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Project-Team IDOPT

Systems optimization and identification in physics and environment

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Activity Report

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1. Team

The IDOPT project is a joint project between the CNRS (SPM department), Joseph Fourier University (Grenoble 1), INPG and INRIA Rhône-Alpes. This project is located in the LMC-IMAG laboratory.

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2. Overall Objectives

Many systems in physics, mechanics and environmental sciences are modelled by partial differential equations with distributed parameters. These equations describe the behavior in space and/or in time of the system variables. From this general formulation two problems arise :

2.1.1. Identification

The usual *direct approach* consists in solving the model equations. However it is frequent that some parameters or some functions appearing in the model are totally or partially unknown (e.g. diffusion coefficients in parabolic equations, source and sink terms in fluid dynamics, initial and/or boundary conditions...). *Inverse problems* are dedicated to the estimation of these unknown parameters using the information provided by experimental observations of the system. Solving inverse problems is useful for physicists: in many cases an approximation only of the unknown parameters is available, and these parameters cannot be measured by devices, either because they are used to parameterize small scale phenomena (e.g. turbulence in fluids) or because the measurement is expensive (e.g. measurements inside the solid earth or in the deep ocean). This point of view is essential in many domains of physics.

2.1.2. Optimization

The physical systems described above may have some inputs (e.g. forcing terms) which can be controlled by an operator. A problem is : how to control the inputs in order to optimize the behavior of the system? The related mathematical problem is the estimation of these optimal inputs in open loop or closed loop (stabilizing feedback).

3. Scientific Foundations

3.1. Optimal control

Participants: Jacques Blum, François-Xavier Le Dimet.

For identification and optimization problems, we have to minimize a functional depending on the solution of a system of Partial Differential Equations (PDEs). The identification problem can be formulated as the minimization of the quadratic difference between the experimental observations and the corresponding quantities calculated by solving the system of PDEs. The control variables are, in this case, the parameters or the functions to be identified. The minimization of functionals depending on the solution of a PDE (e.g. through the initial conditions, the boundary conditions...) follows the optimal control theory [52].

3.2. Data Assimilation

A mathematical model alone is not sufficient to predict the evolution of a geophysical flow. Neither are data alone. Providing a forecast requires to retrieve the state of the flow at some initial time, and that this retrieved field be in agreement with the physical properties of the flow (i.e. satisfies the governing equations). Data Assimilation covers the techniques dedicated to use jointly the mathematical information provided by the equations, the physical information obtained by observation, and the statistical information, in order to retrieve at best the state of the flow. At the present time there exists two basic techniques: variational methods and filtering methods.

3.2.1. Variational methods

Participants: François-Xavier Le Dimet, Jacques Blum, Eric Blayo, Victor Shutyaev, Yousuff Hussaini, David Furbish.

Variational methods are based on the minimization of a function measuring the discrepancy between a solution of the model and the observation. Le Dimet (Le Dimet 1982, Le Dimet and Talagrand 1986) has suggested to use optimal control techniques for this purpose. The inputs of the model are then used as control variables. The Euler Lagrange condition for optimality is found 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. Therefore the OS can be considered as a generalized model.

The adjoint model is a very powerful tool, which allows to conduct sensitivity studies, identification, etc. Despite its high computational cost, this technique has been adopted by the main operational meteorological centers (e.g. MeteoFrance, European Center for Medium Range Weather Forecast).

During these last years the main contributions of IDOPT have addressed the following topics :

- *Reduced order methods* In actual geophysical applications, the size of the control space is often huge, with a poor knowledge of the error statistics. Therefore the minimization can be quite difficult. An interesting alternative can be to try to define some low dimension control space, which contains the main directions of variability of the system. This point has been investigated in the PhD theses of S. Durbiano and C. Robert.
- *Study of second order properties, with application to sensitivity studies* A major problem in the forecast of the evolution of the physical environment is to estimate the quality of the prediction, or in other words the impact of model and data uncertainties on the prediction. A so called second order adjoint has been introduced, which allows to extract the second order properties of the OS (Le Dimet, Navon and Daescu, 2002). It is shown that predictibility properties, i.e. the impact of both model and observation errors, are linked to the properties of the Hessian of the cost function. Using the second-order adjoint it is possible to follow the impact of uncertainties from its source to the prediction (Le Dimet, Shutyaev). The application to underwater propagation is described in a paper by Le Dimet, Shutyaev, Ngepieba, Mu Mu.
- *Control of the model error* Another way to take into account the model error is to add an extra term to the model and to control this term in order to reduce the discrepancy with the observation. Such a study was conducted during the PhD of A. Vidard, and then in a more recent paper by Vidard, Piacentini and Le Dimet.
- *Adequation between models and data* An important topic is the adequation of models and data. It has been demonstrated (Le Dimet, Hussaini, Ngnepieba) that, for the same set of data, the best prediction is not necessarily associated to the best model. Improving the quality of a model may damage the prediction.
- *Assimilation of new types of data* A lot of observational information cannot be easily linked to model variables, and is not used so far for data assimilation. This is for example the case of lagrangian data or of satellite images. Studies are presently conducted on this subject.

3.2.2. Kalman filtering

Participants: Alain Le Breton, Dinh Tuan Pham, Jacques Verron.

Filtering is the basic tool in the sequential approach to the problem of data assimilation into numerical models, especially in meteorology and in oceanography. This approach, of stochastic nature, is justified by the fact that the dynamical system is chaotic and thus behaves similarly to a stochastic system. Moreover, the (unknown) initial state of the system can be conveniently modelled 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 also 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. In applications to meteorology and oceanography, the above filtering approach has encountered two major difficulties. The first one is the nonlinearity of the dynamical equations, which leads to the use of a suboptimal filter, the extended Kalman filter, in which the above equations are linearized around the current estimate of the system state. Such a filter however can be unstable and can sometimes diverge totally. The second difficulty is the very large dimension of the system state vector. The application of the filter would lead to prohibitive calculations. Furthermore this large size poses the problem of adequately specifying the statistical characteristics of the errors.

Our goal in this project is to investigate in depth the possibility of applying the above filtering approach to real data. To this end, we have developed a new filter of extended Kalman type, based on the use of a singular low-rank filter error covariance matrix. The filter operates according to the principle of making no correction along the directions of natural attenuation of the error. The corrections are made only along directions belonging to a subspace, which is constructed initially by the method of empirical orthogonal functions (EOFs), and which evolves in time according to the model equations. This filter is thus called *Singular Evolutive Extended Kalman* [58][59]. It has been first tested in a reduced configuration based on a quasi-geostrophic ocean model, which yielded very satisfying results [58][59]. It has been then successfully experimented for the assimilation of altimetric data in the realistic framework of a primitive equation model of the tropical Pacific ocean [60][57].

Recently, we have worked towards the improvement of the filter, on the one hand to reinforce its robustness with regard to the system nonlinearity [56], and on the other hand to reduce its computational cost without noticeable degradation of its performance.

On the first point, the idea is to drop the linearization in the extended Kalman filter and to use a Monte-Carlo procedure and an interpolation. In this way, we have developed another filter called SEIK (*Singular Evolutive Interpolated Kalman*) [54][55][57], which appears to be both more robust with regard to nonlinearities, and simpler to implement. Moreover, we have explored advanced stochastic filtering techniques to overcome the difficulties related to strong nonlinearities of the system [56].

On the second point, the idea is to enrich the correction basis by addition of some local basis vectors, and to simplify the evolution of the basis by letting only the global basis vectors evolve. This way the correction basis can contain more vectors, better captures the errors, and requires less computation as it is only "semi-evolutive". Such kind of filters have been experimented in various realistic ocean model settings, yielding quite satisfactory results [45][46] [][].

In addition to this work centered on the stochastic approach to the data assimilation, an activity of more theoretical nature is also performed in the domain of filtering, control and identification for stochastic systems with dynamical noise of fractional type [47], [49], [48], [51], [50]. These studies can lead to interesting perspectives in modelling since the eventual phenomenon of long range dependence in the dynamics can be taken into account.

3.3. Statistical inverse problems

Participants: Anestis Antoniadis, Theofanis Sapatinas, Felix Abramovich, Jeremie Bigot.

Wavelets are mathematical building blocks that can be used to represent functions and data sets. They combine useful modeling features such as locality and varying degrees of smoothness. As modeling and analyzing tools they allow us to “zoom-in” on the problem at various scales and therefore are part of what is called “multiscale” and “multiresolution” analyses. In particular, wavelets are a powerful tool for dealing with some inverse problems.

Paper [42], originally drafted in 2002, is an important paper in the field. It is a joint work with Felix Abramovich, Theofanis Sapatinas and Brani Vidakovic. The paper considers the testing problem in fixed-effects functional analysis of variance (FANOVA) models. We show how the existing optimal (in the minimax sense) testing procedures for testing a zero signal in a “signal+noise” model can be adapted for FANOVA and we derive optimal procedures for testing the significance of the components of the FANOVA model. The resulting tests are based on the empirical wavelet coefficients of the data. We performed a simulation study to illustrate the behaviour of these tests and applied them also to a real-life data arising from physiological experiments.

The techniques developed in the above mentioned work were further applied by Jérémie Bigot, a PhD student at the LMC, to address the problem of the alignment of multiple sets of curves and their comparison with FANOVA techniques. In paper [], a non-parametric approach is proposed to estimate the zero-crossing lines of the continuous wavelet transform of a 1-D signal observed with noise. A new tool, the “structural intensity”, is introduced to represent the locations of the significant landmarks of an unknown curve via a probability density function. This technique yields an automatic landmark-based registration method to synchronize a set of curves. A fixed-effects FANOVA model is then used to test the significance of main/interaction effects and to show the usefulness of curve alignment.

4. Application Domains

4.1. Identification and Optimization in Physics

Keywords: *Optimal control*, *electromagnetism*, *free surface flows*, *inverse problems*, *microfluidics*, *nuclear fusion*, *plasma*, *wetting*.

The applications are the plasma physics (nuclear fusion), the coating processes and biotechnologies.

In each of these topics, an optimization is performed in order to identify a physical quantity, to minimize an energy or to compute an optimal Shape.

4.1.1. Real time identification problem in plasma physics

Participant: Jacques Blum.

A method of numerical identification of the plasma current density in a Tokamak fusion reactor from experimental measurements is proposed. This problem consists in the identification of a non-linearity in a semi-linear 2D elliptic equation from Cauchy boundary measurements, from integrals of the magnetic field over several chords and from measurements of magnetic field at specific points.

The problem is solved using fixed-point optimization algorithm based on the finite element method, followed by object-oriented C++ implementation aiming at real-time use as diagnostic at JET and other tokamaks (TORE SUPRA, ITER).

4.1.2. Microfluidics and wetting hydrodynamics

Participant: Jérôme Monnier.

We study mathematical and numerical models treating of liquid droplets spreading on solid surfaces. Such modelling are required for biotechnologies processes and coating technologies. The important phenomena of these free surface flows are interfacial (surface tension, curvature forces, surfactant). These studies are done in collaboration with the PIM project-team, lab LEGI, (Grenoble) and an industrial partner (Belgium).

4.2. Data and Models in Environmental Sciences

Keywords: *Adaptive Meshing*, *Data assimilation*, *Domain Decomposition*, *Filtering*, *High Performance Computing*, *Hydrology*, *Inverse Problems*, *Meteorology*, *Oceanography*, *Optimal Control*.

The use of numerical models for meteorological prediction has been proposed by Charney and Von Neuman in the '40s. This practice became operational in the '60s. Generally geophysical flows have several particularities requiring mathematical and algorithmic developments:

- Geophysical flows are nonlinear. Therefore there is an interaction between the different scales of the models. The small scale effects (smaller than the mesh size) will have to be estimated by some additionnal terms in the equations. These terms cannot be measured by a physical experiment. This is a typical inverse problem.
- Every geophysical episode is unique: a field experiment cannot be reproduced. Therefore the validation of the model has to be carried out with several situations, all different, and the role of the data in this process is crucial.
- The geophysical fluids are non closed i.e. there is always interaction between the components of the environment. The ocean interacts with the atmosphere, the atmosphere interacts with continental water interacting with the ocean. A consequence is that boundary terms, associated to the interactions, will have to be provided in a model dedicated to one component of the environment. The quantitative estimation and parameterization of this term is also a typical inverse problem.

There has been a strong and increasing societal demand for a precise prediction in meteorology, oceanography and hydrology for a few years. Following meteorology, an operational center for oceanic prediction (MERCATOR) and a center for flood prediction (SHARPI) have been recently opened in Toulouse. The development of numerical prediction rises many mathematical and algorithmic problems. The vocation of IDOPT is not to carry out numerical prediction but to be a support for the mathematical problems raised by this approach. In this sense the basic components of the water cycle modelling are studied in IDOPT. Worldwide very few research groups have this particularity.

4.2.1. Oceanography

Participants: Eric Blayo, Didier Bresch, Jacques Blum, Laurent Debreu, Christine Kazantsev, Evgueni Kazantsev, François-Xavier Le Dimet, Carine Lucas, Véronique Martin, Maelle Nodet, Dinh Tuan Pham, Céline Robert, Ehouarn Simon, Jacques Verron.

Understanding and forecasting the ocean circulation is presently the subject of an intensive research effort from the international scientific community. This effort was primarily motivated by the crucial role of the ocean in the earth climate, in the perspective of global change. Moreover important recent research programs aim at developing operational oceanography, i.e. a near real-time forecasting of ocean circulation, with applications to shipping, fisheries, weather forecasting... Another related field is coastal oceanography, dealing for example with pollution, littoral planning, or management of ecosystems. Essential tools for such goals are modelling systems, which require the development of performant numerical models and data assimilation methods. In this context, the IDOPT project conducts efforts on the following topics :

- *Multiresolution 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. From a mathematical and numerical point of view, such model interactions demand specific studies on open boundary conditions, mesh refinement methods, and coupling algorithms.
- *Advanced numerical schemes*: Most ocean models make use of simple second order finite difference schemes on structured grids. We are seeking for higher order schemes allowing both accuracy and good conservation properties, and dealing with irregular boundaries and bottom topography.

- *Parameterization and modelling of boundary layers*: A striking feature of ocean dynamics is the existence of several types of boundary layers, either lateral (near the coastlines), or vertical (near the ocean surface and bottom). Despite their relatively small size, these layers have an important role in the global dynamics, and must be accurately represented in the model. New modelling and numerical approaches to this problem are studied.
- *Data assimilation methods for ocean modelling systems*: As in atmospheric models, the main difficulties encountered when assimilating data in ocean models are the huge dimension of the model state vector (typically 10^6-10^7), 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, and on the design of data assimilation methods for multiresolution models.

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

4.2.2. Control of flow

Participants: François-Xavier Le Dimet, Yousuff Hussaini.

A body in a fluid in motion produces drag. A way to reduce the drag is to use blowing and suction at the surface of the body. In (Daescu, Hussaini, Navon, Le Dimet) it has been shown how the tools of optimal control can be used to optimaly reduce the drag. A possible extension, under works, coupled to data assimilation is to consider a closed loop system, the inputs being the measurements of sensors and the result a minimal drag.

4.2.3. Hydrology and river hydraulics

Participants: William Castaings, Marc Honnorat, François-Xavier Le Dimet, Cyril Mazauric, Jérôme Monnier.

Floods prevention and prediction are critical issues. Flooding is the result of complex interactions of the water cycle between meteorology, hydrology and hydraulics. Mathematical and numerical modelling is becoming accepted as a standard engineering practice for both prevention and prediction of those catastrophic events. The models (1-D and 2-D shallow water equations) and the industrial softwares (e.g. Telemac2D, Carima1D) are quite satisfying for some configurations. Nevertheless for practical applications, initial and boundary conditions (e.g. observed water level, discharge) are partial and difficult to prescribe, and empirical parameters (e.g. land roughness) are calibrated manually using hydraulic expertise. Realistic and reliable forecasting of those catastrophic events requires a completely integrated approach with all components (models and data) integrated in a consistent manner into an hydro-meteorological prediction chain with affordable computational cost.
Data assimilation methods, that have shown their potential in other geosciences like meteorology and oceanography, are now in the forefront in hydrology. This prediction chain is far from being operational.
The problems adressed in IDOPT related to data assimilation for catchment scale hydrology and river hydraulics are part of the investigations to be carried out. The current research topic conducted in IDOPT are the following.

- *Image Data assimilation*. M. Honnorat began his PhD in October 2003, treating of image data assimilation for flood models. The two mathematical problems tackled are the reconstruction of the flow dynamics using images type data and the high sensitivity of the water front with respect to data uncertainties (topography and land roughness). This study is funded by CNES and CNRS.

- *Sensitivity analysis for rainfall-runoff models*. Flash flood events are usually generated by heavy convective precipitation over a relatively small area but catchment hydrology plays a major role in their occurrence. Important factors like initial soil moisture and infiltration parameters govern rainfall abstractions and therefore control the partition of rainwater between infiltration and runoff. Adjoint sensitivity analysis and data assimilation are investigated by W. Castaing for an event-based distributed flash flood model. This work is done in collaboration with Toulouse Fluid Mechanics Institute (IMFT) in the framework of PACTES project.

All these studies are led in the framework of different projects with numerous collaborations.

- The european project ANFAS (1st Jan. 2000 - 31 March 2003) was dedicated to the design of a Decision Support System for flood prevention and protection. During this project, hydraulics models (1D/2D) were adapted to the Loire pilot site.
- The national project PACTES (Prévention Anticipation des Crues au moyen des Techniques Spatiales) was initiated by the French Space Agency (CNES) and the French Ministry of Research, in order to improve the operational management of floods, through a joint approach involving the operational users, scientific laboratories and industry. Scoping interactions in terms of models and data with the continental water cycle, available gauged watersheds for evaluation and validation developed collaborations with the French hydro-meteorological community (Meteo France, CETP, LTHE).
- The regional project (Région Rhône-Alpes) “Numerical Prevention for Floods”, led by J. Monnier, conducts researches in data assimilation and parameter fitting methods, uncertainties propagation and use in real-time of numerical simulations. The participants are applied mathematicians and numericians (team-project IDOPT), hydrolicians (Cemagref Lyon), hydrologists (LTHE Grenoble) and research engineers (Sogreah Company).

5. Software

5.1. Microfluidics/Droplet Impact

Participant: Jérôme Monnier.

MICRALEFE (MICRofluidics ALE Finite Element) is a C++ finite element software solving 2D axisymmetric Navier-Stokes flow with free surface dynamics and curvature forces. It treats of a droplet impact on a solid substrate. The dynamic of the free surface is described using an ALE formulation (Arbitrary Lagrangian Eulerian). The code is based on the Rheolef C++ finite element library.
Micralefe capabilities include the dynamics of the contact angle, the triple point dynamics (liquid-gas-solid), [53], variable surface tension coefficients, slip type boundary conditions and automatic mesh refinement. The code modularity allows us to plan further developments such as coupling with a surfactant model (developments planned for 2005 and co-funded by our industrial partner).

5.2. Hydraulique Fluviale . Cas tests

Participants: Marc Honnorat, Youssef Loukili, Jérôme Monnier.

DASSFLOW is a river hydraulics simulation software designed for variational data assimilation. The model is based on the bidimensional shallow-water equations, solved by the finite volume method using the HLLC approximate Riemann solver. The adjoint code is available, as well as all the optimization framework that is necessary to easily build up new data assimilation experiments. The software is written in Fortran 90. It is currently evolving to take into account Lagrangian data for assimilation experiments.

5.3. Hydraulique Fluviale. Cas Reels

Participants: Youssef Loukili, Marc Honnorat, Jérôme Monnier.

Telemac2D-simple is a reduced research version of software Telemac2D (Telemac2D is an industrial code developed by EDF R&D and distributed by Sogreah Co). This version is basically meant for automatic differentiation by Tapenade, aiming conditions and parameter identification of river flow models. Some of the simulation capabilities kept in Telemac2D-simple involve flooding events with wetting and drying, dam break disasters, flows through flumes, breakwaters, bridge piers and other hydraulic works.
The code need further developments in order to reach our goal: variational data assimilation with real type data.

5.4. Wavelet Denoising MATLAB Toolbox

Participants: Anestis Antoniadis, Jeremie Bigot, Theofanis Sapatinas.

A wavelet toolbox and an accompanying paper "Gaussian Wavelet Denoising Matlab Toolbox" was jointly developed by A. Antoniadis, J. Bigot and T. Sapatinas, where various wavelet shrinkage and wavelet thresholding estimators in nonparametric regression appearing in the literature are discussed in detail and implemented. These estimators arise from a wide range of classical and empirical Bayes methods treating either individual or blocks of wavelet coefficients. See http://www.jstatsoft.org/v06/i06.

5.5. Adaptive Grid Refinement

Participants: Laurent Debreu, Cyril Mazauric.

AGRIF (Adaptive Grid Refinement In Fortran, [44], [43]) 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 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, []). Cyril Mazauric works on the implementation of AGRIF in the standard version of the OPA ocean modelling system (a general circulation model used by the French and European scientific community). AGRIF is licensed under a GNU (GPL) license and can be downloaded at its web site (http://www-lmc.imag.fr/IDOPT/AGRIF). More than two hundred downloads of the software have been done during the last year.

6. New Results

6.1. Microfluidics and wetting hydrodynamics

Participants: Iulian Cotoi, Jérôme Monnier.

During his postdoctoral fellowship (march-august), Iulian Cotoi has developed the software Micralef modeling a droplet impact on a solid substrate. The mathematical model is the Navier-Stokes free surface equations in an ALE formulation, with surface tension forces and local slip type boundary conditions.

6.2. Ocean modelling

6.2.1. Mathematical modelling of the ocean dynamics

Participants: Didier Bresch, Christine Kazantsev, Carine Lucas.

6.2.1.1. Small-Scale induced effects in the oceans

The ocean bottom topography and coasts vary over a wide range of scales, the smallest ones being unresolved in numerical computations. There is a need for the development of simplified models that account implicitly for the impact of the small-scale topography on the large-scale ocean circulation. We have recently developped such nonlinear models in idealized case for the quasigeostrophic system. This gives for instance some nonlinear pde's which governs the western boundary layer extending in some sense the linear one proposed by H.W. Munk (Munk layer). We are now looking at more general cases (other pde's, more general topography and coasts). We also try to see with physicists (LEGI) how such expansions can be used in actual applications.

6.2.1.2. Mathematical justification of asymptotics

The mathematical justifications of formal asymptotics encountoured in geophysics are not straigtforward. They depends of the domain, the data, the pde's that we considered. For instance, we have looked at western intensification of currents for domains with islands for instance showing that we have to add a corrector to the Sverdrup relation in this case. We have also considered rotating fluids in a cylinder showing that the Rossby waves are damped if the lateral section is not a disk (this result is linked to the Schiffer conjecture). This paper concerns ill prepared datas. We have also obtained the first justification of the planetary geostrophic equations from the Primitive one. This problem concerns singular perturbations with an operator which is not skew symmetric as it was in mathematical papers.

6.2.1.3. Influence of the viscous terms (Reynolds closure)

We have proposed new diffusive capillary models of Korteweg type and discuss their mathematical properties. More precisely, we introduce viscous models which provides some additional behavior of the density close to vacuum. We actually prove that if some compatibility conditions and capillarity are satisfied, some extra regularity information on a quantity involving the density is available. We obtain a non-trivial equality deduced from the special structure of the momentum equations. This results allow for instance to justify the link between the viscous shallow water equations and the viscous quasi-geostrophic equations or the viscous lake equations. A numerical study of such properties are actually in progress.

6.2.2. Sensitivity of an ocean model to topography perturbations

Participant: Eugène Kazantsev.

The bottom topography has a strong influence on the ocean circulation. Therefore it is interesting to quantify the sensitivity of an ocean model flow to the representation of this topography. Even if the real bathymetry is well described, its representation on the model grid is not obvious, because of the limited resolution. It is known for 30 years that, requiring the large scale ocean flow to be well represented, one has to smooth the topography in order to keep only its large-scale components. In this case, the influence of topographic subgrid-scales has to be parameterized, which is far from obvious.

A possible way to adapt the real bathymetry to a particular numerical model is to perform some data assimilation with the topography as the control parameter. In order to proceed, we need to evaluate first the sensitivity of a model to the topography variations. In this work we are looking especially to the most sensitive and to the most insensitive modes of the solution with respect to small variations of the topography.

The existence of modes to which the solution is not sensitive helps us to understand whether there exists a unique possibility to reconstruct the topography from observations of the model solution. If the solution exhibits no sensitivity to some particular mode, this shows that this mode can be used to perturb the topography without any change in the model flow. Mathematically speaking, this mode belongs to the null space of the sensitivity operator. The dimension of this null space determines the number of independent topography variations resulting in the same observable flow. In this work we try to estimate its dimension and to find a simple relationship between configurations of the flow and modes in the null space.

On the other hand, the most sensitive modes will form the sensitive space. Any small perturbation of the topography by a function from this space will result in a drastic change of the flow. Concerning the data assimilation procedure, it is this space that has to be controlled in the best way. The dimension of this space shows the minimum number of functions participating in the cost functional.

The model used in our work is a simple barotropic vorticity equation over topography. It is used in two configurations: a square basin with a flat bottom, and a coarse resolution North Atlantic basin with realistic topography. We discuss both the steady state solution and the non-stationary flow.

The quantitative measure is influenced essentially by the error growing time. The longer the time period during which we analyze the sensitivity, the greater the sensitivity. This conclusion is consistent with numerous studies of the model sensitivity to other parameters. Thus, the predictability studies analyzing the sensitivity to initial conditions, reveal the exponential (or close to) growth rate. In this work, we show that at short time scales the sensitivity to topography may differ from the sensitivity to initial conditions. But, for the long time limit, the sensitivity of the solution to any source of perturbation is the same. The intrinsic model instability dominates at these time scales and the source of the perturbation does not matter any longer.

The analysis of the patterns of the most sensitive modes reveals that the solution is more sensitive to the topographc perturbations in regions where the flow is turbulent, whereas the solution exhibits little sensitivity in regions where the flow is laminar. For example, the solution of our barotropic model of the North Atlantic is not sensitive to topography near the european coast. All sensitivity modes corresponding to vanishing eigenvalues are concentrated in this region. This means that performing the procedure of reconstruction of the topography using this model solution would not work in this region, because all modes belong to the null space. One would need an additional information.

Turning attention to more realistic problems, a number of difficulties can be encountered. Using 3-D multi-level models leads to dealing with baroclinic components, which can change the sensitivity of the model, and with different geometries at each level. Moreover, this study gives no information about particular schemes of parameterization of topography. Numerous modern schemes like partial step or shaved cells cannot be distinguished in this work as well as different horizontal grids like Arakawa's ones.

This problem is addressed in details in [].

6.2.3. Multiresolution approaches and coupling methods in oceanography

Participants: Eric Blayo, Laurent Debreu, Veronika Fedorenko, Véronique Martin, Cyril Mazauric.

The implementation of high-resolution local models can be performed in several ways. An usual way consists in designing a local model, and in using some external data to force it at its open boundaries. These data can be either climatological or issued from previous simulations of a large-scale coarser resolution model. The main difficulty in that case is to specify relevant open boundary conditions (OBCs). By performing a critical review of previous related works either in oceanography or applied mathematics, we have shown that such relevant OBCs must be based on the incoming characteristic variables (in the hyperbolic sense) of the model equations, with a consistent use of the external data. Numerical experiments in realistic 2-D ocean models, in collaboration with F. Vandermeirsch, have confirmed this result. The extension to 3-D realistic primitive equation models is presently underway.

Another way of designing such local models is to locally increase the resolution of a large-scale model. The design of local mesh refinement methods requires appropriate boundary conditions at the boundaries between coarse and fine mesh. Main difficulties rely on the treatment of distinct discrete boundary (e.g. due to different topography in ocean modelling) and the preservation of conservation properties. Topographic related issues have been treated specifically during the training period of Antoine Bouquet. When the refinement is adaptive, the initialization procedure is also of tremendous importance ([44]). Last the computer implementation of efficient local mesh refinement involves dynamic memory management, use of structured types and can be even harder when operated on parallel computers. The AGRIF software, presented in section 5.5, has been developed in the IDOPT project and is increasingly used in realistic ocean models.

An interest of the local refinement approach is the two-way interaction between local and global models. However a limitation is that the physics remains (at least nearly) unchanged from the global to the local scale, while it is well-known that large scale physics may be inadequate for representing local phenomena. Therefore a more general approach consists in coupling different models, with possibly different resolutions, numerics, and even physics. We can then use the framework of global-in-time Schwarz domain decomposition methods to derive efficient algorithms with relevant interface conditions.

Our approach is twofold : on one hand, we conduct rigourous mathematical studies on simplified models, in collaboration with applied mathematicians from LAGA - Paris 13 (L. Halpern, C. Japhet, V. Martin). Exact and approximate absorbing interface conditions have been computed for tracer equations and for the 2-D linearized shallow-water system. Corresponding numerical experiments have also been performed.
On the other hand, a realistic configuration for coupling experiments has been realized in collaboration with oceanographers from LEGI - Grenoble (B. Barnier, S. Cailleau). It consists in the coupling of a regional high resolution model of the bay of Biscay with a coarser resolution model of the north Atlantic. Several numerical simulations, with different coupling algorithms, have been realized. They illustrate the pros and cons of each method, from the point of view of the quality of the interior and interface solutions. In particular, the improvement due to the feedback from the regional model onto the global model is clearly shown.
This work is funded by the national MERCATOR program and by the french navy (SHOM).

6.2.4. Mode and wavenumber inversion for shallow water system

Participant: Isabelle Charpentier.

Modes and wavenumbers are the main ingredients that characterize the pressure field in an oceanic waveguide. However, wavenumber and mode inversions are well-known to be a difficult task in underwater acoustics. Moreover, this double inversion has never been performed simultaneously from the same configuration of emitters and receivers. We present a new approach to this problem in a shallow water environment between two vertical arrays of sources and receivers. Starting from a classical modal decomposition of the pressure field, our algorithm focuses on a specific treatment of phase and amplitude variables. The key idea is to run a three-stage optimization by working separately on the phase and amplitude of the acoustic field. The high number of variables of the problem is turned into an advantage by using an adjoint code generated by an Automatic Differentiation software. Numerical results in the presence of noise show that modes and wavenumbers are estimated with high accuracy.

6.3. Data assimilation methods for ocean models

Participants: Didier Auroux, Eric Blayo, Jacques Blum, Laurent Debreu, François-Xavier Le Dimet, Maëlle Nodet, Dinh Tuan Pham, Céline Robert, Ehouarn Simon, Jacques Verron.

Synthesis of reduced-order methods Following several studies led these last years in the IDOPT project on sequential and variational reduced order data assimilation methods, the PhD thesis of C. Robert (defended in december 2004) has consisted in drawing some synthesis of these methods (reduced order 4DVar and SEEK filter). A comparison of their applicability and performances in a realistic oceanic context (assimilation of in situ temperature data in a 3-D model of the tropical Pacific) has been performed for the first time. In the context of twin experiments (the model being supposed perfect), the smoothing nature of the variational approach appears to be an important aspect to correct the model solution for errors linked to propagating waves generated outside the observed area. In the context of the assimilation of real data (i.e. with an imperfect model), a mixed low-rank/full-rank 4DVar method led to the best results.

Finally, a first implementation of an hybrid method has been performed. In this method, the background error covariance matrix used in the variational approach evolves in time using the sequential filter. The preliminary results seem to show that this joint approach can improve further the solution.
Non linear dual data assimilation algorithms The aim of this work is to generalize to a nonlinear case the dual variational algorithm 4D-PSAS. An extended algorithm has been developed and validated in the context of twin experiments using a baroclinic quasi-geostrophic model. Numerical experiments have shown that the extended algorithm gives improved results compared to the 4D-VAR. This work is reported in the PhD of Didier Auroux.
Assimilation of lagrangian data. This work is motivated by the Argo program, which aims at deploying a network of 3000 profiling floats over the world ocean. Argo is part of the international GODAE experiment (Global Ocean Data Assimilation Experiment). These profilers drift at a typical depth of 1500m, and perform a vertical profile of temperature and salinity every ten days. Their position is known every ten days, which

gives a set of lagrangian data. We have developped a variational method in order to assimilate such data. Twin experiments are performed within the OPAVAR model, in an idealized configuration. The first results are available and they show that our method is successful. We presently test the impact on the assimilation of the parameters of the floats network : impact of the frequency of the data, impact of the drifting depth, impact of the number of floats. This work is the subject of the PhD Thesis of Maëlle Nodet.
Assimilation in multiresolution systems. The objectives are to study the mathematical formulation of data assimilation methods for embedded grids (multiresolution systems) and to conduct numerical experiments for validation. This study is divided into two parts: the selection of the assimilated observations as a function of the grid resolution (definition of criteria and sensitivity analysis), and integration of the grid interactions in the assimilation system (the assimilation scheme should allow new types of grid interactions by taking advantage of the iterative minimization procedure to add additional constraints at the coarse/fine grid interfaces). The derivation of the exact adjoint of the multiresolution system has been proposed and numerical experiments in a 1D shallow water model shows promising results. More complex experiments will be part of the work of Ehouarn Simon during his PhD thesis. We will also try to compare this approach with the direct application of local multigrid methods for the solution of the optimality system. This work is granted by the national PATOM and MERCATOR programs.

6.4. Data Assimilation in Agronomy

Participants: François-Xavier Le Dimet, Wu Lin, Claire Lauvernet.

Agronomy is an important field of application for modelling. In this field IDOPT has vevelopped two collaborations. One with the Chinese Academy of Sciences (Institute of Automatics), CIRAD and INRIA Rocquencourt (Philippe de Reffye) the purpose of this collaboration is to insert observational measurement in individual plants models in order to calibrate the models and to optimize plants growths by controlling watering and/or fretilizing. This work is carried out in Wu Lin's Ph.D.
At the other end of the scale, in collaboration with INRA Avigon (Frederic Barret) growth of plants, to predict the harvest, is studied at the level of plot. Data are provided by space imagery (SPOT Satellite). This theme is also devlopped in the framework of ASSIMAGE.

6.4.1. GreenLab - a plant functional-structural model

Started in Beijing in 1998, the GreenLab project aims at a mathematical description of plant growth, especially for the plant functional-structural characteristics. During this year we introduced variational methods to FSPM, and obtained preliminary results in the applications of identification of environmental parameters, optimal control of irrigation, assimilation of model initial conditions and environmental conditions of light and temperature for the functional-structural plant model - GreenLab.

6.4.2. Data Assimilation for Vegetation

For fifty years, crop functioning models grew in number and performances to better describe the state and production of vegetation. Those models use soil, climate and vegetation related data. Some of those characteristics vary in space and time and they are thus difficult to evaluate. Remote sensing observations would allow to better quantify these characteristics through assimilation techniques.

The objective of this study is to develop a method to estimate canopy state variables in time and space using assimilation of high temporal frequency Spot data into vegetation process models. This work belongs to the ADAM project (Assimilation of Data within Agronomic Models), including CNES, INRA, Romanian Soil Science Institute and several other French and Romanian institutes (http://medias.obs-mip.fr/adam/).

Three main studies were conducted this year: the calculation of a complex agronomic model adjoint, SAIL radiative transfert model inversion to study remote sensing data, and développement of a new way to consider spatial properties of the crop within the assimilation technique.

1. The STICS model will be used in the variational assimilation process. STICS (Simulateur mulTI-disciplinaire pour les Cultures Standard, Brisson et al., 1998) is a crop model that simulates canopy

functioning, taking into account climate, soil characteristics, crop properties and cultural practices. Its large number of discontinuities did not permit to derive it quickly and easily.

2. Remote sensing data permits to evaluate canopy biophysical properties by the way of different techniques to translate reflectance. Three inversion techniques have been compared with the help of soil measurements: multi-linear regression, vegetation indices and inversion of a canopy radiative transfert model with iterative methods. This model, SAIL (Scattering by Arbitrary Inclined Leaves) radiative transfer model, with leaf, soil and canopy optical properties, is able to simulate the SPOT data. Its inversion, using radiometric data, permits to include optical properties into the canopy functioning model.

3. In most agronomic studies on assimilation, model parameters are estimated by traditional pixel-based approaches. This means that, at a given date, a radiometric value gives a canopy biophysical characteristics (for exemple Leaf Area Index LAI) on one pixel, which is then assimilated. This technique generates at less 3 critical points:

   – spatial structures relations are not taken into account;
   – the inverse problem is certainly ill-posed;
   – the same work is repeated a large number of times, certainly useless, and generates a non optimal cost.

   In many inverse problems, the computation cost is a large obstacle, and reducing this cost becomes an additional aim. In order to take into account spatial properties within the assimilation of satellite images, another work has been conducted on a more simple model. The following questions then arise naturally:

   i. *Which space structures to exploit to reduce the problem size and to make it invertible?* This has been possible by associating *spatial dependance levels* to parameters: one will speak for example about *cultivar* parameter when this one is equal in all the cases to the same value so much it belongs to the same variety: for example phenologic stages or leaves properties. With a lower degree, some parameters follow an *in-field* variability, like cultural practices. Finally, other parameters depend on the *pixel* level, like soil parameters or ones without any physical meaning.

   ii. *How to transform the traditional assimilation scheme to an ensemble of pixels?* This can be done by the creation of a new agronomic model, taking into account all constraints, and which adjoint is calculated. LAI is now considered as a function of 3 groups of parameters: x is cultivar dependent, y is in-field variable, et z is pixel dependent: LAI $=$ f(x, y, z), where the parameters x are constrained to be equal on all pixels of the same cultivar, and the parameters y must be equal on the same field. This "macro-model" and an associated cost function should be derived in function of as many parameters as there are pixels on the satellite image.

Our main results are the following :

1. The adjoint model of STICS has been calculated though its large number of discontinuities, and will now permit to develop many results: sensitivity analysis, estimation of soil and crop properties, as well as cultural practices, evaluation of the effects of high temporal frequency on the parameter estimation ...within papers quite soon.

2. The three methods used to transform canopy reflectance to its biophysical properties revealed the good precision of vegetation indices (NDVI particularly : Normalized Difference Vegetation Index) as well as the SAIL inversion method. The precision of the latter depends a lot on prior information about soil properties and view and illumination angles in cost function minimized, which is not always easy to determine. Finally regression gives the best results, but its coefficients are only valid in the particular case of ADAM experiment, though NDVI and inversion could be translated to another region.
3. The space constraints add robustness to the method particularly when less observations are available. They make it possible to obtain a result quite as satisfactory as the traditional pixel-based assimilation, in terms of state variable (LAI) estimation, but with a *calculation N times less costly*, where N is the number of pixels (meanly: 30 iterations to converge against 3000 for 100 pixels used). In addition, for a very lower observations number available, they give better results than pixel-based assimilation, and much *more stable face to the change of satellite revisit frequency*. Lastly, the twin experiments made it possible to show that taking into account of the constraints, whatever the frequency of revisits, improves the identification of model parameters, which corresponds in general to the main objective of data assimilation.

6.5. Hydrology

Participants: William Castaings, Marc Honnorat, François-Xavier Le Dimet, Youssef Loukili, Cyril Mazauric, Jérôme Monnier.

6.5.1. Lagrangian Data Assimilation for River Hydraulic Models

M. Honnorat began his PhD in October 2003, addressing the problem of the assimilation of image type data for flood models.

Dynamic images (a series of still images, or a video) of a river flow contain informations that can be used in a data assimilation process for the identification of model parameters, such as topography and land roughness. A crucial problem to tackle in image data assimilation is to work out the correspondance between some characteristics of the data and model variables.

M. Honnorat has adapted a finite volume software modeling river hydraulics test cases to the Automatic Differentiation tool Tapenade abilities. This work has been done in collaboration with Y. Loukili, the developper of the direct model (it is written in Fortran 90). Then, M. Honnorat has developped the full optimization process based on the adjoint code generated by Tapenade and the BFGS minimization algorithm. Preliminary numerical experiments have shown that the trajectories of passive individual tracers on the free surface of a river flow (lagrangian data) can bring valuable information on the flow velocity for the reconstruction of the topography.

The continuation of this approach results in considering the assimilation of a water front, or coherent structures evolving on the surface flow.

This PhD, directed by J. Monnier and F.-X. LeDimet, is funded by CNES and CNRS.

6.5.2. Automatic Differentiation (AD) of Telemac2D by Tapenade

The industrial system Telemac, developed by LNHE-EDF, is an internationally used software dedicated to the hydrodynamical and environmental modeling of maritime and river flows. We took the challenge of designing a modern optimisation chain to its two-dimensional module Telemac2D. In this context, Y. Loukili, postdoctoral fellow supported by Région Rhône-Alpes, prepared and validated a reduced research version of Telemac2D. This lighter version of Telemac2D is both meant for river flows and suitable to be differentiated by Tapenade. Tapenade is the AD tool developed by team-project Tropics, INRIA Sophia-Antipolis. The strategy of differentiation of Telemac2D-simple was set and documented according to the limitations of current releases of Tapenade. This work is done in collaboration with the researchers of Tropics team, L. Hascouet and V. Pascual; it is planned to be finished during a six months master's degree internship in 2005. Once the AD of

Telemac-simple properly completed, data assimilation experiments with real type data will be done. Our final objective is to transfer our knowledge in identification parameters to an operational flood modeling software.

Using a code developed by D. Froehlich (DaveF), our group adapted this model to the Loire pilot site, participated in the development and deployment of a parallel version, conducted model integration to the ANFAS system by specifying features and interfaces. At the end of the ANFAS project, 2D modelling of river/floodplain flood propagation and fuse plug spillway erosion was achieved for a set of scenarios for the Loire river pilot site and fully integrated to demonstrate the facilities provided by the ANFAS decision support system.

W. Castaing began his PhD in spring 2003. It concerns sensitivity analysis and data assimilation applied to rainfall-runoff models. Flash flood events are usually generated by heavy convective precipitation over a relatively small area but catchment hydrology plays a major role in their occurrence. An event based flash flood model was developed by IMFT but the prescription of consistent initial conditions and calibrated parameters is a challenging task. In fact, important factors like initial soil moisture and infiltration parameters govern rainfall abstractions and therefore control the partition of rainwater between infiltration and runoff. Since the model is devoted to be integrated to a hydrometeorogical prediction chain, its interaction in terms of models and data was scoped and the direct model slightly modified. After a review of the application of data assimilation to hydrology, adjoint sensitivity analysis and variational data assimilation was initiated.

6.6. Models of plinian columns

Participant: Isabelle Charpentier.

Many of the processes involved in volcanic eruptive columns may be described through physical models based on conservation laws in which a physical parameterization, called the entrainment function, plays an important role. Among the purposes of these models, the solution of inverse problems and the estimation of the characteristics of ancient eruptions, for instance, require a better knowledge of the characteristics and properties of this function. The first part of the study shows that the three usual shapes chosen for this function yield apparently the same behaviour of the column. However, we prove that a piecewise constant shape may be unsuitable in optimization processes based on gradient methods. It also turns out that the parameters defining the entrainment function cannot be considered as constant.

In the second part of the study, the unique parameter of the remaining two functions is viewed as dependent on the boundary conditions and specified with respect to them. A calibration of the entrainment function with respect to real data is achieved through a power law established between column height and discharge, the latter being related to velocity, radius and bulk density at the vent. According to a discussion on eruptive data, the construction of a mathematical parameterization, with respect to boundary conditions and the heights of the vent and the tropopause, appears to be an unwarranted and difficult task since any new addition in the observed data will definitely modify the power law.

A 4-dimensional data base covering the range of boundary conditions usually found in plinian eruptions, together with an interpolation operator, is constructed in order to provide an approximated parameter for any set of boundary conditions in the range considered. Numerical results with a data base of dimension 9^4 show that the approximated parameter allows one to recover column height very accurately.

6.7. Statistical inverse problems

Participants: Anestis Antoniadis, Theofanis Sapatinas, Felix Abramovich, Jeremie Bigot.

Paper [38] originally drafted in 2004 and submitted for publication, extends our previous results to the class of functional mixed-effects models. Functional mixed-effects models are very useful in analyzing functional data. The work considers a general functional mixed-effects model that inherits the flexibility of linear mixed-effects models in handling complex designs and correlation structures. Wavelet decomposition approaches are used to model both fixed-effects and random-effects in the same functional space, which helps in interpreting the resulting model as a functional data model since it does not contradict the intuition that, if each outcome is a curve, which is the basic unit in functional data analysis, then the population-average curve and the subject-specific curves should have the same smoothness property (i.e., they should lie in the same functional space). A linear mixed-effects representation is then obtained that is used for estimation and inference in the general functional mixed-effects model. Adapting recent methodologies in linear mixed-effects and nonparametric regression models, hypothesis testing procedures are provided for both fixed-effects (testing whether certain fixed-effects functional components or contrasts are equal to zero) and random-effects (testing whether the random-effects functional components are equal to zero). The usefulness of the proposed estimation and testing procedures is illustrated by means of two real-life datasets arising from endocrinology and physiology.

Paper [41] is devoted to a fast, wavelet-based, regression-type method for estimating the parameters of a stable distribution. Fourier domain representations, combined with a wavelet multiresolution approach, are shown to be effective and highly efficient tools for inference in stable law families.

Paper [39], drafted in 2004, considers regression problems with univariate design points. The design points are irregular and no assumptions on their distribution are imposed. The regression function is retrieved by a wavelet based reproducing kernel Hilbert space (RKHS) technique with the penalty equal to the sum of blockwise RKHS norms. Under relevant assumptions on design points the method achieves asymptotic optimality in a wide range of Besov spaces.

Finally paper [40] focusses on nonparametric estimators in inverse problems for Poisson processes involving the use of wavelet decompositions. Adopting an adaptive wavelet Galerkin discretization the proposed method combines the well know theoretical advantages of wavelet-vaguelette decompositions for inverse problems in terms of optimally adapting to the unknown smoothness of the solution, together with the remarquably simple closed form expressions of Galerkin inversion methods.

7. Contracts and Grants with Industry

7.1. National contracts

- A 2-year contract with MERCATOR on the thematic "coupling of ocean models"
- A 2-year contract with MERCATOR on the thematic "Assimilation of lagrangian data in OPAVAR"
- A 2-year contract with SHOM (french navy) on the thematic "coupling of ocean models"
- A. Antoniadis started in 2004 a scientific collaboration with the French Institute of Petrol (IFP, Solaize, France) on a statistical approach for sensitivity analysis.

7.2. International contracts

- IDOPT is a partner of the european MERSEA project (http:///www.mersea.eu.org). This project is led by IFREMER, and aims at developing a european system for operational oceanography.
  Participants: Eric Blayo, Laurent Debreu, Florian Lemarié.
- IDOPT participates to the joint project with the Numerical Mathematics Institute of the russian academy of sciences "Variational data assimilation for geophysical models", co-directed by F.X. Le Dimet (France), V.Shutyaev (Russia) and G. Korotaev (Ukraine), and supported by EGIDE.
  Participants: François-Xavier Le Dimet, Eugène Kazantsev.
- Anestis Antoniadis is the coordinator of the French part of a research European network of the type "Interuniversity Attractions Poles", from 2002-2005, including 5 Belgian Universities (UCL, KUL, ULB, LUC, FUNP(NAMUR),), the UJF (LMC) and a German University (Aachen) on the theme "Statistical techniques and modeling for complex substantive questions with complex data".
  Participants: Anestis Antoniadis, Gerard Grégoire.

8. Other Grants and Activities

8.1. Regional action

Collaborations with various regional research teams:

- MEOM (Modélisation des Écoulements Océaniques et des Marées) team from Laboratoire d'Écoulements Géophysiques et Industriels (Grenoble) : oceanography.
- Laboratoire de Transferts en Hydrologie et Environnement (Grenoble): inverse problems in hydrology.
- Département d'études des matériaux, section d'études de la solidification : CENG (Centre d'Études Nucléaires de Grenoble).
- Institut Laue-Langevin, Institut de Biologie Structurale du CENG et ESRF (Synchrotron) : stochastic methods for inverse problems.
- Pechiney : Centre de recherche de Voreppe.
- Cemagref Lyon, Department Hydrology and Hydraulics.
- LEGI, PIM project-team (Particules Interfaces Microfluidique).
- The regional project (Région Rhône-Alpes) "Numerical Prevention for Floods", led by J. Monnier, conducts researches in data assimilation and parameter fitting methods and uncertainties propagation. The participants are applied mathematicians and numericians (team-project IDOPT), hydraulicians (Cemagref Lyon), hydrologists (LTHE Grenoble) and research engineers (Sogreah Company). Annual meetings with all participants are organized.

8.2. National actions

F.-X. Le Dimet is in charge of the project ASSIMAGE, devoted to the assimilation of images in numerical models in the framework of the ACI "Données Massives".

Interactions with other INRIA projects or actions:

- PARA PROJECT: Operational inverse mode
- ESTIME PROJECT: Optimisation algorithm, operational inverse mode
- TROPICS ACTION: Adjoint code automatic differentiation (TAPENADE), operational inverse mode
- SINUS PROJECT : Operational inverse mode

Collaborations with other research teams in France :

- Participation to the national research programm MERCATOR (oceanography).
- Laboratory "Analyse, Géométrie et Applications" (Paris 13): Domain decomposition and coupling methods
- IFREMER Brest
- IRD Brest
- "Laboratoire de Météorologie Dynamique" in the ENS (Paris): data assimilation for environment
- CEA Cadarache
- Centre National de Recherche Météorologique, Météo-France (Toulouse): Data assimilation for atmospheric models

Participation to national research groupements (GdR) CNRS :

- GdR SPARCH (simulation de faisceaux de particules chargées)
- GdR Optimal design
- GdR Fluids in interaction
- GdR EAPQ (Equations d'Amplitudes et Propriétés Qualitatives)

8.3. European actions

8.3.1. Western Europe

Collaboration of A. Antoniadis and G. Grégoire with the professors I. Gijbels and A. Kneip of the Institut de Statistique de Louvain-La-Neuve. Collaboration of A. Antoniadis with Dr. Umberto Amato of CNR Italien (Naples). Collaboration of A. Antoniadis with Dr. Sylvain Sardy (École Polytechnique Fédérale de Lausanne).
F.-X. Le Dimet participates to the European project ECRASE (modelling in hydrology) and to the European projet PIONEER (coastal oceanography). He is member of the ECMI Educational Board (European Consortium for Mathematics in Industry).
E. Blayo and L. Debreu participate to the European project MERSEA (operational oceanography).

8.4. International actions

On the thematic “plasma physics” : collaboration with M. Vogelius (Rutgers university).
On the thematic “environnement” : F.-X. Le Dimet is in charge of an action (ECCO-NET) of cooperation with Russia (Institute of Numerical Mathematics of the Russian Academy of Sciences) and Ukrain (Institute of Oceanography of the Ukrainian Academy of Sciences). The theme of this cooperation is data assimilation for geophysical flows. On this theme it exists also a strong cooperation with China (Institute of Atmospheric Physics of the Chinese A.S.) (Invitation of F.-X. Le Dimet, in 2004) and Vietnam (Institutes of Mathematics and Institute of Mechanics of the Vietnamese A.S.), (Invitations of F.-X. Le Dimet, in 2004)
IDOPT is in charge of the associated group "SEMINOLE" devoted to promote co-operative research between the Department of Computational Sciences and Information Technology at Florida State University and IDOPT. Several stays both in Grenoble and Tallahassee were carried out in the framework of the agreement. The theme of the agreement is "Data and models for geophysical flows".

9. Dissemination

9.1. Scientific community dissemination

A. Antoniadis is a member of the Editorial board of the *ISUP* journal since 1992.
A. Antoniadis is associate editor of the Journal of the French Statistical Society since 1998.
A. Antoniadis is Editor in Chief of the journal ESAIM: Probability & Statistics since 2001.
A. Antoniadis is associate editor of the Journal “Statistics and Computing” since 2002.
A. Antoniadis has organized and chaired the international conference “Wavelets and Statistics: watering the seed”, partially supported by INRIA, held in Villard de Lans from the 4 to 7 September 2003. J. Blum is member of the scientific commitee of PSMN (Pôle de Simulation et de Modélisation Numérique) of the ENS Lyon.
D. T. Pham is editor in chief of the *Journal of Time Series Analysis* since 1992.
F.-X. Le Dimet is member of the scientific commitee of the european project GIR ECOFOR.
F.-X. Le Dimet is member of the Educational Board of ECMI
F.-X. Le Dimet is member of the scientific commitee of the PNRH (Programme National de Recherches en Hydrologie, CNRS-INSU).

9.2. Teaching

There exists a strong link with the MASTER in applied mathematics of the Joseph Fourier University and the Institut National Polytechnique de Grenoble (ENSIMAG). Most of the staff of the project give lectures in this formation, and our Master and PhD students come from this formation. Among all the lectures given by the staff of the project, we can cite:
- Models and data for geophysical flows (E. Blayo, L. Debreu, F.-X. Le Dimet)
- Domain decomposition methods for PDEs (E. Blayo)

- Inverse problems in medical imagery (A. Antoniadis)
- Control and optimization of systems governed by PDEs (J.Blum, master of the univ. of Nice)

Lectures given in international schools :

- WAMA international school (Cargese, Corsica, organized partially by INRIA in summer 2004) : A. Antoniadis
- GODAE international school (La Londe, France, summer 2004) : E. Blayo - An initiation to Data Assimilation in the Geosciences (Nha Trang, Vietnam, organized by the Vietnamese Academy of Sciences, 2004) : F.-X. Le Dimet.

9.3. conferences, workshops

The joint French-Russian conference “Mathematical methods for geophysical flows” was organized in Grenoble on November 17-19, 2004, by E. Kazantsev and F.-X. Le Dimet.

D. Bresch has co-organized with J. Videman and J.-M. Urbano two international summer schools and one workshop in May-July 2004. One school was around "dynamic of climate and atmospheric sciences" and the other school and the workshop were dedicated to "oceanography, lakes and rivers". See : http://www.mat.uc.pt/~tt2004/

The members of the team have participated to various conferences and workshops. See the bibliography.

10. Bibliography

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