The SEABASS reference configuration of NEMO: a demonstrator of NEMO-ASSIM tools

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Abstract

Coupling a data assimilation (DA) system with a General Circulation Model as NEMO is a complicated task, due to the technical and numerical complexity of these software. To facilitate scientific research in Data Assimilation, NEMO provides NEMO-ASSIM components to interface NEMO core with any DA framework (variational or stochastic) : observation operator (OBS), increment application (ASM) et Tangent linear and Adjoint Models (TAM). However, those tools are also complex to take in hand.
In this work, we present the reference configuration for DA with NEMO, called SEABASS, that is an academic ocean model configuration typical of the mid-latitudes. We expose a few DA works already done with SEABASS and how they used NEMO-ASSIM tools. Some scientifical results obtained with various DA methods, based on SEABASS, will illustrate the relevance of this configuration.
We also show the reference demonstrator of NEMO-ASSIM components, based on SEABASS configuration. It performs a full-state inversion, based on the Incremental 4DVAR algorithm. Its main purpose is to expose how coupling simply a DA system with NEMO, using NEMO-ASSIM tools

Data Assimilation for dummies

The terms "Data Assimilation" (DA) designate the range of objective methods enabling optimal combination of observations, model simulation and error statistics, in order to reduce as much as possible the uncertainty of ocean state estimations involved in short-term predictions or more or less long-term reanalyses.
Mathematically, DA problem can be viewed as illustrated on the scheme 1.

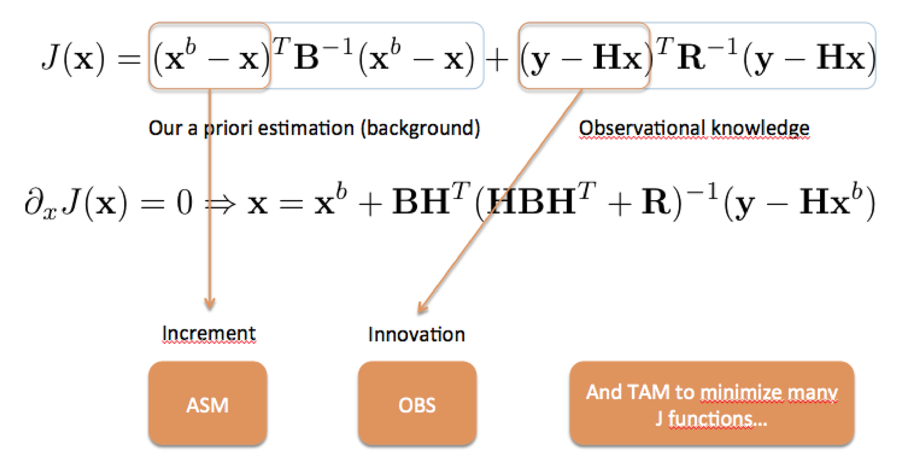

Figure 1: *Mathematical formulation of the DA problem and relations with NEMO-ASSIM components*

Briefly speaking, those two mathematical views of the DA problem correspond to two different categories of algorithms which can be distinguished to solve the DA inverse problems: the optimal control approach, most often based on the variational adjoint method and the stochastic methods mostly derived from the Kalman filter concept.

What is NEMO-ASSIM?

NEMO-ASSIM was initially established as a working group (members of CERFACS, CNRS, ECMWF, INGV/CMCC, INRIA, MERCATOR, MetOffice and NEMO System Team) involving experts in the development of data assimilation systems for operational and research applications. This group proposed a strategy to implement an assimilation component associated to the NEMO code in order to easily interface the ocean model configurations with a variety of Data Assimilation systems.
Three major components are integrated in the NEMO numerical core:

- **NEMO-OBS**: $\mathbf{y} - \mathbf{Hx}$ needs to be computed. This vector is usually known as the innovation vector, and is a direct product of OBS. OBS is developed by the UK Met-Office and allows to compute equivalent model for each observation, gathered in input files at the feedback NetCDF file format. It can manage quality control, and handle several types of observations, such as SLA, SST, profiles.
- **NEMO-ASM**: In most of the assimilation methods relevant to NEMO, the trajectory is controlled by introducing a correction $\delta \mathbf{x}$ to the model state. This correction, or increment is produced by the analysis step on variables linked to a control vector. The increment updates the model trajectory $\mathbf{x} = \mathbf{x}^b + \delta \mathbf{x}$ either directly, or in a gradual manner over a time period around the analysis date. This latter approach, usually referred to as the Incremental Analysis Updates (IAU). These increment application is done by the ASM component.
- **NEMO-TAM**: In variational DA methods, one minimizes a cost function that is a measure of the model-data misfit, and the adjoint variables are used to build the gradient for descent algorithms. Similarly the tangent model is used in the context of the incremental algorithms to linearize the cost function around a background control. Assimilation-wise Tangent-linear and Adjoint Models are mainly used for variational assimilation applications. However they are also powerful tools for the analysis of physical processes. More details can be found in [Vidard et al., 2014].

Those components allows to plug any assimilation scheme with NEMO numerical core.

SEABASS: A NEMO configuration for DA

To help DA users and developers to take NEMO-ASSIM tools in hand, a NEMO reference configuration for DA, called SEABASS (SEA Box for ASSimilation, is proposed. Here its main characteristics:

- It is an academic ocean basin double-gyre configuration. The rectangular domain of this configuration, extends from 24°N to 44°N and over 30° in longitude.
- Any horizontal resolution can be simply specified. For a 1/4° horizontal resolution, the grid contains only 121 points in longitude and 81 points in latitude.
- The ocean is sliced into 11 verticals levels, from surface to 4000 meters, described with a z-coordinate.
- Lateral boundaries conditions are frictionless and bottom boundary condition exerts a linear friction. The circulation is only forced by a stationary zonal wind.
- The circulation is only forced by a zonal wind. Lateral dissipation is performed on dynamics and tracers with a biharmonic diffusion operator. The vertical diffusion is constant.

More details about physical and numerical choices of this configuration can be found in [Cosme et al., 2010].

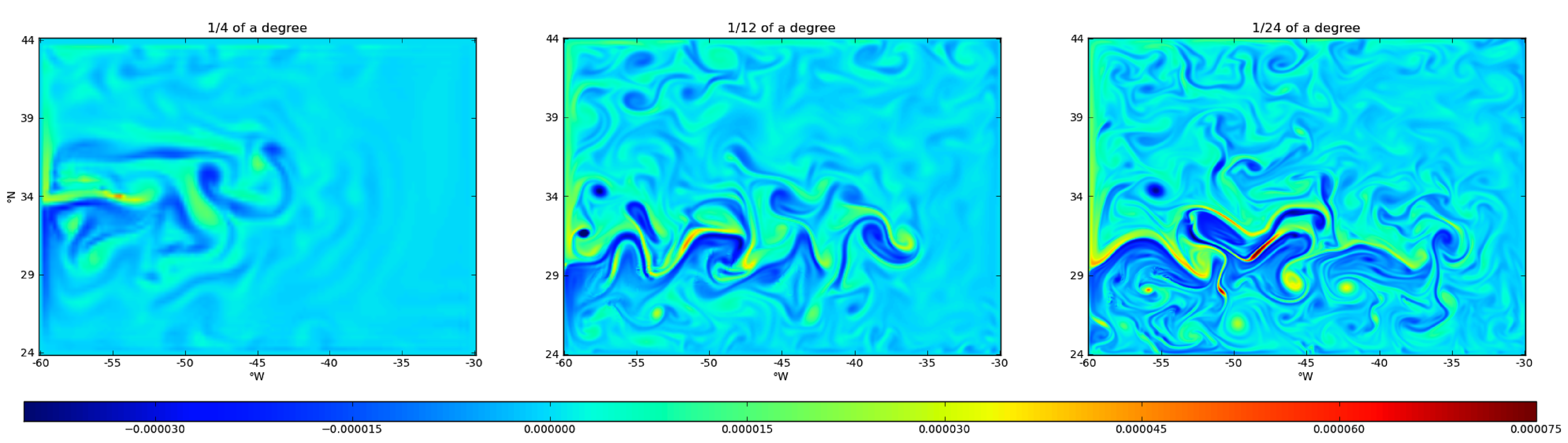

Figure 2: *Instantaneous relative vorticity fields, from the SEABASS configuration, taken at different horizontal resolutions (from left to right 1/4°, 1/12°; 1/24°)*

SEABASS is a compromise between simplicity and a good representation of non-linear dynamical processes, increasing with its horizontal resolution, as illustrated on the Figure 2.
From a practical point of view, this configuration presents many advantages for DA:

- easy to maintain across NEMO evolutions
- For variational DA, this configuration is fully differentiable, which ensures that Tangent and Adjoint Models do not contain approximations of the direct model
- In spite of its simplicity the SEABASS configuration enables the simulation of non-linear dynamics associated to the ocean circulation at mid-latitudes, which is considered as a challenging est case for conventional data assimilation methods.

SEABASS applications examples

Several DA methods have also already been studied and tested on this configuration:

- SEEK filter and smoother ([Cosme et al., 2010], [Yan et al., 2014])
- Variational DA methods, 3D-FGAT and Incremental 4D-VAR algorithms ([Boutttier et al., prep])
- Nudging and Back-and-Forth nudging ([Ruggiero et al.,])

SEABASS was identified as the "medium case benchmark" configuration in the FP7 SANGOMA project. Having reference results with various DA methods is crucial to promote SEABASS as a DA reference configuration.
Another important aspect of SEABASS is that it mimics the circulation of regions very well observed thanks to altimetry. This feature has been exploited in studies that show the impact of the observational dataset characteristic, illustrated in the

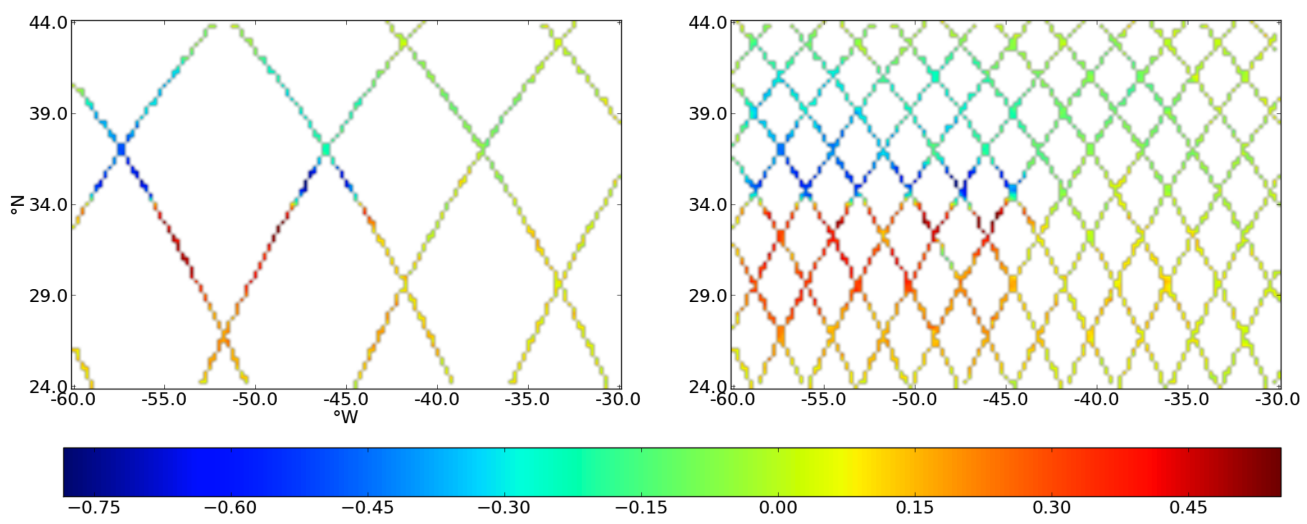

Figure 3: *Synthetic altimetric along-tracks, produced by Jason-2 orbit after 2 days (left) and 10 day (right)*

A demonstrator for NEMO-ASSIM tools

Why a demonstrator? NEMO-ASSIM tools are available, and they can be used to set-up DA systems with. However, as the NEMO numerical core, they does not remain trivial to take in hand for the users. To tackle this issue, we propose a demonstrator to help users:

- To understand the technical behavior of NEMO-ASSIM components
- To adapt their DA systems to NEMO-ASSIM interfaces
- To serve as a testbed for assessing the performance of new assimilation tools

We have chosen to implement first a full-state inversion algorithm.

Principle The full-state inversion principle consists in recovering an analyzed initial state given a "true" final condition $\mathbf{x}_T^t$ and an "background" initial condition $\mathbf{x}_0^b$. If we express this in term of variational formalism, this problem consists in minimizing this cost function:

$$J(\mathbf{x_0}) = \|\mathbf{y} - H(\mathcal{M}_{0\rightarrow T_f}(\mathbf{x_0}))\|_R \quad (1)$$

where $\mathbf{y} = \mathbf{x}_T^t$, $\mathcal{M}$ is the model operator (NEMO) propagating initial condition, H the observation operator and R a observational covariance error matrix. $\mathbf{y} - H(\mathcal{M}_{0\rightarrow T_f}(\mathbf{x_0}))$ is called the *innovation vector*. The minimization can be performed by a Quasi-Newton algorithm.

First, this demonstrator uses all NEMO-ASSIM components (TAM, OBS and ASM) and the SEABASS configuration. Its principle is relatively easy to understand and to take in hand. Finally, it is a first step that will be enriched with other applications examples, such as ensemble DA methods or characteristic vectors computation.

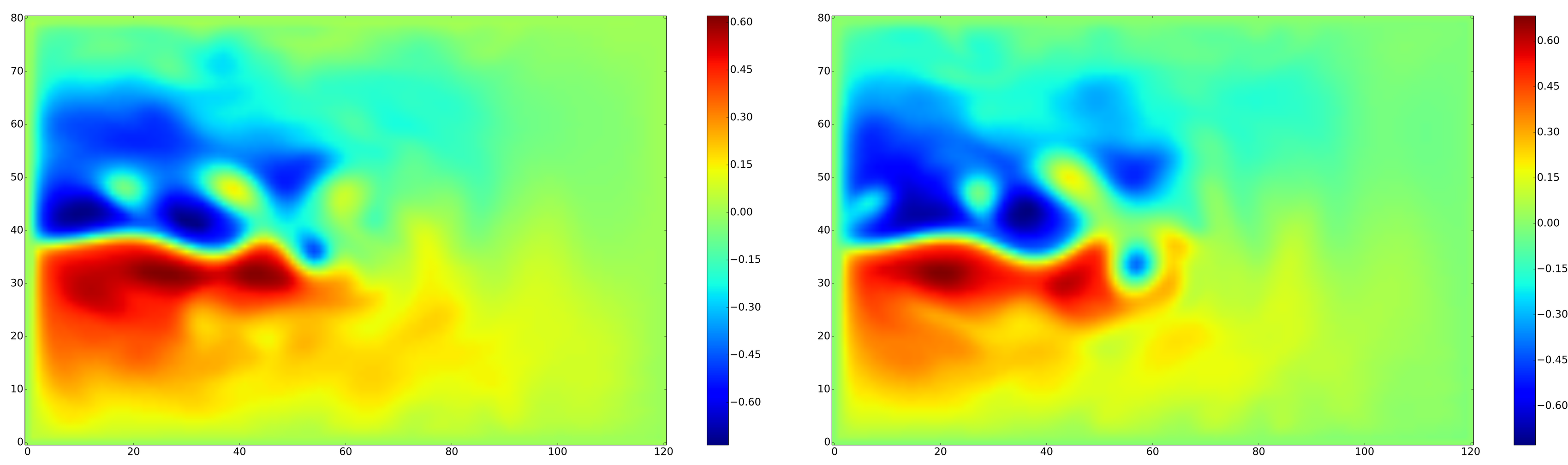

Figure 4: *SSH initial condition (left) (in meters) and SSH final condition (right) after 1 month of SEABASS4 integration.*

For the users, except a complete technical documentation with reference results given by this demonstrator, a background initial state and the true initial state will be provided (illustrated on the Figure 4). The observation file will be also included.

Conclusions

NEMO-ASSIM provides to users the necessary tools to plug any DA system with NEMO, that are currently used for research and operational oceanography. SEABASS, the reference configuration for DA with NEMO, ensures NEMO-ASSIM to propose reference DA results with NEMO, which can help to validate new developments. SEABASS is also easy to take in hand and to test a new DA system plugged with NEMO. Finally, The demonstrator that we propose helps users to understand NEMO-ASSIM components and show how to adapt their DA schemes to NEMO-ASSIM interfaces.

In the future, this demonstrator will be enriched with other application examples for NEMo-ASSIM components. We will continue to promote the potential of these tools through scientifical studies.

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