SANGOMA: Stochastic Assimilation for the Next Generation Ocean Model Applications EU FP7 SPACE-2011-1 project 283580

Final report

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Chapter 1

Summary

1.1 How to use this document

The present document is meant to provide a quick overview of the main achievements of the SANGOMA project and is not intended to include all relevant or detailed information from the individual reports on deliverables. It contains pointers to the most important deliverables for further reading.

1.2 Project objectives

The objectives and expected impacts from the project description did not change during the project evolution and read

> SANGOMA will provide new developments in data assimilation to ensure that future operational systems make use of state-of-the-art data-assimilation and related analysis tools. We are a European network of expert teams in advanced data assimilation. In the project we will extend existing modular data assimilation systems that have high flexibility in type of ocean model and assimilation method. Following specific design rules, new modules can be used in different modular systems. The systems will allow for efficient operational testing of the latest data assimilation methods, and quick comparison of assimilation methods for operational use. Furthermore, we will develop and implement modules that objectively determine the impact of existing and new observation types. This dedicated web portal will provide access to validated products, including documented performances on a variety of test cases. Consolidated versions will be made available to the science community and Marine Forecasting Centres with indications on best practice implementation. Workshops and summer schools on advanced assimilation methods and modular systems will ensure fast and efficient training of next generation oceanographers, ensuring world-leading operational oceanographic products for costumers and decision makers.
>
> The developments of SANGOMA will also serve costumers of MyOcean products, which is the first European project dedicated to the

implementation of the GMES Marine Core Service for ocean monitoring and forecasting. For this purpose, we will concentrate on data-assimilation methods that deliver probabilistic information on the products. To this end, existing ensemble methods will be included and new methods that allow for nonlinear and non-Gaussian systems will be developed.

1.3 Achievements

- WP1: The planned harmonization of data models and interfaces was not easy *a priori* and an "Keep it simple and short" approach was chosen. The objective has been achieved and, interestingly, the defined standards proven adequate after the fact, including for the advanced EWPF (Equivalent Weight Particle Filter) implementation.

- WP2: A nice collection of tools was elaborated with a complete set of examples. Particularly diagnostic tools with simple and advanced techniques are of wide interest. Also a common framework for a series of variants of EnKF (Ensemble Kalman Filter) was provided as a starting point for newcomers in data assimilation.

- WP3: Nice reviews and presentations of the EnKF variants in a coherent framework and terminology were synthesized. New theoretical methods were developed and tested, from which two (EWPF+Anamorphosis) were implemented into toolboxes with SANGOMA standards.

- WP4: It includes benchmark definitions (taken up by other groups outside of SANGOMA) with new metrics, in particular probabilistic metrics for ensemble approaches.

- WP5: Realistic applications with new data types were implemented and analyzed.

- WP6: Disseminated the results and achieved a strong scientific output.

Chapter 2

Objectives and achievements

2.1 WP1: Harmonization

This workpackage aimed at standardizing assimilation tools and file formats for easier exchange and use both by project partners and other data assimilation experts. The first year has been focusing on

- analysing the different toolboxes currently in use (content, data model, calling interfaces, etc.),
- defining an initial list of exiting tools from those toolboxes to be shared,
- defining a data model and calling interface for SANGOMA tools.

A crucial point was the definition of data models and calling interfaces. Here, the adopted solution was to keep them simple in order to allow for rapid use of the tools by non specialists in advanced programming methods. Furthermore, the broad range of interfaces and programming languages used in the existing toolboxes made necessary a common denominator, leading to the following:

- for data exchange via files: use of netCDF files in CF compliant form. As the format allows for some variants, the general strategy is to "keep it simple" and to provide output files in a similar form than input files (even if not perfectly fitting CF conditions as is the case for some model outputs). Also version 3 features of netCDF are to be preferred over version 4 to enhance backward compatibility. Finally, ensembles will be treated by working on a collection of files instead of a single big file.
- for data exchange in memory (subroutine call): Use of basic FORTRAN structure `arrays`. No derived types are allowed (too much programming overhead in filling or adapting data types). For more complex interfacing or data structures the `call-back` approach has to be used. Example: if the observational error variance matrix $\mathbf{R}$ is non-diagonal and a tool needs to evaluate $\mathbf{R}\,\mathbf{y}$, the interface of the tool must include a call-back function which when called with argument $\mathbf{y}$ returns the product $\mathbf{R}\,\mathbf{y}$. In this case, in the call-back program more complex (system specific) structures can be used without the need to define complicated interfacing in the SANGOMA tools. C-binding specifications are also provided.

```
module sangoma_callback

    use, intrinsic :: ISO_C_BINDING
    use sangoma_base, only:REALPREC, INTPREC
    implicit none

contains

   subroutine some_operation(x, n, f_callback) &
              bind(C,name="callback_some_operation")

      use, intrinsic :: ISO_C_BINDING
      implicit none

      integer(INTPREC), value, intent(in) :: n
      real(REALPREC),          intent(in) :: x(n)

      interface
         subroutine f_callback(x,n) bind(C)
            use, intrinsic :: ISO_C_BINDING
            use sangoma_base, only:REALPREC, INTPREC

            integer(INTPREC), value, intent(in) :: n
            real(REALPREC),          intent(in) :: x(n)
         end subroutine
      end interface
```

The proposed formats and interfaces defined in the first reporting period were well accepted (internally and externally to the project, as proved by the survey) and implementation started. Only minor details regarding the definitions remained to be clarified and were discussed at the second progress meeting:

F90/F77 : As legacy of F77 is still important it was decided not to force people to use .F90 interfaces and keep things as simple as possible. For Fortran 90 users, it would be useful to provide a SANGOMA module, so that the compiler can automatically check if all mandatory parameters are present and have the correct type. Partners investigated a way to provide a Fortran 77 library and a Fortran 90 module without duplicating the code base.

Single/double : some special handling is needed when interfacing with BLAS/LAPACK libraries when different precisions are used. As we cannot serve all situations and as users will generally optimize anyway the codes (memory/speed) when necessary it is decided to focus on the readability of the codes and examples provided with the codes rather than on fully flexible codes with selectable precision. Therefore double precision is retained as reference for SANGOMA.

Storage ordering : The memory storage of arrays (as specified in the common data specification) is column-major (which is used in Fortran and Matlab/Octave). Row-major languages such as C and Java need to change the order of the indices. For performance reason, no explicit memory reordering is performed. The adopted approach is equivalent to the one used in the NetCDF library where the order of the dimensions in a C program is reversed compared to the order of dimensions in a Fortran program.

The specifications have been presented in the MyOcean Science days followed by an on-line survey http://www.surveymonkey.com/s/ZX3P9D8. The specifications found a large positive feedback in the DA community as well as the advisory board.

The main deliverable of WP1 is therefore DL1.3. The other deliverables reflect the process of tool selections for inclusion in the common toolbox during the project life. The final outcome of this process is highlighted in the tool descriptions of WP2.

2.1.1 Deviations from DOW

None

Highlight:
The partners found a common approach despite using quite different data models at their institutes. The adopted internal standard did not need a revision during the project live and also allowed to encompass the case of the advanced Data assimilation tool (EWPF) coupled to the different DA toolboxes using the defined SANGOMA standards and interfaces. For technical details see DL1.3.

2.2 WP2: Sharing and collaborative development

This workpackage aimed at sharing tools in a collaborative way using standards set up in WP1.

Technically, the sharing was done via a server with version control. The SANGOMA project was registered on `http://sourceforge.net/projects/sangoma/` as it allows not only sharing of files but also easy setup of discussion forums, download procedures etc. All SANGOMA scientists have registered and are allowed to upload changes (commit of software changes). The site not only contains assimilation-related software but also `html` files for the web server and document templates so that each partner was able to easily contribute.

Within WP2 of SANGOMA, a collection of tools of general interest for data assimilation applications was prepared. These tools provide additional functionality outside of the core of the different tool boxes for data assimilation.

The tools can be categorized as follows:

- **Diagnostic tools**: These tools provide functionality to perform diagnostic operation for data assimilation applications. For example, the efficiency of assimilation techniques can be assessed and statistics significance tests can be performed.

- **Perturbation tools**: These tools allow the user to generate perturbations with prescribed properties in order to generate ensembles of model states or to perform perturbed ensemble integrations.

- **Transformation tools**: Assimilation algorithms that base on the Kalman filter assume Gaussian distributions for optimality. These tools provide functionality to perform preliminary transformations of variables or ensembles to improve the performance with non-Gaussian distributions.

- **Utilities**: Tools of this category provide additional functionality. Examples are tools for efficient manipulations of sparse matrices or the treatment of particular observation types.

- **Analysis steps**: Tools to compute the analysis step of an ensemble data assimilation method.

The release V0 of the SANGOMA tools represented a collection of tools that exist among the partners of SANGOMA. They were not yet adapted to the final standard interface structure, which is documented in the Deliverable D1.5. The following release V1 included tools that are adapted to the standard data model and interface structure. Both tools from the V0 release as well as additional tools were included. All tools were independent of the particular data-assimilation framework and should be usable with any other implementation of data-assimilation algorithms. Next to the documentation in this document, the tool release V1 also included examples on how to use a particular tool.

The final release V2 of the SANGOMA tools extended the collection of tools. The implementation work focused on diagnostic tools. However, it was also decided to add the analysis step of several variants of ensemble Kalman filters. With this, a user can also compute an analysis step using some ensemble of model states and a set of observation. These analysis steps are simplified compared to those implemented in the different available tools boxes. For example, they don't provide parallelization and dynamic allocation of internal arrays. With these simplifications, the tools are usable for moderately-sized problems (e.g. state dimensions of $O(10^5)$), but for larger systems and for higher efficiency, we recommend to use one of the data assimilation toolboxes that have been described in DL1.1 of SANGOMA.

The tools release package can be downloaded from the project web site at `http://www.data-assimilation.net/Tools/`. In addition, the collection of tools is available at Source Forge at `http://sourceforge.net/projects/sangoma/` where it will remain available after the end of the SANGOMA project.

2.2.1 Overview of tools

Diagnostic Tools

Fortran

sangoma_CheckEnsSpread	Compute ensemble spread and deviation of ensemble mean from an input state
sangoma_CheckNormality	Anderson-Darling Test to check normality of a sample
sangoma_CheckWhiteness	Check whiteness of innovations
sangoma_CompareObsDiag	Compare observation-space diagnostics
sangoma_ComputeBRIER	Compute the Brier skill score and its decomposition, and the entropy
sangoma_ComputeCRIGN	Compute CRPF and CRIGN scores
sangoma_ComputeCRPS	Compute the CRPS and its decomposition
sangoma_ComputeEffSample	Compute the effective sample size of a particle filter
sangoma_ComputeEnsStats	Compute ensemble statistics
sangoma_ComputeHistogram	Compute ensemble rank histograms
sangoma_ComputeInvStats	Compute innovation statistics
sangoma_ComputeMutInf	Compute the mutual information
sangoma_ComputeRCRV	Compute the bias & the dispersion of the RCRV
sangoma_ComputeRE	Calculate the relative entropy
sangoma_ComputeSMatrix	Compute scaled ensemble observation anomalies
sangoma_ComputeSensitivity	Calculate the sensitivity matrix with **H** as matrix
sangoma_ComputeSensitivity_op	Calculate the sensitivity matrix with **H** as operator
sangoma_arm	Calculate array modes
sangoma_armca	Check the consistency of an ensemble using array modes
sangoma_ObsDiag	Compute sampled observation-space diagnostics

Matlab/Octave

computeBRIER	Compute the Brier skill score and its decomposition, and the entropy
computeCRPS	Compute the CRPS and its decomposition
computeRCRV	Compute the bias & the dispersion of the RCRV
computeHistogram	Compute ensemble rank histograms
mutual_information	Compute mutual information in a particle filter
relative_entropy	Compute relative entropy in a particle filter
sensitivity	Compute sensitivity of posterior mean to observations in a particle filter

Perturbation Tools

Fortran

sangoma_pseudornd2D	Generate random fields with given correlation length
sangoma_MVNormalize	Perform multivariate normalization
sangoma_EOFCovar	Initialize covariance matrix from EOF decomposition

Matlab/Octave

Weakly constrained ensemble perturbations	Create ensemble perturbations that have to satisfy an a priori linear constraint

Transformation Tools

Fortran

sangoma_Anamorphosis	Computes local Gaussian anamorphosis
sangoma_ComputeQuantiles	Computes ensemble quantiles as input for anamorphosis

Matlab/Octave

Empirical Gaussian Anamorphosis	Determine the empirical transformation function such that a transformed variable follows a Gaussian distribution

Utilities

Fortran

sangoma_computepod	Computes dominant POD modes from an ensemble of snapshots
sangoma_costgrad	Computes the values of Objective function and Gradient using reduced state dimensions
mod_sangoma_utils	Module of utilities for easy porting from Matlab

Matlab/Octave

hfradar_extractf	Observation operator for HF radar surface currents

Analysis

Fortran

sangoma_ens_analysis	Computes the analysis ensemble using the ETKF scheme
sangoma_local_ensemble_analysis	Computes the local analysis ensemble using the ETKF scheme
sangoma_enkf_analysis	Compute analysis ensemble using the EnKF with perturbed observations (globally or with covariance localization)
sangoma_ensrf_analysis	Compute analysis ensemble using the EnSRF with serial observation processing (globally or with covariance localization)
sangoma_estkf_analysis	Compute analysis ensemble using the global ESTKF method
sangoma_etkf_analysis	Compute analysis ensemble using the global ETKF method
sangoma_lestkf_analysis	Compute analysis ensemble using the ESTKF method with observation localization
sangoma_letkf_analysis	Compute analysis ensemble using the ETKF method with observation localization
sangoma_netf_analysis	Compute analysis ensemble using the NETF method

Matlab/Octave

sangoma_ensemble_analysis	Computes the analysis ensemble using the EnSRF, EAKF, ETKF, ETKF2, SEIK, ESTKF or EnKF scheme
sangoma_local_ensemble_analysis	Computes the local analysis ensemble using the EnSRF, EAKF, ETKF, ETKF2, SEIK, ESTKF or EnKF scheme (domain localization)
sangoma_local_EnKF	Computes the local analysis ensemble using the EnKF (covariance localization)

2.2.2 Using the tools

Directory structure of the release

In the code package of the release we distinguish in between tools implemented in Fortran and tools for use with Matlab or Octave. The directory structure is as follows:

```
Fortran/
        ____ diagnostics/
                                 _________ examples/
        ____ perturbations/
                                   _______ examples/
        ____ transformations/
                                     _____ examples/
        ____ utilities/
                               ___________ examples/
        ____ analysis/
                               ___________ examples/
Matlab/
       _____ diagnostics/
                                 _________ examples/
       _____ perturbations/
                                   _______ examples/
       _____ transformations/
                                     _____ examples/
       _____ utilities/
                               ___________ examples/
        ____ analysis/
                               ___________ examples/
```

The directories are named after the four categories. For each category there is a sub-directory `examples/` in which example implementations are included that show how to use a particular tool.

All tools come with a complete description and examples.

The main deliverable of WP2 is DL2.5 presenting a detailed technical description of the tools. For the mathematical background of the methods, WP3 provides the necessary information.

2.2.3 Deviations from DOW

None

Highlight:
The collection contains a nice mix of advanced and simple routines, including standard EnKF versions. Of particular interest to users already exploiting an assimilation tool is the collection of advanced diagnostic tools and the anamorphosis transformation tool. DL2.5 provides detailed information.

2.3 WP3: Innovative Data Assimilation techniques

This WP has been focusing on stochastic DA methods, developments of new DA methods (including non-linear observation operators), comparisons of non-Gaussian assumptions and developing algorithms for assessing observing systems. This WP had the most academic freedom of research leading to interesting discussions within the project and new lines of research.

Each group made significant progress in advanced data-assimilation techniques which will pave the way for additional features in future operational data assimilation.

2.3.1 Scientific and technical highlights

Classical particle filter methods are subjected to the curse of dimensionality, demanding the ensemble size to grow exponentially with the problem dimension size. A particle filter method trying to avoid the curse of dimensionality was thus developed further: The equivalent weight particle filter (EWPF) tries to avoid the collapsing of the ensembles by keeping a relatively small number of particles with equal weights at analysis time. For this, simple nudging terms are added to the equation to provide a proposal density, which modify the particle weights, and a resampling technique exploiting the maximum weight each particle can achieve. The calculation of this maximum weight is possible analytically only if the observing operator is linear. The method was successfully applied to a 2D case with a nonlinear barotropic flow. For cases with nonlinear observing operators, an iterative solver to find the maximum weights was implemented

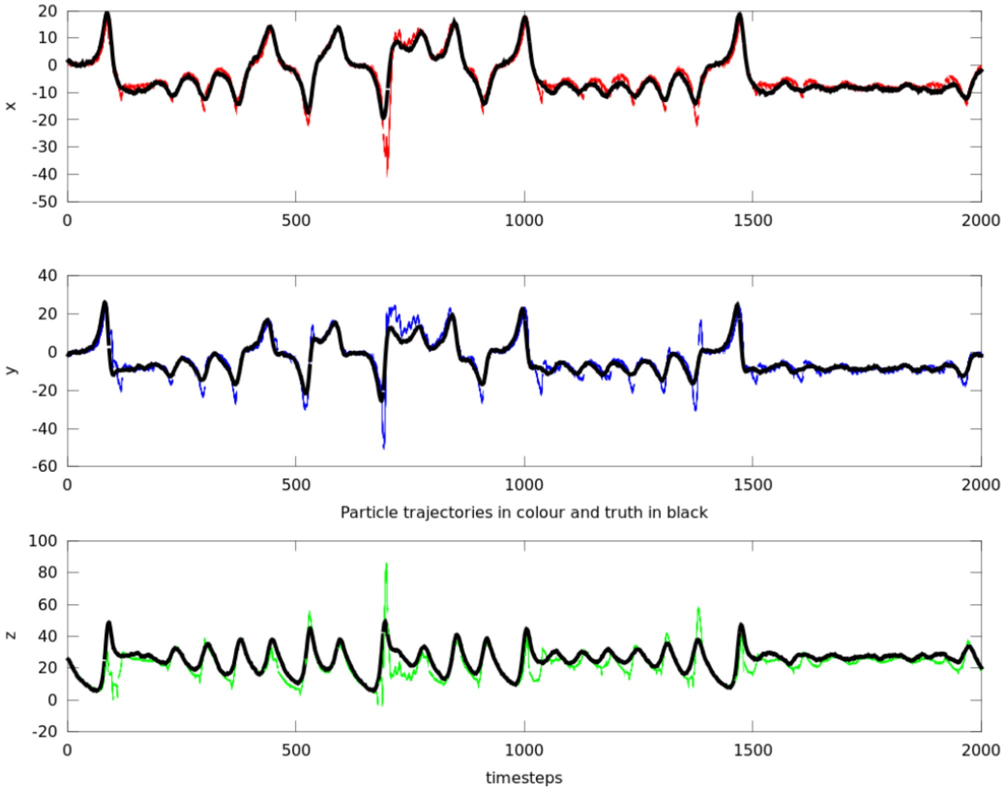


Figure 2.1: Results of EWPF application to the Lorenz 63 system when observing yz.

and tested on the chaotic Lorenz 63 system. The most challenging nonlinear observations in this case are those which can lead to two different states (of different signs) because the observation of the product for example does not allow to distinguish which combination to retain. For details see http://www.data-assimilation.net/Events/Year3/WP3.pdf (Presentation at progress meeting) and http://www.data-assimilation.net/Events/Year3/SANGOMASanita.pdf (Presentation on nonlinear H)

A Multivariate Rank Histogram Filter (MRHF) exploits joint probability density functions to infer unobserved variables from observed ones. When working in a low dimensional system, the approach performs very well for non-gaussian problems, but in higher dimensions some strong hypotheses need to be formulated. By neglecting unobserved variables in some of the conditional statements a feasible MRHF is within reach but good insight in the effect of the hypotheses is needed. For details see http://www.data-assimilation.net/Events/Year3/MRHF.pdf (Presentation at progress meeting) and http://das6.umd.edu/program/Daily/slides/2.2-Metref_Sammy.pdf (Poster)

An original method to include stochastic perturbations into a model was

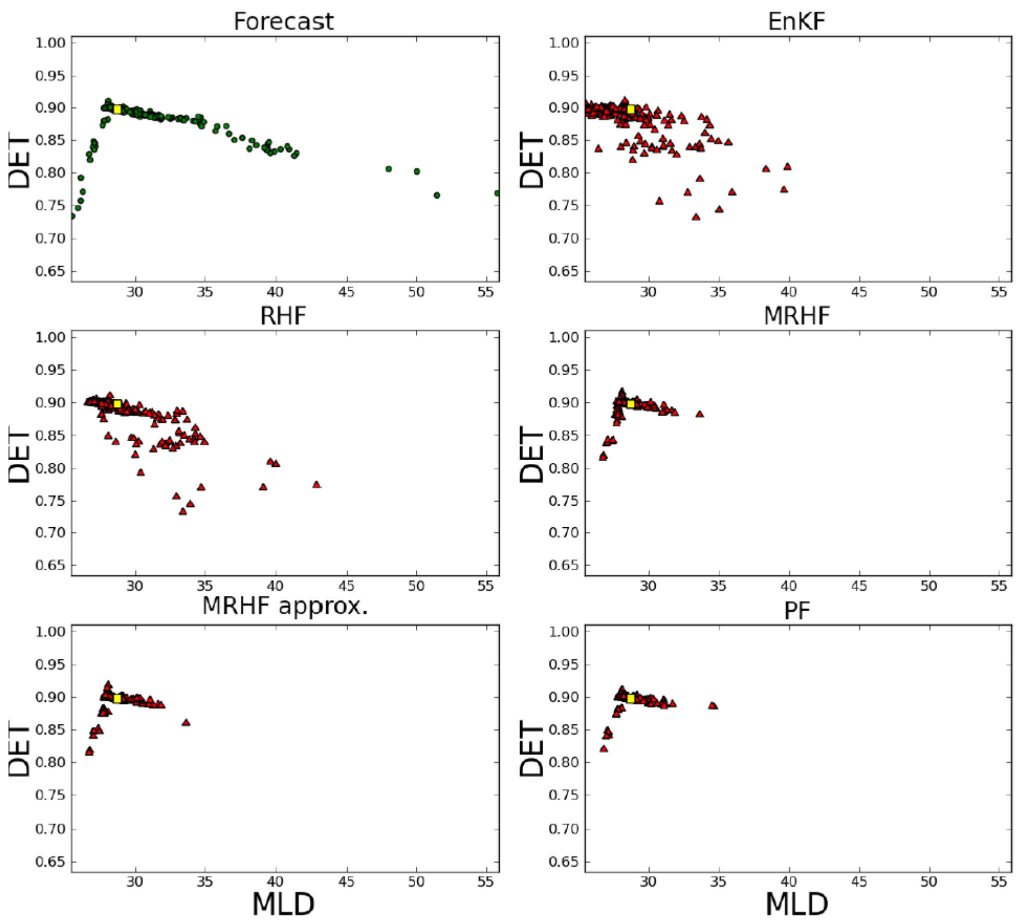


Figure 2.2: Application of the MRHF to the NATL025 implementation with bio-chemical model. Chl is observed and mixed layer depth and detritus are analysed. The members of the MRHF with or without the approximation in the joint probabilities work very well in this case.

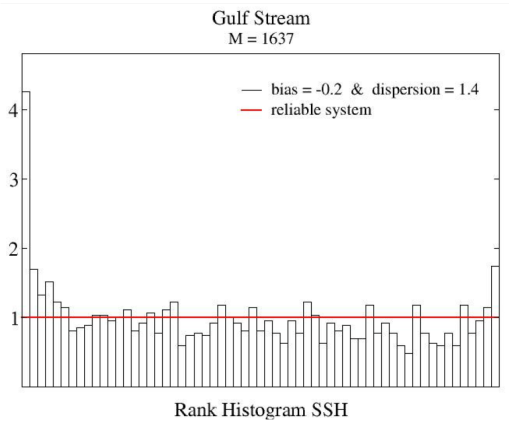


Figure 2.3: Application of stochastic perturbations on the state equation of the NATL025 implementation. SSH is observed and the rank histogram exhibits the nice ensemble spread.

developed. By using stochastic perturbations applied to the state equation one retrieves perturbations in which heat and salt are conserved. Also the perturbations lead to a nice and stable ensemble spread. For details see `http://www.data-assimilation.net/Events/Year3/brankartGC.pdf` (Presentation at progress meeting) and `http://dx.doi.org/10.1016/j.ocemod.2013.02.004` Brankart (2013).

Ensemble methods heavily exploit the reduced rank of the covariance matrix for efficient matrix inversions via the famous Woodbury formula. A new method combining such reduced rank matrices with local parametric covariances was developed to be able to combine large scale processes well modeled ensemble covariances the with smaller scale processes generally well modeled by parametric covariance functions. The combination normally does not lend itself to efficient inversion but with an iterative approach it still leads to efficient computations. In addition it allows for scale separations in the analysis. For details see `http://www.ocean-sci-discuss.net/11/895/2014/osd-11-895-2014.pdf` Beckers *et al.* (2014b).

Anamorphosis (data based change of variables) is a way to deal with data having a non-gaussian distribution, by transforming the data such that the transformed variables have a gaussian distribution. The transformation was tested in a coupled physical-biochemical model and indicates better spatial correlations when using the transformation. Therefore better corrections during assimilations can be expected. For details see `http://www.ocean-sci.net/8/121/2012/os-8-121-2012.pdf` Brankart *et al.* (2012).

For operational systems, error calculations can be quite time consuming when Optimal interpolation or 3DVar approaches are used. Simplified and approximate methods can alleviate the problem as shown in Beckers *et al.* (2014a).

The main deliverables of the workpackage are a state of the art (DL3.1)

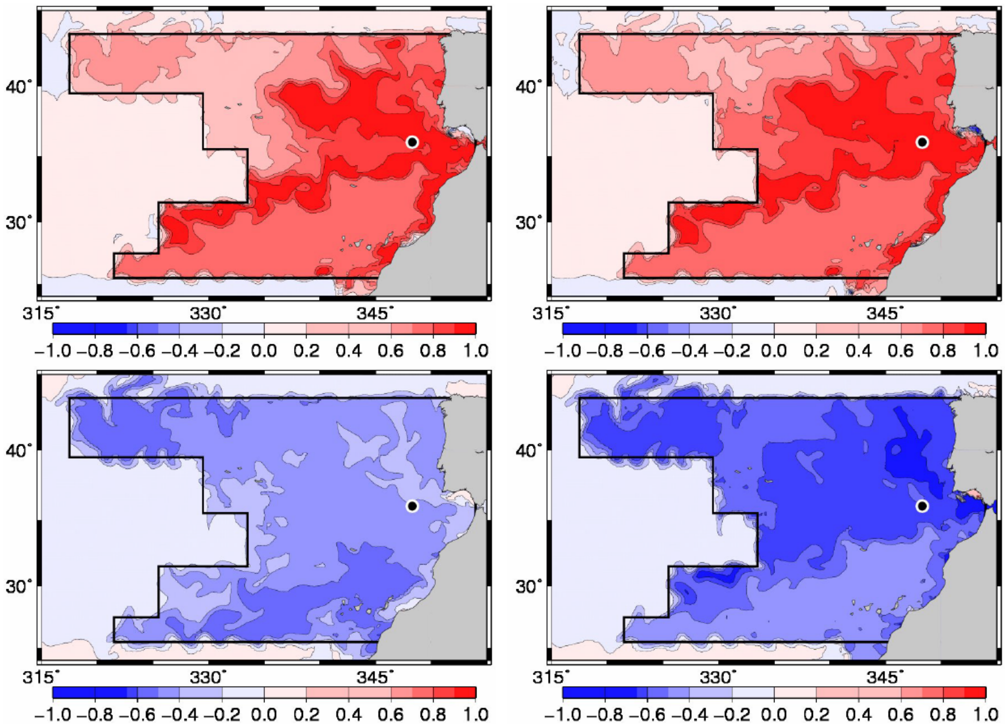


Figure 2.4: Phytoplankton (top panels) and nitrate (bottom panels) horizontal correlation structure with respect to phytoplankton without anamorphosis (left panels), and after local anamorphosis transformations (right panels).

described in a coherent framework (link between different EnKF version), the EWPF implementation in several toolboxes used as a common implementation of an advanced method (DL3.3) and new methods at exploratory level (DL3.4) or included in the SANGOMA collection (DL3.5).

2.3.2 Deviations from DOW

None

Highlight:
Working version of EWPF in several toolboxes using the defined standards (proof of concept of both the DA method and the SANGOMA data model/interface), uniform description of state of the art DA methods and several new advanced DA techniques.

2.4 WP4: Benchmarks

This workpackage aimed to provide some well documented and representative test cases for comparing data assimilation techniques. It also focused on adequate metrics to assess quality in non-linear regimes. The first year was concentrating in defining the details of the setup of the benchmark models. As planned, a small size (Lorenz 96), medium size (double gyre) and large size problem (Atlantic Ocean) was formulated. The setup of the benchmark models is completely specified and documented and some basic metrics are defined. A list of metrics not relying on the Gaussian-distribution assumption have also been prepared and discussed within the group and will serve as a basis for future assessment. It is also worth noting that the benchmark setup and use within an assimilation toolbox seems quite well prepared, as internal tests showed that a newcomer (both for NEMO and the toolbox) could reach a fully working ensemble assimilation within three month.

All benchmarks have been fully documented and implemented and executed by at least two partners. Details on which perturbations and ensemble members to generate were discussed and specified.

2.4.1 Scientific and technical highlights

In the first reporting period, the 3 SANGOMA benchmarks (small, medium and large case) had been defined, together with statistical metrics to evaluate stochastic assimilation methods (DL4.1).

Then, these 3 benchmarks have been implemented by the SANGOMA partners to evaluate various kinds of assimilation methods.

- Deliverable 4.2 lists the benchmarks that are being implemented by every SANGOMA partner, and provides the list of assimilation methods that will be evaluated by each partner.
- Deliverable 4.3 provides detailed information on how the probabilistic metrics are applied on small and medium benchmarks.

At the SANGOMA progress meeting of April 2014, presentations of the various benchmark implementations have shown that valuable results have already been obtained. In particular :

- Five implementations of the medium case benchmark allowed to intercompare different assimilation methods.
- Two implementations of the large scale benchmark (by GHER and LGGE as planned in the project) have been tested with a 6-month assimilation experiment (assimilating real-world ocean observations). Evaluation of these experiments has been performed, by applying more physical metrics at GHER and more probabilistic metrics at LGGE. Also the two implementations use complementary perturbations (density or external forcing).

In addition to standard metrics used to assess the quality of forecasts, the following probabilistic metrics haven been used:

- Rank Histogram
- Reduced Centered Random Variable (RCRV)
- Continuous Ranked Probability Scores (CRPS)
- Brier score Entropy

It has been shown that they provide additional insight into the quality of the simulations and therefore have been added to the SANGOMA tools list.

2.4.2 Deviations from DOW

None

Highlight:
Fully documented benchmarks, also taken up by NEMOVAR, a series of probabilistic metrics documented and included into the toolbox. Main deliverable: Benchmark description (DL4.1) and use of new metrics on benchmarks, including probabilistic ones. Among the highlights we can also mention that the medium size benchmark was successfully implemented by a post-doc new to the assimilation toolbox and the NEMO model within 3 month.

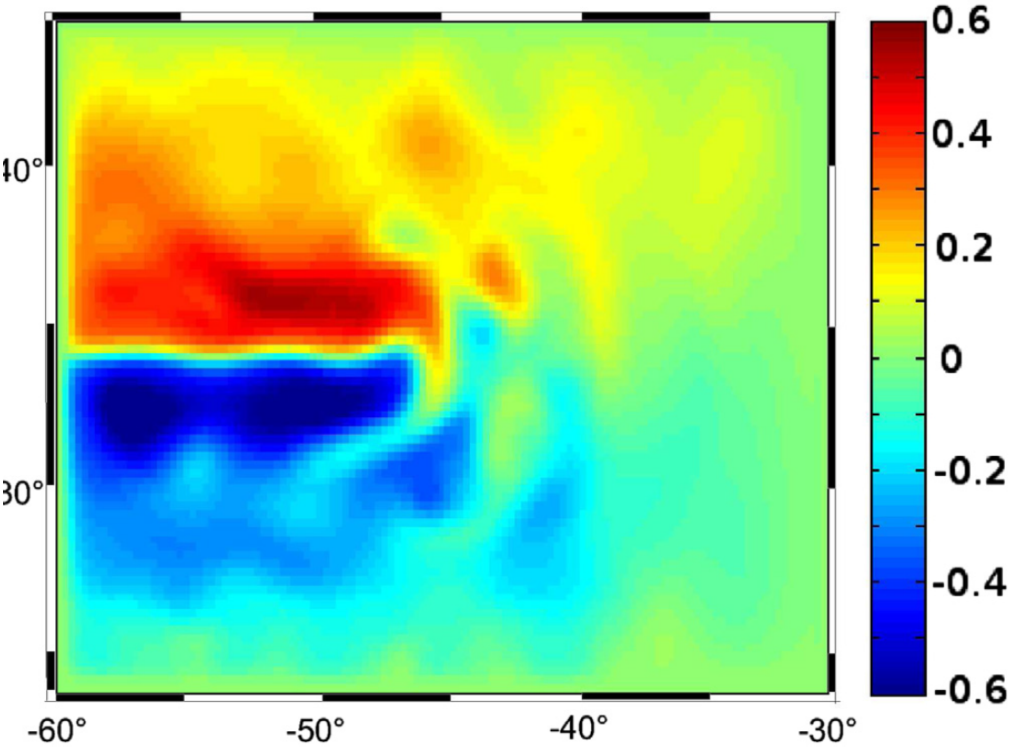


Figure 2.5: Snapshoot of SSH in the medium-size benchmark.

2.5 WP5: Data Assessment

This WP tried to assess the impact of new remote sensed ocean data on the model state estimations and their potential in a data assimilation setup in a future operational context.

The new data types have been identified and characterized. Several model implementations have been achieved for assessing observing systems and impact of new data types.

2.5.1 Scientific and technical highlights

Task 5.1 Identify new data types: This taks has been completed by the Delivery of DL5.1, a list of remote-sensed variables with their associated characteristics.

Task 5.2 Assessing observing systems: The work from G. Candille, CNRS-LEGI evaluated the relative impact of different altimeters constellations (Envisat and/or Jason 1) for the reduction of uncertainties and the improvement of model skills for unobserved temperature and salinity profiles. The work has used the large-scale NEMO benchmark from WP4. DL5.2 reported on the impact of new ecosystem data, although the contents is more related to ocean physics than ecosystem, consistently with the work performed in WP4.

Task 5.3 Large-scale models: This tasks has build up on the synthetic data experiments carried out by G. Candille (CNRS-LEGI) in WP4. The results on assimilating real along-track altimeter data (Altika and SWOT) were analyzed in DL5.3 and DL5.4 with large-scale ocean models. In particular correlated observational errors were analyzed and resulted in a way to transform data so that a diagonal covariance matrix can be used.

Task 5.4 Regional scale models: The work used a 1/60th deg ROMS model of the Ligurian Sea, using realistic forcings and real observations from two WERA HF radar systems operating during 2009 and 2010. The initial work has focused on the representation of model errors and covariance localization using as success criteria both the statistical robustness of increments and the expected error reduction. Localization is often applied for ensemble methods to avoid long range corrections introduced by artificial correlations found when undersampling due to the number of members of the ensemble. Two problems which occur in this context can now be tackled: how to build the localization function objectively and how to maintain global conservation constraints when adding localization. For the limitation in space of the corrections based on an observation, the criterium is that the expected improvement brought by the correction should be larger than the error introduced by an incorrect specification of covariances. The latter effect is measured by a bootstrap method so that

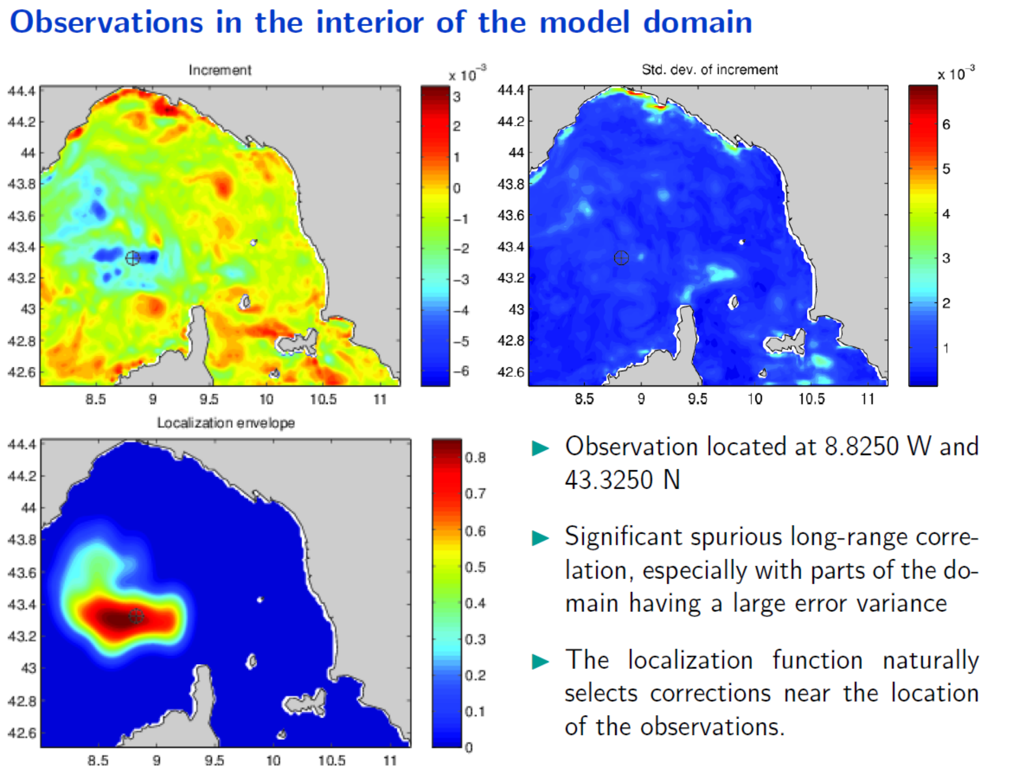


Figure 2.6: Application of the objective localisation determination in the ROMS Ligurian sea implementation. Velocity is observed by radar and the original increment shows spurious long range correlations particularly in regions where the error covariance is uncertain. With the objective localisation detection increments will be applied only in relevant points.

the localization function can be calculated. For maintaining conservation properties when applying the localisation approach, one has to modify the ensemble covariance such that the error variance on the conserved property is zero. This can be formulated mathematically rather easily for the forecast error but requires special care when updating the analysis error covariance. For details see `http://www.data-assimilation.net/Events/Year3/assimlocens.pdf` (Presentation at progress meeting) DL5.6 summarizes the results of a data assimilation experiment with a regional-scale ocean model in particular the duration of the correction's impact and the different assimilation strategies (EnKS, vs AEnKF, window size).

Task 5.5 Lagrangian sea ice parameters The work has been initiated in an external collaboration with F. Massonnet at Université Catholique de Louvain la Neuve. Assimilation of satellite sea ice drift data in a NEMO-LIM model has been performed with the EnKF and global pa-

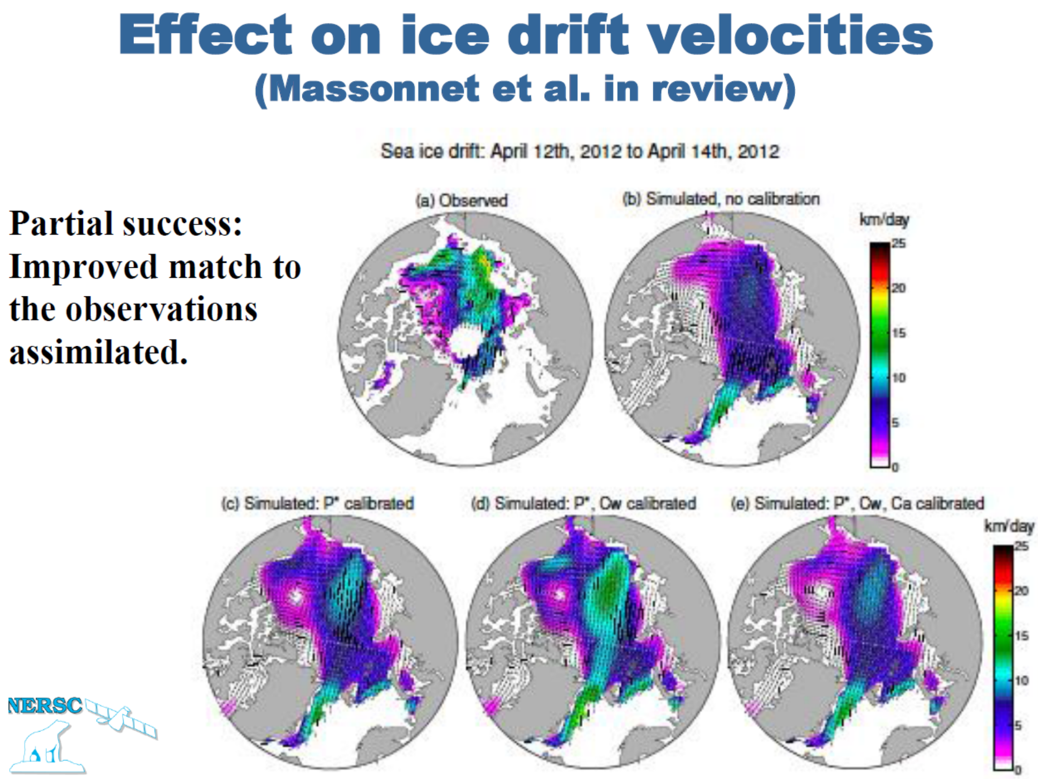


Figure 2.7: Assimilation of ice drift

rameters of sea ice drag coefficients and sea ice strength (known as P* in the (Elastic)-Viscous-Plastic sea ice rheology) have been estimated by a technique of state augmentation. The results show strong improvements for the estimation of two parameters (one drag coefficient and P*) but the only the ratio of air and ocean drag coefficient can be estimated correctly. DL5.7 discusses the results of the data assimilation experiment aiming to estimate Lagrangian sea ice parameters in a twin experiment scenario and using real observations. Estimating ice-related dynamic parameters with the assimilation tool reduced the errors in large areas.

Task 5.6 Prior errors detection by observational arrays A diagnostic code has been tested by CNRS-LEGOS on a coastal oceanographic application and shared with CNRS-LEGI. DL5.8 provided the RMSpectrum library and results of array performance analyses.

Selecting among different locations and combinations of observing systems is simplified by characterizing the incremental information via the spectrum of the observed part of the error covariance of the forecast. This leads to selection criteria which allow to distinguish the added value of ferryboxes vs gliders for example

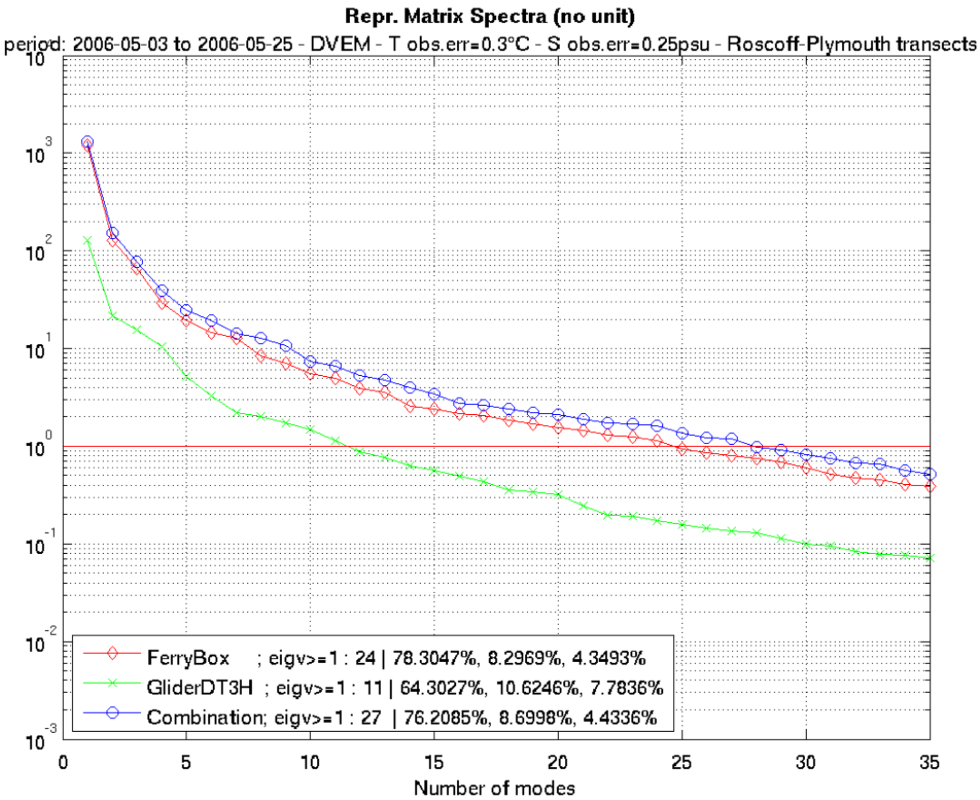


Figure 2.8: Eigenvalues of the representers from Ferrybox (red) remain larger than baseline from obervations (flat line) for a larger number of eigenvalues than the one deducted for gliders (green line). Hence they potentially have a larger range of detectable modes

2.5.2 Deviations from DOW

None

Highlight:

Description of new data types (DL5.1), general assessment tools (DL5.8), implementation of assimilation of new data types with interesting results:

- Along-track altimetry data (Envisat and Altika): stochastic parameterizations of the model dynamical uncertainties proved to be suitable
- Wide-swath sea surface height measurements (SWOT mission): Efficient method to account for the correlation of observational error
- HF Radar current observation: Space-time covariance suitable to capture inertial osciallation
- Sea-ice thickness: Useful to calibrate relevant parameters of the sea-ice

2.6 WP6: Knowledge transfer

This WP had to ensure that knowledge gained from the project and tools developed in it will be exploited outside of the SANGOMA consortium. Among the general activities we find the releases the code, publication of papers and presentation of the project partners at different meetings.

An important point is that the tools developed by SANGOMA are useful to the scientific and operational community:

- For scientific groups, the open sharing of tools and benchmarks will allow other scientist to test their new ideas and their effect by comparing them to results from SANGOMA. Also reports on DA techniques and new data types will speed up uptake of new techniques by scientist using data assimilation. We reached this community by standard scientific publications and communications but also via the Ph.D workshops, schools and student exchanges.
- myOcean: a strong involvement of myOcean representatives in SANGOMA was planned and implemented (two partners are

also partners in myOcean, one as MFC; the steering committee of SANGOMA includes E. Dombrowsky as representative of myOcean; already two of the variable advisory-board members emerged from myOcean: D. Obaton and C.E. Testut; a specific consortium agreement between SANGOMA and myOcean was set up; myOcean science days workshop on data assimilation was organised with SANGOMA.)

– Other GMES service evolution projects showed interest (OSS2015 and myWave for data assimilation techniques) but no particular action has emerged.

– Operational centers (within myOcean and outside) should find in the SANGOMA toolboxes and benchmarks easy ways to test new techniques before deciding to optimise them for their operational implementation. Diagnostic tools should also be of direct interest. To make sure our work is relevant we submitted a list of tools to be developed to myOcean.

– Private firms have shown their interest in using tested tools as they generally have less time for reimplementing documented tools. For these firms, we kept them informed and invited them to the Liège Colloquium.

– Contacts with ESA (ESFRI) through the advisory board participation at the kick-off meeting were kept alive, notably to prepare the ESA summerschool contribution from SANGOMA through the UREAD group. NERSC is also involved in ESA's Ocean Colour CCI in which he uses data assimilation techniques further developed within SANGOMA.

– a workshop with operational users was planned at month 12. During GMES marine projects coordination meeting on 24/05/2012 in Brussels we discussed this matter with the myOcean group and it was agreed that we should reach this community together during the myOcean Science Days. Therefore, invitations were send via the myOcean contact list but also directly from the SANGOMA side to a dozen of additional institutes interested in operational modelling (like Actimar and MUMM).

– During the myOcean Science Days, 60-70 participants attended the workshop on data assimilation. Four oral presentations and four posters showed the SANGOMA approach. A call for feedback was also launched and a survey http://www.surveymonkey.com/s/ZX3P9D8 indicating very positive views on our proposed data model and interfaces.

– The Liège colloquium 2015 focused on DA and SANGOMA took a leading role there, gathering almost 200 scientists.

– Web pages of SANGOMA have been updated regularly (see DL6.2) and include scientific highlights.

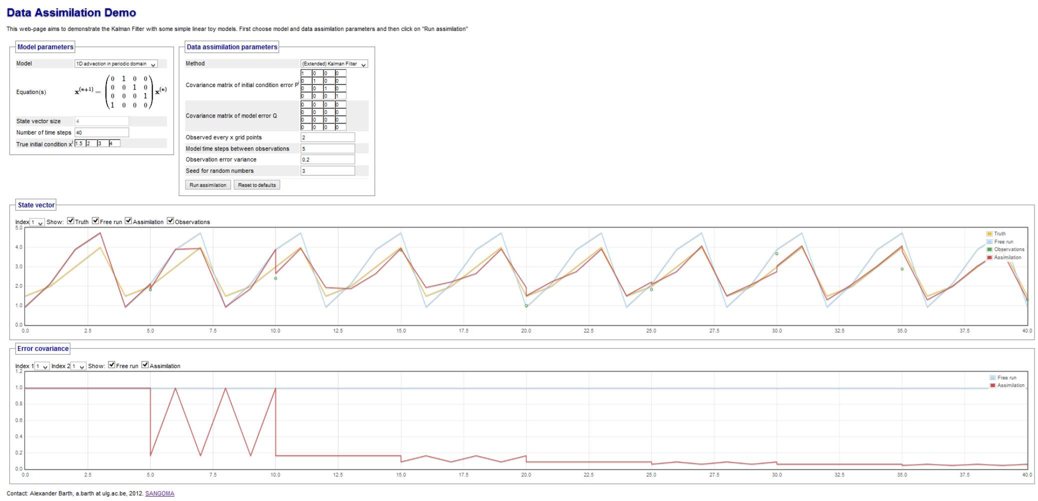
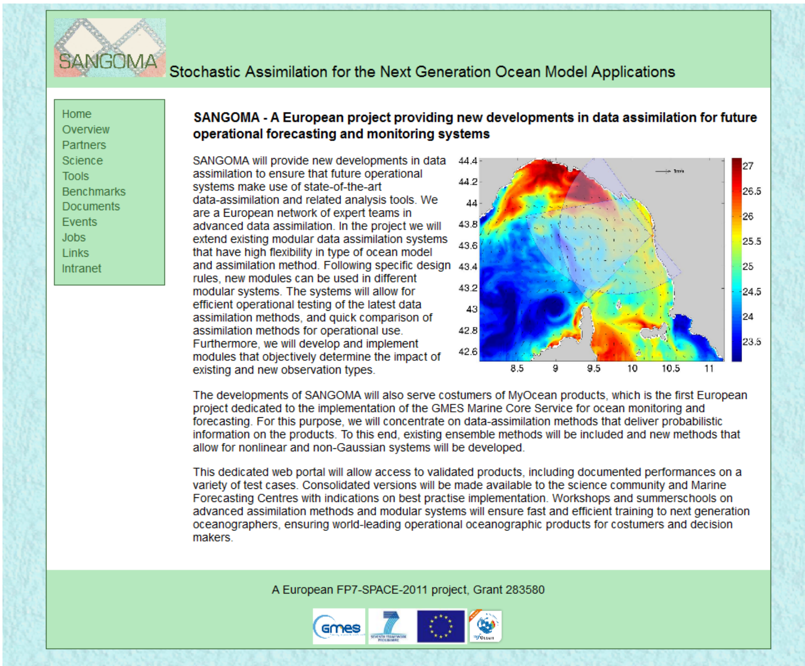


Figure 2.9: Web interface to data assimilation demonstration

– For demonstration purposes, a web interface to some assimilation techniques was installed to illustrate the concepts: `http://www.data-assimilation.net/Tools/AssimDemo/`



SANGOMA web site `http://www.data-assimilation.net`.

2.6.1 Deviations from DOW

Less workshops than planned were organized, due to difficulty to reach and mobilize stakeholders to join.

Highlight:
Software distributed (500 downloads at the project end; the bundled V2 software was also released with the documentation DL6.14), SVN server still up and being updated, 87 different dissemination activities, Liège Colloquium 2015, web based DA demonstration tool.

2.7 WP7: Management

The only significant deviation form the plan was the delay in final report delivery.

Chapter 3

Evolutions

A problem posed by the end of the SANGOMA project is the durability of our collaborative approach.

The scientists involved will certainly continue to collaborate but the future of the SANGOMA software and standards needs attention.

On a short term, ULg will maintain the SVN servers and web pages and in view of the permanent positions of the scientists at ULg involved, the maintenance should be easily ensured during the next decade.

For adding content ULg will be able to make small bug corrections but for major enhancement new projects are needed. A few possible ways to prepare such projects are the following

- The report of the 4th NEMO-ASSIM meeting January 29th 2015, included reference to the SANGOMA approach and also the desire to come up with a reference setup for testing DA with NEMO, very close to our medium size benchmark.
- Partners should propose their (national or other) projects highlighting they will feeding back their new findings into the SANGOMA toolbox: The benefit for the proposal is to show its uptake strategy and the benefit for the SANGOMA consortium is the sustainability of the consortium. This approach was already taken in the past with an OSTST-ASSIM for the French groups EUMETSAT/CNES call.
- Sangoma WP5 links to the Sentinel missions should be exploited: Task 5.3 prepares for using future ocean altimeter onboard the Sentinel-3 mission. Task 5.5 prepares for using sea ice altimeter onboard the Sentinel-3 mission.
- Arising opportunities to include the methods in Copernicus Marine Services in H2020.
- Ensure GMEMS participations.

- SMEs using the toolbox might wish to include some of their work into the toolbox (as it would provide additional testing from other scientists).

New problems to be tackled in the future will include assimilation in unstructured grid models and coastal benchmarks, as well as the problem of big data assimilation.

Chapter 4

Other information

The publication list originating from the project at the end of it is provided from the EU portal. For updated version, with papers published later, please visit http://www.data-assimilation.net/Documents/. Dissemination activities are also those reported to EU.

Project Publications (Peer reviewed publication)

Order Nº	Nº	D.O.I.	Title	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access is/will be provided to this publication	Status	Actions
	1	10.5194/os-8-121-2012	Towards an improved description of ocean uncertainties: effect of local anamorphic transformations on spatial correlations	J.-M. Brankart, C.-E. Testut, D. Béal, M. Doron, C. Fontana, M. Meinvielle, P. Brasseur, and J. Verron	Ocean Science	Vol. 8, issue 2, 2012	Copernicus Publications on behalf of the European Geosciences Union		06/03/2012	121-142	Yes	VALIDATED	
	2	10.1016/j.ocemod.2013.11.002	Comparison of different assimilation schemes in a sequential Kalman filter assimilation system	Y. Yan , A. Barth , J.M. Beckers	Ocean Modelling	Vol. 73	null		01/01/2014	123-137		VALIDATED	
	3	10.1016/j.cageo.2012.03.026	Software for ensemble-based data assimilation systems—Implementation strategies and scalability	L. Nerger and W. Hiller	Computers and Geosciences	55	Elsevier Limited		01/06/2013	110-118		VALIDATED	
	4	10.5194/osd-11-895-2014	Multi-scale optimal interpolation: application to DINEOF analysis spiced with a local optimal interpolation	J.-M. Beckers , A. Barth , I. Tomazic , A. Alvera-Azcárate	Ocean Science Discussions	Vol. 11/Issue 2	European Geosciences Union	Germany	01/01/2014	895-941		VALIDATED	
	5	10.1175/JTECH-D-13-00130.1	Approximate and Efficient Methods to Assess Error Fields in Spatial Gridding with Data Interpolating Variational Analysis (DIVA)	Jean-Marie Beckers , Alexander Barth , Charles Troupin , Aida Alvera-Azcárate	Journal of Atmospheric and Oceanic Technology	Vol. 31/Issue 2	American Meteorological Society	United States	01/02/2014	515-530		VALIDATED	
	6	10.1175/MWR-D-13-00246.1	On the Choice of an Optimal Localization Radius in Ensemble Kalman Filter Methods	Paul Kirchgessner , Lars Nerger , Angelika Bunse-Gerstner	Monthly Weather Review	Vol. 142/Issue 6	American Meteorological Society	United States	01/06/2014	2165-2175		VALIDATED	
	7	10.1016/j.ocemod.2013.02.004	Impact of uncertainties in the horizontal density gradient upon low resolution global ocean modelling	Jean-Michel Brankart	Ocean Modelling	Vol. 66	null		01/06/2013	64-76		VALIDATED	
	8	10.1175/MWR-D-14-00398.1	Linking the Anomaly Initialization Approach to the Mapping Paradigm: A Proof-of-Concept Study	Robin J. T. Weber , Alberto Carrassi , Francisco J. Doblas-Reyes	Monthly Weather Review	Vol. 143/Issue 11	American Meteorological Society	United States	01/11/2015	4695-4713		VALIDATED	
	9	10.5194/os-11-425-2015	Assessment of an ensemble system that assimilates Jason-1/Envisat altimeter data in a probabilistic model of the North Atlantic ocean circulation	G. Candille , J.-M. Brankart , P. Brasseur	Ocean Science	Vol. 11/Issue 3	European Geosciences Union	Germany	01/01/2015	425-438		VALIDATED	
	10	10.1002/2014JC010349	Ensemble assimilation of ARGO temperature profile, sea surface temperature, and altimetric satellite data into an eddy permitting primitive equation model of the North Atlantic Ocean	Y. Yan , A. Barth , J. M. Beckers , G. Candille , J. M. Brankart , P. Brasseur	Journal of Geophysical Research: Oceans	Vol. 120/Issue 7	AGU		01/07/2015	5134-5157		VALIDATED	
	11	10.5194/npg-21-869-2014	A non-Gaussian analysis scheme using rank histograms for ensemble data assimilation	S. Metref , E. Cosme , C. Snyder , P. Brasseur	Nonlinear Processes in Geophysics	Vol. 21/Issue 4	European Geosciences Union		01/01/2014	869-885		VALIDATED	
	12	10.5194/gmd-8-1285-2015	A generic approach to explicit simulation of uncertainty in the NEMO ocean model	J.-M. Brankart , G. Candille , F. Garnier , C. Calone , A. Melet , P.-A. Bouttier , P. Brasseur , J. Verron	Geoscientific Model Development	Vol. 8/Issue 5	Copernicus GmbH (Copernicus Publications), EGU	Germany	01/01/2015	1285-1297		VALIDATED	
	13	10.1175/mwr-d-14-00375.1	Extending the Square Root Method to Account for Additive Forecast Noise in Ensemble Methods	Patrick Nima Raanes , Alberto Carrassi , Laurent Bertino	Monthly Weather Review	Vol. 143/Issue 10	American Meteorological Society	United States	01/10/2015	3857-3873		VALIDATED	
	14	10.1002/qj.2451	Accounting for model error due to unresolved scales within ensemble Kalman filtering	Lewis Mitchell , Alberto Carrassi	Quarterly Journal of the Royal Meteorological Society	Vol. 141/Issue 689	John Wiley and Sons Ltd	United Kingdom	01/04/2015	1417-1428		VALIDATED	
	15	doi:10.1002/2013JC009705	Calibration of sea ice dynamic parameters in an ocean-sea ice model using an ensemble Kalman filter	F. Massonnet , H. Goosse , T. Fichefet , F. Counillon	Journal of Geophysical Research: Oceans	Vol. 119/Issue 7	AGU		01/07/2014	4168-4184		VALIDATED	
	16		On the influence of model nonlinearity and localization on ensemble Kalman smoothing	Lars Nerger , Svenja Schulte , Angelika Bunse-Gerstner	Quarterly Journal of the Royal Meteorological Society	Vol. 140/Issue 684	John Wiley and Sons Ltd	United Kingdom	01/10/2014	2249-2259		VALIDATED	
	17	10.1175/MWR-D-15-0073.1	Assessment of a Nonlinear Ensemble Transform Filter for High-Dimensional Data Assimilation	Julian Tödter , Paul Kirchgessner , Lars Nerger , Bodo Ahrens	Monthly Weather Review	Vol. 144/Issue 1	American Meteorological Society	United States	01/01/2016	409-427		VALIDATED	

Nº	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed	Status	Actions	Order
1	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	CNRS-LEGOS contribution to SANGOMA	24/10/2011	Liège, Belgique (SANGOMA European Project kick-off meeting)	Scientific community (higher education, Research)		International	VALIDATED		
2	Flyers	UNIVERSITE DE LIEGE	Stochastic Assimilation for the Next Generation Ocean Model applications	01/11/2011	Belgium, United Kingdom, Germany, Netherlands, France, Norway	Scientific community (higher education, Research)		International	VALIDATED		
3	Publication	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Towards an improved description of ocean uncertainties: effect of local anamorphic transformations..	06/03/2012	European Geosciences Union	Scientific community (higher education, Research)		International	VALIDATED		
4	Presentations	UNIVERSITE DE LIEGE	Assimilation of high-frequency radar currents in the Ligurian Sea	18/04/2012	Livorno, Italy (Workshop MOMAR)	Scientific community (higher education, Research)		International	VALIDATED		
5	Posters	UNIVERSITE DE LIEGE	Data assimilation in Ligurian Sea using HF radars	19/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
6	Posters	TECHNISCHE UNIVERSITEIT DELFT	The OpenDA data-assimilation toolbox	19/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
7	Posters	UNIVERSITE DE LIEGE	Ensemble Data Assimilation in a global coupled sea ice model	19/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
8	Posters	THE UNIVERSITY OF READING	A fully nonlinear filter for high-dimensional systems	19/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
9	Presentations	TECHNISCHE UNIVERSITEIT DELFT	Wave data-assimilation for SWAN using OpenDA	20/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
10	Presentations	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Advanced assimilation methods for the next generation of ocean monitoring and forecasting centres	20/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
11	Presentations	ALFRED-WEGENER-INSTITUT FUER POLAR- UND MEERESFORSCHUNG	An ensemble-based forecasting system for the North and Baltic Seas using the BSH circulation model..	20/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
12	Presentations	UNIVERSITE DE LIEGE	Development of Stochastic Assimilation for the Next Generation Ocean Model Applications	20/11/2012	Geesthacht, Germany (MyOcean Science Days 2012)	Scientific community (higher education, Research)		International	VALIDATED		
13	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Array testing and impact of observations in the coastal ocean by ensemble methods.	01/02/2013	Lecce, Italy (Second International Workshop of the GODAE OceanView Coastal and Shelf Seas Task Team)	Scientific community (higher education, Research)		International	VALIDATED		
14	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	On non Gaussian Ensemble data assimilation	17/02/2013	Banff, Probabilistic Approaches to Data Assimilation for Earth Systems	Scientific community (higher education, Research)		International	VALIDATED		
15	Oral presentation to a scientific event	UNIVERSITE DE LIEGE	Assimilation of simulated satellite altimetric data and ARGO temperature data into a double-gyre NEMO ocean model	07/04/2013	EGU2013 Vienna	Scientific community (higher education, Research)		International	VALIDATED		
16	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Groupe de travail sur l'assimilation de données dans le Golfe de Gascogne et mers côtières	23/04/2013	Toulouse, France (Journées 2013 du Groupe Mission MERCATOR-CORIOLIS)	Scientific community (higher education, Research)		International	VALIDATED		
17	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Impact of observations	24/06/2013	Bologna, Italy (Bologna Advanced Data Assimilation Summer School)	Scientific community (higher education, Research)		International	VALIDATED		
18	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	A non-Gaussian analysis scheme using rank histograms for ensemble data assimilation	07/10/2013	6th WMO SYMPOSIUM	Scientific community (higher education, Research)		International	VALIDATED		
19	Posters	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Array and model testing and impact of observations (with applications in the coastal ocean)	13/01/2014	Toulouse, France (Colloque LEFE)	Scientific community (higher education, Research)		International	VALIDATED		
20	Posters	ALFRED-WEGENER-INSTITUT FUER POLAR- UND MEERESFORSCHUNG	A comparison of linear and non-linear linear data assimilation techniques using a toy model	24/02/2014	LMU Munich International Symposium on Data Assimilation 2014	Scientific community (higher education, Research)		International	VALIDATED		
21	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Stochastic array design with the sangoma_arm tool	01/04/2014	Liège, Belgium (SANGOMA Project meeting)	Scientific community (higher education, Research)		International	VALIDATED		
22	Oral presentation to a scientific event	UNIVERSITE DE LIEGE	Assimilation of ARGO temperature profile, sea surface temperature and altimetric satellite data into an eddy permitting primitive equation model of the North Atlantic Ocean	27/04/2014	EGU 2014 Vienna	Scientific community (higher education, Research)		International	VALIDATED		

	a scientific event		equation model of the North Atlantic Ocean			Research)		
23	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Advances in Climate Theory	25/08/2014	Royal Meteorological Institute of Belgium, Brussels, BELGIUM	Scientific community (higher education, Research)	International	VALIDATED
24	Posters	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Assessment of stochastic filters for assimilation of high-frequency observations in a coupled physical-biological model of the Ligurian Sea	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
25	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	The SANGOMA tools for data assimilation	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
26	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Extending NEMO For Ensemble Data Assimilation On Supercomputers With The Parallel Data Assimilation Framework PDAF	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
27	Posters	THE UNIVERSITY OF READING	Recent Progress In Nonlinear Data Assimilation	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
28	Posters	UNIVERSITE DE LIEGE	Ensemble Assimilation Of ARGO Temperature Profile, Sea Surface Temperature And Altimetric Satellite Data Into An Eddy Permitting Primitive Equation Model Of The North Atlantic Ocean	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
29	Posters	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Towards data assimilation in a state-of-the-art physical-model of the North Atlantic: Estimation of model uncertainties using Stochastic parametrizations	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
30	Posters	UNIVERSITE DE LIEGE	Reanalysis of the Southern Ocean with assimilation of sea surface temperature, ice concentration and ice drift	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
31	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Modeling and data assimilation developments of the TOPAZ system in support of operational oceanography in the Arctic	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
32	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble-based array performance assessment	10/12/2014	Toulouse, France (OSEval-TT/E-AIMS /CLIVAR/GSOP workshop)	Scientific community (higher education, Research)	International	VALIDATED
33	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	EPSRC Centre for Doctoral Training - Mathematics of Planet Earth	28/01/2015	Imperial College London & University of Reading, UK	Scientific community (higher education, Research)	International	VALIDATED
34	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble-based array performance assessment in coastal ocean models	06/03/2015	CSIRO, Hobart, Tasmanie	Scientific community (higher education, Research)	International	VALIDATED
35	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Lessons learnt from 1200 EnKF cycles with TOPAZ.	06/04/2015	France (Les Houches Workshop)	Scientific community (higher education, Research)	International	VALIDATED
36	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Extending the square root method to account for model noise in the ensemble Kalman filter	06/04/2015	France (Les Houches Workshop)	Scientific community (higher education, Research)	International	VALIDATED
37	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Les Houches Ensemble data assimilation workshop	06/04/2015	France (Les Houches Workshop)	Scientific community (higher education, Research)	International	VALIDATED
38	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Optimizing observation networks in the Bay of Biscay and English Channel	27/04/2015	Brest, France (JERICO Science Days)	Scientific community (higher education, Research)	International	VALIDATED
39	Posters	UNIVERSITE DE LIEGE	Assimilation of sea surface temperature, sea ice concentration and sea ice drift in a model of the Southern Ocean	06/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
40	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Building Ensemble-Based Data Assimilation Systems for High-Dimensional Models	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
41	Oral presentation to a scientific event	THE UNIVERSITY OF READING	Non-Gaussian Data Assimilation Methods	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
42	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	A comparison of linear and non-linear data assimilation methods using the NEMO ocean model	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
43	Oral presentation to a scientific event	THE UNIVERSITY OF READING	Using EMPIRE to assess the impact of a fully non-linear data assimilation method with NEMO	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
44	Oral presentation to a scientific event	TECHNISCHE UNIVERSITEIT DELFT	OpenDA-NEMO framework for Ocean Data Assimilation	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED

45	Oral presentation to a scientific event	UNIVERSITE DE LIEGE	Local ensemble assimilation scheme with global constraints and conservation	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
46	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Data assimilation in a ¼ ° coupled physical-biogeochemical model of the North Atlantic using error modelling based on stochastic parametrizations of biogeochemical uncertainties	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
47	Oral presentation to a scientific event	UNIVERSITE DE LIEGE	Assimilation of HF radar in the Ligurian Sea: Spatial and Temporal scale considerations	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
48	Oral presentation to a scientific event	UNIVERSITE DE LIEGE	Bias correction with data assimilation.	07/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
49	Posters	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	A New Dual Ensemble Kalman Filter for State-Parameters Estimation in Subsurface Hydrology	09/05/2015	International EnKF workshop, Flåm, Norway	Scientific community (higher education, Research)	International	VALIDATED
50	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Monitoring and Predicting Subsurface Organic Contaminants in the Port of Rotterdam using a Hybrid Ensemble Kalman Filter	09/05/2015	International EnKF workshop, Flåm, Norway	Scientific community (higher education, Research)	International	VALIDATED
51	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Nonlinear Dynamics, Extremes, Geo-hazards and Predictability of the Earth System	26/05/2015	University of Hamburg, GERMANY	Scientific community (higher education, Research)	International	VALIDATED
52	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Probabilistic Approaches (and Risk Assessment) in the Coastal Ocean	08/06/2015	Biddeford, Maine, USA (Gordon Research Conference on Coastal Ocean Modelling)	Scientific community (higher education, Research)	International	VALIDATED
53	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	AMICO 1a: Assimilation de données par méthode ensembliste et descente d'échelles dans le Golfe de Gascogne	15/06/2015	Toulouse, France (Journées 2015 du GMMC)	Scientific community (higher education, Research)	International	VALIDATED
54	Posters	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Data assimilation by delay coordinate nudging	06/09/2015	Dynamics Day EU	Scientific community (higher education, Research)	International	VALIDATED
55	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Data assimilation in a state-of-the-art physical-biogeochemical model of the North Atlantic: toward synergistic usage of Sea Level, SST and Ocean Colour observations	13/05/2013	University of Liège, Belgium (45th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
56	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	The control of non-linear mesoscale ocean circulation through altimetric data assimilation revisited using a variational approach	07/10/2013	Boulder, USA (2013 OSTST meeting)	Scientific community (higher education, Research)	International	VALIDATED
57	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Towards an ensemble strategy for altimetric data assimilation into eddy-resolving ocean circulation models	07/10/2013	Boulder, USA (2013 OSTST meeting)	Scientific community (higher education, Research)	International	VALIDATED
58	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Towards an ensemble strategy for data assimilation into eddy-resolving ocean circulation models	04/11/2013	Baltimore, USA (International GODAE OceanView symposium)	Scientific community (higher education, Research)	International	VALIDATED
59	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Towards data assimilation in a coupled Physical-Biogeochemical model of the North Atlantic: Estimation of model uncertainties using stochastic parametrizations	24/02/2014	Honolulu, USA (AGU Ocean Science Meeting)	Scientific community (higher education, Research)	International	VALIDATED
60	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble data assimilation in a North Atlantic, eddy-permitting ocean circulation model using stochastic parameterization of the model dynamics	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
61	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Stochastic estimation of parameters describing forcing uncertainties in a biogeochemical model	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
62	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble assimilation of JASON/ENVISAT and JASON/AltiKA altimetric observations with stochastic parameterization of the model dynamical uncertainties	28/10/2014	Lake Constance, Germany (2014 OSTST meeting)	Scientific community (higher education, Research)	International	VALIDATED
63	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Impact of altimetric data assimilated in a eddy-permitting, coupled physical-biogeochemical model of the North Atlantic ocean	28/10/2014	Lake Constance, Germany (2014 OSTST meeting)	Scientific community (higher education, Research)	International	VALIDATED
64	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Toward variational assimilation of SARAL/Altika altimeter data in a North Atlantic circulation model at eddy-permitting resolution: assessment of a NEMO-based 4D-VAR system	28/10/2014	Lake Constance, Germany (2014 OSTST meeting)	Scientific community (higher education, Research)	International	VALIDATED
65	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Reduced-order data assimilation methods	24/06/2013	Bologna, Italy (Bologna Advanced Data Assimilation Summer School)	Scientific community (higher education, Research)	International	VALIDATED
66	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Impact of uncertainties in the horizontal density gradient upon low resolution global ocean modelling	18/03/2013	University of Oxford, UK (Workshop)	Scientific community (higher education, Research)	International	VALIDATED

67	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	System evaluation	10/03/2015	Melbourne, Australia (Australian National Shelf Reanalysis Technical Task Team Workshop)	Scientific community (higher education, Research)	International	VALIDATED
68	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	On the impact of nonlinearity on ensemble smoothing	08/04/2013	Vienna, Austria (EGU General Assembly)	Scientific community (higher education, Research)	International	VALIDATED
69	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Localization in ensemble data assimilation	08/10/2012	Deutscher Wetterdienst Offenbach, Germany (International Symposium on data assimilation)	Scientific community (higher education, Research)	International	VALIDATED
70	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Ensemble smoothing under the influence of nonlinearity	02/07/2013	Reading, UK (Seminar at University of Reading)	Scientific community (higher education, Research)	International	VALIDATED
71	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Adaptive localization in ensemble Kalman fitler methods by controlling the observation space	07/10/2013	College Park, Maryland, USA (WMO Symposium on Data Assimilation)	Scientific community (higher education, Research)	International	VALIDATED
72	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Ensemble Data Assimilation: Algorithmic and Practical Aspects	21/11/2013	Frankfurt am Main, Germany (Colloquium at Department of Meteorology, Goethe University)	Scientific community (higher education, Research)	International	VALIDATED
73	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	A comparison of linear and no-linear data assimilation techinques using a toy model	24/02/2014	Munich, Germany (International Symposium on Data Assimilation)	Scientific community (higher education, Research)	International	VALIDATED
74	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	The HBM-PDAF assimilation system for operational forecasts in the North and Baltic Seas	28/10/2014	Lisbon, Portugal (EuroGOOS 2014)	Scientific community (higher education, Research)	International	VALIDATED
75	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Extending NEMO for Ensemble Data Assimilation on Supercomputers with the Parallel Data Assimilation Frame	29/01/2015	Grenoble, France (NEMO Assimilation Meeting)	Scientific community (higher education, Research)	International	VALIDATED
76	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Building Ensemble-Based Data Assimilation Systems	13/04/2015	Vienna, Austria (EGU General Assembly)	Scientific community (higher education, Research)	International	VALIDATED
77	Oral presentation to a scientific event	STIFTELSEN NANSEN SENTER FOR MILJOOG FJERNMALING	Extending the square root method to account for model noise in the ensemble Kalman filter	09/05/2015	Flåm, Norway (International EnKF workshop)	Scientific community (higher education, Research)	International	VALIDATED
78	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	CNRS-LEGOS contribution to SANGOMA	26/11/2012	University of Liège, Belgium (First project meeting)	Scientific community (higher education, Research)	International	VALIDATED
79	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Impact of observations (TD, travaux dirigés)	24/06/2013	Bologna, Italy (Bologna Advanced Data Assimilation Summer School)	Scientific community (higher education, Research)	International	VALIDATED
80	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	The SANGOMA Tools For Data Assimilation	22/09/2014	Toulouse, France (MyOcean Science Days 2014)	Scientific community (higher education, Research)	International	VALIDATED
81	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Toward variational assimilation of SARAL/Altika altimeter data in a North Atlantic circulation model at eddy-permitting resolution: assessment of a NEMO-based 4D-VAR system	13/04/2015	Vienna, Austria (EGU 2015)	Scientific community (higher education, Research)	International	VALIDATED
82	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble assimilation of ARGO temperature profile, sea surface temperature and Altimetric satellite data into an eddy permitting primitive equation model of the North Atlantic ocean	13/04/2015	Vienna, Austria (EGU 2015)	Scientific community (higher education, Research)	International	VALIDATED
83	Oral presentation to a scientific event	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Ensemble assimilation of JASON/ENVISAT and JASON/AltiKA altimetric observations with stochastic parameterization of the model dynamical uncertainties	13/04/2015	Vienna, Austria (EGU 2015)	Scientific community (higher education, Research)	International	VALIDATED
84	Oral presentation to a scientific event	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	A comparison of linear and non-linear data assimilation methods using the NEMO ocean model	28/05/2015	Frankfurt am Main, Germany (Seminar at Goethe University Frankfurt)	Scientific community (higher education, Research)	International	VALIDATED
85	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	The SANGOMA Tools For Data Assimilation	04/05/2015	University of Liège, Belgium (47th Liège Colloquium on Ocean Dynamics)	Scientific community (higher education, Research)	International	VALIDATED
86	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	A comparison of linear and non-linear data assimilation methods using the NEMO ocean model	13/04/2015	Vienna, Austria (EGU 2015)	Scientific community (higher education, Research)	International	VALIDATED
87	Posters	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUER POLAR- UND MEERESFORSCHUNG	Extending NEMO for ensemble data assimilation on supercomputers with the parallel data assimilation framework PDAF	27/04/2014	Vienna, Austria (EGU 2014)	Scientific community (higher education, Research)	International	VALIDATED