Evaluating in situ sampling strategies for SWOT satellite validation

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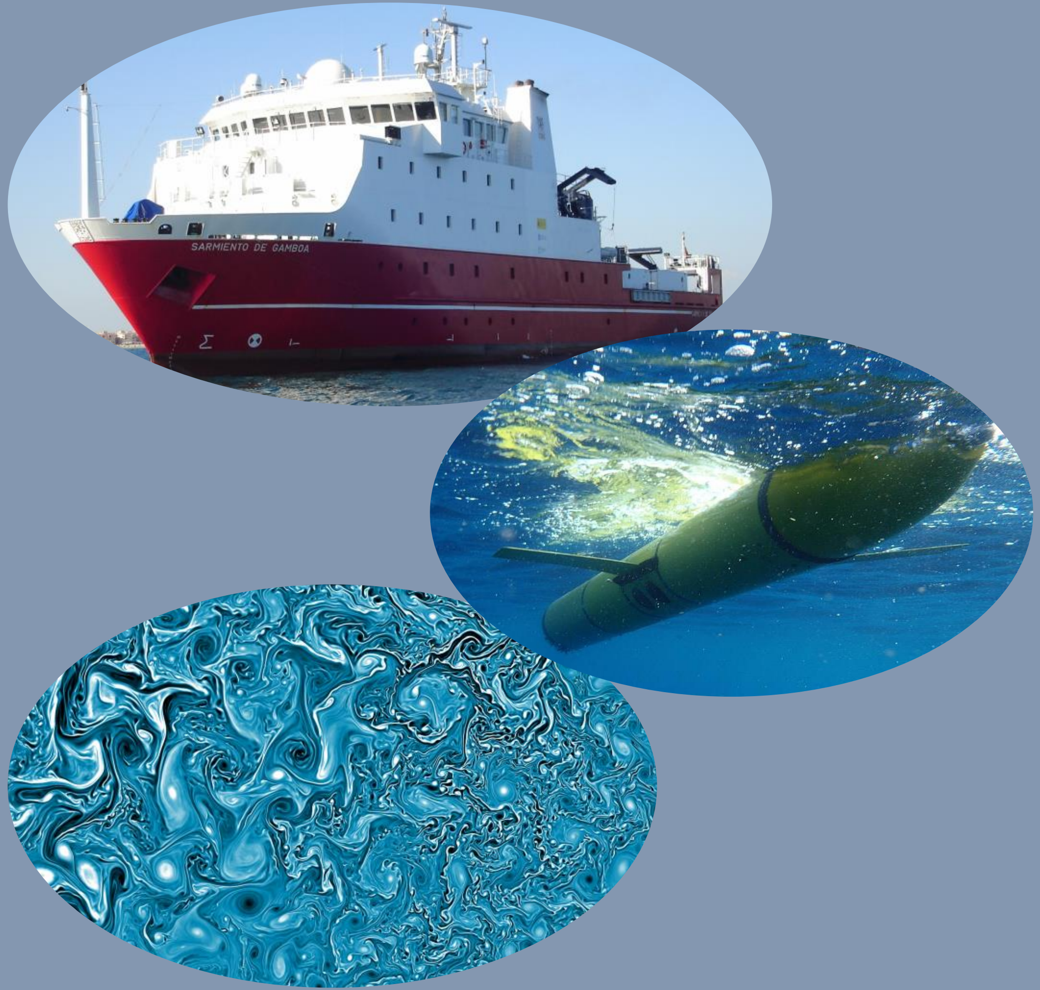
EuroSea/OceanPredict workshop

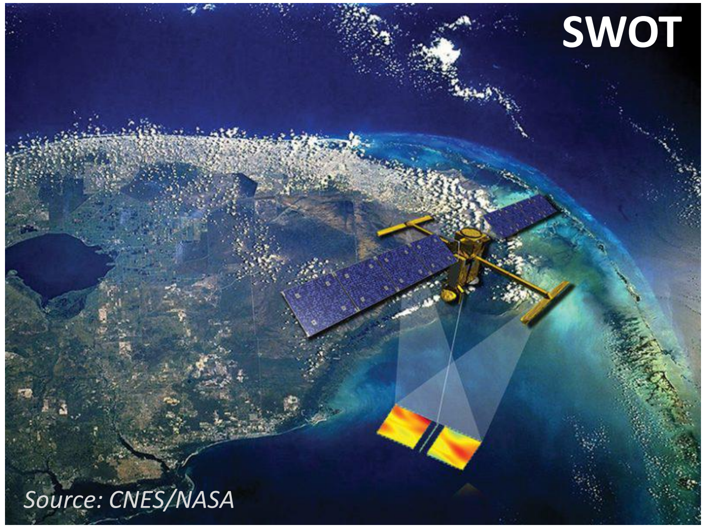


*The EuroSea project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 862626.

Context: SWOT mission validation

- The Surface Water Ocean Topography **(SWOT)** satellite mission will be a game changer in the observation of ocean circulation

2D sea surface height (SSH) maps at unprecedented spatial resolutions of 15-30 km

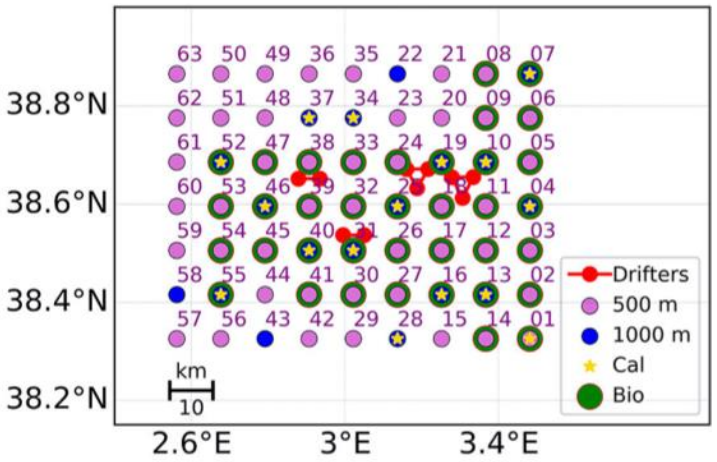


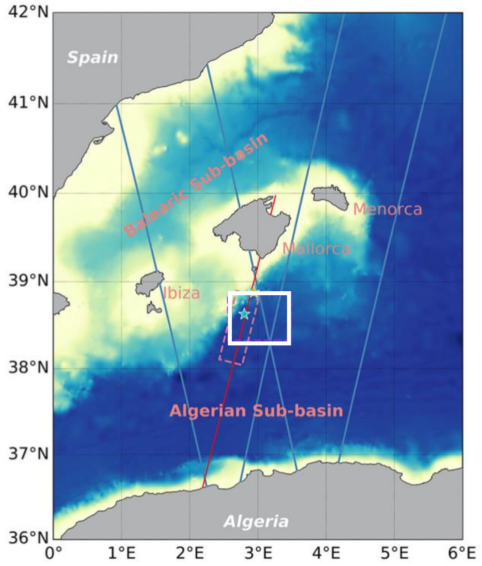
- Need to define **strategies for SWOT validation** using integrated high-resolution multi-platform observations

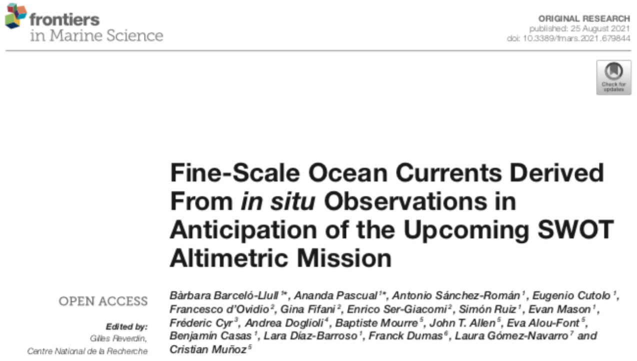
Context: PRE-SWOT experiment in 2018

- In preparation for SWOT validation: PRE-SWOT multi-platform experiment in 2018
  - Collect in situ data from different platforms (CTD, ADCP, drifters, water samples) to explore the 3D circulation at scales of 20 km wavelength (SWOT scales)

PRE-SWOT sampling strategy



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ORIGINAL RESEARCH
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Fine-Scale Ocean Currents Derived From *in situ* Observations in Anticipation of the Upcoming SWOT Altimetric Mission

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Edited by:
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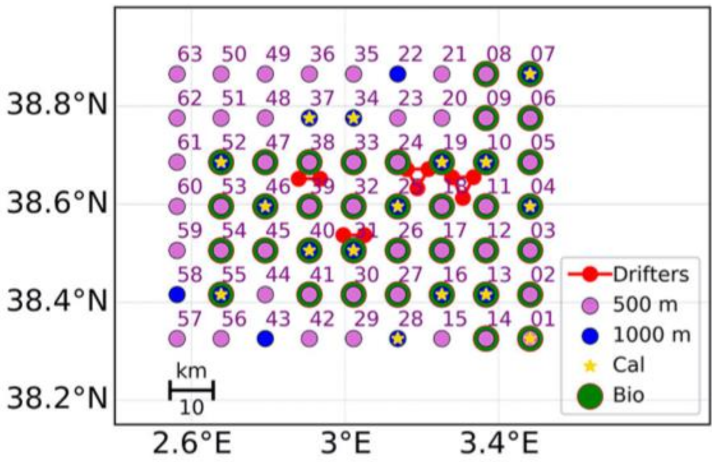
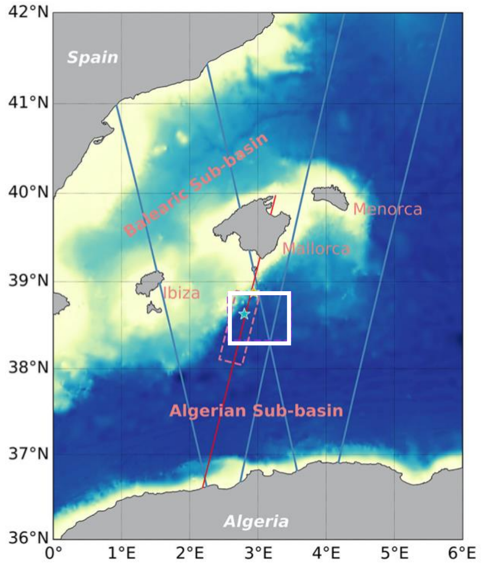
Barceló-Llull, Pascual, et al. (2021)

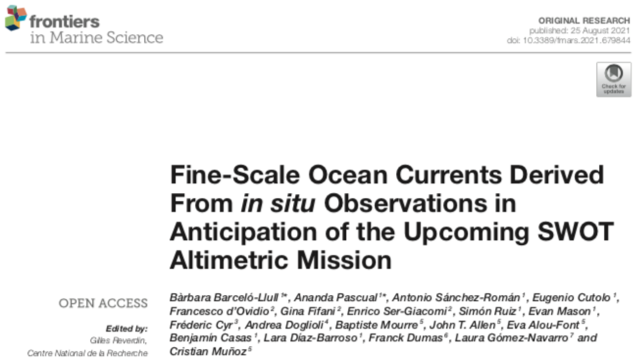
Context: PRE-SWOT experiment in 2018

- In preparation for SWOT validation: PRE-SWOT multi-platform experiment in 2018
  - Collect in situ data from different platforms (CTD, ADCP, drifters, water samples) to explore the 3D circulation at scales of 20 km wavelength (SWOT scales)
- Spatial optimal interpolation to reconstruct the observations of T and S
  - Widely used in field experiments (e.g., Rudnick, 1996; Pascual et al., 2004; Barceló-Llull et al., 2017; Ruiz et al., 2019)
  - It assumes quasi-synoptic observations

PRE-SWOT sampling strategy



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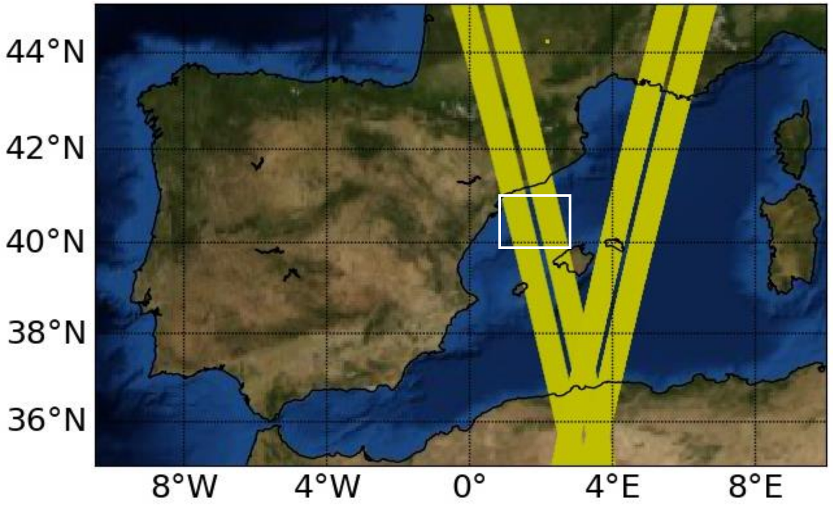
Barceló-Llull, Pascual, et al. (2021)

Optimizing multi-platform sampling strategies through OSSEs

Objective: Improve the design of multi-platform experiments aimed to validate SWOT observations through Observing System Simulation Experiments (OSSEs)



- Focus on SWOT scales ~20 km
- Results for the Mediterranean

Observing System Simulation Experiments

Models

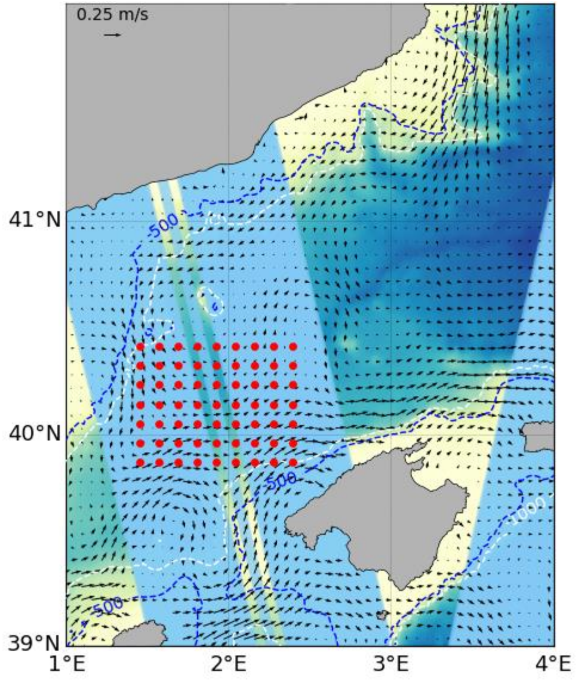
eNATL60	1.5 km, hourly *Ajayi et al. (2020)*
WMOP	2 km, daily *Mourre et al. (2018)* *Aguiar et al. (2020)*
CMEMS	4 km, daily *Escudier et al. (2020)*

- Models used to simulate CTD observations and as the "ocean truth"
- 3 models to test sensitivity

Configurations

Reference	• CTD casts • z_{max}: 1000 m • dx: 10 km • Summer
#1	z_{max}: 500 m
#2	dx: 5, 8, 12, 15 km
#3	uCTD
#4	Winter
#5	Gliders

CTD profiles of the Reference configuration



- Region of study within a swath of SWOT

More details in the Deliverable 2.1: https://doi.org/10.3289/eurosea_d2.1

Improvement of the optimal interpolation (OI) algorithm

Before reconstructing all configurations…

Drawbacks of the spatial OI used in field experiments

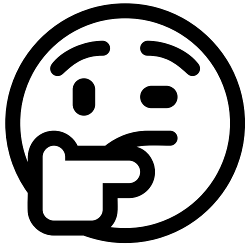
1) Assumption of quasi-synopticity
2) No specific date for the resulting map

Spatio-temporal OI algorithm

$$C(r,t) = e^{-\frac{r^2}{2L^2}} e^{-\left(\frac{t}{T}\right)^2}$$

Escudier et al. (2013)

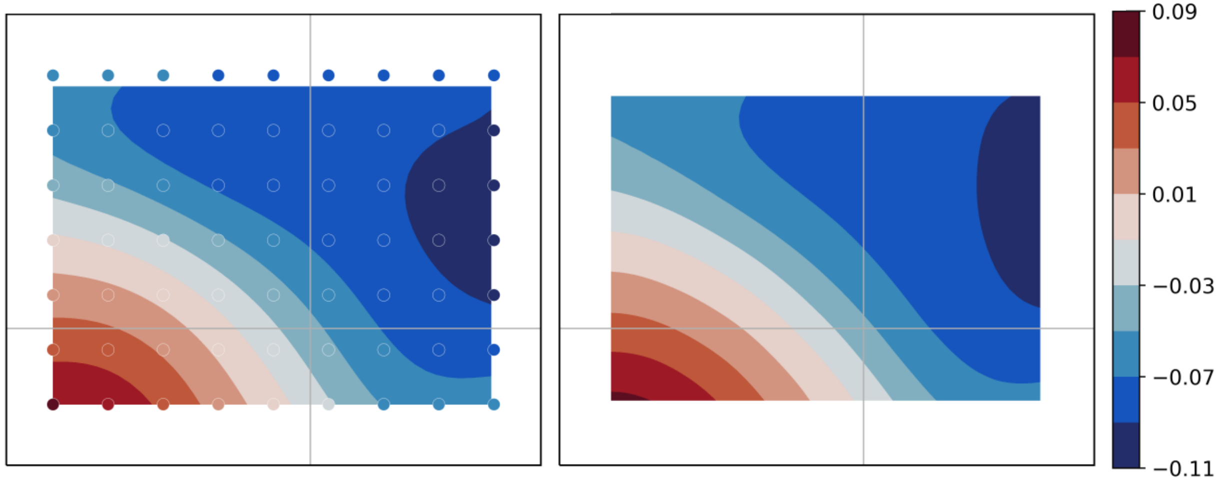
Which temporal correlation scale should we use?



Analysis of the temporal correlation scale (Lt)

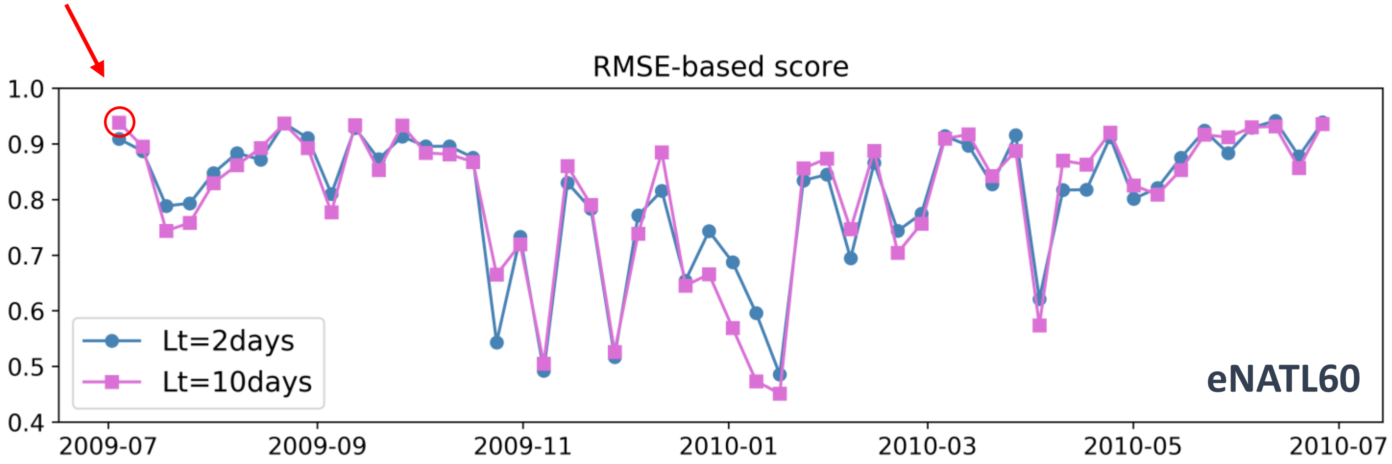
Reconstructed SSH (m)
Pseudo-observations + OI map

“Ocean truth” SSH (m)



Reconstruction and “ocean truth” date: 2009-07-04 03:30
Spatio-temporal OI with **Lt = 10 days**

RMSEs = 0.94

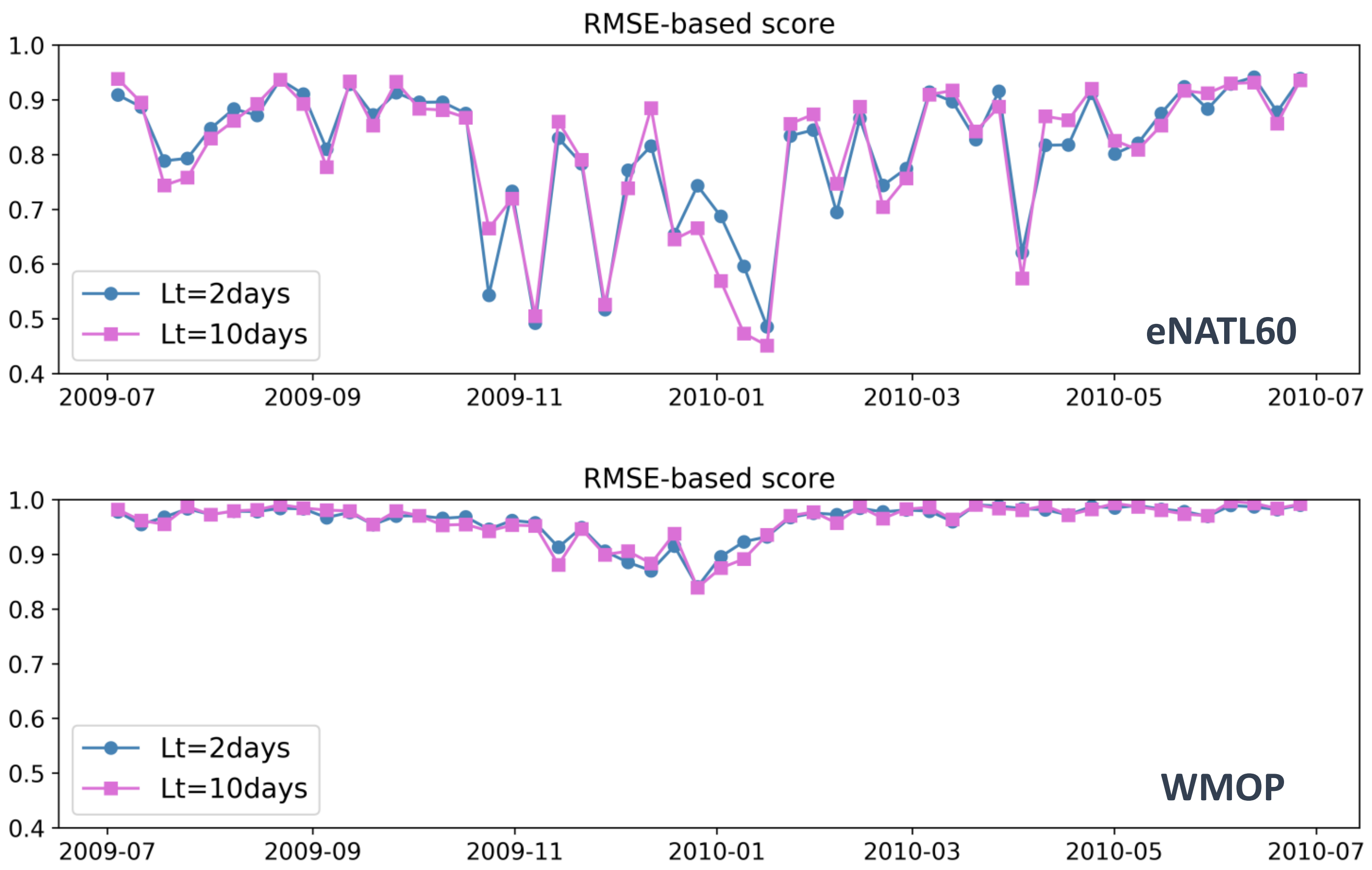


RMSE-based score (RMSEs)

$$RMSEs = 1 - [RMS(SSH_{rec} - SSH_{true})/RMS(SSH_{true})]$$

1 = perfect reconstruction; 0 = bad reconstruction

Analysis of the temporal correlation scale (Lt)



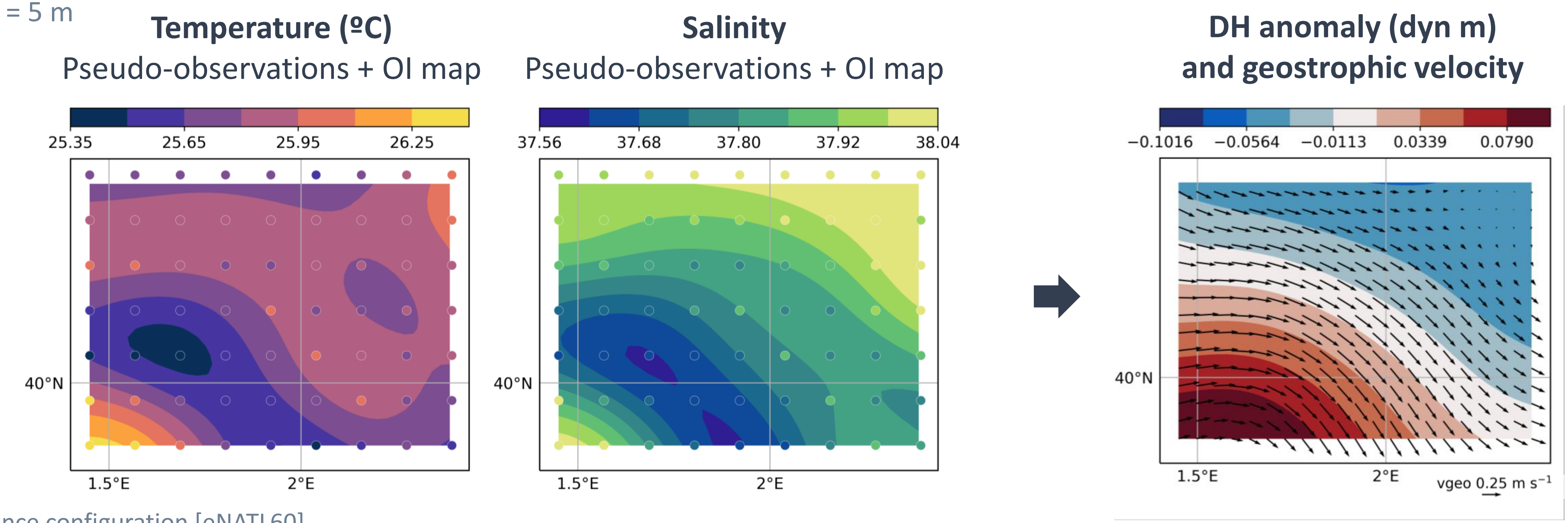
Similar RMSEs for both Lt:
we can use Lt = 10 days and consider quasi-synoptic pseudo-observations

Spatio-temporal OI reconstruction

Reconstruct all configurations with the spatio-temporal OI

1) Interpolate T and S pseudo-observations:
   - Linear interpolation on the vertical
   - Spatio-temporal OI on each depth layer (Lx=20km, Lt=10days)
2) Calculate DH and geostrophic velocity magnitude at the upper layer

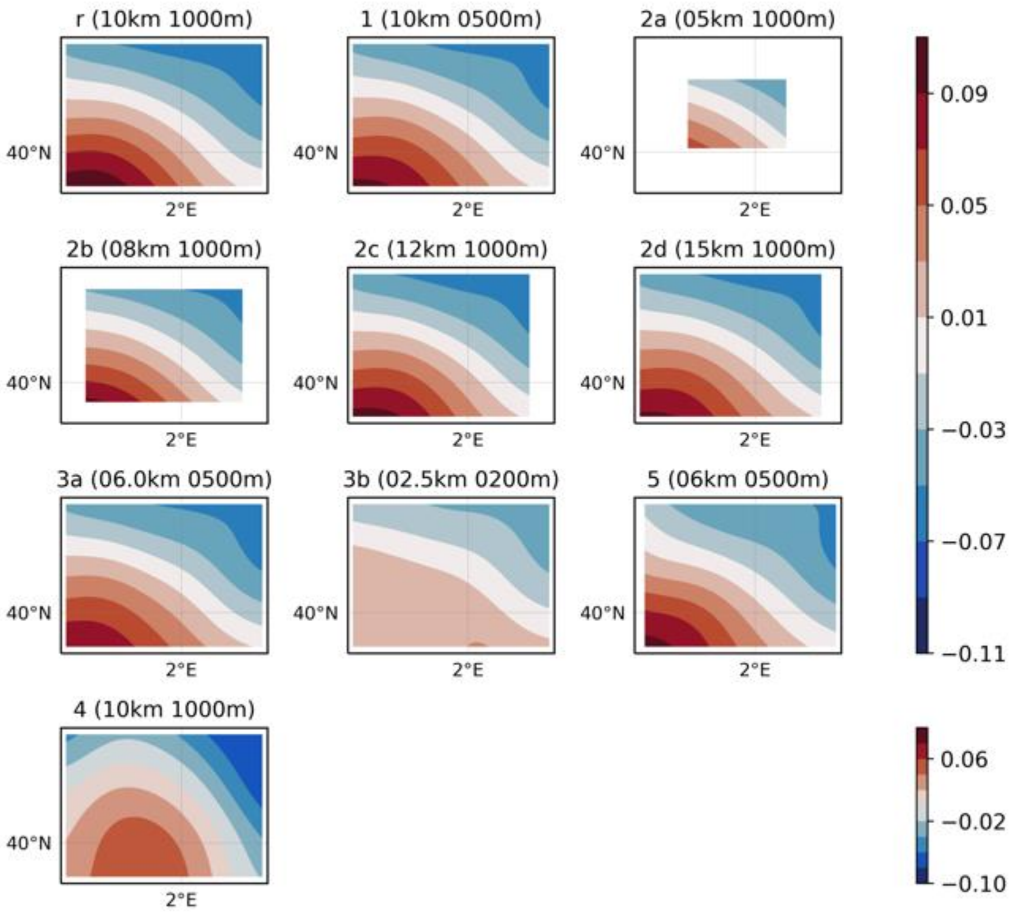
dep = 5 m



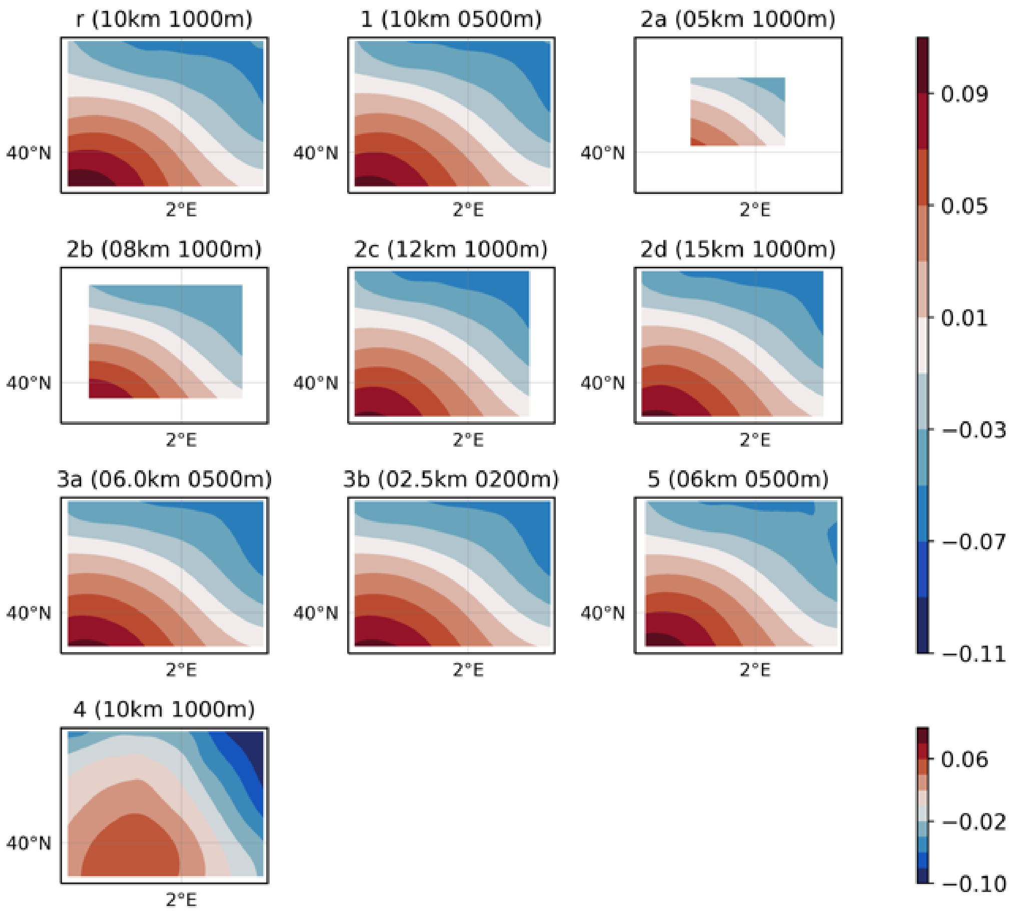
Reference configuration [eNATL60]
Date OI map: 2009-09-03 03:45

Reconstructed DH [eNATL60]

Reconstructed DH anomaly (dyn m)
at the upper layer for all configurations [eNATL60]

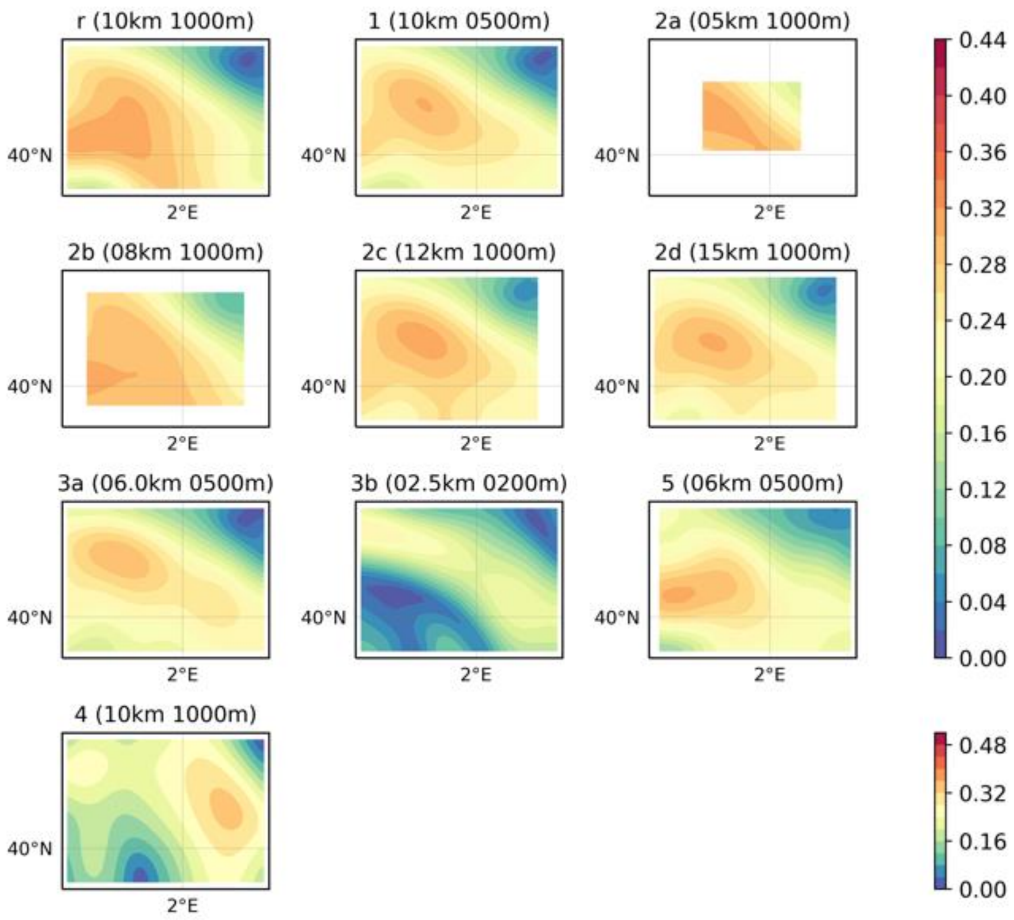


"Ocean truth" SSH anomaly (m)
at the upper layer for all configurations [eNATL60]

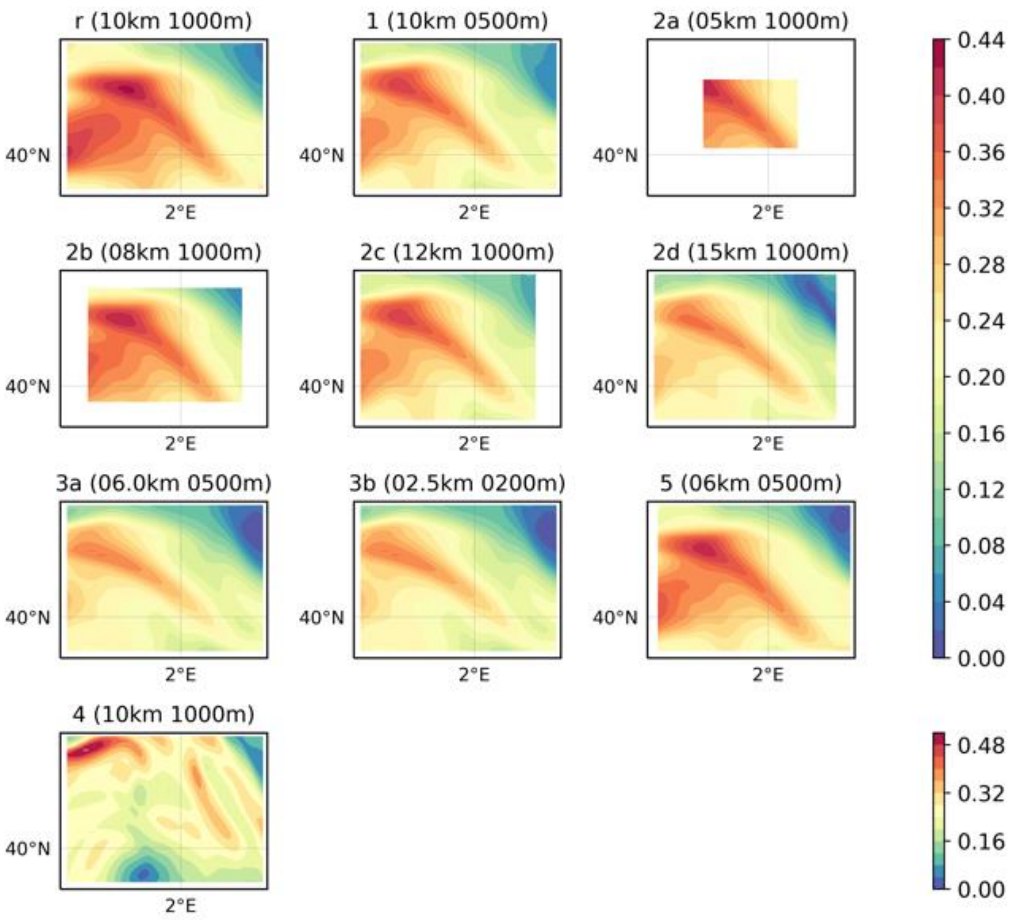


Reconstructed geostrophic velocity magnitude [eNATL60]

Reconstructed geostrophic velocity mag. (m/s)
at the upper layer for all configurations [eNATL60]

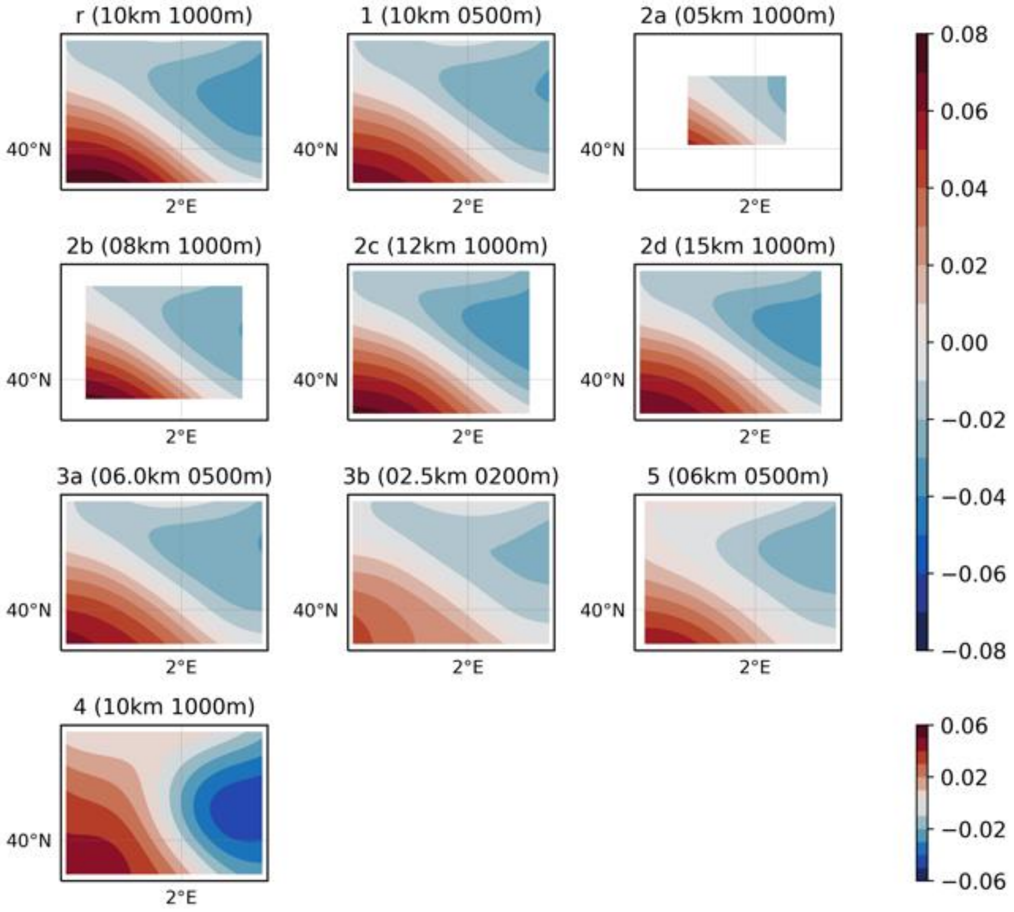


"Ocean truth" horizontal velocity magnitude (m/s)
at the upper layer for all configurations [eNATL60]

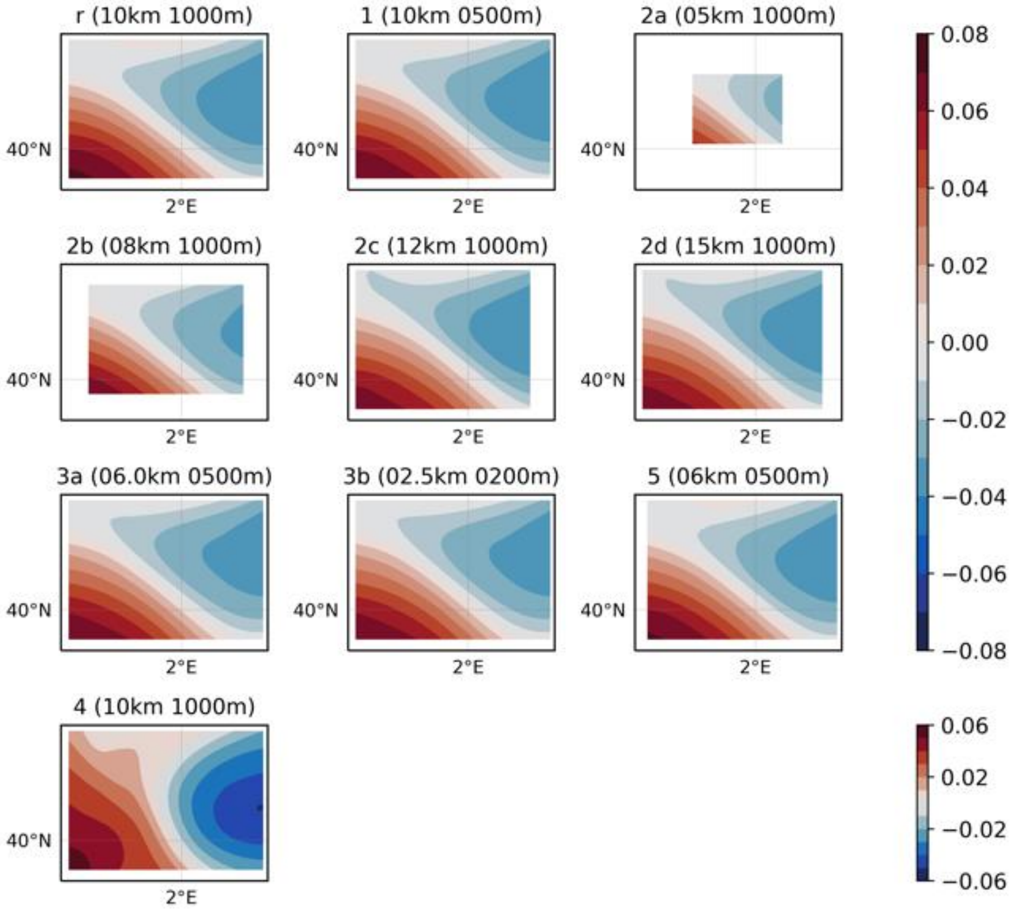


Reconstructed DH [WMOP]

Reconstructed DH anomaly (dyn m)
at the upper layer for all configurations [WMOP]



"Ocean truth" SSH anomaly (m)
at the upper layer for all configurations [WMOP]



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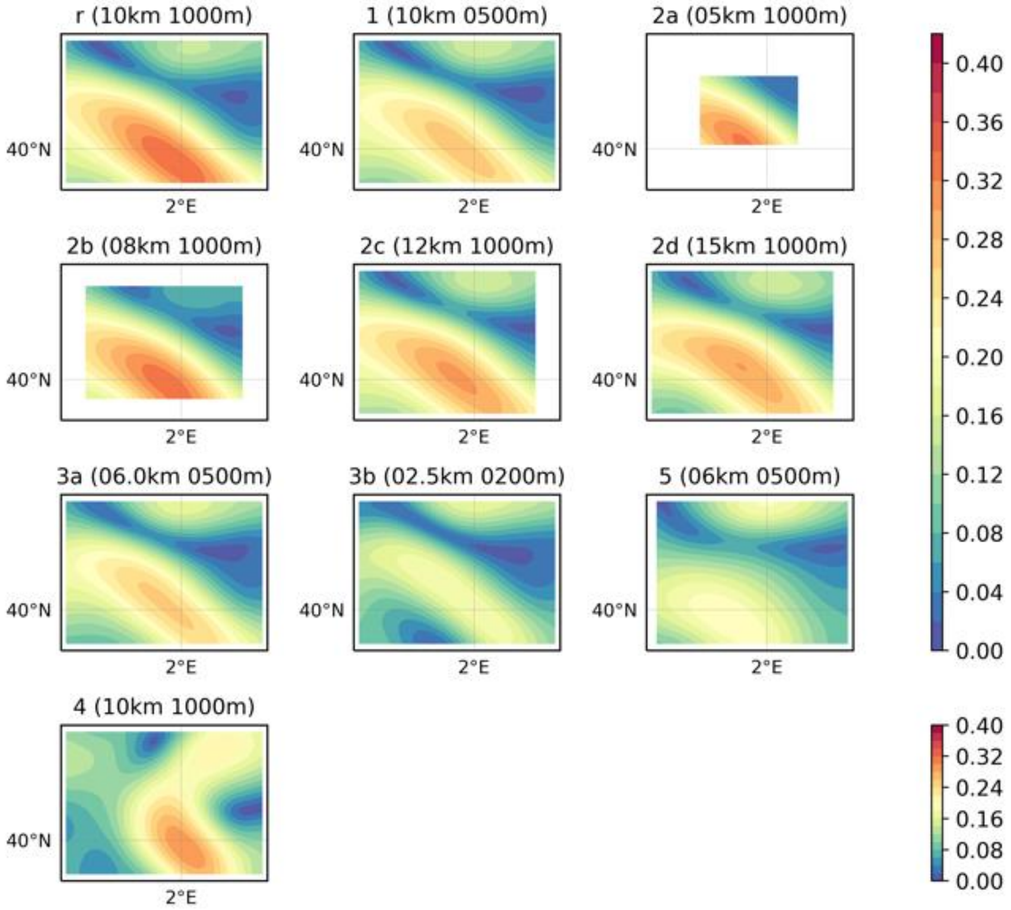

"Ocean truth" horizontal velocity magnitude (m/s)
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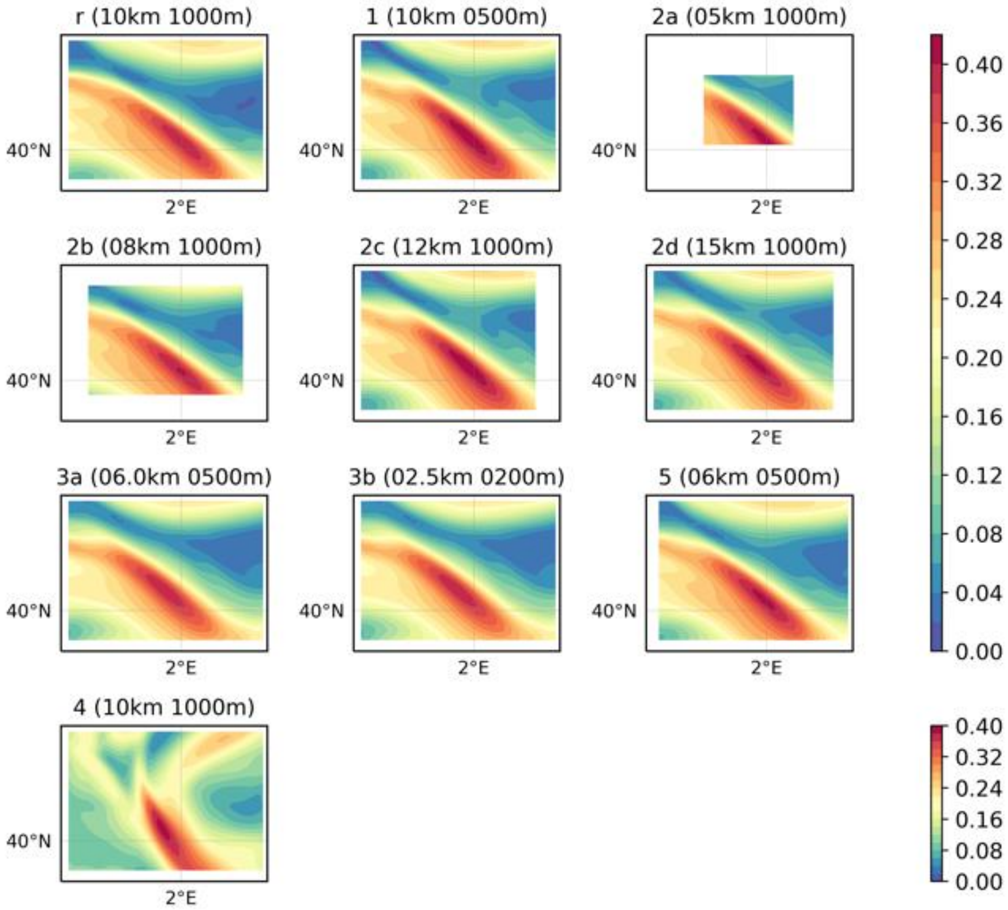

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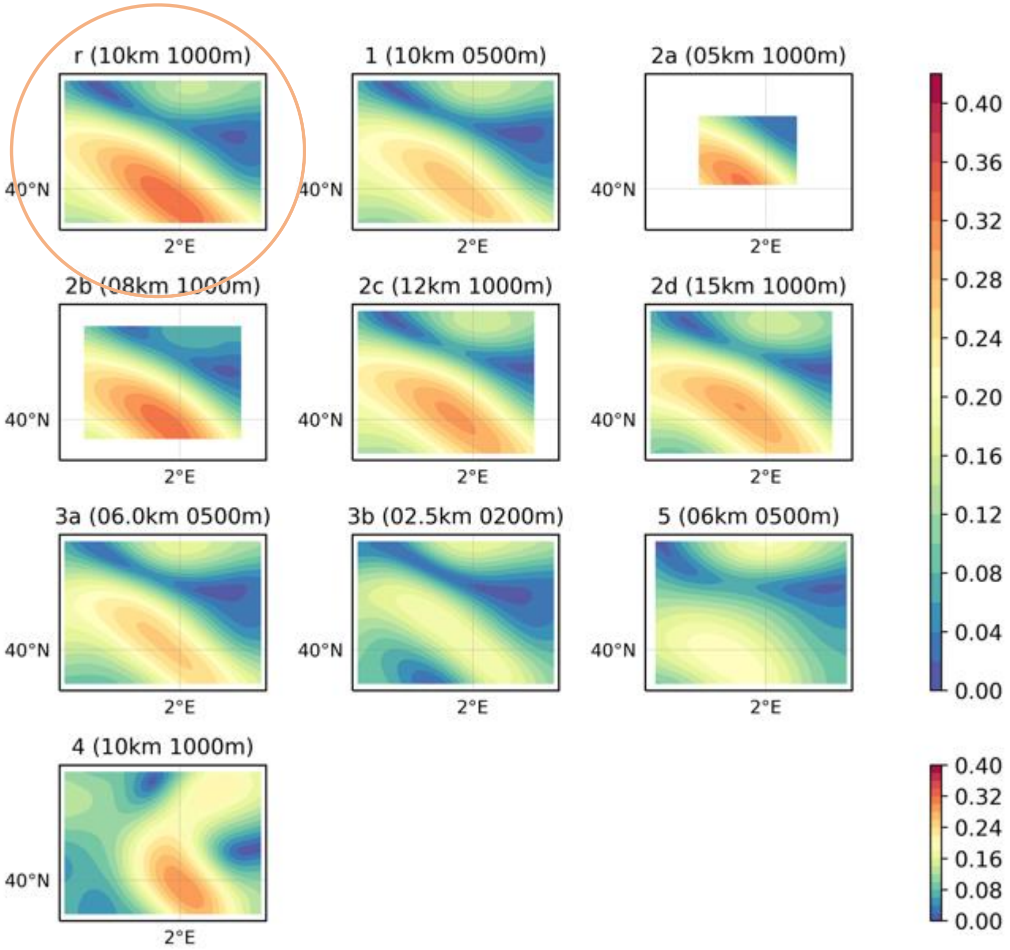
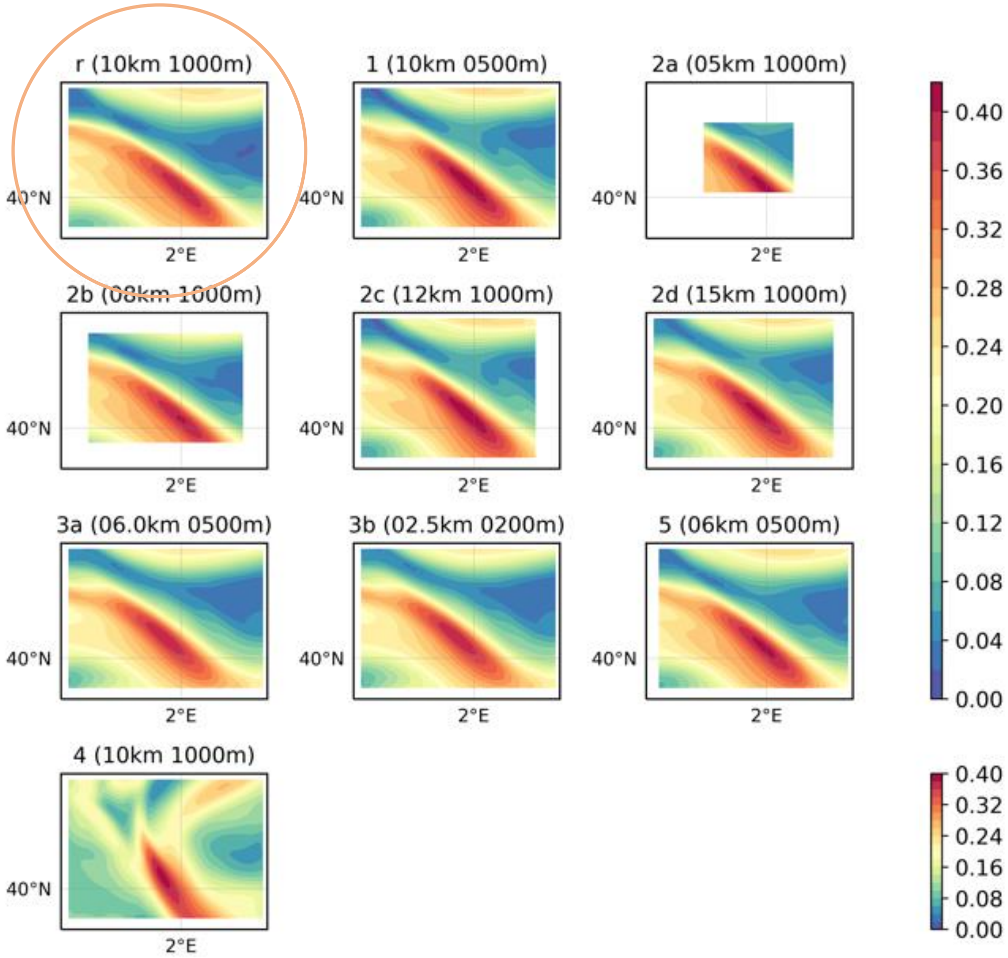
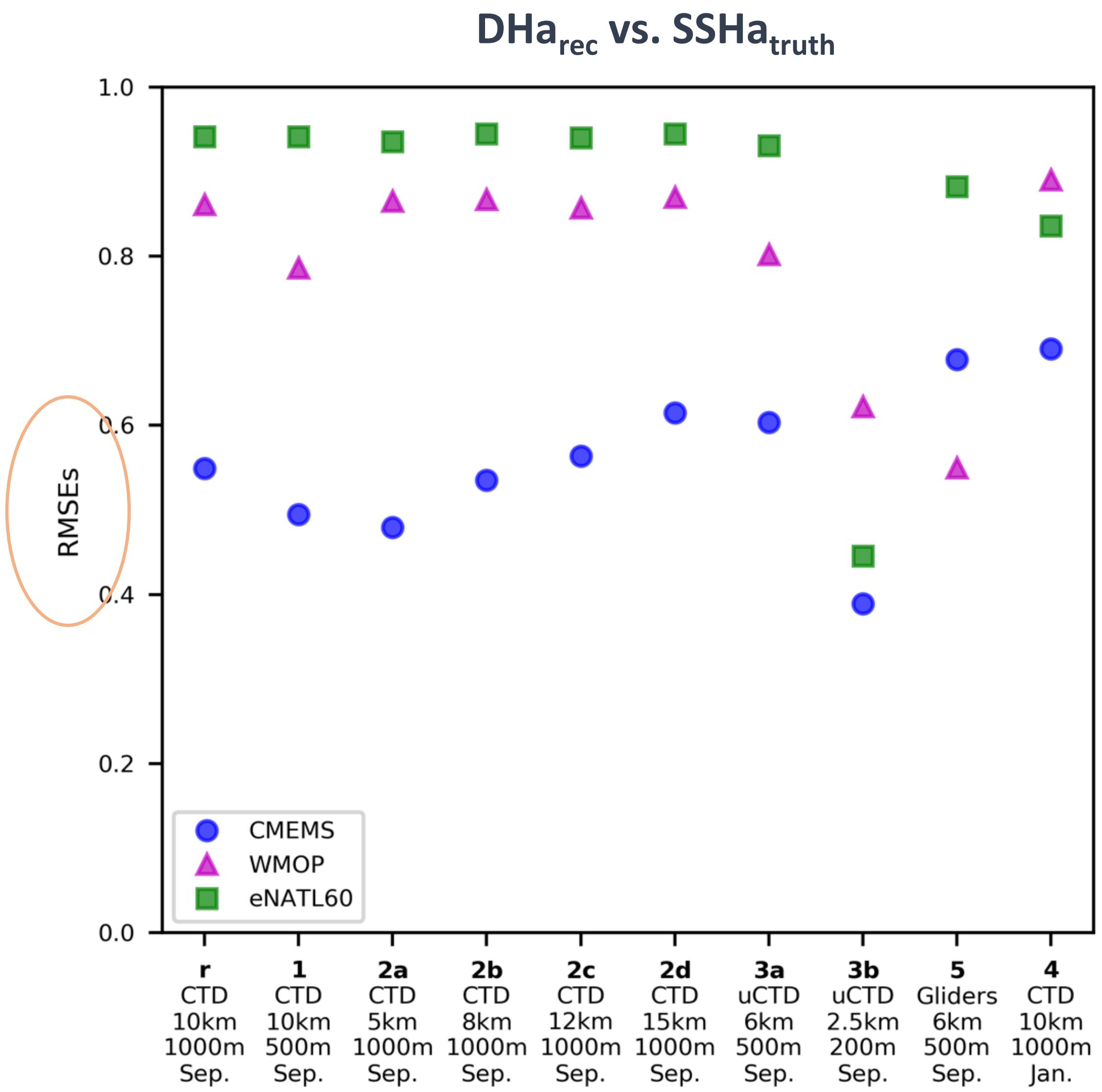


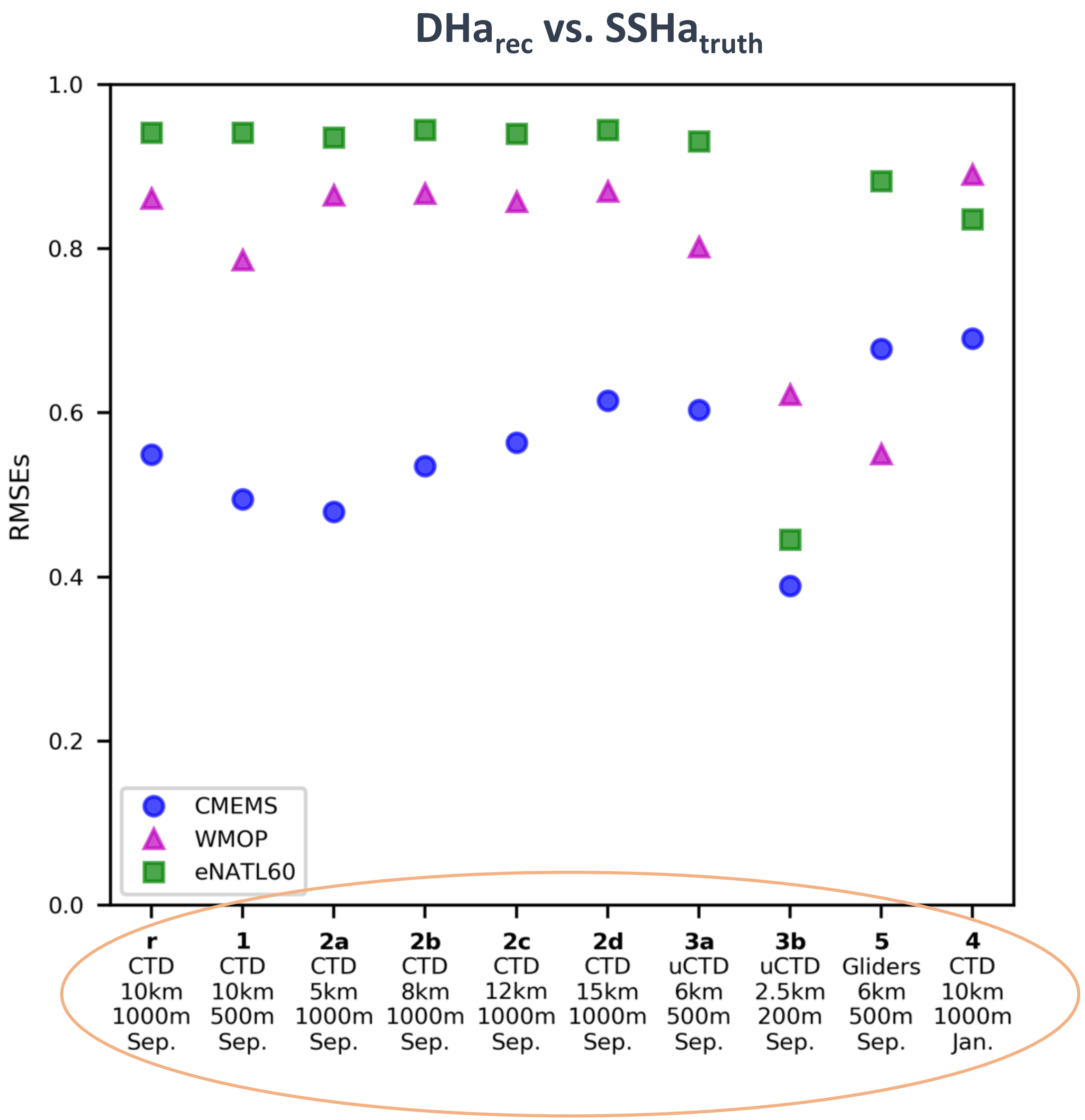
"Ocean truth" horizontal velocity magnitude (m/s)
at the upper layer for all configurations [WMOP]



Comparison through the RMSE-based score



Comparison through the RMSE-based score



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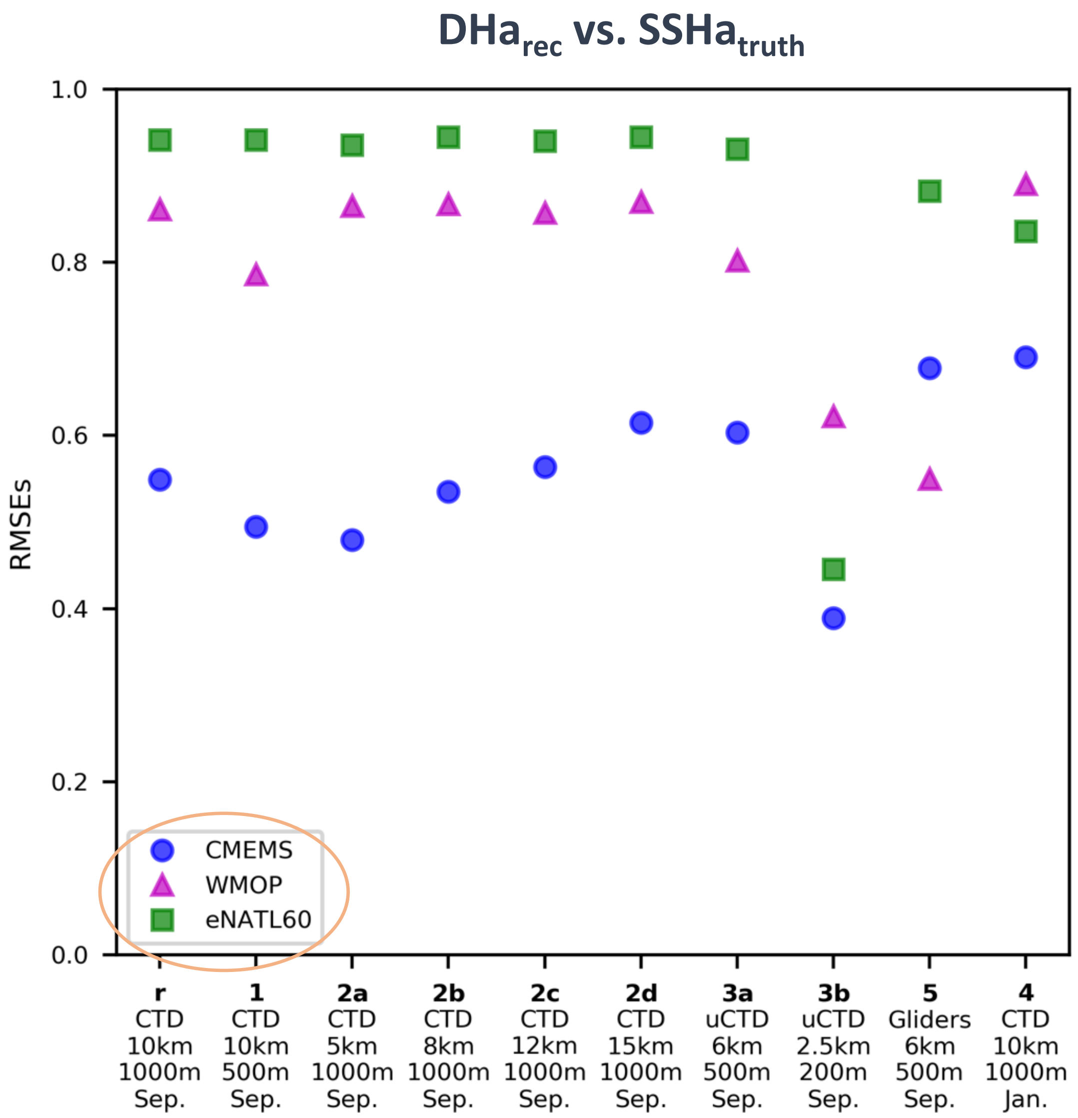

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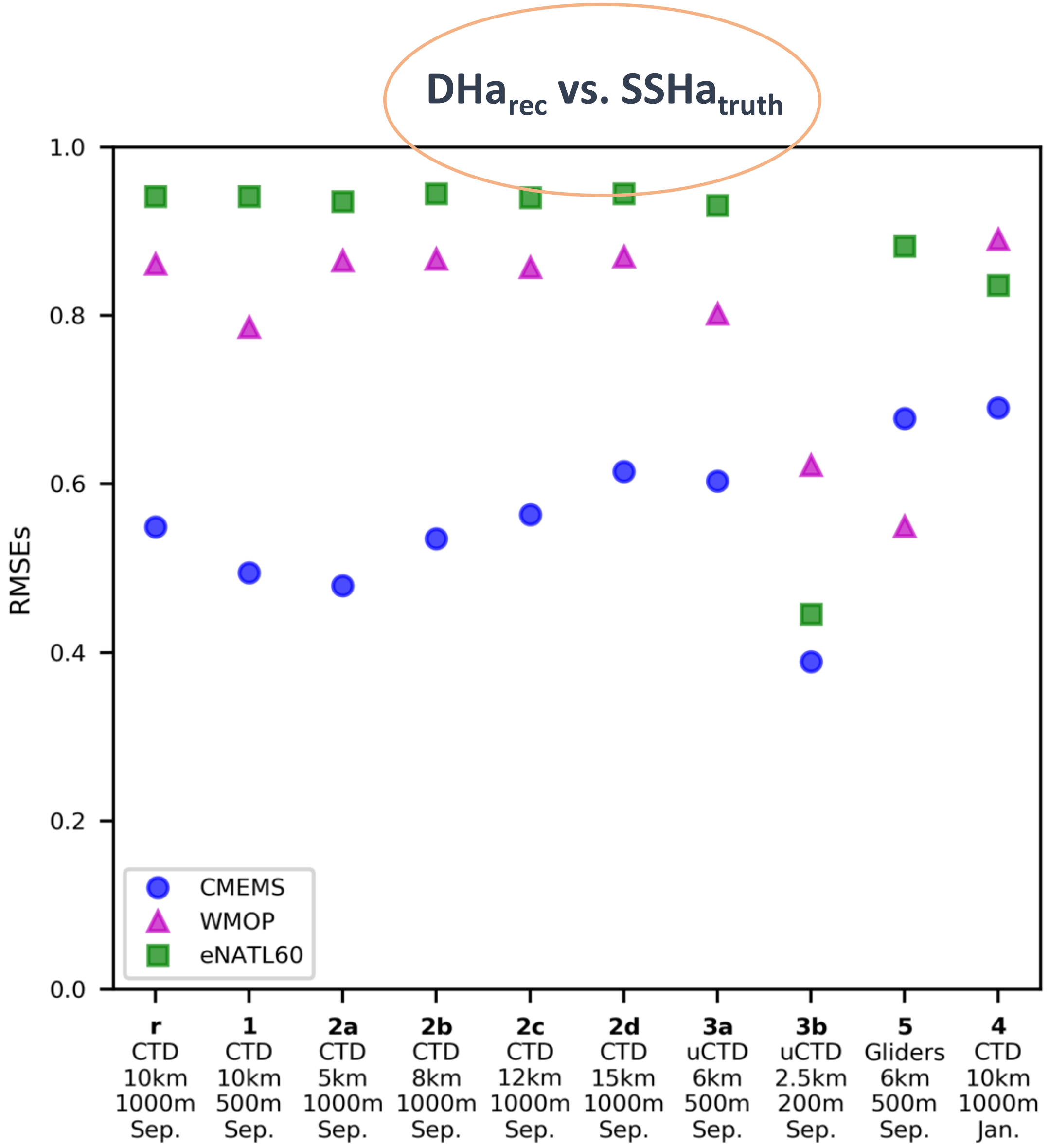

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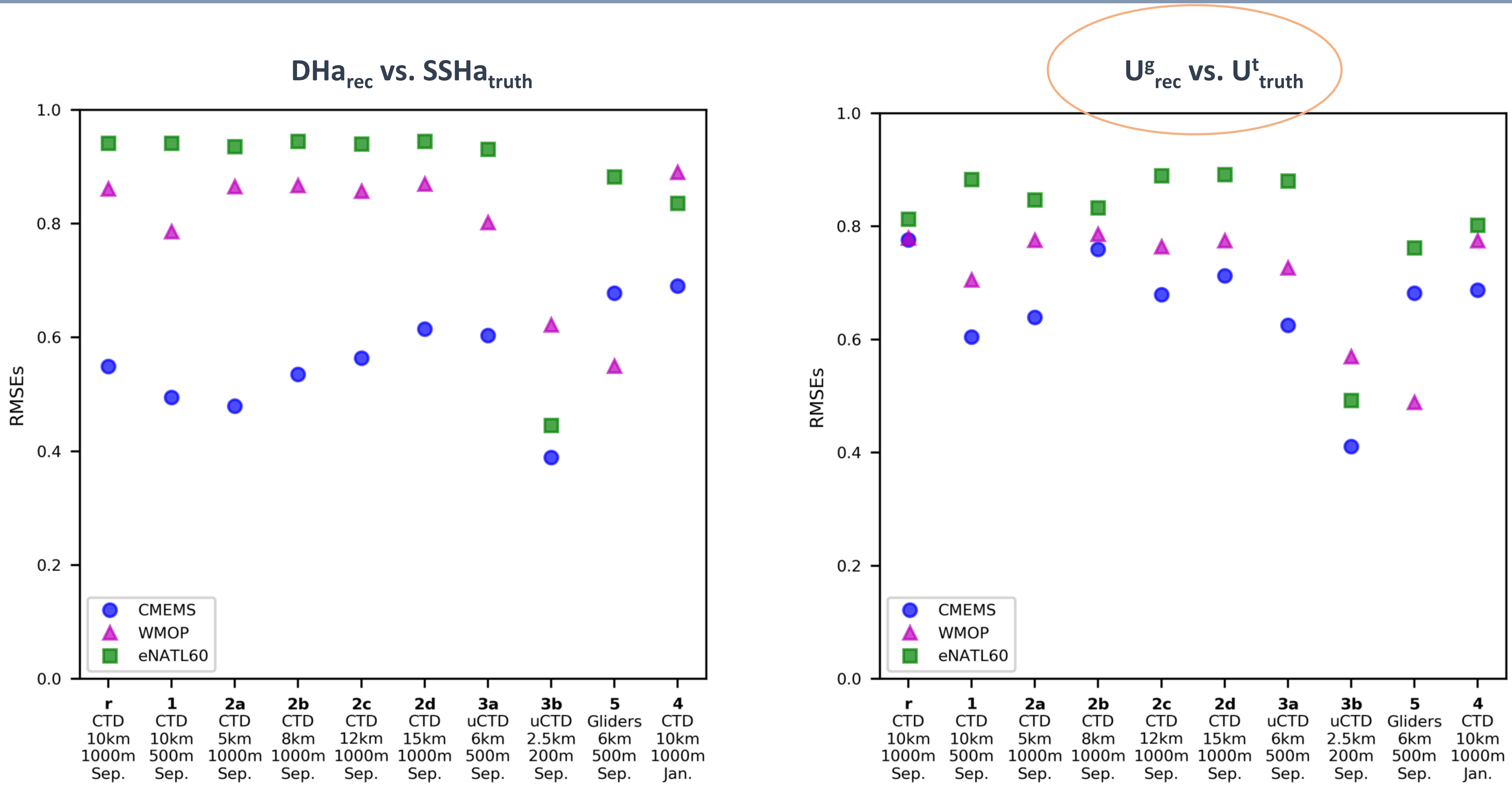

Analysis of the results

Best sampling strategies:

- Different configurations provide reconstructions with high scores (= good sampling strategies).
- A good compromise is the **reference configuration: CTD casts separated by 10 km and down to 1000 m depth (4.3 days).**
- To sample the domain faster, a valid strategy is **configuration 1: CTD profiles down to 500 m depth (3.1 days)**. *The reconstructed geostrophic velocity field has a lower magnitude than in the reference configuration → decrease of 0.07 in the RMSEs, while the pattern is maintained similar.*
- An even faster valid sampling consists of **replacing rosette CTD casts for an underway CTD with a horizontal spacing between profiles of 6 km and a vertical extension of 500 m (1.8 days)**. *The RMSEs reduction is 0.05 → better option than configuration 1.*

Analysis of the results

Sampling strategy not appropriate for our objective:

- Configuration in which **rosette CTD casts are replaced by an underway CTD sampling one profile every 2.5 km and with a vertical extension of 200 m.**

- This suggests that **profiles deeper than 200 m depth are needed to reconstruct the DH and geostrophic velocities at the ocean upper layer**, *while the decrease of the horizontal separation between profiles does not introduce improvements with respect to the other configurations.*

Analysis of the results

Impact of season:

- **Reference configuration in winter** instead of in summer:

  ✓ **High scores for the DH reconstruction** with the three models.

  ✓ **High scores for the geostrophic velocity magnitude reconstruction** and comparable to the score obtained in summer for the three models.

    ✓ Reconstructed fields are **smoother than the ocean truth**. *Ocean truth has higher small-scale variability than in summer due to different dynamics. The sampling resolution and the correlation scale applied to the OI prevent the representation of scales < 20km.*

In conclusion, even with distinct dynamics, the reference configuration is a sampling strategy that provides reconstructions similar to the ocean truth in both seasons (summer and winter).

Conclusions

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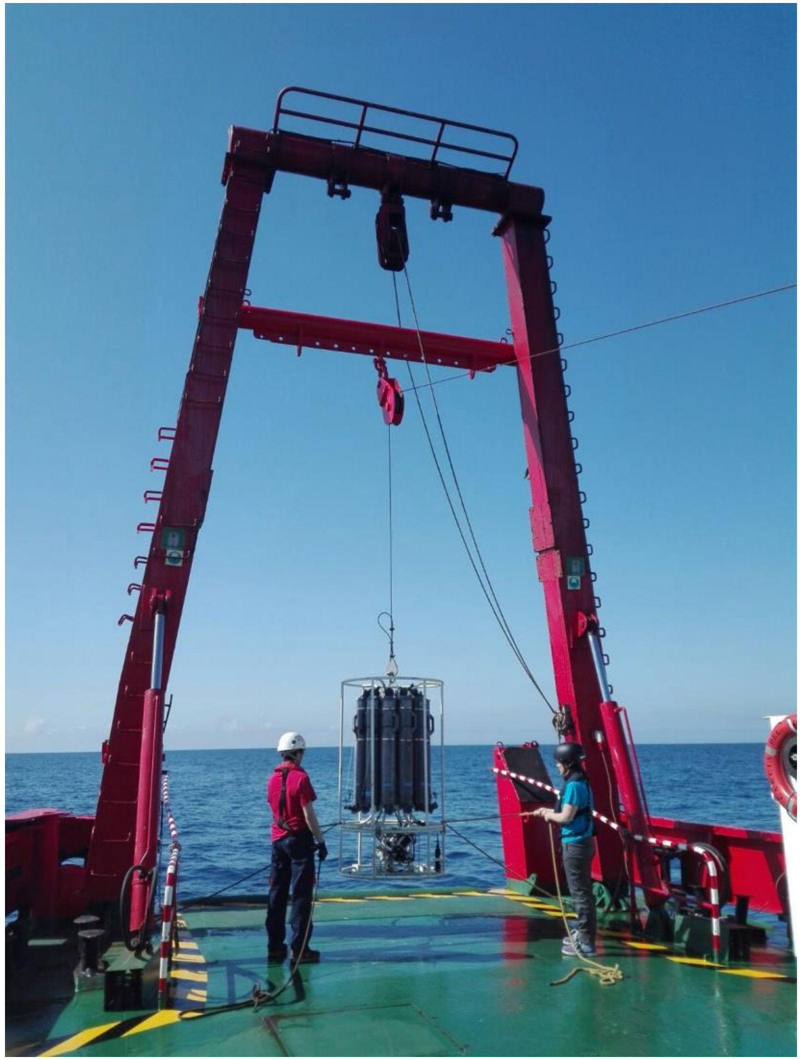
- Evaluation of different sampling strategies for SWOT validation through OSSEs using 3 models (eNATL60, WMOP, CMEMS)
- Spatio-temporal OI algorithm to reconstruct in situ observations
- Sensitivity test of the temporal correlation scale: low sensitivity for values ranging from 2 to 10 days
- Best reconstruction considering all models: reference configuration (CTD casts, dx = 10 km, z_{max} = 1000 m; similar to PRE-SWOT sampling strategy)
- Faster alternatives:
  - CTD casts, dx = 10 km, z_{max} = 500 m
  - uCTD, dx = 6 km, z_{max} = 500 m



PRE-SWOT (Barceló-Llull et al., 2021)

Conclusions

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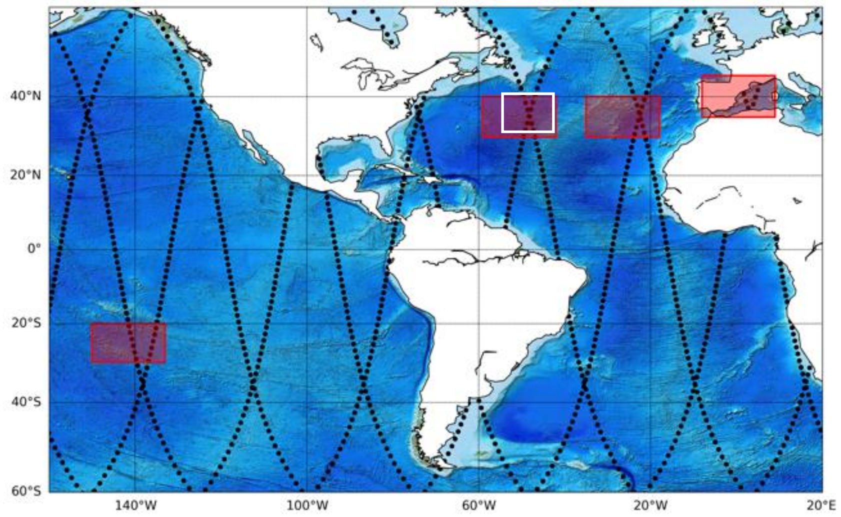
Additional analysis done:

✓ Evaluation of the best sampling strategy in the Atlantic:
- Reference configuration good compromise
- High seasonality

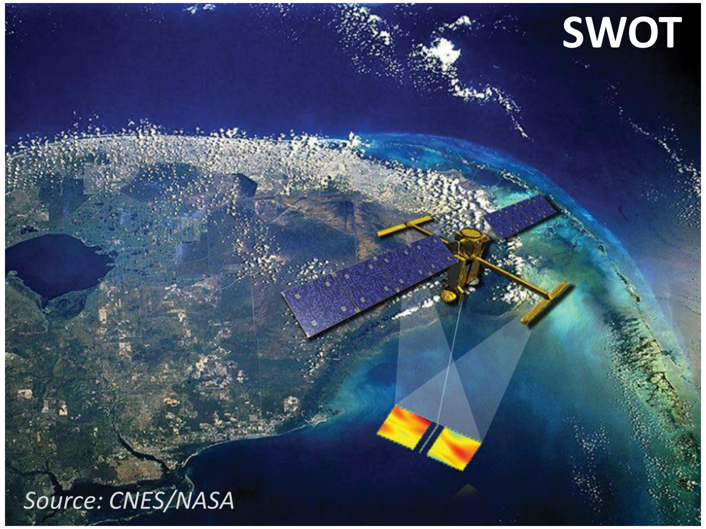


✓ Test different methods of reconstruction: machine learning techniques (IMT-Atlantique) and model data assimilation (SOCIB)

Perspectives:

- Full analysis published in Eurosea.eu (Deliverable 2.3) at the end of July 2022

- Real multi-platform experiment during the SWOT fast-sampling phase in 2023 (pending funding 🤞)



Thank you!

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