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Institut polytechnique de Grenoble

Université Joseph Fourier (Grenoble)

Activity Report 2012

Project-Team MOISE

Modelling, Observations, Identification for Environmental Sciences

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Observation and Modeling for Environmental Sciences

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Project-Team MOISE

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

The MOISE project-team, LJK-IMAG laboratory (UMR 5224), is a joint project between CNRS, Inria, Institut Polytechnique de Grenoble (Grenoble INP), Joseph Fourier University (UJF) and Pierre-Mendès-France University (UPMF). Team leader is Eric Blayo.

This project-team is located in the LJK laboratory.

Creation of the Project-Team: July 01, 2006 .

1. Members

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Jose-Raphael Leon-Ramos [Caracas University, 2 weeks]
Victor Shutyaev [Russian Academy of Sciences, 2 weeks]
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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, mud or lava flows...

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

François-Xavier Le Dimet has been nominated Fellow of the American Meteorological Society. He received this distinction in New Orleans on the January, 22, 2012 during the annual General Assembly of the Association. He is the second French scientist to get this award. See http://www.ujf-grenoble.fr/universite/medias-et-communication/actualities/francois-xavier-le-dimet-elu-fellow-of-the-american-meteorological-society-244259.htm?RH=UJF

The paper *"Variational algorithms for analysis and assimilation of meteorological observations."* by F.-X. Le Dimet and O. Talagrand [86] has received more than 1 000 citations.

3. Scientific Foundations

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, David Cherel, Laurent Debreu, Jérémie Demange, Marc Honnorat, Christine Kazantsev, Eugène Kazantsev, François-Xavier Le Dimet, Bénédicte Lemieux-Dudon, Xavier Meunier, Maëlle Nodet, Antoine Rousseau, Manel Tayachi, Arthur Vidard.

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, Habib Toye Mahamadou Kele.

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, 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 want to tackle these issues, in particular in the framework of a partnership with the French electricity company EDF.

5. Software

5.1. Adaptive Grid Refinement

Participants: Laurent Debreu, Marc Honnorat.

AGRIF (Adaptive Grid Refinement In Fortran, [80],[6]) 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), OPA-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 2012, a new contract has been signed with IFREMER to optimize parallel capabilities of the software. 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 will be published early 2013.

5.3. DatIce

Participants: Bénédicte Lemieux-Dudon, Habib Toye Mahamadou Kele.

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 ([84], [85]) has already been applied simultaneously to EPICA EDML and EDC, Vostok and NGRIP drillings. The DatIce tool has aroused some interest in the glaciological and paleo-community since 2009.

The code has been recently applied in two publications [2] and [22] 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 (Méso-NH code) for the atmospheric boundary layer (from 0 to 750 meters in the vertical direction), in the neutral case.

5.5. CompModSA package

Alexandre Janon is a contributor of the packages CompModSA - Sensitivity Analysis for Complex Computer Models (see http://cran.r-project.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.

6. New Results

6.1. Mathematical Modelling of the Ocean Dynamics

6.1.1. Beyond the traditional approximation on the Coriolis force

Participant: Antoine Rousseau.

Formerly, A. Rousseau has performed some theoretical and numerical studies around the derivation of quasi-hydrostatic models. With C. Lucas, he proved that it is sometimes necessary to take into account the cosine part of the Coriolis force (which is usually neglected, leading to the so-called Traditional Approximation).
They have also shown that the non-traditional terms do not raise any additional mathematical difficulty in the primitive equations: well-posedness for both weak and strong solutions.
A. Rousseau and J. McWilliams (UCLA) proposed a mathematical justification of the tilt of convective plumes in the quasi-geostrophic regime, thanks to the account of the complete Coriolis force in the so-called quasi-hydrostatic quasi-geostrophic (QHQG) model. The new model has been presented in international conferences [59] and [60].

6.1.2. Coupling Methods for Oceanic and Atmospheric Models

Participants: Eric Blayo, David Cherel, Laurent Debreu, Antoine Rousseau, Manel Tayachi.

6.1.2.1. 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.
A first step towards the coupling between Navier-Stokes and primitive equations has been made in 2012. Starting from the optimized boundary conditions obtained for the Navier-Stokes equations, we performed an asymptotic analysis in order to obtain boundary conditions that should supplement the hydrostatic Navier-Stokes equations. These results have been presented in national and international conferences [47], [46], a paper is in preparation. David Cherel defended his PhD on Dec. 12th, 2012.

6.1.2.2. 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 is the framework of our partnership with EDF in the project MECSICO. In her PhD, M. Tayachi is aimed to build a theoretical and numerical framework to couple 1D, 2D and 3D models for river flows.

In [65], 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 shallow0water equations and primitive equations has been started recently.

6.1.3. Numerical schemes for ocean modelling

Participants: Laurent Debreu, Jérémie Demange.

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 a recent paper [87], 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 satisfying the Peclet constraint.

In 2012, in collaboration with F. Lemarié at UCLA, this work has been extended in order to render the biharmonic diffusion operator scheme unconditionally stable [17]. 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.

In his PhD, Jérémie Demange begins a work on advection-diffusion schemes for ocean models (Supervisors : L. Debreu, P. Marchesiello (IRD)). His work will focus 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 [49], [48].

Salinity at 1000 m in the Southwest Pacific ocean is shown in figure 1. 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).

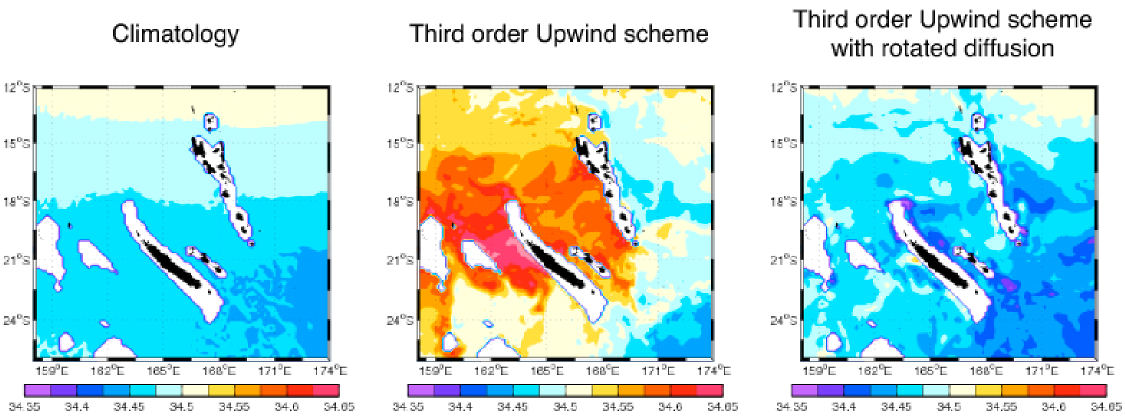

Figure 1. Salinity at 1000m in the Southwest Pacific ocean.

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.

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 has been submitted late 2012.
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. This part of the project is now well advanced and encouraging preliminary results are available on an idealized numerical configuration of an oceanic basin (see Figure 2). Several novative diagnostics have been also developed in this framework

6.2.2. Identification of pollution.

Participant: François-Xavier Le Dimet.

The problem is the next : potential sources of pollution are known but the contribution of each source to a local site is unknown. The problem is to identify the contribution of each source. This is a very common situation both at the local scale and at the synoptic scale. Thanks to second order methods we have been able to reach this goal, the theoretical part is done at FSU and application at the Institute of Mechanics of the Vietnamese Academy of Sciences. One paper has been submitted for publication [75]. At FSU M.Y. Hussaini and I. Souopgui are involved in this project

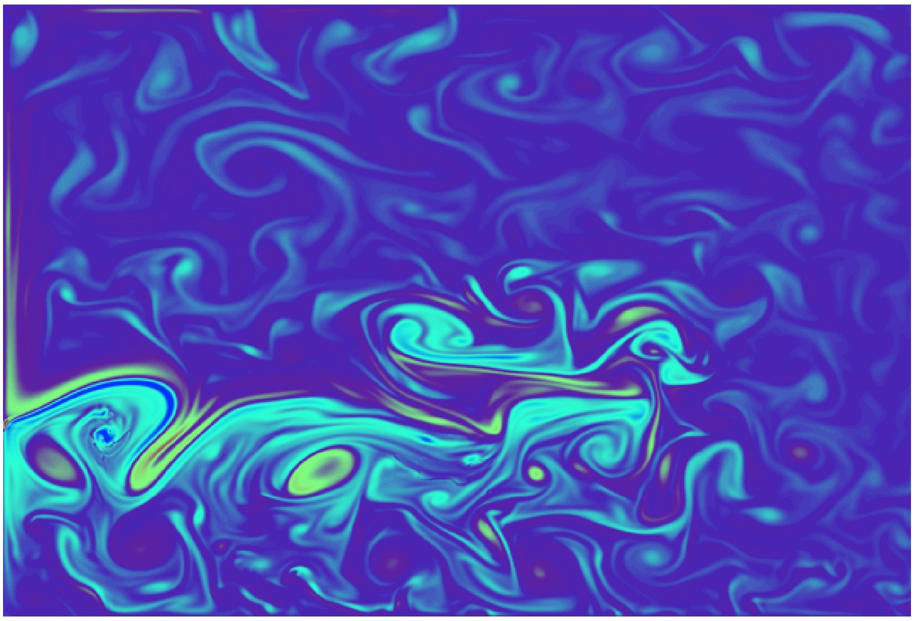

Figure 2. Surface relative vorticity of a 1/24th of a degree NEMO configuration

The quality of water ressources is an important problem for Vietnam. With scientists of the Institute of Mechanics (Ha Tran Thua, Hoang Van Lai, Nguyen Ba Hung) in [31] and [53] we have used the methods described in [75] for water pollution studies, in parallel Tran Thu Ha and Pham Dinh Tuan (LJK) have been working on the application of Kalman filter for this problem. Several talks have been given and papers published.

6.2.3. Variational data assimilation 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 adjoint 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. We wish to make the most of all available data and evaluate what new observations to add, where and when. Sensitivity analysis, and in particular the adjoint method, allows to identify the most influential parameters and variables and can help to design the observation network.

B. Bonan started his PhD in September 2010 on this subject. We implemented the 4D-Var algorithm for a flowline Shallow-Ice model, called Winnie, developed by C. Ritz at LGGE. In a simple configuration, we were able to generate the adjoint code by automatic differentiation. First results were encouraging and were presented at EGU [58] and Les Houches Summer School [30].

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

Participants: Bertrand Bonan, Maëlle Nodet, Catherine Ritz.

We are also interested in comparing variational methods to stochastic filtering. In the framework of B. Bonan PhD, we then implemented Ensemble Transform Kalman Filter (ETKF) on Winnie, which we would like to compare to variational assimilation methods. First results are promising and were presented at three conferences [39], [37], [38].

6.2.5. Inverse methods for full-Stokes glaciology models

Participants: Olivier Gagliardini, Maëlle Nodet, Catherine Ritz.

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 published in The Cryosphere Discussion [11] and presented at three conferences [52], [28], [57]. Figure 3 presents the reconstructed surface velocities compared to the observations, where we can see a good agreement of the main features, thus success of the assimilation process.

6.2.6. Dating ice matrix and gas bubbles with DatIce

Participants: Eric Blayo, Bénédicte Lemieux-Dudon, Habib Toye Mahamadou Kele.

H. Toye Mahamadou Kele joined the MOISE team for 2 years as an Inria young engineer. A shared memory parallelization of the code and a more friendly user interface have been developed. Efforts have been made to calibrate the error covariance matrices by the mean of a posteriori diagnostics.

The MOISE team was involved in the Antarctic Ice Core Chronology 2012 (AICC2012) through a tight collaboration with the Laboratoire de Glaciologie et de Géophysique de l'Environnement (LGGE), the Laboratoire des Sciences du Climat et de l'Environnement (LSCE), and other European laboratories. The AICC2012 project aimed at constructing an unified chronology for several Antarctic ice cores. A special issue is dedicated to AICC2012 in Climate of the Past http://www.clim-past-discuss.net/special_issue53.html. MOISE efforts on the DatIce code lead to two important articles currently reviewed in the Open Discussion process http://www.clim-past-discuss.net/papers_in_open_discussion.html: [2] and [22].

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 limitation 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.

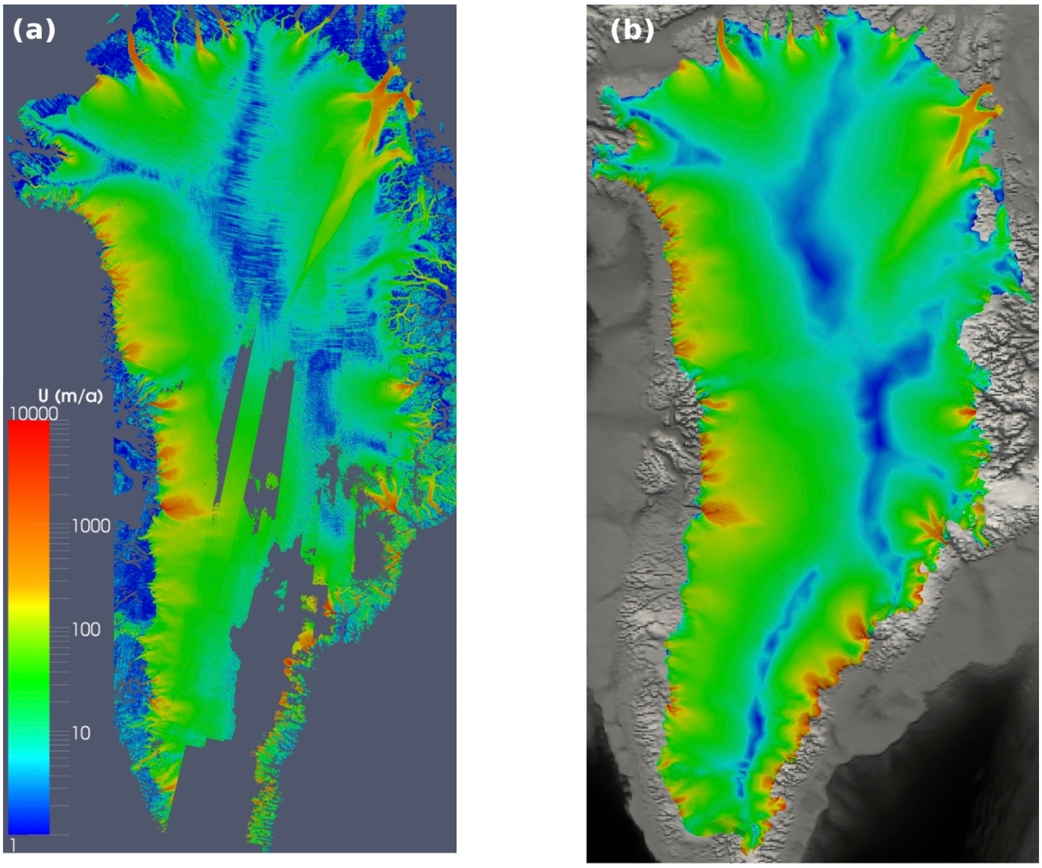

Figure 3. Surface velocities of Greenland Ice Sheet, in meters per year. On the left (a), the velocities which are observed by satellites. On the right (b), velocities obtained after assimilation.

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. Variational Data Assimilation and Control of Boundary Conditions

Participant: Eugène Kazantsev.

A variational data assimilation technique applied to the identification of the optimal discretization of interpolation operators and derivatives in nodes that are adjacent to the boundary of the domain is discussed in two contexts: a simplified case of a shallow water model and the ORCA-2 configuration of the NEMO model.

Experiments with a non-linear shallow water model in [14] show that controlling the discretization of operators near a rigid boundary can bring the model solution closer to observations both within and beyond the assimilation window. This type of control allows also to improve climatic variability of the model. These properties have been studied in two different configurations: an academic case of assimilation of artificially generated observational data in a square box configuration and assimilation of real observations in a model of the Black sea.

The sensitivity of the shallow water model in the previously described configurations has been studied in detail in [15]. It is shown in both experiments that boundary conditions near a rigid boundary influence the solution higher than the initial conditions. This fact points out the necessity to identify optimal boundary approximation during a model development.

Considering a full-physics global ocean model, we apply the 4D-Var data assimilation technique to ORCA-2 configuration of the NEMO in order to identify the optimal parametrization of boundary conditions on the lateral boundaries as well as on the bottom and on the surface of the ocean [71]. The influence of boundary conditions on the solution is analyzed as in the assimilation window and beyond the window. It is shown that optimal surface and bottom boundary conditions allow us to better represent the jet streams, such as Gulf Stream and Kuroshio. Sea Surface Height in the North Atlantic before and after control is shown in fig.4). 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 [55].

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.

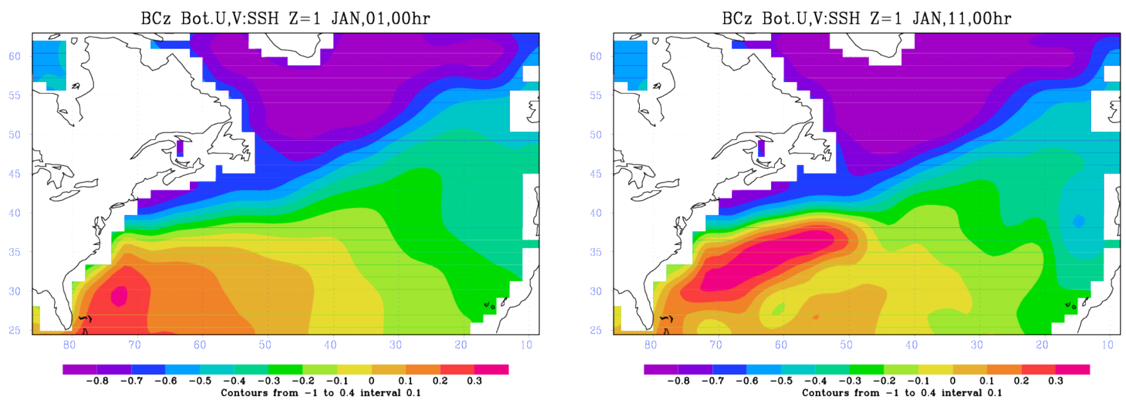

Figure 4. Sea surface elevation in the North Atlantic on the 1st (classical boundary) and on the 11th (optimal boundary) of January, 2006.

6.3.3. 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 current follow-up GeoFluids (along with EPI FLUMINANCE and CLIME, and LMD, IFREMER and Météo-France)

During the ADDISA project we developed Direct Image Sequences Assimilation (DISA) and proposed a new scheme for the regularization of optical flow problems [95]. 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 [78]. 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 mains structures within each image. This can be done using, for example, a wavelet representation of images. 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.

6.3.4. Assimilation of ocean images

Participants: Vincent Chabot, Maëlle Nodet, Nicolas Papadakis, Arthur Vidard, Alexandros Makris.

In addition with the direct assimilation approach previously described, a particular attention has been given to the study of data noise for ocean image assimilation. A journal paper is about to be submitted on this subject in Tellus A. In the context of assimilation of structures contained in satellite images, a two step registration approach using computer vision tools has been proposed within the post-doctorate of Alexandros Makris [33], [56].

6.4. Quantifying Uncertainty

6.4.1. Sensitivity analysis for West African monsoon

Participants: Anestis Antoniadis, Céline Helbert, Clémentine Prieur, Laurence Viry.

6.4.1.1. Geophysical context

The West African monsoon is the major atmospheric phenomenon which drives the rainfall regime in Western Africa. Therefore, this is the main phenomenon in water resources over the African continent from the equatorial zone to the sub-Saharian one. Obviously, it has a major impact on agricultural activities and thus on the population itself. The causes of inter-annual spatio-temporal variability of monsoon rainfall have not yet been univocally determined. Spatio-temporal changes on the see surface temperature (SST) within the Guinea Gulf and Saharian and Sub-Saharian Albedo are identified by a considerable body of evidences as major factors to explain it.

The aim of this study is to simulate the rainfall by a regional atmospheric model (RAM) and to analyze its sensitivity to the variability of these inputs parameters. Once precipitations from RAM are compared to several precipitation data sets we can observe that the RAM simulates the West African monsoon reasonably.

6.4.1.2. Statistical methodology

As mentioned in the previous paragraph, our main goal is to perform a sensitivity analysis for the West African monsoon. Each simulation of the regional atmospheric model (RAM) is time consuming, and we first have to think about a simplified model. We deal here with spatio-temporal dynamics, for which we have to develop functional efficient statistical tools. In our context indeed, both inputs (albedo, SST) and outputs (precipitations) are considered as time and space indexed stochastic processes. A first step consists in proposing a functional modeling for both precipitation and sea surface temperatures, based on a new filtering method. For each spatial grid point in the Gulf of Guinea and each year of observation, the sea surface temperature is measured during the active period on a temporal grid. A Karhunen-Loève decomposition is then performed at each location on the spatial grid [97]. The estimation of the time dependent eigenvalues at different spatial locations generates great amounts of high-dimensional data. Clustering algorithms become then crucial in reducing the dimensionality of such data.

Thanks to the functional clustering performed on the first principal component at each point, we have defined specific subregions in the Gulf of Guinea. On each subregion, we then choose a referent point for which we keep a prescribed number of principal components which define the basis functions. The sea surface temperature at any point in this subregion is modeled by the projection on this truncated basis. The spatial dependence is described by the coefficients of the projection. The same approach is used for precipitation. Hence for both precipitation and sea surface temperatures, we obtain a decomposition where the basis functions are functions depending on time and whose coefficients are spatially indexed and time independent. Then, the most straightforward way to model the dependence of precipitation on sea surface temperatures is through a multivariate response linear regression model with the output (precipitation) spatially indexed coefficients in the above decomposition and the input (SST) spatially indexed coefficients being predictors. A naive approach consists in regressing each response onto the predictors separately; however it is unlikely to produce satisfactory results, as such methods often lead to high variability and over-fitting. Indeed the dimensions of both predictors and responses are large (compared to the sample size).

We apply a novel method recently developed by [91] in integrated genomic studies which takes into account both aspects. The method uses an ℓ_1-norm penalty to control the overall sparsity of the coefficient matrix of the multivariate linear regression model. In addition, it also imposes a *group* sparse penalty. This penalty puts a constraint on the ℓ_2 norm of regression coefficients for each predictor, which thus controls the total number of predictors entering the model, and consequently facilitates the detection of important predictors. The dimensions of both predictors and responses are large (compared to the sample size). Thus in addition to assuming that only a subset of predictors enter the model, it is also reasonable to assume that a predictor may affect only some but not all responses. By the way we take into account the complex and spatio-temporal dynamics. This work has been published in [1].

6.4.1.3. Distributed Interactive Engineering Toolbox

An important point in the study described above is that the numerical storage and processing of model inputs/outputs requires considerable computation resources. They were performed in a grid computing environment with a middleware (DIET) which takes into account the scheduling of a huge number of computation requests, the data-management and gives a transparent access to a distributed and heterogeneous platform on the regional Grid CIMENT (http://ciment.ujf-grenoble.fr/).

Thus, a different DIET module was improved through this application. An automatic support of a data grid software (http://www.irods.org) through DIET and a new web interface designed for MAR was provided to physicians.
These works involve also partners from the Inria project/team GRAAL for the computational approach, and from the Laboratory of Glaciology and Geophysical Environment (LGGE) for the use and interpretation of the regional atmospheric model (RAM).

6.4.2. Tracking for mesoscale convective systems

Participants: Anestis Antoniadis, Céline Helbert, Clémentine Prieur, Laurence Viry, Roukaya Keinj.

6.4.2.1. Scientific context

In this section, we are still concerned with the monsoon phenomenon in western Africa and more generally with the impact of climate change. What we propose in this study is to focus on the analysis of rainfall system monitoring provided by satellite remote sensing. The available data are micro-wave and IR satellite data. Such data allow characterizing the behavior of the mesoscale convective systems. We wish to develop stochastic tracking models, allowing for simulating rainfall scenari with uncertainties assessment.

6.4.2.2. Stochastical approach

The chosen approach for tracking these convective systems and estimating the rainfall intensities is a stochastic one. The stochastic modeling approach is promising as it allows developping models for which confidence in the estimates and predictions can be evaluated. The stochastic model will be used for hydro-climatic applications in West Africa. The first part of the work will consist in implementing a model developed in [96] on a test set to evaluate its performances, our ability to infer the parameters, and the meaning of these parameters. Once the model well fitted on toy cases, this algorithm should be run on our data set, and compared with previous results by [89] or by [88]. The model developed by [96] is a continuous time stochastic model to multiple target tracking, which allows in addition to birth and death, splitting and merging of the targets. The location of a target is assumed to behave like a Gaussian Process when it is observable. Targets are allowed to go undetected. Then, a Markov Chain State Model decides when the births, death, splitting or merging of targets arise. The tracking estimate maximizes the conditional density of the unknown variables given the data. The problem of quantifying the confidence in the estimate is also addressed. Roukaya Keinj started working on this topic with a two years postdoctoral position in November 2011. She left the team in October 2012, and is now replaced by Alexandros Makris.

6.4.3. 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, Jean-Yves Tissot, Federico Zertuche.

6.4.3.1. 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 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.

6.4.3.2. Estimating sensitivity indices

A first task is to develop tools for estimated sensitivity indices. Among various tools a particular attention was first paid to FAST and its derivatives. In [21], the authors present a general way to correct a positive bias which occurs in all the estimators in random balance design method (RBD) and in its hybrid version, RBD-FAST. Both these techniques derive from Fourier amplitude sensitivity test (FAST) and, as a consequence, are faced with most of its inherent issues. And up to now, one of these, the well-known problem of interferences, has always been ignored in RBD. After presenting in which way interferences lead to a positive bias in the estimator of first-order sensitivity indices in RBD, the authors explain how to overcome this issue. They then extend the bias correction method to the estimation of sensitivity indices of any order in RBD-FAST. They also give an economical strategy to estimate all the first-order and second-order sensitivity indices using RBD-FAST. A more theoretical work [77] revisit FAST and RBD in light of the discrete Fourier transform (DFT) on finite subgroups of the torus and randomized orthogonal array sampling. In [77] the authors study the estimation error of both these methods. This allows to improve FAST and to derive explicit rates of convergence of its estimators by using the framework of lattice rules. A natural generalization of the classic RBD is also provided, by using randomized orthogonal arrays having any parameters, and a bias correction method for its estimators is proposed. In variance-based sensitivity analysis, another classical tool is the method of Sobol' [94] 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 [93] and more recently by Owen [90] but the quantities they estimate still require $O(d)$ samples. In a recent work [76] the authors 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. They establish theoretical properties of such a method for the first-order Sobol' indices and discuss the generalization to higher-order indices. As an illustration, they 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.

6.4.3.3. 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 [12], 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. The present preprint is under review. 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 [13]. In a more recent work [69], the authors deal with asymptotic confidence intervals in the double limit where the sample size goes to infinity and the metamodel converges to the true model. Implementations have to be conducted on more general models such as Shallow-Water models. 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 senses has been submitted, dealing with goal oriented uncertainties assessment [70].

6.4.3.4. 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 [82] in the case where input parameters are correlated. A PhD started in October 2010 on this topic (Gaëlle Chastaing). We obtained first results [4], deriving a general functional ANOVA for dependent inputs, allowing defining new variance based sensitivity indices for correlated inputs.

6.4.3.5. Multy-fidelity modeling for risk analysis

Federico Zertuche 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 ([83], [92]) : 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.

6.4.4. Multivariate risk indicators

In collaboration with Véronique Maume-Deschamps (ISFA Lyon 1), Elena Di Bernardino (CNAM), Anne-Catherine Favre (LTHE Grenoble) and Peggy Cenac (Université de Bourgogne), we are interested in defining and estimating new multivariate risk indicators. This is a major issue with many applications (environmental, insurance, ...). Two papers were accepted for publication and two other ones are submitted. The first submitted one deals with the estimation of bivariate tails [79]. In [81] and [68] we propose estimation procedures for multivariate risk indicators. In [5] we propose to minimize multivariate risk indicators by using a Kiefer-Wolfowitz approach to the mirror stochastic algorithm.

6.4.5. Quasi-second order analysis for the propagation and characterization of uncertainties in geophysical prediction

We have developed a new approach for the propagation and characterization of uncertainties in geophysical prediction. Most of the method presently used are based on Monte-Carlo type (ensemble) methods, they are expensive from the computational point of view and have received a poor theoretical justification especially in the case of strongly non linear models. We have proposed a new method based on quasi-second order analysis, with a theoretical background and robust for strongly non linear models. Several papers have been published [20], [10], [19], [51] and the application to complex models are presently under development. Igor Gejadze and Victor Shutyaev have been staying both for a total of four weeks in MOISE.

6.5. Image processing

6.5.1. Image processing

Participant: Nicolas Papadakis.

In collaboration with the Inria team MC2 of the Bordeaux-Sud-Ouest center, we investigate the application of image assimilation to medical issues. The objective is here to use MRI images in order to monitor EDP models dealing with tumor growth in lungs or brains. Using such images, we would like to define a patient specific process allowing to calibrate the numerical model with respect to the observed tumor. First works based on convex relaxation of the binary segmentation problem [34] have been realized in this direction by proposing a 3D segmentation method dedicated to glioblastomas from a set of MRI brain images. The obtained automatic segmentation results are very close to specialist manual segmentations (errors of 5%) and will be used as pseudo-observations for an assimilation system based on the numerical model describing the tumor growth. The final issue will be to define an observation operator linking images with the model in order to realize a direct assimilation.

Next, in collaboration with Vicent Caselles (Pompeu Fabra University, Barcelona, Spain) we tackled the problem of histogram equalization of different images. Our aim has been to include spatial information on color repartition during the histogram transfer for inpainting and shadow removal purposes [18]. We also focused with Jean-François Aujol (Institut de Mathématiques de Bordeaux), on the convexification of non linear problems such as optical flow estimation and submitted a jounal paper on this subject in SIAM Journal on Imaging Sciences.

6.5.2. Optimal transport

Participants: Maëlle Nodet, Nicolas Papadakis, Arthur Vidard.

Within the optimal transport project TOMMI funded by the ANR white program, some new algorithms had been proposed to take into account the physics (rigidity, elesticity) of the density to transport [40]. A journal paper has been submitted on this topic in M2AN.

6.6. Mathematical modelling for CFD-environment coupled systems

Participant: Antoine Rousseau.

6.6.1. 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 an implicit representation of the spatial inhomogenity 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. During the internship of S. Barbier (co-advised by A. Rousseau and A. Rapaport (INRA-MODEMIC)) 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. This will lead to a publication. In addition, bioremediation algorithms proposed by the authors have been sent to Inria Technology Transfert Services for a patent registration.

6.6.2. 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.
In [9], A. Rousseau and E. Frénod improve 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 5). This was presented in an international conference [60].

6.7. CO_2 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 CO_2 storage in geological environment. This work is following the study of Franck Diedro in the same subject [8]. 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.

6.8. Land Use and Transport models calibration

Participants: 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 been accepted and will start early 2013.

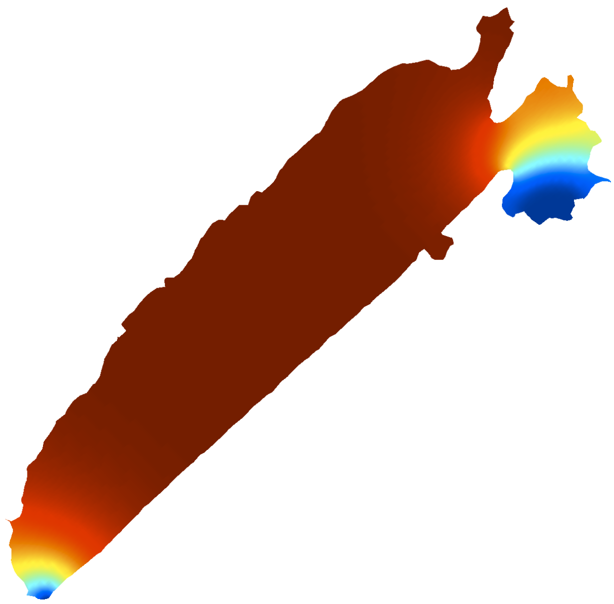

Figure 5. Confinement map in the Thau Lagoon (France). See [60].

7. Bilateral Contracts and Grants with Industry

7.1. Contracts with Industry

- 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 3-year contract with EDF: project MeCSiCo (coupling methods for the simulation of river flows): see 4.4
- A 3-year contract with ADEME on the thematic "Stochastic Downscaling Method": see 5.4.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- E. Blayo is a member of the scientific committee of the regional Institut des Sciences Complexes (IXXI) http://www.ixxi.fr.
- E. Blayo is a member of the scientific committee of the Pôle Alpin Risques Naturels http://www.risknat.org.
- E.Blayo and M. Nodet are responsible for the workpackage "numerical modelling" within the regional project (Région Rhône-Alpes) "**Envirhonalp**" http://www.envirhonalp.fr.
- 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.

- M. Nodet is involved in E. Maitre MSTIC project MENTOL about Optimal Transport.
- Nicolas Papadakis is responsible of the ASIOME project (Assimilation de Structures d'Images Océanographiques et Modélisation d'Erreurs) funded by the Pôle Mathématiques Sciences et Technologies de l'Information et de la Communication (MSTIC) of the Joseph Fourier University, Grenoble. and the LEFE/MANU program of INSU (CNRS).6.3.4

8.1.1. Collaborations with Various Regional Research Teams

- LEGI, MEOM team : 6.3.4,6.1.2,6.2.1,6.3.3.
- LGGE Grenoble, Edge team (C. Ritz, O. Gagliardini, F. Gillet-Chaulet, G. Durand), see paragraphs 6.2.3, 6.2.4 and 6.2.5.
- LGGE, Statistical methodology,6.4.1
- LGGE, DatIce tool, 5.3
- LTHE, Anne-Catherine Favre: multivariate extremal risk indicators, project "Soutien à l'Excellence et à l'Innovation Grenoble INP" MEPIERA (MEthodologies innovantes Pour l'Ingénierie de l'Eau et des Risques Associés)
- LTHE, Thierry Lebel, Théo Vischel: tracking of mesoscale convective systems,
- Building energy (G2ELab, Mathilde Grandjacques). : 6.4.1,6.4.2

8.2. National Initiatives

8.2.1. Interactions with other Inria Project-Teams or Actions

Participants	Inria Project-Team	Research topic	Link
L.Debreu, E.Blayo	CLIME, FLUMINANCE	Multiscale data assimilation	6.2.1
N. Papadakis	MC2	Image segmentation and assimilation for tumor growth modeling	6.5.1
M. Nodet	SCIPORT	Automatic differentiation	6.2.3
C.Prieur, Laurence Viry	GRAAL	Grid deployment for the study of West African Monsoon	6.4
C. Helbert, C.Prieur	STEEP	Sensitivity analysis for LUTI models	6.4
A. Rousseau	TOSCA	Stochastic Downscaling Method	
A. Rousseau	MODEMIC	Bioremediation of natural resources	6.6
A. Vidard M. Nodet F.X. Le Dimet	CLIME, FLUMINANCE	Image assimilation	6.3.3
A. Vidard, M. Nodet, E.Kazantsev	TROPICS	Ocean Adjoint Modelling	6.2.1,6.3.2
C. Prieur, A. Vidard, N. Papadakis	STEEP	Calibration of Land Use and Transport Integrated (LUTI) models.	6.8

8.2.2. Collaborations with other Research Teams in France

Participants	Research Team	Research topic	Link
N. Papadakis	(Labri, IMB, Bordeaux)	image processing problems (histogram equalization and image inpainting)	6.5.1
C. Prieur	IMT Toulouse, IFP Rueil, EDF, CEA Cadarache	Sensitivity analysis	6.4.1
C. Prieur	ISFA Lyon 1, Université de Bourgogne	Multivariate risk indicators	6.4.4
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	
E.Blayo, A.Rousseau	LAMFA (Amiens), LAGA (Paris 13)	Coupling methods	6.1.2
A. Rousseau	IFREMER (Sète), UMR Ecosym (Montpellier)	Coupling fluids and life sciences	6.6
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:

- 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
- E. Blayo was a member of the 2012 ANR evaluation panel "Earth, Environment, Space".
- Nicolas Papadakis is involved in the SWOT-Ocean group in charge of the use of the high resolution data that will be provided by the future SWOT satellite (CNES/NASA mission). This work is realized in collaboration with Jacques Verron of the Laboratoire des Écoulements Géophysique et Industriels. 6.3.4
- M. Nodet is PI of the project "Méthodes inverses en glaciologie" supported by INSU-LEFE.
- M. Nodet is involved in GDR Calcul and GDR Ondes.
- 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, J.-Y. Tissot and G. Chastaing. http://www.gdr-mascotnum.fr/doku.php
- L. Debreu is the coordinator of the national group COMODO (Numerical Models in Oceanography)
- 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.

8.2.4. ANR

- A 4-year ANR contract: ANR TOMMI (Transport Optimal et Modèles Multiphysiques de l'Image), see paragraphs 6.5.2,6.3.3.

- A 4-year ANR contract: ANR ADAGe (Adjoint ice flow models for Data Assimilation in Glaciology, see paragraph 6.2.3) .
- 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 6.3.3) .
- 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
- CITIES ANR project (numerical models project selected in 2012). http://steep.inrialpes.fr/?page_id=46
- A 4 year ANR contract (2011-2015): ANR COMODO (Communauté de Modélisation Océanographique) on the thematic "Numerical Methods in Ocean Modelling". (coordinator L. Debreu) 6.1.3
- A. Vidard was the coordinator of the ANR VODA (Variational Ocean Data Assimilation for multi-scales applications) 4-year contract ended mid 2012.

8.3. European Initiatives

8.3.1. Collaborations with Major European Organizations

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.

Partner: Vicent Caselles of the Pompeu Fabra University, Barcelona Spain

Subject: Image processing problems such as histogram transfer [18] or optical flow estimation. 6.5.1

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 fo 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. Exceter (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: British Antarctic Survey, Cambridge, UK,

Subject: Antarctic ice core chronology (AICC2012).

Partner: University of Copenhagen, Ice and Climate Group, Denmark

Subject: Antarctic ice core chronology (AICC2012).

Partner: University of Strathclyde (Glasgow, UK)

Subject: Quasi-second order analysis for the propagation and characterization of uncertainties in geophysical prediction 6.4.5

Partner: Institute of Numerical Mathematics, Russian Academy of Sciences

Subject: Quasi-second order analysis for the propagation and characterization of uncertainties in geophysical prediction 6.4.5

8.4. International Initiatives

8.4.1. Participation In International Programs

- F.-X. Le Dimet collaborates with Vietnamese Academy of Sciences (Institute of Mechanics, Hanoi) on the quality of water ressources, that is an important problem for Vietnam (see 6.2.2)
- F.-X. Le Dimet collaborates with Florida State University on subjects of Identification of pollution (see 6.2.2) and Assimilation of Images (see 6.3.3).
- 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).

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Angie Pineda (invited 6 weeks in 2012 by C. Prieur through the ECOS Nord project),
- Jose R. León (invited 2 weeks in 2012 by C. Prieur through the ECOS Nord project).
- Victor Shutyaev, Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow (invited for 2 weeks by F.-X. Le Dimet, see 6.4.5)
- Igor Gejadze, University of Strathclyde, Glasgow, UK (invited for 1 week by F.-X. Le Dimet, see 6.4.5)
- 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 has been elected « Fellow of the American Meteorological Society », he is the second French scientist (after Michel Jarraud, General Secretary of the World Meteorological Organization) to get this distinction.
- F.-X. Le Dimet has been named « Adjunct Professor » at the Department of Mathematics at Florida State University, (USA) This nomination is valid from 2012 to 2016.
- F.X. Le Dimet has been invited to Caltech (USA) and Jet Propulsion Laboratory in May 2012 where he gave seminars on Assimilation of Images. Invited Speaker at the International Conference ACME in July 2012.

9. Dissemination

9.1. Scientific Animation

- E. Blayo has organized, with M. Bocquet (EPI CLIME) and E. Cosme (LEGI, Grenoble), a 3-week international summer school on Advanced Data Assimilation for Geosciences. Les Houches, May 28 - June 15, 55 participants from more than 20 countries http://houches2012.gforge.inria.fr
- E. Blayo is one of the organizers of the 4th National Conference on Data Assimilation. Nice, December 17-19, 2012. http://sama.ipsl.jussieu.fr/Fr/events/workshops/2012_12_17_CNA2012.html
- L. Debreu and E. Blayo have organized, with the Inria Valorization service, a one-day In'Tech seminar "Atmosphere and meteorological forecast: new tools, new usages". http://www.inria.fr/centre/grenoble/agenda/seminaire-in-tech-atmosphere-et-previsions-meteorologiques

- 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 25 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.
- A. Rousseau is member of the editorial board of *Discrete and Continuous Dynamical Systems -* Series S (DCDS-S).
- N.Papadakis is a Co-Organisator of the "Journés Bordelaises d'Analyse Mathématique des Images". November, 12-14, 2012 http://www.math.u-bordeaux1.fr/~jaujol/conf2012/JBAMI2012.html,
- 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.
- 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 are organizing jointly with H. Monod and R. Faivre (INRA) a school on sensitivity analysis for environmental models (les Houches, 7-12 april, 2013).
- C. Prieur is member of the board of the group mathematical statistics of the French society of statistics (SFdS).
- C. Prieur organized a session on sensitivity analysis in the Journées MAS (SMAI) 2013.
- C. Prieur organized a mini-symposium on sensitivity analysis for correlated inputs in the SIAM conference on uncertainty quantifications in Raileigh in April 2012.
- L. Debreu organized a one-day meeting on numerical kernels of ocean and atmospheric models, Paris, October 18, 2012.
- L. Debreu organized a three day tutorial on the use of realistic of ocean and atmospheric models at the 11th African conference on research in Computer Science and Applied Mathematics (CARI), Algiers, October 9-11, 2012.
- B.Lemieux gave a seminar at LSCE (Saclay) to present the DatIce tool http://www.lsce.ipsl.fr/Phocea/Vie_des_labos/Seminaires/index.php?y=2012&id=206.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

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

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

Licence: E. Blayo: Mathematics for engineers, 72h, L1, university of Grenoble, France

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

Master : E. Blayo: Coupling methods for PDEs, 27h, M2, university of Grenoble, France

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

Master: A.Rousseau: Modèles mathématiques spatialisés pour les sciences de l'environnement, 12h, niveau M2, Université de Montpellier 2, France

Master: L.Debreu: Numerical Modelling for coastal oceanography, 18H, M2, Brest University, France.

Doctorat: E. Blayo: Introduction to data assimilation, 16h, university of Grenoble, France

Doctorat: A.Vidard: "Data Assimilation, an introduction", 8h, Université de Grenoble

9.2.2. Internships

Alexis Jacq and Marie Leturcq did internships for their L3 and M1 degrees, they both worked with M. Nodet and B. Bonan about data assimilation for glaciology.

Sébastien Barbier, M2R Internship (6 months), Modélisation de stratégies de dépollution d'une ressource hydrique en milieu naturel advised by A. Rousseau.

Jean-Philippe Bernard, M2R Internship (6 months), Développement et implémentation de modèles couplant descriptions fluides et biologiques pour les écosystèmes côtiers advised by A. Rousseau.

Alexandre Hoffmann, L3 internship, he worked with V. Chabot, A. Vidard and M. Nodet about interpolation methods for image assimilation.

9.2.3. Supervision

HdR : Arthur Vidard, "Assimilation de données et méthodes adjointes pour la géophysique", Université de Grenoble, 13/12/2012

PhD : Jean-Yves Tissot, Sur la décomposition ANOVA et l'estimation des indices de Sobol'. Application à un modèle d'écosystème marin., UJF, 16 novembre 2012, Clémentine Prieur et Eric Blayo

PhD : David Cherel, Décomposition de domaine pour des systèmes issus des équations de Navier-Stokes, UJF, 12 décembre 2012, Eric Blayo et Antoine Rousseau

PhD : Alexandre Janon, Analyse de sensibilité et réduction de dimension. Application à l'océanographie, Université de Grenoble, 15 novembre 2012, C. Prieur and M. Nodet

PhD in progress : Manel Tayachi, Couplages de modèles hydrologiques et océanographiques, 01/05/2010, E. Blayo & A. Rousseau

PhD in progress : Bertrand Bonan, Assimilation de données pour des modèles de calotte polaire, Université de Grenoble, M. Nodet and C. Ritz

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

PhD in progress : Manel Tayachi, Couplages de modèles hydrologiques et océanographiques, 01/05/2010, E. Blayo & A. Rousseau

PhD in progress : Laurent Violeau (EPI TOSCA), Stochastic Lagrangian Models and Applications to Downscaling in Fluid Dynamics, 01/10/2010, M. Bossy (EPI TOSCA, Inria Sophia) & A. Rousseau

PhD in progress : Vincent Chabot, "Assimilation de données pour l'estimation de structures 2D et 3D dans des séquences d'images", started the 23rd of October 2010, Maëlle Nodet and Arthur Vidard supervisors.

9.2.4. Juries

- E. Blayo was a referee of PhD thesis of Pierre Allain: Analyse et synthèse de mouvements de foules par contrôle optimal.. Université de Bretagne Sud, January 27, 2012
- E. Blayo was a member of the jury for the PhD defense of Dorothée Robert: Caractérisation et modélisation de la dynamique de l'évapotranspiration en Afrique soudanienne en zone de socle : interaction entre les aquifères et la végétation. Université de Grenoble, August 30, 2012.
- E. Blayo was a member of the jury for the HDR defense of Arthur Vidard: Assimilation de données et méthodes adjointes pour la géophysique. Université de Grenoble, December 13, 2012.
- A. Rousseau was a member of the Inria Board for Research Positions 2012 (6 juniors and 2 seniors researchers).
- A. Rousseau is a member of Inria Evaluation Comittee
- A. Rousseau participated in a career fair at MIT with M. Thonnat (Deputy Scientific Director at Inria), A. Theis-Viémont and E. Chareyre (Human Resources at Inria). The European Career Fair is an annual recruiting event, organized by the MIT European Club, that connects employers from Europe with the most talented candidates that live in the US.

- M. Nodet is a member of the Jury Agregation Externe de Mathematiques
- C. Prieur was a referee of the PhD jury of Sylvain Girard, Mines Paris Tech December,17, 2012
- C. Prieur was the president of the PhD jury of Yann Caniou, Université de Clermont-Ferrand. November,29, 2012
- C. Prieur was a referee of the PhD jury of Catalina Ciric, Université Lyon 1. September, 6, 2012
- C. Prieur was the president of the HdR jury of S. Gadat, Université de Toulouse. November, 22, 2012
- C. Helbert was a referee of the PhD jury of Jean-Yves Tissot, Université de Grenoble. November, 16, 2012

9.3. Popularization

- In the context of the Mathc2+ program, E. Blayo has given a conference "Applied maths: mathematics for the society and its environment". Grenoble, June 19, 2012.
- 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" presenting the activities of the IREM of Grenoble.
- A. Rousseau gave a lecture to the first National Conference of Mathematics Popularization in Orléans, http://www.animath.fr/conf/conferences.php.
- A. Rousseau is a member of the french executive board of "Mathématiques pour la planète Terre 2013", http://www.mpt2013.fr.
- A. Rousseau gave 5 short interviews on France Inter (national radio), http://www.franceinter.fr/player/reecouter?play=475445, http://www.franceinter.fr/player/reecouter?play=477677, http://www.franceinter.fr/player/reecouter?play=478643, http://www.franceinter.fr/player/reecouter?play=479435, http://www.franceinter.fr/player/reecouter?play=480603.
- M. Nodet and A. Rousseau (with S. Minjeaud, CNRS Nice) published a popularization paper on basic principles in oceanography : http://interstices.info/circulation-oceanique
- E. Kazantsev has given a conference "Geophysical Hydrodynamics for dummies and for all others" at the meeting of professors of secondary schools of the Grenoble region organized by IREM of Grenoble http://www-irem.ujf-grenoble.fr/irem/accueil/

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

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