# Report of the 4th NEMO-ASSIM meeting

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## 1. Context and objectives

An initiative towards the development of an assimilation component within the NEMO code system was established in 2009, with the long-term objective of making assimilation tools for NEMO more readily available to the user community. Three meetings between experts engaged in developing data assimilation tools for the NEMO system and members of the NEMO System Team were held in Paris, on June 2009, January 2011 and January 2013. These meetings led to the definition of several priorities and to the development of several bricks of a NEMO assimilation component. Two important milestones were see the synthesis document “Options for development of a NEMO assimilation component”, 12pp, November 2009 and a reference paper describing the NEMO-ASSIM strategy and first results, published by Bouttier et al. (2012). This paper also describes the different NEMO DA components (OBS, ASM and NEMOTAM) which have been developed until now.

It clearly emerges from these meetings that the NEMO Assimilation initiative has already been successful, in particular in creating 3 components (OBS, ASM and TAM) that are now included in NEMO and that answer to actual needs of the users. It must be noted that a substantial part of these tools is also of interest for the modelling community for various scientific studies. However, since the previous meeting, the main recommendations from the NEMO Data Assimilation working group to the NEMO steering committee were to enhance existing tools and promote them to the NEMO community.  There was a lack of new perspectives for NEMO Data Assimilation development at mid and long terms.

Considering that it is now time to define a more ambitious perspective for the NEMO Data Assimilation developments in the future, the main objective of the 4th NEMO-ASSIM meeting was to revitalize the working group and identify new activities. To achieve this goal, new participants have been invited in order to complete our overview of DA systems working with NEMO and also to gather new ideas from these NEMO DA users or developers. As noticed at the last NEMO-ASSIM meeting, new DA initiatives with NEMO have emerged in the past two years, such as the FP7 SANGOMA project (which is largely based on NEMO configurations as test cases for new DA methods). Considering that, people from these initiatives have been invited.

This report summarizes the NEMO DA activities discussed in the presentations and extracts important outcomes from the discussion that were held during the meeting. The list of the meeting participants as well as the meeting program is given in the appendices.

# 2. Summary of the presentations

## 2.1 Operational centers

The first set of presentations was given by members of operational centers. Mercator-Océan, UK Met Office and CMCC were represented. They gave an overview of their on-going work regarding DA with NEMO and some aspects for their future directions. Without entering in details (presentations are available at this URL: insert URL here), we can notice several interesting points:

- Variational algorithms (mainly 3D-FGAT for now) are developed and used at UK Met-Office and CMCC.
- Mercator-Océan is planning to undertake a major revision of their DA system
- There is an strong interest in assimilating data in a coupled context for operational centers (ocean dynamic + sea-ice + biogeochemistry)
- For CMCC and Mercator-Océan, DA methods based on ensemble methods will be investigated in the next years.

UK Met Office mentioned their intend to simplify the NEMO-OBS code in 2015. Today, only UK Met Office among all represented operational centers is using the NEMO-OBS component

## 2.2 Research activities

The second set of presentations was given by researchers who develop DA activities with NEMO. These can be separated in two categories: DA systems working with NEMO, and innovative tools of interest to NEMO Data Assimilation.

First, three new DA systems which work with NEMO were presented:

- PDAF (Parallel Data Assimilation Framework), developed by Nerger and Hiller (2013). The assimilation kernel is based on several Ensemble Kalman Filter algorithms and a very small amount of changes in the NEMO code is required to couple it with PDAF. However, PDAF does not use NEMO DA component (OBS or ASM)
- EMPIRE, developed at University of Reading (UK) (see Leuween presentation for more details). The assimilation kernel of EMPIRE proposes Particular Filters and Ensemble Kalman Filters algorithms. It is planned to propose 4D-En-Var in the future.
- VERDANDI, developed by two INRIA teams. This DA system can perform various DA methods such as Ensemble Kalman filters, 4D-VAR (for which the adjoint model is required) and optimal interpolation.

One can notice, despite of different technical approaches, that these DA systems need a very
few changes in the NEMO source code. However, some developments in the NEMO code could facilitate the coupling between NEMO and external DA systems, as direct access to the innovation vector or the control vector as variables (routine argument).

Two other presentations have addressed innovative methods for data assimilation, in terms of tools and methodology:

- J.-M. Brankart showed how to simulate model uncertainties by a stochastic parameterization of NEMO variables coupled to an ensemble run generator. These tools are considered as very interesting for both modeling and data assimilation NEMO communities.
- S. Mueller exposed how the NEMO tangent and adjoint models (NEMOTAM) can be used to compute linear optimal perturbations (presentation not available for now). This reveals the interest of NEMO data assimilation tools for modeling communities.

# 3. Discussions

The afternoon discussion had three objectives:

- Gathering preliminary ideas to improve existing NEMO DA tools or to propose new functionalities to be implemented in NEMO. The goal here is not to prepare a list of recommendations for the NEMO community but to open short and mid term perspectives.
- Investigate how NEMO DA tools should be better promoted and exploited by different kinds of new users from both the assimilation and modelling communities.
- (Re)Defining the missions of the NEMO DA working group and an efficient organization to achieve them in the future

We summarize here the conclusions on these three topics.

## 3.1 Improvements of the NEMO DA component

### 3.1.1 NEMO DA tools as interfaces to external DA systems

NEMO DA components (OBS, ASM and NEMOTAM) have been implemented in the NEMO core because **they are essential interfaces to external DA systems.** It has been pointed out that these components could be very useful to many DA systems (including those exposed during the meeting) but are **currently underexploited.**

Currently the strategy of NEMO DA tools is to work with files for NEMO inputs and outputs (e.g. observation and model equivalent files, increment file). It has been noticed that for many DA systems, **it is more efficient (technically and computationally) to give access to innovation and control vectors as a code variable** more than stored in NEMO output files. It seems reasonable and feasible to give the choice to the users to access them by file or by variable.

### 3.1.2 Specific improvements by tools

Some specific improvements and pending issues for each tools were suggested. These are listed here below.

Regarding the observation operator, **NEMO-OBS**:

- As we already said, it could be useful in some cases to give access **to model equivalent as a code variable** rather than in a output file.
- UK Met Office has announced his willingness to **simplify the NEMO-OBS code** this year, which seems to be necessary for many reasons: e.g. to make it easier to take in

hand, to add new types of observations. This simplification will consist in a first step in keeping only one input and output file format and removing duplicated code.
- For a few types of observations, the feedback format file (which is a standardized NETCDF format especially for OBS, in input and output) might be ill-suited. The format is designed for point wise observation but for structured observation, with very dense spatial sampling (such as image for example), it leads to a lack of computational efficiency. No solution has been proposed but this issue must be addressed in the future.

Regarding the increment application operator, **NEMO-ASM**:
- It was suggested to add more modularity in the ASM code to add easily new variables that can be corrected (for biogeochemistry for example). Another application of this code design is also to add easily new IAU functions.

Regarding the Tangent linear and Adjoint models, **NEMOTAM**:
- It would be beneficial to have **corresponding representations of a sea-ice model available in the non-linear, tangent-linear and adjoint model version**. First, It could be a quite simple model, much simpler than the usual configuration of LIM2 or LIM3. For example, a first step could be an extremely simple configuration of the standard sea-ice model in NEMO such as a differentiable version of a one-layer and single-ice category model.
- Adding **Restart facility for the tangent-linear and adjoint models** will be beneficial for different applications. This would provide more flexibility for applications that require a high amount of computational resources. It should facilitate the implementation of a checkpointing scheme that would massively reduce the extremely large storage requirements for long model trajectories at the expense of some redundancy in running the non-linear model. And finally, it will be useful to facilitate testing and validating developments in NEMOTAM.
- **The integration of the ASM functionality in NEMOTAM** would be useful to directly output assimilation-increments from NEMOTAM in a consistent way.
- Exploring the possibility to apply **automatic differentiator to the NEMO code** will be a major step for inverse problem applications with NEMO. Currently, the TAM hand-coded approach avoids to apply easily parameter control or sensitivity analysis methods (however, this approach ensures a computationally efficient code). The automatic differentiation will lead to a large range of applications of interest for both modelling and assimilation communities.

### 3.1.3 New NEMO DA tools

It was announced that the Brankart **stochastic parameterization approach** (see J.-M. Brankart presentation) will be implemented in the NEMO core in the next month, for the 3.6_STABLE NEMO version.

Aside from that, **the functionality of generating ensemble simulation** was discussed. The main idea is to propose in the NEMO core a way to generate easily an ensemble and to manage outputs for such a run. Such a functionality might be useful for new users who need to perform ensemble simulation and who are not familiar with the NEMO environment.

However there are many ways to generate an ensemble. Those ones chosen for NEMO might not cover the entire spectrum of ensemble generation. But it was noticed that the use of such a module is not mandatory for the users and they can apply their own ensemble generation methods. Moreover, **a standard ensemble generator will provide also the management environment for ensemble run.**

## 3.2 Exploitation of the NEMO DA component

The second point of the discussion was about the need to encourage more extensive use of NEMO DA tools. The main remark about this topic is the lack of visibility of NEMO DA component. This was confirmed during the day by the fairly low use of these tools by the participants of the meeting.

**The implementation of a demonstrator based on a reference configuration for DA** (called SEABASS) is planned in the next month. This will be a first step to show simply how technically NEMO DA tools could be used.

Based on this reference configuration, it was proposed **to establish a catalog of various DA systems** that can be easily interfaced with NEMO. There are two objectives for such a list:

- To show how to couple NEMO with very different DA systems
- To provide reference results useful for users to make preliminary tests of their own DA systems

This catalog could be hosted on the NEMO website, with links to external DA websites, explaining how to set up them with SEABASS configuration.

## 3.3 Future organization of NEMO DA working group

The final point on the discussion was about the NEMO DA working group organization.

First, the NEMO development context was briefly recalled. Each year, NEMO consortium members establish a working plan for the next year, based of their needs and also different NEMO working groups (including NEMO DA working group). This workplan is approved or amended by the NEMO steering committee at the end of the year.

One can notice that until now, the NEMO-ASSIM meeting was organized every two year with a large number of participants. This scheduling is not in phase with NEMO development process, while the NEMO community is expecting recommendations from the NEMO DA working group each year. In addition it is difficult for a large group to work efficiently and make useful recommendations to NEMO system team.

In order to work more efficiently and identify more useful recommendations to the NEMO consortium about DA with NEMO, it was proposed:

- **To reconsider the terms of reference** for the NEMO DA working group
- To revise the membership to the **working group** (between 5 to 10 people) in phase with the new terms of reference
- To revise the scheduling of activities consistently with the other NEMO working groups in order to establish the workplan for the next year.

However, **the NEMO-ASSIM meetings are always relevant**, so it is proposed to keep this format punctually to enrich our view of the DA activities around NEMO.

## 4. Conclusion

The 4rd NEMO-ASSIM meeting was successful in many aspects.

In inviting new people outside the traditional NEMO-ASSIM perimeter, new ideas about NEMO DA tools or NEMO-ASSIM organization have clearly emerged. That reveals that a real dynamic raises up around DA activities with NEMO.

The NEMO DA working group will be precisely defined this year to work optimally and make relevant recommendations regarding data assimilation to the NEMO community. Pierre-Antoine Bouttier will propose terms of reference for the working before the end of this semester.

Technical and scientific suggestions and ideas emitted during this meeting will be very precious to help the NEMO DA working group in its missions. In Appendix C, there is a table of identified possible tasks for future developments concerning NEMO DA components.

This meeting was also the transition in the head of the organization of NEMO-ASSIM from Eric Blayo to Pierre-Antoine Bouttier. We thank Eric for all the work done during the six past years.

# Appendix

## A. List of participants

Eric Blayo (LJK, Université de Grenoble)
P.-A. Bouttier (OSUG/LGGE, CNRS)
Julien Brajard (LOCEAN, CNRS)
J.-M. Brankart (LGGE, CNRS)
Pierre Brasseur (LGGE, CNRS)
Nicolas Claude (LOCEAN, CNRS)
Emmanuel Cosme (LGGE, Université de Grenoble)
Keith Haines (University of Reading) Daniel Lea (UK Met Office)
Simon Mueller (NOCS)
Lars Nerger (Alfred Wegener Institute)
Andrea Storto (CMCC)
C.-E. Testut (Mercator-Océan)
Maria Valdivieso (University of Reading)
Peter Jan Van Leeuwen (University of Reading)
Sanita Vetra-Carvalho (University of Reading)
Arthur Vidard (LJK, INRIA)
Yajing Yan (LISTIC, Université de Savoie)

# B. Agenda

**Introduction (9h00 – 9h30)**

- Welcome presentation (Eric Blayo) (9h00 - 9h15)
- NEMO-ASSIM achievements: What has been achieved during the past five years? (P.-A. Bouttier) (9h15-9H30)

**DA system from NEMO partners (9h30 - 10h30)**
(20 min presentation + questions for each)
Presentation from NEMO partners about their DA systems. It could be focus on the following questions:
- What scientifical and technical choices have been made? - Characteristics/specificities of DA systems
- Perspectives/options about their evolution
Pressentation from :

- CMCC, Andrea Storto
- Mercator Océan, C.-E. Testut
- UK Met Office, Daniel Lea

**Additional DA initiatives with NEMO (11h00 - 12h40)**
Extending NEMO for ensemble data assimilation on supercomputers with the parallel data assimilation framework PDAF, Lars Nerger (Alfred Wegener Institute)
Time-Offset Data Assimilation with NEMO: A Tool for Ocean Predictability Studies, Simon Mueller (NOCS), Florian Sévellec
Verdandi framework and NEMO, Julien Brajart (LOCEAN, CNRS), Nicolas Claude
Coupling EMPIRE and NEMO, Peter Jan Van Leuween (University of Reading), Sanita Vetra-Carvalho
Explicit simulation of uncertainties in NEMO, Jean-Michel Brankart (LGGE, CNRS)

**Discussion (14h00 - 15h30)**
Following the morning presentation, a discussion will be organized around these topics:
- Identification of necessary tools to enrich NEMO platform regarding data assimilation
- Further investigations that have to be done by NEMO-ASSIM working group - Definition and composition of the NEMO-ASSIM group core (to maximize its efficiency)

**Conclusion (P.-A. Bouttier) (15h45 - 16h15)**

## C. Possible future developments

Future developments that could be done in the future are listed in the table below. The future NEMO DA working group will have to prioritize those tasks and identified precisely needed resources to carry them out. The tasks in italic are already ongoing.

| NEMO DA Component | Tasks<br>(the order is irrelevant here) |
|---|---|
| **ASM** | T1. Add correction for new variables (biogeochemistry)<br>T2. Add new IAU functions |
| **OBS** | T1. Give access to model equivalent vector as a code variable that can be passed as argument through extermal routines.<br>T2. Rethink the feedback file format to handle efficiently structured observations, very dense in space or/and in time (e.g. SWOT products)<br>T3. Simplify the OBS code |
| **NEMOTAM** | T1. Add the representation of a sea-ice model in TAM (which can be a simplified model than the non-linear model)<br>T2. Add restart facility for the tangent linear and adjoint models.<br>T3. Integrate ASM functionality in NEMOTAM<br>T4. Explore the possibility of applying automatic differentiator to NEMO |
| **New tools** | T1. Add a stochastic parametrization module<br>T2. Add the functionality of an ensemble generation and ensemble run management. |
| **Valorization** | T1. Promote a reference configuration for Data Assimilation with NEMO<br>T2. Make a catalog of various DA systems that can be easily interfaced with NEMO. |