IN PARTNERSHIP WITH:
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Centre d'expertise des risques, de l'environnement, des mobilités et de l'aménagement

Sorbonne Université (UPMC)

Activity Report 2018

Project-Team ANGE

Numerical Analysis, Geophysics and Environment

IN COLLABORATION WITH: Laboratoire Jacques-Louis Lions (LJLL)

RESEARCH CENTER
Paris

THEME
Earth, Environmental and Energy Sciences

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Creation of the Team: 2012 November 01, updated into Project-Team: 2014 January 01

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1. Team, Visitors, External Collaborators

Research Scientists

Jacques Sainte-Marie [Team leader, Inria, Senior Researcher, HDR]
Vivien Mallet [Inria, Researcher]
Martin Parisot [Inria, Researcher]
Yohan Penel [Inria, Researcher]
Julien Salomon [Inria, Senior Researcher, HDR]

Faculty Members

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Cindy Guichard [Sorbonne Université, Associate Professor]
Boris Haspot [Univ de Dauphine, Associate Professor, HDR]

Anne Mangeney [IPGP, Professor, HDR]

Post-Doctoral Fellows

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Janelle Hammond [Inria, from Sep 2018]

PhD Students

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Léa Boittin [Inria]
Nelly Boulos Al Makary [Univ Paris-Nord, from Oct 2018]
Virgile Dubos [Sorbonne Université]
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Antoine Lesieur [Inria]
Liudi Lu [Sorbonne Université, from Oct 2018]
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Technical staff

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Fabien Souillé [Inria, until Sep 2018]

Interns

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Pierrick Quémar [Univ. Paris-Nord]

2. Overall Objectives

2.1. Presentation

Among all aspects of geosciences, we mainly focus on gravity driven flows arising in many situations such as

- hazardous flows (flooding, rogue waves, landslides...),
- sustainable energies (hydrodynamics-biology coupling, biofuel production, marine energies...),
- risk management and land-use planning (morphodynamic evolutions, early warning systems...)

There exists a strong demand from scientists and engineers in fluid mechanics for models and numerical tools able to simulate not only the water depth and the velocity field but also the distribution and evolution of external quantities such as pollutants or biological species and the interaction between flows and structures (seashores, erosion processes...). The key point of the researches carried out within ANGE is to answer this demand by the development of efficient, robust and validated models and numerical tools.

2.2. Scientific challenges

Due to the variety of applications with a wide range of spatial scales, reduced-size models like the shallow water equations are generally required. From the modelling point of view, the main issue is to describe the behaviour of the flow with a reduced-size model taking into account several physical processes such as non-hydrostatic terms, biological species evolution, topography and structure interactions within the flow. The mathematical analysis of the resulting model do not enter the field of hyperbolic equations anymore and new strategies have to be proposed. Moreover, efficient numerical resolutions of reduced-size models require particular attention due to the different time scales of the processes and in order to recover physical properties such as positivity, conservativity, entropy dissipation and equilibria.

The models can remain subject to uncertainties that originate from incomplete description of the physical processes and from uncertain parameters. Further development of the models may rely on the assimilation of observational data and the uncertainty quantification of the resulting analyses or forecasts.

3. Research Program

3.1. Overview

The research activities carried out within the ANGE team strongly couple the development of methodological tools with applications to real–life problems and the transfer of numerical codes. The main purpose is to obtain new models adapted to the physical phenomena at stake, identify the main properties that reflect the physical meaning of the models (uniqueness, conservativity, entropy dissipation, ...), propose effective numerical methods to approximate their solution in complex configurations (multi-dimensional, unstructured meshes, well-balanced, ...) and to assess the results with data in the purpose of potentially correcting the models.

The difficulties arising in gravity driven flow studies are threefold.

- Models and equations encountered in fluid mechanics (typically the free surface Navier-Stokes equations) are complex to analyze and solve.
- The underlying phenomena often take place over large domains with very heterogeneous length scales (size of the domain, mean depth, wave length, ...) and distinct time scales, *e.g.* coastal erosion, propagation of a tsunami, ...
- These problems are multi-physics with strong couplings and nonlinearities.

3.2. Modelling and analysis

Hazardous flows are complex physical phenomena that can hardly be represented by shallow water type systems of partial differential equations (PDEs). In this domain, the research program is devoted to the derivation and analysis of reduced complexity models compared to the Navier-Stokes equations, but relaxing the shallow water assumptions. The main purpose is then to obtain models well-adapted to the physical phenomena at stake.

Even if the resulting models do not strictly belong to the family of hyperbolic systems, they exhibit hyperbolic features: the analysis and discretisation techniques we intend to develop have connections with those used for hyperbolic conservation laws. It is worth noticing that the need for robust and efficient numerical procedures is reinforced by the smallness of dissipative effects in geophysical models which therefore generate singular solutions and instabilities.

On the one hand, the derivation of the Saint-Venant system from the Navier-Stokes equations is based on two approximations (the so-called shallow water assumptions), namely

- the horisontal fluid velocity is well approximated by its mean value along the vertical direction,
- the pressure is hydrostatic or equivalently the vertical acceleration of the fluid can be neglected compared to the gravitational effects.

As a consequence the objective is to get rid of these two assumptions, one after the other, in order to obtain models accurately approximating the incompressible Euler or Navier-Stokes equations.

On the other hand, many applications require the coupling with non-hydrodynamic equations, as in the case of micro-algae production or erosion processes. These new equations comprise non-hyperbolic features and a special analysis is needed.

3.2.1. Multilayer approach

As for the first shallow water assumption, *multi-layer* systems were proposed to describe the flow as a superposition of Saint-Venant type systems [30], [33], [34]. Even if this approach has provided interesting results, layers are considered separate and non-miscible fluids, which implies strong limitations. That is why we proposed a slightly different approach [31], [32] based on a Galerkin type decomposition along the vertical axis of all variables and leading, both for the model and its discretisation, to more accurate results.

A kinetic representation of our multilayer model allows to derive robust numerical schemes endowed with crucial properties such as: consistency, conservativity, positivity, preservation of equilibria, ... It is one of the major achievements of the team but it needs to be analyzed and extended in several directions namely:

- The convergence of the multilayer system towards the hydrostatic Euler system as the number of layers goes to infinity is a critical point. It is not fully satisfactory to have only formal estimates of the convergence and sharp estimates would provide an optimal number of layers.
- The introduction of several source terms due for instance to the Coriolis force or extra terms from changes of coordinates seems necessary. Their inclusion should lead to substantial modifications of the numerical scheme.
- Its hyperbolicity has not yet been proven and conversely the possible loss of hyperbolicity cannot be characterised. Similarly, the hyperbolic feature is essential in the propagation and generation of waves.

3.2.2. Non-hydrostatic models

The hydrostatic assumption consists in neglecting the vertical acceleration of the fluid. It is considered valid for a large class of geophysical flows but is restrictive in various situations where the dispersive effects (like wave propagation) cannot be neglected. For instance, when a wave reaches the coast, bathymetry variations give a vertical acceleration to the fluid that strongly modifies the wave characteristics and especially its height.

Processing an asymptotic expansion (w.r.t. the aspect ratio for shallow water flows) into the Navier-Stokes equations, we obtain at the leading order the Saint-Venant system. Going one step further leads to a vertically averaged version of the Euler/Navier-Stokes equations involving some non-hydrostatic terms. This model has several advantages:

- it admits an energy balance law (that is not the case for most dispersive models available in the literature),
- it reduces to the Saint-Venant system when the non-hydrostatic pressure term vanishes,
- it consists in a set of conservation laws with source terms,
- it does not contain high order derivatives.

3.2.3. Multi-physics modelling

The coupling of hydrodynamic equations with other equations in order to model interactions between complex systems represents an important part of the team research. More precisely, three multi-physics systems are investigated. More details about the industrial impact of these studies are presented in the following section.

- To estimate the risk for infrastructures in coastal zones or close to a river, the resolution of the shallow water equations with moving bathymetry is necessary. The first step consisted in the study of an additional equation largely used in engineering science: The Exner equation. The analysis enabled to exhibit drawbacks of the coupled model such as the lack of energy conservation or the strong variations of the solution from small perturbations. A new formulation is proposed to avoid these drawbacks. The new model consists in a coupling between conservation laws and an elliptic equation, like the Euler/Poisson system, suggesting to use well-known strategies for the analysis and the numerical resolution. In addition, the new formulation is derived from classical complex rheology models and allowed physical phenomena like threshold laws.

- Interaction between flows and floating structures is the challenge at the scale of the shallow water equations. This study requires a better understanding of the energy exchanges between the flow and the structure. The mathematical model of floating structures is very hard to solve numerically due to the non-penetration condition at the interface between the flow and the structure. It leads to infinite potential wave speeds that could not be solved with classical free surface numerical schemes. A relaxation model was derived to overcome this difficulty. It represents the interaction with the floating structure with a free surface model-type.
- If the interactions between hydrodynamics and biology phenomena are known through laboratory experiments, it is more difficult to predict the evolution, especially for the biological quantities, in a real and heterogeneous system. The objective is to model and reproduce the hydrodynamics modifications due to forcing term variations (in time and space). We are typically interested in phenomena such as eutrophication, development of harmful bacteria (cyanobacteria) and upwelling phenomena.

3.2.4. Data assimilation and inverse modelling

In environmental applications, the most accurate numerical models remain subject to uncertainties that originate from their parameters and shortcomings in their physical formulations. It is often desirable to quantify the resulting uncertainties in a model forecast. The propagation of the uncertainties may require the generation of ensembles of simulations that ideally sample from the probability density function of the forecast variables. Classical approaches rely on multiple models and on Monte Carlo simulations. The applied perturbations need to be calibrated for the ensemble of simulations to properly sample the uncertainties. Calibrations involve ensemble scores that compare the consistency between the ensemble simulations and the observational data. The computational requirements are so high that designing fast surrogate models or metamodels is often required.

In order to reduce the uncertainties, the fixed or mobile observations of various origins and accuracies can be merged with the simulation results. The uncertainties in the observations and their representativeness also need to be quantified in the process. The assimilation strategy can be formulated in terms of state estimation or parameter estimation (also called inverse modelling). Different algorithms are employed for static and dynamic models, for analyses and forecasts. A challenging question lies in the optimization of the observational network for the assimilation to be the most efficient at a given observational cost.

3.3. Numerical analysis

3.3.1. Non-hydrostatic scheme

The main challenge in the study of the non-hydrostatic model is to design a robust and efficient numerical scheme endowed with properties such as: positivity, wet/dry interfaces treatment, consistency. It must be noticed that even if the non-hydrostatic model looks like an extension of the Saint-Venant system, most of the known techniques used in the hydrostatic case are not efficient as we recover strong difficulties encountered in incompressible fluid mechanics due to the extra pressure term. These difficulties are reinforced by the absence of viscous/dissipative terms.

3.3.2. Space decomposition and adaptive scheme

In the quest for a better balance between accuracy and efficiency, a strategy consists in the adaptation of models. Indeed, the systems of partial differential equations we consider result from a hierarchy of simplifying assumptions. However, some of these hypotheses may turn out to be irrelevant locally. The adaptation of models thus consists in determining areas where a simplified model (*e.g.* shallow water type) is valid and where it is not. In the latter case, we may go back to the “parent” model (*e.g.* Euler) in the corresponding area.

This implies to know how to handle the coupling between the aforementioned models from both theoretical and numerical points of view. In particular, the numerical treatment of transmission conditions is a key point. It requires the estimation of characteristic values (Riemann invariant) which have to be determined according to the regime (torrential or fluvial).

3.3.3. Asymptotic-Preserving scheme for source terms

Hydrodynamic models comprise advection and sources terms. The conservation of the balance between source terms, typically viscosity and friction, has a significant impact since the overall flow is generally a perturbation around an equilibrium. The design of numerical schemes able to preserve such balances is a challenge from both theoretical and industrial points of view. The concept of Asymptotic-Preserving (AP) methods is of great interest in order to overcome these issues.

Another difficulty occurs when a term, typically related to the pressure, becomes very large compared to the order of magnitude of the velocity. At this regime, namely the so-called *low Froude* (shallow water) or *low Mach* (Euler) regimes, the difference between the speed of the gravity waves and the physical velocity makes classical numerical schemes inefficient: firstly because of the error of truncation which is inversely proportional to the small parameters, secondly because of the time step governed by the largest speed of the gravity wave. AP methods made a breakthrough in the numerical resolution of asymptotic perturbations of partial-differential equations concerning the first point. The second one can be fixed using partially implicit scheme.

3.3.4. Multi-physics models

Coupling problems also arise within the fluid when it contains pollutants, density variations or biological species. For most situations, the interactions are small enough to use a splitting strategy and the classical numerical scheme for each sub-model, whether it be hydrodynamic or non-hydrodynamic.

The sediment transport raises interesting issues from a numerical aspect. This is an example of coupling between the flow and another phenomenon, namely the deformation of the bottom of the basin that can be carried out either by bed load where the sediment has its own velocity or suspended load in which the particles are mostly driven by the flow. This phenomenon involves different time scales and nonlinear retroactions; hence the need for accurate mechanical models and very robust numerical methods. In collaboration with industrial partners (EDF–LNHE), the team already works on the improvement of numerical methods for existing (mostly empirical) models but our aim is also to propose new (quite) simple models that contain important features and satisfy some basic mechanical requirements. The extension of our 3D models to the transport of weighted particles can also be here of great interest.

3.3.5. Optimisation

Numerical simulations are a very useful tool for the design of new processes, for instance in renewable energy or water decontamination. The optimisation of the process according to a well-defined objective such as the production of energy or the evaluation of a pollutant concentration is the logical upcoming challenge in order to propose competitive solutions in industrial context. First of all, the set of parameters that have a significant impact on the result and on which we can act in practice is identified. Then the optimal parameters can be obtained using the numerical codes produced by the team to estimate the performance for a given set of parameters with an additional loop such as gradient descent or Monte Carlo method. The optimisation is used in practice to determine the best profile for turbine pales, the best location for water turbine implantation, in particular for a farm.

4. Application Domains

4.1. Overview

Sustainable development and environment preservation have a growing importance and scientists have to address difficult issues such as: management of water resources, renewable energy production, bio/geo-chemistry of oceans, resilience of society w.r.t. hazardous flows, urban pollutions, ...

As mentioned above, the main issue is to propose models of reduced complexity, suitable for scientific computing and endowed with stability properties (continuous and/or discrete). In addition, models and their numerical approximations have to be confronted with experimental data, as analytical solutions are hardly accessible for these problems/models. A. Mangeney (IPGP) and N. Goutal (EDF) may provide useful data.

4.2. Geophysical flows

Reduced models like the shallow water equations are particularly well-adapted to the modelling of geophysical flows since there are characterized by large time or/and space scales. For long time simulations, the preservation of equilibria is essential as global solutions are a perturbation around them. The analysis and the numerical preservation of non-trivial equilibria, more precisely when the velocity does not vanish, are still a challenge. In the fields of oceanography and meteorology, the numerical preservation of the so-called geostrophic state, which is the balance between the gravity field and the Coriolis force, can significantly improve the forecasts. In addition, data assimilation is required to improve the simulations and correct the dissipative effect of the numerical scheme.

The sediment transport modelling is of major interest in terms of applications, in particular to estimate the sustainability of facilities with silt or scour, such as canals and bridges. Dredging or filling-up operations are expensive and generally not efficient in the long term. The objective is to determine a configuration almost stable for the facilities. In addition, it is also important to determine the impact of major events like emptying dam which is aimed at evacuating the sediments in the dam reservoir and requires a large discharge. However, the downstream impact should be measured in terms of turbidity, river morphology and flood.

4.3. Hydrological disasters

It is a violent, sudden and destructive flow. Between 1996 and 2005, nearly 80% of natural disasters in the world have meteorological or hydrological origines. The main interest of their study is to predict the areas in which they may occur most probably and to prevent damages by means of suitable amenities. In France, floods are the most recurring natural disasters and produce the worst damages. For example, it can be a cause or a consequence of a dam break. The large surface they cover and the long period they can last require the use of reduced models like the shallow water equations. In urban areas, the flow can be largely impacted by the debris, in particular cars, and this requires fluid/structure interactions be well understood. Moreover, underground flows, in particular in sewers, can accelerate and amplify the flow. To take them into account, the model and the numerical resolution should be able to treat the transition between free surface and underground flows.

Tsunamis are another hydrological disaster largely studied. Even if the propagation of the wave is globally well described by the shallow water model in oceans, it is no longer the case close to the epicenter and in the coastal zone where the bathymetry leads to vertical accretions and produces substantial dispersive effects. The non-hydrostatic terms have to be considered and an efficient numerical resolution should be induced.

While viscous effects can often be neglected in water flows, they have to be taken into account in situations such as avalanches, debris flows, pyroclastic flows, erosion processes, ...*i.e.* when the fluid rheology becomes more complex. Gravity driven granular flows consist of solid particles commonly mixed with an interstitial lighter fluid (liquid or gas) that may interact with the grains and decrease the intensity of their contacts, thus reducing energy dissipation and favoring propagation. Examples include subaerial or subaqueous rock avalanches (e.g. landslides).

4.4. Biodiversity and culture

Nowadays, simulations of the hydrodynamic regime of a river, a lake or an estuary, are not restricted to the determination of the water depth and the fluid velocity. They have to predict the distribution and evolution of external quantities such as pollutants, biological species or sediment concentration.

The potential of micro-algae as a source of biofuel and as a technological solution for CO2 fixation is the subject of intense academic and industrial research. Large-scale production of micro-algae has potential for biofuel applications owing to the high productivity that can be attained in high-rate raceway ponds. One of the key challenges in the production of micro-algae is to maximize algae growth with respect to the exogenous energy that must be used (paddlewheel, pumps, ...). There is a large number of parameters that need to be optimized (characteristics of the biological species, raceway shape, stirring provided by the paddlewheel). Consequently our strategy is to develop efficient models and numerical tools to reproduce the flow induced by the paddlewheel and the evolution of the biological species within this flow. Here, mathematical models can greatly help us reduce experimental costs. Owing to the high heterogeneity of raceways due to gradients of temperature, light intensity and nutrient availability through water height, we cannot use depth-averaged models. We adopt instead more accurate multilayer models that have recently been proposed. However, it is clear that many complex physical phenomena have to be added to our model, such as the effect of sunlight on water temperature and density, evaporation and external forcing.

Many problems previously mentioned also arise in larger scale systems like lakes. Hydrodynamics of lakes is mainly governed by geophysical forcing terms: wind, temperature variations, ...

4.5. Sustainable energy

One of the booming lines of business is the field of renewable and decarbonated energies. In particular in the marine realm, several processes have been proposed in order to produce electricity thanks to the recovering of wave, tidal and current energies. We may mention water-turbines, buoys turning variations of the water height into electricity or turbines motioned by currents. Although these processes produce an amount of energy which is less substantial than in thermal or nuclear power plants, they have smaller dimensions and can be set up more easily.

The fluid energy has kinetic and potential parts. The buoys use the potential energy whereas the water-turbines are activated by currents. To become economically relevant, these systems need to be optimized in order to improve their productivity. While for the construction of a harbour, the goal is to minimize swell, in our framework we intend to maximize the wave energy.

This is a complex and original issue which requires a fine model of energy exchanges and efficient numerical tools. In a second step, the optimisation of parameters that can be changed in real-life, such as bottom bathymetry and buoy shape, must be studied. Eventually, physical experiments will be necessary for the validation.

4.6. Urban environment

The urban environment is essentially studied for air and noise pollutions. Air pollution levels and noise pollution levels vary a lot from one street to next. The simulations are therefore carried out at street resolution and take into account the city geometry. The associated numerical models are subject to large uncertainties. Their input parameters, e.g. pollution emissions from road traffic, are also uncertain. Quantifying the simulation uncertainties is challenging because of the high computational costs of the numerical models. An appealing approach in this context is the use of metamodels, from which ensembles of simulations can be generated for uncertainty quantification.

The simulation uncertainties can be reduced by the assimilation of fixed and mobile sensors. High-quality fixed monitoring sensors are deployed in cities, and an increasing number of mobile sensors are added to the observational networks. Even smartphones can be used as noise sensors and dramatically increase the spatial coverage of the observations. The processing and assimilation of the observations raises many questions regarding the quality of the measurements and the design of the network of sensors.

4.7. SmartCity

There is a growing interest for environmental problems at city scale, where a large part of the population is concentrated and where major pollutions can occur. Numerical simulation is well established to study the urban environment, *e.g.* for road traffic modelling. As part of the smartcity movement, an increasing number of sensors collect measurements, at traditional fixed observation stations, but also on mobile devices, like smartphones. They must properly be taken into account given their number but also their potential low quality.

Pratical applications include air pollution and noise pollution. These directly relate to road traffic. Data assimilation and uncertainty propagation are key topics in these applications.

5. Highlights of the Year

5.1. Highlights of the Year

Human resources

A major event in the year was new positions of J. Sainte-Marie (Détachement at Inria, 2 years position) and of Y. Penel (Advanced Research Position, 3 years position). Two new students have started a PhD (Liudi Lu and Nelly Boulos Al Makary).

Evaluation of the team

This year, the team went through the first evaluation since its creation. The report was very positive, as this excerpt shows:

The activity of the team in modeling and mathematical and numerical analysis has lead to significant contributions in various areas. In particular, we mention the study of models that can reproduce specific 'dispersive effects,' observed in nature, or the review of several multi-physics models that incorporate the coupling of heterogeneous systems. The theoretical analysis of the models has often led to the proposal of new algorithmic developments and new numerical techniques and, in general, it has resulted in a significant advancement of scientific knowledge.

Scientific activities There has been major achievements within the team in the framework of dispersive models.

As detailed in Section 10.1, members of the team were involved in the organisation of a substantial number of scientific events, either in the framework of national initiatives or due to the expertise in the field. Members are is particularly involved in the mathematical community.

5.1.1. Awards

- Léa Boittin received the award of the best presentation at GDR-EGRIN summer school in June,
- Léa Boittin was rewarded by Best Phd Student Poster Award, at CMWR XXII, Saint-Malo,
- Janelle Hammond received a post-doctoral grant from DIM Math Innov 2018.

6. New Software and Platforms

6.1. Freshkiss

FREe Surface Hydrodynamics using KInetic SchemeS

KEYWORDS: Finite volume methods - Hydrostatic Navier-Stokes equations - Free surface flows

FUNCTIONAL DESCRIPTION: Freshkiss3D is a numerical code solving the 3D hydrostatic and incompressible Navier-Stokes equations with variable density.

- Participants: Fabien Souille, Emmanuel Audusse, Jacques Sainte Marie and Marie-Odile Bristeau
- Partners: UPMC - CEREMA
- Contact: Jacques Sainte Marie

6.2. TSUNAMATHS

KEYWORDS: Modeling - Tsunamis
FUNCTIONAL DESCRIPTION: Tsunamaths is an educational platform aiming at simulating historical tsunamis. Real data and mathematical explanations are provided to enable people to better understand the overall process of tsunamis.

- Participants: Emmanuel Audusse, Jacques Sainte Marie and Raouf Hamouda
- Contact: Jacques Sainte Marie
- URL: http://tsunamath.paris.inria.fr/

6.3. Verdandi

KEYWORDS: HPC - Model - Software Components - Partial differential equation
FUNCTIONAL DESCRIPTION: Verdandi is a free and open-source (LGPL) library for data assimilation. It includes various such methods for coupling one or several numerical models and observational data. Mainly targeted at large systems arising from the discretization of partial differential equations, the library is devised as generic, which allows for applications in a wide range of problems (biology and medicine, environment, image processing, etc.). Verdandi also includes tools to ease the application of data assimilation, in particular in the management of observations or for a priori uncertainty quantification. Implemented in C++, the library may be used with models implemented in Fortran, C, C++ or Python.

- Participants: Dominique Chapelle, Gautier Bureau, Nicolas Claude, Philippe Moireau and Vivien Mallet
- Contact: Vivien Mallet
- URL: http://verdandi.gforge.inria.fr/

6.4. Polyphemus

KEYWORD: Simulation
FUNCTIONAL DESCRIPTION: Polyphemus is a modeling system for air quality. As such, it is designed to yield up-to-date simulations in a reliable framework: data assimilation, ensemble forecast and daily forecasts. Its completeness makes it suitable for use in many applications: photochemistry, aerosols, radionuclides, etc. It is able to handle simulations from local to continental scales, with several physical models. It is divided into three main parts:

libraries that gather data processing tools (SeldonData), physical parameterizations (AtmoData) and post-processing abilities (AtmoPy),

programs for physical pre-processing and chemistry-transport models (Polair3D, Castor, two Gaussian models, a Lagrangian model),

model drivers and observation modules for model coupling, ensemble forecasting and data assimilation.

- Participants: Sylvain Doré and Vivien Mallet
- Contact: Vivien Mallet
- URL: http://cerea.enpc.fr/polyphemus/

6.5. Urban noise analysis

KEYWORD: Environment perception

FUNCTIONAL DESCRIPTION: This software processes mobile observations collected by the application Ambiciti (previously known as SoundCity). It can merge simulated noise maps with the mobile observations.

- Authors: Raphaël Ventura, Vivien Mallet and Guillaume Cherel
- Contact: Vivien Mallet

6.6. Freshkiss3D

- Authors: Jacques Sainte Marie, Marie-Odile Bristeau, Anne-Céline Boulanger, Raouf Hamouda, Emmanuel Audusse, Alain Dervieux, Bijan Mohammadi and David Froger
- Partner: UPMC
- Contact: Jacques Sainte Marie

7. New Results

7.1. Numerical methods for fluid flows

Participants: Jacques Sainte-Marie, Virgile Dubos, Cindy Guichard, Martin Parisot, Marie-Odile Bristeau, Fabien Souillé, Edwige Godlewski, Yohan Penel.

7.1.1. Advancing dynamical cores of oceanic models across all scales

Oceanic numerical models are used to understand and predict a wide range of processes from global paleoclimate scales to short-term prediction in estuaries and shallow coastal areas. One of the overarching challenges, and the main topic of the COMMODORE workshop, is the appropriate design of the dynamical cores given the wide variety of scales of interest and their interactions with atmosphere, sea-ice, biogeochemistry, and even societal processes. The construction of a dynamical core is a very long effort which takes years and decades of research and development and which requires a collaborative mixture of scientific disciplines. In [14], we present a significant number of fundamental choices, such as which equations to solve, which horizontal and vertical grid arrangement is adequate, which discrete algorithms allows jointly computational efficiency and sufficient accuracy, etc.

7.1.2. A Well-balanced Finite Volume Scheme for Shallow Water Equations with Porosity

Our work [20] aims to study the ability of a single porosity-based shallow water model to modelize the impact of vegetation in open-channel flows. More attention on flux and source terms discretizations are required in order to archive the well-balancing and shock capturing. We present a new Godunov-type finite volume scheme based on a simple-wave approximation and compare it with some other methods in the literature. A first application with experimental data was performed.

7.1.3. The gradient discretisation method

The monograph [21] is dedicated to the presentation of the gradient discretisation method (GDM) and to some of its applications. It is intended for masters students, researchers and experts in the field of the numerical analysis of partial differential equations.The GDM is a framework which contains classical and recent discretisation schemes for diffusion problems of different kinds: linear or non-linear, steady-state or time-dependent.

7.1.4. Entropy-satisfying scheme for a hierarchy of dispersive reduced models of free surface flow

This work [29] is devoted to the numerical resolution in multidimensional framework of a hierarchy of reduced models of the free surface Euler equations. In a first part, entropy-satisfying scheme is proposed fo the monolayer dispersive model [Green, Naghdi '76] and [Bristeau, Mangeney, Sainte-Marie, Seguin '15]. In a second part, the strategy is extended to the layerwise models proposed in [Fernandez-Nieto, Parisot, Penel, Sainte-Marie]. To illustrate the accuracy and the robustness of the strategy, several numerical experiments are performed. In particular, the strategy is able to deal with dry areas without particular treatment.

7.1.5. Numerical approximation of the 3d hydrostatic Navier-Stokes system with free surface

In this work [23], we propose a stable and robust strategy to approximate the 3d incompressible hydrostatic Euler and Navier-Stokes systems with free surface. Compared to shallow water approximation of the Navier-Stokes system, the idea is to use a Galerkin type approximation of the velocity field with piecewise constant basis functions in order to obtain an accurate description of the vertical profile of the horizontal velocity.

7.1.6. Congested shallow water model: floating object

In [27], we are interested in the floating body problem on a large space scale. We focus on objects floating freely in the water such as icebergs or wave energy converters. The formulation of the fluid-solid interaction using the congested shallow water model for the fluid and Newton's second law of motion for the solid is given and a strong coupling between the two systems is explained. The energy transfer between the solid and the water is focused on since it is of major interest for energy production. A numerical resolution based on the coupling of a finite volume scheme for the fluid and a Newmark scheme for the solid is presented. An entropy correction based on an adapted choice of discretization for the coupling terms is made in order to ensure a dissipation law at the discrete level. Simulations are presented to validate the method and to show the feasibility of more complex cases.

7.1.7. Numerical strategies for a dispersive layer-averaged model

A hierarchy of models has been derived in [12] to approximate the Euler equations by means of a layer-averaging procedure. This results in several dispersive models with one velocity field per layer. The structure of the equations induces issues of efficiency. The standard splitting between hydrostatic and non-hydrostatic components leads to a prohibitive computational costs. In a work in progress, we are investigating a new strategy to solve the projection step in a cheaper way. This is assessed by means of steady nontrivial solutions of the dispersive equations.

7.1.8. Methods of Reflections

The basic idea of the method of reflections appeared almost two hundred years ago; it is a method of successive approximations for the interaction of particles within a fluid, and it seems intuitively related to the Schwarz domain decomposition methods, the subdomains being the complements of the particle domains. We show in [25] that indeed there is a direct correspondence between the methods of reflections and Schwarz methods in the two particle/subdomain case. This allows us to give a new convergence analysis based on maximum principle techniques with precise convergence estimates that one could not obtain otherwise. We then show however also that in the case of more than two particles/subdomains, the methods of reflections and the Schwarz methods are really different methods, with different convergence properties. We finally also introduce for the first time coarse corrections for the methods of reflections to make them scalable in the case when the number of particles becomes large.

7.2. Modelling

Participants: Marie-Odile Bristeau, Jacques Sainte-Marie, Fabien Souillé, Emmanuel Audusse, Léa Boitin, Martin Parisot, Di Martino Bernard, Anne Mangeney.

7.2.1. How do microalgae perceive light in a high-rate pond? Towards more realistic Lagrangian experiments

In [10], we present a multidisciplinary downscaling study, where we first reconstructed single cell trajectories in an open raceway using an original hydrodynamical model offering a powerful discretization of the Navier–Stokes equations tailored to systems with free surfaces. The trajectory of a particular cell was selected and the associated high-frequency light pattern was computed. This light pattern was then experimentally reproduced in an Arduino-driven computer controlled cultivation system with a low density Dunaliella salina culture. The effect on growth and pigment content was recorded for various frequencies of the light pattern, by setting different paddle wheel velocities.

7.2.2. Modeling and simulation of sediment transport

A previous derivation of the sediment layer model has then been extended. Depending on the scaling chosen for the physical parameters, different models are obtained. The model we are interested in is the non-local model (with a viscosity term). Several numerical schemes are implemented and studied to simulate this model. Only one of these schemes is satisfactory. Simulations of the coupled water-sediment systems are made. The influence of the viscosity is emphasized. Turning on the non-local term allows to simulate dune growth and propagation.

Following the previous work, a numerical scheme for the sediment layer is proposed. The numerical scheme is tested. The influence of the viscosity on the behaviour of the sediment layer is studied. A numerical strategy for the resolution of the coupled model (water layer and sediment layer) is implemented. The behaviour of the coupled system is numerically assessed. Academic test cases are performed.

7.2.3. The Navier-Stokes system with temperature and salinity for free-surface flows

We model free surface flows where density variations coming e.g. from temperature or salinity differences play a significant role. Starting from the compressible Navier-Stokes system, a model is derived by performing the incompressible limit (the dependence of the density on the pressure is removed). A layer-averaged formulation of the model is proposed. The layer-averaged model satisfies a dissipative energy balance. A numerical scheme is proposed. It verifies several stability properties (positivity, well-balancing, maximum principle on the density). Numerical simulations are performed. The differences with models relying on the classical Boussinesq approximation are shown.

7.2.4. Various analytical solutions for the incompressible Euler and Navier-Stokes systems with free surface

In this paper [24], we propose several time dependent analytical solutions for the incompressible Euler and Navier-Stokes systems with free surface. The given analytical solutions concerns the hydrostatic and nonhydrostatic Euler and Navier-Stokes systems.

7.3. Functional analysis of PDE models in Fluid Mechanics

Participants: Bilal Al Taki, Boris Haspot.

7.3.1. New functional inequality and its application

In [22], we prove by simple arguments a new kind of Logarithmic Sobolev inequalities generalizing two known inequalities founded in some papers related to fluid dynamics models. As a by product, we show how our inequality can help in obtaining some important a priori estimates for the solution of the Navier-Stokes-Korteweg system.

7.3.2. Vortex solutions for the compressible Navier-Stokes equations with general viscosity coefficients in 1D: regularizing effects or not on the density

We consider Navier-Stokes equations for compressible viscous fluids in the one-dimensional case with general viscosity coefficients. We prove the existence of global weak solution when the initial momentum $\rho_0 u_0$ belongs to the set of the finite measure $\mathcal{M}(\mathbf{R})$ and when the initial density ρ_0 is in the set of bounded variation functions $BV(\mathbf{R})$. In particular it allows to deal with initial momentum which are Dirac masses and initial density which admit shocks. We can observe in particular that this type of initial data have infinite energy. Furthermore we show that if the coupling between the density and the velocity is sufficiently strong then the initial density which admits initially shocks is instantaneously regularized and becomes continuous. This coupling is expressed via the regularity of the so called effective velocity $v = u + \frac{\mu(\rho)}{\rho^2}\psi_x\rho$ with $\mu(\rho)$ the viscosity coefficient. Inversely if the coupling between the initial density and the initial velocity is too weak (typically $\rho_0 v_0 \in \mathcal{M}(\mathbf{R})$) then we prove the existence of weak energy in finite time but the density remains a priori discontinuous on the time interval of existence.

7.3.3. Strong solution for Korteweg system

In this paper we investigate the question of the local existence of strong solution for the Korteweg system in critical spaces when $N \geq 1$ provided that the initial data are small. More precisely the initial momentum $\rho_0 u_0$ belongs to $\mathrm{bmo}_T^{-1}(\mathbf{R}^N)$ for $T > 0$ and the initial density ρ_0 is in $L^\infty(\mathbf{R}^N)$ and far away from the vacuum. This result extends the so called Koch-Tataru theorem for the incompressible Navier-Stokes equations to the case of the Korteweg system. It is also interesting to observe that any initial shock on the density is instantaneously regularized inasmuch as the density becomes Lipschitz for any $\rho(t,\cdot)$ with $t > 0$. We also prove the existence of global strong solution for small initial data $(\rho_0 - 1, \rho_0 u_0)$ in the homogeneous Besov spaces $(\dot{B}^{\mathbf{N}-1}_{2,\infty}(\mathbf{R^N} \cap \dot{B}^{\mathbf{N}}_{2,\infty}(\mathbf{R^N} \cap L^\infty(\mathbf{R^N})) \times (\dot{B}^{\mathbf{N}-1}_{2,\infty}(\mathbf{R^N}))^{\mathbf{N}}$. This result allows in particular to extend in dimension $N = 2$ the notion of Oseen solutions defined for incompressible Navier-Stokes equations to the case of the Korteweg system when the vorticity of the momentum $\rho_0 u_0$ is a Dirac mass $\alpha\delta_0$ with α sufficiently small. However unlike the Navier Stokes equations

7.4. Assessments of models by means of experimental data and assimilation

Participants: Vivien Mallet, Ngoc Bao Tran Le, Antoine Lesieur, Frédéric Allaire, Hammond Janelle.

7.4.1. Uncertainty quantification of on-road traffic emissions

Road traffic emissions of air pollutants depend on both traffic flow and vehicle emission factors. At metropolitan scale, traffic flow can be obtained by traffic assignment models, and emission factors can be computed from the traffic flow using COPERT IV formulas. Global sensitivity analyses, especially the computation of Sobol' indices, was carried out for the traffic model and the air pollutant emissions. In the process, the traffic model was replaced by a metamodel, or surrogate model, in order to reduce the high computational burden. The results identified the most important input parameters, e.g., the demand associated with small travel distances (for the traffic flow) or the gasoline car share (for the air pollutant emissions). Furthermore, the uncertainties in traffic flow and pollutant emissions was quantified by propagating into the model the uncertainties in the input parameters. Large ensembles of traffic flows were generated and evaluated with traffic flow measurements.

7.4.2. Uncertainty quantification in atmospheric dispersion of radionuclides

In collaboration with IRSN (Institute of Radiation Protection and Nuclear Safety), we investigated the uncertainties of the atmospheric-dispersion forecasts that are used during an accidental release of radionuclides such as the Fukushima disaster. These forecasts are subject to considerable uncertainties which originate from inaccurate weather forecasts, poorly known source term and modeling shortcomings. In order to quantify the uncertainties, we designed a metamodel and investigated the calibration of the probability distribution of the input variables like the source term or the meteorological variables.

7.4.3. Metamodeling corrected by observational data

An air quality model at urban scale computes the air pollutant concentrations at street resolution based on various emissions, meteorology, imported pollution and city geometry. Because of the computational cost of such model, we previously designed a metamodel using dimension reduction and statistical emulation. Novel work was dedicated to the correction of this metamodel using observational data. The proposed approach builds a corrected metamodel that is still much faster than the original model, but also performs better when compared to new observations.

7.4.4. Sensitivity analysis and metamodeling of an urban noise model

Urban noise mapping models simulate the propagation of noise, originating from emission sources (e.g., road traffic), in all street of a city, based on its geometry. They are subject to uncertainties due to incomplete and erroneous data. We carried out screening studies in order to evaluate the sensitivity of the computed noise to the uncertain data. Further work dealt with the development of a metamodel, which will open the way to uncertainty quantification. The work was carried out with the model NoiseModelling and applied to the noise mapping of Lorient (France).

7.4.5. Monte Carlo simulation and ensemble evaluation for wildland fire propagation

We worked on Monte Carlo simulations of wildland fires. The objective was to evaluate how the uncertainties lying in all the inputs of a fire propagation model can be propagated through the model. A careful review of the literature allowed us to define varying intervals for all the uncertain inputs. The Monte Carlo simulations were then evaluated with ensemble scores, using the observations of the final contours for a number of real cases. The ensemble scores were inspired by classical scores used in meteorology, but were adapted to the nature of the fire observations.

7.4.6. Metamodeling of a complete air quality simulation chain

With the objective of uncertainty quantification, we worked in [15] on the generation of a metamodel for the simulation of urban air quality, using a complete simulation chain including dynamic traffic assignment, the computation of air pollutant emissions and the dispersion of the pollutant in a city. The traffic model and the dispersion model are computationally costly and operate in high dimension. We employed dimension reduction, and coupled it with Kriging in order to build a metamodel for the complete simulation chain.

7.5. Software Devlopments

Participant: Cédric Doucet.

Improvements in the FRESHKISS3D code Several improvements have been achieved in FreshKiss3D :

1. installation step is simpler due to the usage of a YAML file listing third-party libraries;
2. Mac OS is now supported;
3. continuous integration is performed on Ubuntu 16 and OSX with different compilers (GCC, Clang) and different builds (debug, release);
4. a major bug in the computation of fluxes has been fixed;
5. the number of third-party libraries has been minimized (geomalgo, metis4py);
6. build automation is now based on CMake (instead of Waf);
7. documentation has been updated and it is now published during the continuous integration process by means of Gitlab pages;
8. continuous integration has been optimized (better slaves, parallelization)

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- A contract (2016-2018) has been made (130.000 euros) with SAUR, IAV (Institut d'Aménagement de la Vilaine) and Agence de l'eau Loire-Bretagne in collaboration with SciWorks Technologies. It deals with the modelling and the simulation of chlorides entry in the Vilaine reservoir.
- A part of the ANR project Hyflo-Eflu relies on a collaboration with the company "HydroTube Energie". It comprises the recruitment of a young engineer (J. Ledoux) and regular meetings with industrial (Bordeaux) and academic partners (Nantes). See below for more details about the scientific content of this project.
- A part of the ANR project ESTIMAIR includes the SME NUMTECH for a commercial deployment of the project results. (Bordeaux) and academic partners (Nantes). See below for more details about the scientific content of this project.
- J. Sainte-Marie, C. Guichard, Y. Penel, J. Salomon are part of an agreement between Institut Carnot SMILES (Sorbonne Univ., Thomas Boiveau) and the corporation GTT about the improvement of a modeling tool for gas flows in the isolation spaces of LNG tanks

8.2. Bilateral Grants with Industry

P. Quémar's PhD thesis is funded by EDF (CIFRE). His PhD is entitled "3D numerical simulations of environmental hydrolics: application to Telemac".

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR MFG (2016-2021)

Participant: Julien Salomon.

Project acronym: MFG

Project title: Mean Field Games

Coordinator: Sébastien Boyaval (LHSV/ENPC)

Funding: 299 160 euros.

CMean field game theory (MFG) is a new and active field of mathematics, which analyses the dynamics of a very large number of agents. Introduced about ten years ago, MFG models have been used in different fields: economics, finance, social sciences, engineering,... MFG theory is at the intersection of mean field theory, mathematical game theory, optimal control, stochastic analysis, variation calculation, partial differential equations and scientific calculation. Drawing on an internationally recognized French team on the subject, the project seeks to obtain major contributions in 4 main directions: the "medium field" aspect (i.e., how to obtain macroscopic models from microscopic models); the analysis of new MFG systems; their numerical analysis; the development of new applications. In this period of rapid expansion of MFG models, the project seeks to foster French leadership in the field and attract new researchers from related fields.

9.1.2. ANR INFAMIE (2015-2019)

Participant: Boris Haspot.

Program: ANR Défi de tous les savoirs (DS10) 2015

Project acronym: INFAMIE

Project title: INhomogeneous Flows : Asymptotic Models and Interfaces Evolution

Coordinator: Raphaël Danchin (Univ. Paris-Est)

Funding: 232 960 euros.

Our project aims at a better mathematical understanding of several models for the evolution of inhomogeneous flows. Through three main lines of research (see below), we will pursue a twofold final objective. First, we want to develop the current theory of regular solutions for several equations for the evolution of fluids, proposing a new approach and developing tools that are likely to be efficient in various areas of PDEs. Second, for a few selected concrete systems that describe flows in the earth environment or in astrophysics, we wish to use this general approach to extract as much information as possible concerning the qualitative behavior of the solutions.

9.1.3. ANR SEDIFLO (2015-2019)

Participants: Emmanuel Audusse, Martin Parisot.

Program: ANR Défi 1 "Gestion sobre des ressources et adaptation au changement climatique" (JCJC)

Project acronym: SEDIFLO

Project title: Modelling and simulation of solid transport in rivers

Coordinator: Sébastien Boyaval (LHSV/ENPC)

Based on recent theoretical and experimental results, this project is aimed at modelling transport of sediments within rivers. It will rely on innovations from the point of view of rheology as well as advanced mathematical tools (asymptotic model reduction, PDE discretisation).

9.1.4. ANR Hyflo-Eflu (2016-2019)

Participants: Jérémy Ledoux, Martin Parisot, Jacques Sainte-Marie, Julien Salomon.

ANR project call: Energies marines renouvelables

Project acronym: Hyflo-Eflu

Project title: Hydroliennes flottantes et énergie fluviale

Coordinator: Julien Salomon

The project is a collaboration between the Inria-team ANGE, specialist of free surface flow and optimisation, and the industrial developers of the turbine, HYDROTUBE ENERGIE. The objective of the project HyFlo-EFlu is to deliver a numerical software able to simulate the dynamic of a floating water turbine in real context. For the academic partner, the main challenge is in the simulation of the floating structure at the scale of the river, and the modelling of the vertical and horisontal axis turbine. For the industrial partner, the objective is the validation of the stability of the structure and the performance in term of energy production.

9.1.5. ANR CHARMS (2016-2020)

Participant: Cindy Guichard.

ANR project call: Transformations et inter-conversions énergétiques

Project acronym: CHARMS

Project title: Modèles de réservoirs quantitatifs pour les systèmes hydrothermaux complexes

Coordinator: Simon Lopez (BRGM)

Funding: 73k euros for LJLL (in 767k euros for the whole project)

CHARMS ANR project is focused on the mathematical methods and software tools dedicated to the simulation of the physical models issued from geothermal engineering. The final objective is the achievement of a highly parallel code, validated on realistic cases.

9.1.6. CNRS Mocha (2017-2018)

Participant: Martin Parisot.

CNRS project call: LEFE

Project acronym: MOCHA

Project title: Multi-dimensiOnal Coupling in Hydraulics and data Assimilation

Coordinator: Martin Parisot

Funding: 14k euros

In collaboration with S. Barthélémy, N. Goutal, S. Ricci, M. Hoang Le.

Multi-dimensionnal coupling in river hydrodynamics offers a conveninent solution to properly model complex flow while limiting the computational cost and making the most of pre-exsiting models. The project aims to adapt the lateral interface coupling proposed in [35] to the implicit version and test it on real data for the Garonne River.

9.1.7. Inria Project Lab "Algae in Silico" (2015-2018)

Participants: Marie-Odile Bristeau, Yohan Penel, Jacques Sainte-Marie, Fabien Souillé.

In the aftermath of the ADT In@lgae (2013–2015), we developed a simulation tool for microalgae culture. An Inria Project Lab "Algae in Silico" has started in collaboration with Inria teams BIOCORE and DYLISS. It concerns microalgae culture for biofuel production and the aim is to provide an integrated platform for numerical simulation "from genes to industrial processes".

9.1.8. Inria Project Lab "CityLab" (2015-2018)

Participants: Vivien Mallet, Raphaël Ventura.

CityLab@Inria studies ICT solutions toward smart cities that promote both social and environmental sustainability.

9.1.9. GdR EGRIN (2017–2021)

Participants: Emmanuel Audusse, Bernard Di Martino, Nicole Goutal, Cindy Guichard, Anne Mangeney, Martin Parisot, Jacques Sainte-Marie.

EGRIN stands for Gravity-driven flows and natural hazards. J. Sainte-Marie is the head of the scientific committee of this CNRS research group and A. Mangeney is a member of the committee. Other members of the team involved in the project are local correspondents. The scientific goals of this project are the modelling, analysis and simulation of complex fluids by means of reduced-complexity models in the framework of geophysical flows.

9.1.10. ANR FireCaster (2017-2020)

Participants: Frédéric Allaire, Vivien Mallet.

ANR project call: DS0104

Project acronym: FireCaster

Project title: Plateforme de prévision incendie et de réponse d'urgence

Coordinator: Jean-Baptiste Filippi (Univ. Corse)

Funding: 442k euros

The goal of the FireCaster project is to prototype a fire decision support system at the national scale to estimate upcoming fire risk (H+24 to H+48) and in case of crisis, to predict fire front position and local pollution (H+1 to H+12).

9.1.11. ANR CENSE (2017-2020)

Participants: Antoine Lesieur, Vivien Mallet.

ANR project call: DS0601

Project acronym: CENSE

Project title: Caractérisation des environnements sonores urbains : vers une approche globale associant données libres, mesures et modélisations

Coordinator: Judicaël Picaut (IFSTTAR)

Funding: 856k euros

The CENSE project aims at proposing a new methodology for the production of more realistic noise maps, based on an assimilation of simulated and measured data through a dense network of low-cost sensors.

9.1.12. ANR RAVEX (2017-2020)

Participant: Anne Mangeney.

ANR project call: DS0106

Project acronym: RAVEX

Project title: Développement d'une approche intégrée pour la réduction des Risques Associés au Volcanisme EXplosif, de la recherche sur l'aléa aux outils de gestion de crise : le cas de la Martinique

Coordinator: Olivier Roche (IRD)

Funding: 619k euros

9.1.13. ANR CINE-PARA (2015-2019)

Participant: Julien Salomon.

ANR project call: DS0708

Project acronym: CINE-PARA

Project title: Méthodes de parallélisation pour cinétiques complexes

Coordinator: Yvon Maday (LJLL)

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

9.2.1.1. ERC Consolidator Grant (2013-2018)

Participants: Anne Mangeney, Hugo Martin.

The project SLIDEQUAKES is about detection and understanding of landslides by observing and modelling gravitational flows and generated earthquakes and is funded by the European Research Council (2 million euros). More precisely, it deals with the mathematical, numerical and experimental modelling of gravitational flows and generated seismic waves coupled with field measurements to better understand and predict these natural hazards and their link with volcanic, seismic and climatic activities.

9.2.1.2. EoCoE (2015-2018)

Participant: Vivien Mallet.

Title: Energy oriented Centre of Excellence for computer applications

Program: H2020

Duration: October 2015 - October 2018

Coordinator: Édouard Audit (CEA)

Partners: CEA (Commissariat à l'Énergie Atomique et aux Énergies Alternatives, France), Forschungszentrum Julich (Germany), Max Planck Gesellschaft (Germany), ENEA (Agenzia Nazionale Per le Nuove Tecnologie, l'energia E Lo Sviluppo Economico Sostenibile, Italy), CERFACS (European Centre for Research and Advanced Training in Scientific Computing, France), Instytut Chemii Bioorganicznej Polskiej Akademii Nauk (Poland), Universita Degli Studi di Trento (Italy), Fraunhofer Gesellschaft (Germany), University of Bath (United Kingdom), CYL (The Cyprus Institute, Cyprus), CNR (National Research Council of Italy), Université Libre de Bruxelles (Belgium), BSC (Centro Nacional de Supercomputacion, Spain)

Inria contact: Michel Kern (Serena team)

Abstract: The aim of the projevt is to establish an Energy Oriented Centre of Excellence for computing applications (EoCoE). EoCoE (pronounce “Echo”) will use the prodigious potential offered by the ever-growing computing infrastructure to foster and accelerate the European transition to a reliable and low carbon energy supply. To achieve this goal, we believe that the present revolution in hardware technology calls for a similar paradigm change in the way application codes are designed. EoCoE will assist the energy transition via targeted support to four renewable energy pillars: Meteo, Materials, Water and Fusion, each with a heavy reliance on numerical modelling. These four pillars will be anchored within a strong transversal multidisciplinary basis providing high-end expertise in applied mathematics and HPC. EoCoE is structured around a central Franco-German hub coordinating a pan-European network, gathering a total of 8 countries and 23 teams. Its partners are strongly engaged in both the HPC and energy fields; a prerequisite for the long-term sustainability of EoCoE and also ensuring that it is deeply integrated in the overall European strategy for HPC. The primary goal of EoCoE is to create a new, long lasting and sustainable community around computational energy science. At the same time, EoCoE is committed to deliver high-impact results within the first three years. It will resolve current bottlenecks in application codes, leading to new modelling capabilities and scientific advances among the four user communities; it will develop cutting-edge mathematical and numerical methods, and tools to foster the usage of Exascale computing. Dedicated services for laboratories and industries will be established to leverage this expertise and to foster an ecosystem around HPC for energy. EoCoE will give birth to new collaborations and working methods and will encourage widely spread best practices.

9.2.2. Collaborations with Major European Organisations

9.2.2.1. CNRS PICS NHML (2017-2019)

Participants: Martin Parisot, Yohan Penel, Jacques Sainte-Marie.

Program: CNRS PICS (projet international de collaboration scientifique)

Project acronym: NHML

Project title: non-hydrostatic multilayer models

Duration: 01/17-12/19

Coordinator: Yohan Penel (Inria)

Other partners: IMUS (Sevilla, Spain)

Other Participants: Enrique Fernández-Nieto (Sevilla), Tomas Morales de Luna (Cordoba)

Funding: 12k euros

Abstract: This collaboration aims at designing a hierarchy of multilayer models with a non-hydrostatic pressure as a discretisation along the vertical axis of the Euler equations. The hierarchy relies on the degree of approximation of the variables discretised with a Discontinuous Galerkin method for the vertical direction. These innovative models will imply a theoretical study and the development of numerical tools in dimensions 1 and 2 before the modelling of other physical phenomena (viscosity effects, ...).

9.3. International Initiatives

9.3.1. Informal International Partners

Four collaborations with foreign colleagues are to be mentioned:

- **Spain** - A collaboration with Spanish researchers has been initiated in 2016 to derive accurate models and effecient algorithms for free surface flows including non-hydrostatic effects. ANGE applied in 2018 to the Inria Associate Team programme in order to strenghten the collaboration.
- **USA** A joint work with R. LeVeque (Univ. Seattle) and M. Berger (New York Univ.) consists in modelling the impact of asteroids on the generation of tsunamis.
- **Germany** A collaboration with researchers from the University of Constance has been initiated in 2018 about domain decomposition and identifaction algorithms (G. Ciaramella, S. Volkwein).
- **Hong-Kong** A collaboration with F. Kwok on time parallelization for assimilation algorithm has been initiated in 2018.

9.4. International Research Visitors

- Y. Penel spent twice two weeks (May, October)at the university of Sevilla (Spain) to collaborate with E. Fernández-Nieto.

9.4.1. Visits of International Scientists

- G. Ciaramella visited J. Salomon (28.05-01.06) to work on a reduction method for identification problem.

10. Dissemination

10.1. Promoting Scientific Activities

- Y. Penel and J. Sainte-Marie organised (with E. Fernández-Nieto) the workshop "non-hydrostatic effects in oceanography " that took place at Sevilla univ. on 15-16th October and that gathered 35 international researchers [1].
- J. Sainte-Marie took part of the organization of the 6th EGRIN summer school that took place at Le Lioran from 18th to 21st of June and that gathered 40 researchers [2].
- J. Sainte-Marie took part of the organization of the Workshop COMMODORE "Community for the numerical modeling of the global, regional and coastal ocean" [3] (17-19/9/18).
- B. Haspot and Y. Penel organise the monthly ANGE seminar [4].
- J. Salomon co-organises the LJLL-Inria meetings [5] (twice a month).
- J. Salomon co-organised the minisymposium "Domain-decomposition methods for integral equation problems " at the 25th International Domain Decomposition Conference, DD XXV, in St. John's, Newfoundland, Canada, July 23-27, 2018.
- L. Boittin co-organises the Junior Seminar at Inria–Paris.
- M. Parisot and J. Salomon organise a workshop entitled "Scientific computing and optimisation processes for renewable energies" at Inria [6] on January 2018.

10.1.1. Journal

The summary of the reviewing activities of the team is given in the next table.

Member	**Journal**
Julien Salomon	CRAS, SIAM SISC
Cindy Guichard	J. Comp. Phys., J. Sci. Comp., CRAS, J. Comp. Math., Num. Math.
Jacques Sainte-Marie	M2AN, Computer and Fluids, Ocean Modelling, J. Comp. Phys., J. Sci. Comp. Adances in Comp. Math.
Martin Parisot	J. Hydraulic Research, Computers and Fluids, J. Comp. Phys., J. de Math. Pures et Appliquées
Vivien Mallet	ANR, Journal of Machine Learning Research
Edwige Godlewski	Sinum

[1] https://team.inria.fr/ange/workshop-non-hydrostatic-effects-in-oceanography/
[2] https://indico.math.cnrs.fr/event/3345/overview
[3] https://commodore2018.sciencesconf.org/
[4] https://team.inria.fr/ange/gdt-slides/
[5] https://project.inria.fr/rencontresljll/fr/
[6] https://emrsim2018.sciencesconf.org/

10.1.2. Invited and contributed Talks

Conference	Location	Month	Members involved
Julien Salomon	7-th Parallel-in-time Integration Workshop (PinT 2018).	Roscoff, France	02-05/05/2018
Julien Salomon	25-th International Conference on Domain Decomposition Methods (DD25).	St-Johns, Canada	23-27/07/18
Julien Salomon	Séminaire du laboratoire de mathématiques Blaise Pascal.	Clermont-Ferrand, France	01/02/18
Julien Salomon	Séminaire du CMAP.	Palaiseau, France	15/5/18
Julien Salomon	Séminaire du Laboratoire J.-L. Lions	Paris, France	30/03/18
Julien Salomon	Séminaire du groupe d'analyse	Universität Konstanz	14/11/18
Fabien Wahl	Simulation et Optimisation pour les Energies Marines Renouvelables	Inria Paris	11/01/18
Fabien Wahl	GdT ANGE	Inria Paris	10/10/18
Fabien Wahl	EGRIN	Le Grand Lioran	18/06/18
Bilal Al Taki	Journée interne du LJLL	Paris diderot (P7)	05/04/18
Bilal Al Taki	Séminaire du laboratoire	Marseille	20/11/18
Frédéric Allaire	8th International Conference on Forest Fire Research (ICFFR)	Coimbra, Portugal	12-16/11/18
Virgile Dubos, Martin Parisot	Non-hydrostatic effects in oceanography	Séville, Espagne	15-16/10/18
Virgile Dubos	18th Spanish-French Sch. J-L. Lions, Num. Sim. in Phy. and Eng.	Las Palmas, Espagne	25-29/06/18
Cindy Guichard	rencontres Inria-LJLL en calcul scientifique	Paris	05/11
Cindy Guichard	Mini-symposium, CANUM	Cap d'Agde	29/05
Cindy Guichard	séminaire d'analyse numérique, CEA/DIF	Bruyères-le-Châtel	03/05/18
Cindy Guichard	journée interne du LJLL	Paris	05/04/18
Cindy Guichard	séminaire d'analyse numérique des EDP	univ. Orsay	22/03/18
Yohan Penel	Mini-symposium, CANUM	Cap d'Agde	29/05/18
Yohan Penel	GDR Manu (poster)	Roscoff, France	02/07/18
Yohan Penel	Workshop "non-hydrostatic effects in oceanography"	Séville, Espagne	16/10/18
Jacques Sainte-Marie	Plenary in " Free Surface Flows: from Hydrostatic to Non-Hydrostatic Models"	Saint-Malo	6/6/18
Jacques Sainte-Marie	Séminaire du laboratoire N. Oresme - université de Caen	Caen	12/02/18
Léa Boittin	GdT ANGE	Inria Paris	21/02/18
Léa Boittin	GTT LJLL	LJLL, Paris	30/1
Léa Boittin	CMWR XXII (poster)	Saint-Malo	04/06/18
Léa Boittin	EGRIN	Le Grand Lioran	18/6/18
Martin Parisot	Seminaire d'équipe LEMON	Montpellier	6/2/18
Martin Parisot	SIMAI-UMI Congres	Wroclaw, Poland	16-20/09/18
Martin Parisot	Séminaire du Laboratoire Jean Leray	Nantes	11/10/18
Martin Parisot	Conference Balance laws in fluid mechanics, geophysics, biology	Orléans	19-22/10/18
Martin Parisot	Séminaire "Math et Eau"	Montpellier	25/10/18
Martin Parisot	Colloque LEFE	Clermont-Ferrand	28-30/03/18
Martin Parisot	Workshop Non Hydro, Séville	Séville	10/18
Jacques Sainte-Marie	Séminaire du laboratoire de	Beyrouth université	19/12/2018

10.1.3. Leadership within the Scientific Community

Yohan Penel is a member of the Council Administration of SMAI (2015-2018).

10.1.4. Scientific Expertise

- Yohan Penel was rewiewer for the grant CNRS INSU LEFE
- Vivien Mallet was reviewer for ANR

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Member	Level	Institution	Duration	Type	Topic
J. Salomon	M2	Univ. Paris-Dauphine	15	CM	Cours de rentrée : méthodes numériques pour les EDP
J. Salomon	M2	Univ. Paris-Dauphine	30	CM	Méthodes numériques pour des modèles incluants des EDP
L. Lu	L1	SU	27.4	TD	Analyse et algèbre pour les sciences
B. Al Taki	L1	SU	36	TD	Analyse et algèbre pour les sciences
F. Allaire	L1	SU	38.5	TD	Calculus
V. Dubos	L3	Polytech Sorbonne	32	TP	Mathématiques appliquées
V. Dubos	M1	Polytech Sorbonne	14+22	CM+TP	Traitement numérique
V. Dubos	L3	Polytech Sorbonne	10	TP	Projet d'initiation
C. Guichard	M2	SU	22	CM+TD	Méthodes numériques
C. Guichard	M1	SU	58	TP	Fondements des méthodes numériques
C. Guichard	L3	SU	21	TP	Python
C. Guichard	M1	SU	18	CM	Mise en oeuvre de la méthode des éléments finis
B. Di Martino	L1	Univ. Corse	18	CM+TD	Techniques mathématiques et physiques pour les sciences de la vie
B. Di Martino	L2	Univ. Corse	72	CM+TD+TP	Analyse et TP Python Sage algèbre et analyse
B. Di Martino	L3	Univ. Corse	54	CM+TD+TP	Analyse numérique matricielle
B. Di Martino	M2	Univ. Corse	24	CM+TD+TP	Modélisation master Gestion Intégrée du Littoral et Valorisation Halieutique
Y. Penel	L2	SU	12	CM	Analyse vectorielle et intégrales multiples
Y. Penel	M1	Univ. Paris Descartes	37.5	CM+TD+TP	Modélisation déterministe en sciences du vivant
J. Sainte-Marie	M1	IPGP	40	CM	Modélisation des écoulements gravitaires
J. Sainte-Marie	M2	IPGP	30	CM et TP	Méthodes numériques, appli. géosciences
J. Sainte-Marie	M2	SU	20	CM	Méthodes numériques pour les systèmes hyperboliques Applications aux énergies renouvelables
N. Boulos	L1	Paris 13	48	TD	Mathématiques pour le parcours aménagé
L. Boittin	L3	SU	24,5	TD	Méthodes numériques pour les EDO
M. Parisot	L3	Polytech	46	CM+TP	Méthodes numériques

10.2.2. Supervision

Supervisor ANGE	Type	Name	Institution	Time	Title
JS	PhD	Sebastian Reyes-Riffo	Paris-Dauphine	2016-2019	Méthodes numériques pour les énergies marines renouvelables
JS, VM	PhD	Antoine Lesieur	Inria	2017-2020	Estimation d'état et modélisation inverse appliquées à la pollution sonore en milieu urbain
JS	PhD	Nadia Jbili	Paris-Dauphine	2016-2019	Contrôle optimal pour la résonance magnétique nucléaire
JS, JSM	PhD	Liudi Lu	Inria	2018-2021	Approches Lagrangiennes pour la modélisation et l'optimisation du couplage hydrodynamique-photosynthèse
JSM, VM	PhD	Frédéric Allaire	Inria	2017-2020	Quantification du risque incendie par méta-modélisation de la propagation de feux de forêt
YP, CG, JSM	PhD	Virgile Dubos	SU	2017-2020	Numerical methods for the elliptic/parabolic parts of non-hydrostatic fluid models
BDM, BH	Post Doc	Bilal AL Taki	Inria	09/17-12/18	Understanding and modeling the rheology of complex surface flow
NA, EA, MP	stage M2	Nelly BOULOS	Inria	04-08/2018	Analyse et simulation de modèles d'écoulement à surface libre intégrés selon la verticale
EA, MP, JSM, MOB	PhD	Léa Boittin	Paris 6	2015-2019	Modelling, analysis and efficient numerical resolution for erosion processes,
MP, NA, EA, MP	PhD	Nelly BOULOS	Paris 13	2018-2021	Modélisation et simulation numérique de la dynamique d'un acquifère érodable
VM	PhD	Ngoc Bao Tran Le	Inria	2016-2019	Uncertainty quantification based on model reduction for atmospheric dispersion
VM	Post Doc	Janelle Hammond	Inria	2017-2019	Uncertainty quantification, metamodeling and data assimilation applied to urban air quality
EA, MP,JSM	PhD	Léa Boittin	inria	2016-2019	Modelling, analysis and efficient numerical resolution for erosion processes

JS : J. Salomon, VM : Vivien Mallet, JSM : Jacques Sainte-Marie, YP : Yohan Penel, CG : Cindy Guichard, BDM : Bernard Di Martino, BH : Boris Haspot, NA: Nina Aguillon, EA : Emmanuel Audusse, MP : Martin Parisot, EG : Edwige Godlewski

10.2.3. Juries

Member	Date	Type (PhD, HdR)	role	Name	Institution	Title
JS	Novembre	PhD	rapporteur	Quentin Ansel	Univ. Dijon, TUM Munich	Optimal control ofinhomogeneous spin ensembles: Applications in NMR and Quantum optics
JS	Décembre	PhD	rapporteur	Pierre Terrier	ENPC, Université Paris-Est	Simulations numériques pour la prédiction de l'évolution microstructurale d'alliages ferritiques.Une étude de la dynamique d'amas.
JS	Décembre	PhD	rapporteur	Amina Benaceur	ENPC, Université Paris-Est	Réduction de modèles en thermique etmécanique non-linéaires
YP	Septembre	comité de mi-thèse	examinateur	Moustoifa Rafiou	Univ. Toulon	Modélisation et simulation numérique d'un écoulement à faible nombre de Mach. Application à un réacteur à eaux pressurisées.
JSM	Novembre	PhD	rapporteur	Nicolas Peton	IFPEN et univ. Paris-Saclay	Étude et simulation d'un modèle stratigraphique advecto-diffusif non-linéaire avec frontières mobiles
JSM	Janvier	PhD	président	Charles Demay	EDF et univ. Savoie Mont-Blanc	Modelling and simulation of transient air-water two-phase flows in hydraulic pipes
EG	mars	PhD	membre	Alexis Marboeuf	Ecole Polytechnique	Schémas ALE multi-matériaux totalement conservatifs pour l'hudrodynamique
EG	juillet	PhD	présidente	Camilla Fiorini	UVSQ	Analyse de sensibilité pour systèmes hyperboliques non linéaires
EG	octobre	PhD	présidente	Julie Llobell	UCA (Nice)	Schémas Volumes Finis à mailles décalées pour la dynamique des gaz
EG	novembre	PhD	présidente	Nicolas Cagnart	SU	Quelques approches non linéaires en réduction de complexité
EG	novembre	PhD	rapporteure	David Iampetro	AMU (EDF Saclay)	Contribution à la simulation

JS : J. Salomon, VM : Vivien Mallet, JSM : Jacques Sainte-Marie, YP : Yohan Penel, EG : Edwige Godlewski

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Julien Salomon is a member of the "Comité des usagers de la rue Barrault" in view of the move of Paris Inria Center to Rue Barrault.

10.3.2. Articles and contents

Julien Salomon wrote a vulgarization article "Décomposer et itérer pour résoudre un problème " for the CNRS website " Images des mathématiques " (12/2018)

10.3.3. Education

- Edwige Godlewski is the president of the "commission française pour l'enseignement des mathématiques" (CFEM)
- Jacques Sainte-Marie is a member of the "Groupe de travail : Recherche et développement durable" at the French Ministry of Research.

10.3.4. Interventions

- Julien Salomon took part of the "Salon Culture et Jeux mathématiques" - Stand AMIES (Paris, 24/05/18)
- Julien Salomon gave a talk at Waterford Kamhlaba United World College, Mbabane, Eswatini (Swaziland, 5/8/2018).
- Julien Salomon took part of "Fête de la science", and gave a talk at école rue st-Isaure, 18ème (Paris,11/10/2018)
- Léa Boittin 25/5/18 took part of the "Salon Culture et Jeux mathématiques" - Stand AMIES (Paris, 25/05/18)
- Vivien Mallet gave a talk "Bruit dans la ville", for the association "Versailles environnement initiative" (01/12/18)

10.3.5. Internal action

Julien Salomon gave talk (3.4.18) at the internal meeting "La demi-heure de science": "Décomposer et itérer pour résoudre un problème complexe, quelques exemples en calcul scientifique".

Anne Mangeney gave talk (4.9.18) at the internal meeting "La demi-heure de science": "Les ondes sismiques : une mine d'informations sur les risques naturels".

11. Bibliography

Major publications by the team in recent years

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[4] J. SAINTE-MARIE. *Vertically averaged models for the free surface Euler system. Derivation and kinetic interpretation*, in "Math. Models Methods Appl. Sci. (M3AS)", 2011, vol. 21, n° 3, pp. 459-490, http://dx.doi.org/10.1142/S0218202511005118

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[5] R. VENTURA. *Estimation of urban noise pollution with the assimilation of mobile measurements*, Université Pierre & Marie Curie - Paris 6, June 2018, https://hal.inria.fr/tel-01910084

[6] F. WAHL. *Modeling and analysis of interactions between free surface flows and floating structures*, Sorbonne Université, December 2018, https://tel.archives-ouvertes.fr/tel-01955798

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[7] P. AUMOND, A. CAN, V. MALLET, B. DE COENSEL, C. RIBEIRO, D. BOTTELDOOREN, C. LAVANDIER. *Kriging-based spatial interpolation from measurements for sound level mapping in urban areas*, in "Journal of the Acoustical Society of America", 2018, vol. 143, n° 5, pp. 2847-2857 [*DOI :* 10.1121/1.5034799], https://hal.archives-ouvertes.fr/hal-01826354

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[11] M. FARIN, A. MANGENEY, J. DE ROSNY, R. TOUSSAINT, P.-T. TRINH. *Link Between the Dynamics of Granular Flows and the Generated Seismic Signal: Insights From Laboratory Experiments*, in "Journal of Geophysical Research : Earth Surface", June 2018, vol. 123, n° 6, pp. 1407-1429 [*DOI :* 10.1029/2017JF004296], https://hal.archives-ouvertes.fr/hal-01907646

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[19] V. MALLET, R. VENTURA, V. ISSARNY, P. G. RAVERDY. *Assimilation d'observations participatives issues de l'application mobile Ambiciti*, in "Acoustique et Techniques : trimestriel d'information des professionnels de l'acoustique", January 2018, https://hal.inria.fr/hal-01909880

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[20] M. H. LE, V. DUBOS, M. OUKACINE, N. GOUTAL. *A Well-balanced Finite Volume Scheme for Shallow Water Equations with Porosity Application to Modelling of Open-Channel Flow through Rigid and Emergent Vegetation*, in "River Flow 2018 - 9th International Conference on Fluvial Hydraulics", Lyon-Villeurbanne, France, September 2018, pp. 1-7, https://hal.archives-ouvertes.fr/hal-01706777

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[21] J. DRONIOU, R. EYMARD, T. GALLOUËT, C. GUICHARD, R. HERBIN. *The gradient discretisation method*, Mathématiques et Applications, Springer International Publishing AG, August 2018, vol. 82, Cf file "changelog_hal.pdf" [*DOI :* 10.1007/978-3-319-79042-8], https://hal.archives-ouvertes.fr/hal-01382358

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[25] G. CIARAMELLA, M. J. GANDER, L. HALPERN, J. SALOMON. *Methods of Reflections: relations with Schwarz methods and classical stationary iterations, scalability and preconditioning*, November 2018, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01930232

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