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Evolution of the Copernicus Marine Service global ocean analysis and forecasting high-resolution system: focus on data assimilation updates

Jean-Michel Lellouche, Eric Greiner, Giovanni Ruggiero, Romain Bourdallé-Badie, Charles-Emmanuel Testut, Olivier Le Galloudec, Mounir Benkiran, Gilles Garric

- 1. Data assimilation system**
- 2. Objective and ingredients of the new system**
- 3. Description of the main updates of the system**
- 4. Performances of the new system compared to the previous one**

Data assimilation system

- **Analysis kernel:**

- Based on the SEEK kernel formulation
- 3DFGAT method to calculate innovation vector
- $2D_{x,y}$ Localization technique
- Weakly-coupled DA system using 2 separate analyses
 - Ocean Analysis : State vector [SST, H, HBRST, HBAR, T, S, U, V]
 - Sea Ice Analysis : State vector [SIC]

$$K = S_n \left[I + (HS_n)^T R^{-1} (HS_n) \right]^{-1} (HS_n)^T R^{-1}$$

- **Background error covariances P^f : multivariate 3D or 4D anomalies**

Error sub-space is built from an ensemble of anomalies (A)

$$P^f = \frac{1}{n} AA^T = S_n S_n^T$$

- **Adaptive scheme for the background error variance**

- **IAU:**

Incremental Analysis Update → to distribute the correction in time on *H, T, S, U, V, SIC*

- **Assimilated observations:**

- Altimetric along-track SLA, satellite SST, T/S vertical profiles (Argo network, XBTs, CTDs, ...)
- Satellite sea ice concentration

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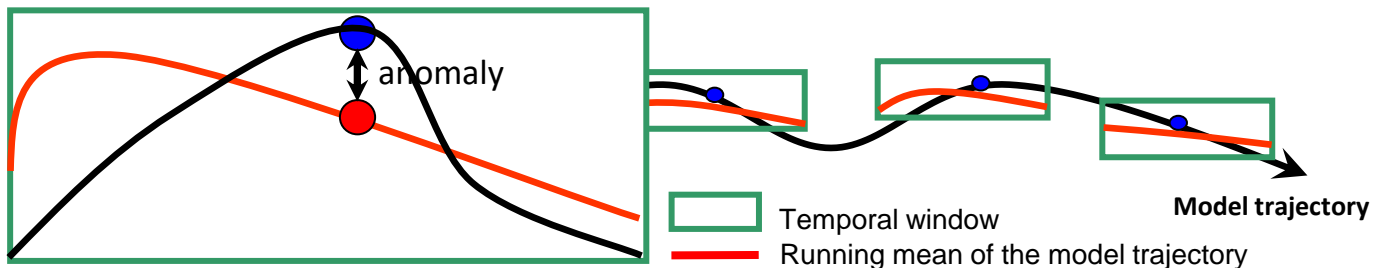
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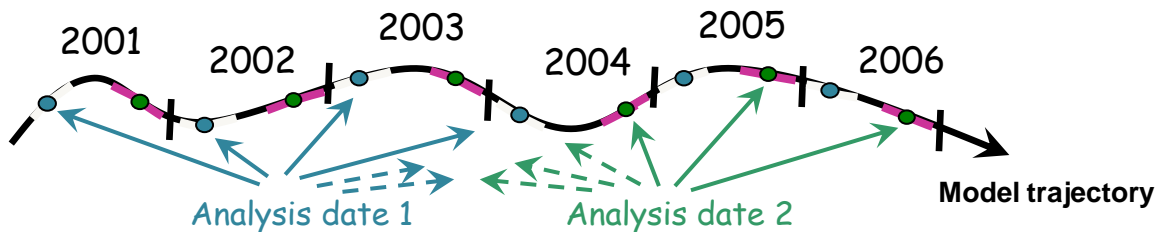
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Background error covariances:
Represented by 3D modes coming from a set of anomalies (statistical approach)

- The method consists to generate a set of anomalies from a long simulation



- Use of this set of anomalies for the analysis stage to compute P^f



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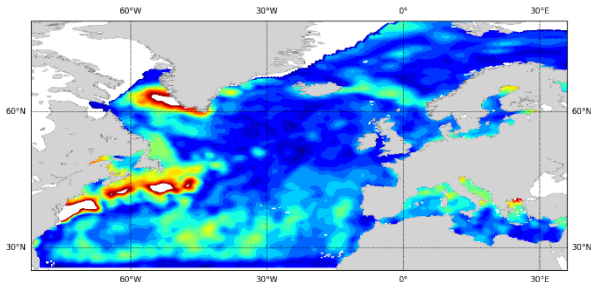
The adaptativity technic is based on the work of Desroziers and Ivanov (2001) and aims to estimate a scalar α for each local region, that multiplies the local restriction of \mathbf{P} in order to be consistent with innovation statistics, so that the following equation is satisfied for each local region and each analysis cycle:

$$d^T [\alpha(HS)(HS)^T + R] d = n$$

n = number of independent data

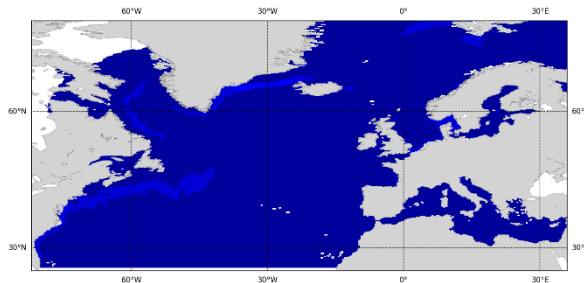
SST

$\sqrt{\text{diag}(dd^T)}$



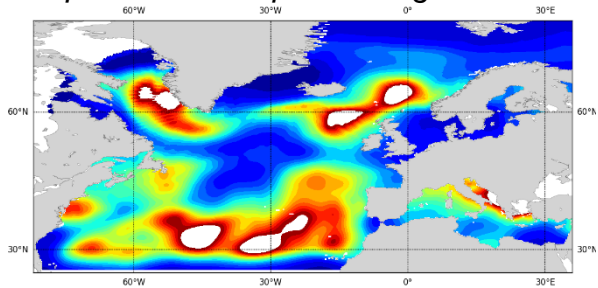
Prior background error

$\sqrt{\text{diag}((HS)(HS)^T)}$



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Amplification α of prior background error

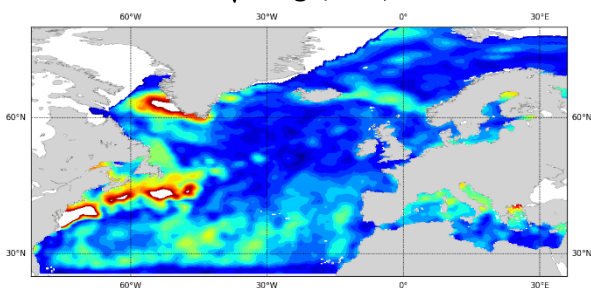


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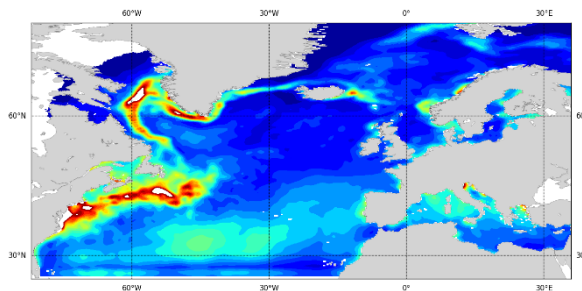
SST

$\sqrt{\text{diag}(dd^T)}$



Adapted background error

$$\sqrt{\text{diag}(\alpha(HS)(HS)^T)}$$



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Objective and ingredients of the new system

Objective: Develop a new version of PSY4 (called GLO12) in order to improve, among others:

- Analysis and forecast skills, representation of mesoscale activity
- Mass / steric distribution (loss of mass and too much steric in the current system...)
- Equatorial dynamics and interaction with biogeochemistry

Main ingredients to achieve this objective:

- NEMO3.6 + LIM3 sea ice model
- HR spatial and temporal atmospheric forcing
- 5 bands light penetration + GLS

} Model

- SLA (new filtering) + new MDT
- SST HR ODYSSEA L3S instead of OSTIA L4 product

} New data

- SAM2 4D analysis
- Use of “super-observations”
- New version of SAM2 (adaptativity, ...)
- New multiscale anomalies bases from GLORYS12 reanalysis
- Bias correction optimized

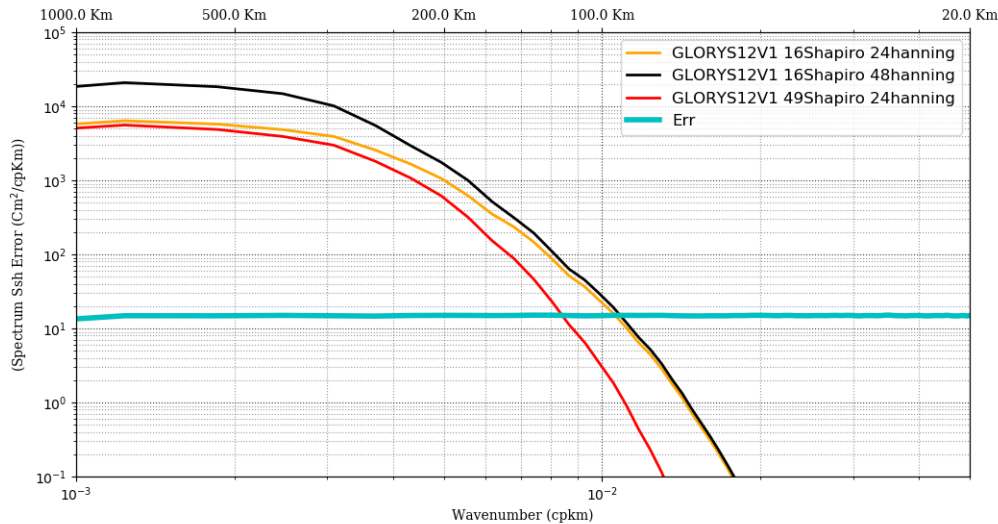
} Assimilation

Description of the main updates of the system

- ❑ Update of the **NEMO** model with the possibility to activate **new numerical schemes** (Time-splitting, VVL) and **new functionalities** (parallel I/O management), update of sea-ice model (LIM2 → **LIM3**) and use of **multi sea ice categories**

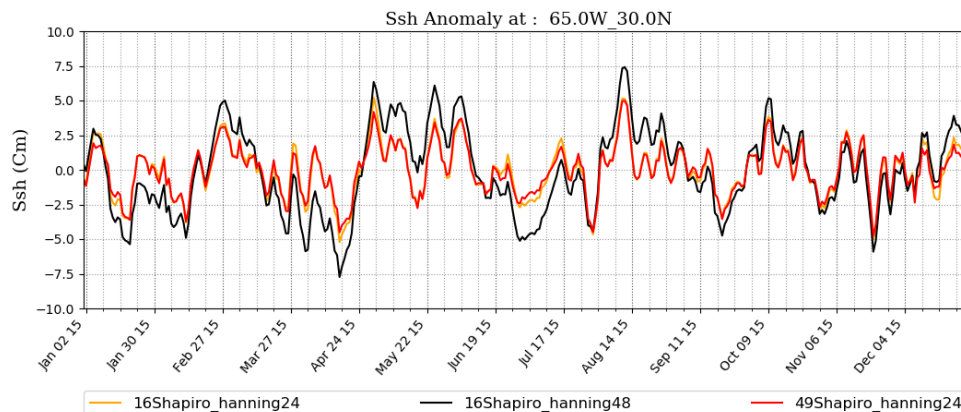
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Power spectral density of the SSH anomalies over the Gulf Stream region

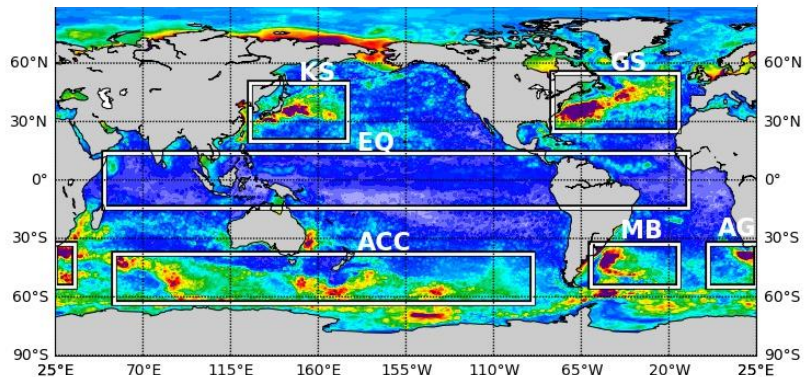


Anomalies bases	Spatial filtering (Shapiro)	Temporal filtering (Hanning)
-----	~ 7 dx	~ 24 days
-----	~ 4 dx	~ 24 days
-----	~ 4 dx	~ 48 days

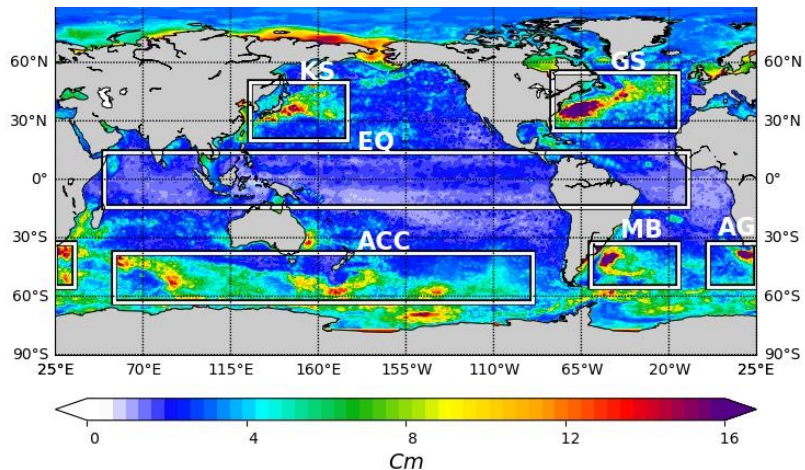
As the analysis increment is a linear combination of anomalies, this allows us to get an idea of the scales that the analysis system will be able to correct.



With old model error covariances

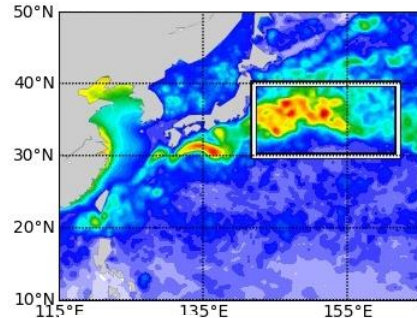


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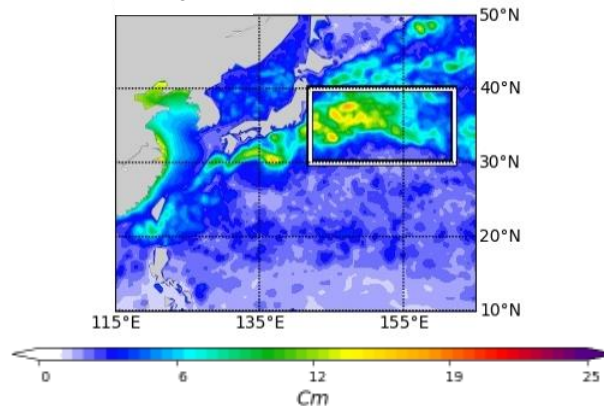


Standard deviation of the SSH error

Old



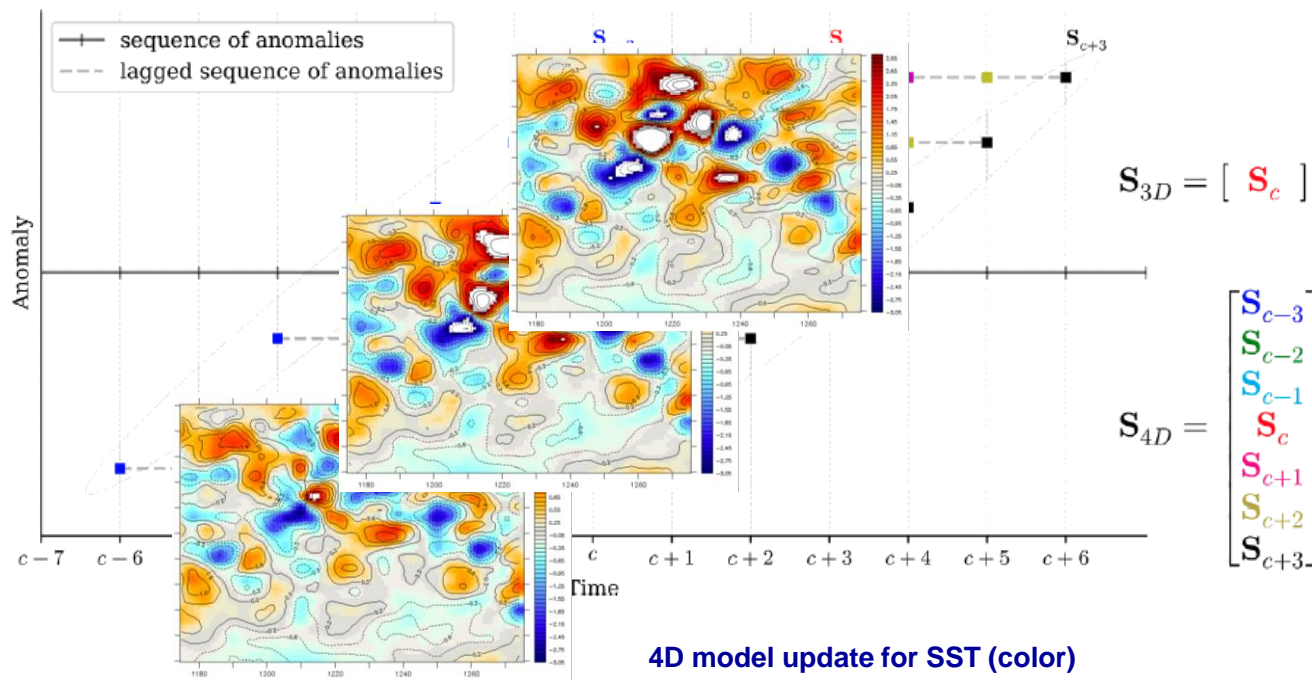
New



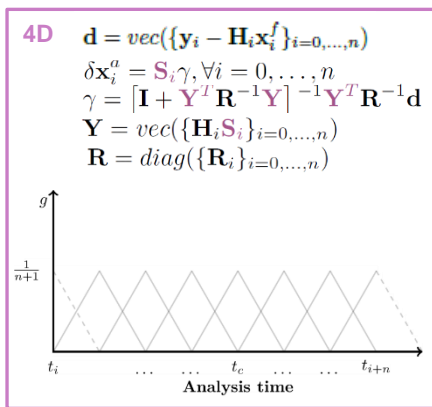
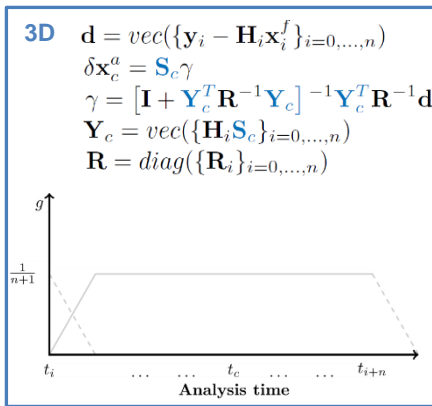
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- ❑ A **4D extension** of the data assimilation scheme allowing a better spatiotemporal continuity of mesoscale structures

The 4D method uses an ensemble of trajectories of climatological model anomalies to fit the innovation in the Data Assimilation window. The 4D scheme allows a better approximation of the anomaly matrix.

from Benkiran et al., 2021

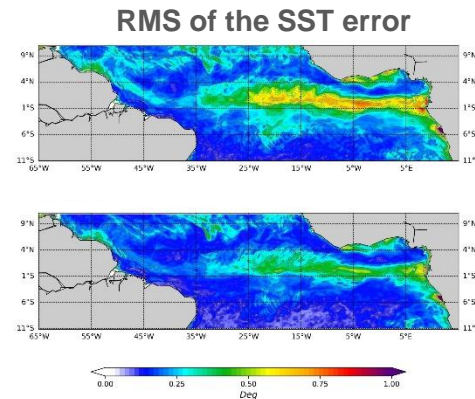
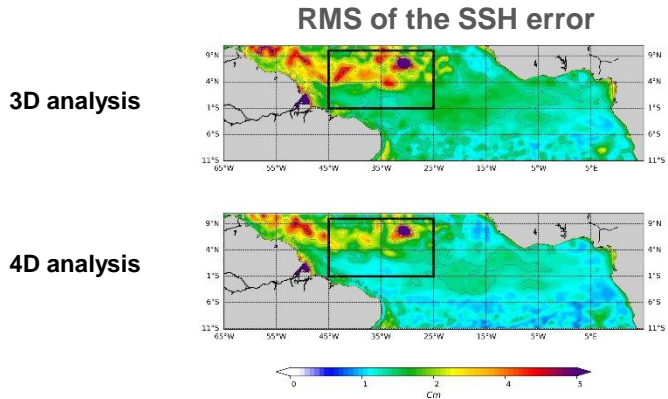
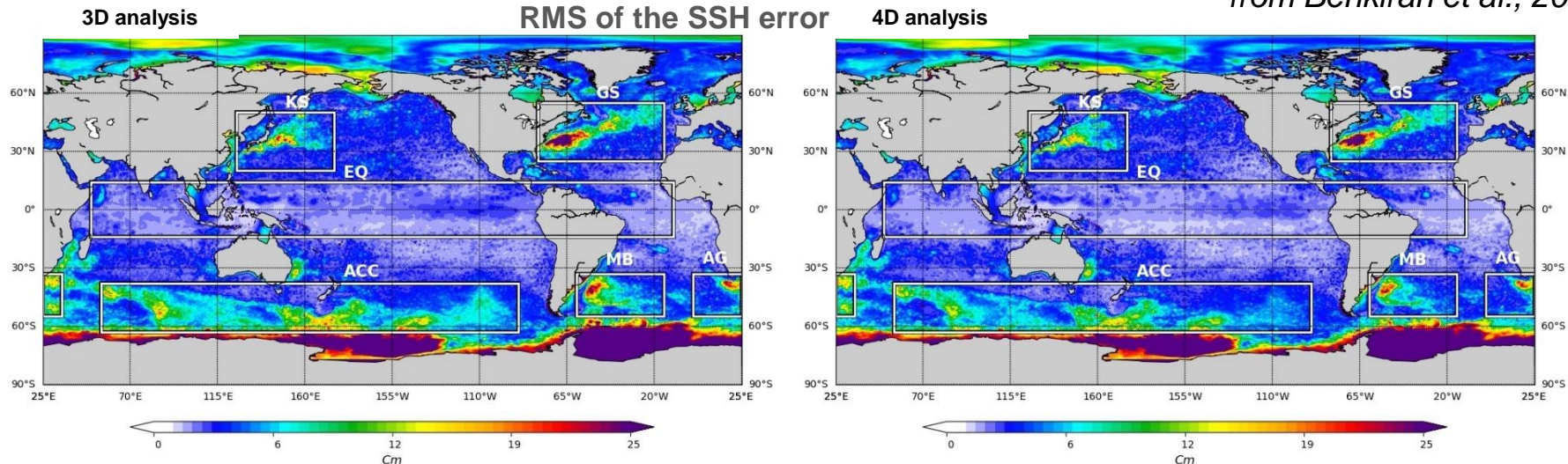


4D model update for SST (color)
vs
4D innovation of SST (isoline)



Use a 4D version of analysis

from Benkiran et al., 2021

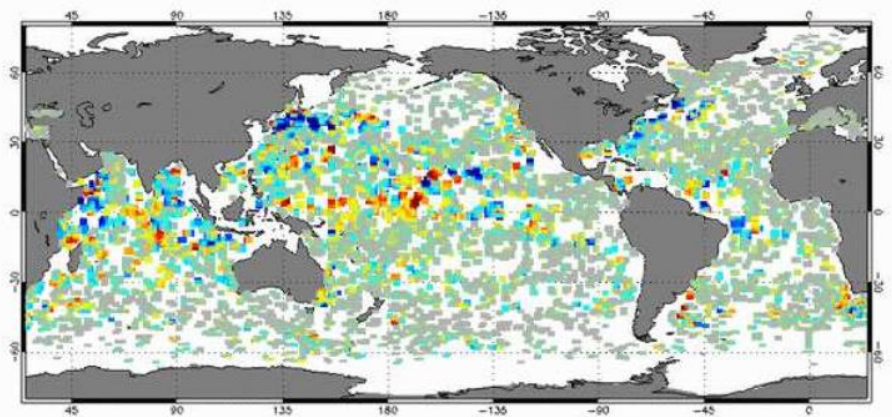


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- ❑ New parameterizations of the temperature and salinity **bias correction method**

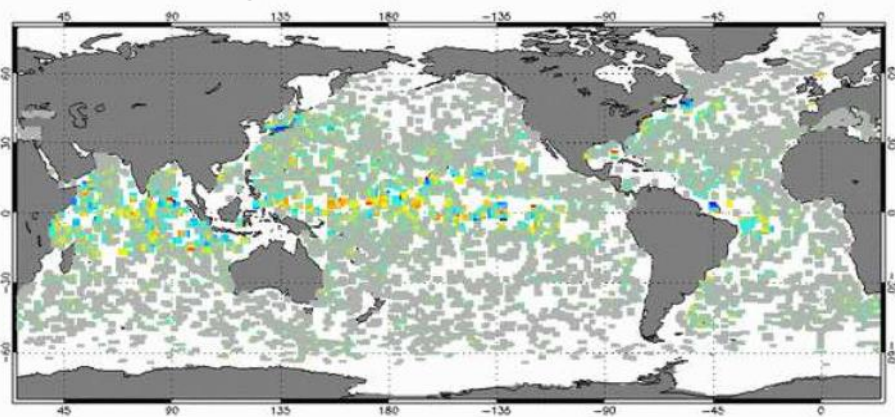
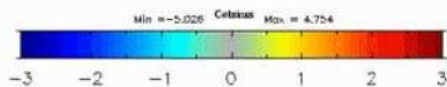
Parameters optimization for bias correction

Residual of temperature at 140 m (left: actual parameters, right: new optimized parameters)



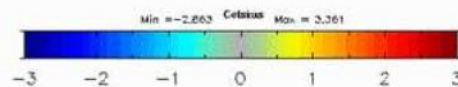
avg: -0.0056Celsius

Contour 0.25 Celsius



avg: 0.0012Celsius

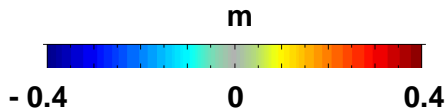
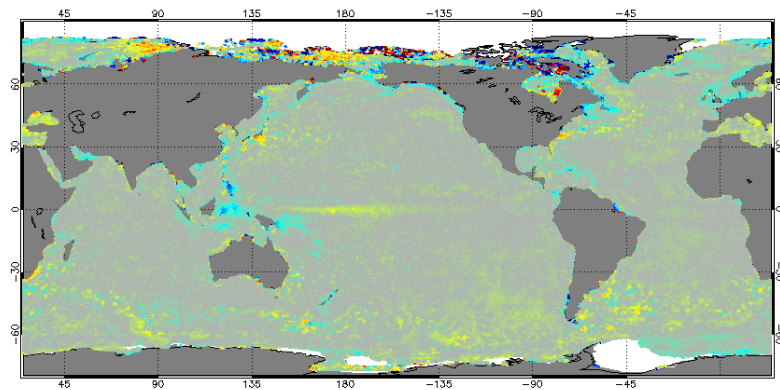
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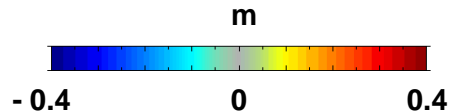
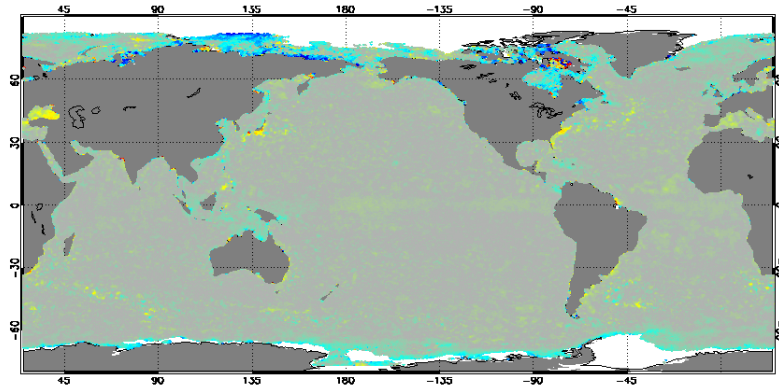
Performances of the new system compared to the previous one

GLO12 has less regional bias in SLA

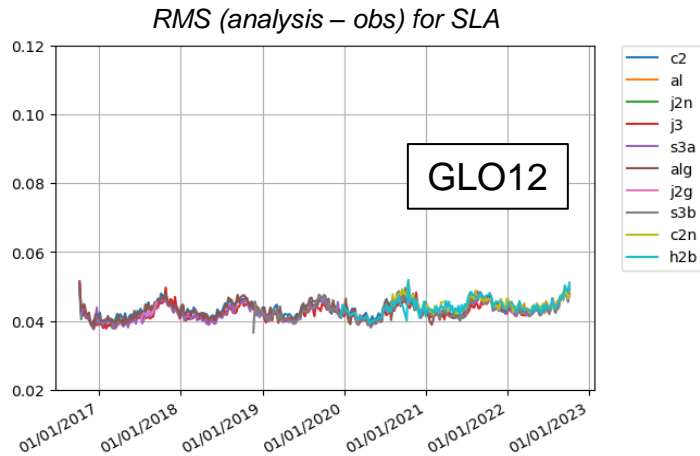
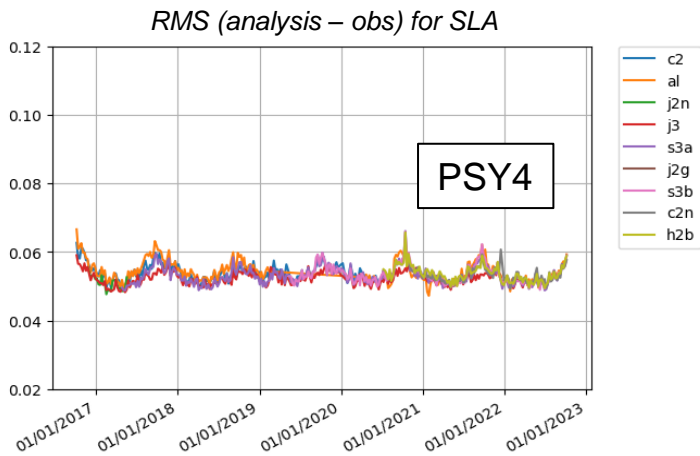
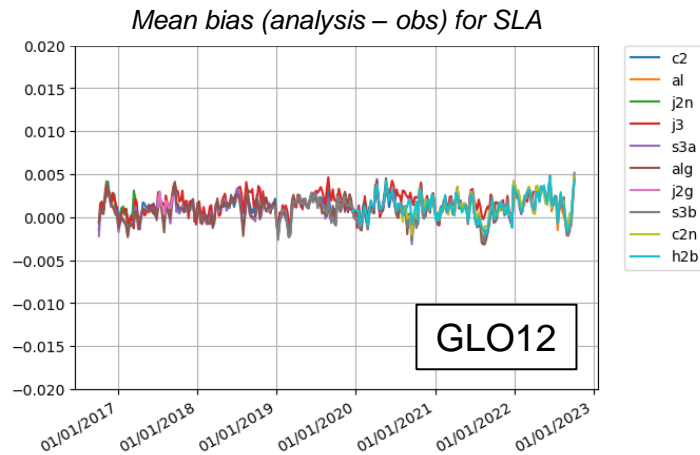
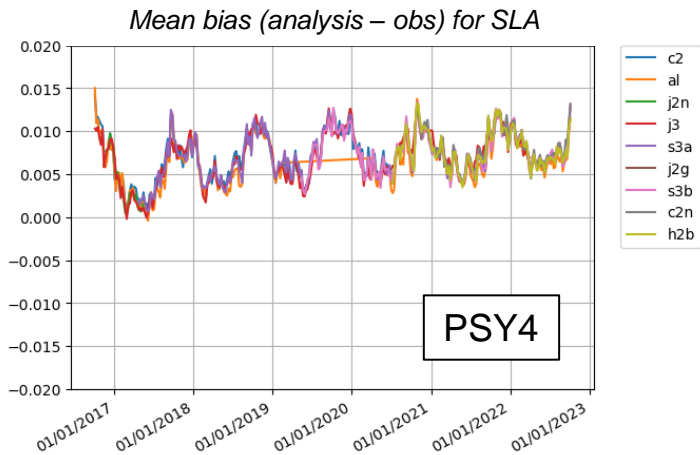
PSY4 mean SLA innovation



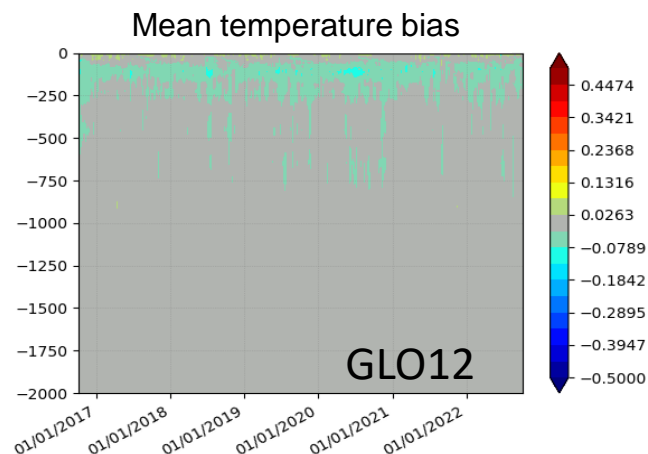
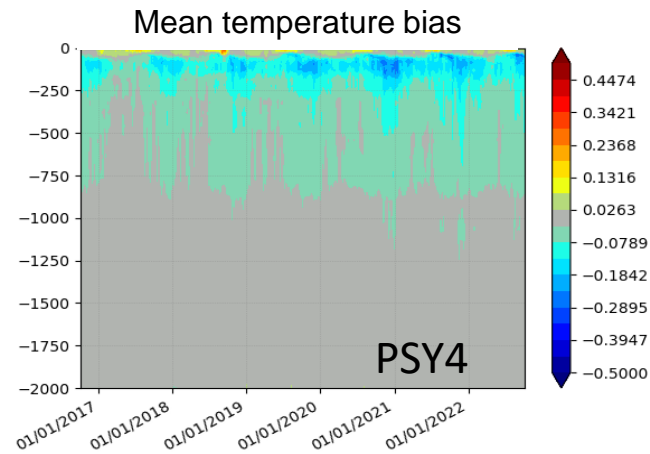
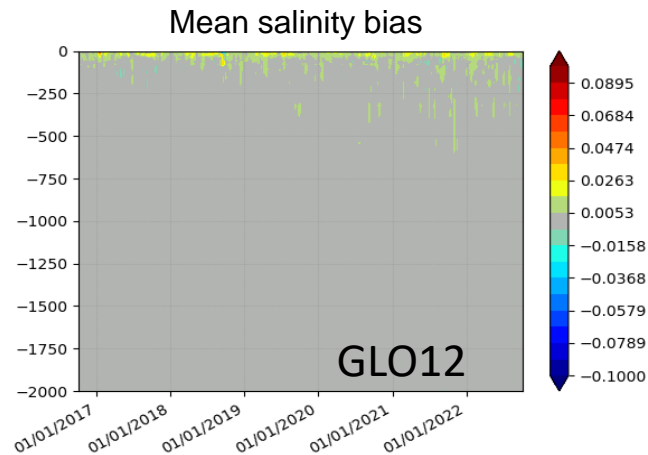
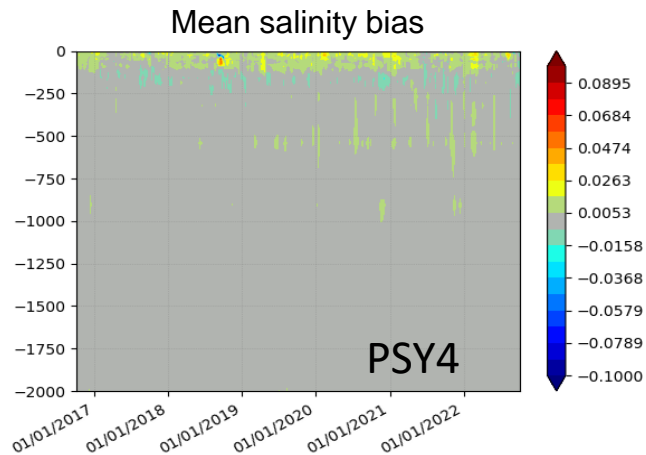
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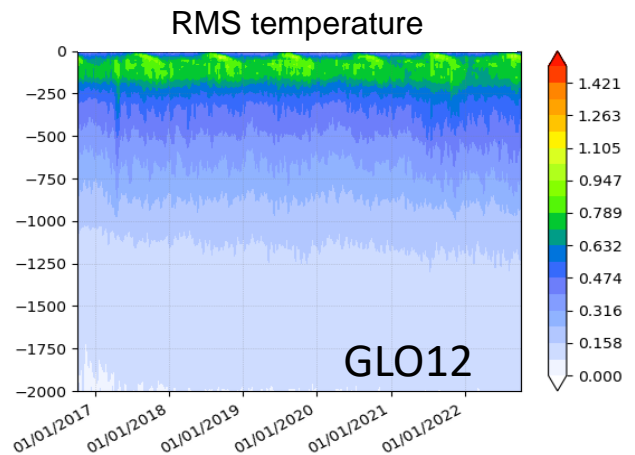
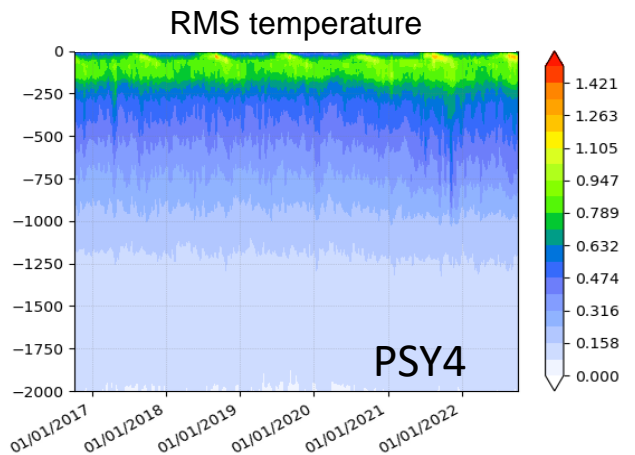
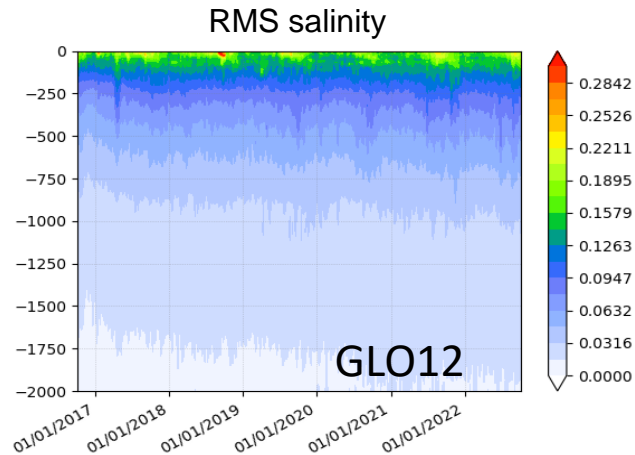
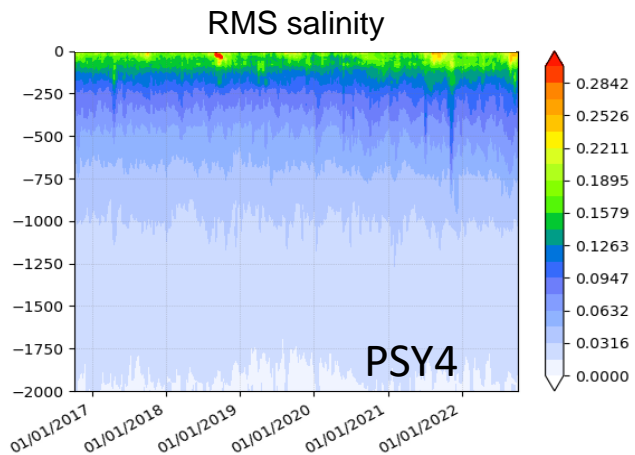
SLA



insitu



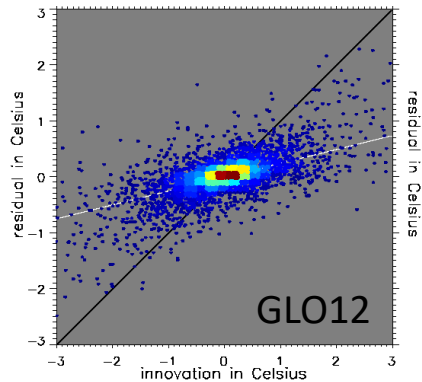
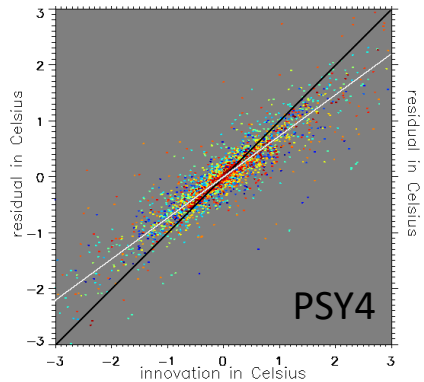
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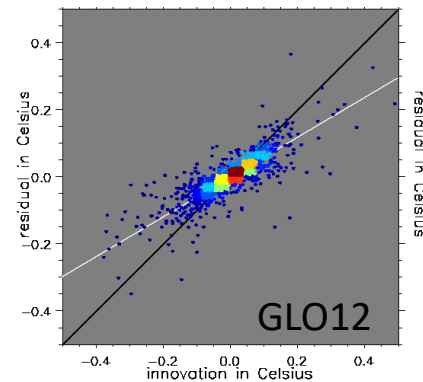
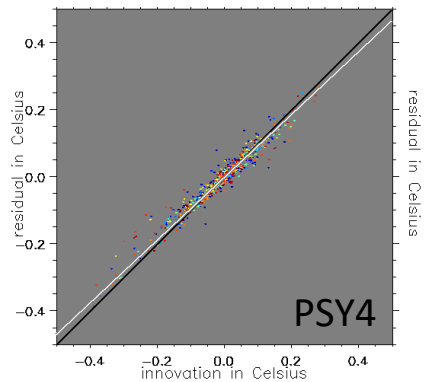
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Cloud dispersion

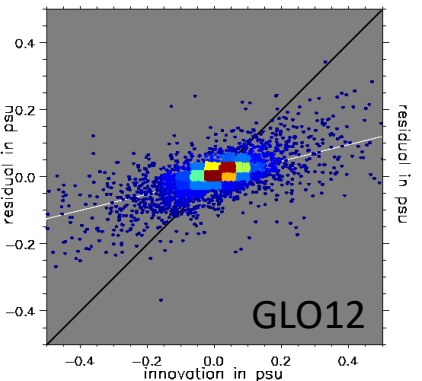
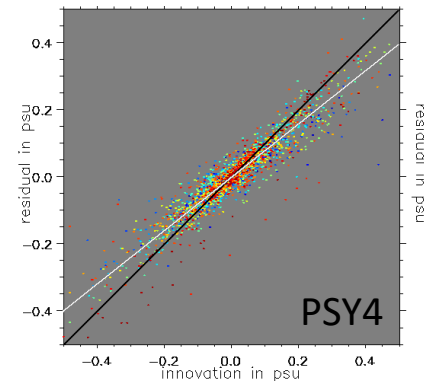
Residual vs innovation Temperature at 150 m



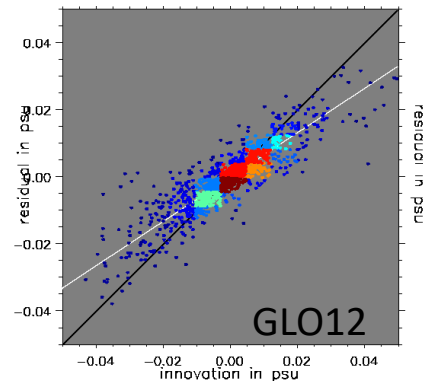
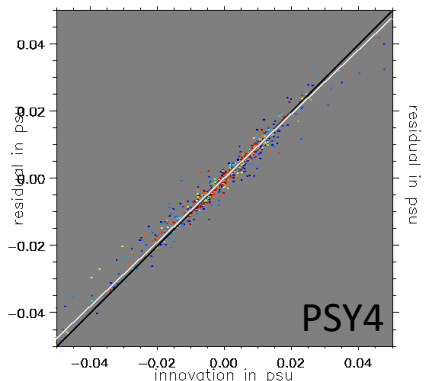
Residual vs innovation Temperature at 1950 m



Residual vs innovation Salinity at 90 m

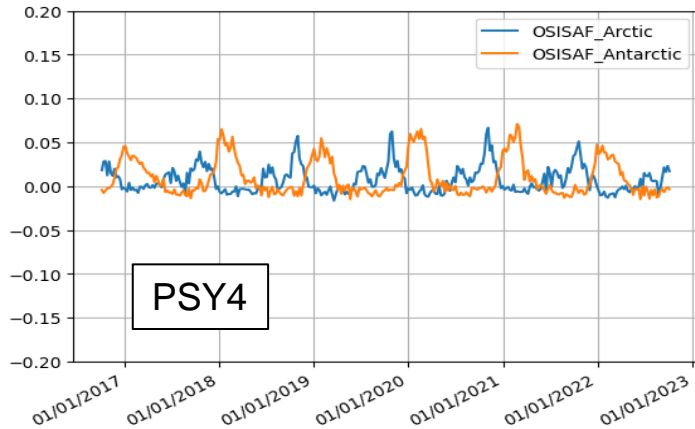


Residual vs innovation Salinity at 1950 m

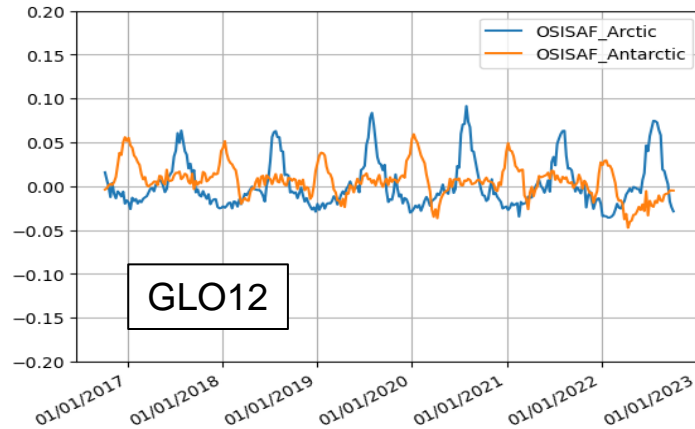


SIC

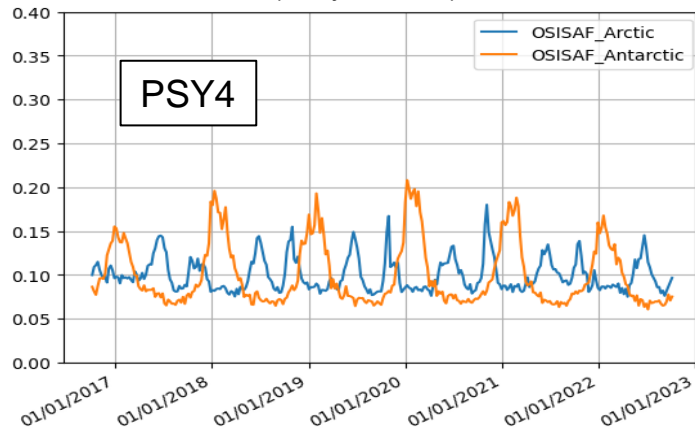
Mean bias (analysis – obs) for SIC



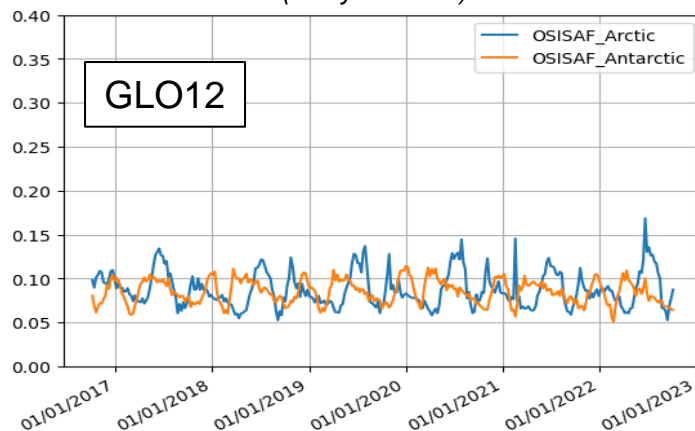
Mean bias (analysis – obs) for SIC



RMS (analysis – obs) for SIC



RMS (analysis – obs) for SIC



A major release of the Copernicus Marine Service global ocean analysis and forecasting high-resolution system is available since the beginning of 2023.

The objective of this major release is to improve, among other things, the analysis and forecast skills, the representation of mesoscale activity, the mass/steric distribution (loss of mass and too much steric in the current system), the equatorial dynamics and interaction with biogeochemistry.

This release includes:

- A new version of NEMO ocean and sea ice models (new numerical schemes, coherent bulk formulation with the atmospheric forcing, multi-categories sea ice model);
- Higher spatial and temporal resolution ($1/15^\circ$ - 1 hour) atmospheric forcing from IFS ECMWF analyses and forecasts;
- A new assimilated SST observation (assimilation of L3 ODYSSEA SST high resolution product instead of L4 OSTIA gridded product);
- A new Mean Dynamic Topography for SLA assimilation;
- A different parametrization of the model error covariance with a new anomalies base deduced from the Mercator Ocean reanalysis at $1/12^\circ$ (Lellouche et al., 2021);
- A 4D extension of the data assimilation scheme allowing a better spatiotemporal continuity of mesoscale structures;
- The assimilation of “super-observations” to filter out noisy data and scales that the model does not resolve;
- The use of satellite-based monthly estimates of the Global Mean Sea Level to better constrain the ocean mass and the steric height;
- New parameterizations of the temperature and salinity bias correction method.