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Towards a Mercator reanalysis and forecasting system using an Ensemble Kalman Filter

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Outline

1. A new framework for the Mercator reanalysis and forecasting system
2. Experiment design
3. Some results
4. Ensemble forecasting
5. Conclusions and next steps

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A new framework for the Mercator reanalysis and forecasting system

Data Assimilation Plans

- Currently MOI operates multi systems at multi resolution
  - They are all using the same DA approach (for covariance estimation and state update)
  - There is no interaction between them

- System complexity is increasing
  - Coupling: BGC - ocean, Sea-ice – ocean, ABL/ATM – ocean
  - Very High resolution, tides, Lagragian vertical coordinates, multi grid

- Need to improve coherence between them through DA, otherwise improvements on one system may degrade the others (e.g improving the ocean state vector may disrupt “balance” on BGC variables)

MOI is progressively moving towards ensemble approaches and coupled DA

Towards a probabilistic DA system

Deterministic Forecast + Climatological Covariance

Developments

Probabilistic Forecast + Ensemble Covariance

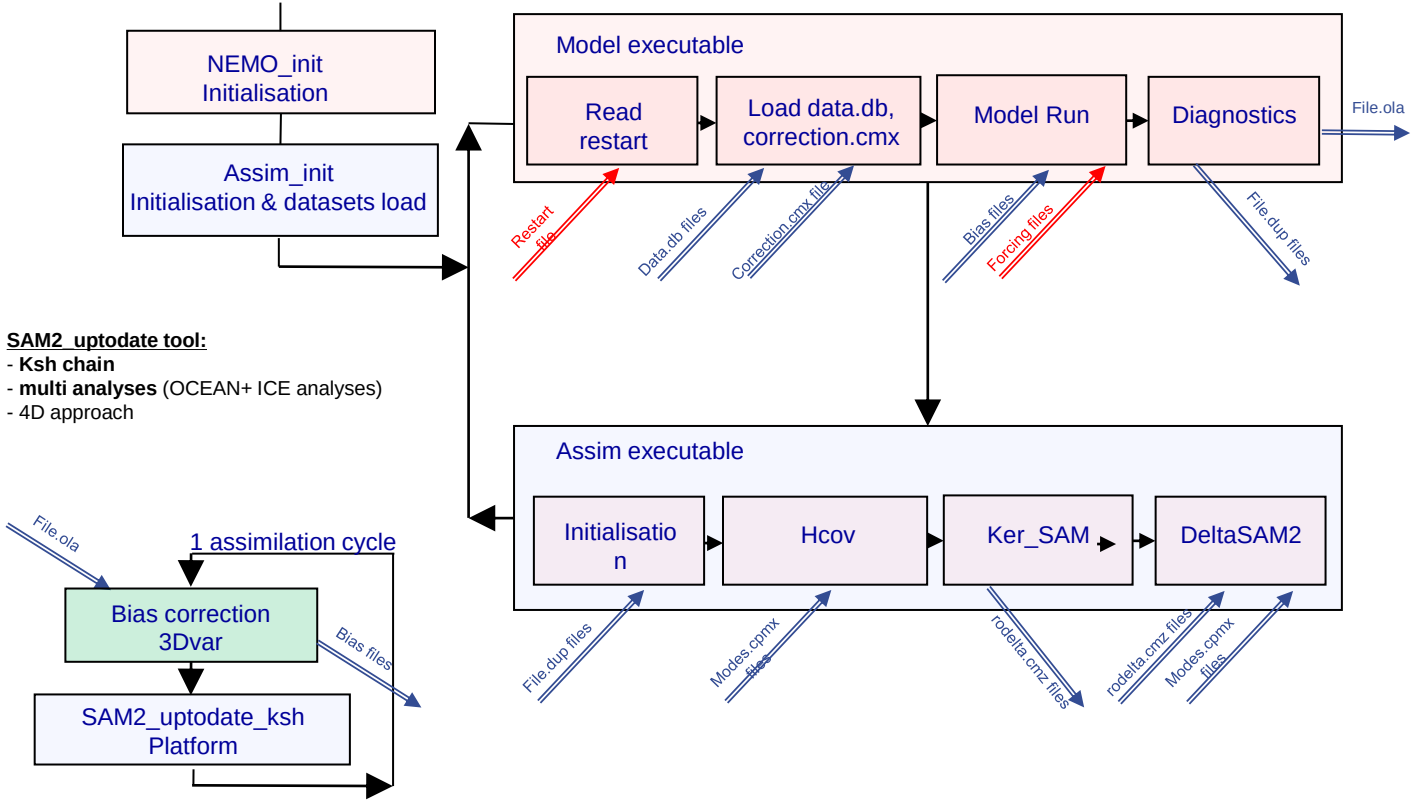
1° Step

- Development of different methodologies producing relevant model error for ocean/ice/bio components
- Testing ensemble solutions against observations (rank histograms, RCRV statistical moments, crps, etc)

2° Step

- Development of SAM2V2 w/ special attention to I/O capabilities and on-line probabilistic QC and diagnostics
- Implement a full LETKF algorithm, but also EnKF, EnOI.

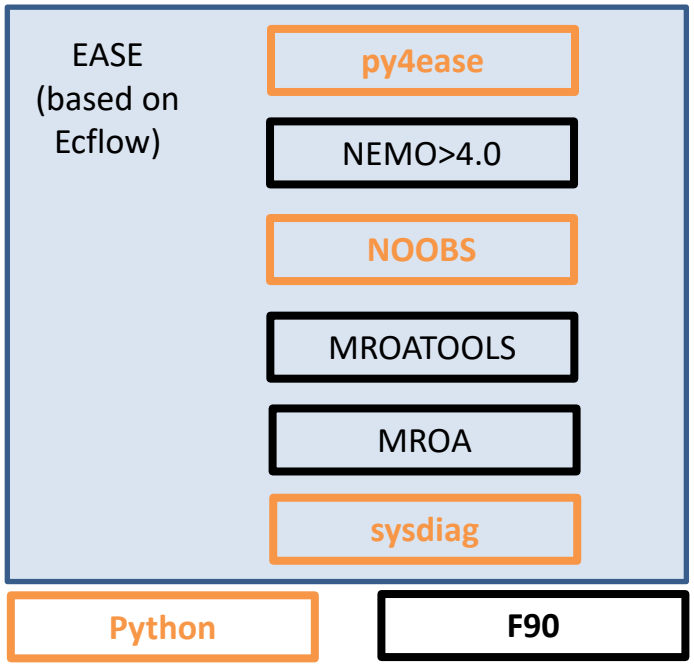
SAM2 platform



SAM2 platform is still used in the current deterministic operational system

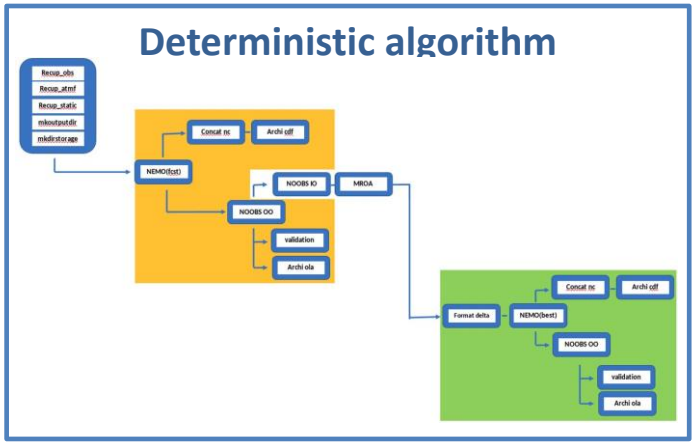
A new framework for the MOI system

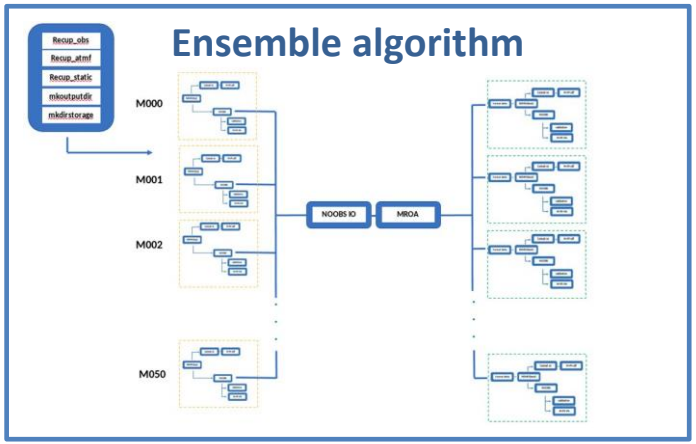
A modular approach using Python and Fortran tools manage by a Python software (Ease) based on Ecflow library

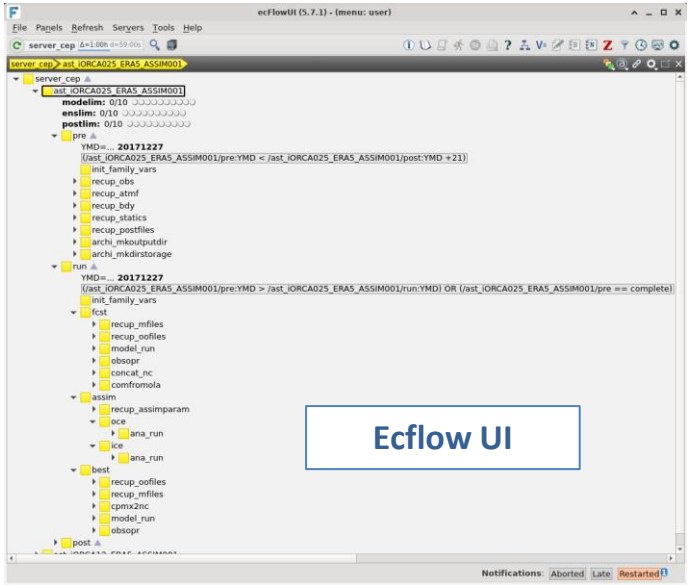


- Flexible: used at MF and ECMWF (old and new HPC facilities)
- **NEMO** code is in a standalone mode and we can compile directly the nemo.exe from the Main
- The observation operator (**NOOBS**) is off-line
- The analysis (**MROA**) is also stand alone
- The information exchange between each module is done through the disk
- Tools may be used within the “EASE env” or in standalone mode (e.g., **NOOBS** is used by modelers, **sysdiag** is already used in the GLO12 workflow to be operational by Nov 2022)

A new framework for the MOI system







Ecflow UI

Algorithms under development :

- Dual grid with a GLO12 model using a GLO4 analysis
- 3Dvar Bias correction
- Agrif configuration

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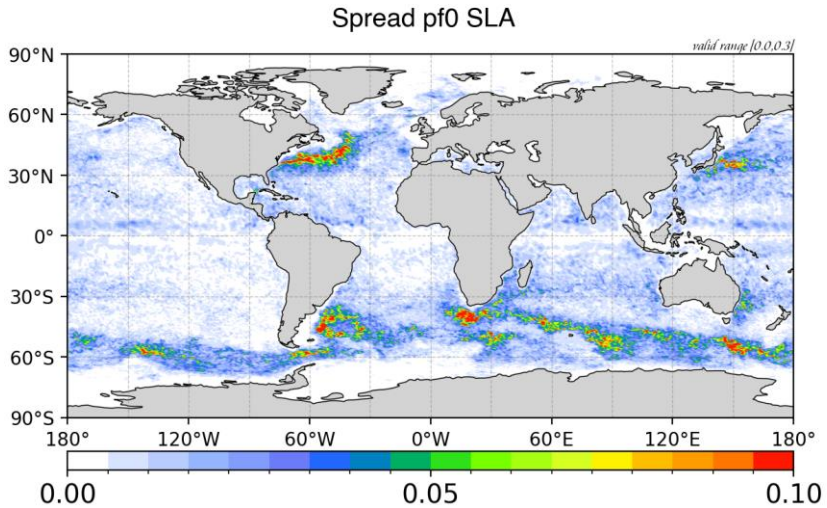
Experiment design

Model characteristics

Model

- Nemo 4.2, SI3 Multi-category(5)
- Global ¼
- 75 levels
- IFS forcing



Ensemble run

- 8, 16 or 50 members + 1 CTL simulation (M000)

- Start from very short ensemble spinup builded from deterministic reanalysis with various CI around the initial day for each member (+- 8 days for the 16 members simulation)

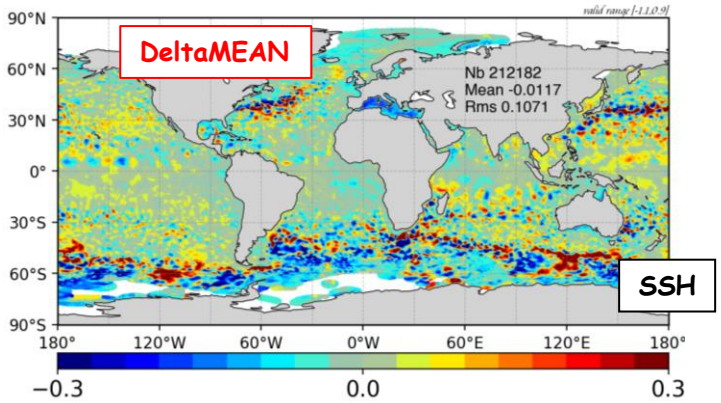
- Stochastic pert. on ocean parameters perturbing advective and diffusive fluxes

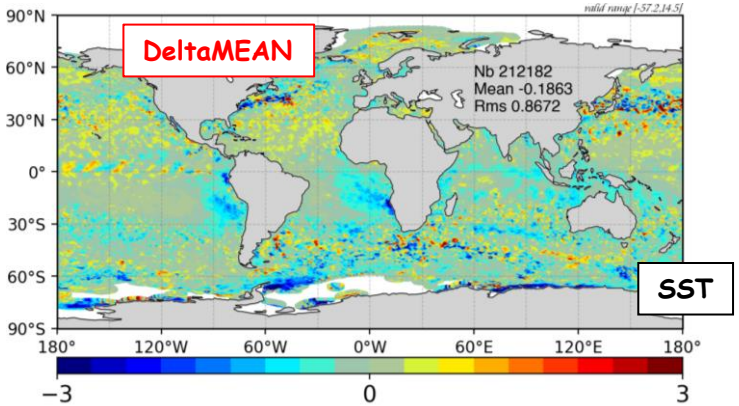
- Stochastic pert. on ice parameters perturbing (P* ,C*) and drag ocean-ice, drag ice-atm

Assimilation characteristics

Analyses

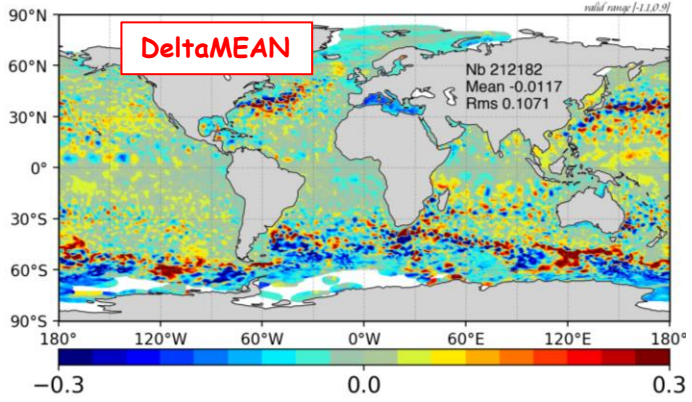
- 7 days cycle
- Data assimilation scheme based on a 2D local multivariate LETKF filter
- Weakly-coupled DA system using 2 separate analyses
    - Ocean Analysis (SLA, InSitu Data from CORA, OSTIA SST) , IAU on (h,T,S,U,V)
    - Sea Ice Analysis (OSISAF Sea Ice Concentration)
- No 3Dvar analysis for the bias, no bogus
- Adaptative scheme for the variance of the background error



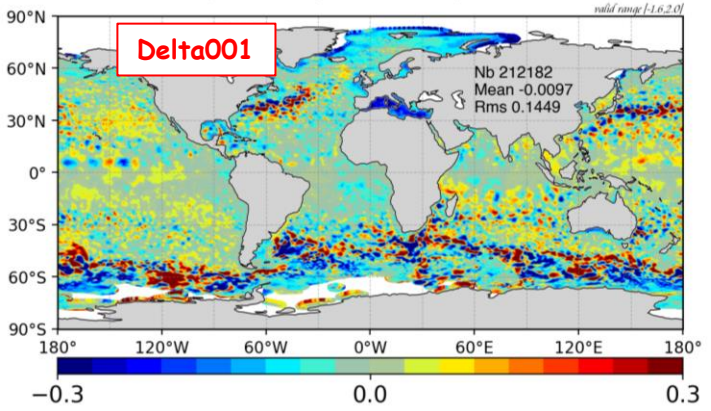


In a LETKF, Ensemble update is computed using the innovation of the ensemble mean

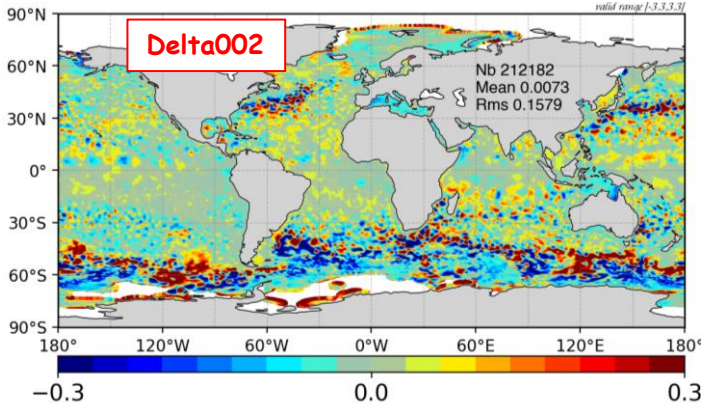
Delta from Ensemble analysis (8 Members)

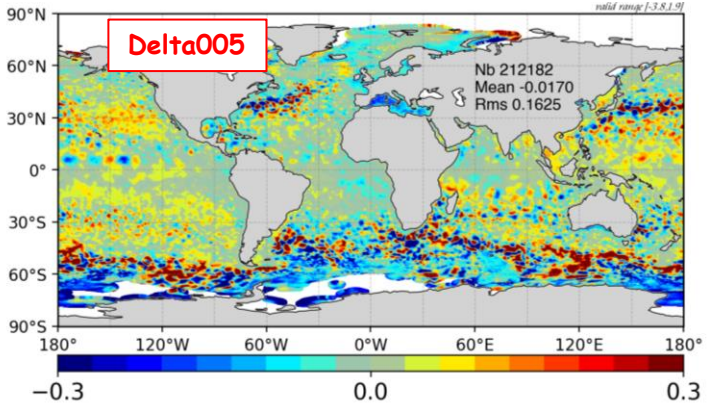


SSH



iORCA025
01/01/2021
Ens8modes
LETKF





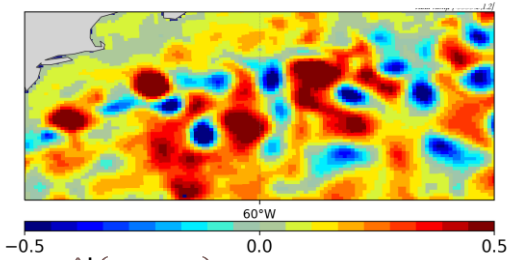
In a LETKF, Ensemble update is computed using the innovation of the ensemble mean

Some results

GLO4-Ens (50 Members)

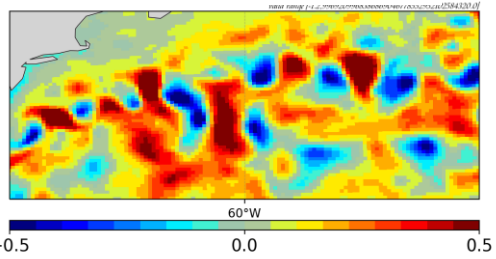
SLA fields at the GS and for the seventh day forecast and AVISO L4 at the same day

Assim ctl50: 7°d FCST

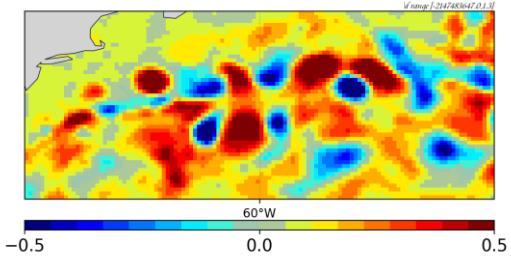


$\hat{\eta}|(\eta_{t<t-7})$

GLO12V4: 7°d FCST

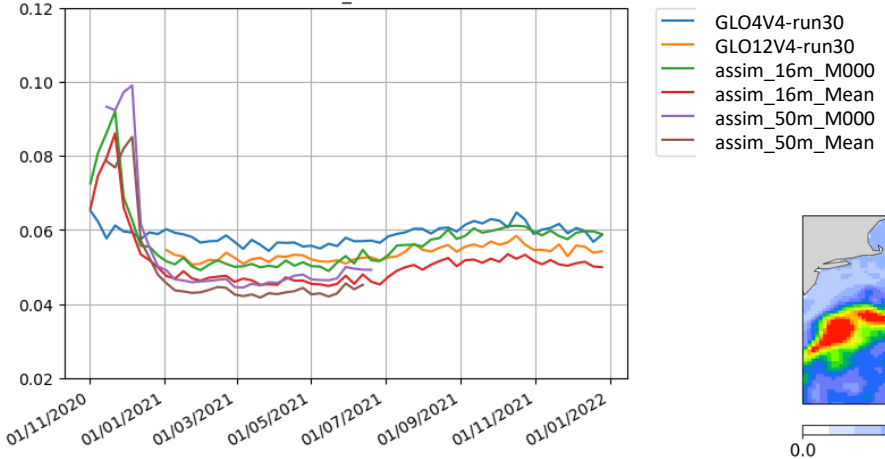


AVISO L4

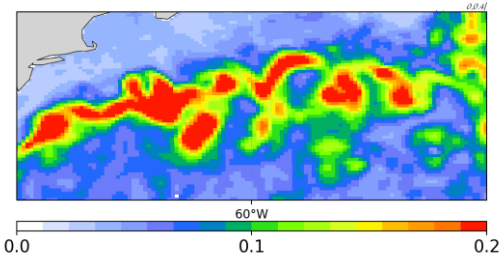


$\hat{\eta}|(\eta_{t-10}, \cdots, \eta_{t+10})$

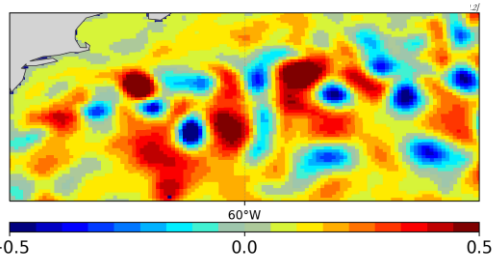
SLA FCST Global rms mistfit



Ens Std: 7°d FCST

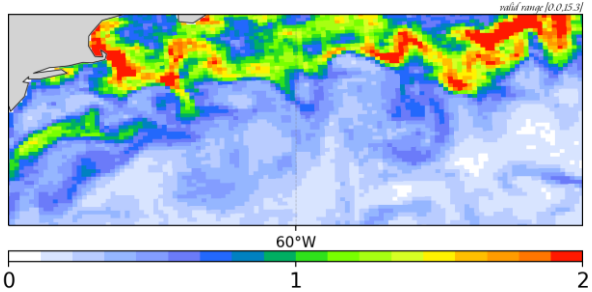


Ens Mean: 7°d FCST

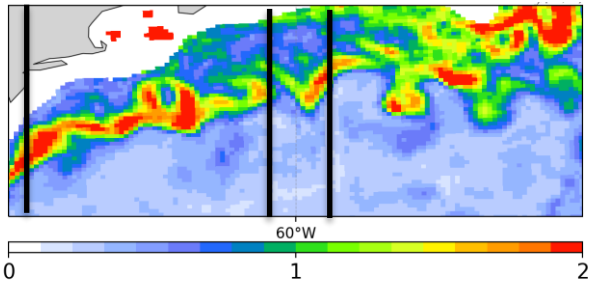


Temperature

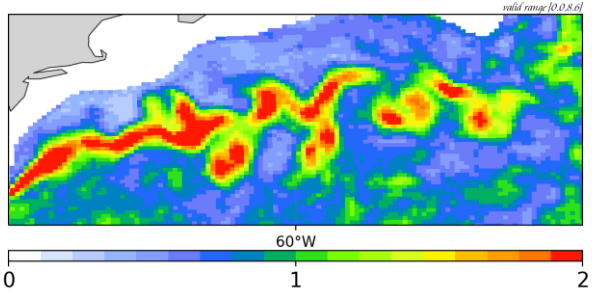
0.5m

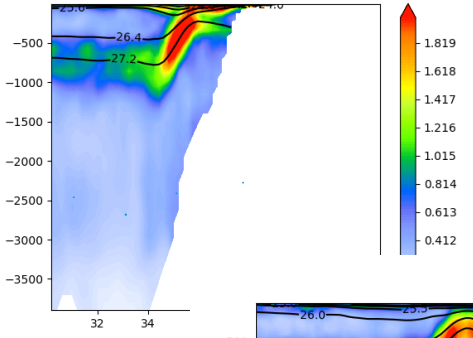


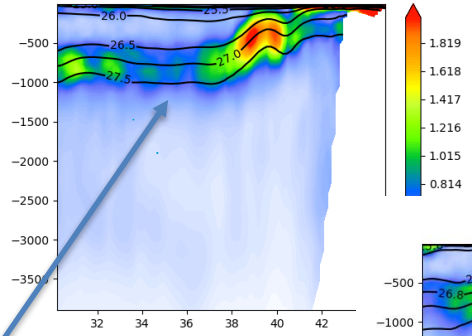
221m

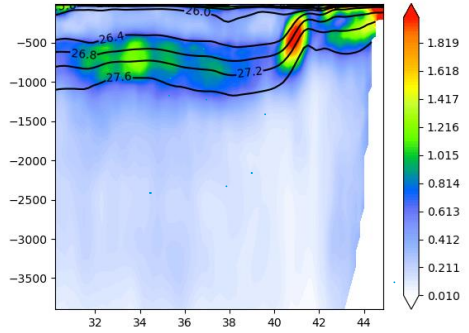


628m





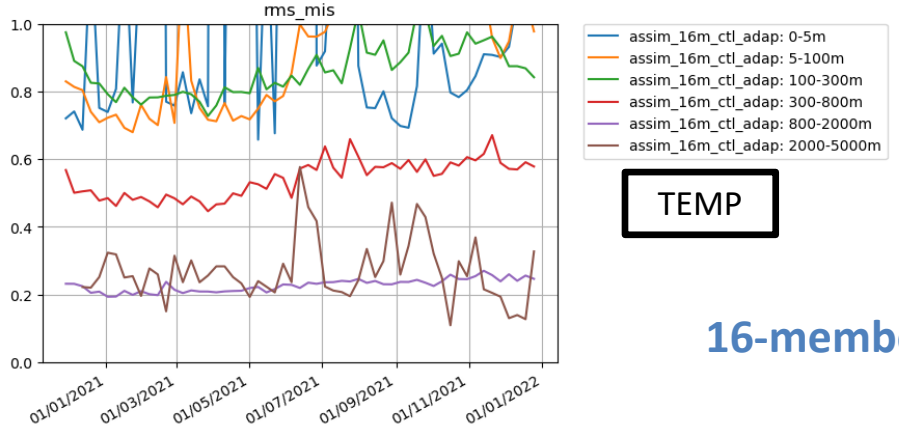




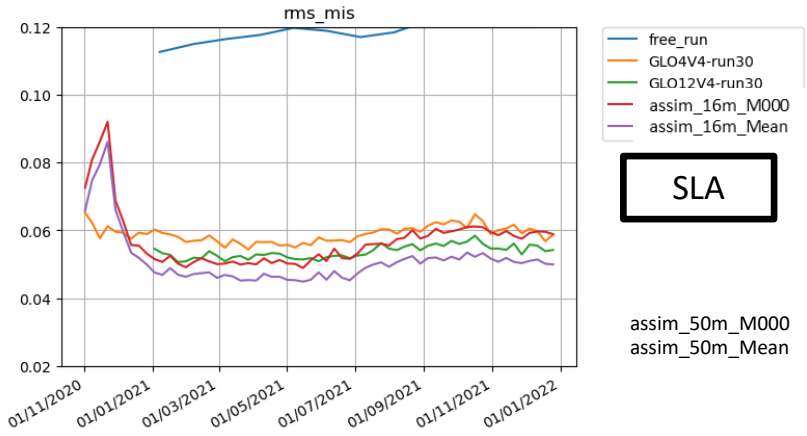
Ensemble spread for the 7th day forecast at the Gulf Stream region

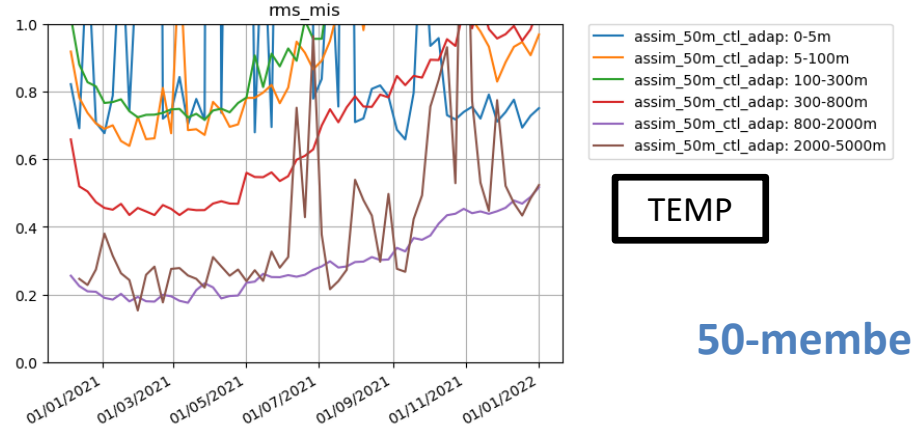
Ensemble spread mostly important in regions of strong gradients

Ensemble reanalysis have drift

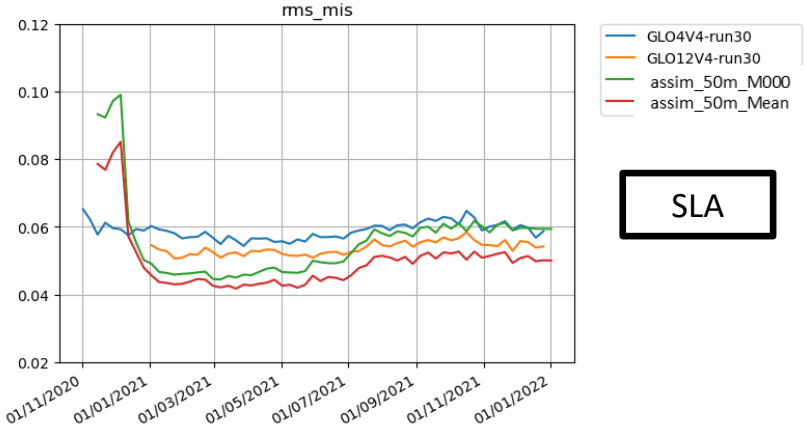


16-members





50-members



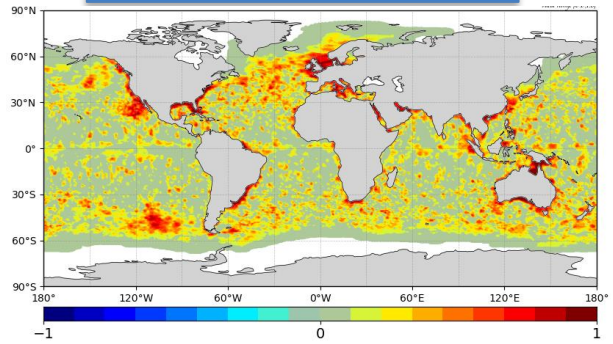
Ensemble reanalysis have drift

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

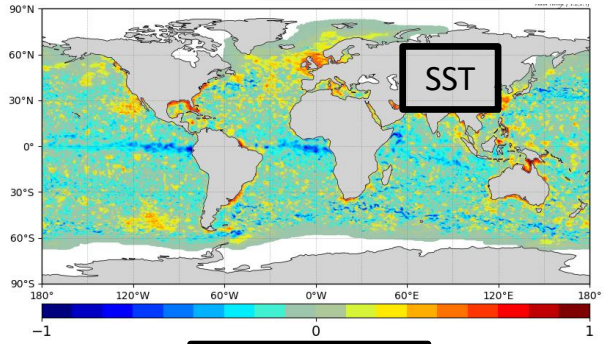
n = number of independent data

from forecast ensemble spread to updated ensemble error

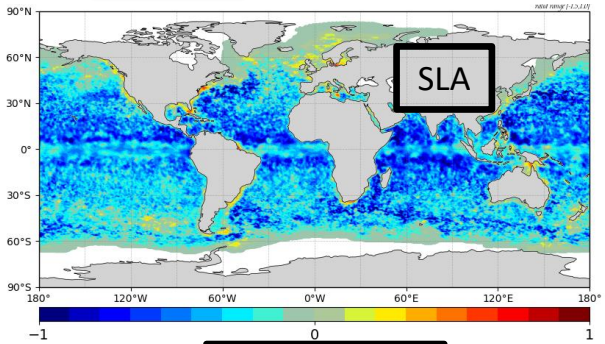
Pf0 => Adaptive scheme => **Pf= α Pf0** => Analysis => **Pa**



Log (α)



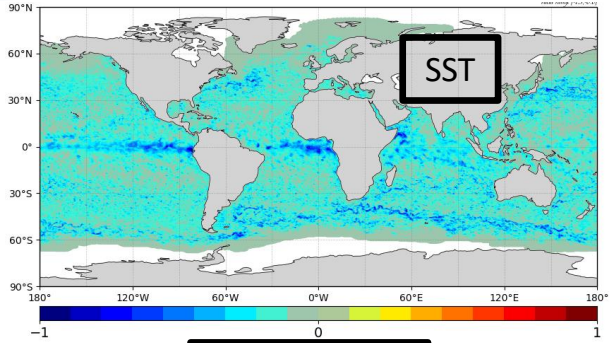
Log (Pa/Pf0)



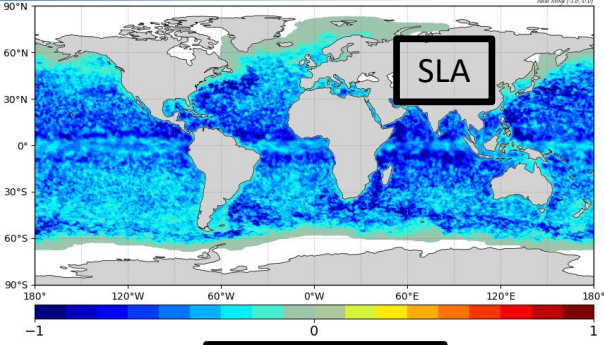
Log (Pa/Pf0)

Ensemble reanalysis
without adaptive scheme

Pf= Pf0 => Analysis => **Pa**



Log (Pa/Pf0)

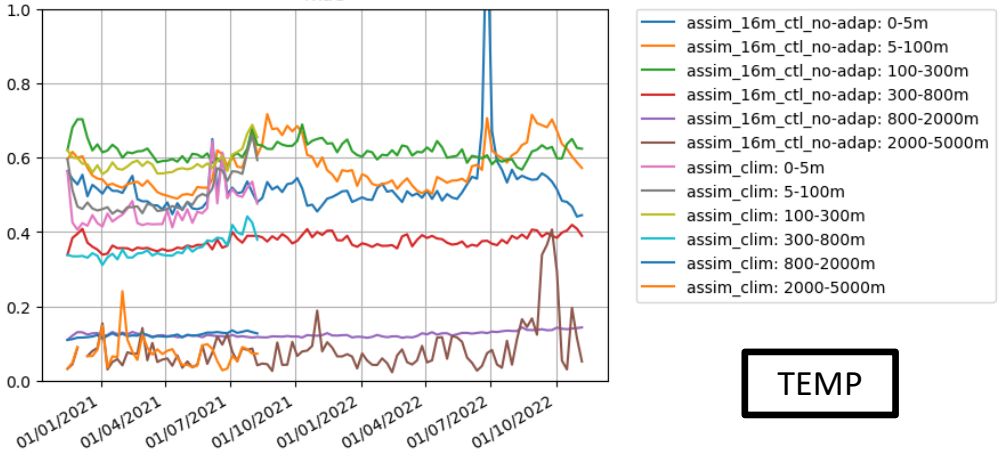


Log (Pa/Pf0)

Ensemble reanalysis without adaptive scheme

Temperature

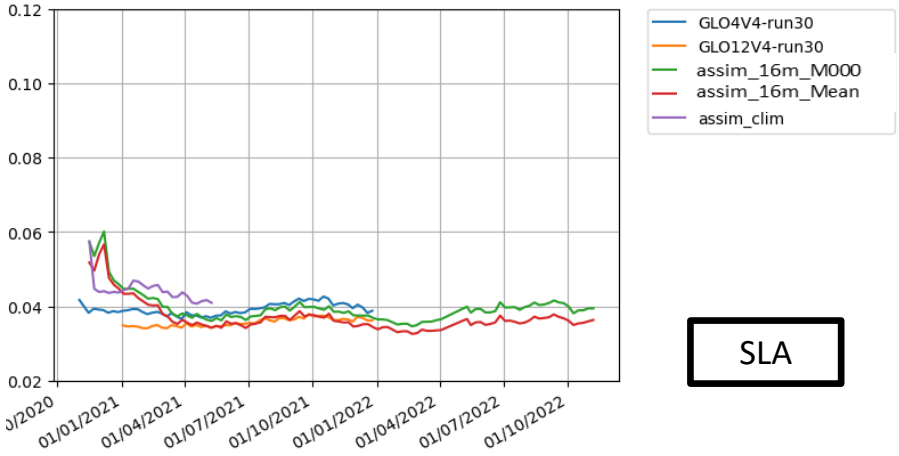
Mean absolute error (MAE)



TEMP

SLA MAE

Mean absolute error (MAE)



SLA

Ensemble reanalysis without adaptive scheme are more stables

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Ensemble Forecasting

GLO4ENS 28-days re-forecast forced by the ECMWF ensemble

The system is based on NEMO4.2 at ¼° resolution.

50 members running weekly in a scheme of nowcast (7-days window) followed by a forecast initialized by an analyzed nowcast.

The Local Ensemble Kalman Filter is used in the analysis step and provides 50 perturbed initial conditions conditioned by the observations.

28-days forecasts are forced by the ECMWF extended forecast

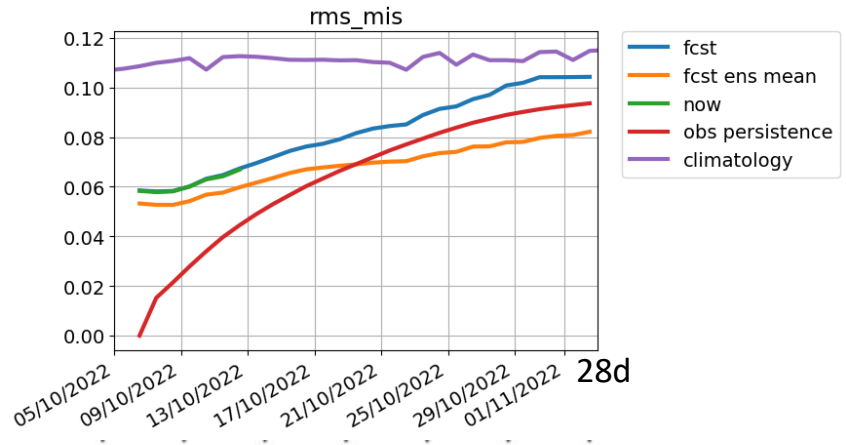
Both nowcasts and forecasts uses stochastic perturbations to model “model errors”

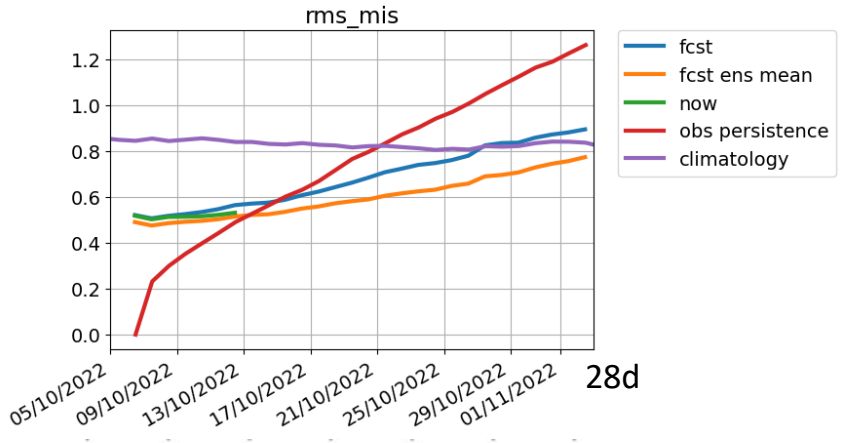
The objective is to demonstrate that the ensemble system can produce informative forecasts for leading times longer than the week for SLA and SST

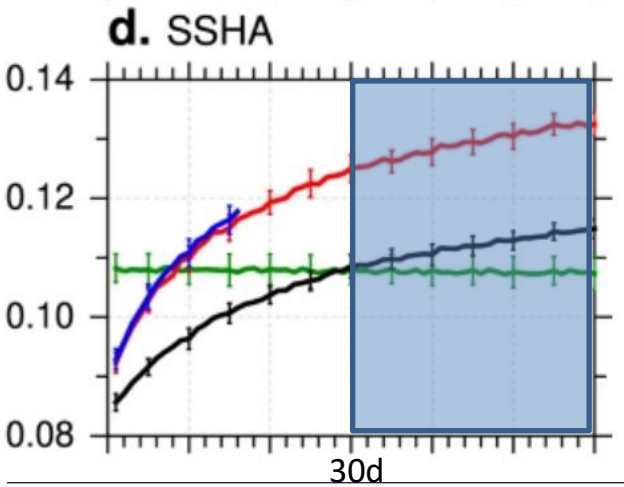
We use two metrics:

- Deterministic skill by comparing the rms of the ensemble mean and the control forecasts with the rms of the monthly climatology
- Probabilistic skill by calculating the **reduced centered random variable** standard deviation and bias over the forecast

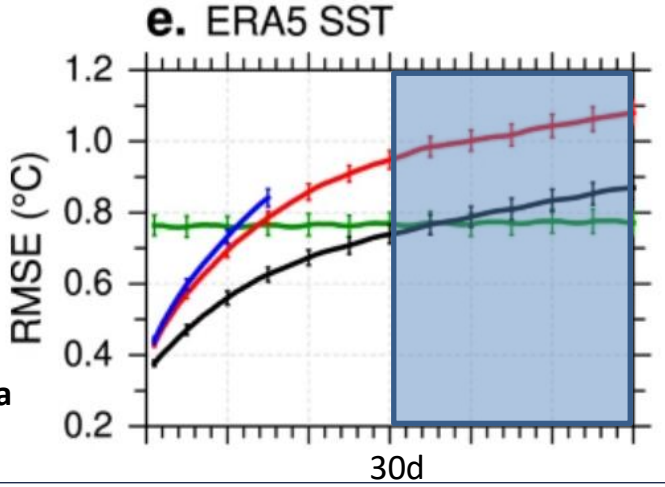
GLO4ENS 28-days re-forecast forced by the ECMWF ensemble





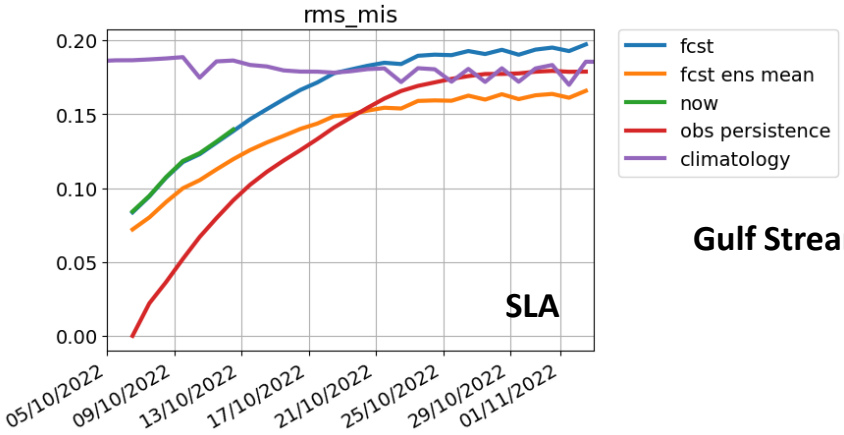


1/25 det
1/12 det
1/12 ensmea
climatology

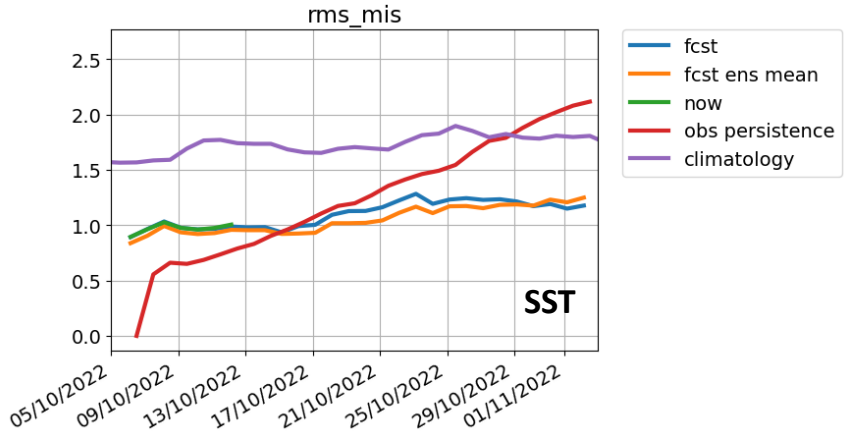


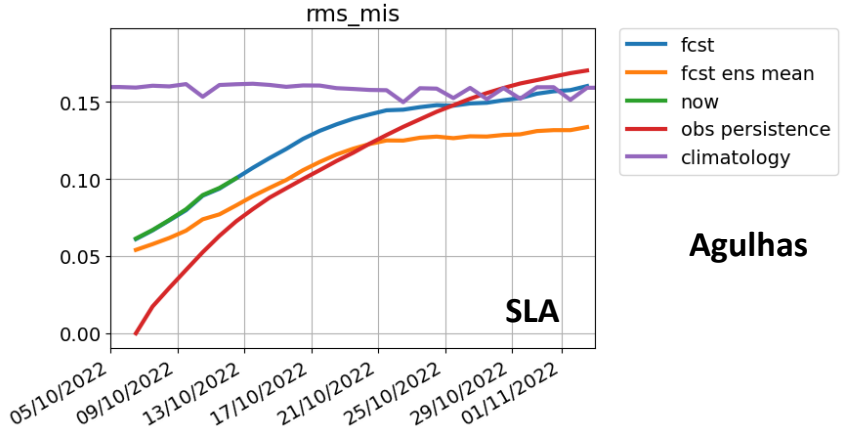
Thoppil, P.G., Frolov, S., Rowley, C.D. et al. Ensemble forecasting greatly expands the prediction horizon for ocean mesoscale variability. Commun Earth Environ 2, 89 (2021). https://doi.org/10.1038/s43247-021-00151-5

GLO4ENS 28-days re-forecast forced by the ECMWF ensemble

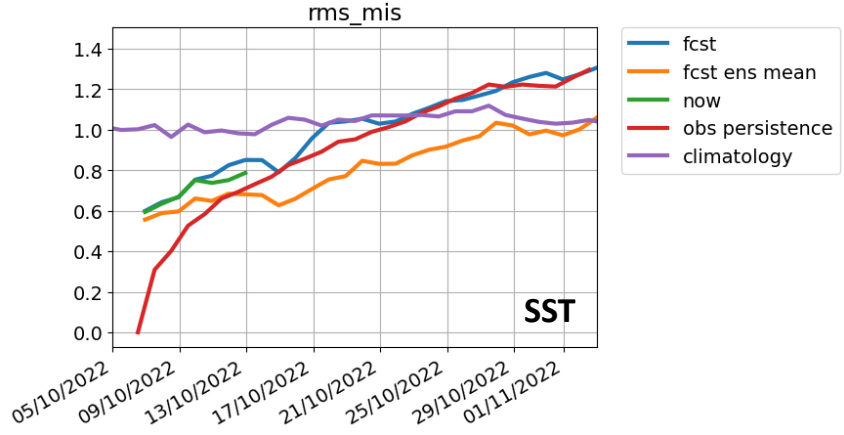


Gulf Stream





Agulhas



Conclusions and next steps

Concluding remarks and next steps

- An ensemble system within a completely new software architecture has been implemented
- Deterministic scores shows the system agree with the available observations
- Predicted mesoscale uncertainty at key regions is reliable
- Still need to further analyze what is happening for very large scales (>1000km)

- Implementing the 3D-var and/or large time-space scale analysis to the new working env
- Implement features needed to run an operational-like workflow forced by the ECMWF ensemble forecasts
- Final tests of the GLO4-Ens with 3D-var bias correction and fine tunning
- First tests of a multiscale analysis (most technical devs will be finalized this year) ➔ GLO12-ENS4