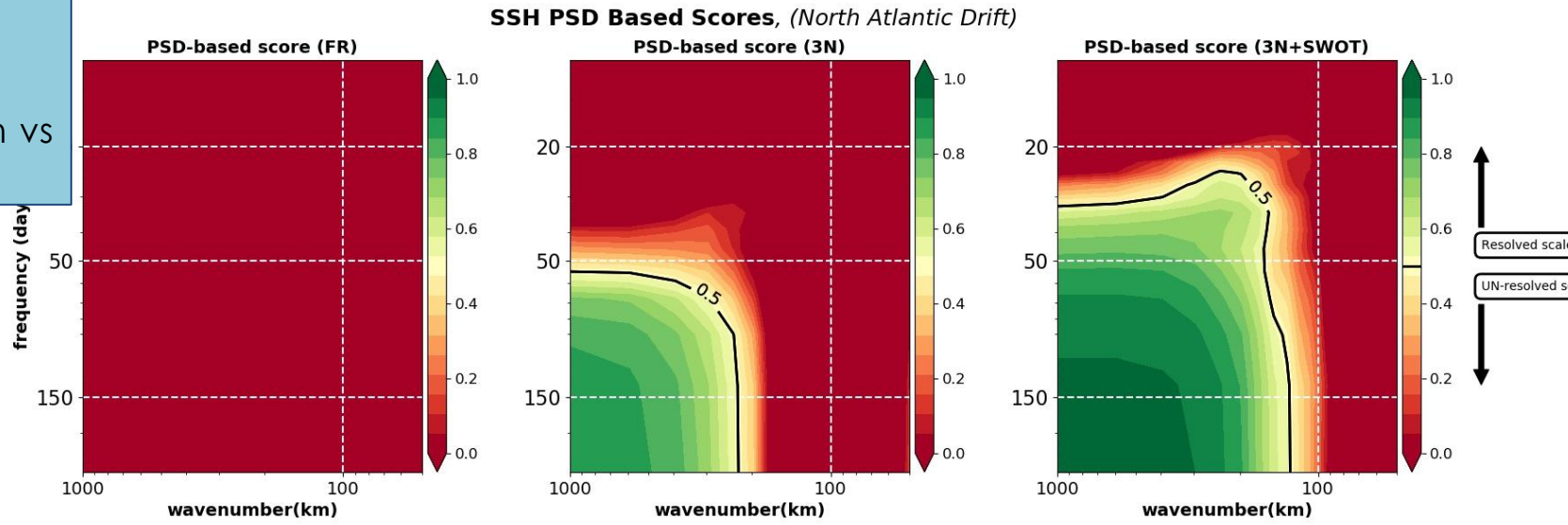


Adding SWOT (North Atlantic Drift)

- ✓ Reduction of SSH RMS Error
- ✓ Improvement space coherence:
- ✓ 50days to 25days : time coherence (Natrun vs OSSEs) : Improvement around 50%.

(As proposed by Le Guillou, 2021)

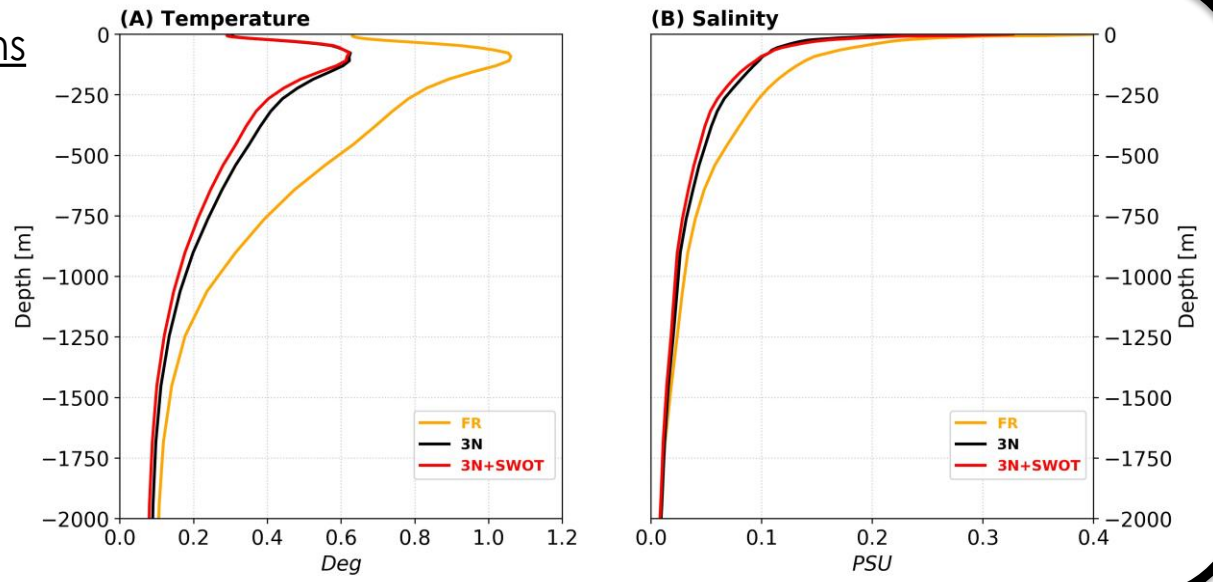
2D Coherence Spectral



SWOT Study: Impact on Temp , Sal and velocities at Various Depths

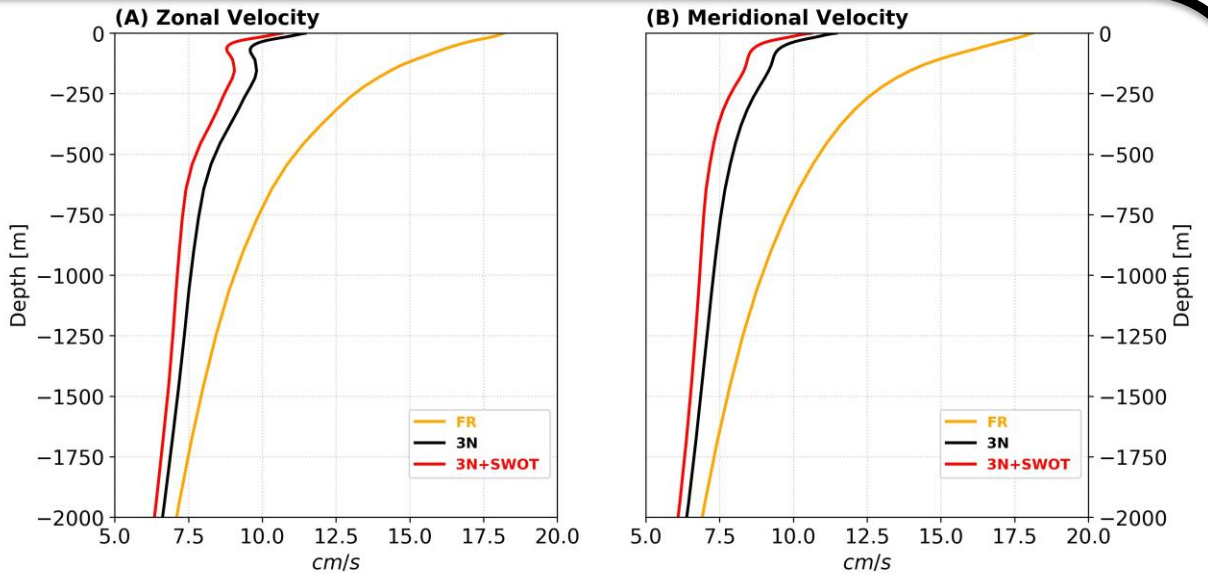
Global RMS Error: Temperature and salinity at Various Depths

- Significantly reduced by assimilation (3Nadirs, black profiles) vs Free Run(orange profiles)
- Assimilation (Adding) SWOT (red profiles) :
  - No degradation
  - Improvement 100-750m depth



Global RMS Error: velocities (U & V) at Various Depths

- Significantly reduced by assimilation vs Free Run (orange profiles)
- Assimilation (Adding) SWOT (red profiles) :
  - No degradation
  - improvement over the whole water column in zonal and meridional velocity



Main findings /SWOT OSSEs

- **SWOT observations**: significant improvement in the quality of ocean analyses and forecasts
- **Impact of SWOT observations**: Very different depending on the geographical area.
- **3 Nadirs +SWOT**: global reduction in SSH and U&V errors by ~36% and ~24% compared to 3 nadirs.
- **Spatial scales < 200 km**: global reduction of SSH error by ~40% outside tropical regions compared to 3 Nadirs
- **Adding of SWOT** : improvement of SSH Space/Time coherence with Natrun
- More important improvements at high latitudes where SWOT space-time coverage is denser

The Mercator Ocean and Copernicus Marine Service high-resolution global analysis and forecasting system is ready to assimilate SWOT data. The impact is very positive at all latitudes and space-time scales.

Idealized experiment : only random noise was considered.

NatRun vs Assimilated Run

TABLE 1 | Differences in model parameterisation between (NatRun) NR and (Free Run model) FR.

	Nature run	Free run
Nemo version	NEMO3.6	NEMO3.1
vertical levels	75	50
Forcing flux	ERA-Interim reanalysis (3 h for dynamic, 24 h for flux) (Dee et al., 2011)	ECMWF IFS-operational analysis (3 h for all variables)
Bulk formulae	IFS implemented in Aerobulk package (Brodeau et al., 2017)	NCAR (Large and Yeager, 2009)
Ocean stress computation	Absolute wind	50% of ocean velocity are taken into account (Bidlot, 2012)
Atmospheric pressure	Apply though Inverse barometer force.	No
Free surface formulation	Explicit barotropic and baroclinic modes solved by a split-explicit method (Shchepetkin and McWilliams, 2005)	Filtered free surface (Roullet and Madec, 2000)
Sea level	Variable volume (Adcroft and Campin, 2004)	Fixed ocean volumes
horizontal momentum advection	UBS scheme (Shchepetkin and McWilliams, 2008) without explicit diffusion	Centered advection scheme with an explicit biharmonic diffusion ($-1.5 \times 10^{-9} m^3\ s^{-3}$)
Vertical mixing	k-espilon (Rodi, 1987)	TKE (Blanke and Delécluse, 1993)

Benkiran et al 2021