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**Institut polytechnique de
Grenoble**

**Université Joseph Fourier
(Grenoble)**

Activity Report 2013

Project-Team MOISE

Modelling, Observations, Identification for Environmental Sciences

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
**Earth, Environmental and Energy
Sciences**

Table of contents

1. Members	1
2. Overall Objectives	2
2.1. Overall Objectives	2
2.2. Highlights of the Year	2
3. Research Program	3
3.1. Introduction	3
3.2. Numerical Modelling	3
3.3. Data Assimilation and Inverse Methods	3
3.4. Sensitivity Analysis - Quantification of Uncertainties	4
4. Application Domains	5
4.1. Introduction	5
4.2. Oceanography and the Ocean-Atmosphere System	5
4.3. Glaciology	6
4.4. River Hydraulics	7
5. Software and Platforms	7
5.1. Adaptive Grid Refinement	7
5.2. NEMOVAR	7
5.3. DatIce	8
5.4. SDM toolbox	8
5.5. CompModSA package	9
6. New Results	9
6.1. Mathematical Modelling of the Ocean Dynamics	9
6.1.1. Coupling Methods for Oceanic and Atmospheric Models	9
6.1.1.1. Interface conditions for coupling ocean models	9
6.1.1.2. Coupling dimensionally heterogeneous models	9
6.1.1.3. Ocean-Atmosphere coupling	10
6.1.2. Numerical schemes for ocean modelling	10
6.2. Data Assimilation for Geophysical Models	12
6.2.1. Development of a Variational Data Assimilation System for OPA9/NEMO	12
6.2.2. Ensemble Kalman filtering for large scale ice-sheet models	13
6.2.3. Inverse methods for full-Stokes glaciology models	13
6.3. Development of New Methods for Data Assimilation	14
6.3.1. Variational Data Assimilation with Control of Model Error	14
6.3.2. Direct assimilation of sequences of images	15
6.3.3. Image processing, Optimal transport	15
6.3.4. A Nudging-Based Data Assimilation Method: the Back and Forth Nudging	15
6.3.5. Multigrid methods for Variational Data Assimilation.	16
6.3.6. Variational Data Assimilation and Control of Boundary Conditions	16
6.4. Quantifying Uncertainty	16
6.4.1. Sensitivity analysis for forecasting ocean models	16
6.4.1.1. Scientific context	16
6.4.1.2. Estimating sensitivity indices	17
6.4.1.3. Intrusive sensitivity analysis, reduced models	17
6.4.1.4. Sensitivity analysis with dependent inputs	18
6.4.1.5. Multy-fidelity modeling for risk analysis	18
6.4.2. Evaluation of a posteriori covariance errors	18
6.4.3. Second Order Information in Variational Data Assimilation	19
6.5. Tracking of mesoscale convective systems	19
6.5.1. Scientific context	19

6.5.2. Results	19
6.6. Multivariate risk indicators	19
6.6.1. Scientific context	19
6.6.2. Results	19
6.7. Non-parametric estimation for kinetic diffusions	20
6.8. CO ₂ Storage	20
6.9. Land Use and Transport models calibration	20
6.10. Mathematical modelling for CFD-environment coupled systems	21
6.10.1. Minimal-time bioremediation of natural water resources	21
6.10.2. Mathematical modelling for the confinement of lagoons	21
7. Bilateral Contracts and Grants with Industry	21
8. Partnerships and Cooperations	22
8.1. Regional Initiatives	22
8.2. National Initiatives	23
8.2.1. Interactions with other Inria Project-Teams or Actions	23
8.2.2. Collaborations with other Research Teams in France	23
8.2.3. Other National Initiatives:	24
8.2.4. ANR	25
8.3. European Initiatives	25
8.3.1. FP7 Projects	25
8.3.2. Collaborations with Major European Organizations	25
8.4. International Initiatives	26
8.4.1. Inria International Labs	26
8.4.2. Participation In other International Programs	26
8.5. International Research Visitors	26
8.5.1. Visits of International Scientists	26
8.5.2. Visits to International Teams	26
9. Dissemination	26
9.1. Scientific Animation	26
9.2. Teaching - Supervision - Juries	27
9.2.1. Teaching	27
9.2.2. Supervision	27
9.2.3. PhD and HdR Juries	28
9.2.4. Other Juries and Evaluation Committees	29
9.3. Popularization	29
10. Bibliography	30

Project-Team MOISE

Keywords: Environment, Inverse Problem, Modeling, Numerical Methods, Statistical Methods

Creation of the Project-Team: 2006 July 01.

1. Members

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2. Overall Objectives

2.1. Overall Objectives

MOISE is a research project-team in applied mathematics and scientific computing, focusing on the development of **mathematical and numerical methods for direct and inverse modelling in environmental applications** (mainly geophysical fluids). The scientific backdrop of this project-team is the **design of complex forecasting systems**, our overall applicative aim being to contribute to the improvement of such systems, especially those related to natural hazards: climate change, regional forecasting systems for the ocean and atmosphere, decision tools for floods, ...

A number of specific features are shared by these different applications: interaction of different scales, multi-component aspects, necessity of combining heterogeneous sources of information (models, measurements, images), uniqueness of each event. The development of efficient methods therefore requires to take these features into account, a goal which covers several aspects, namely:

- Mathematical and numerical modelling
- Data assimilation (deterministic and stochastic approaches)
- Quantification of forecast uncertainties

Pluridisciplinarity is a key aspect of the project-team. The part of our work more related to applications is therefore being conducted in close collaboration with specialists from the different fields involved (geophysicists, etc).

2.2. Highlights of the Year

MOISE was a main contributor of the success of the MPT2013 event in France. Maëlle Nodet and Antoine Rousseau were co-authors of a movie that was presented at the MPT launch, at UNESCO. In addition, Maëlle and Antoine strongly participated to the initiative *Un jour, une brève*¹ in which Antoine was both executive editor and webmaster. This website - dedicated to scientific outreach - was visited by more than 1000 unique visitors each and every day of 2013. On the research side of MPT2013, several team members were in the main board of *Maths In Terre*²

¹See <http://mpt2013.fr>

²A French national program that was built to propose ANR a national strategy regarding applied mathematics and environmental sciences, see <http://mathsinterre.fr>.

3. Research Program

3.1. Introduction

Geophysical flows generally have a number of particularities that make it difficult to model them and that justify the development of specifically adapted mathematical and numerical methods:

- Geophysical flows are non-linear. There is often a strong interaction between the different scales of the flows, and small-scale effects (smaller than mesh size) have to be modelled in the equations.
- Every geophysical episode is unique: a field experiment cannot be reproduced. Therefore the validation of a model has to be carried out in several different situations, and the role of the data in this process is crucial.
- Geophysical fluids are non closed systems, i.e. there are always interactions between the different components of the environment (atmosphere, ocean, continental water, etc.). Boundary terms are thus of prime importance.
- Geophysical flows are often modeled with the goal of providing forecasts. This has several consequences, like the usefulness of providing corresponding error bars or the importance of designing efficient numerical algorithms to perform computations in a limited time.

Given these particularities, the overall objectives of the MOISE project-team described earlier will be addressed mainly by using the mathematical tools presented in the following.

3.2. Numerical Modelling

Models allow a global view of the dynamics, consistent in time and space on a wide spectrum of scales. They are based on fluid mechanics equations and are complex since they deal with the irregular shape of domains, and include a number of specific parameterizations (for example, to account for small-scale turbulence, boundary layers, or rheological effects). Another fundamental aspect of geophysical flows is the importance of non-linearities, i.e. the strong interactions between spatial and temporal scales, and the associated cascade of energy, which of course makes their modelling more complicated.

Since the behavior of a geophysical fluid generally depends on its interactions with others (e.g. interactions between ocean, continental water, atmosphere and ice for climate modelling), building a forecasting system often requires **coupling different models**. Several kinds of problems can be encountered, since the models to be coupled may differ in numerous respects: time and space resolution, physics, dimensions. Depending on the problem, different types of methods can be used, which are mainly based on open and absorbing boundary conditions, multi-grid theory, domain decomposition methods, and optimal control methods.

3.3. Data Assimilation and Inverse Methods

Despite their permanent improvement, models are always characterized by an imperfect physics and some poorly known parameters (e.g. initial and boundary conditions). This is why it is important to also have **observations** of natural systems. However, observations provide only a partial (and sometimes very indirect) view of reality, localized in time and space.

Since models and observations taken separately do not allow for a deterministic reconstruction of real geophysical flows, it is necessary to use these heterogeneous but complementary sources of information simultaneously, by using **data assimilation methods**. These tools for **inverse modelling** are based on the mathematical theories of optimal control and stochastic filtering. Their aim is to identify system parameters which are poorly known in order to correct, in an optimal manner, the model trajectory, bringing it closer to the available observations.

Variational methods are based on the minimization of a function measuring the discrepancy between a model solution and observations, using optimal control techniques for this purpose. The model inputs are then used as control variables. The Euler Lagrange condition for optimality is satisfied by the solution of the "Optimality System" (OS) that contains the adjoint model obtained by derivation and transposition of the direct model. It is important to point out that this OS contains all the available information: model, data and statistics. The OS can therefore be considered as a generalized model. The adjoint model is a very powerful tool which can also be used for other applications, such as sensitivity studies.

Stochastic filtering is the basic tool in the sequential approach to the problem of data assimilation into numerical models, especially in meteorology and oceanography. The (unknown) initial state of the system can be conveniently modeled by a random vector, and the error of the dynamical model can be taken into account by introducing a random noise term. The goal of filtering is to obtain a good approximation of the conditional expectation of the system state (and of its error covariance matrix) given the observed data. These data appear as the realizations of a random process related to the system state and contaminated by an observation noise.

The development of data assimilation methods in the context of geophysical fluids, however, is difficult for several reasons:

- the models are often strongly non-linear, whereas the theories result in optimal solutions only in the context of linear systems;
- the model error statistics are generally poorly known;
- the size of the model state variable is often quite large, which requires dealing with huge covariance matrices and working with very large control spaces;
- data assimilation methods generally increase the computational costs of the models by one or two orders of magnitude.

Such methods are now used operationally (after 15 years of research) in the main meteorological and oceanographic centers, but tremendous development is still needed to improve the quality of the identification, to reduce their cost, and to make them available for other types of applications.

A challenge of particular interest consists in developing methods for assimilating image data. Indeed, images and sequences of images represent a large amount of data which are currently underused in numerical forecast systems. However, despite their huge informative potential, images are only used in a qualitative way by forecasters, mainly because of the lack of an appropriate methodological framework.

3.4. Sensitivity Analysis - Quantification of Uncertainties

Due to the strong non-linearity of geophysical systems and to their chaotic behavior, the dependence of their solutions on external parameters is very complex. Understanding the relationship between model parameters and model solutions is a prerequisite to design better models as well as better parameter identification. Moreover, given the present strong development of forecast systems in geophysics, the ability to provide an estimate of the uncertainty of the forecast is of course a major issue. However, the systems under consideration are very complex, and providing such an estimation is very challenging. Several mathematical approaches are possible to address these issues, using either variational or stochastic tools.

Variational approach. In the variational framework, the sensitivity is the gradient of a response function with respect to the parameters or the inputs of the model. The adjoint techniques can therefore be used for such a purpose. If sensitivity is sought in the context of a forecasting system assimilating observations, the optimality system must be derived. This leads to the study of second-order properties: spectrum and eigenvectors of the Hessian are important information on system behavior.

Global stochastic approach. Using the variational approach to sensitivity leads to efficient computations of complex code derivatives. However, this approach to sensitivity remains local because derivatives are generally computed at specific points. The stochastic approach of uncertainty analysis aims at studying global criteria describing the global variabilities of the phenomena. For example, the Sobol sensitivity index is given by the ratio between the output variance conditionally to one input and the total output variance. The computation of such quantities leads to statistical problems. For example, the sensitivity indices have to be efficiently estimated from a few runs, using semi or non-parametric estimation techniques. The stochastic modeling of the input/output relationship is another solution.

4. Application Domains

4.1. Introduction

The evolution of natural systems, in the short, mid, or long term, has extremely important consequences for both the global Earth system and humanity. Forecasting this evolution is thus a major challenge from the scientific, economic, and human viewpoints.

Humanity has to face the problem of **global warming**, brought on by the emission of greenhouse gases from human activities. This warming will probably cause huge changes at global and regional scales, in terms of climate, vegetation and biodiversity, with major consequences for local populations. Research has therefore been conducted over the past 15 to 20 years in an effort to model the Earth's climate and forecast its evolution in the 21st century in response to anthropic action.

With regard to short-term forecasts, the best and oldest example is of course **weather forecasting**. Meteorological services have been providing daily short-term forecasts for several decades which are of crucial importance for numerous human activities.

Numerous other problems can also be mentioned, like **seasonal weather forecasting** (to enable powerful phenomena like an El Niño event or a drought period to be anticipated a few months in advance), **operational oceanography** (short-term forecasts of the evolution of the ocean system to provide services for the fishing industry, ship routing, defense, or the fight against marine pollution), **air pollution** prediction systems, the prediction of **floods**, or the simulation of **mud flows** and **snow avalanches** for impact studies and regional planning.

As mentioned previously, mathematical and numerical tools are omnipresent and play a fundamental role in these areas of research. In this context, the vocation of MOISE is not to carry out numerical prediction, but to address mathematical issues raised by the development of prediction systems for these application fields, in close collaboration with geophysicists.

4.2. Oceanography and the Ocean-Atmosphere System

Participants: Eric Blayo, Pierre-Antoine Bouttier, Vincent Chabot, Laurent Debreu, Jérémie Demange, Marc Honnorat, Christine Kazantsev, Eugène Kazantsev, François-Xavier Le Dimet, Florian Lemarié, Bénédicte Lemieux-Dudon, Maëlle Nodet, Antoine Rousseau, Manel Tayachi, Arthur Vidard.

Keywords: Multi-resolution, Coupling Methods, Data Assimilation, Ocean, Atmosphere

Understanding and forecasting the ocean circulation is currently the subject of an intensive research effort by the international scientific community. This effort was primarily motivated by the crucial role of the ocean in determining the Earth's climate, particularly from the perspective of global change. In addition, important recent research programs are aimed at developing operational oceanography, i.e. near real-time forecasting of ocean circulation, with applications for ship routing, fisheries, weather forecasting, etc. Another related field is coastal oceanography, dealing for example with pollution, littoral planning, or the ecosystems management. Local and regional agencies are currently very interested in numerical modelling systems for coastal areas.

Both ocean-alone models and coupled ocean-atmosphere models are being developed to address these issues. In this context, the MOISE project-team conducts efforts mainly on the following topics:

- *Multi-resolution approaches and coupling methods*: Many applications in coastal and operational oceanography require high resolution local models. These models can either be forced at their boundaries by some known data, or be dynamically coupled with a large-scale coarser resolution model. Such model interactions require specific mathematical studies on open boundary conditions, refinement methods (like mesh refinement or stochastic downscaling), and coupling algorithms. The latter have also to be studied in the context of ocean-atmosphere coupled systems.
- *Advanced numerical schemes*: Most ocean models use simple finite difference schemes on structured grids. We are seeking for better schemes allowing both accuracy and good conservation properties, and dealing with irregular boundaries and bottom topography.
- *Data assimilation methods for ocean modelling systems*: The main difficulties encountered when assimilating data in ocean or atmosphere models are the huge dimension of the model state vector (typically 10^6 - 10^8), the strongly nonlinear character of the dynamics, and our poor knowledge of model error statistics. In this context, we are developing reduced order sequential and variational data assimilation methods addressing the aforementioned difficulties. We are also working on the assimilation of lagrangian data, of sequences of images, and on the design of data assimilation methods for multi-resolution models and for coupled systems.

Most of these studies are led in strong interaction with geophysicists, in particular from the Laboratoire des Ecoulements Géophysiques et Industriels (LEGI, Grenoble).

4.3. Glaciology

Participants: Eric Blayo, Bertrand Bonan, Bénédicte Lemieux-Dudon, Maëlle Nodet.

Keywords: Inverse Methods, Data Assimilation, Glaciology, Ice Core Dating

The study of past climate is a means of understanding climatic mechanisms. Drillings in polar ice sheets provide a huge amount of information on paleoclimates: correlation between greenhouse gases and climate, fast climatic variability during the last ice age, etc. However, in order to improve the quantitative use of the data from this archive, numerous questions remain to be answered because of phenomena occurring during and after the deposition of snow. An important research aim is therefore to optimally model ice sheets in the vicinity of drilling sites in order to improve their interpretation: age scale for the ice and for the gas bubbles, mechanical thinning, initial surface temperature and accumulation when snow is deposited, spatial origin of ice from the drilling.

In another respect, ice streams represent an important feature of ice flows since they account for most of the ice leaving the ice sheet (in Antarctic, one estimates that ice streams evacuate more than 70% of the ice mass in less than 10% of the coast line). Furthermore, recent observations showed that some important ice streams are presently accelerating. Thus, we seek to improve models of ice sheets, by developing data assimilation approaches in order to calibrate them using available observations.

Another objective is the evaluation of the state of the polar ice caps in the past, and their interactions with the other components of the earth climate, in order to forecast their evolution in the forthcoming centuries. The joint use of models and data, through data assimilation techniques, to improve system description is relatively new for the glaciological community. Therefore inverse methods have to be developed or adapted for this particular purpose.

By gaining and loosing mass, glaciers and ice-sheets are playing a key role in the sea level evolution. This is obvious when regarding past as, for example, collapse of the large northern hemisphere ice-sheets after the Last Glacial Maximum has contributed to an increase of 120 m of sea level. This is particularly worrying when the future is considered. Indeed, recent observations clearly indicate that important changes in the velocity structure of both Antarctic and Greenland ice-sheets are occurring, suggesting that large and irreversible changes may have been initiated. This has been clearly emphasized in the last report published

by the Intergovernmental Panel on Climate Change (IPCC). IPCC has further insisted on the poor current knowledge of the key processes at the root of the observed accelerations and finally concluded that reliable projections of sea-level rise are currently unavailable. In this context, our general aim is to develop data assimilation methods related to ice flow modelling purpose, in order to provide accurate and reliable estimation of the future contribution of ice-sheets to Sea Level Rise.

Development of ice flow adjoint models is by itself a scientific challenge. This new step forward is clearly motivated by the amount of data now available at both the local and the large scales.

4.4. River Hydraulics

Participants: Eric Blayo, Mehdi-Pierre Daou, Antoine Rousseau, Manel Tayachi.

Shallow Water (SW) models are widely used for the numerical modeling of river flows. Depending on the geometry of the domain, of the flow regime, and of the level of accuracy which is required, either 1D or 2D SW models are implemented. It is thus necessary to couple 1D models with 2D models when both models are used to represent different portions of the same river. Moreover, when a river flows into the sea/ocean (e.g. the Rhône river in the Mediterranean), one may need to couple a 2D SW with a full 3D model (such as the Navier-Stokes equations) of the estuary. These issues have been widely addressed by the river-engineering community, but often with somehow crude approaches in terms of coupling algorithms. This may be improved thanks to more advanced boundary conditions, and with the use of Schwarz iterative methods for example. We tackled these issues, in the past in the framework of a partnership with the French electricity company EDF, and now thanks to another contract with ARTELIA Group.

5. Software and Platforms

5.1. Adaptive Grid Refinement

Participants: Laurent Debreu, Marc Honnorat.

AGRIF (Adaptive Grid Refinement In Fortran, [85], [84]) is a Fortran 90 package for the integration of full adaptive mesh refinement (AMR) features within a multidimensional finite difference model written in Fortran. Its main objective is to simplify the integration of AMR potentialities within an existing model with minimal changes. Capabilities of this package include the management of an arbitrary number of grids, horizontal and/or vertical refinements, dynamic regridding, parallelization of the grids interactions on distributed memory computers. AGRIF requires the model to be discretized on a structured grid, like it is typically done in ocean or atmosphere modelling. As an example, AGRIF is currently used in the following ocean models: MARS (a coastal model developed at IFREMER-France), ROMS (a regional model developed jointly at Rutgers and UCLA universities), NEMO ocean modelling system (a general circulation model used by the French and European scientific community) and HYCOM (a regional model developed jointly by University of Miami and the French Navy).

In 2013, a new contract has been signed with IFREMER to add online degradation capabilities. The software will be used operationally to attain a resolution of 500meters along the French coasts. (<http://www.previmer.org>) AGRIF is licensed under a GNU (GPL) license and can be downloaded at its web site (<http://ljk.imag.fr/MOISE/AGRIF/index.html>).

5.2. NEMOVAR

Participants: Arthur Vidard, Pierre-Antoine Bouttier, Bénédicte Lemieux-Dudon.

NEMOVAR is a state-of-the-art multi-incremental variational data assimilation system dedicated to the European ocean modelling platform NEMO for research and operational applications. It is co-developed by MOISE, CERFACS (FR), ECMWF (EU) and MetOffice (UK) under the CeCILL license, written in fortran and python. It is now in use in both ECMWF and MetOffice for their operational oceanic forecasting systems. It has also been used for specific studies in collaboration with Mercator-Ocean, LPO, LOCEAN and LEGI in France and University of Namur in Belgium. It is also a likely candidate for becoming the future Black-Sea forecasting system of the Marine Hydrographical Institute of Ukraine with whom we collaborate actively. Previously part of NEMOVAR, NEMO-TAM (Tangent and adjoint models for NEMO) that have been developed by the MOISE team will be now distributed directly by the NEMO consortium. The first official tagged release including NEMO-TAM has been published early 2013.

5.3. DatIce

Participant: Bénédicte Lemieux-Dudon.

Antarctic and Greenland ice cores provide a mean to study the phase relationships of climate changes in both hemispheres. They also enable to study the timing between climate and greenhouse gases or orbital forcings. One key step for such studies is to improve the absolute and relative precisions of ice core age scales (for ice and trapped gas), and beyond that, to try to reach the best consistency between chronologies of paleo-records of any kind.

The DatIce tool is designed to increase the consistency between pre-existing core chronologies (also called background). It formulates a variational inverse problem which aims at correcting three key quantities that uniquely define the core age scales: the accumulation rate, the total thinning function, and the close-off depth. For that purpose, it integrates paleo-data constraints of many types among which age markers (with for instance documented volcanoes eruptions), and stratigraphic links (with for instance abrupt changes in methane concentration). A cost function is built that enables to calculate new chronologies by making a trade-off between all the constraints (background chronologies and paleo-data).

DatIce enables to circumvent the limits encountered with other dating approaches, in particular because it controls the model errors, which are still large despite efforts to better describe the firn densification, the ice flow and the forcing fields (ice sheet elevation, temperature and accumulation rate histories). Controlling the model error makes it possible to assimilate large set of observations, to constrain both the gas and ice age scales, and to apply the process on several cores at the same time by including stratigraphic links between cores. This approach greatly improves the consistency of ice cores age scales.

The method presented in [93], [94] has already been applied simultaneously to EPICA EDML and EDC, Vostok and NGRIP drillings. The code has also been applied in two publications [78] and [106] which aimed at the construction of a unified chronology for Antarctic ice cores. LGGE, LSCE and MOISE are partners to extend the code to marine and terrestrial cores. On going development efforts are made to ensure the robustness of the dating solution (diagnostics on the assimilation system, calibration of the background error covariance matrices).

5.4. SDM toolbox

Participant: Antoine Rousseau.

The computation of the wind at small scale and the estimation of its uncertainties is of particular importance for applications such as wind energy resource estimation. To this aim, we develop a new method based on the combination of an existing numerical weather prediction model providing a coarse prediction, and a Lagrangian Stochastic Model adapted from a pdf method introduced by S.B. Pope for turbulent flows. This Stochastic Downscaling Method (SDM <http://sdm.gforge.inria.fr/>) is thus aimed to be used as a refinement toolbox of large-scale numerical models. SDM requires a specific modelling of the turbulence closure, and involves various simulation techniques whose combination is totally new (such as Poisson solvers, optimal transportation mass algorithm, original Euler scheme for confined Langevin stochastic processes, and stochastic particle methods). Since 2011, we work on the comparison of the SDM model (endowed with

a physical geostrophic forcing and a wall log law) with simulations obtained with a LES method (Mésos-NH code) for the atmospheric boundary layer (from 0 to 750 meters in the vertical direction), in the neutral case.

5.5. CompModSA package

Participants: Clémentine Prieur, Alexandre Janon, Céline Helbert.

Alexandre Janon is a contributor of the packages CompModSA - Sensitivity Analysis for Complex Computer Models (see <http://cran.open-source-solution.org/web/packages/CompModSA/index.html>), and sensitivity (see <http://cran.r-project.org/web/packages/sensitivity/index.html>). These packages are useful for conducting sensitivity analysis of complex computer codes.

Celine Helbert is now the maintainer of the packages DiceDesign (see <http://cran.r-project.org/web/packages/DiceDesign/index.html>) and DiceEval (see <http://cran.r-project.org/web/packages/DiceEval/index.html>). These packages are useful for conducting design and analysis of computer experiments.

6. New Results

6.1. Mathematical Modelling of the Ocean Dynamics

6.1.1. Coupling Methods for Oceanic and Atmospheric Models

Participants: Eric Blayo, Mehdi-Pierre Daou, Laurent Debreu, Florian Lemarié, Antoine Rousseau, Manel Tayachi.

6.1.1.1. Interface conditions for coupling ocean models

Many physical situations require coupling two models with not only different resolutions, but also different physics. Such a coupling can be studied within the framework of global-in-time Schwarz methods. However, the efficiency of these iterative algorithms is strongly dependent on interface conditions. As a first step towards coupling a regional scale primitive equations ocean model with a local Navier-Stokes model, a study on the derivation of interface conditions for 2-D $x - z$ Navier-Stokes equations has been performed in D. Cherel PhD thesis. It has been shown theoretically that several usual conditions lead to divergent algorithms, and that a convergent algorithm is obtained when using transmission conditions given by a variational calculation.

D. Cherel has implemented a Schwarz-based domain decomposition method, for which he developed optimized absorbing boundary conditions that mix the velocity and pressure variables on an Arakawa-C grid. The numerical results confirm the rate of convergence that has been obtained theoretically, thanks to a Fourier analysis of the semi-discretized problem. New optimized conditions offer much better convergence than classical Dirichlet-Dirichlet conditions, even when domains overlap. A paper is now ready for submission.

6.1.1.2. Coupling dimensionally heterogeneous models

The coupling of different types of models is gaining more and more attention recently. This is due, in particular, to the needs of more global models encompassing different disciplines (*e.g.* multi-physics) and different approaches (*e.g.* multi-scale, nesting). Also, the possibility to assemble different modeling units inside a friendly modelling software platform is an attractive solution compared to developing more and more global complex models. More specifically one may want to couple 1D to 2D or 3D models, such as Shallow Water and Navier Stokes models: this was the framework of our partnership with EDF in the project MECSICO, now extended with ARTELIA Group. In her PhD (defended Oct. 28th, 2013) [4], M. Tayachi built a theoretical and numerical framework to couple 1D, 2D and 3D models for river flows.

In [103] (now accepted for publication), we propose and analyze an efficient iterative coupling method for a dimensionally heterogeneous problem. We consider the case of a 2-D Laplace equation with non symmetric boundary conditions with a corresponding 1-D Laplace equation. We first show how to obtain the 1-D model from the 2-D one by integration along one direction, by analogy with the link between shallow water equations and the Navier-Stokes system. Then we focus on the design of a Schwarz-like iterative coupling method. We discuss the choice of boundary conditions at coupling interfaces. We prove the convergence of such algorithms and give some theoretical results related to the choice of the location of the coupling interface, and to the control of the difference between a global 2-D reference solution and the 2-D coupled one. These theoretical results are illustrated numerically. The extension of this work to shallow water equations has been started in 2013 with the PhD thesis of Medhi Pierre Daou (funded by ARTELIA). An extension to primitive equations is envisaged: a post-doc position has been proposed in 2013 (not funded) and will renewed in 2014.

6.1.1.3. Ocean-Atmosphere coupling

Coupling methods routinely used in regional and global climate models do not provide the exact solution to the ocean-atmosphere problem, but an approached one [75]. This finding has motivated a deep numerical analysis of multi-physics coupling problems, first on simplified academic cases based on diffusion equations. In this context, Schwarz-like iterative domain decomposition methods have been analyzed and efficient interface conditions have been determined to optimize the convergence rate of the method [19], [20], [53], [79]. This method has then been applied to the coupling of realistic oceanic and atmospheric models to simulate the propagation of a tropical cyclone (cyclone erica, Fig. 1). Sensitivity tests to the coupling method have been carried out in an ensemblist approach. We showed that with a mathematically consistent coupling, compared to coupling methods en vogue in existing coupled models, the spread of the ensemble is reduced, thus indicating a much reduced uncertainty in the physical solution [24], [75].

The next step is now to complete the theoretical work done on a diffusion problem by including the formulation of physical parameterizations to tackle a problem more representative of the realistic models: a PhD thesis should start on this subject in fall 2014. In parallel, an important perspective is to assess the impact of our work on IPCC-like climate models, this task will be initiated in 2014 through a collaboration between the MOISE project-team and the LSCE (Laboratoire des Sciences du Climat et de l'Environnement).

In collaboration with geophysicists, number of studies to investigate important small-scales air-sea feedbacks are in progress [45]. Through those studies, the aim will be to mathematically derive a metamodel able to represent important processes in the marine atmospheric boundary layers. The medium term objective will be to use this metamodel to force high-resolution oceanic operational models for which the use of a full atmospheric model is not possible due to a prohibitive computational cost.

6.1.2. Numerical schemes for ocean modelling

Participants: Laurent Debreu, Jérémie Demange, Florian Lemarié.

Reducing the traditional errors in terrain-following vertical coordinate ocean models (or sigma models) has been a focus of interest for the last two decades. The objective is to use this class of model in regional domains which include not only the continental shelf, but the slope and deep ocean as well. Two general types of error have been identified: 1) the pressure-gradient error and 2) spurious diapycnal diffusion associated with steepness of the vertical coordinate. In ([92],[46]) we have studied the problem of diapycnal mixing. The solution to this problem requires a specifically designed advection scheme. We propose and validate a new scheme, where diffusion is split from advection and is represented by a rotated biharmonic diffusion scheme with flow-dependent hyperdiffusivity. The main numerical development was to render the biharmonic diffusion operator scheme unconditionally stable. This is particularly needed when the slopes between coordinates lines and isopycnal surfaces are important so that the rotation of the biharmonic leads to strong stability condition along the vertical coordinate where the grid size is relatively small. This work also extends more classical results on the stability of Laplacian diffusion with mixed derivatives.

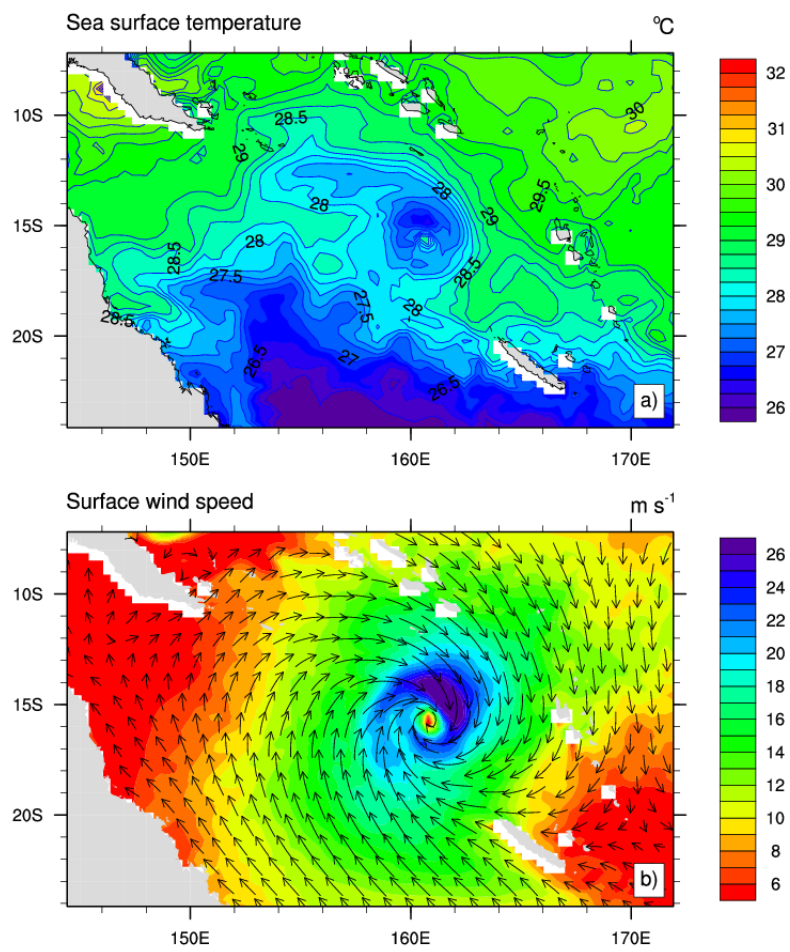


Figure 1. Snapshots (March 12, 2003 at 8 p.m. GMT) of (a) oceanic sea surface temperature (b) atmospheric 10 meter winds during a coupled simulation.

In his PhD, Jérémie Demange works on advection-diffusion schemes for ocean models (Supervisors : L. Debreu, P. Marchesiello (IRD)). His work focuses on the link between tracers (temperature and salinity) and momentum advection and diffusion in the non hyperbolic system of equations typically used in ocean models (the so called primitive equations with hydrostatic and Boussinesq assumptions). We also investigated the use of a depth dependent barotropic mode in free surface ocean models. When most ocean models assume that this mode is vertically constant, we have shown that the use of the true barotropic mode, derived from a normal mode decomposition, allows more stability and accuracy in the representation of external gravity waves.

Salinity at 1000 m in the Southwest Pacific ocean is shown in figure 2. The use of traditional upwind biased schemes (middle) exhibits a strong drift in the salinity field in comparison with climatology (left). The introduction of high order diffusion rotated along geopotential surfaces prevents this drift while maintaining high resolution features (right).

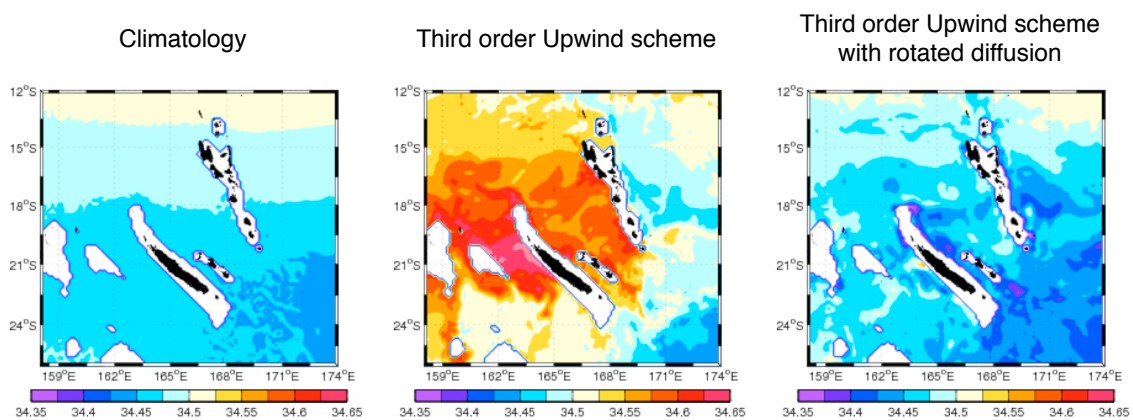


Figure 2. Salinity at 1000m in the Southwest Pacific ocean.

6.2. Data Assimilation for Geophysical Models

6.2.1. Development of a Variational Data Assimilation System for OPA9/NEMO

Participants: Arthur Vidard, Bénédicte Lemieux-Dudon, Pierre-Antoine Bouttier, Eric Blayo.

We are heavily involved in the development of NEMOVAR (Variational assimilation for NEMO). For several years now, we built a working group (coordinated by A. Vidard) in order to bring together various NEMOVAR user-groups with diverse scientific interests (ranging from singular vector and sensitivity studies to specific issues in variational assimilation). It has led to the creation of the VODA (Variational Ocean Data Assimilation for multi scales applications) ANR project (ended in 2012). A new project, part of a larger EU-FP7 project (ERA-CLIM2) has been submitted late 2012 and will start early 2014.

The project aims at delivering a common NEMOVAR platform based on NEMO platform for 3D and 4D variational assimilation. Following 2009-11 VODA activities, a fully parallel version of NEMOTAM (Tangent and Adjoint Model for NEMO) is now available for the community in the standard NEMO version. This version is based on the released 3.4.1 version of NEMO.

We are also investigating variational data assimilation methods applied to high resolution ocean numerical models (see figure 3). This part of the project is now well advanced and encouraging preliminary results are available on an idealised numerical configuration of an oceanic basin. Several novative diagnostics have been also developed in this framework as part of P.A. Bouttier's PhD that will be defended early 2014

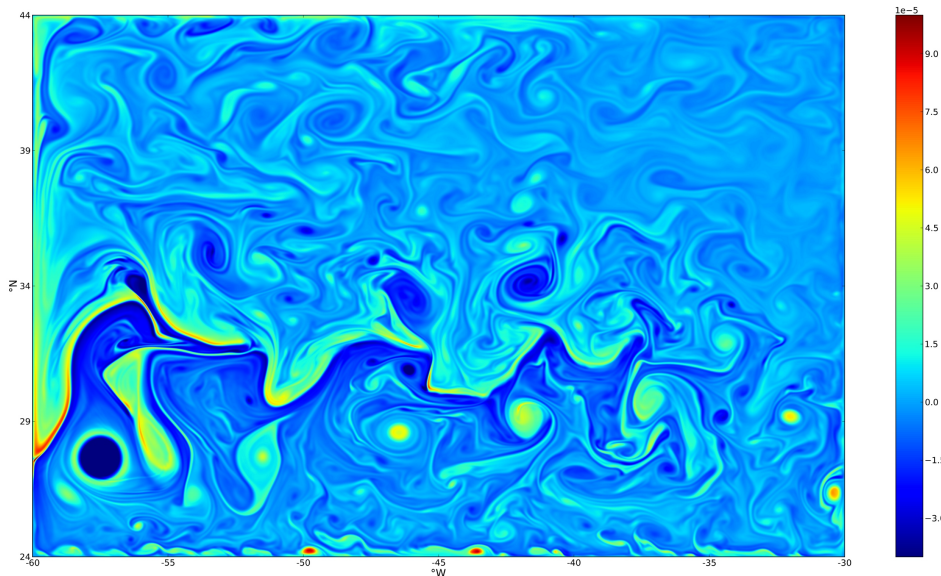


Figure 3. Snapshot of the relative vorticity field (1/s) for an academic oceanic basin model at $1/100^\circ$ horizontal resolution.

Lastly, multi resolution algorithms have been developed to solve the variational problem, and preliminary results were presented in two international communications [52], [51].

6.2.2. Ensemble Kalman filtering for large scale ice-sheet models

Participants: Bertrand Bonan, Maëlle Nodet, Catherine Ritz.

In collaboration with C. Ritz (CNRS, Laboratoire de Glaciologie et Geophysique de l'Environnement (LGGE), Grenoble), we aim to develop inverse methods for ice cap models.

In the framework of global warming, the evolution of sea level is a major but ill-known phenomenon. It is difficult to validate the models which are used to predict the sea level elevation, because observations are heterogeneous and sparse.

Data acquisition in polar glaciology is difficult and expensive. Satellite data have a good spatial coverage, but they allow only indirect observation of the interesting data. Moreover, ice dynamics processes are highly non linear and involve many feedback loops, so that classical linear data assimilation give poor results.

B. Bonan defended his PhD [1] in November 2013 on this subject. We implemented the Ensemble Transform Kalman Filter (ETKF) algorithm for a flowline Shallow-Ice model, called Winnie, developed by C. Ritz at LGGE. On twin experiments we got interesting results. Figures 4 show the reconstruction of the bedrock topography for various ensemble sizes. We can see that the obtained bedrock is very close to the true one, even for small ensemble sizes. This is very promising for the future, as we want to implement this method into a full 3D model. A journal paper has been submitted on this subject, and the results have been presented at many conferences [27], [37], [48], [38], [39].

6.2.3. Inverse methods for full-Stokes glaciology models

Participants: Olivier Gagliardini, Maëlle Nodet, Catherine Ritz.

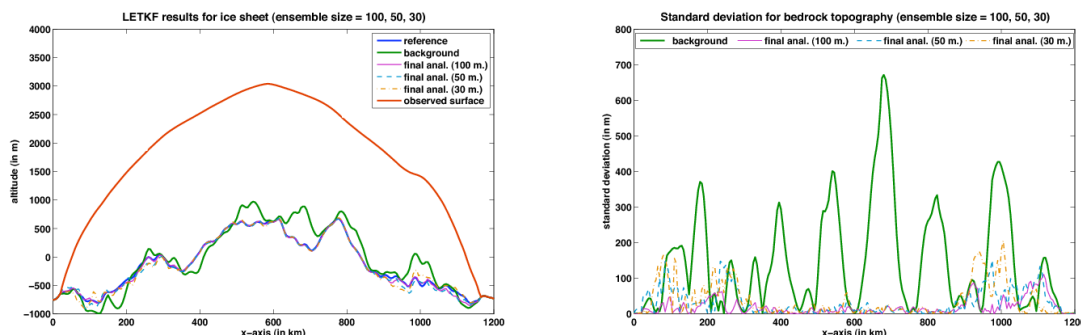


Figure 4.

Left: Bedrock topography after 20 years of the LETKF with inflation. The background (green) is compared to reference (blue) and the analyses for various ensemble sizes: 100 members (purple), 50 members (cyan) and 30 members (orange).

Right: Standard deviation of the errors (compared to the reference) for the bedrock topography after 20 years of the LETKF with inflation. The background (green) is compared to the analyses for various ensemble sizes: 100 members (purple), 50 members (cyan) and 30 members (orange).

We are investigating the means to apply inverse modeling to another class of glaciology models, called full-Stokes model. Such a model is developed by LGGE and CSC in Finland, called Elmer/Ice. Contrary to large scale models, Elmer/Ice is based on the full Stokes equations, and no assumptions regarding aspect ratio are made, so that this model is well adapted to high resolution small scale modelling, such as glaciers (and more recently the whole Greenland ice-sheet).

In collaboration with O. Gagliardini, F. Gillet-Chaulet and C. Ritz (Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE), Grenoble), we investigated a new method to solve inverse problems for a Full-Stokes model of Groenland, which consisted in solving iteratively a sequence of Neumann and Dirichlet problems within a gradient descent algorithm. We also compared this method to an approximate variational algorithm, using the fact that the full Stokes equations are almost self-adjoint. These results have been presented at an international conference [44].

6.3. Development of New Methods for Data Assimilation

6.3.1. Variational Data Assimilation with Control of Model Error

Participants: Bénédicte Lemieux-Dudon, Arthur Vidard.

One of the main limitations of the current operational variational data assimilation techniques is that they assume the model to be perfect, mainly because of computing cost issues. Numerous researches have been carried out to reduce the cost of controlling model errors by controlling the correction term only in certain privileged directions or by controlling only the systematic and time correlated part of the error.

Both the above methods consider the model errors as a forcing term in the model equations. Trémolet (2006) describes another approach where the full state vector (4D field: 3D spatial + time) is controlled. Because of computing cost one cannot obviously control the model state at each time step. Therefore, the assimilation window is split into sub-windows, and only the initial conditions of each sub-window are controlled, the junctions between each sub-window being penalized. One interesting property is that, in this case, the computation of the gradients, for the different sub-windows, are independent and therefore can be done in parallel.

This method is now implemented in a realistic oceanic framework using OPAVAR/ NEMOVAR. An extensive documentation has been produced and we are now assessing the improvement over the previous scheme

6.3.2. *Direct assimilation of sequences of images*

Participants: François-Xavier Le dimet, Maëlle Nodet, Nicolas Papadakis, Arthur Vidard, Vincent Chabot.

At the present time the observation of Earth from space is done by more than thirty satellites. These platforms provide two kinds of observational information:

- Eulerian information as radiance measurements: the radiative properties of the earth and its fluid envelops. These data can be plugged into numerical models by solving some inverse problems.
- Lagrangian information: the movement of fronts and vortices give information on the dynamics of the fluid. Presently this information is scarcely used in meteorology by following small cumulus clouds and using them as Lagrangian tracers, but the selection of these clouds must be done by hand and the altitude of the selected clouds must be known. This is done by using the temperature of the top of the cloud.

MOISE was the leader of the ANR ADDISA project dedicated to the assimilation of images, and is a member of its follow-up GeoFluids (along with EPI FLUMINANCE and CLIME, and LMD, IFREMER and Météo-France) that just ended in 2013.

During the ADDISA project we developed Direct Image Sequences Assimilation (DISA) and proposed a new scheme for the regularization of optical flow problems [101]. Thanks to the nonlinear brightness assumption, we proposed an algorithm to estimate the motion between two images, based on the minimization of a nonlinear cost function. We proved its efficiency and robustness on simulated and experimental geophysical flows [77]. As part of the ANR project GeoFluids, we are investigating new ways to define distance between a couple of images. One idea is to compare the gradient of the images rather than the actual value of the pixels. This leads to promising results. Another idea, currently under investigation, consists in comparing main structures within each image. This can be done using, for example, a wavelet representation of images. Both approaches have been compared, in particular their relative merits in dealing with observation errors, in a submitted paper late 2013 [63] and presented in a national conference [34]

We are also part of TOMMI, another ANR project started mid 2011, where we are investigating the possibility to use optimal transportation based distances for images assimilation.

6.3.3. *Image processing, Optimal transport*

Participants: Maëlle Nodet, Nicolas Papadakis, Arthur Vidard, Nelson Feyeux.

Within the optimal transport project TOMMI funded by the ANR white program, a new optimization scheme based on proximal splitting method has been proposed to solve the dynamic optimal transport problem. This work allows the computation of generalized optimal transports and will be published in SIAM Journal on Imaging Sciences [96]. We investigate also the use of optimal transport based distances for data assimilation. N. Feyeux just started his PhD on this subject, and his PhD project has been presented in a regional workshop [49].

6.3.4. *A Nudging-Based Data Assimilation Method: the Back and Forth Nudging*

Participants: Maëlle Nodet, Jacques Blum, Didier Auroux.

The Back and Forth Nudging (BFN) algorithm has been recently introduced for simplicity reasons, as it does not require any linearization, nor adjoint equation, or minimization process in comparison with variational schemes. Nevertheless it provides a new estimation of the initial condition at each iteration.

Previous theoretical results showed that BFN was often ill-posed for viscous partial differential equations. To overcome this problem, we proposed a new version of the algorithm, which we called the Diffusive BFN, and which showed very promising results on one-dimensional viscous equations. Experiments on more sophisticated geophysical models, such as Shallow-Water equations and NEMO ocean model are still in progress, in collaboration with University of Nice, and have been presented at the MAMERN conference [30].

6.3.5. Multigrid methods for Variational Data Assimilation.

Participants: Laurent Debreu, François-Xavier Le Dimet, Arthur Vidard.

In order to lower the computational cost of the variational data assimilation process, we investigate the use of multigrid methods to solve the associated optimal control system. On a linear advection equation, we study the impact of the regularization term on the optimal control and the impact of discretization errors on the efficiency of the coarse grid correction step. We show that even if the optimal control problem leads to the solution of an elliptic system, numerical errors introduced by the discretization can alter the success of the multigrid methods. The view of the multigrid iteration as a preconditioner for a Krylov optimization method leads to a more robust algorithm. A scale dependent weighting of the multigrid preconditioner and the usual background error covariance matrix based preconditioner is proposed and brings significant improvements. This work is presented in a paper submitted to QJRM (68).

6.3.6. Variational Data Assimilation and Control of Boundary Conditions

Participant: Eugène Kazantsev.

A variational data assimilation technique is applied to the identification of the optimal boundary conditions for two configurations of the NEMO model.

The first one is a full-physics low-resolution configuration, known as ORCA-2 model. In this experiment we identify optimal parametrizations of boundary conditions on the lateral boundaries as well as on the bottom and on the surface of the ocean [17]. The influence of boundary conditions on the solution is analyzed as in the assimilation window and beyond the window. It is shown that the influence of the lateral boundaries is not significant in this configuration, while optimal surface and bottom boundary conditions allow us to better represent the jet streams, such as Gulf Stream and Kuroshio. Analyzing the reasons of the jets reinforcement, we notice that data assimilation has a major impact on parametrization of the bottom boundary conditions for u and v [23].

The second configuration of the Nemo model is devoted to the identification of the optimal parametrization of lateral boundary conditions. The model in a rectangular box placed in mid-latitudes and subjected to the classical single or double gyre wind forcing is studied. The model grid can be rotated on a desired angle around the center of the rectangle in order to simulate the boundary approximated by a staircase-like coastlines. The solution of the model on the grid aligned with the box borders was used as a reference solution and as artificial observational data. It is shown that optimal boundary has a rather complicated geometry which is neither a staircase, nor a strait line. The boundary conditions found in the data assimilation procedure brings the solution toward the reference solution allowing to correct the influence of the rotated grid (see fig. 5).

Adjoint models, necessary to variational data assimilation, have been produced by the TAPENADE software, developed by the TROPICS team. This software is shown to be able to produce the adjoint code, that can be used in data assimilation after a memory usage optimization.

6.4. Quantifying Uncertainty

6.4.1. Sensitivity analysis for forecasting ocean models

Participants: Anestis Antoniadis, Eric Blayo, Gaëlle Chastaing, Céline Helbert, Alexandre Janon, François-Xavier Le Dimet, Simon Nanty, Maëlle Nodet, Clémentine Prieur, Federico Zertuche, Simon Nanty, Laurent Gilquin.

6.4.1.1. Scientific context

Forecasting ocean systems require complex models, which sometimes need to be coupled, and which make use of data assimilation. The objective of this project is, for a given output of such a system, to identify the most influential parameters, and to evaluate the effect of uncertainty in input parameters on model output. Existing stochastic tools are not well suited for high dimension problems (in particular time-dependent problems), while deterministic tools are fully applicable but only provide limited information. So the challenge is to gather expertise on one hand on numerical approximation and control of Partial Differential Equations, and

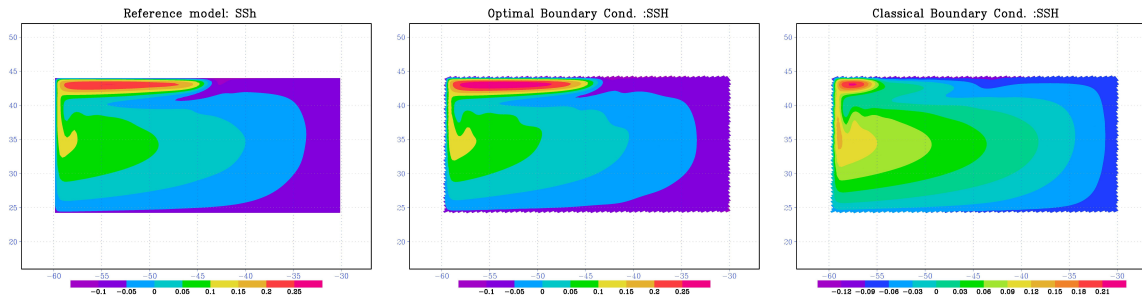


Figure 5. Sea surface elevation: reference solution on the aligned grid (left), solutions on the 30° rotated grid with optimal (center) and classical (right) boundary conditions.

on the other hand on stochastic methods for sensitivity analysis, in order to develop and design innovative stochastic solutions to study high dimension models and to propose new hybrid approaches combining the stochastic and deterministic methods.

6.4.1.2. Estimating sensitivity indices

A first task is to develop tools for estimated sensitivity indices. In variance-based sensitivity analysis, a classical tool is the method of Sobol' [100] which allows to compute Sobol' indices using Monte Carlo integration. One of the main drawbacks of this approach is that the estimation of Sobol' indices requires the use of several samples. For example, in a d -dimensional space, the estimation of all the first-order Sobol' indices requires $d + 1$ samples. Some interesting combinatorial results have been introduced to weaken this defect, in particular by Saltelli [98] and more recently by Owen [95] but the quantities they estimate still require $O(d)$ samples. In a recent work [104] we introduce a new approach to estimate for any k all the k -th order Sobol' indices by using only two samples based on replicated latin hypercubes. We establish theoretical properties of such a method for the first-order Sobol' indices and discuss the generalization to higher-order indices. As an illustration, we propose to apply this new approach to a marine ecosystem model of the Ligurian sea (northwestern Mediterranean) in order to study the relative importance of its several parameters. The calibration process of this kind of chemical simulators is well-known to be quite intricate, and a rigorous and robust — i.e. valid without strong regularity assumptions — sensitivity analysis, as the method of Sobol' provides, could be of great help. The computations are performed by using CIGRI, the middleware used on the grid of the Grenoble University High Performance Computing (HPC) center. We are also applying these estimates to calibrate integrated land use transport models. It is the first step in the PhD of Laurent Gilquin (started in October 2013). Laurent Gilquin is supervised by Clémentine Prieur and Elise Arnaud (EPI STEEP) and his PhD is funded by the ANR project CITIES.

We can now wonder what are the asymptotic properties of these new estimators, or also of more classical ones. In [67], the authors deal with asymptotic properties of the estimators. In [70], the authors establish also a multivariate central limit theorem and non asymptotic properties.

6.4.1.3. Intrusive sensitivity analysis, reduced models

Another point developed in the team for sensitivity analysis is model reduction. To be more precise regarding model reduction, the aim is to reduce the number of unknown variables (to be computed by the model), using a well chosen basis. Instead of discretizing the model over a huge grid (with millions of points), the state vector of the model is projected on the subspace spanned by this basis (of a far lesser dimension). The choice of the basis is of course crucial and implies the success or failure of the reduced model. Various model reduction methods offer various choices of basis functions. A well-known method is called "proper orthogonal decomposition" or "principal component analysis". More recent and sophisticated methods also exist and may be studied, depending on the needs raised by the theoretical study. Model reduction is a natural

way to overcome difficulties due to huge computational times due to discretizations on fine grids. In [10], the authors present a reduced basis offline/online procedure for viscous Burgers initial boundary value problem, enabling efficient approximate computation of the solutions of this equation for parametrized viscosity and initial and boundary value data. This procedure comes with a fast-evaluated rigorous error bound certifying the approximation procedure. The numerical experiments in the paper show significant computational savings, as well as efficiency of the error bound. When a metamodel is used (for example reduced basis metamodel, but also kriging, regression, ...) for estimating sensitivity indices by Monte Carlo type estimation, a twofold error appears : a sampling error and a metamodel error. Deriving confidence intervals taking into account these two sources of uncertainties is of great interest. We obtained results particularly well fitted for reduced basis metamodels [90]. We are now considering problems related to more general models such as Shallow-Water models. In [15], the authors provide asymptotic confidence intervals in the double limit where the sample size goes to infinity and the metamodel converges to the true model.

Let us come back to the output of interest. Is it possible to get better error certification when the output is specified. A work in this sense has been submitted, dealing with goal oriented uncertainties assessment [89].

6.4.1.4. Sensitivity analysis with dependent inputs

An important challenge for stochastic sensitivity analysis is to develop methodologies which work for dependent inputs. For the moment, there does not exist conclusive results in that direction. Our aim is to define an analogue of Hoeffding decomposition [88] in the case where input parameters are correlated. Clémentine Prieur supervised Gaëlle Chastaing's PhD thesis on the topic (defended in September 2013) [2]. We obtained first results [81], deriving a general functional ANOVA for dependent inputs, allowing defining new variance based sensitivity indices for correlated inputs. We then adapted various algorithms for the estimation of these new indices. These algorithms make the assumption that among the potential interactions, only few are significant. Two papers have been submitted [64], [66].

Céline Helbert and Clémentine Prieur supervise the PhD thesis of Simon Nanty (funded by CEA Cadarache). The subject of the thesis is the analysis of uncertainties for numerical codes with temporal and spatio-temporal input variables, with application to safety and impact calculation studies. This study implies functional dependent inputs. A first step is the modeling of these inputs.

6.4.1.5. Multy-fidelity modeling for risk analysis

Federico Zertuche's PhD concerns the modeling and prediction of a digital output from a computer code when multiple levels of fidelity of the code are available. A low-fidelity output can be obtained, for example on a coarse mesh. It is cheaper, but also much less accurate than a high-fidelity output obtained on a fine mesh. In this context, we propose new approaches to relieve some restrictive assumptions of existing methods ([91], [97]) : a new estimating method of the classical cokriging model when designs are not nested and a nonparametric modeling of the relationship between low-fidelity and high-fidelity levels. The PhD takes place in the REDICE consortium and in close link with industry. The first year was also dedicated to the development of a case study in fluid mechanics with CEA in the context of the study of a nuclear reactor.

The second year of the thesis was dedicated to the development of a new sequential approach based on a course to fine wavelets algorithm.

6.4.2. Evaluation of a posteriori covariance errors

In the context of data assimilation, taking into account the a priori covariance error on the prediction and on the observations, the model and the observations, an analysis can be obtained followed by a prediction. This one makes sense only if an estimation of the error can be provided. The tendency is to use "ensemble methods" i.e. to realize a large number of predictions and estimate statistics on the results. This method raises two problems: the high computational cost and the weak theoretical justification. We have proposed a new method based on the fact that in the linear case the covariance is the inverse of the Hessian. The principle of our method is to add a correcting term to the Hessian in the non linear case. This work has been published in 2013 [14]. This paper has also been presented at the 6th WMO Symposium on Data Assimilation held in College Park, MD, USA in October 2013 [73].

6.4.3. Second Order Information in Variational Data Assimilation

This theme is centered around sensitivity analysis with respect to the observations. The link between data and models is made only in the Optimality System. Therefore a sensitivity analysis on the observations must be carried out on the Optimality System thus using second order information. This research is done in cooperation with Victor Shutyaev (Institute of Numerical Mathematics, Moscow), Tran Thu Ha (Institute of Mechanics, Ha Noi, Vietnam). One paper is published in the Russ. J. Of Numerical Analysis [18]. Another application to identification of parameters in a hydrological model is submitted [105].

6.5. Tracking of mesoscale convective systems

Participants: Clémentine Prieur, Alexandros Makris.

6.5.1. Scientific context

We are interested in the tracking of mesoscale convective systems. A particular region of interest is West Africa. Data and hydrological expertise is provided by T. Vischel and T. Lebel (LTHE, Grenoble).

6.5.2. Results

A first approach involves adapting the multiple hypothesis tracking (MHT) model originally designed by the NCAR (National Centre for Atmospheric Research) for tracking storms [102] to the data for West Africa. With A. Makris (working on a post-doctoral position), we proposed a Bayesian approach [76], which consists in considering that the state at time t is composed on one hand by the events (birth, death, splitting, merging) and on the other hand by the targets' attributes (positions, velocities, sizes, ...). The model decomposes the state into two sub-states: the events and the targets positions/attributes. The events are updated first and are conditioned to the previous targets sub-state. Then given the new events the target substate is updated. A simulation study allowed to verify that this approach improves the frequentist approach by Storlie et al. (2009). It has been tested on simulations and must now be investigated in the specific context of real data on West Africa. Using PHD (probability hypothesis density) filters adapted to our problem, generalising recent developments in particle filtering for spatio-temporal branching processes (e.g. [80]) could be an interesting alternative to explore. The idea of a dynamic, stochastic tracking model should then provide the base for generating rainfall scenarios over a relatively vast area of West Africa in order to identify the main sources of variability in the monsoon phenomenon.

6.6. Multivariate risk indicators

Participants: Clémentine Prieur, Patricia Tencaliec.

6.6.1. Scientific context

Studying risks in a spatio-temporal context is a very broad field of research and one that lies at the heart of current concerns at a number of levels (hydrological risk, nuclear risk, financial risk etc.). Stochastic tools for risk analysis must be able to provide a means of determining both the intensity and probability of occurrence of damaging events such as e.g. extreme floods, earthquakes or avalanches. It is important to be able to develop effective methodologies to prevent natural hazards, including e.g. the construction of barrages.

6.6.2. Results

Different risk measures have been proposed in the one-dimensional framework. The most classical ones are the return level (equivalent to the Value at Risk in finance), or the mean excess function (equivalent to the Conditional Tail Expectation CTE). However, most of time there are multiple risk factors, whose dependence structure has to be taken into account when designing suitable risk estimators. Relatively recent regulation (such as Basel II for banks or Solvency II for insurance) has been a strong driver for the development of realistic spatio-temporal dependence models, as well as for the development of multivariate risk measurements that effectively account for these dependencies. We refer to [82] for a review of recent extensions of the notion of return level to the multivariate framework. In the context of environmental risk, [99] proposed

a generalization of the concept of return period in dimension greater than or equal to two. Michele et al. proposed in a recent study [83] to take into account the duration and not only the intensity of an event for designing what they call the dynamic return period. However, few studies address the issues of statistical inference in the multivariate context. In [9], [86], we proposed non parametric estimators of a multivariate extension of the CTE. As might be expected, the properties of these estimators deteriorate when considering extreme risk levels. In collaboration with Elena Di Bernardino (CNAM, Paris), Clémentine Prieur is working on the extrapolation of the above results to extreme risk levels.

Elena Di Bernardino, Véronique Maume-Deschamps (Univ. Lyon 1) and Clémentine Prieur also derived an estimator for bivariate tail [10]. The study of tail behavior is of great importance to assess risk.

With Anne-Catherine Favre (LTHE, Grenoble), Clémentine Prieur supervises the PhD thesis of Patricia Tencaliec. We are working on risk assessment, concerning flood data for the Durance drainage basin (France). The PhD thesis started in October.

6.7. Non-parametric estimation for kinetic diffusions

Participant: Clémentine Prieur.

This research is the subject of a collaboration with Venezuela (Professor Jose R. Leon, Caracas Central University) and is partly funded by an ECOS Nord project.

We are focusing our attention on models derived from the linear Fokker-Planck equation. From a probabilistic viewpoint, these models have received particular attention in recent years, since they are a basic example for hypercoercivity. In fact, even though completely degenerated, these models are hypoelliptic and still verify some properties of coercivity, in a broad sense of the word. Such models often appear in the fields of mechanics, finance and even biology. For such models we believe it appropriate to build statistical non-parametric estimation tools. Initial results have been obtained for the estimation of invariant density, in conditions guaranteeing its existence and unicity [8] and when only partial observational data are available. A paper on the non parametric estimation of the drift has been submitted recently [62] (see Samson et al., 2012, for results for parametric models). As far as the estimation of the diffusion term is concerned, we obtained promising results, in collaboration with J.R. León (Caracas, Venezuela) and P. Cattiaux (Toulouse). These results should be submitted shortly.

6.8. CO₂ Storage

Participant: Céline Helbert.

In collaboration with Bernard Guy (EMSE, Saint-Etienne) and more specifically in the context the PhD of Joharivola Raveloson (EMSE, Saint-Etienne), we are interested in the study of the water-rock interactions in the case of CO₂ storage in geological environment. This work is following the study of Franck Diedro in the same subject [87]. In this study we focus on the scale of observation of geochemical phenomena while taking into account the heterogeneity of the reservoir. This heterogeneity at small and large scale helps to maintain a local variability of the chemical composition and influence reaction rates at the pore as well at the reservoir scale. To connect the parameters at both scale (pore and reservoir) we use deterministic and stochastic simulations of a reactive transport code developed by IFPEN.

6.9. Land Use and Transport models calibration

Participants: Thomas Capelle, Laurent Gilquin, Clémentine Prieur, Nicolas Papadakis, Arthur Vidard.

Given the complexity of modern urban areas, designing sustainable policies calls for more than sheer expert knowledge. This is especially true of transport or land use policies, because of the strong interplay between the land use and the transportation systems. Land use and transport integrated (LUTI) modelling offers invaluable analysis tools for planners working on transportation and urban projects. Yet, very few local authorities in charge of planning make use of these strategic models. The explanation lies first in the difficulty to calibrate these models, second in the lack of confidence in their results, which itself stems from the absence of any well-defined validation procedure. Our expertise in such matters will probably be valuable for improving the reliability of these models. To that purpose we participated to the building up of the ANR project CITiES lead by the STEEP EPI. This project has just started early 2013 and Two PhD about sensitivity analysis and calibration were launched this fall.

6.10. Mathematical modelling for CFD-environment coupled systems

Participants: Antoine Rousseau, Maëlle Nodet.

6.10.1. Minimal-time bioremediation of natural water resources

The objective of this work is to provide efficient strategies for the bioremediation of natural water resources. The originality of the approach is to couple minimal time strategies that are determined on a simplified model with a faithful numerical model for the hydrodynamics. Based on a previous paper that deals with an implicit representation of the spatial inhomogeneity of the resource with a small number of homogeneous compartments (with a system of ODEs), we implement a coupled ODE-PDE system that accounts for the spatial non-homogeneity of pollution in natural resources. The main idea is to implement a Navier-Stokes model in the resource (such as a lake), with boundary conditions that correspond to the output feedback that has been determined to be optimal for the simple ODEs model of a (small) bioreactor. A first mathematical model has been introduced and numerical simulations have been performed in academic situations. We built a reduced model that approximates the reference PDE model thanks to a set of ODEs with parameters. Numerical optimization is performed on these parameters in order to better fit the reference model. In addition, bioremediation algorithms proposed by the authors have been sent to Inria Technology Transfert Services for a patent registration. Two publications (ready for submission) will be sent as soon as the patent submission process is complete.

Finally, A. Rousseau spent 2 weeks in Santiago (April 2013) upon Inria Chile's invitation in order to work on the bioremediation of natural resources. AR and Inria Chile made a common answer to a chilean funding program (by COPEC) that was not chosen.

6.10.2. Mathematical modelling for the confinement of lagoons

This work deals with the concept of confinement of paralic ecosystems. It is based on a recent paper by E. Frénod that presents a modelling procedure in order to compute the confinement field of a lagoon.

A. Rousseau and E. Frénod improve in 2012 the existing model in order to account for tide oscillations in any kind of geometry such as a non-rectangular lagoons with a non-flat bottom. The new model, that relies on PDEs rather than ODEs, is then implemented thanks to the finite element method. Numerical results confirm the feasibility of confinement studies thanks to the introduced model. During the internship of J.-P. Bernard, we implemented the proposed method in a realistic situation, namely the Etang de Thau in Languedoc-Roussillon, France (see Figure 6). This led to two publications in 2013 [5] and [13], plus one accepted paper in 2014 [6].

7. Bilateral Contracts and Grants with Industry

7.1. Contracts with Industry

- A 3-year contract with EDF: project MeCSiCo (coupling methods for the simulation of river flows): see 4.4
- A 3-year contract with ARTELIA Group: funding for the PhD thesis of M.P. Daou (CIFRE): see 4.4

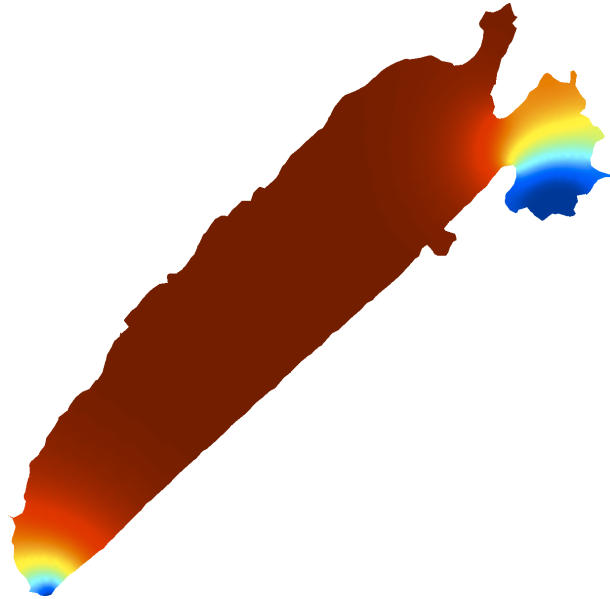


Figure 6. Confinement map in the Thau Lagoon (France).

- A 2-year contract with ADEME and MAIA EOLIS on the thematic "Stochastic Downscaling Method": see 5.4.
- A 4-year contract named ReDICE (Re Deep Inside Computer Experiments) with EDF, CEA, IRSN, RENAULT, IFP on the thematic computer experiments
- A 3-year contract with CEA Cadarache related to Simon Nanty's PhD.
- A 1-year contract with IFREMER on the thematic "Online degradation using the AGRIF software": see 5.1

8. Partnerships and Cooperations

8.1. Regional Initiatives

- M. Nodet is responsible for the workpackage "numerical modelling" within the regional project (Région Rhône-Alpes) "**Envirhonalp**" <http://www.envirhonalp.fr>.
- M. Nodet is involved in E. Maitre MSTIC project MENTOL about Optimal Transport.
- A. Rousseau leads the working group *Couplage Fluide/Vivant* in Montpellier for the study of coupled systems (fluid dynamics and life sciences) in nearshore regions. This research is funded by the Labex NUMEV in Montpellier.
- Clémentine Prieur is a member of the project "Soutien à l'Excellence et à l'Innovation Grenoble INP" MEPIERA (Méthodologies innovantes Pour l'Ingénierie de l'Eau et des Risques Associés) led by A.- C. Favre (LTHE).

8.1.1. Collaborations with Various Regional Research Teams

- LGGE, MEOM team : 6.3.2,6.2.1,6.3.2,6.3.6, 6.3.5, 6.1.2.

- LGGE Grenoble, Edge team (C. Ritz, O. Gagliardini, F. Gillet-Chaulet, G. Durand), see paragraphs [6.2.2](#) and [6.2.3](#).
- LTHE, A.C. Favre: hydrological risk assessment.
- LTHE, Thierry Lebel, Théo Vischel: tracking of mesoscale convective systems,
- LTHE, MISTIS, LJK: PEPS (CNRS, PRES Grenoble) project AGREE on multivariate risk assessment. The project was funded in 2013 and led by M. Clausel (LJK).
- LTHE, MISTIS, LJK: AGIR project. Clémentine Prieur obtained the funding for a thesis on risk assessment.
- Building energy (G2ELab, Mathilde Grandjacques, Benoît Delinchant). : [6.4.1,6.5](#)
- Univ. Lyon 1 collaboration with V. Maume-Deschamps and S. Loisel.

8.2. National Initiatives

8.2.1. Interactions with other Inria Project-Teams or Actions

Participants	Inria Project-Team	Research topic	Link
F. Lemarié	POMDAPI	Coupling methods	6.1.1
A. Rousseau	TOSCA	Stochastic Downscaling Method	5.4
A. Rousseau	MODEMIC	Bioremediation of natural resources	6.10
C.Prieur, P. Tencaliec	MISTIS	hydrological risk assessment	6.6
C. Helbert, C.Prieur, A. Vidard, N. Papadakis	STEEP	Calibration and sensitivity analysis for LUTI models	6.9
A. Vidard M. Nodet F.X. Le Dimet	CLIME, FLUMINANCE	Image assimilation	6.3.2
A. Vidard, M. Nodet, E.Kazantsev	TROPICS	Ocean Adjoint Modelling	6.2.1,6.3.6
L.Debreu,	CLIME, FLUMINANCE	Multiscale data assimilation	6.2.1
C.Prieur, L. Viry	GRAAL	Grid deployment for the study of West African Monsoon	6.4

8.2.2. Collaborations with other Research Teams in France

Participants	Research Team	Research topic	Link
L. Debreu, F. Lemarié	IFREMER (Brest), LOCEAN (Paris)	Ocean modelling, Ocean-atmosphere coupling	6.1.2 , 6.1.1
F. Lemarié	CNRM (Toulouse)	Ocean-atmosphere coupling	6.1.1
A. Rousseau	Institut de Mathématiques et de Modélisation de Montpellier (I3M)	Modelling and simulation of coastal flows	6.1
A. Rousseau	Laboratoire de Météorologie Dynamique (Ecole Polytechnique)	Stochastic Downscaling Method	5.4
E.Blayo, A.Rousseau, F. Lemarié	LAMFA (Amiens), LAGA (Paris 13)	Coupling methods	6.1.1 , 6.1.1
A. Rousseau	IFREMER (Sète), UMR Ecosym (Montpellier)	Coupling fluids and life sciences	6.10
C. Prieur	IMT Toulouse, IFP Rueil, EDF, CEA Cadarache	Sensitivity analysis	6.4.1
C. Prieur	ISFA Lyon 1, Université de Bourgogne, CNAM	Multivariate risk indicators	6.6
C. Prieur	IMT Toulouse, Caracas	non parametric estimation for hypoelliptic diffusions	6.7
A. Vidard	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (Toulouse), Mercator-Océan (Toulouse), Laboratoire de Physique des Océans (Brest),	Ocean Data Assimilation	6.2.1
A. Vidard	LOCEAN (Paris)	Ocean Adjoint Modelling	6.2.1
A. Vidard	LPO (Brest), CERFACS	Ocean data assimilation	6.2.1
B.Lemieux	LSCE (Laboratoire des Sciences de l'Environnement et du Climat)	DatIce tool	5.3

8.2.3. Other National Initiatives:

- A. Vidard leads a group of projects gathering multiple partners in France and UK on the topic "Variational Data Assimilation for the NEMO/OPA9 Ocean Model", see [6.2.1](#).
- C. Prieur chairs GdR MASCOT NUM, in which are also involved M. Nodet, E. Blayo, A. Rousseau, C. Helbert, L. Viry, A. Janon, S. Nanty, L. Gilquin and G. Chastaing. <http://www.gdr-mascotnum.fr/doku.php>
- M. Nodet is PI of the project "Méthodes inverses en glaciologie" supported by INSU-LEFE.
- A. Rousseau is PI of the project COCOA "Couplages Côtes, Océan, Atmosphère" supported by INSU-LEFE.
- F. Lemarié leads a group of projects gathering multiple partners in France on the topics « ocean-atmosphere coupling » and « numerical analysis of time schemes in ocean models » (funded by CNRS-INSU LEFE).
- E.Kazantsev, E.Blayo, F. Lemarié participate in the project "PACO - Vers une meilleure paramétrisation de la côte et des conditions limites dans les modèles d'océan" supported by LEFE-GMMC and LEFE-MANU .

- M. Nodet is involved in GDR Calcul and GDR Ondes.
- E. Blayo is the chair of the CNRS-INSU research program on mathematical and numerical methods for ocean and atmosphere LEFE-MANU. <http://www.insu.cnrs.fr/co/lefe>
- L. Debreu is the coordinator of the national group COMODO (Numerical Models in Oceanography)

8.2.4. ANR

- A 4-year ANR contract: ANR COSTA-BRAVA (Complex Spatio-Temporal Dynamics Analysis by Reduced Models and Sensitivity Analysis) http://www.math.univ-toulouse.fr/COSTA_BRAVA/index.html
- A 4-year ANR contract: ANR ADAGe (Adjoint ice flow models for Data Assimilation in Glaciology).
- A 4-year ANR contract: ANR Geo-FLUIDS (Fluid flows analysis and simulation from image sequences: application to the study of geophysical flows, see paragraph 6.3.2) .
- A 4-year ANR contract: ANR TOMMI (Transport Optimal et Modèles Multiphysiques de l'Image), see paragraphs 6.3.3, 6.3.2.
- A 4 year ANR contract (2011-2015): ANR COMODO (Communauté de Modélisation Océanographique) on the thematic "Numerical Methods in Ocean Modelling". (coordinator L. Debreu) 6.1.2
- A 3.5 year ANR contract: ANR CITiES (numerical models project selected in 2012). http://steep.inrialpes.fr/?page_id=46

8.3. European Initiatives

8.3.1. FP7 Projects

8.3.1.1. ERA-CLIM2

Type: COOPERATION

Instrument: Specific Targeted Research Project

Program: Collaborative project FP7-SPACE-2013-1

Project acronym: ERA-CLIM2

Project title: European Reanalysis of the Global Climate System

Duration: 01/2014 - 12/2016

Coordinator: Dick Dee (ECMWF, Europe)

Other partners: Met Office (UK), EUMETSAT (Europe), Univ Bern (CH), Univ. Vienne (AT), FFCUL (PT), RIHMI-WDC (RU), Mercator-Océan (FR), Météo-France (FR), DWD (DE), CER-FACS (FR), CMCC (IT), FMI (FI), Univ. Pacifico (CL), Univ. Reading (UK), Univ. Versailles St Quentin en Yvelines (FR)

Inria contact: Arthur Vidard

8.3.2. Collaborations with Major European Organizations

Partner: European Centre for Medium Range Weather Forecast. Reading (UK)

World leading Numerical Weather Centre, that include an ocean analysis section in order to provide ocean initial condition for the coupled ocean atmosphere forecast. They play a significant role in the NEMOVAR project in which we are also partner.

Partner: Met Office (U.K) National British Numerical Weather and Oceanographic service. Exeter (UK).

We do have a strong collaboration with their ocean initialization team through both our NEMO, NEMO-ASSIM and NEMOVAR activities. They also are our partner in the NEMOVAR consortium.

Partner: Marine Hydrographic Institute, Natinal Ac.Sci. Ukraine, Sevastopol.

We have a long term collaboration about data assimilation with the Black Sea. This collaboration is getting to a new level with their plan to adopt NEMO and NEMOVAR for their operational forecasting system. On our side, we will benefit from their expertise on the Black Sea dynamics, that is an excellent test case for our developments and methods.

Partner: GDR-E CONEDP

Subject: Control of Partial Differential Equations.

Partner: University of Reading, Department of Meteorology, Department of Mathematics

Subject: Data assimilation for geophysical systems.

8.4. International Initiatives

8.4.1. Inria International Labs

- A. Rousseau spent 2 weeks in Santiago in April 2013 and started a collaboration with Inria Chile.

8.4.2. Participation In other International Programs

- C. Prieur collaborates with Antonio Galves (University Sao Paulo) and Jose R. Leon (UCV, Central University of Caracas). She is a member of a USP-COFECUB project on the study of stochastic models with variable length memory (2010-2013) with University of Sao Paulo.
- C. Prieur is leader of a project ECOS Nord with Venezuela (2012-2015).
- F.-X. Le Dimet collaborates with the Institute of Mechanics of the Vietnamese Academy of Sciences Ha Noi, and with the Institute of Numerical Mathematics of the Russian Academy of Sciences.
- F. Lemarié collaborates with A.F. Shchepetkin and J.C. McWilliams from the University of California at Los Angeles (UCLA).

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Angie Pineda (invited 6 weeks in 2013 by C. Prieur through the ECOS Nord project),
- Jose R. León (invited 2 weeks in 2013 by C. Prieur through the ECOS Nord project).
- Victor Shutyaev, Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow (invited for 4 weeks by F.-X. Le Dimet, see 6.4.2, 6.4.3)
- Igor Gejadze, University of Strathclyde, Glasgow, UK (invited for 4 week by F.-X. Le Dimet, see 6.4.2)
- Nancy Nichols, University of Reading, invited for 1 week by A. Vidard and M. Nodet

8.5.2. Visits to International Teams

- F.-X. Le Dimet was invited to the Florida State University for 6 weeks in May 2013 and to the Institute of Numerical Mathematics Moscow for 2 weeks in June 2013

9. Dissemination

9.1. Scientific Animation

- A. Rousseau is a member of the editorial board of *Discrete and Continuous Dynamical Systems - Series S (DCDS-S)*.
- F. Lemarié and A. Rousseau organized a mini-symposium «Domain Decomposition Methods for Environmental Modeling» during the DD22 international conference in Lugano (Switzerland) [47].

- C. Prieur is a member of the editorial board of the section "états de l'art" of Journal of the French Statistical Society (SFdS).
- C. Prieur is in the scientific committee of the SAMO 2013 conference which will be held in Nice in July 2013, jointly with MASCOT NUM annual conference. The SAMO conference has now (since September 2013) a permanent board. C. Prieur is a member of that board.
- C. Prieur, E. Blayo, A. Rousseau have taken part in 2013 to the wide consortium of the Prospective think tank: MATHématiqueS en INteractions pour la TERRE whose purpose is to help the French National Research AgencyNR defining the research-funding program on the theme Mathematics for the Earth.
- C. Prieur was in the scientific committee of the Journées MAS 2013 (SMAI) which were held in Clermont-Ferrand in August 2012.
- C. Prieur and L. Viry organize jointly with H. Monod and R. Faivre (INRA) a school on sensitivity analysis for environmental models (les Houches, 7-12 April, 2013; 4-9 May, 2014).
- C. Prieur is a member of the scientific council of the French Mathematical Society (SMF).
- C. Prieur is member of the board of the group mathematical statistics of the French society of statistics (SFdS) since 2008.
- C. Prieur organized a session on sensitivity analysis in the Journées MAS (SMAI) 2013.
- C. Prieur organized a session on statistical estimation for PDE in the SMAI workshop 2013.
- M. Nodet co-organised with S. Labbé and Ch. Prieur the annual workshop of the GDRE research group in Grenoble, <http://ljk.imag.fr/membres/Maëlle.Nodet/GDRE2013>
- A. Vidard is deputy scientific leader to data assimilation for the NEMO consortium
- F.-X. Le Dimet participates in the organisation of the Sasaki Symposium in the framework of AOGS 2013 (Brisbane, June 2013) and of the Coupling Systems with heterogeneous information ERC (Rennes, January 2014)
- Since 2010, Ch. Kazantsev is the Director of the IREM of Grenoble <http://www-irem.ujf-grenoble.fr/irem/accueil/>. The Institute is under rapid development now, joining about 30 teachers of secondary schools of the Grenoble region and 15 university professors. They work together 16 times a year on the development of the teaching strategy for the educational community. In addition to this, IREM is the editor of two journals: "Grand N" destined to primary schools teachers and "Petit x" – to the secondary schools.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence: M. Nodet: Statistics, 80h, L2, Université de Grenoble, France

Licence: E. Blayo: Statistics, 36h, L2, Université de Grenoble, France

Master: M. Nodet: Inverse Methods, 28h, M2, Université de Grenoble, France

Licence: E. Blayo, M. Nodet : Mathematics for engineers, 80h, L1, university of Grenoble, France

Master : E. Blayo: Finite element methods, 45h, M1, university of Grenoble, France

Master: E. Blayo: Data assimilation in oceanography, 2h, M2, Ecole des ponts Paris Tech, France

Master : L. Debreu, Numerical ocean modelling, 12H, M2, University of Brest, France

Doctorat: E. Blayo, A. Vidard, introduction to data assimilation, 20h, Université de Grenoble, France

9.2.2. Supervision

HdR : M. Nodet, Inverse problems for the environment: tools, methods and applications, Université de Grenoble, November 28th 2013, [3]

PhD : B. Bonan, Assimilation de données pour l'initialisation et l'estimation de paramètres d'un modèle d'évolution de calotte polaire, Université de Grenoble, Nov 15th 2013, advisers: M. Nodet and C. Ritz. [1]

PhD : Manel Tayachi, Couplage de modèles de dimensions hétérogènes et application en hydrodynamique, Université Joseph Fourier, 28 octobre 2013, Eric Blayo and Antoine Rousseau, [4]

PhD : Gaëlle Chastaing, Estimation des indices de sensibilité sous conditions de dépendance, Université Joseph Fourier, 2013, C. Prieur and F. Gamboa, [2].

PhD in progress : Pierre-Antoine Bouttier, Variational data assimilation into highly nonlinear ocean models, October 2009, E. Blayo and J. Verron

PhD in progress : Vincent Chabot, Nouvelles distances pour l'assimilation de séquence d'images, start Nov 2010, advisers: A. Vidard and M. Nodet

PhD in progress : N. Feyeux, Transport optimal pour l'assimilation de séquences d'images, start Nov 2013, advisers: A. Vidard and M. Nodet

PhD in progress : Jérémie Demange, Numerical schemes for tracers and momentum advection in ocean models, 15/12/2010, Supervisors : L. Debreu and P. Marchesiello (IRD).

PhD in progress : Mehdi Pierre Daou, Développement d'une méthodologie de couplage multi-modèles avec changements de dimension. Validation sur un cas-test réaliste en dynamique littorale, May 2013, E. Blayo and A. Rousseau

PhD in progress: Federico Zertuche, Exploitation des simulateurs multifidelites pour l'analyse de risque, Octobre 2011, C. Prieur and C. Helbert.

PhD in progress : Simon Nanty, Approche stochastique pour la quantification des incertitudes et l'analyse de sensibilité des codes de calcul à entrées temporelles et spatio-temporelles : application aux études de sûreté et de calcul d'impact, October 2012, C. Prieur, C. Helbert

PhD in progress : Laurent Gilquin, October 2013, C. Prieur

PhD in progress : Patricia Tencaliec, Gestion des risques multivariés extrêmes, application à des données de débit sur le bassin versant de la Durance October 2013, C. Prieur

PhD in progress : Thomas Capelle, Recherche sur des methodes d'optimisation pour la mise en place de modeles integres de transport et usage des sols, October 2013, P. Sturm, A. Vidard

9.2.3. PhD and HdR Juries

- E. Blayo was a referee of PhD thesis of Selime Gurol: Solving regularized nonlinear least-squares problem in dual space. Université de Toulouse, June 14, 2013
- E. Blayo was a referee of PhD thesis of Sébastien Beyou: Estimation de la vitesse des courants marins à partir de séquences d'images satellitaires. Université de Rennes, July 12, 2013
- E. Blayo was a member of the jury for the PhD defense of Gaëlle Chastaings: Indices de Sobol généralisés pour variables dépendantes. Université de Grenoble, September 23, 2013.
- E. Blayo was a member of the jury for the PhD defense of Lucile Gaultier: Couplage des observations spatiales dynamiques et biologiques pour la restitution des circulations océaniques: une approche conjointe par assimilation de données altimétriques et de traceurs. Université de Grenoble, October 16, 2013.
- E. Blayo was a member of the jury for the HDR defense of Frédéric Parrenin: Sur l'âge de la glace et des bulles de gaz dans les calottes polaires. Université de Grenoble, October 21, 2013.
- E. Blayo was a member of the jury for the PhD defense of Olivier Vannier: Apport de la modélisation hydrologique régionale à la compréhension des processus de crue en zone méditerranéenne. Université de Grenoble, November 22, 2013
- F.-X. Le Dimet was a member of the jury for the HDR defense of Benjamin Ivorra: Méthodes et techniques de Modélisation, de Simulation et d'Optimisation appliquées à divers problèmes industriels, Université de Montpellier 2, February, 7, 2013.

- C. Prieur was a chair of the PhD jury of Matthias De Lozzo, INSA Toulouse,
- C. Prieur was a chair of the PhD jury of Jonathan El Methni, Université Grenoble 1
- C. Prieur was a chair of the PhD jury of Gérémy Panthou, Université Grenoble 1
- C. Prieur was a member of the PhD jury of Anne Sabourin, Université Lyon 1
- C. Prieur was a member of the PhD jury of Gaëlle Chastaing, Université Grenoble 1
- A. Rousseau was member of the PhD committee of Vincent Visseq (Université Montpellier II)
- A. Rousseau was member of the PhD committee of Nathan Martin (INSA Toulouse)
- A. Vidard was member of the PhD jury of Lucille Gaultier, Université Grenoble I
- A. Vidard was reviewer of the PhD of Alexandre Imperiale, Université Paris VI

9.2.4. Other Juries and Evaluation Committees

- M. Nodet is a member of the national board of Agregation externe de mathématiques 2013
- M. Nodet was a member of the recruiting committee of an assistant professor in applied mathematics in ENSEEIT Toulouse.
- C. Prieur was a member of the jury of the EADS Foundation's Best Thesis Prize reward.
- C. Prieur was a member of the AERES evaluation committee of the LAMA (Univ. Paris Est Marne la Vallée, Univ. Paris Est Créteil), in December, 2013.
- A. Rousseau is a member of Inria Evaluation Committee
- A. Rousseau was member of Inria Bordeaux committee for young graduate scientists
- A. Rousseau was member of Inria Grenoble committee for young graduate scientists
- A. Rousseau was member of the national Inria committee for research positions (both starting and advanced)
- A. Rousseau was member of the national Inria committee for internal competition « Assistant Ingénieur »

9.3. Popularization

- E. Blayo gave several conferences for highschool students on the topics of applied mathematics and applied mathematics for environment.
- A. Rousseau is the Grenoble Rhône-Alpes scientific correspondent for outreach
- A. Rousseau and M. Nodet wrote an outreach article in the APMEP journal about mathematical modelling for the environment [59].
- A. Rousseau, M. Nodet and S. Minjeaud (Nice) developed an impressive outreach effort on the subject of ocean circulation, called "Bottles and Oceanography". They first wrote a paper and designed a numerical experiment, then they proposed a physical experiment as well. This whole package has been presented at UNESCO for the launch of Maths for Planet Earth 2013 <http://mpe2013.org/mpe-day-at-unesco>, and is a part of the IMAGINARY platform for outreach <http://imaginary.org/films/flaschen-und-ozeanographie>. It has also been presented at the Comité International des Jeux mathématiques [57], and has been published in the journal Textes et Documents pour la Classe (resources for highschool teachers) [56].
- A. Rousseau and M. Nodet are members of the editorial committee of Maths for Planet Earth "Un jour une brève" operation <http://mpt2013.fr>, which aimed and succeeded to publish every day a short outreach article in 2013. Moreover, A. Rousseau is also webmaster and member of the executive board (6 people) of the operation.
- A. Rousseau and M. Nodet gave conferences during the Science Fair / Fete de la Science, for highschool students and their teachers, on the topics of mathematical modelling for the environment.

- M. Nodet gave a talk at the JELU workshop, which regroups university teachers and highschool teachers on teaching methods.
- M. Nodet wrote and outreach article about glaciology in the journal of the French society for applied mathematics SMAI, in the special issue MATAPLI number 100 on the occasion of Mathematics for Planet Earth 2013.
- M. Nodet gave a conference at the Mathematics Weeks in Valence for highschool students and their teachers, on the topic of mathematics for the environment and meteorology.
- Ch. Kazantsev begins a collaboration with Morocco, she has presented the IREM and IREM activities to the Ecole Normale de Rabat who wants now to create such an Institute.
- In the context of the program "100 parrains-100 classes", Ch. Kazantsev gives a weekly lectures to pupils of one secondary school in Grenoble.
- Ch. Kazantsev has participated in the "Fête de sciences" and in the "Semaine des maths" presenting the activities of the IREM of Grenoble.
- F. Zertuche and J. Calandreau have participated in the "Fête de sciences" presenting the activities of Moise.

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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