Toward an ensemble data assimilation strategy for eddy-resolving ocean circulation models

Guillem Candille, Jean-Michel Brankart and Pierre Brasseur

MEOM team, LGGE/CNRS, Grenoble, France.

Abstract : The objective of this project is to develop advanced data assimilation methods (applied here to altimetric data) suitable for eddy-resolving ocean circulation models, currently needed in operational and research applications. This work is carried out jointly with the SANGOMA (Stochastic Assimilation for the Next Generation Ocean Model Applications) consortium, funded by EU under the GMES umbrella over the 2012-2015 period. In this framework, a realistic circulation model of the North Atlantic ocean at 1/4° resolution (NATL025 NEMO configuration) has been adapted to include effects of unresolved scales on the dynamics. This is achieved by introducing **stochastic perturbations** of the equation of state to represent the associated model uncertainty. Assimilation experiments are designed using **altimetric data** from past and on-going missions (Jason 1, Envisat but also SARAL/Altika missions) to better control the Gulf Stream circulation, focusing on frontal regions which are predominantly affected by the non-resolved dynamical scales. An ensemble based on such stochastic perturbations is then produced and evaluated using the model equivalent along-track altimetry observations. These three elements (stochastic parametrization, ensemble simulation and **4D observation operator**) are used together to perform, for the first time, optimal 4D analysis of along-track altimetry over 10-days windows. In this poster, we show the statistical properties of the produced ensembles: dispersion analysis, and reliability through the rank histogram and the RCRV.

STOCHASTIC PARAMETRIZATION OF MODEL UNCERTAINTIES

Using a set of T/S perturbations ΔT_i and ΔS_i to simulate the unresolved temperature & salinity fluctuations in the equation of state (Brankart 2013):

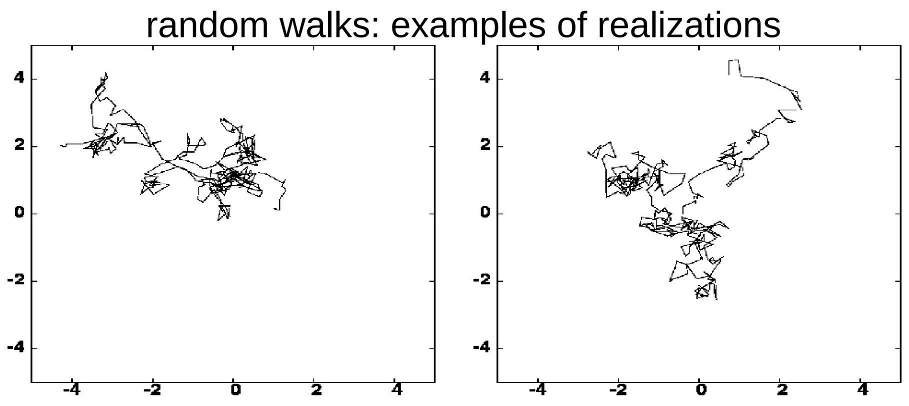
$$\rho = \frac{1}{2p}\sum_{i=1}^{p}\left\{\rho\left[T+\Delta T_i, S+\Delta S_i, p_0(z)\right] + \rho\left[T-\Delta T_i, S-\Delta S_i, p_0(z)\right]\right\}$$

- remarks: - no effect if equation of state is linear
  - proportional to the square of unresolved fluctuations.

Computation of the random perturbations ΔT_i and ΔS_i as a scalar product of the local gradient with random walks ξ_i :

$$\Delta T_i = \xi_i . \nabla T \quad \text{and} \quad \Delta S_i = \xi_i . \nabla S$$

random walks: examples of realizations



Assumptions

AR 1 random processes

Uncorrelated on the horizontal

Fully correlated along the vertical

10-day time correlation

Horizontal std : 1,4 grid point

Vertical std : 0,7 grid point

4D OBSERVATIONAL UPDATE ALGORITHM

SEEK algorithm with localization (Brasseur & Verron 2006), equivalent to LETKF (Bishop *et al* 2001).

- Ensemble mean $\overline{\mathbf{x}^f}$ and anomalies $\delta\mathbf{x}_i^f$:

$$\mathbf{x}_i^f = \overline{\mathbf{x}^f} + \delta\mathbf{x}_i^f$$

- Update of ensemble mean:

$$\overline{\mathbf{x}^a} = \overline{\mathbf{x}^f} + \sum_{i=1}^{m}\alpha_i\,\delta\mathbf{x}_i^f$$

- Update of ensemble anomalies:

$$\delta\mathbf{x}_i^a = \sum_{j=1}^{m}\beta_{ij}\,\delta\mathbf{x}_j^f$$

- Update ensemble:

$$\mathbf{x}_i^a = \overline{\mathbf{x}^a} + \delta\mathbf{x}_i^a$$

Coefficients α_i and β_{ij} computed as a function of
- innovation: $y^o - \mathcal{H}\mathbf{x}^f$
- observation error covariance: R
- observation equivalent of ensemble anomalies: $\delta\left(\mathcal{H}\mathbf{x}_i^f\right)$

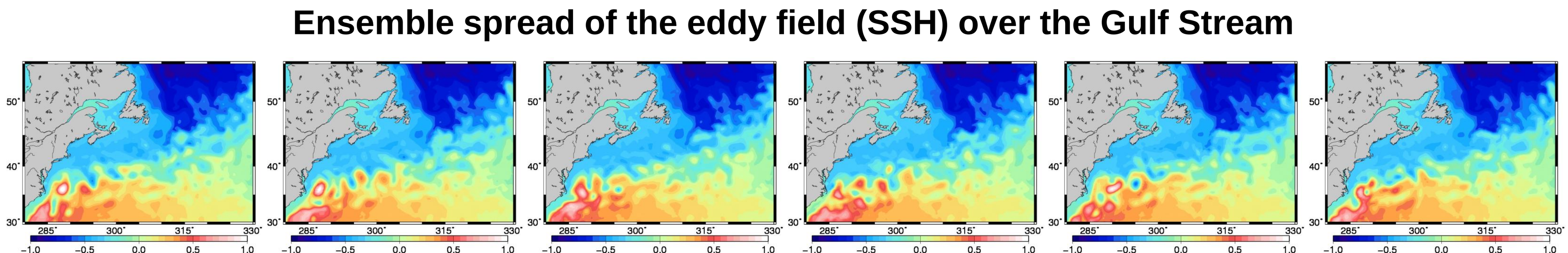
Observation equivalent $\mathcal{H}\mathbf{x}^f$ of ensemble mean and ensemble anomalies at appropriate time (4D).

Square root algorithm not requiring perturbations of the observations.

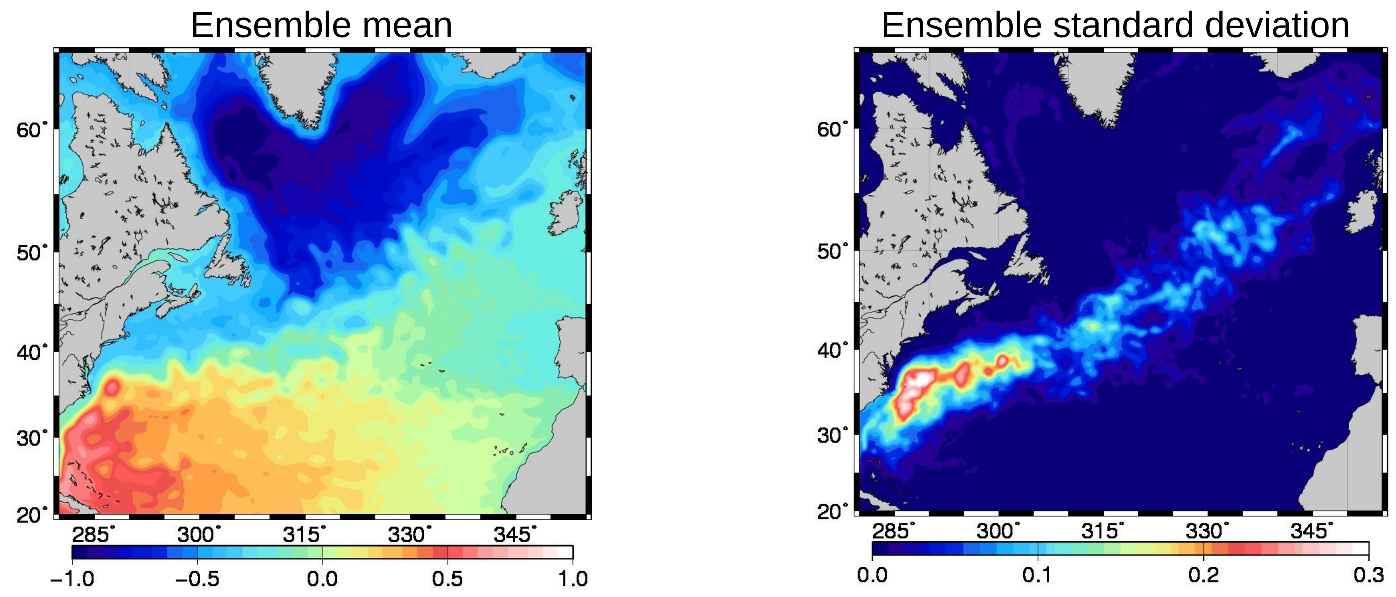
DESCRIPTION OF PRIOR ENSEMBLE

- 60-members ensemble produced by stochastic perturbations at 06/24/2005, starting from a free NATL025 unperturbed run (01/01/2005).

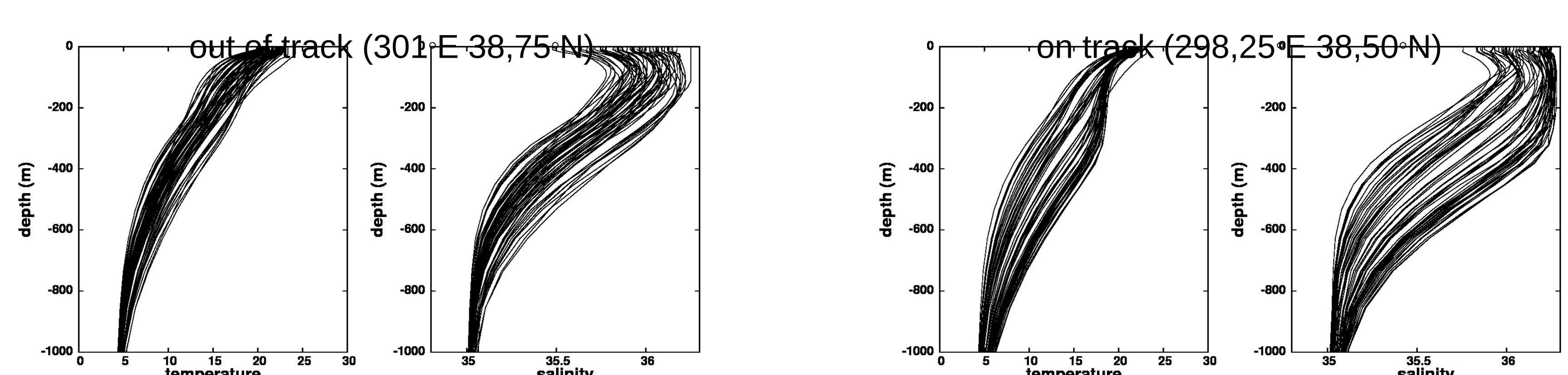
Ensemble spread of the eddy field (SSH) over the Gulf Stream



Ensemble mean | Ensemble standard deviation



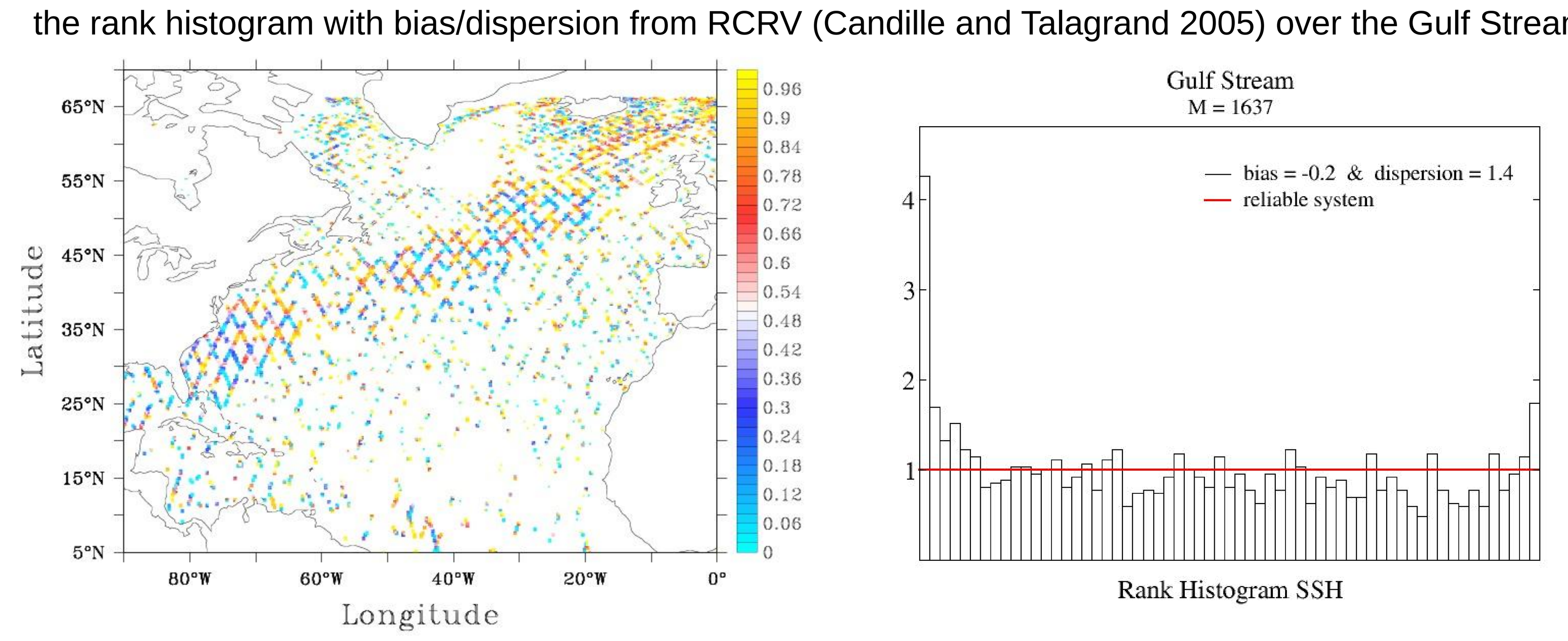
Spread of T/S vertical structure



Rank of the observation, altimetric data from Jason 1 mission, in the prior ensemble

and

the rank histogram with bias/dispersion from RCRV (Candille and Talagrand 2005) over the Gulf Stream.

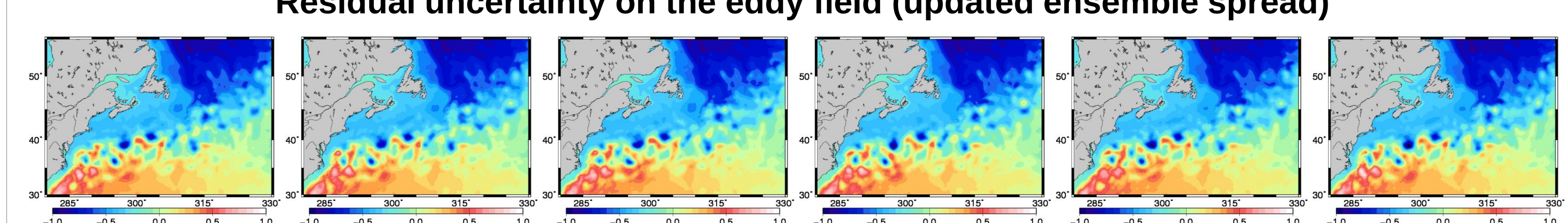


Summary: Over the Gulf Stream, the ensemble shows spread which is relatively well calibrated considering the observations along-tracks: 20%-negative bias and 40%-underdispersion.

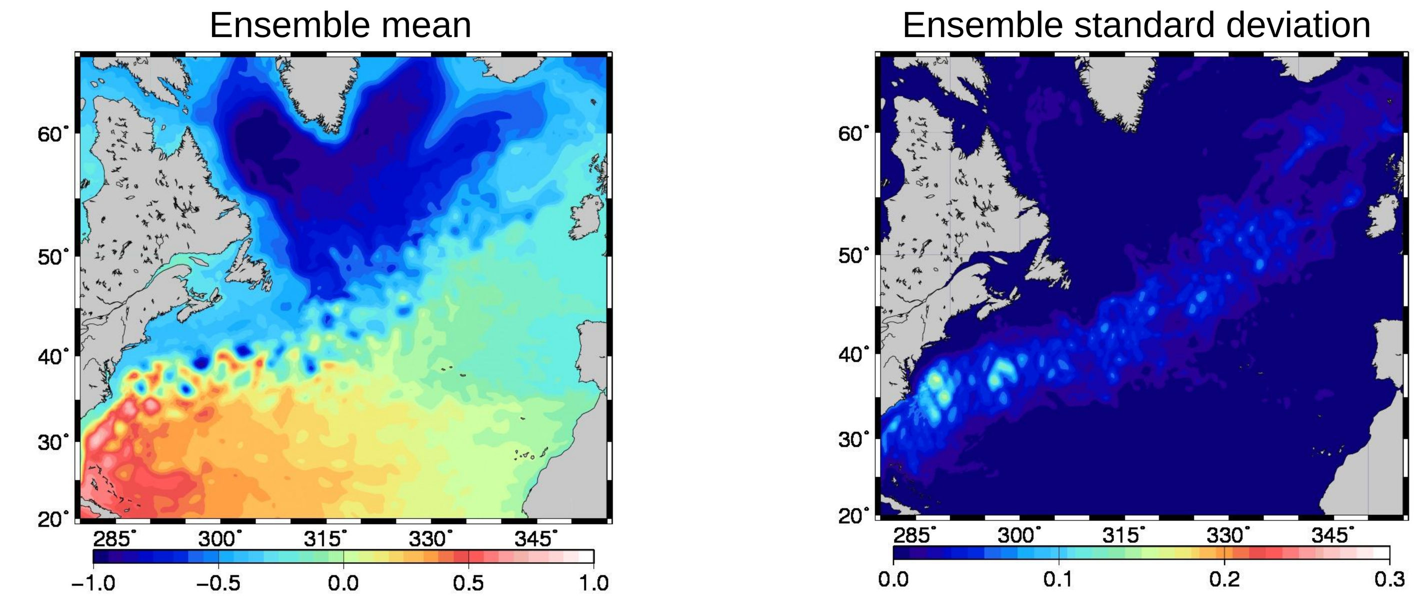
UPDATE OF 4D ENSEMBLE USING ALONG-TRACK ALTIMETRIC OBSERVATIONS

- SSH updated with Jason 1 and Envisat (same track as Altika) data over 10-day centered assimilation window (from 06/19/2005 to 06/29/2005).

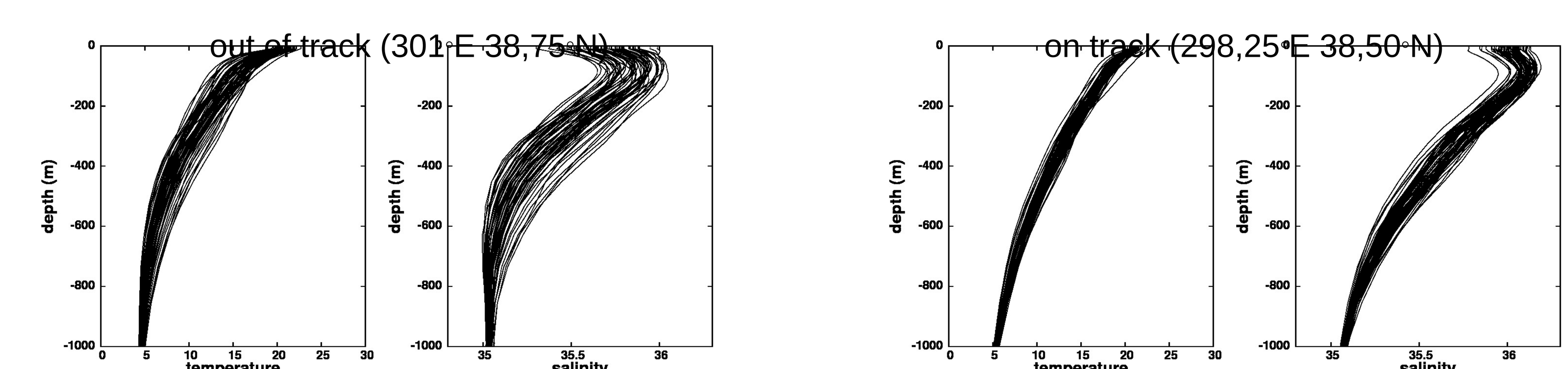
Residual uncertainty on the eddy field (updated ensemble spread)



Ensemble mean | Ensemble standard deviation



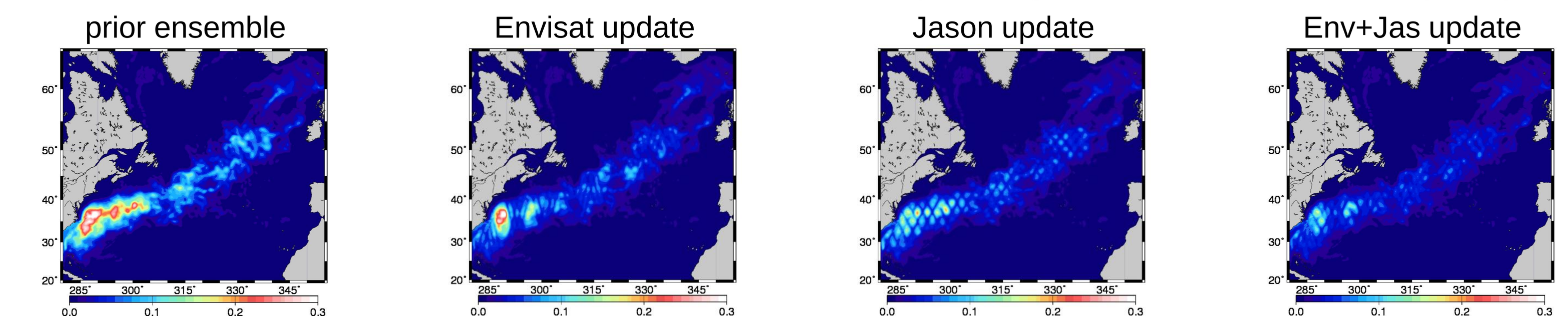
Updated T/S ensemble spread



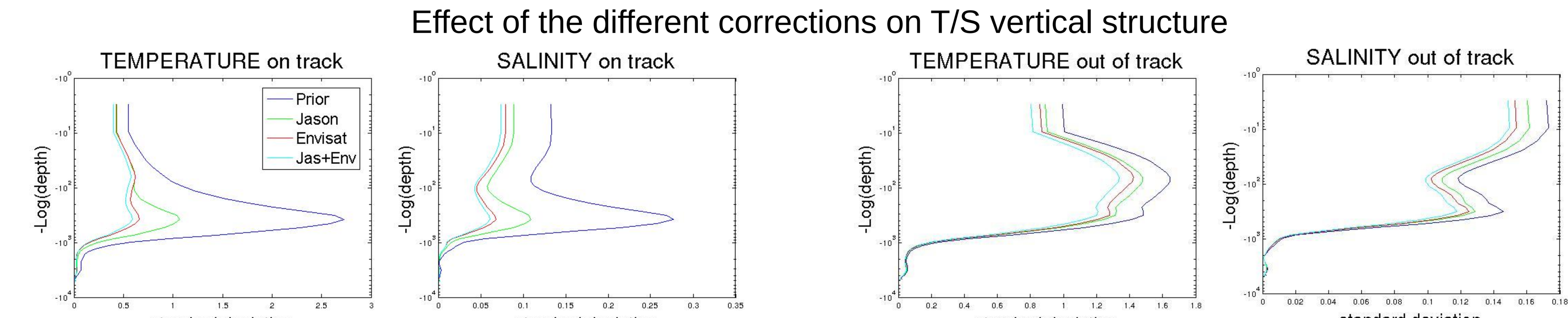
Summary: The update reduces the ensemble spread, SSH but also the T/S, especially along-tracks

SENSITIVITY TO SATELLITE SPACE-TIME SAMPLING

Reduction of the ensemble standard deviation depending on satellites data sets (SSH)



Effect of the different corrections on T/S vertical structure



Conclusion & perspectives: The core ingredients of a full 4D ensemble assimilation scheme with altimetric data are presented here . A prior ensemble is defined by stochastic perturbations of T/S in the equation of state in order to simulate the non-resolved scales of the Gulf Stream circulation. The ensemble then is updated with real altimetric data by a canonical square root algorithm but with 4D observation equivalents of the ensemble, meaning the background error covariance evolves with time over the assimilation window. The resulting ensemble spread is obviously reduces for the SSH, but also on T/S vertical structure. These promising preliminary results are leading to the definition of increments which are introduced in a IAU assimilation cycle. The production and the evaluation of this new assimilated ensemble is still in progress.

Acknowledgement: This work is a contribution to the OSTST project *Toward the Next Generation of Altimeter Data Assimilation for Physical Ocean and Marine Ecosystem Monitoring and Prediction* supported by CNES. Partial support from the European Community's Seventh Framework Program FP7/2007-2013 under grant agreements n° 283367 (MyOcean2) and n° 283580 (SANGOMA). The calculations were performed using NEC-SX8 from GENCI-IDRIS resources (project i20130111279).

References:
- Bishop H.C., B.J. Etherton and S.J. Majumdar, 2001. Adaptive sampling with the Ensemble Transform Kalman Filter. Part I: theoretical aspects. *Mon. Wea. Rev* **129** 420-436.
- Brankart J.-M., 2013. Impact of uncertainties in the horizontal density gradient upon low resolution global ocean modelling. *Ocean Modelling* **66** 64-76.
- Brasseur P. and J. Verron, 2006. The SEEK filter method for data assimilation in oceanography : a synthesis. *Ocean Dynamics* **56** 650-661.
- Candille G. and O. Talagrand, 2005. Evaluation of probabilistic prediction systems for a scalar variable. *Q.J.R.M.S.* **131** 2131-2150.