IN PARTNERSHIP WITH:
Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture

Activity Report 2017

Project-Team FLUMINANCE

Fluid Flow Analysis, Description and Control from Image Sequences

IN COLLABORATION WITH: Institut de recherche mathématique de Rennes (IRMAR)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Earth, Environmental and Energy Sciences

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Creation of the Project-Team: 2009 July 01

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1. Personnel

Research Scientists

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Dominique Heitz [IRSTEA, Researcher]
Cédric Herzet [Inria, Researcher]

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Pierre Derian [Inria, until Aug 2017]
Mamadou Diallo [Inria, until Sep 2017]
Thibaut Tronchin [Inria, until Oct 2017]

PhD Students

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2. Overall Objectives

2.1. Overall Objectives

The research group that we have entitled FLUMINANCE from a contraction between the words "Fluid" and "Luminance" is dedicated to the extraction of information on fluid flows from image sequences and to the development of tools for the analysis and control of these flows. The objectives of the group are at the frontiers of several important domains that range from fluid mechanics to geophysics. One of the main originality of the FLUMINANCE group is to combine cutting-edge researches on data-assimilation and flow numerical modeling with an ability to conduct proper intensive experimental validations on prototype flows mastered in laboratory. The scientific objectives decompose in four main themes:

- **Fluid flows characterization from images**
  In this first axis, we aim at providing accurate measurements and consistent analysis of complex fluid flows through image analysis techniques.The application domain ranges from industrial processes and experimental fluid mechanics to environmental sciences. This theme includes also the use of non-conventional imaging techniques such as Schlieren techniques, Shadowgraphs, holography. The objective will be here to go towards 3D dense velocity measurements.
- **Coupling dynamical model and image data**
  We focus here on the study, through image data, of complex and partially known fluid flows involving complex boundary conditions, multi-phase fluids, fluids and structures interaction problems. Our credo is that image analysis can provide sufficiently fine observations on small and medium scales to construct models which, applied at medium and large scale, account accurately for a wider range of the dynamics scales. The image data and a sound modeling of the dynamical uncertainty at the observation scale should allow us to reconstruct the observed flow and to provide efficient real flows (experimental or natural) based dynamical modeling. Our final goal will be to go towards a 3D reconstruction of real flows, or to operate large motion scales simulations that fit real world flow data and incorporate an appropriate uncertainty modeling.
- **Control and optimization of turbulent flows**

We are interested on active control and more precisely on closed-loop control. The main idea is to extract reliable image features to act on the flow. This approach is well known in the robot control community, it is called visual servoing. More generally, it is a technique to control a dynamic system from image features. We plan to apply this approach on flows involved in various domains such as environment, transport, microfluidic, industrial chemistry, pharmacy, food industry, agriculture, etc.

- **Numerical models for geophysical flows simulation and analysis** Numerical models are very useful for environmental applications. Several difficulties must be handled simultaneously, in a multidisciplinary context. For example, in geophysics, media are highly heterogeneous and only few data are available. Stochastic models are often necessary to describe unresolved physical processes. Computational domains are characterized by complex 3D geometries, requiring adapted space discretization. Equations modeling flow and transport are transient, requiring also adapted time discretization. Moreover, these equations can be coupled together or with other equations in a global nonlinear system. These large-scale models are very time and memory consuming. High performance computing is thus required to run these types of scientific simulations. Supercomputers and clusters are quite powerful, provided that the numerical models are written with a parallel paradigm.

3. Research Program

3.1. Estimation of fluid characteristic features from images

The measurement of fluid representative features such as vector fields, potential functions or vorticity maps, enables physicists to have better understanding of experimental or geophysical fluid flows. Such measurements date back to one century and more but became an intensive subject of research since the emergence of correlation techniques [49] to track fluid movements in pairs of images of a particles laden fluid or by the way of clouds photometric pattern identification in meteorological images. In computer vision, the estimation of the projection of the apparent motion of a 3D scene onto the image plane, referred to in the literature as optical-flow, is an intensive subject of researches since the 80's and the seminal work of B. Horn and B. Schunk [62]. Unlike to dense optical flow estimators, the former approach provides techniques that supply only sparse velocity fields. These methods have demonstrated to be robust and to provide accurate measurements for flows seeded with particles. These restrictions and their inherent discrete local nature limit too much their use and prevent any evolutions of these techniques towards the devising of methods supplying physically consistent results and small scale velocity measurements. It does not authorize also the use of scalar images exploited in numerous situations to visualize flows (image showing the diffusion of a scalar such as dye, pollutant, light index refraction, flurocein,...). At the opposite, variational techniques enable in a well-established mathematical framework to estimate spatially continuous velocity fields, which should allow more properly to go towards the measurement of smaller motion scales. As these methods are defined through PDE's systems they allow quite naturally constraints to be included such as kinematic properties or dynamic laws governing the observed fluid flows. Besides, within this framework it is also much easier to define characteristic features estimation procedures on the basis of physically grounded data model that describes the relation linking the observed luminance function and some state variables of the observed flow. The Fluminance group has allowed a substantial progress in this direction with the design of dedicated dense estimation techniques to estimate dense fluid motion fields. See [7] for a detailed review. More recently problems related to scale measurement and uncertainty estimation have been investigated [56]. Dynamically consistent and highly robust techniques have been also proposed for the recovery of surface oceanic streams from satellite images [52]. Very recently parameter-free approaches relying on uncertainty concept has been devised [53]. This technique outperforms the state of the art.

3.2. Data assimilation and Tracking of characteristic fluid features

Real flows have an extent of complexity, even in carefully controlled experimental conditions, which prevents any set of sensors from providing enough information to describe them completely. Even with the highest levels of accuracy, space-time coverage and grid refinement, there will always remain at least a lack of resolution and some missing input about the actual boundary conditions. This is obviously true for the complex flows encountered in industrial and natural conditions, but remains also an obstacle even for standard academic flows thoroughly investigated in research conditions.

This unavoidable deficiency of the experimental techniques is nevertheless more and more compensated by numerical simulations. The parallel advances in sensors, acquisition, treatment and computer efficiency allow the mixing of experimental and simulated data produced at compatible scales in space and time. The inclusion of dynamical models as constraints of the data analysis process brings a guaranty of coherency based on fundamental equations known to correctly represent the dynamics of the flow (e.g. Navier Stokes equations) [11]. Conversely, the injection of experimental data into simulations ensures some fitting of the model with reality.

To enable data and models coupling to achieve its potential, some difficulties have to be tackled. It is in particular important to outline the fact that the coupling of dynamical models and image data are far from being straightforward. The first difficulty is related to the space of the physical model. As a matter of fact, physical models describe generally the phenomenon evolution in a 3D Cartesian space whereas images provides generally only 2D tomographic views or projections of the 3D space on the 2D image plane. Furthermore, these views are sometimes incomplete because of partial occlusions and the relations between the model state variables and the image intensity function are otherwise often intricate and only partially known. Besides, the dynamical model and the image data may be related to spatio-temporal scale spaces of very different natures which increases the complexity of an eventual multiscale coupling. As a consequence of these difficulties, it is necessary generally to define simpler dynamical models in order to assimilate image data. This redefinition can be done for instance on an uncertainty analysis basis, through physical considerations or by the way of data based empirical specifications. Such modeling comes to define inexact evolution laws and leads to the handling of stochastic dynamical models. The necessity to make use and define sound approximate models, the dimension of the state variables of interest and the complex relations linking the state variables and the intensity function, together with the potential applications described earlier constitute very stimulating issues for the design of efficient data-model coupling techniques based on image sequences.

On top of the problems mentioned above, the models exploited in assimilation techniques often suffer from some uncertainties on the parameters which define them. Hence, a new emerging field of research focuses on the characterization of the set of achievable solutions as a function of these uncertainties. This sort of characterization indeed turns out to be crucial for the relevant analysis of any simulation outputs or the correct interpretation of operational forecasting schemes. In this context, stochastic modeling play a crucial role to model and process uncertainty evolution along time. As a consequence, stochastic parameterization of flow dynamics has already been present in many contributions of the Fluminance group in the last years and will remain a cornerstone of the new methodologies investigated by the team in the domain of uncertainty characterization.

This wide theme of research problems is a central topic in our research group. As a matter of fact, such a coupling may rely on adequate instantaneous motion descriptors extracted with the help of the techniques studied in the first research axis of the FLUMINANCE group. In the same time, this coupling is also essential with respect to visual flow control studies explored in the third theme. The coupling between a dynamics and data, designated in the literature as a Data Assimilation issue, can be either conducted with optimal control techniques [63], [64] or through stochastic filtering approaches [57], [60]. These two frameworks have their own advantages and deficiencies. We rely indifferently on both approaches.

3.3. Optimization and control of fluid flows with visual servoing

Fluid flow control is a recent and active research domain. A significant part of the work carried out so far in that field has been dedicated to the control of the transition from laminarity to turbulence. Delaying, accelerating or modifying this transition is of great economical interest for industrial applications. For instance, it has been shown that for an aircraft, a drag reduction can be obtained while enhancing the lift, leading consequently to limit fuel consumption. In contrast, in other application domains such as industrial chemistry, turbulence phenomena are encouraged to improve heat exchange, increase the mixing of chemical components and enhance chemical reactions. Similarly, in military and civilians applications where combustion is involved, the control of mixing by means of turbulence handling rouses a great interest, for example to limit infra-red signatures of fighter aircraft.

Flow control can be achieved in two different ways: passive or active control. Passive control provides a permanent action on a system. Most often it consists in optimizing shapes or in choosing suitable surfacing (see for example [55] where longitudinal riblets are used to reduce the drag caused by turbulence). The main problem with such an approach is that the control is, of course, inoperative when the system changes. Conversely, in active control the action is time varying and adapted to the current system's state. This approach requires an external energy to act on the system through actuators enabling a forcing on the flow through for instance blowing and suction actions [67], [59]. A closed-loop problem can be formulated as an optimal control issue where a control law minimizing an objective cost function (minimization of the drag, minimization of the actuators power, etc.) must be applied to the actuators [51]. Most of the works of the literature indeed comes back to open-loop control approaches [66], [61], [65] or to forcing approaches [58] with control laws acting without any feedback information on the flow actual state. In order for these methods to be operative, the model used to derive the control law must describe as accurately as possible the flow and all the eventual perturbations of the surrounding environment, which is very unlikely in real situations. In addition, as such approaches rely on a perfect model, a high computational costs is usually required. This inescapable pitfall has motivated a strong interest on model reduction. Their key advantage being that they can be specified empirically from the data and represent quite accurately, with only few modes, complex flows' dynamics. This motivates an important research axis in the Fluminance group.

3.4. Numerical models applied to hydrogeology and geophysics

The team is strongly involved in numerical models for hydrogeology and geophysics. There are many scientific challenges in the area of groundwater simulations. This interdisciplinary research is very fruitful with cross-fertilizing subjects.

In geophysics, a main concern is to solve inverse problems in order to fit the measured data with the model. Generally, this amounts to solve a linear or nonlinear least-squares problem.

Models of geophysics are in general coupled and multi-physics. For example, reactive transport couples advection-diffusion with chemistry. Here, the mathematical model is a set of nonlinear Partial Differential Algebraic Equations. At each timestep of an implicit scheme, a large nonlinear system of equations arise. The challenge is to solve efficiently and accurately these large nonlinear systems.

3.5. Numerical algorithms and high performance computing

Linear algebra is at the kernel of most scientific applications, in particular in physical or chemical engineering. The objectives are to analyze the complexity of these different methods, to accelerate convergence of iterative methods, to measure and improve the efficiency on parallel architectures, to define criteria of choice.

4. Application Domains

4.1. Introduction

By designing new approaches for the analysis of fluid-image sequences the FLUMINANCE group aims at contributing to several application domains of great interest for the community and in which the analysis of complex fluid flows plays a central role. The group focuses mainly on two broad application domains:

- Environmental sciences;
- Experimental fluid mechanics and industrial flows.

We detail hereafter these two application domains.

4.2. Environmental sciences

The first huge application domain concerns all the sciences that aim at observing the biosphere evolution such as meteorology, climatology or oceanography but also remote sensing study for the monitoring of meteorological events or human activities consequences. For all these domains image analysis is a practical and unique tool to *observe, detect, measure, characterize or analyze* the evolution of physical parameters over a large domain. The design of generic image processing techniques for all these domains might offer practical software tools to measure precisely the evolution of fluid flows for weather forecasting or climatology studies. It might also offer possibilities of close surveillance of human and natural activities in sensible areas such as forests, river edges, and valley in order to monitor pollution, floods or fire. The need in terms of local weather forecasting, risk prevention, or local climate change is becoming crucial for our tomorrow's life. At a more local scale, image sensors may also be of major utility to analyze precisely the effect of air curtains for safe packaging in agro-industrial.

4.3. Experimental fluid mechanics and industrial flows

In the domain of **experimental fluid mechanics**, the visualization of fluid flows plays a major role, especially for turbulence study since high frequency imaging has been made currently available. Together with analysis of turbulence at different scales, one of the major goals pursued at the moment by many scientists and engineers consists in studying the ability to manipulate a flow to induce a desired change. This is of huge technological importance to enhance or inhibit mixing in shear flows, improve energetic efficiency or control the physical effects of strain and stresses. This is for instance of particular interest for:

- military applications, for example to limit the infra-red signatures of fighter aircraft;
- aeronautics and transportation, to limit fuel consumption by controlling drag and lift effects of turbulence and boundary layer behavior;
- industrial applications, for example to monitor flowing, melting, mixing or swelling of processed materials, or preserve manufactured products from contamination by airborne pollutants, or in industrial chemistry to increase chemical reactions by acting on turbulence phenomena.

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5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

First prize of the second Mathematics of Planet Earth international competition. Module "Simulating the melting of ice caps", authors M. Nodet and J. Erhel.

BEST PAPER AWARD:

[44]
M. NODET, J. ERHEL. *Simulating the melting of ice caps*, 2017, This is an interactive module to explain to a wide audience the simulating of ice caps.Sea levels are rising for various reasons related to global warming. The glaciers of Antarctica and Greenland, known as ice caps or ice sheets, play a major role in sea level rise. Is it possible to predict future changes in these ice caps, and particularly the calving of icebergs into the ocean?The module answers to this question by showing numerical simulations of ice sheet dynamics.It can be viewed or downloaded at https://imaginary.org/program/simulating-the-melting-of-ice-caps, https://hal.inria.fr/hal-01643852

6. New Software and Platforms

6.1. 2DLayeredMotion

Estimation of 2D independent mesoscale layered atmospheric motion fields
FUNCTIONAL DESCRIPTION: This software enables to estimate a stack of 2D horizontal wind fields corresponding to a mesoscale dynamics of atmospheric pressure layers. This estimator is formulated as the minimization of a global energy function. It relies on a vertical decomposition of the atmosphere into pressure layers. This estimator uses pressure data and classification clouds maps and top of clouds pressure maps (or infra-red images). All these images are routinely supplied by the EUMETSAT consortium which handles the Meteosat and MSG satellite data distribution. The energy function relies on a data model built from the integration of the mass conservation on each layer. The estimator also includes a simplified and filtered shallow water dynamical model as temporal smoother and second-order div-curl spatial regularizer. The estimator may also incorporate correlation-based vector fields as additional observations. These correlation vectors are also routinely provided by the Eumetsat consortium.

- Participant: Étienne Mémin
- Contact: Étienne Mémin
- URL: http://fluid.irisa.fr/index.html

6.2. 3DLayeredMotion

Estimation of 3D interconnected layered atmospheric motion fields
FUNCTIONAL DESCRIPTION: This software extends the previous 2D version. It allows (for the first time to our knowledge) the recovery of 3D wind fields from satellite image sequences. As with the previous techniques, the atmosphere is decomposed into a stack of pressure layers. The estimation relies also on pressure data and classification clouds maps and top of clouds pressure maps. In order to recover the 3D missing velocity information, physical knowledge on 3D mass exchanges between layers has been introduced in the data model. The corresponding data model appears to be a generalization of the previous data model constructed from a vertical integration of the continuity equation.

- Contact: Étienne Mémin
- URL: http://fluid.irisa.fr

6.3. DenseMotion

Estimation of 2D dense motion fields
FUNCTIONAL DESCRIPTION: This code allows the computation from two consecutive images of a dense motion field. The estimator is expressed as a global energy function minimization. The code enables the choice of different data models and different regularization functionals depending on the targeted application. Generic motion estimators for video sequences or fluid flows dedicated estimators can be set up. This software allows in addition the users to specify additional correlation based matching measurements. It enables also the inclusion of a temporal smoothing prior relying on a velocity vorticity formulation of the Navier-Stoke equation for Fluid motion analysis applications.

- Participant: Étienne Mémin
- Contact: Étienne Mémin
- URL: http://fluid.irisa.fr/index.html

6.4. Low-Order-Motion

Estimation of low order representation of fluid motion

FUNCTIONAL DESCRIPTION: This code enables the estimation of a low order representation of a fluid motion field from two consecutive images.The fluid motion representation is obtained using a discretization of the vorticity and divergence maps through regularized Dirac measure. The irrotational and solenoidal components of the motion fields are expressed as linear combinations of basis functions obtained through the Biot-Savart law. The coefficient values and the basis function parameters are formalized as the minimizer of a functional relying on an intensity variation model obtained from an integrated version of the mass conservation principle of fluid mechanics.

- Participants: Anne Cuzol and Étienne Mémin
- Contact: Étienne Mémin
- URL: http://fluid.irisa.fr

6.5. TYPHOON

- Participants: Christopher Mauzey, Étienne Mémin and Pierre Dérian
- Partner: CSU Chico
- Contact: Étienne Mémin
- URL: http://phys.csuchico.edu/lidar/typhoon/

6.6. H2OLab

KEYWORDS: Energy - Contamination - Groundwater - Hydrogeology - Heterogeneity - Uncertainly - Multi-scale - Simulation
SCIENTIFIC DESCRIPTION: The software platform contains a database which is interfaced through the web portal H2OWeb. It contains also software modules which can be used through the interface H2OGuilde. The platform H2OLab is an essential tool for the dissemination of scientific results. Currently, software and database are shared by the partners of the h2mno4 project.
FUNCTIONAL DESCRIPTION: The software platform H2OLab is devoted to stochastic simulations of groundwater flow and contaminant transport in highly heterogeneous porous and fractured geological media.

-Modeling and numerical simulation of aquifers -Porous and fractured heterogeneous media -Flow with mixed finite elements -Solute transport with a Lagrangian method -Stochastic modeling for data uncertainty.

- Participants: Géraldine Pichot, Grégoire Lecourt, Jean-Raynald De Dreuzy and Jocelyne Erhel
- Partners: Université de Rennes 1 - CNRS - Université de Lyon - Université de Poitiers
- Contact: Jocelyne Erhel
- URL: http://h2olab.inria.fr/

6.7. PALMTREE

KEYWORD: Monte-Clarlo
FUNCTIONAL DESCRIPTION: We present an easy-to-use package for the parallelization of Lagrangian methods for partial differential equations. In addition to the reduction of computation time, the code aims at satisfying three properties:

simplicity: the user just has to add the algorithm governing the behaviour of the particles. portability: the possibility to use the package with any compiler and OS. action-replay: the ability of the package to replay a selected batch of particles.

The last property allows the user to replay and capture the whole sample path for selected particles of a batch. This feature is very useful for debugging and catching some relevant information.

- Authors: Lionel Lenôtre, Géraldine Pichot, Lionel Lenôtre and Lionel Lenôtre
- Contact: Géraldine Pichot

6.8. GRT3D

KEYWORDS: Geochemistry - Dispersion - Scientific calculation - Simulation - Advection
SCIENTIFIC DESCRIPTION: Participants : Édouard Canot, Jocelyne Erhel [correspondant] .

Version: version 2.0, April 2014

APP: registered

Programming language: C

Abstract: Reactive transport modeling has become an essential tool for understanding complex environmental problems. It is an important issue for MoMaS and C2S@EXA partners (see sections 8.2.5 , 8.2.3), in particular Andra. We have developed a method coupling transport and chemistry, based on a method of lines such that spatial discretization leads to a semi-discrete system of algebraic differential equations (DAE system). The main advantage is to use a complex DAE solver, which controls simultaneously the timestep and the convergence of Newton algorithm. The approach SIA uses a fixed-point method to solve the nonlinear system at each timestep, whereas the approach SNIA uses an explicit scheme.

The software suite GRT3D has four executable modules:

SIA1D: Sequential Iterative Approach for 1D domains,

GDAE1D: Global DAE approach for 1D domains,

SNIA3D: Sequential Non Iterative Approach for 1D, 2D or 3D domains.

GDAE3D: Global DAE approach for 1D, 2D or 3D domains. This module has three variants: the original one with logarithms, an optimized one still with logarithms, an optimized one which does not use logarithms.

Current work: extension of the chemistry module and parallelization.
FUNCTIONAL DESCRIPTION: Reactive transport modeling has become an essential tool for understanding complex environmental problems. It is an important issue for MoMaS and C2S@EXA partners, in particular Andra. We have developed a method coupling transport and chemistry, based on a method of lines such that spatial discretization leads to a semi-discrete system of algebraic differential equations (DAE system). The main advantage is to use a complex DAE solver, which controls simultaneously the timestep and the convergence of Newton algorithm. The approach SIA uses a fixed-point method to solve the nonlinear system at each timestep, whereas the approach SNIA uses an explicit scheme.

The software suite GRT3D has four executable modules:

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GDAE3D: Global DAE approach for 1D, 2D or 3D domains. This module has three variants: the original one with logarithms, an optimized one still with logarithms, an optimized one which does not use logarithms.

- Participants: Caroline De Dieuleveult, Édouard Canot, Jocelyne Erhel, Nadir Soualem and Souhila Sabit
- Partner: ANDRA
- Contact: Jocelyne Erhel

7. New Results

7.1. Fluid motion estimation

7.1.1. Stochastic uncertainty models for motion estimation

Participants: Shengze Cai, Etienne Mémin, Musaab Khalid Osman Mohammed.

The objective consists here in relying on a stochastic transport formulation to propose a luminance conservation assumption dedicated to the measurement of large-scale fluid flows velocity. This formulation, relying on the modeling under location uncertainty principle developed in the team, has the great advantage to incorporate from the beginning an uncertainty on the unresolved (turbulent) motion measurement. This uncertainty modeled as a possibly inhomogeneous random field uncorrelated in time can be estimated jointly to the motion estimates. Such a formulation, besides providing estimates of the velocity field and of its associated uncertainties, allows us to naturally define a linear multiresolution scale-space framework. It provides also a reinterpretation, in terms of uncertainty, of classical regularization functionals proposed in the context of motion estimation. Nevertheless, at variance to classical motion estimation methods, this approach enables to estimate the so-called regularization parameter, which is in our framework related to the variance of the unresolved component of motion component. The resulting parameter-free estimator has shown to outperform state-of-the-art results of the literature [14]. This kind of method is applied on turbulent flows and in the context of river hydrologic applications through a collaboration with the Irstea Lyon research group (HHLY). A method for the 3D reconstruction of the river plane has been also proposed in this context.This study is performed within the PhD thesis of Musaab Mohammed.

7.1.2. *Surface Currents estimation from Shore-Based Videos*

Participant: Pierre Derian.

A wavelet based motion estimator has been extended for the recovery of instantaneous fields of surface current from shore-based and unmanned aerial vehicle videos. This study published in [16] and [34] demonstrated clearly the high potential of this method in the nearshore, where the rapid development of webcams and drones offers a large amount of applications for swimming and surfing safety, engineering and naval security and research purpose, by providing quantitative information. This work has been conducted within a collaboration with the Legos laboratory.

7.1.3. *Development of an image-based measurement method for large-scale characterization of indoor airflows*

Participants: Dominique Heitz, Etienne Mémin, Romain Schuster.

The goal is to design a new image-based flow measurement method for large-scale industrial applications. From this point of view, providing *in situ* measurement technique requires: (i) the development of precise models relating the large-scale flow observations to the velocity; (ii) appropriate large-scale regularization strategies; and (iii) adapted seeding and lighting systems, like Hellium Filled Soap Bubles (HFSB) and led ramp lighting. This work conducted within the PhD of Romain Schuster in collaboration with the compagny ITGA has started in february 2016. The first step has been to evaluate the performances of a stochastic uncertainty motion estimator when using large scale scalar images, like those obtained when seeding a flow with smoke. The PIV characterization of flows on large fields of view requires an adaptation of the motion estimation method from image sequences. The backward shift of the camera coupled to a dense scalar seeding involves a large scale observation of the flow, thereby producing uncertainty about the observed phenomena. By introducing a stochastic term related to this uncertainty into the observation term, we obtained a significant improvement of the estimated velocity field accuracy [41].

7.1.4. *3D flows reconstruction from image data*

Participants: Dominique Heitz, Cédric Herzet.

Our work focuses on the design of new tools for the estimation of 3D turbulent flow motion in the experimental setup of Tomo-PIV. This task includes both the study of physically-sound models on the observations and the fluid motion, and the design of low-complexity and accurate estimation algorithms.

This year, we continued our investigation on the problem of efficient volume reconstruction. During the last years, we have focussed our attention on several families of convex optimization algorithms allowing to accelerate the standard procedures encountered in the Tomo-PIV literature while accounting for the non-negativity and the sparsity of the sought solutions. So far, the assessment of the proposed algorithms were exclusively done on synthetic data. This year, we started the process of validating the proposed procedures on real experimental data.

We started through a collaboration with Irstea to study ensemble assimilation methods for the fast reconstruction of 3D tomo-PIV motion field. The approach relies on a simplified dynamics of the flow and is a generalization of one of the popular emerging flow reconstruction technique of the PIV community referred to as "Shake the box". The study will be developed within an Irstea post-doctoral funding.

7.1.5. Sparse-representation algorithms

Participant: Cédric Herzet.

The paradigm of sparse representations is a central concept in many domains of signal processing. In particular, in the field of fluid motion estimation, sparse representation appears to be potentially useful at several levels: (i) it provides a relevant model for the characterization of the velocity field in some scenarios; (ii) it plays a crucial role in the recovery of volumes of particles in the 3D Tomo-PIV problem.

Unfortunately, the standard sparse representation problem is known to be NP hard. Therefore, heuristic procedures have to be devised to access to the solution of this problem. This year, we continued our investigations on “screening” methodologies, that is procedures allowing for the rapid identification of (some of) the zeros of the sought sparse vector. More specifically, we designed low-complexity procedures enabling to screen groups of atoms by only performing one single test. This work has been submitted to the IEEE international conference on acoustic, speech and signal processing (ICASSP).

7.2. Tracking, Data assimilation and model-data coupling

7.2.1. Optimal control techniques for the coupling of large scale dynamical systems and image data

Participants: Mohamed Yacine Ben Ali, Pranav Chandramouli, Dominique Heitz, Etienne Mémin.

In this axis of work we are exploring the use of optimal control techniques for the coupling of Large Eddies Simulation (LES) techniques and 2D image data. The objective is to reconstruct a 3D flow from a set of simultaneous time resolved 2D image sequences visualizing the flow on a set of 2D plans enlightened with laser sheets. This approach is experimented on shear layer flows and on wake flows generated on the wind tunnel of Irstea Rennes. Within this study we aim to explore techniques to enrich large-scale dynamical models by the introduction of uncertainty terms or through the definition of subgrid models from the image data. This research theme is related to the issue of turbulence characterization from image sequences. Instead of predefined turbulence models, we aim here at tuning from the data the value of coefficients involved in traditional LES subgrid models. A 4DVar assimilation technique based on the numerical code Incompact3D has been implemented for that purpose to control the inlet and initial conditions in order to reconstruct a turbulent wake flow behind an unknown obstacle. We are actually extending this first data assimilation technique to control the subgrid parameters. This study is performed in collaboration with Sylvain Laizet (Imperial College). In another axis of research, in collaboration with the CSTB Nantes centre and within the PhD of Yacine Ben Ali we will explore the definition of efficient data assimilation schemes for wind engineering. The goal will be here to couple Reynolds average model to pressure data at the surface of buildings. The final purpose will consist in proposing improved data-driven simulation models for architects.

7.2.2. Ensemble variational data assimilation of large-scale dynamics with uncertainty

Participant: Etienne Mémin.

This study is focused on the coupling of a large scale representation of the flow dynamics built from the location uncertainty principle with image data of finer resolution. The velocity field at large scales is described as a regular smooth component whereas the complement component is a highly oscillating random velocity field defined on the image grid but living at all the scales. Following this route we have assessed the performance of an ensemble variational assimilation technique with direct image data observation. Good results have been obtained for simulation under location uncertainty of 1D and 2D shallow water models [26]. This open the way to the definition of efficient data assimilation schemes for the coupling of high resolution data with large scale dynamical system.

7.2.3. Reduced-order models for flows representation from image data

Participants: Mamadou Diallo, Dominique Heitz, Cédric Herzet, Etienne Mémin, Valentin Resseguier.

During the PhD thesis of Valentin Resseguier we proposed a new decomposition of the fluid velocity in terms of a large-scale continuous component with respect to time and a small-scale non continuous random component. Within this general framework, an uncertainty based representation of the Reynolds transport theorem and Navier-Stokes equations can be derived, based on physical conservation laws. This physically relevant stochastic model has been applied in the context of POD-Galerkin methods. This uncertainty modeling methodology provides a theoretically grounded technique to define an appropriate subgrid tensor as well drift correction terms. The pertinence of this stochastic reduced order model has been successfully assessed on several wake flows at different Reynold number. It has been shown to be much more stable than the usual reduced order model construction techniques. Beyond the definition of a stable reduced order model, the modeling under location uncertainty paradigm offers a unique way to analyse from the data of a turbulent flow the action of the small-scale velocity components on the large-scale flow [25]. Regions of prominent turbulent kinetic energy, direction of preferential diffusion, as well as the small-scale induced drift can be identified and analyzed to decipher key players involved in the flow. This study has been published in the journal of fluid mechanics. Note that these reduced order models can be extended to a full system of stochastic differential equation driving all the temporal modes of the reduced system (and not only the small-scale modes). This full stochastic system has been evaluated on wake flow at moderate Reynolds number. For this flow the system has shown to provide very good uncertainty quantification properties as well meaningful physical behavior with respect to the simulation of the neutral modes of the dynamics. This study described in the PhD of Valentin Resseguier will be soon submitted to a journal paper.

On the other hand, in the following of several approaches proposed by the team [50], [54], we continued our investigations on the estimation of deterministic reduced order model from partial observations. In this line of research, we proposed a Bayesian framework for the construction of reduced-order models from image data. Our framework combines observation and prior information on the system to reduce the model and takes into account the uncertainties on the parameters of the model. The proposed approach reduces to some well-known model-reduction techniques for complete observations (i.e., the observation operator can be inverted). A theoretical analysis of our methodology has been investigated in a simplified context (namely, the observations are supposed to be noiseless linear combinations of the state of the system). This result provides worst-case guarantees on the reconstruction performance which can be achieved by a reduced model built from the data. These contributions have led to publications in a journal [18] and a conference [33].

7.3. Analysis and modeling of turbulent flows and geophysical flows

7.3.1. Geophysical flows modeling under location uncertainty

Participants: Pierre Derian, Long Li, Etienne Mémin, Valentin Resseguier.

In this research axis we have devised a principle to derive representation of flow dynamics under uncertainty. Such an uncertainty is formalized through the introduction of a random term that enables taking into account large-scale approximations or truncation effects performed within the dynamics analytical constitution steps. This includes for instance the modeling of unresolved scales interaction in large eddies simulation (LES) or in Reynolds average numerical simulation (RANS), but also partially known forcing. Rigorously derived from a stochastic version of the Reynolds transport theorem [9], this framework, referred to as modeling under location uncertainty, encompasses several meaningful mechanisms for turbulence modeling. It indeed introduces without any supplementary assumption the following pertinent mechanisms for turbulence modeling: (i) a dissipative operator related to the mixing effect of the large-scale components by the small-scale velocity; (ii) a multiplicative noise representing small-scale energy backscattering; and (iii) a modified advection term related to the so-called *turbophoresis* phenomena, attached to the migration of inertial particles in regions of lower turbulent diffusivity.

In a series of papers we have shown how such modeling can be applied to provide stochastic representations of a variety of classical geophysical flows dynamics [24], [23], [22]. Numerical simulations and uncertainty quantification have been performed on Quasi Geostophic approximation (QG) of oceanic models. It has been shown that such models lead to remarkable estimation of the unresolved errors at variance to classical eddy viscosity based models. The noise brings also an additional degree of freedom in the modeling step and pertinent diagnostic relations and variations of the model can be obtained with different scaling assumptions of the turbulent kinetic energy (i.e. of the noise amplitude). The performances of such systems have been assessed also on an original stochastic representation of the Lorenz 63 derived from the modeling under location uncertainty [15]. In this study it has been shown that the stochastic version enabled to explore in a much faster way the region of the deterministic attractor. This effort has been undertaken within a fruitful collaboration with Bertrand Chapron (LOPS/IFREMER). In the PhD of Long Li, starting this year, we will continue this effort. The goal will be to propose relevant techniques to define or calibrate the noise term from data. In that prospect, we intend to explore statistical learning techniques.

7.3.2. Large eddies simulation models under location uncertainty

Participants: Mohamed Yacine Ben Ali, Pranav Chandramouli, Dominique Heitz, Etienne Mémin.

The models under location uncertainty recently introduced by Mémin (2014) [9] provide a new outlook on LES modeling for turbulence studies. These models are derived from a stochastic transport principle. The associated stochastic conservation equations are similar to the filtered Navier- Stokes equation wherein we observe a sub-grid scale dissipation term. However, in the stochastic version, an extra term appears, termed as "velocity bias", which can be treated as a biasing/modification of the large-scale advection by the small scales. This velocity bias, introduced artificially in the literature, appears here automatically through a decorrelation assumption of the small scales at the resolved scale. All sub-grid contributions for the stochastic models are defined by the small-scale velocity auto-correlation tensor. This large scale modeling has been assed and compared to several classical large-scale models on several flows, namely a flow over a circular cylinder at Re $\sim$ 3900 [32], a smooth channel flow at Re(tau) $\sim$ 395 [31] and Taylor-Green vortex flows at Reynolds 1600, 3000 and 5000 [20]. For all these flows the modeling under uncertainty has provided better results than classical large eddies simulation models. Within the PhD of Yacine Ben Ali we will explore with the CSTB Nantes centre the application of such models for the definition of Reynolds average simulation (RANS) models for wind engineering applications.

7.3.3. Singular and regular solutions to the Navier-Stokes equations (NSE) and relative turbulent models

Participants: Roger Lewandowski, Etienne Mémin, Benoit Pinier.

The common thread of this work is the problem set by J. Leray in 1934 : does a regular solution of the Navier-Stokes equations (NSE) with a smooth initial data develop a singularity in finite time, what is the precise structure of a global weak solution to the Navier-Stokes equations, and are we able to prove any uniqueness result of such a solution. This is a very hard problem for which there is for the moment no answer. Nevertheless, this question leads us to reconsider the theory of Leray for the study of the Navier-Stokes equations in the whole space with an additional eddy viscosity term that models the Reynolds stress in the context of large-scale flow modelling. It appears that Leray's theory cannot be generalized turnkey for this problem, so that things must be reconsidered from the beginning. This problem is approached by a regularization process using mollifiers, and particular attention must be paid to the eddy viscosity term. For this regularized problem and when the eddy viscosity has enough regularity, we have been able to prove the existence of a global unique solution that is of class C^∞ in time and space and that satisfies the energy balance. Moreover, when the eddy viscosity is of compact support in space, uniformly in time, we recently shown that this solution converges to a turbulent solution to the corresponding Navier-Stokes equations when, the regularizing parameter goes to 0. These results are described in a paper that has been submitted to the journal Archive for Rational Mechanics and Analysis (ARMA).

In the same direction, we also finalized a paper in collaboration with L. Berselli (Univ. Pisa, Italy) about the well known Bardina's turbulent model. In this problem, we consider the Helmholtz filter usually used within the framework of Large Eddy Simulation. We carry out a similar analysis, by showing in particular that no singularity occurs for Bardina's model.

Another study in collaboration with B. Pinier, P. Chandramouli and E. Memin has been undertaken. This work takes place within the context of the PhD work of B. Pinier. We considered the standard turbulent models involving the Navier-Stokes equations with an eddy viscosity that depends on the Turbulent Kinetic Energy (TKE), coupled with a supplementary equation for the TKE. The problem holds in a 3D bounded domain, with the Manning law at the boundary for the velocity. We have modeled a flux condition at the boundary for the TKE. We prove that with these boundary conditions, the resulting problem has a distributional solution. Then a serie of numerical tests has been performed in a parallelepiped with a non trivial bottom, showing the accuracy of the model in comparison with a direct numerical simulation of the Navier-Stokes equations. This work will be submitted to a journal.

7.3.4. Turbulence similarity theory for the modeling of Ocean Atmosphere interface

Participants: Roger Lewandowski, Etienne Mémin, Benoit Pinier.

The Ocean Atmosphere interface plays a major role in climate dynamics. This interaction takes place in a thin turbulent layer. To date no sastifying universal models for the coupling of atmospheric and oceanic models exists. In practice this coupling is realized through empirically derived interaction bulks. In this study, corresponding to the PhD thesis of Benoit Pinier, we aim at exploring similarity theory to identify universal mean profile of velocity and temperature within the mixture layer. The goal of this work consists in exhibiting eddy viscosity models within the primitive equations. We will also explore the links between those eddy viscocity models and the subgrid tensor derived from the uncertainty framework studied in the Fluminance group. In that prospect, we have studied the impact of the introduction of a random modeling of the friction velocity on the classical wall law expression. This model derived within the modeling under location uncertainty principle enabled us to propose an improved model of the velocity profile with a clear formulation in particular in the buffer turbulent area between the viscous zone and the turbulent region. Preliminary results on chanel flows are very promising. We are actually assessing this model on turbulent boundary layer flow at high Reynold.

7.3.5. Hot-wire anemometry at low velocities

Participant: Dominique Heitz.

A new dynamical calibration technique has been developed for hot-wire probes. The technique permits, in a short time range, the combined calibration of velocity, temperature and direction calibration of single and multiple hot-wire probes. The calibration and measurements uncertainties were modeled, simulated and controlled, in order to reduce their estimated values. Based on a market study the french patent application has been extended this year to a Patent Cooperation Treaty (PCT) application.

7.3.6. Numerical and experimental image and flow database

Participants: Pranav Chandramouli, Dominique Heitz.

The goal was to design a database for the evaluation of the different techniques developed in the Fluminance group. The first challenge was to enlarge a database mainly based on two-dimensional flows, with three-dimensional turbulent flows. Synthetic image sequences based on homogeneous isotropic turbulence and on circular cylinder wake have been provided. These images have been completed with time resolved Particle Image Velocimetry measurements in wake and mixing layers flows. This database provides different realistic conditions to analyse the performance of the methods: time steps between images, level of noise, Reynolds number, large-scale images. The second challenge was to carried out orthogonal dual plane time resolved stereoscopic PIV measurements in turbulent flows. The diagnostic employed two orthogonal and synchronized stereoscopic PIV measurements to provide the three velocity components in planes perpendicular and parallel to the streamwise flow direction. These temporally resolved planar slices observations will be used in 4DVar assimilation technique, integrating Direct Numerical Simulation (DNS) and Large Eddies Simulation (LES), to reconstruct three-dimensional turbulent flows. This reconstruction will be conducted within the PhD of Pranav Chandramouli. The third challenge was to carried out a time resolved tomoPIV experiments in a turbulent wake flow. Then this data will be used to assess the performances of the 4DVar assimilation technique developed in the context of Pranav Chandramouli's PhD to reconstruct three-dimensional turbulent flows.

7.4. Visual servoing approach for fluid flow control

7.4.1. Closed-loop control of a spatially developing shear layer

Participants: Christophe Collewet, Johan Carlier.

This study aims at controlling one of the prototypical flow configurations encountered in fluid mechanics: the spatially developing turbulent shear layer occuring between two parallel incident streams with different velocities. Our goal is to maintain the shear-layer in a desired state and thus to reject upstream perturbations. In our conference IFAC paper (https://hal.inria.fr/hal-01514361) we focused on perturbations belonging to the same space that the actuators, concretely that means that we were only able to face perturbations of the actuator itself, like failures of the actuator. This year we enlarged this result to purely exogenous perturbations. An optimal control law has been derived to minimize the influence of the perturbation on the flow. To do that, an on-line estimation of the perturbation has been used. This work will be submitted to the upcoming IEEE Conference on Decision and Control. We have also generalized the works initiated during the post-doctoral stay of Tudor-Bogdan Airimitoaie (https://hal.archives-ouvertes.fr/hal-01101089) concerning the benefits of increasing the controlled degrees of freedom in the particular case of the heat equation. This work has been validated on the shear flow.

7.5. Coupled models in hydrogeology

7.5.1. Coupling of subsurface and seepage flows

Participants: Jocelyne Erhel, Jean-Raynald de Dreuzy.

Hillslope response to precipitations is characterized by sharp transitions from purely subsurface flow dynamics to simultaneous surface and subsurface flows. Locally, the transition between these two regimes is triggered by soil saturation. Here we develop an integrative approach to simultaneously solve the sub- surface flow, locate the potential fully saturated areas and deduce the generated saturation excess over- land flow. This approach combines the different dynamics and transitions in a single partition formulation using discontinuous functions. We propose to regularize the system of partial differential equations and to use classic spatial and temporal discretization schemes. We illustrate our methodology on the 1D hillslope storage Boussinesq equations. We first validate the numerical scheme on previous numerical experiments without saturation excess overland flow. Then we apply our model to a test case with dynamic transitions from purely subsurface flow dynamics to simultaneous surface and subsurface flows. Our results show that discretization respects mass balance both locally and globally, converges when the mesh or time step are refined. Moreover the regularization parameter can be taken small enough to ensure accuracy without suffering of numerical artefacts. Applied to some hundreds of realistic hillslope cases taken from Western side of France (Brittany), the developed method appears to be robust and efficient. This study performed within the H2MNO4 ANR project has been published in the journal Advances in Water Ressources [21].

7.5.2. Characterizations of Solutions in Geochemistry

Participant: Jocelyne Erhel.

We study the properties of a geochemical model involving aqueous and precipitation-dissolution reactions at a local equilibrium. By reformulating the model as an equivalent optimization problem, we prove existence and uniqueness of a solution. It is classical in thermodynamic to compute diagrams representing the phases of the system. We introduce here the new precipitation diagram that describes the mineral speciation in function of the parameters of the system. Using the polynomial structure of the problem, we provide characterizations and an algorithm to compute the precipitation diagram. Numerical computations on some examples illustrate this approach. This work, is part of the H2MNO4 initiative. It has been recently submitted to a journal for publication [46].

7.5.3. Reactive transport in fractured-porous media

Participants: Yvan Crenner, Jean-Raynald de Dreuzy, Jocelyne Erhel.

Fractures must be carefully considered for the geological disposal of radioactive wastes. They critically enhance diffusivity, speed up solute transport, extend mixing fronts, and in turn, modify the physico-chemical conditions of reactivity in the Excavation Damaged Zone (EDZ) of the galleries. On the other hand, the pyrite oxidation could be considered like the main reaction due to the diffusion of oxygen through the gallery. Moreover, we assume that this reaction is complete in these geological conditions. First, we propose a numerical explicit reactive transport model in a fractured medium for an overall reaction. Afterwards, we present simulations outputs of the pyrite-oxygen reaction in EDZ zone. This study supported by ANDRA has been published in a conference [27].

7.5.4. Reactive transfers for multi-phasic flows

Participants: Jocelyne Erhel, Bastien Hamlat.

This study focuses on the mathematical modeling of reactive transfers for multi-phasic flows in porous medium. This study supported by IFPEN has been presented in a conference paper [37].

7.6. Linear solvers

7.6.1. Variable s-step GMRES

Participants: Jocelyne Erhel, David Imberti.

Sparse linear systems arise in computational science and engineering. The goal is to reduce the memory requirements and the computational cost, by means of high performance computing algorithms. We introduce a new variation on s-step GMRES in order to improve its stability, reduce the number of iterations necessary to ensure convergence, and thereby improve parallel performance. In doing so, we develop a new block variant that allows us to express the stability difficulties in s-step GMRES more fully. This work supported by the EoCoE grant has been published in a conference proceeding [38] and in the journal [28].

7.6.2. Krylov method applied to reactive transport

Participant: Jocelyne Erhel.

Reactive transport models couple advection dispersion equations with chemistry equations. If the reactions are at thermodynamic equilibrium, then the system is a set of partial differential and algebraic equations. After space and implicit time discretizations, a nonlinear system of equations must be solved at each time step. The Jacobian matrix of the nonlinear system can be written with a Kronecker product coupling transport and chemistry. Krylov methods are well-suited to solve such linear systems because the matrix vector product can be done efficiently. The main challenge is to design a preconditioning matrix. We propose here to use the special structure of the matrix. Preliminary experiments show that Krylov methods are much more efficient than a direct method which does not use the coupled structure. This work supported by ANDRA has been published at the occasion of an invited conference [28].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Contract CERSAT/IFREMER

Participants: Etienne Mémin, Valentin Resseguier.

duration 39 months. This partnership between Inria and Ifremer funded the PhD of Valentin Resseguier, which aimed to study image based data assimilation strategies for oceanic models incorporating random uncertainty terms. The goal targeted will consist in deriving appropriate stochastic version of oceanic model and on top of them to devise estimation procedures from noisy data to calibrate the associated subgrid models.

8.1.2. Contract inter Carno IFREMER Inria

Participants: Etienne Mémin, Thibaut Tronchin.

duration 36 months. This contract was centred on the elaboration of an image-based tools for the analysis of the hydraulic load of an immersed body. This project tooke place within an inter Carnot cooperation between Ifremer and Inria.

8.1.3. Contract ITGA

Participants: Dominique Heitz, Etienne Mémin.

duration 36 months. This partnership between Inria, Irstea and ITGA funds the PhD of Romain Schuster. The goal of this PhD is to design new image-based flow measurement methods for the study of industrial fluid flows. Those techniques will be used in particular to calibrate industrial fume hood.

8.1.4. Contract CSTB

Participants: Mohamed Yacine Ben Ali, Dominique Heitz, Etienne Mémin.

duration 36 months. This partnership between Inria, Irstea and CSTB funds the PhD of Yacine Ben Ali. This PhD aims to design new data assimilation scheme for Reynolds Average Simulation (RANS) of flows involved in wind engineering and buildings construction. The goal pursued here consists to couple RANS models and surface pressure data in order to define data driven models with accurate turbulent parameterization.

8.1.5. ANDRA project

Participants: Yvan Crenner, Benjamin Delfino, Jean-Raynald de Dreuzy, Jocelyne Erhel.

Contract with ANDRA (National Agency for Nuclear Waste)
Duration: three years from November 2015.
Title: reactive transport in fractured porous media
Coordination: Jocelyne Erhel.
Partners: Geosciences Rennes.
Abstract: Even in small numbers, fractures must be carefully considered for the geological disposal of radioactive waste. They critically enhance diffusivity, speed up solute transport, extend mixing fronts and, in turn, modify the physicochemical conditions of reactivity around possible storage sites. Numerous studies in various fields have shown that fractures cannot be simply integrated within an equivalent porous medium with a simple enhancement of its petro-physical properties (porosity and permeability). We propose a combined numerical and experimental approach to determine the influence on reactivity of typical fracture patterns found in some radioactive waste applications.

8.1.6. IFPEN project

Participants: Bastien Hamlat, Jocelyne Erhel.

Contract with IFPEN (Institut Français du Pétrole et Energies Nouvelles)
Duration: three years from October 2016.
Title: Fully implicit Formulations for the Simulation of Multiphase Flow and Reactive Transport
Coordination: Jocelyne Erhel.
Abstract: Modeling multiphase flow in porous media coupled with fluid-rock chemical reactions is essential in order to understand the origin of sub-surface natural resources and optimize their extraction. This project aims to determine optimal strategies to solve the coupled transport and chemical reaction equations describing the physical processes at work in reactive multiphase flow in porous media. Three different formulations show great potential to accurately solve these equations. Two are fully implicit ("Reactive Coats" and "Semi-smooth Newton)" and one is an operator splitting approach. These formulations are still incomplete at the moment. The work will focus on extending the existing formulations to more complex physical phenomena, study their stability, convergence and theoretical equivalence. Another objective is to provide practical solutions to efficiently solve the resulting non-linear systems.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. Comins'lab: SEACS : Stochastic modEl-dAta-Coupled representationS for the analysis, simulation and reconstruction of upper ocean dynamics

Participants: Pierre Derian, Cédric Herzet, Etienne Mémin.

duration 48 months. The SEACS project whose acronym stands for: "Stochastic modEl-dAta-Coupled representationS for the analysis, simulation and reconstruction of upper ocean dynamics" is a Joint Research Initiative between the three Britanny clusters of excellence of the "Laboratoires d'Excellence" program: Cominlabs, Lebesgue and LabexMer centered on numerical sciences, mathematics and oceanography respectively. Within this project we aim at studying the potential of large-scale oceanic dynamics modeling under uncertainty for ensemble forecasting and satellite image data assimilation.

9.1.2. ANR JCJC GERONIMO : Advanced GEophysical Reduced-Order Model construction from IMage Observations

Participants: Mamadou Diallo, Cédric Herzet.

duration 48 months. The GERONIMO project which started in March 2014 aims at devising new efficient and effective techniques for the design of geophysical reduced-order models from image data. The project both arises from the crucial need of accurate low-order descriptions of highly-complex geophysical phenomena and the recent numerical revolution which has supplied the geophysical scientists with an unprecedented volume of image data. The project is placed at the intersection of several fields of expertise (Bayesian inference, matrix factorization, sparse representations, etc.) which will be combined to handle the uncertainties associated to image measurements and to characterize the accurate reduced dynamical systems.

9.1.3. ANR BECOSE : Beyond Compressive Sensing: Sparse approximation algorithms for ill-conditioned inverse problems.

Participants: Dominique Heitz, Cédric Herzet.

duration 48 months. The BECOSE project aims to extend the scope of sparsity techniques much beyond the academic setting of random and well-conditioned dictionaries. In particular, one goal of the project is to step back from the popular L1-convexification of the sparse representation problem and consider more involved nonconvex formulations, both from a methodological and theoretical point of view. The algorithms will be assessed in the context of tomographic Particle Image Velocimetry (PIV), a rapidly growing imaging technique in fluid mechanics that will have strong impact in several industrial sectors including environment, automotive and aeronautical industries. The consortium gathers the Fluminance and Panama Inria research teams, the Research Center for Automatic Control of Nancy (CRAN), The Research Institute of Communication and Cybernetics of Nantes (IRCCyN), and ONERA, the French Aerospace Lab.

9.1.4. ANR-MN: H2MNO4 project

Participants: Yvan Crenner, Benjamin Delfino, Jean-Raynald de Dreuzy, Jocelyne Erhel, Lionel Lenôtre.

Contract with ANR, program Modèles Numériques
Duration: four years from November 2012 until April 2017.
Title: Original Optimized Object Oriented Numerical Model for Heterogeneous Hydrogeology.
Coordination: Jocelyne Erhel and Géraldine Pichot, with Fabienne Cuyollaa.
Partners: Geosciences Rennes, University of Poitiers, University of Lyon 1, Andra, Itasca.
International collaborations: University of San Diego (USA), UPC, Barcelona (Spain)
Web page: http://h2mno4.inria.fr/

Abstract: The project H2MNO4 develops numerical models for reactive transport in heterogeneous media. It defines six mathematical and computational challenges and three applications for environmental problems with societal impact.

9.1.5. GDR MANU

Participants: Yvan Crenner, Jocelyne Erhel, Bastien Hamlat.

Title: Mathematics for Nuclear industry
Duration: From 2016 to 2019
Coordination: C. Cancès
Webpage: http://gdr-manu.math.cnrs.fr/
Abstract: The working group MANU is a follow-up to the group MOMAS. It covers many subjects related to mathematical modeling and numerical simulations for problems arising from nuclear industry and nuclear waste disposal. The team organizes a workshop on reactive transport, Paris, February 2018.

9.2. International Initiatives

9.2.1. Inria Associate Teams Not Involved in an Inria International Labs

9.2.1.1. LFD-FLU

Title: Large-scale Fluid Dynamics analysis from FLow Uncertainty

International Partner (Institution - Laboratory - Researcher):

Universidad de Buenos Aires (Argentina) - Department of Computer Science and Electrical Engineering - Guillermo Artana

Start year: 2016

See also: http://www.irisa.fr/prive/memin/LFD-FLU/

The first objective of this associate team is primarily concerned with the establishment of efficient fluid flow image data analysis procedures. This concerns for instance data assimilation issues to reconstruct meaningful numerical representation of experimental fluid flows for analysis purpose. The second objective focuses on the incorporation of uncertainties in the flow dynamical evolution models

9.2.1.2. Informal International Partners

Imperial College, London (UK), Collaboration with Dan Crisan and Darryl Holm on Stochastic transport for the upper ocean dynamics

Chico California State University (USA), We have pursued our collaboration with the group of Shane Mayor on the GPU implementation of wavelet based motion estimator for Lidar data. This code is developped in coproperty between Inria and Chico.

9.2.2. Participation in Other International Programs

Royal Society funding, collaboration between Dominique Heitz, Etienne Mémin and Sylvain Laizet (Imperial College) on Stochastic large-eddies simulation and data assimilation for the reconstruction of 3D turbulent flows.

China Scholarship Council funding, Collaboration between Etienne Memin, Shengze Cai and Chao Xu (Zhejiang University, College of Control Science & Engineering), on turbulent motion estimation and modeling under uncertainty.

9.3. International Research Visitors

- 3 weeks visit of Alejandro Gronskis (Researcher Conicet Argentina) to work with Dominique Heitz, Etienne Mémin and Pranav Chandramouli within the associate team LFD

- Sojourn of 12 month of Shengze Cai PhD student in the College of Control Science & Engineering, Zhejiang University to work with Etienne Mémin

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- J. Erhel organizes with J-R. de Dreuzy and T. Le Borgne the international conference CWMR (Saint-Malo, France, June 2018).
- E. Mémin organizes the national colloquium on data assimilation (Rennes, september 2018).

10.1.1.2. Member of the Organizing Committees

Jocelyne Erhel

- organizes with J-R. de Dreuzy and T. Le Borgne (OSUR) the international conference CWMR (Saint-Malo, France, June 2018).
- organizes with T. Faney and A. Michel (IFPEN) a workshop on reactive transport (Paris, France, February 2018).

Etienne Mémin

- "Data Science & Environment", workshop + summer school, 3-7 July 2017, Brest, France

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

Jocelyne Erhel

- international advisory committee of the parallel CFD conferences (Glasgow, UK, May 2017).
- program committee of the international conference PARENG 2017 (Pecs, Hungary, May 2017).
- program committee of the workshop Visualization in Environmental Sciences 2017 (co-event of EuroVis)

Cedric Herzet

- Co-organisateur & co-chair of the special session: « Compressed sensing et inversion » of the Gretsi 2017

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Jocelyne Erhel

- member of the editorial board of ETNA.
- member of the editorial board of ESAIM:Proceedings and Surveys.

Etienne Mémin

- Associate editor for the Int. Journal of Computer Vision (IJCV)
- Associate editor for the Image and Vision Computing Journal (IVC)

10.1.3.2. Reviewer - Reviewing Activities

Jocelyne Erhel: Reviewer for the journals ADWR, ARIMA, JCAM, MATCOM
Dominique Heitz: Reviewer for Exp. in Fluids, SIGGRAPH, ICPMS, Im. Vis. Comp.

Cédric Herzet: Reviewer for IEEE Tr. on Signal Processing, IEEE Tr. on Information Theory, Gresti 2017, ICASSP 2017
Etienne Mémin: Reviewer for Tellus-A, Journ. of Fluid Mech., Im. Vis. Comp., Exp. in Fluids, Nonlinear Proc. in Geophysics., Journ. of Comp. Phys.

10.1.4. Invited Talks

Dominique Heitz

- 2nd Workshop on Data Assimilation & CFD Processing for PIV and Lagrangian Particle Tracking, Delft, Nederland, 13-14, December, 2017.
- Journée Technique 41- Association Française de Vélomimétrie Laser, Meudon, France, May 11, 2017.

Cédric Herzet

- Séminaire, LIMSI Model Reduction from Partial Observations Jan. 2017
- Séminaire, IMT Atlantique, nov. 2017
- Séminaire, UMR Lab-sticc, Brest, avril 2017

Roger Lewandowski

- Colloquium Univ. Pisa, May 2017.

Etienne Mémin

- AFVL, Meudon, Stratégies d'assimilation de données pour la reconstruction d'écoulements, France, March 2017
- Imperial College, Math. for Planet Earth Centre for doctoral training, Stochastic representation of fluid flow dynamics, November 2017.
- Imperial College, London (UK), Math. for Planet Earth Centre for doctoral training, Stochastic representation of fluid flow dynamics, Nov. 2017.
- Center for Earth System Research and Sustainability, Hamburg (Ger.), Stochastic representation of fluid flow dynamics, Dec. 2017.
- Université de Grenoble, Comodo workshop, Stochastic representation of fluid flow dynamics, Dec. 2017.

10.1.5. Leadership within the Scientific Community

- J. Erhel is scientific coordinator of the website Interstices (since June 2012). https://interstices.info.

10.1.6. Scientific Expertise

- J. Erhel is a member of the scientific council of IFPEN, since April 2016.
- C. Herzet was reviewer for ANR.

10.1.7. Research Administration

Jocelyne Erhel

- correspondent of Maison de la Simulation for Inria Rennes.
- correspondent of AMIES for Inria Rennes, from September 2015.
- member of the Inria national committee for secondment, 2016.
- coordination of the working group for a team creation at Inria Rennes.
- member of the Inria local committee for health and safety (référent chercheur) from January 2016.
- member of the Inria administrative commission (CAP) for researchers, from January 2016.

Dominique Heitz
- Responsible of the Irstea ACTA Team
- Member of Pôle Cristal scientific council
- Member of Irstea OPAALE research unit Executive Committee
- Member of Irstea center of Rennes Executive Committee

Roger Lewandowski
- Elected president of the SMAI-GAMNI thematic group on Advances of Engineering Numerical Methods
- Correspondant SMAI

Etienne Mémin
- Responsible of the "Commission Développement Technologique" Inria Rennes
- Member of the "Commission Personnel" Inria-IRISA Rennes

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence: Jocelyne Erhel, Optimisation, 24h, niveau L3, ENSAI Rennes
Licence : Dominique Heitz, Mécanique des fluides, 30h, niveau L2 INSA Rennes
Master: Jocelyne Erhel, arithmétique flottante, 4h, niveau M1, INSA Rennes
Master : Dominique Heitz, Mécanique des fluides, 25h, niveau M1, Dep GMA INSA Rennes
Master : Cédric Herzet, « Smart Sensing », 24h, master international « Smart Sensing and Big Data », ENSAI
Master : Cédric Herzet, Représentations parcimonieuses et compressed sensing, niveau M2, niveau M2, INSA, 10h
Master: Roger Lewandowski, Euler and the Navier-Stokes equations, M2, master « fondamental mathematics ».
Master : Etienne Mémin, Analyse du mouvement, Mastere Informatique, 15h, niveau M2, Université de Rennes 1.
Master : Etienne Mémin, Vision par ordinateur , 15h, niveau M2, ESIR Université de Rennes 1.

10.2.2. Supervision

PhD in progress: Pierre-Marie Gibert, University of Lyon, October 2015, co-advisors D. Tromeur-Dervout and Jocelyne Erhel.
PhD in progress: Bastien Hamlat, University of Rennes 1, October 2016, co-advisors Jocelyne Erhel and A. Michel.
PhD in progress : Benoit Pinier, Scale similarity and uncertainty for Ocean-Atmosphere coupled models, started 01/10/2014, supervisors: Roger Lewandowski, Etienne Mémin
PhD in progress : Musaab Khalid Osman Mohammed, Motion analysis techniques for flood images, started february 2015, Lionel Penard (Irstea/Lyon) and Etienne Mémin
PhD in progress : Pranav Chandamouli, Turbulent complex flows reconstruction via data assimilation in large eddy models, started october 2015, Dominique Heitz, Etienne Mémin.
PhD in progress : Romain Schuster, Large-scale fluid motion estimation, started october 2016, Dominique Heitz, Etienne Mémin.
PhD in progress : Long Li, Data assimilation and stochastic transport for the upper ocean dynamics, started november 2017, Etienne Mémin.
PhD in progress : Yacine Ben Ali, Variational assimilation of RANS models for wind engineering, started november 2017, Dominique Heitz, Etienne Mémin.
PhD in progress : Dinh Duong Nguyen, Regular and singular solutions of Navier-Stokes equations with eddy viscosity, started in september 2017 , Roger Lewandowski.

10.2.3. Juries

Johan Carlier
- Kevin Chatelain, PhD, Polytech'Orléans, (examinateur)

Jocelyne Erhel

- Martin Bachet, PhD, Univ. PSL Mines ParisTech (rapporteur)
- Daniel Jara Heredia, PhD, Univ. Rennes (présidente)
- Antoine Plet, PhD, ENS Lyon (présidente)
- Tangi Migot, PhD, INSA Rennes (examinatrice)

Dominique Heitz

- Robin Yegavian, PhD Ecole Polytechnique (Rapporteur)

Cédric Herzet

- Jean-François Determe PhD université catholique de Louvain, Belgique(Examinateur)

Roger Lewandowski

- Charles Pelletier, PhD Univ. Grenoble Alpes(Rapporteur)

Etienne Mémin

- Olivier Barrois, PhD Univ. Grenoble Alpes(Rapporteur)
- Jean-Matthieu Haussaire, PhD Univ. Paris-Est (Examinateur),

10.3. Popularization

Jocelyne Erhel

- présidente du jury du rallye de mathématiques du CNED, 2017 and 2018.
- First prize of the second Mathematics of Planet Earth international competition. Module "Simulating the melting of ice caps", authors M. Nodet and J. Erhel.

Dominique Heitz

- Interview dans L'Usine Nouvelle, No 3479, pp. 30-31, 2016

11. Bibliography

Major publications by the team in recent years

[1] K. BURRAGE, J. ERHEL. *On the performance of various adaptive preconditioned GMRES*, in "Numerical Linear Algebra with Applications", 1998, vol. 5, pp. 101-121

[2] J. CARRAYROU, J. HOFFMANN, P. KNABNER, S. KRÄUTLE, C. DE DIEULEVEULT, J. ERHEL, J. VAN DER LEE, V. LAGNEAU, K. MAYER, K. MACQUARRIE. *Comparison of numerical methods for simulating strongly non-linear and heterogeneous reactive transport problems. The MoMaS benchmark case*, in "Computational Geosciences", 2010, vol. 14, n^{o} 3, pp. 483-502

[3] T. CHACÓN-REBOLLO, R. LEWANDOWSKI. *Mathematical and Numerical Foundations of Turbulence Models and Applications*, Modeling and Simulation in Science, Engineering and Technology, Birkhäuser Basel, 2014

[4] T. CORPETTI, D. HEITZ, G. ARROYO, E. MÉMIN, A. SANTA-CRUZ. *Fluid experimental flow estimation based on an optical-flow scheme*, in "Experiments in fluids", 2006, vol. 40, pp. 80–97

[5] J.-R. DE DREUZY, A. BEAUDOIN, J. ERHEL. *Asymptotic dispersion in 2D heterogeneous porous media determined by parallel numerical simulations*, in "Water Resource Research", 2007, vol. 43, n^{o} W10439, doi:10.1029/2006WR005394

[6] A. GRONSKIS, D. HEITZ, E. MÉMIN. *Inflow and initial conditions for direct numerical simulation based on adjoint data assimilation*, in "Journal of Computational Physics", 2013, vol. 242, pp. 480-497 [*DOI :* 10.1016/J.JCP.2013.01.051], http://www.sciencedirect.com/science/article/pii/S0021999113001290

[7] D. HEITZ, E. MÉMIN, C. SCHNOERR. *Variational Fluid Flow Measurements from Image Sequences: Synopsis and Perspectives*, in "Experiments in fluids", 2010, vol. 48, n^o 3, pp. 369–393

[8] H. HOTEIT, J. ERHEL, R. MOSÉ, B. PHILIPPE, P. ACKERER. *Numerical Reliability for Mixed Methods Applied to Flow Problems in Porous Media*, in "Computational Geosciences", 2002, vol. 6, pp. 161-194

[9] E. MÉMIN. *Fluid flow dynamics under location uncertainty*, in "Geophysical & Astrophysical Fluid Dynamics", 2014, vol. 108, n^o 2, pp. 119-146, http://dx.doi.org/10.1080/03091929.2013.836190

[10] N. NASSIF, J. ERHEL, B. PHILIPPE. *Introduction to computational linear Algebra*, CRC Press, 2015

[11] N. PAPADAKIS, E. MÉMIN. *A variational technique for time consistent tracking of curves and motion*, in "Journal of Mathematical Imaging and Vision", 2008, vol. 31, n^o 1, pp. 81–103, http://www.irisa.fr/fluminance/publi/papers/Papadakis-Memin-JMIV07.pdf

[12] Y. SAAD, M. YEUNG, J. ERHEL, F. GUYOMARC'H. *A deflated version of the Conjugate Gradient Algorithm*, in "SIAM Journal on Scientific Computing", 2000, vol. 21, n^o 5, pp. 1909-1926

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] V. RESSEGUIER. *Mixing and fluid dynamics under location uncertainty*, Université Rennes 1, January 2017, https://tel.archives-ouvertes.fr/tel-01507292

Articles in International Peer-Reviewed Journals

[14] S. CAI, E. MÉMIN, P. DÉRIAN, C. XU. *Motion Estimation under Location Uncertainty for Turbulent Fluid Flow*, in "Experiments in Fluids", 2017, pp. 1-17, forthcoming, https://hal.inria.fr/hal-01589642

[15] B. CHAPRON, P. DÉRIAN, E. MÉMIN, V. RESSEGUIER. *Large scale flows under location uncertainty: a consistent stochastic framework*, in "Quarterly Journal of the Royal Meteorological Society", 2017, vol. 00, pp. 1 - 15, forthcoming, https://hal.inria.fr/hal-01629898

[16] P. DÉRIAN, R. ALMAR. *Wavelet-Based Optical Flow Estimation of Instant Surface Currents From Shore-Based and UAV Videos*, in "IEEE Transactions on Geoscience and Remote Sensing", 2017, pp. 1 - 8 [*DOI :* 10.1109/TGRS.2017.2714202], https://hal.archives-ouvertes.fr/hal-01573715

[17] J. ERHEL, S. SABIT. *Analysis of a global reactive transport model and results for the MoMaS benchmark*, in "Mathematics and Computers in Simulation", 2017, vol. 137, pp. 286-298 [*DOI :* 10.1016/J.MATCOM.2016.11.008], https://hal.inria.fr/hal-01405698

[18] P. HÉAS, C. HERZET. *Reduced Modeling of Unknown Trajectories*, in "Archives of Computational Methods in Engineering", January 2018, vol. 25, n^o 1, pp. 87-101, https://arxiv.org/abs/1702.08846 [*DOI :* 10.1007/S11831-017-9229-0], https://hal.archives-ouvertes.fr/hal-01490572

[19] D. IMBERTI, J. ERHEL. *Vary the s in Your s-step GMRES*, in "Electronic Transactions on Numerical Analysis (ETNA)", 2017, pp. 1-27, forthcoming, https://hal.inria.fr/hal-01299652

[20] S. KADRI HAROUNA, E. MÉMIN. *Stochastic representation of the Reynolds transport theorem: revisiting large-scale modeling*, in "Computers and Fluids", August 2017, vol. 156, pp. 456-469 [*DOI :* 10.1016/J.COMPFLUID.2017.08.017], https://hal.inria.fr/hal-01394780

[21] J. MARÇAIS, J.-R. DE DREUZY, J. ERHEL. *Dynamic coupling of subsurface and seepage flows solved within a regularized partition formulation*, in "Advances in Water Resources", 2017, vol. 109, pp. 94-105 [*DOI :* 10.1016/J.ADVWATRES.2017.09.008], https://hal-insu.archives-ouvertes.fr/insu-01586870

[22] V. RESSEGUIER, E. MÉMIN, B. CHAPRON. *Geophysical flows under location uncertainty, Part I Random transport and general models*, in "Geophysical and Astrophysical Fluid Dynamics", April 2017, vol. 111, n^{o} 3, pp. 149-176, https://arxiv.org/abs/1611.02572 [*DOI :* 10.1080/03091929.2017.1310210], https://hal.inria.fr/hal-01391420

[23] V. RESSEGUIER, E. MÉMIN, B. CHAPRON. *Geophysical flows under location uncertainty, Part II Quasi-geostrophy and efficient ensemble spreading*, in "Geophysical and Astrophysical Fluid Dynamics", April 2017, vol. 111, n^{o} 3, pp. 177-208 [*DOI :* 10.1080/03091929.2017.1312101], https://hal.inria.fr/hal-01391476

[24] V. RESSEGUIER, E. MÉMIN, B. CHAPRON. *Geophysical flows under location uncertainty, Part III SQG and frontal dynamics under strong turbulence conditions*, in "Geophysical and Astrophysical Fluid Dynamics", April 2017, vol. 111, n^{o} 3, pp. 209-227 [*DOI :* 10.1080/03091929.2017.1312102], https://hal.inria.fr/hal-01391484

[25] V. RESSEGUIER, E. MÉMIN, D. HEITZ, B. CHAPRON. *Stochastic modelling and diffusion modes for proper orthogonal decomposition models and small-scale flow analysis*, in "Journal of Fluid Mechanics", October 2017, vol. 828, 29 p. , https://arxiv.org/abs/1611.06832 [*DOI :* 10.1017/JFM.2017.467], https://hal.inria.fr/hal-01400119

[26] Y. YANG, E. MÉMIN. *High-resolution data assimilation through stochastic subgrid tensor and parameter estimation from 4DEnVar*, in "Tellus A", April 2017, 19 p. , https://hal.inria.fr/hal-01500140

Invited Conferences

[27] Y. CRENNER, J. ERHEL. *Influence of a fractured medium on pyrite oxidation reaction*, in "MAMERN 2017 - International Conference on Approximation Methods and Numerical Modelling in Environment and Natural Resources", Oujda, Morocco, May 2017, https://hal.inria.fr/hal-01646245

[28] J. ERHEL. *Krylov methods applied to reactive transport models*, in "SIAM Conference on Mathematical and Computational Issues in the Geosciences", Erlangen, Germany, September 2017, https://hal.inria.fr/hal-01646268

International Conferences with Proceedings

[29] D. ANDA-ONDO, J. CARLIER, C. COLLEWET. *Closed-loop control of a spatially developing free shear flow around a steady state*, in "20th World Congress of the International Federation of Automatic Control", Toulouse, France, International Federation of Automatic Control, July 2017, https://hal.inria.fr/hal-01514361

[30] S. CAI, E. MÉMIN, P. DÉRIAN, C. XU. *Location Uncertainty Principle: Toward the Definition of Parameter-free Motion Estimators **, in "EMMCVPR 2017 - 11th International Conference on Energy Minimization Methods in Computer Vision and Pattern Recognition", Venice, Italy, Springer, October 2017, pp. 1-15, https://hal.inria.fr/hal-01654184

[31] P. CHANDRAMOULI, D. HEITZ, E. MÉMIN, S. LAIZET. *A Comparative Study of LES Models Under Location Uncertainty*, in "Congrès Français de Mécanique", Lille, France, August 2017, https://hal.inria.fr/hal-01584736

[32] P. CHANDRAMOULI, D. HEITZ, E. MÉMIN, S. LAIZET. *Analysis of Models Under Location Uncertainty within the Framework of Coarse Large Eddy Simulation (cLES)*, in "The 16th European Turbulence Conference", Stockholm, Sweden, European Mechanics Society, August 2017, https://hal.inria.fr/hal-01584735

[33] P. HÉAS, C. HERZET. *Optimal Low-Rank Dynamic Mode Decomposition*, in "Proceedings of the 2017 IEEE International Conference on Acoustics, Speech and Signal Processing, New Orleans 2017", New Orleans, United States, March 2017, https://arxiv.org/abs/1701.01064 [*DOI :* 10.1109/ICASSP.2017.7952999], https://hal.archives-ouvertes.fr/hal-01429975

Conferences without Proceedings

[34] R. ALMAR, A. N. LERMA, P. DÉRIAN, B. CASTELLE, T. SCOTT. *Transient Surf Zone Circulation Induced by Rhythmic Swash Zone at a Reflective Beach*, in "Coastal Dynamics 2017", Helsingør, Denmark, June 2017, https://hal.archives-ouvertes.fr/hal-01573717

[35] D. ANDA-ONDO, J. CARLIER, C. COLLEWET. *Contrôle en boucle fermée d'une couche de mélange spatiale*, in "congrès français de mécanique", Lille, France, August 2017, https://hal.archives-ouvertes.fr/hal-01578477

[36] A. GRONSKIS, D. HEITZ, E. MÉMIN. *A new hybrid optimization algorithm for variational data assimilation of unsteady wake flows*, in "2nd Workshop on Data Assimilation & CFD Processing for Particle Image and Tracking Velocimetry", Delft, Netherlands, December 2017, https://hal.archives-ouvertes.fr/hal-01671776

[37] B. HAMLAT, J. ERHEL, A. MICHEL, T. FANEY. *Modélisation des systèmes cinétiques limités*, in "SMAI 2017", La Tremblade, France, June 2017, https://hal.inria.fr/hal-01646320

[38] D. IMBERTI, J. ERHEL. *Solving large sparse linear systems with a variable s-step GMRES preconditioned by DD*, in "DD24 - International Conference on Domain Decomposition Methods", Longyearbyen, Norway, February 2017, https://hal.inria.fr/hal-01528636

[39] M. KHALID, L. PÉNARD, E. MÉMIN. *Application of optical flow for river velocimetry*, in "IGARSS 2017 - 37th IEEE Geoscience and Remote Sensing Symposium", Fort Worth, Texas, United States, July 2017, pp. 1-4, https://hal.archives-ouvertes.fr/hal-01657202

[40] K. ROCHA-BROWNELL, P. DÉRIAN, D. H. RICHTER, P. P. SULLIVAN, S. D. MAYOR. *Evaluation of a wavelet-based optical flow algorithm through the use of large eddy simulations*, in "28th International Laser Radar Conference", Bucarest, Romania, June 2017, https://hal.archives-ouvertes.fr/hal-01573724

[41] R. SCHUSTER, D. HEITZ, E. MÉMIN, A. GUIBERT, P. LOISEL. *Stochastic observation model for large scale motion measurement*, in "CFM 2017 - 23ème Congrès Français de Mécanique", Lille, France, August 2017, pp. 1-12, https://hal.archives-ouvertes.fr/hal-01648441

[42] Y. YANG, S. CAI, E. MÉMIN, D. HEITZ. *Ensemble-Variational methods in data assimilation*, in "2nd Workshop on Data Assimilation & CFD Processing for Particle Image and Tracking Velocimetry", Delft, Netherlands, December 2017, https://hal.archives-ouvertes.fr/hal-01671751

Research Reports

[43] S. CAI, E. MÉMIN, Y. YANG, C. XU. *Sea Surface Flow Estimation via Ensemble-based Variational Data Assimilation**, Inria Rennes - Bretagne Atlantique ; IRMAR, University of Rennes 1, September 2017, https://hal.inria.fr/hal-01589637

Scientific Popularization

[44] *Best Paper*
M. NODET, J. ERHEL. *Simulating the melting of ice caps*, 2017, This is an interactive module to explain to a wide audience the simulating of ice caps.Sea levels are rising for various reasons related to global warming. The glaciers of Antarctica and Greenland, known as ice caps or ice sheets, play a major role in sea level rise. Is it possible to predict future changes in these ice caps, and particularly the calving of icebergs into the ocean?The module answers to this question by showing numerical simulations of ice sheet dynamics.It can be viewed or downloaded at https://imaginary.org/program/simulating-the-melting-of-ice-caps, https://hal.inria.fr/hal-01643852.

Other Publications

[45] L. C. BERSELLI, R. LEWANDOWSKI. *On the Bardina's model in the whole space*, 2017, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01590760

[46] J. ERHEL, T. MIGOT. *Characterizations of Solutions in Geochemistry: Existence, Uniqueness and Precipitation Diagram*, September 2017, working paper or preprint, https://hal.inria.fr/hal-01584490

[47] P. HÉAS, C. HERZET. *Optimal Kernel-Based Dynamic Mode Decomposition*, 2017, working paper or preprint [*DOI :* 10.10919], https://hal.archives-ouvertes.fr/hal-01634542

[48] R. LEWANDOWSKI. *Navier-Stokes equations in the whole space with an eddy viscosity*, May 2017, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01531260

References in notes

[49] R. ADRIAN. *Particle imaging techniques for experimental fluid mechanics*, in "Annal Rev. Fluid Mech.", 1991, vol. 23, pp. 261-304

[50] G. ARTANA, A. CAMMILLERI, J. CARLIER, E. MÉMIN. *Strong and weak constraint variational assimilations for reduced order fluid flow modeling*, in "J. of Comput. Phys", 2012, vol. 231, n^{o} 8, pp. 3264–3288

[51] T. BEWLEY. *Flow control: new challenges for a new Renaissance*, in "Progress in Aerospace Sciences", 2001, vol. 37, pp. 21–58

[52] S. BEYOU, A. CUZOL, S. GORTHI, E. MÉMIN. *Weighted Ensemble Transform Kalman Filter for Image Assimilation*, in "TellusA", January 2013, vol. 65, n^{o} 18803

[53] S. CAI, E. MÉMIN, P. DÉRIAN, C. XU. *Motion Estimation under Location Uncertainty for Turbulent Fluid Flow*, in "Exp. in Fluids", 2018, vol. 59, n^o 8

[54] A. CAMMILLERI, F. GUENIAT, J. CARLIER, L. PASTUR, E. MÉMIN, F. LUSSEYRAN, G. ARTANA. *POD-Spectral Decomposition for Fluid Flow Analysis and Model Reduction*, in "Theor. and Comp. Fluid Dyn", 2013, Accepted for publication

[55] H. CHOI, P. MOIN, J. KIM. *Direct numerical simulation of turbulent flow over riblets*, in "Journal of Fluid Mechanics", 1993, vol. 255, pp. 503–539

[56] T. CORPETTI, E. MÉMIN. *Stochastic Uncertainty Models for the Luminance Consistency Assumption*, in "IEEE Trans. Image Processing", 2012, vol. 21, n^o 2, pp. 481–493

[57] G. EVENSEN. *Sequential data assimilation with a non linear quasi-geostrophic model using Monte Carlo methods to forecast error statistics*, in "J. Geophys. Res.", 1994, vol. 99 (C5), n^o 10, pp. 143–162

[58] J. FAVIER. *Contrôle d'écoulements : approche expérimentale et modélisation de dimension réduite*, Institut National Polytechnique de Toulouse, 2007

[59] J. FAVIER, A. KOURTA, G. LEPLAT. *Control of flow separation on a wing profile using PIV measurements and POD analysis*, in "IUTAM Symposium on Flow Control and MEMS", London, UK, September 19-22, 2006

[60] N. GORDON, D. SALMOND, A. SMITH. *Novel approach to non-linear/non-Gaussian Bayesian state estimation*, in "IEEE Processing-F", April 1993, vol. 140, n^o 2

[61] A. GUÉGAN, P. SCHMID, P. HUERRE. *Optimal energy growth and optimal control in swept Hiemenz flow*, in "J. Fluid Mech.", 2006, vol. 566, pp. 11–45

[62] B. HORN, B. SCHUNCK. *Determining Optical Flow*, in "Artificial Intelligence", August 1981, vol. 17, n^o 1-3, pp. 185–203

[63] F.-X. LE DIMET, O. TALAGRAND. *Variational algorithms for analysis and assimilation of meteorological observations: theoretical aspects*, in "Tellus", 1986, n^o 38A, pp. 97–110

[64] J. LIONS. *Optimal Control of Systems Governed by Partial Differential Equations*, Springer-Verlag, 1971

[65] L. MATHELIN, O. LE MAÎTRE. *Robust control of uncertain cylinder wake flows based on robust reduced order models*, in "Computer and Fluids", 2009, vol. 38, pp. 1168–1182

[66] B. PROTAS, J. WESFREID. *Drag force in the open-loop control of the cylinder wake in the laminar regime*, in "Physics of Fluids", February 2002, vol. 14, n^o 2, pp. 810–826

[67] I. WYGNANSKI. *Boundary layer flow control by periodic addition of momentum*, in "4th AIAA Shear Flow Control Conference", USA, June 29-July 2, 1997