# THE CONTROL OF NON-LINEAR MESOSCALE OCEAN CIRCULATION THROUGH ALTIMETRIC DATA ASSIMILATION REVISITED USING A VARIATIONAL APPROACH

P.-A. Bouttier[1,2], E. Blayo[1], J. Verron[2], P. Brasseur[2] and A. Vidard[1]

Pierre-Antoine.Bouttier@imag.fr, Eric.Blayo@imag.fr, Jacques.Verron@hmg.inpg.fr

[1]: Jean Kuntzmann Lab., CNRS, INRIA and University of Grenoble, France; [2]: LGGE Lab., CNRS and University of Grenoble, France

## Abstract

We investigate the response of an ocean data assimilation (DA) system to different altimetric scenarios. The Incremental 4DVAR is applied to a primitive equation ocean model in an eddy-resolving configuration typical of the mid-latitudes. An important issue is to relate the space and time altimetric satellite sampling to the performances of the assimilation system, which also depends on the length of the DA window.

From our experiments with the incremental 4DVAR method, it appears that the spatial resolution of the observational satellite network is more important than the temporal resolution. For a $1/4^\circ$ model horizontal resolution, simulated tracks based on SARAL/AltiKA characteristics are more adapted to reduce efficiently analysis error than Jason-1-like tracks or both coupled networks. At higher resolution ($1/12^\circ$), the combinaison of both networks is necessary to reduce efficiently analysis error at smaller scales. However, SARAL/AltiKA simulated contains the most of the useful information for controlling these error scales.

## Context and objectives

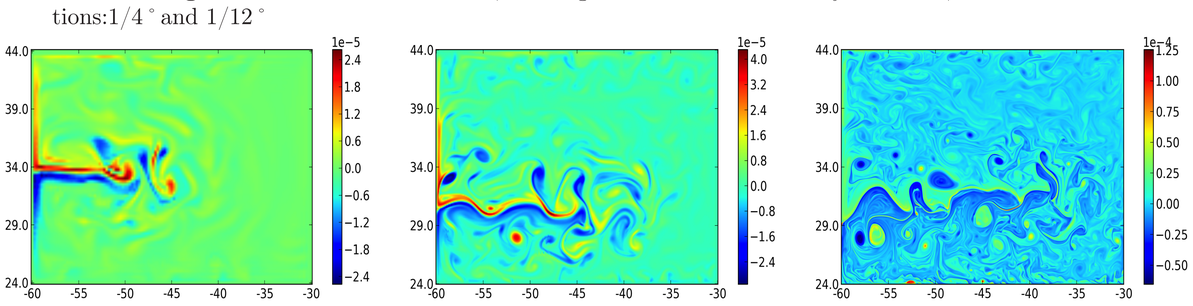
The present work takes place in the context of applying the 4DVAR DA technique to oceanic flows, in order to make an optimal use of altimeter data from various missions.The present work aims at investigating:

- The capability of the Incremental 4DVAR to cope with nonlinear ocean models
- The impact of the model horizontal resolution on the 4DVAR performances
- To explore the impact of various altimetric sampling (Jason-1 vs. SARAL/AltiKA) on incremental 4DVAR performances

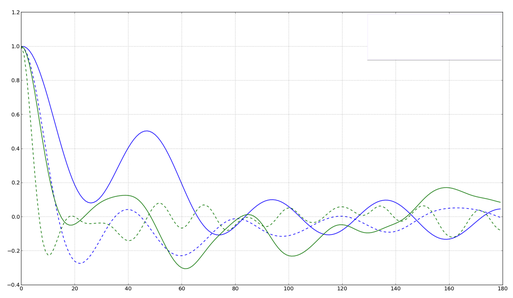
## Experimental approach

**Method and Strategy** As a first step towards more realistic cases, we consider in this study the simple test case of a double gyre circulation in a rectangular box, which mimics the typical behavior of an unstable mid-latitude jet.

**Model and configuration** NEMO ocean code, rectangular box of 3000 km by 2000 km, Two horizontal resolutions:$1/4^\circ$ and $1/12^\circ$



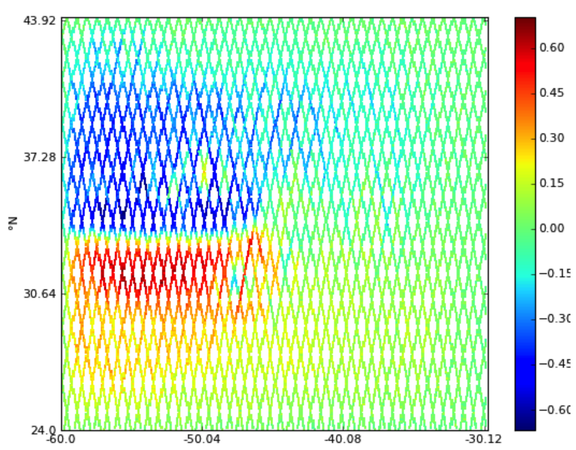
*Examples of surface relative vorticity fields at different horizontal resolutions: from left to right $1/4^\circ$, $1/12^\circ$ and $1/100^\circ$*



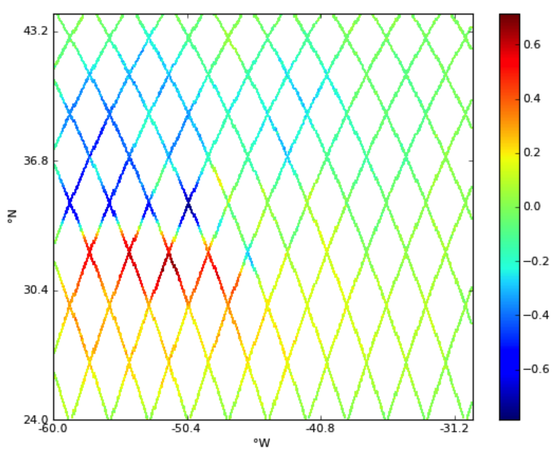
When the horizontal resolution increases, the non-linearity level also increases, as it is illustrated by the figure on the left.

*Decorrelation time (in days) of the configuration states, for the $1/4^\circ$ (in blue) and $1/12^\circ$ (in green)*

**Data** Our data are simulated from the model (twin experiments), with a 3 cm white noise error, and following SARAL/AltiKA and Jason-1 satellite orbits, illustrated by Figures below. SARAL/AltiKA orbits has a longer repetitivity period and higher spatial resolution (35 days and 70 km inter-track spacing at the equator) than Jason-1 (10 days and 300 km inter-track spacing at the equator).



*Example of SARAL/AltiKA simulated altimeter SSH measurements*

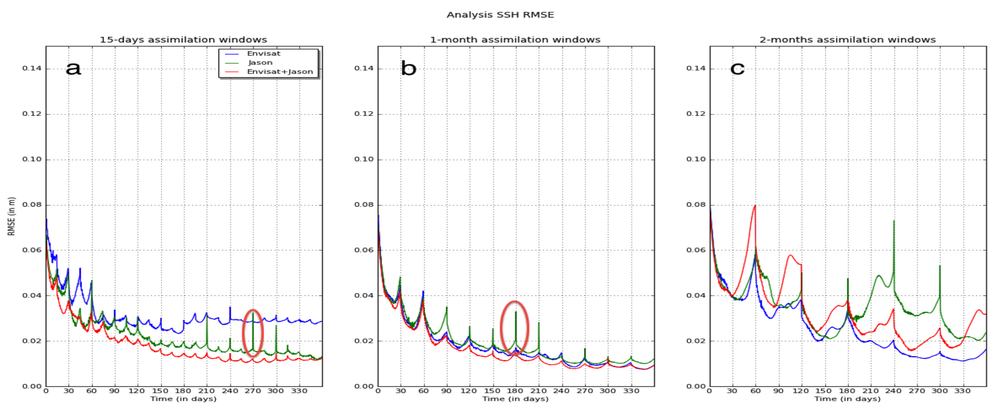


*Example of Jason-1 simulated altimeter SSH measurements*

According to these two kinds of tracks, we have studied three different scenarios : simulated SARAL/AltiKA data only, simulated Jason-1 data only, and both kind together.

## Altimetric networks and 4DVAR incremental: $1/4^\circ$ case

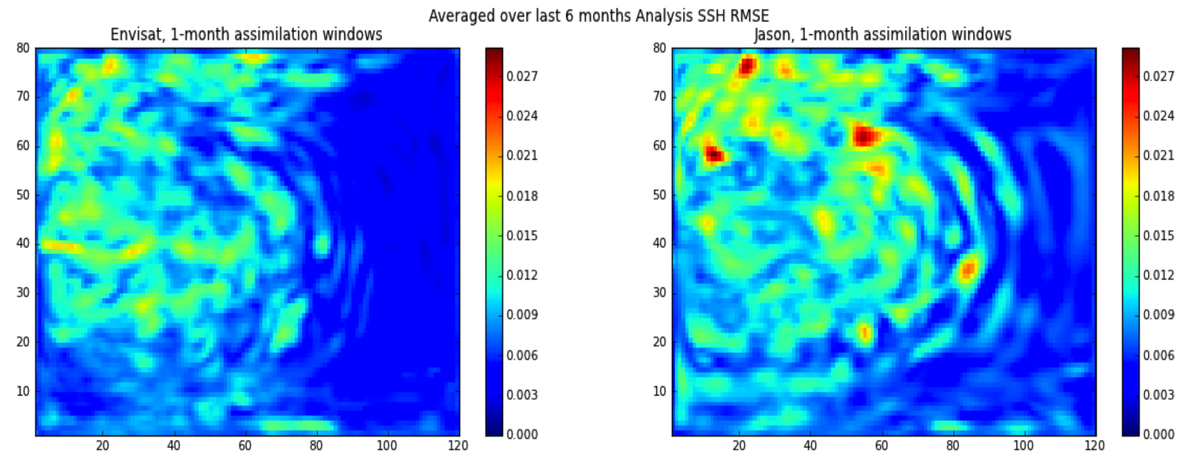
- For longer DA window, SARAL/AltiKA simulated tracks give a lower error level.
- For the longest DA window, taking both satellites into account degradates cost function conditionning, and give stronger error than considering only SARAL/AltiKA.




*Time evolution of spatially averaged analysis SSH RMSE, for the three altimetric scenarios, and for 15-day, 1-month and 2-month assimilation windows.*

## Altimetric networks and 4DVAR incremental: $1/4^\circ$ case (cont'd)

Figure below shows that the scales of principal analysis error structures fit with inter-track spacing, larger with Jason-1 network than SARAL/AltiKA network.

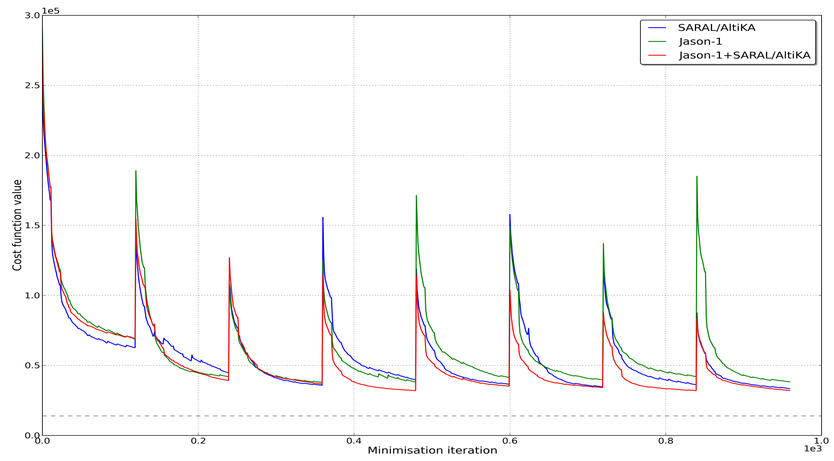



*Averaged analysis SSH RMSE fields, for the two altimetric scenarios : Jason-1 (left) and SARAL/AltiKA (right)*

Variational methods approach directly an optimal temporal interpolation. On the opposite, horizontal interpolation is mainly driven by the parametrization of the background error covariance matrix. Consequently, **for a given number of observations, it is better in the present case using an incremental 4D-VAR assimilation technique to increase the spatial resolution rather than the time resolution**.

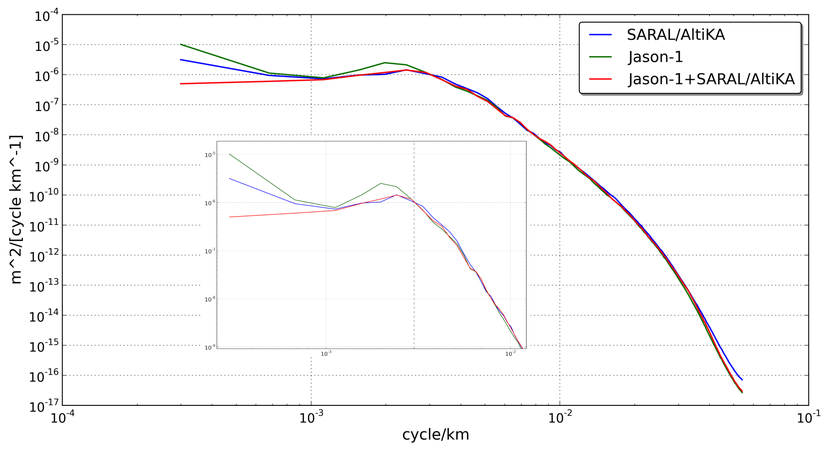
## Altimetric networks and 4DVAR incremental: $1/12^\circ$ case

When the model horizontal increased, minimisation is more difficult. As seen on the Figure below, inside each DA cycles, cost functions are not fully minimised. The poorest convergence is in the Jason-1 case. This result confirmed thus obtained with the $1/4^\circ$ model. The two other scenarios give comparable convergence behavior.




*Evolution of cost functions, during minimisation process, for 8 cycles with 1-month DA windows*

The Figure below shows that SARAL/AltiKA scenario reduces more efficiently analysis error until 300 km than Jason-1 scenario. However, both altimeters permit to control better the largest scales.




*PSD (in $m^2/cycle\ km^{-1}$) of SSH analysis error fields of three altimetric scenarios (Jason-1 in red, SARAL/AltiKA in green, both in blue) (x-axis in $cycle/km^{-1}$)*

The $1/12^\circ$ model contains more spatial and temporal scales, in the physical space than $1/4^\circ$ model, leading to an increasing level of non-linearity. The necessary information flow to control efficiently all those scales is increased. **Consequently, as the spatial model resolution increases, the observational sampling of both satellites (high temporal resolution with Jason 1 and high spatial resolution with SARAL/AltiKA) is required to obtain the best performances in the variational DA framework.**

## Conclusions

This assimilation system proved to be quite robust under different contexts for long DA windows. However, increasing horizontal model resolution slows the convergence of the minimisation algorithm.

For eddy-permitting model resolution, SARAL/AltiKA simulated tracks gives best results in terms of reduction of the analysis error. At higher resolution, combinaison of different altimetric networks, which have different sampling characteristics, is indicated to control a larger spectrum of the scales contained in the analysis error.

Further works will explore similarly the impact of the SWOT-like observational sampling on this variational DA system, for a $1/100^\circ$ model.

## References

[Cosme et al., 2010] Cosme, E., Brankart, J.-M., Verron, J., Brasseur, P., and Krysta, M. (2010). Implementation of a reduced rank square-root smoother for high resolution ocean data assimilation. *Ocean Modelling*, 33:87–100.

[Luong et al., 1998] Luong, B., Blum, J., and Verron, J. (1998). A variational method for the resolution of a data assimilation problem in oceanography. *Inverse Problems*, 14:979–997.

[Weaver et al., 2005] Weaver, a. T., Deltel, C., Machu, E., Ricci, S., and Daget, N. (2005). A multivariate balance operator for variational ocean data assimilation. *Quarterly Journal of the Royal Meteorological Society*, 131(613):3605–3625.