Complementarity of altimetric and Argo observations in constraining the global ocean 1/12° Mercator Ocean forecasting system

Elisabeth Rémy[1], **Mounir Benkiran[1]**, Mathieu Hamon[1], Florent Gasparin[1] and Jean-Michel Lellouche[1]
[1]Mercator Ocean

mercator-ocean.eu/marine.copernicus.eu

OSEs with the Global 1/12° system

Ocean surface analysis, at least at global scale in the open ocean, are quite well constrained by satellite observations, SST & SLA, and drifting buoys, as the ocean interior is much less constrained with sparse in situ observations, especially below 2000m depth and at high latitude.

- How in situ vertical profiles constrain the water column at global scale?
- How satellite observation data assimilation modify the vertical structure of the ocean?
- Complementary of Argo and Altimetry to constrain the ocean interior?
- Are in situ & satellite observation coherent ?

1-year OSEs were performed with the global 1/12° system.

- To revisit the impact of Argo observation done with the MOi global ¼° system by V. Turpin in 2016 (OSEs) & Florent Gasparin (OSSEs).
- *Assess the impact of observations on ocean « weather » monitoring indicators such as TCHP, MHW, WWV,…*

Work funded by European projects:

OSEs experimental setup

Copernicus Marine Service global 1/12° modelling and data assimilation system

✓ Model : Nucleus for European Modelling of the Ocean (NEMOv3.6)

✓ Assimilation system: « SAM2 » multivariate « Mercator »

- Localized En OI using a collection of climatological model anomalies
- 3Dvar large bias correction de-activated: not tuned for very sparse in situ obs.

✓ Assimilated observations

- Multi-sensor L3 Sea Surface Temperature (ODYSSEA, 1/10°, Daily)
- In-Situ Temperature and Salinity profiles from the CORIOLIS database (Copernicus Marine In situ Thematic Assembly Center)
- Along Track Sea Level Anomaly: Jason-3, Sentinel-3A, Sentinel-2B, Sentinel-6A, Haiyang-2B, Cryosat-2 referenced to a « hybrid » Model/CNES-CLS MDT
- Sea Ice Concentration

- Covered period: **sept. 2023-sept. 2024**

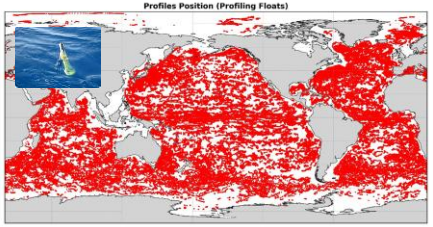
List of performed OSEs

	SST	SLA	Argo	Other In situ than Argo
Free (No DA)	No	No	No	No
Ref/Ctrl	yes	yes	Yes	Yes
OSE Only in situ	No	No	Yes	Yes
OSE0 Only satt.	yes	yes	No	No
OSE1 No Argo	yes	yes	No	Yes
OSE2 Without Half Argo	yes	yes	50%	Yes
OSE4 Without Argo	yes	yes	yes	No

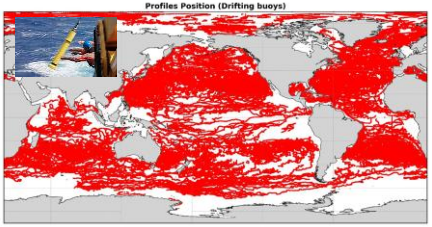
Other OSEs were performed with a similar setup: OSEs for Tropical moorings, deep Argo, SWOT & 3 & 6 nadir altimeters.

Available In situ observations for the 1-y OSEs

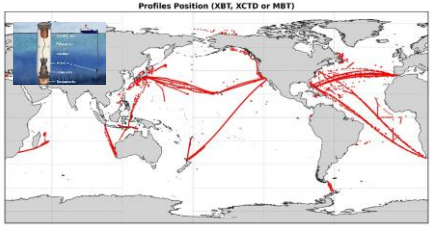
Spatial distribution of the most numerous real time observations in the Coriolis database (INS TAC) from sept. 2023 to sept. 2024



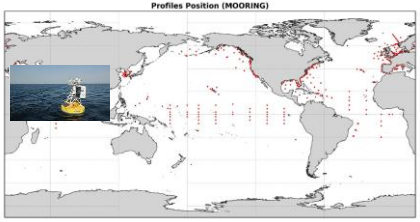
Drifting buoys



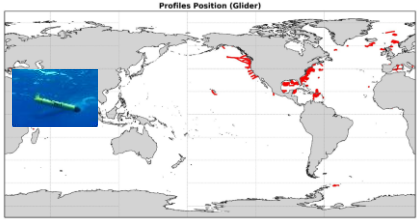
Profiling Floats



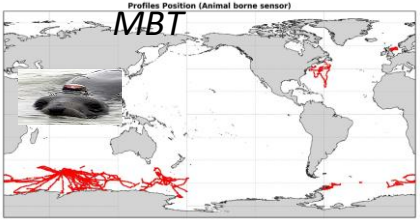
XBT, XCTD, MBT



Moorings



Gliders



Animal Borne Sensors

Other in situ data are available from FerryBox, ThermoSalinograph, tide gauges & fishing vessels.

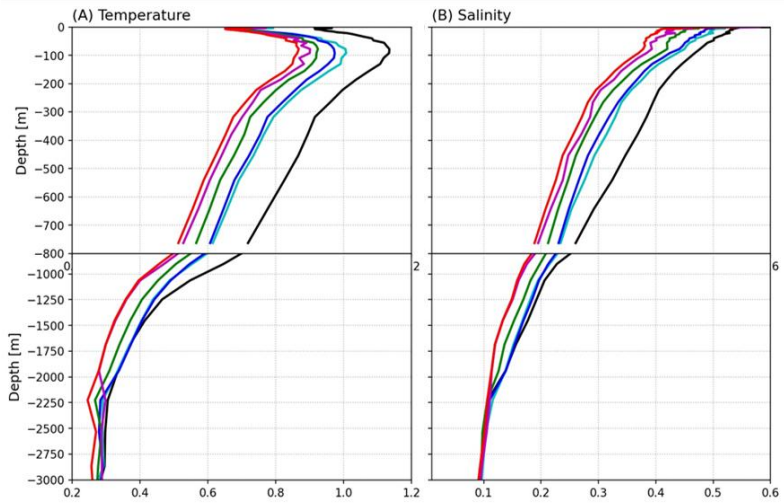
- many observations at the surface mostly by drifting buoys and Argo floats
- at depth, globally, the Argo array is dominating.

Data Assimilation efficacy against assimilated observations

Global RMS Difference between in situ T&S observations and OSE analysis

Best to worse fit to **in situ** observations:

All obs assim >
Argo Only assim >
SST & SLA & 50% Argo assim >
SST & SLA & other than Argo >
SST & SLA assim >
No obs assimilated



- Maximum RMS error in temperature at the thermocline depth, the surface temperature is well constrained by satellite & in situ observations.
- Maximum RMS error in salinity at the surface.
- Similar global RMSD profiles found in ¼° global OSEs by Turpin et al. (2016)

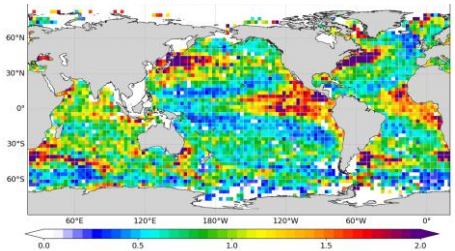
➢ **Satellite only observation DA improves RMSD at global scale to observed T&S profiles, Argo and other in situ brings further improvement.**

➢ **The Argo only OSE is the closest to the control OSE** with in situ, SST & SLA assimilated above 2000 m depth.

RMSD against in situ temperature observations

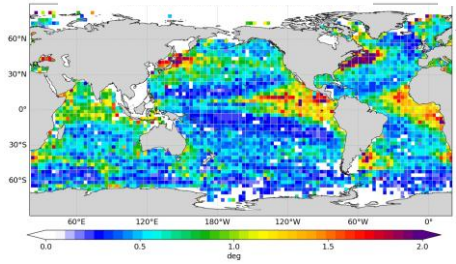
5-100 m depth temperature RMS differences *between in situ profiles and the OSE forecasts (innovations) from sept.2023-sept.2024.*

Free simulation

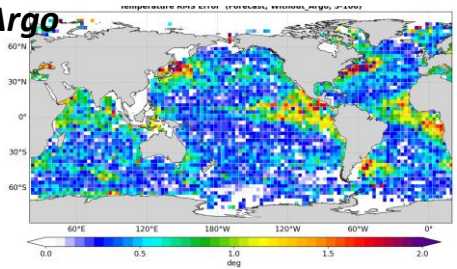


- SST & SLA data assimilation strongly improves the fit the in situ 5-100 m depth observations.
- Other in situ than Argo observation brings an additional significant improvement.
- The addition of Argo does not significantly improves this fit.

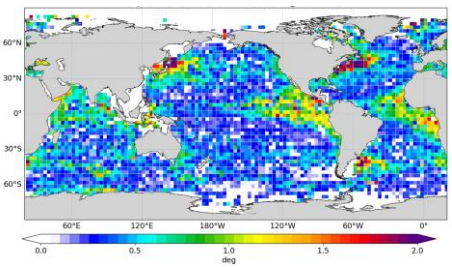
SST & SLA



*SST, SLA & **in situ without Argo***



*SST, SLA & in situ with **Argo***

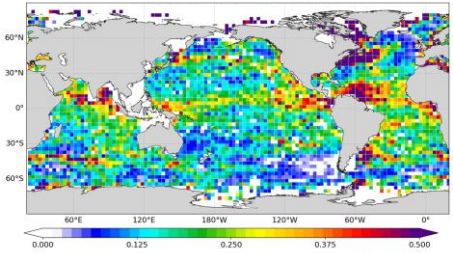


➢ SST, SLA & other than Argo observations (most likely drifting buoys) are playing the most important to improve 5 to 100 m forecasted temperature.

RMSD against in situ salinity observations

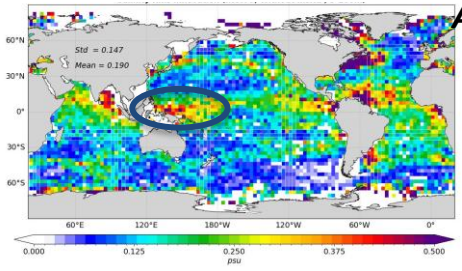
5-100 m depth salinity RMS differences *between in situ profiles and the OSE forecasts (innovations) from sept.2023-sept.2024.*

Free simulation

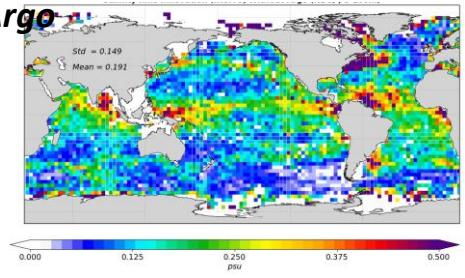


- Large salinity error in regions influenced by strong river outflows and the Pacific tropical ocean.
- Slight improvement with SST&SLA assimilation
- Nonsignificant change when adding other than Argo in situ observations

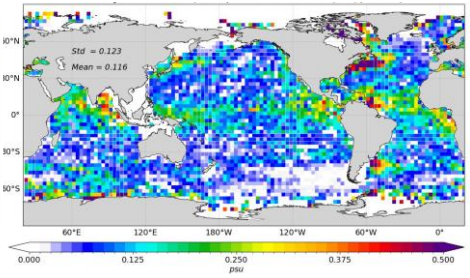
SST & SLA



SST, SLA & ***in situ without Argo***



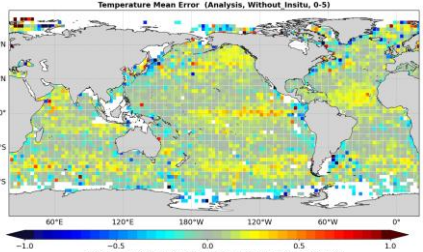
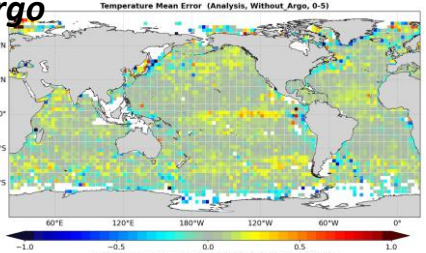
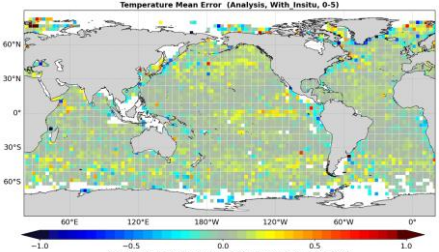
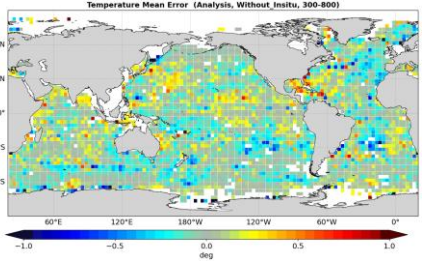
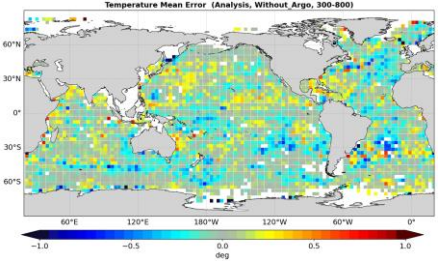
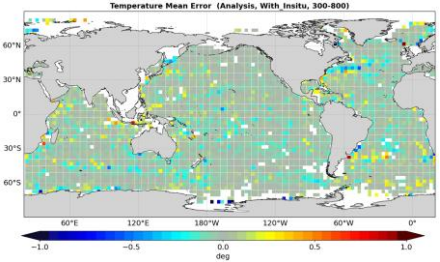
SST, SLA & in situ with ***Argo***



➢ Argo floats are the most impactful observations in reducing the salinity RMSD to in situ observations between 5 to 100 m depth.

Bias against in situ temperature observations

0-5 m & 300-800 m depth T Mean differences *between the model analysis and the Argo profiles for the different OSEs from sept.2023-sept.2024.*

	SST & SLA	*SST, SLA & **in situ without Argo***	*SST, SLA & in situ with **Argo***
0-5 m			
300-800 m			

Large scale cold bias (gyres) close to the surface & warm bias at depth:

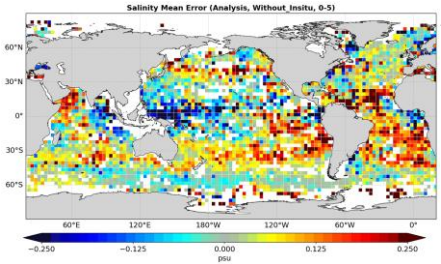
- SST & SLA observations are the most impactful (NOT SHOWN) at the surface
- In situ observations at the surface helps in reducing those biases
- Argo observations helps to reduce deep temperature bias.

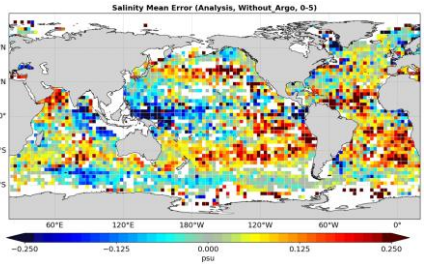
Bias against in situ salinity observations

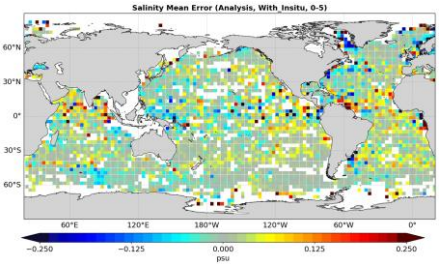
0-5 m & 300-800 m depth S Mean differences *between the model analysis and the Argo profiles for the different OSEs from sept.2023-sept.2024.*

SST & SLA | *SST, SLA & **in situ without Argo*** | *SST, SLA & in situ with **Argo***

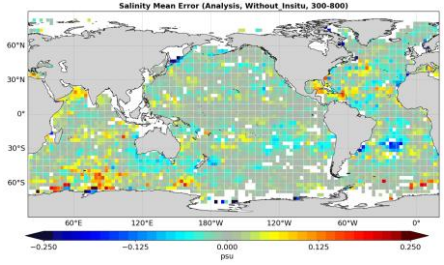
0-5 m

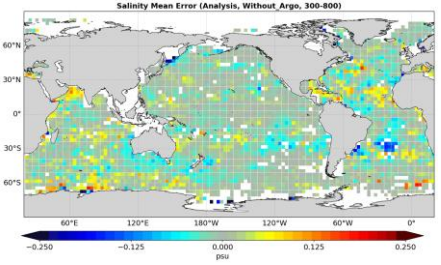


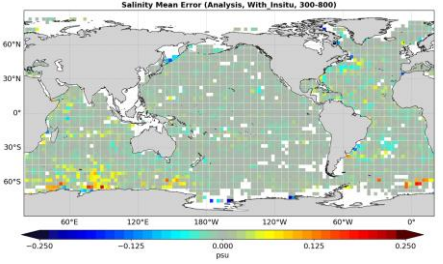




300-800 m







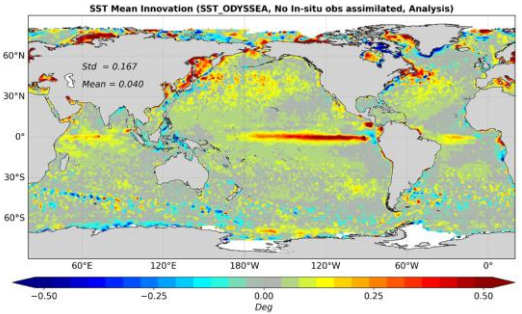
Large scale biases close to the surface & to salty areas at depth

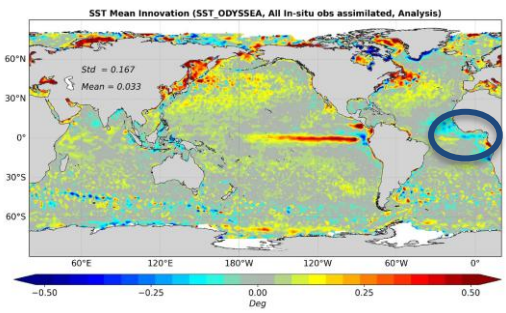
- Argo observations are key to correct salinity bias. Very few other platforms are observing salinity & no SSS DA nor restoring term in the system.

Misfits to assimilated SST & non assimilated SWOT SLA

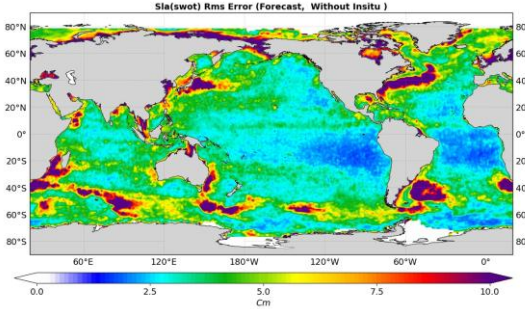
SST & SLA only assimilated | **SST, SLA & all in situ**

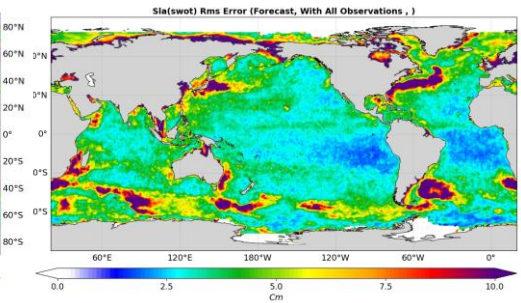
Mean analysis differences to ODYSSEA Sea Surface Temperature





RMS difference to SWOT SLA





The mean misfit to Odyssea SST & RMS misfit to SWOT SLA observations (not assimilated) is slightly improved when assimilating in situ observations, including Argo in addition to SST & nadir along track SLA.

- No strong incoherency seen between in situ and satellite observation (more complete analysis needed).

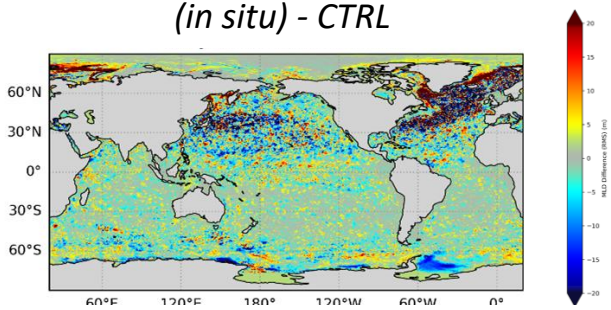
Winter mean Mixed Layer Depth estimates

- Argo removal impact *(similar to Argo + other in situ removal)*:
  - Kuroshio front changes
  - MLD(SST+SLA) estimate deeper than MLD(CTRL) in the NATL

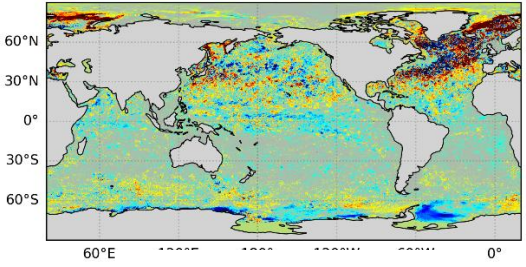
➢ MLD probably too deep in the NATL in GLO12: in situ observations help to improve it.

- SST & SLA DA removal:
  - Smaller scale changes when removing SLA&SST,
  - some incoherency with the in situ DA impact in the tropical Pacific.

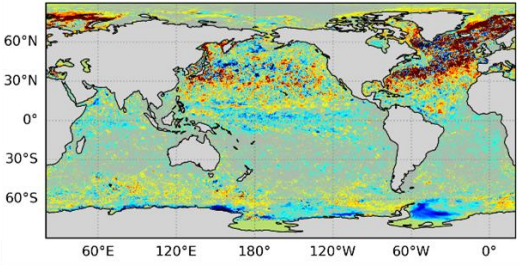
(in situ) - CTRL



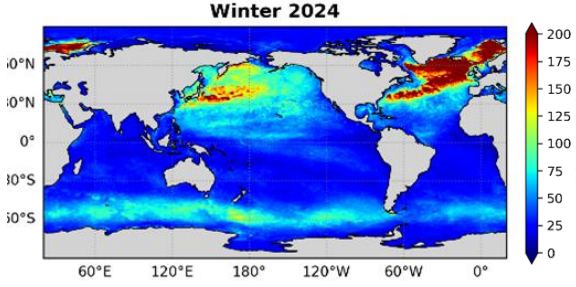
(SST&SLA&in situ without Argo) - CTRL



(SST&SLA) - CTRL

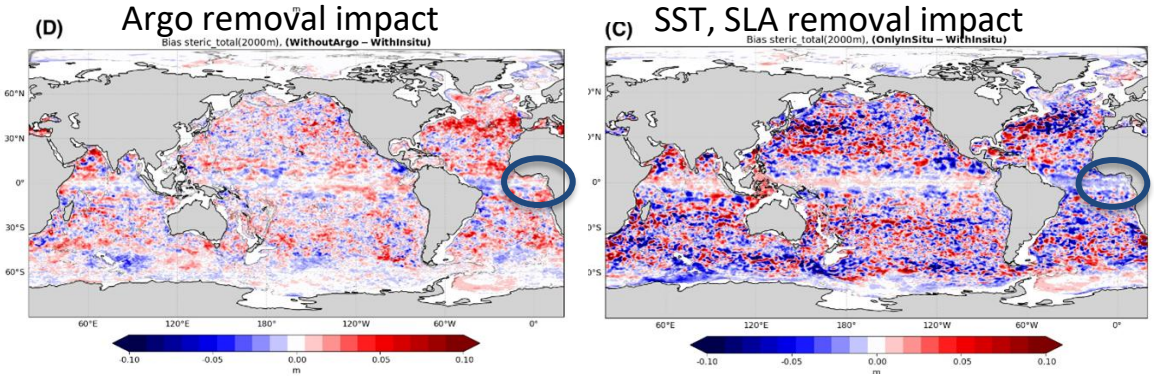


MLD_CTRL



Impact of Argo & SST&SLA DA on steric height

Difference between OSE and the CTRL simulation (SST & SLA & In situ DA) mean steric height



- Argo *(+ other in situ)* removal: large scale patterns with a strong bias in the North Atlantic: incoherency between the MDT and Argo profile mean steric height?
- SST & SLA removal: small scales impact (eddies) & bias in the Equatorial Pacific: « Displacement of the mesoscale features » ?

➢ Different contribution in scales from in situ & satellite observations, *coherent with Gasparin et al. (2023) analysis.*

➢ Potential incoherency in North and Equatorial atlantic.

➢ *Bias in T&S can have opposite sign depending on the depth: further analysis to understand the "depth" of the change in bias contributing to different SH in the Atlantic. Mean SLA innovations tend to show bias in GLO12.*

Conclusion

Global RMS Fit to in situ T/S profile observations

- Satellite only observation DA improves RMSD at global scale to observed T&S profiles, other in situ and Argo brings further improvement.
- *The Argo only OSE is the closest to the control OSE*

Weak but positive impact of in situ Data Assimilation on **SST & SLA observation misfits**

Argo

Argo floats are the most impactful observations in reducing the **salinity analysis error.** Argo observations helps to reduce **deeper temperature misfits**.

SST & SLA

SST, SLA *& other than Argo observations* (most likely drifting buoys) are the most impactful to improve temperature close to the surface

Winter MLD & Steric Height

Different contribution in scales from in situ (larger/bias) & satellite (smaller) observations

Potential incoherency in North and Equatorial Atlantic. between Satellite & in-situ obs.

-> to investigate

Open questions & perspectives

- **Drifting buoys** (not assimilated in the previous OSE/OSSE) brings complexity to disentangle the role of satellite & in situ observations in improving surface temperature
- **Order of removal of data** influences the impact of each array
- **Difficulty to find independent observations to evaluate** the changes between OSEs
- Could be interesting to more precisely point **incoherent model misfits across platforms highlighting potential observation bias** ?
- ***Large scale T/S Bias correction*** *have been de-activated to have the same experimental design: conclusion will differ if kept when not enough in situ data*

Further analysis will be performed including:

- Evaluation of Impact on **ocean « weather » monitoring index**: MHW, TCHP, WWV, convective & upwelling regions, …
- **MHW** (SST & 50m depth criteria) shows little Argo impact – only changes in intensity **(ongoing analysis)**
- **Deep Argo assimilation** shows a model warm deep bias (0,05 to 0,1°C) in NRT GLO12 & Argo deep OSE (& GLORYS12 reanalysis: reason to explore !!