Projet Partner

Assessing the impact of the assimilation of SWOT observations in a global high-resolution analysis and forecasting system

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Introduction and Objectives

Objective:

- Prepare the assimilation of SWOT in Mercator Ocean analysis and forecasting systems.
- Answer a few questions:
  - ✓ How to integrate this new dataset into forecasting systems?
  - ✓ What is SWOT's contribution to the quality of ocean forecasting and analysis?
  - ✓ What is the impact of SWOT measurements on small scales (mesoscale and sub-mesoscale)
  - ✓ How the model will propagate (in time and space) the assimilated SWOT data.
- 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)

Introduction and Objectives

- 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.

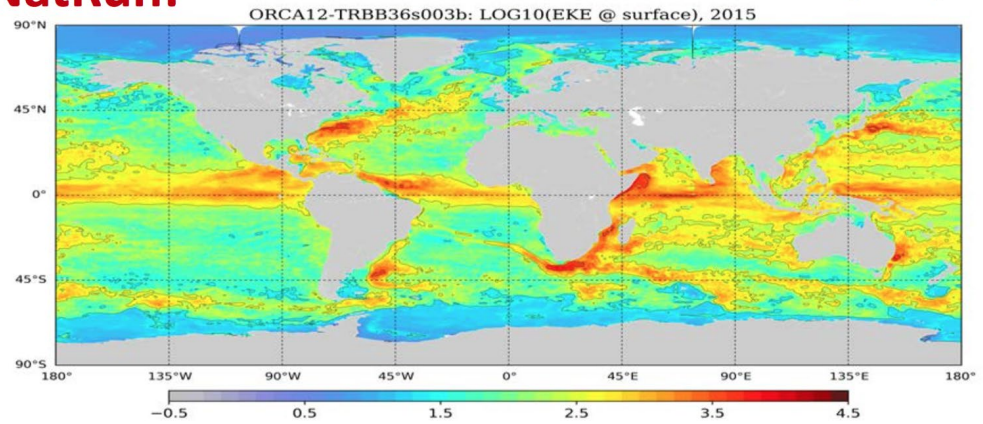
Results of the study : Two papers concerning this work have been plublished in Frontiers

Benkiran et al. 2021: Methods

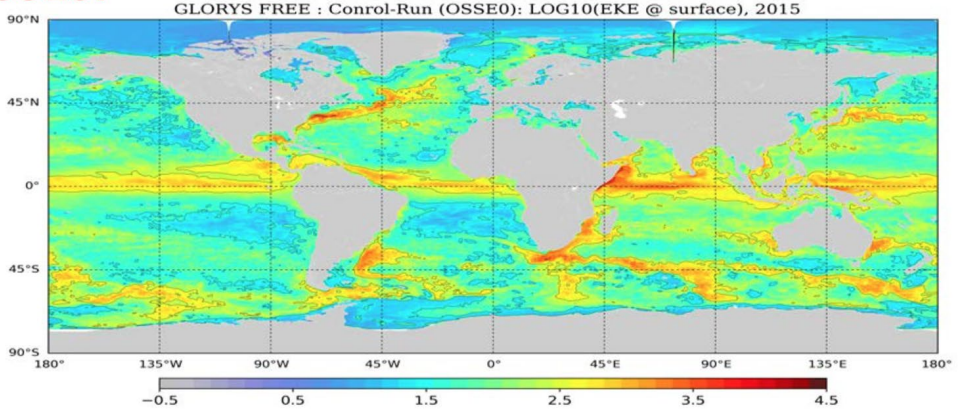
Tchonang et al, 2021: Results

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

NatRun: EKE (2015)



OSSEs: EKE (2015)



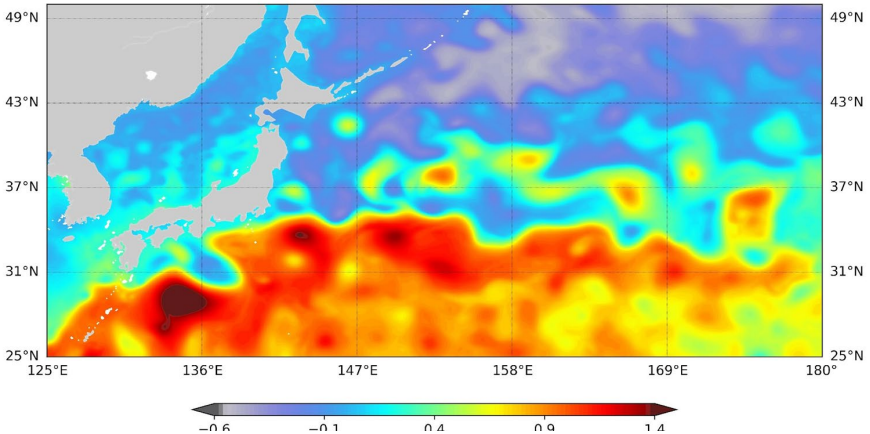
OSSE Study (Simulation of Observation):

- Simulated SSH :
  - **Swot** (6 Kms x 6 Kms) data:
    NatRun SSH + Karin noise (SWH=2m)
  - **Nadirs** altimeter data (1Hz):
    NatRun SSH (**LRM mode** : **Jason3, Sentinel3A, Sentinel3B**)
- SST (L3S (ODYSSEA), 10km , daily)
- T&S profiles (CORA4.1)
- Sea Ice Concentration

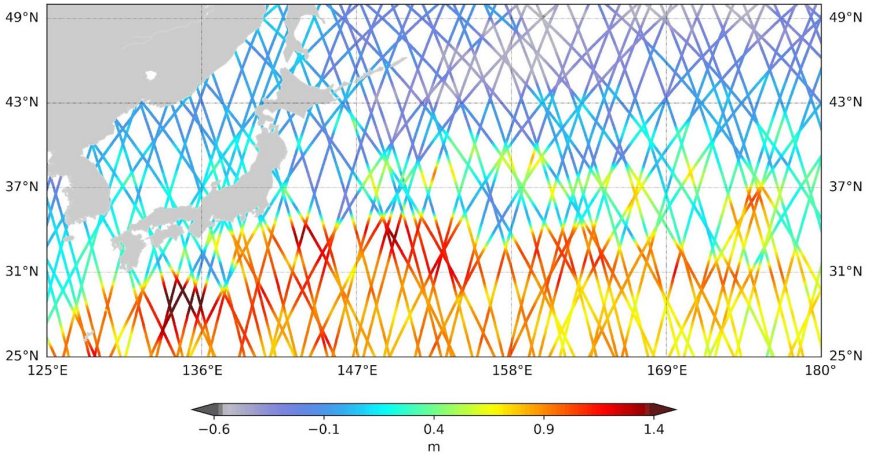
Observing System Simulation Experiments(OSSEs) global system (1/12°)

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

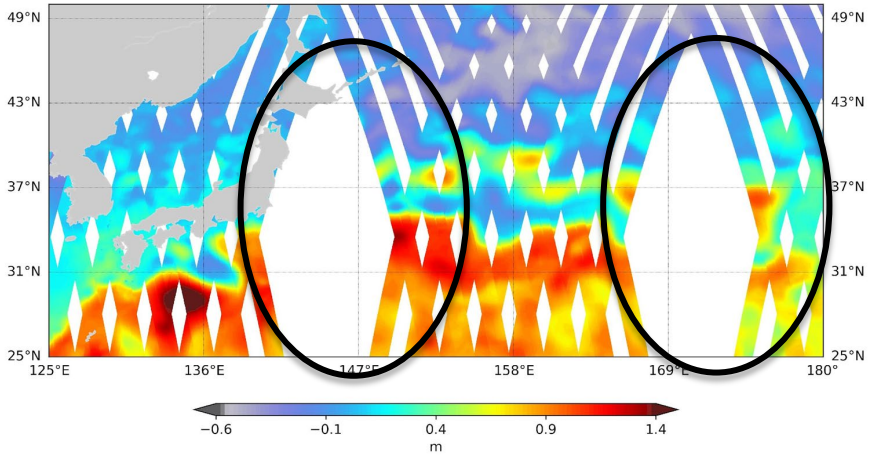
SSH NatRun Snapshot January 4, 2015



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

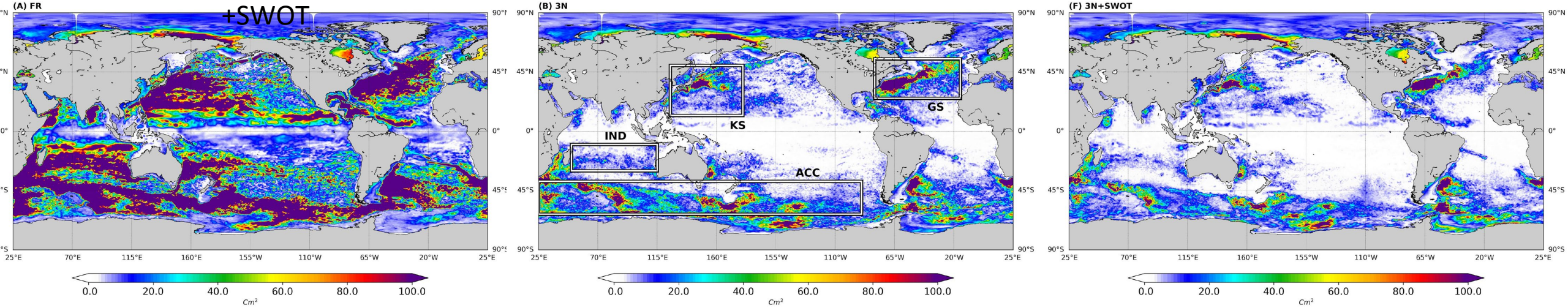
SSH Variance Error : 3Nadirs vs SWOT (Analysis, 2015)

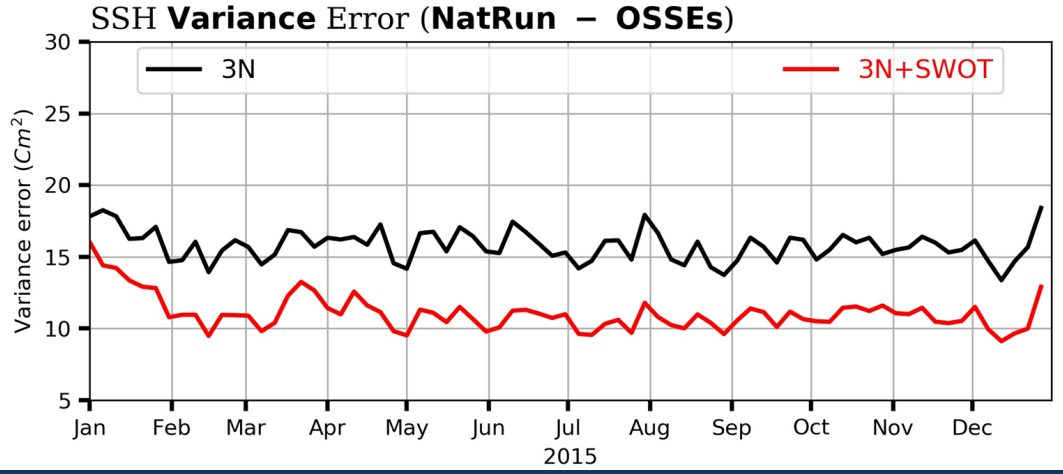
Error = NatRun - OSSEs

Control Run +SWOT

3Nadirs

3Nadirs





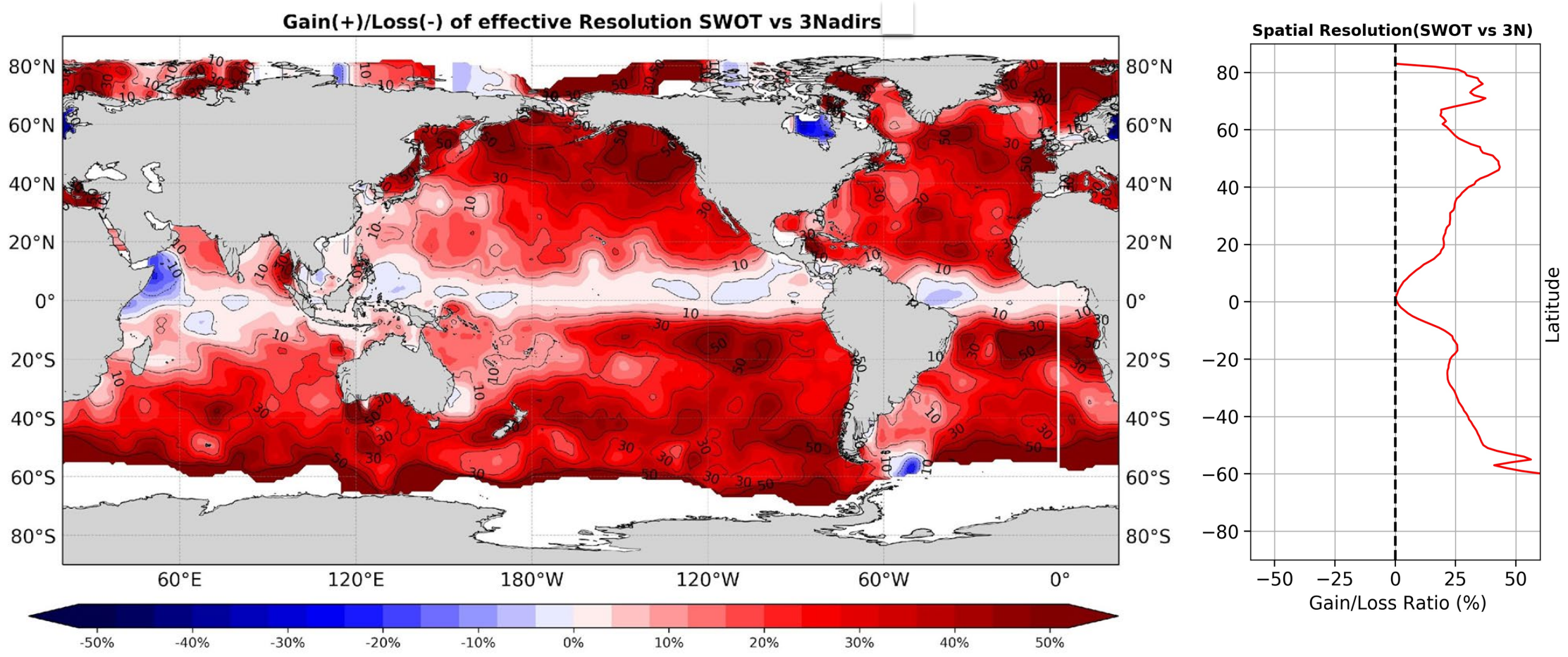
<u>Improvement (36%, average) :</u>

OSSE3 (3N+SWOT) = 11Cm² compared to **OSSE1(3N)** =15Cm²

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

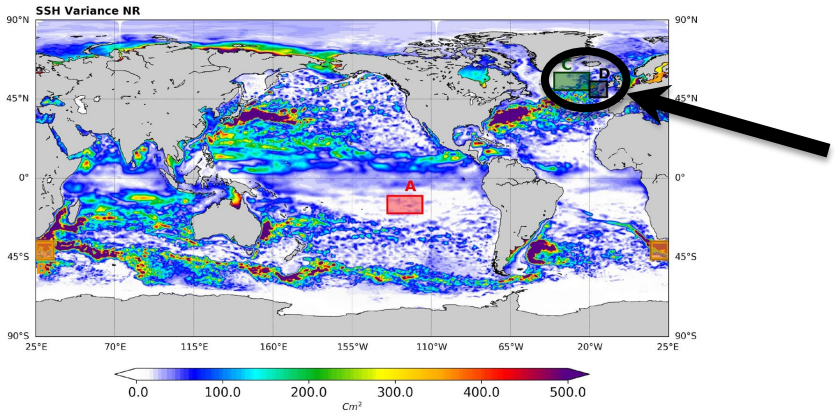
Effective resolution : SWOT vs 3Nadirs

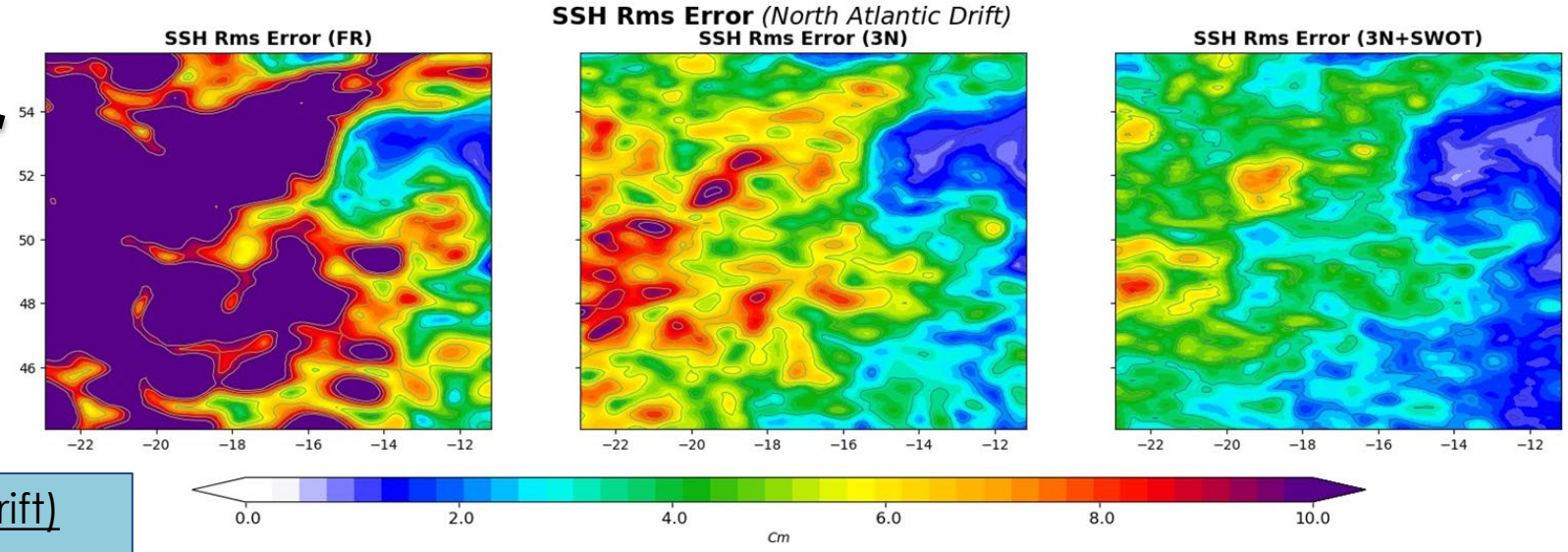
(As proposed by Ballarotta et al 2019)



- improvement : Very different depending on the geographical area.

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

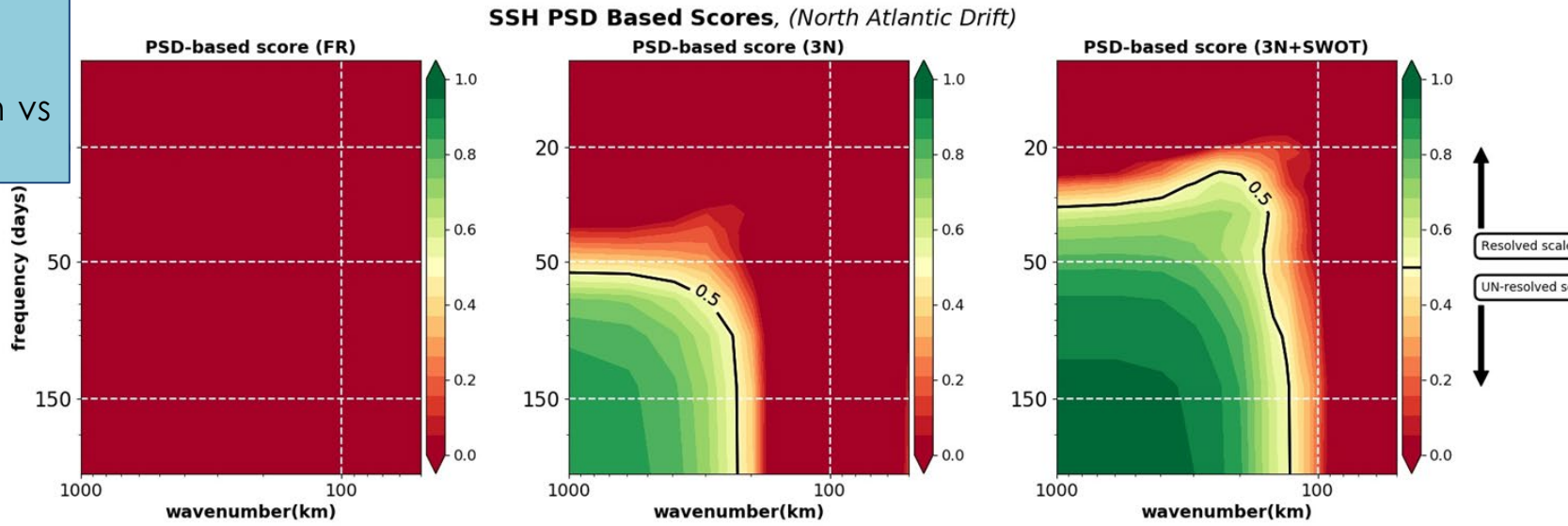




Add SWOT (3N +SWOT, North Atlantic Drift)

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

2D Coherence Spectral

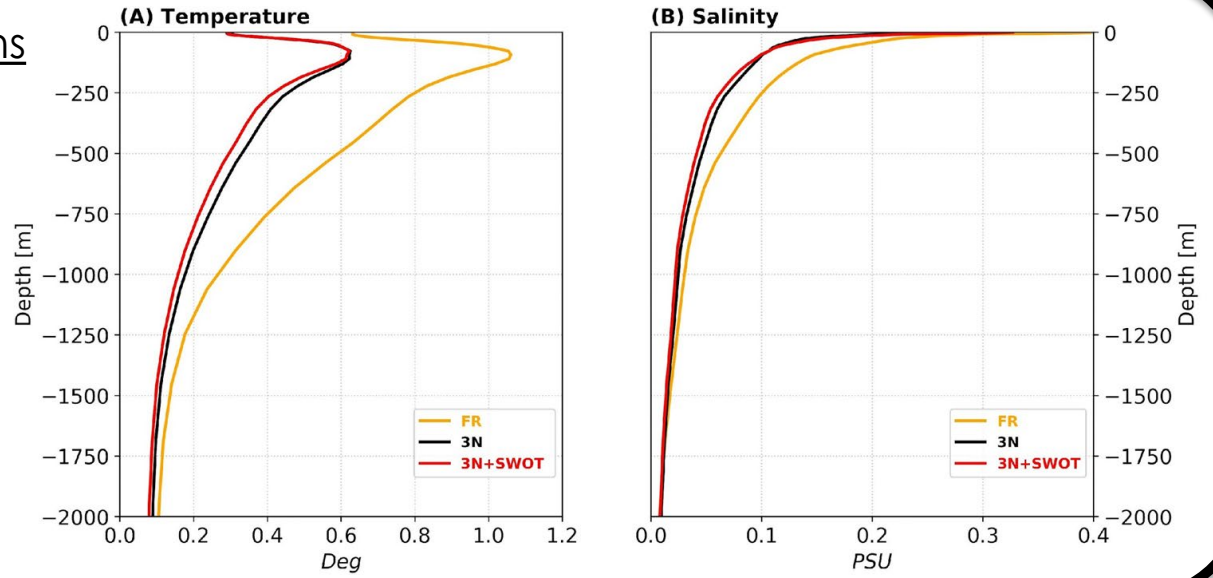


(As proposed by Le Guillou, 2021)

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

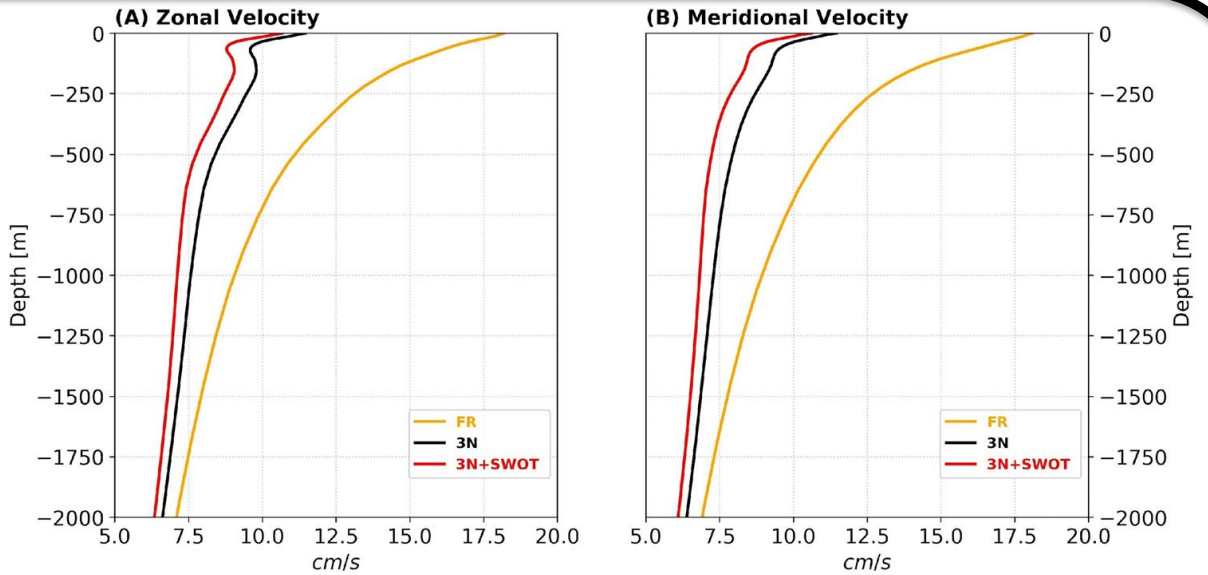
Global RMS Error: Temperature and salinity at Various Depths

- Significantly reduced by assimilation (3N, 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



Conclusions

- **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.

Next steps

- Assimilation with scale separation (multiscale analysis, work in progress)
- New diagnostics (e.g. vertical velocity)
- Introduce wave maps (daily) to simulate observations error (Impact on KaRIn)
- Add correlated error terms (eg roll errors) in the OSSEs including their reduction through the DUACS L3 processing system (cross-calibration) (preferred) or directy in the assimilation system
- Test with real data (SWOT 1 day phase)
- **Objective** : be ready to assimilate SWOT data in the global Mercator Ocean/Copernicus Marine Service system in a demonstration mode at the end of 2023 (nominal 21 day phase).

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)

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SWOT Study: Impact on the surface velocities

Temporal evolution of global error variance for velocities

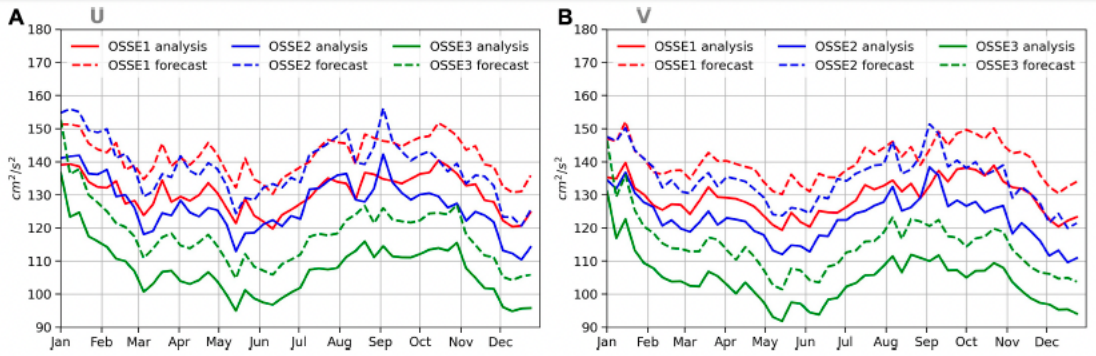

FIGURE 11 | Temporal evolution of **(A)** zonal velocity (U) and **(B)** meridional velocity (V) error variance (in cm^2/s^2) for 7-day ocean analysis (plain lines) and 7-day ocean forecast (dash lines) over the period from January 1 to December 29, 2015. The results were obtained by comparing U and V in the OSSE1 (red lines), OSSE2 (blue lines), and OSSE3 (green lines) experiments with the U and V from the NR. See **Table 2** for a description of each experiment.

OSSE1: Red : 3Nadirs
OSSE2: Blue : SWOT
OSSE3: Green : 3Nadirs+SWOT

dash lines : Forecast
plain lines : Analysis

- Seasonal variation in error with a peak in summer for all OSSEs
- The variance of errors decreased from OSSE1 to OSSE3.

TABLE 7 | Global statistics of zonal (U) velocity error variance for both analysis (ANA) and forecast (FCST) over the period of March to December 2015.

U	VAR Error (cm^2/s^2)		∝ (%)	
	FCST	**ANA**	**FCST**	**ANA**
OSSE0	401		–	
OSSE1	141	130	35	32
OSSE2	136	125	33	30
OSSE3	115	105	28	26

Error variances (VAR Error) are given in Column 1. Column 2 represents the error relative to the FR error variance (α).

- Adding SWOT in the global Ocean :
  Improvement (24% in Analysis and 23% in Forecast)

(Tchonang et al. 2021)