IN PARTNERSHIP WITH:
CNRS

Centre d'expertise des risques, de l'environnement, des mobilités et de l'aménagement

Université Pierre et Marie Curie (Paris 6)

Activity Report 2016

Project-Team ANGE

Numerical Analysis, Geophysics and Ecology

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

RESEARCH CENTER
Paris

THEME
Earth, Environmental and Energy Sciences

Table of contents

Project-Team ANGE

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

Keywords:

Computer Science and Digital Science:

6. - Modeling, simulation and control
6.1. - Mathematical Modeling
6.1.1. - Continuous Modeling (PDE, ODE)
6.1.4. - Multiscale modeling
6.1.5. - Multiphysics modeling
6.2. - Scientific Computing, Numerical Analysis & Optimization
6.2.1. - Numerical analysis of PDE and ODE
6.2.6. - Optimization
6.3. - Computation-data interaction
6.3.2. - Data assimilation

Other Research Topics and Application Domains:

3. - Environment and planet
3.3. - Geosciences
3.3.2. - Water: sea & ocean, lake & river
3.3.3. - Littoral
3.4. - Risks
3.4.1. - Natural risks
3.4.3. - Pollution
4. - Energy
4.3. - Renewable energy production
4.3.1. - Biofuels
4.3.2. - Hydro-energy

1. Members

Research Scientists

Jacques Sainte-Marie [Team leader, CEREMA, Senior Researcher, HDR]
Martin Parisot [Inria, Researcher]
Yohan Penel [CEREMA, Researcher]

Faculty Members

Bernard Di Martino [Inria secondment, on leave from Univ. Corse, Associate Professor, until Aug. 16, HDR]
Edwige Godlewski [Univ. Pierre et Marie Curie, Professor, HDR]
Cindy Guichard [Univ. Pierre et Marie Curie, Associate Professor]
Boris Haspot [CNRS secondment, on leave from Univ. Paris Dauphine, Associate Professor, from Sept. 16, HDR]
Anne Mangeney [CEREMA secondment, on leave from Univ. Paris Diderot, Professor, HDR]
Julien Salomon [Inria secondment, on leave from Univ. Paris Dauphine, Associate Professor, from Sept. 16, HDR]
Nicolas Seguin [Univ. Pierre et Marie Curie, Associate Professor, until Feb. 16, HDR]

Engineers

David Froger [Inria – SED 70%, until May 16]
Fabien Souillé [Inria, from Nov. 16]
Jérémy Ledoux [Univ. Paris Dauphine, from Sept. 16]

PhD Students

Nora Aïssiouene [Inria]
Léa Boittin [Inria]
Do Minh Hieu [Univ. Paris 13]
Dena Kazerani [Univ. Pierre et Marie Curie, until Oct. 2016]
Hugo Martin [IPGP]
Ethem Nayir [Univ. Pierre et Marie Curie]
Pierrick Quémar [Univ. Paris 13]
Sebastian Reyes-Riffo [Univ. Paris Dauphine]
Amandine Sergeant [IPGP, from Aug. 16]
Fabien Wahl [Univ. Pierre et Marie Curie]

Post-Doctoral Fellow

Pierre-Olivier Lamare [Inria]

Visiting Scientist

Marie-Odile Bristeau [Senior Researcher, retired]

Administrative Assistant

Maryse Desnous [Inria]

Others

Albin Grataloup [ENS Lyon, intern, from May 16 until July 16]
Emmanuel Audusse [Univ. Paris 13, Associate Professor]
Nicole Goutal [EDF, Senior Researcher, HDR]

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. Last but not least, efficient numerical resolutions of reduced-size models requires 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.

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 sense of the models (uniqueness, conservativity, entropy dissipation, ...) and propose effective numerical methods to estimate their solution in complex configurations (multi-dimensional, unstructured meshes, well-balanced, ...).

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 discretization 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, so-called shallow water assumptions, namely

- the horizontal 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 must rely on a special analysis.

3.2.1. Multilayer approach

As for the first shallow water assumption, *multi-layer* systems were proposed describing the flow as a superposition of Saint-Venant type systems [31], [33], [34]. Even if this approach has provided interesting results, layers are considered separate and non-miscible fluids, which imply strong limitation. That is why we proposed a slightly different approach [1], [2] based on Galerkin type decomposition along the vertical axis of all variables and leading, both for the model and its discretization, to more accurate results.

A kinetic representation of our multilayer model allows to derive robust numerical schemes endowed with 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 enable to guess the optimal number of layers.
- The introduction of several source terms due for instance to Coriolis forces 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 proved and conversely the possible loss of hyperbolicity cannot be characterized. 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.

When 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 integrating the 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-physic 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 zone 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 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 system Euler/Poisson, 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 such as threshold laws.
- Interaction between flows and floating structures is the challenge at the scale of the shallow water equations. This study needs 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 scheme. 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.

3.3. 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 has to 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

The hydrodynamic models comprise advection and sources terms. The conservation of the balance between the source terms, typically viscosity and friction, has a significant impact since the overall flow is generally a perturbation around one 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 potential waves and the physical velocity makes classical numerical schemes not efficient: 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 potential 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. Optimization

Numerical simulations are a very useful tool for the design of new processes, for instance in renewable energy or water decontamination. The optimization 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 optimization 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, biogeochemistry of oceans, resilience of society w.r.t. hazardous flows, ...

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 quasisteady 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 costly and generally not efficient in long term. The objective is to determine a configuration almost stable with 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 the 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.

5. Highlights of the Year

5.1. Highlights of the Year

While the theory and the numerics related to the nonlinear shallow water equations are extensively studied, the understanding of more complex models including dispersive ones is not achieved. Two PhD theses about these issues were defended in 2016 within the team (N. Aïssiouene and D. Kazerani). To go further, a collaboration with spanish collaborators from the university of Sevilla was launched with multiple trips in Spain and France resulting in a preprint [25]. The collaboration is expected to be made more formal in 2017.

Moreover, the team has been reinforced by two young engineers: J. Ledoux in the framework of the ANR project Hyflo-Eflu and F. Souillé. The latter recruitment has been allowed by the Inria ADT grant F2O ("Freshkiss to Others") and is aimed at easing the transfer of the Freshkiss code in cooperation with SciWorks Technologies.

6. New Software and Platforms

6.1. Freshkiss3D (FREe Surface Hydrodynamics using KInetic SchemeS)

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

- Participants: Nora Aïssiouene, Marie-Odile Bristeau, David Froger, Jacques Sainte-Marie, Fabien Souillé
- Formerly: Emmanuel Audusse, Anne-Céline Boulanger, Alain Dervieux, Raouf Hamouda, Bijan Mohammadi
- Partners: CEREMA – UPMC
- Contact: Jacques Sainte-Marie

A review of last developments is given in § 7.5.1. See [20] for recent numerical results obtained thanks to the Freshkiss3D software.

6.2. TSUNAMATHS

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, Raouf Hamouda, Jacques Sainte-Marie
- Contact: Jacques Sainte-Marie
- URL: http://ange.raoufhamouda.com/tsunami/en_motivation.htm

7. New Results

7.1. Modelling of complex flows

7.1.1. The Shallow Water model with Roof: derivation and simulation

Participants: Edwige Godlewski, Cindy Guichard, Martin Parisot, Jacques Sainte-Marie, Fabien Wahl.

In view of taking into account interactions with floating structures, a shallow water type model is derived. In a first step a constraint corresponding to a static roof is considered and a relaxation approach is proposed in order to solve the model numerically. A particular attention is paid to the energy law as an application to marine energy devices is planned. The CPR scheme proposed in [17] is adapted to our case and implemented in one space dimension. Finally the numerical results are tested on analytical solutions, as well stationary as non-stationary ones [26].

7.1.2. Modelling of Sediment Transport

Participants: Emmanuel Audusse, Léa Boittin, Martin Parisot, Jacques Sainte-Marie.

A new model for sediment transport in river context is proposed. The model is derived from the Navier-Stokes equations by performing simultaneously the thin layer approximation and the diffusive limit. The well-posedness of the model is studied in a simplified case.

7.1.3. Layer-averaged Euler and Navier-Stokes equation

Participants: Marie-Odile Bristeau, Bernard Di Martino, Cindy Guichard, Jacques Sainte-Marie.

In [3], we propose a strategy to approximate incompressible hydrostatic free surface Euler and Navier-Stokes models. The proposed strategy extends previous works approximating the Euler and Navier-Stokes systems using a multilayer description. Here, the required closure relations are obtained using an energy-based optimality criterion instead of an asymptotic expansion. Moreover, the layer-averaged description is successfully applied to the Navier-Stokes system with a general form of the Cauchy stress tensor.

7.1.4. Layerwise Discretization for Non-Hydrostatic flows

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

In collaboration with Enrique Fernández-Nieto (Sevilla).

The work presented in [25] aims at deriving a new semi-discretisation with respect to the vertical variable of the Euler equations. It results in a hierarchy of multilayer model involving both hydrostatic and non-hydrostatic parts of the pressure field. All models are proven to satisfy an energy inequality. Moreover, the linear dispersion relation is given for each one with an explicit formula which converges to the exact Airy formula when the number of layers goes to infinity.

7.1.5. Two-phase (grains/fluid) model for geophysical debris flows

Participant: Anne Mangeney.

We developped a thin-layer depth-averaged model describing the two-phase flow made of granular material saturated by a fluid and include compression/dilatation effects. We solved numerically these equations and were able to accurately reproduce laboratory experiments.

7.1.6. Multi-layer model for viscoplastic granular flows

Participant: Anne Mangeney.

In collaboration with Enrique Fernández-Nieto and Gladys Narbona-Reina (Sevilla).

A multi-layer model was developped to simulate granular flow dynamics and deposit based on viscoplastic behaviour ($\mu(I)$-rheology). The numerical model made it possible to reproduce for the first time the increase of runout distance of granular material when flowing on erodible beds.

7.2. Assessments of models by means of experimental data

7.2.1. Hydrodynamics and biology coupling in the context of algae growth

Participants: Marie-Odile Bristeau, Jacques Sainte-Marie.

In collaboration with BIOCORE (especially O. Bernard) in the framework of the IPL Algae in Silico.

Hydrodynamics in a high rate production reactor for microalgae cultivation affects light history perceived by the cells. The interplay between cell movement and medium turbidity leads to a light pattern forcing photosynthesis dynamics. The purpose of this multidisciplinary downscaling study is to reconstruct single cell trajectories in an open raceway and experimentally reproduce such high frequency light pattern to observe its effect on growth. We show that the frequency of such a realistic signal plays a determinant role in the dynamics of photosynthesis. This study highlights the need for experiments with more realistic light stimuli in order to better understand microalgal growth at high cell density.

7.2.2. 2D Drucker-Prager and $\mu(I)$ granular flow model

Participant: Anne Mangeney.

In collaboration with François Bouchut, Ioan Ionescu, Alexandre Ern, Christelle Lusso and Nathan Martin.

We developped 2D (horizontal/vertical) models of granular flows solving the yield behaviour of Drucker-Prager type laws using either a duality method or a regularization method. We included the effect of the lateral wall friction and get very good agreement with laboratory experiments of granular collapses over horizontal and inclined planes.

7.2.3. Analytical and numerical description of the static/flowing interface deduced from 2D Drucker-Prager model

Participant: Anne Mangeney.

In collaboration with François Bouchut, Alexandre Ern and Christelle Lusso.

We proposed analytical and numerical solution of the static/flowing interface and compared it with laboratory experiments of granular flows. Our study show how the static/flowing interface dynamics depends on the slope, friction angle, viscosity and normal velocity profiles.

7.2.4. Seismic inversion and numerical modelling of the force generated by landslides on the topography or by iceberg calving

Participant: Anne Mangeney.

By inverting the long period seismic signal to recover the force generating seismic waves and simulating this force with mechanical models of granular flows, we can provide a unique constraint on the dynamics of the phenomenon at stake and on its characteristics.

7.2.5. Data assimilation

Participants: Sebastian Reyes-Riffo, Julien Salomon.

In collaboration with Felix Kwok.

Taking advantage of a PROCORE-FRANCE/HONG KONG grant obtained in the latter spring, we work on a time-parallelization strategy for an assimilation algorithm. The target application also deals with wave energy: we aim at forecasting in real-time the characteristics of the wave coming on an extracting device, in order to adapt it in a continuous way.

7.3. Analysis of models in Fluid Mechanics

7.3.1. Weak solutions of multilayer Hydrostatic Flows

Participants: Bernard Di Martino, Boris Haspot, Yohan Penel.

We investigate the existence of global weak solutions for the multilayer model introduced by Audusse et al. [2] which is related to incompressible free surface flows. More precisely, in [22] we prove the global stability of weak solutions over the torus. We observe that this model admits the so called BD-entropy and a gain of integrability on the velocity in the spirit of the work of Mellet and Vasseur. The main difficulty comes from the terms describing the transfer of flux between the layers which are not taken into account in the immiscible case.

7.3.2. Hyperbolicity of the Layerwise Discretized Hydrostatic Euler equation: the bilayer case

Participants: Emmanuel Audusse, Edwige Godlewski, Martin Parisot.

In collaboration with Nina Aguillon (UPMC).

Several model of free surface flows described in the literature are based on a layerwise discretization of the Euler equations. The question addressed in the current work is about the hyperbolicity of the layerwise discretized model. More precisely, we focus on the 2-layer case and we prove the well-posedness of the Riemann problem in two dimensional framework. Due to the mass exchange, the 2D Riemann problem is not a simple extension of the 1D Riemann problem.

7.3.3. Normal mode perturbation for the shallow water equations

Participants: Emmanuel Audusse, Albin Grataloup, Yohan Penel.

This work focuses on the shallow water equations for a fluid flow in subcritical regime with an arbitrary topography. A normal mode perturbation was performed around a 1D steady state in the 2D model. The resulting system of ODE was studied in terms of eigenvalues of the corresponding matrix and the derivation of a dispersion relation.

7.3.4. Global well-posdness of the Euler-Korteweg system for small irrotational data

Participant: Boris Haspot.

In collaboration with C. Audiard (UPMC).

The Euler-Korteweg equations are a modification of the Euler equations that takes into account capillary effects. In the general case they form a quasi-linear system that can be recast as a degenerate Schrödinger type equation. We prove here that under a natural stability condition on the pressure, global well-posedness holds in dimension $d \geq 3$ for small irrotational initial data. The proof is based on a modified energy estimate, standard dispersive properties if $d \geq 5$, and a careful study of the nonlinear structure of the quadratic terms in dimensions 3 and 4 involving the theory of space time resonance.

7.4. Numerical methods for free-surface flows

7.4.1. A two-dimensional method for a dispersive shallow water model

Participants: Nora Aïssiouene, Marie-Odile Bristeau, Edwige Godlewski, Jacques Sainte-Marie.

We propose a numerical method for a two-dimensional dispersive shallow water system with topography. This model is a depth averaged Euler system and takes into account a non-hydrostatic pressure which implies to solve an incompressible system. From the variational formulation of the mixed problem proposed in [6], we apply a finite element method with compatible spaces to the two-dimensional problem on unstructured grids.

7.4.2. Numerical Discretization for Coriolis Effects

Participants: Emmanuel Audusse, Do Minh Hieu, Yohan Penel.

Efficient computations near the geostrophic equilibrium need to carefully design numerical schemes. This question is investigated in the context of colocated finite volume approach and extends previous works by Bouchut et al. [32], Dellacherie [35], Buet and Despres [36].

7.4.3. Optimization of topography

Participants: Sebastian Reyes-Riffo, Julien Salomon.

We work on a method to compute optimal topographies for wave-energy production. The first part of the work was devoted to the numerical analysis of the scheme used to simulate waves. In this way, we have obtained stability conditions that enable to couple it with an optimization loop.

7.4.4. An adaptive numerical scheme for solving incompressible two-phase and free-surface flows

Participant: Dena Kazerani.

We present a numerical scheme for solving two-phase or free surface flows. The interface/free surface is modelled using the level-set formulation. Besides, the mesh is anisotriopic and adapted at each iteration. The incompressible Navier–Stokes equations are temporally discretized using the method of characteristics and are solved at each time iteration by a first order Lagrange–Galerkin method. The level-set function representing the interface/free surface satisfies an advection equation which is also solved using the method of characteristics.

7.4.5. Propeler design

Participants: Jérémy Ledoux, Julien Salomon.

We work on a usual algorithm in propeler design: based on the so-called “Blade Element Momentum Theory”, this approach reduces the simulation to a 2D system by coupling the latter with a outer loop of low computational cost. So far, this method has not been analyzed mathematically, hence our interest.

7.5. Software developments and assessments

7.5.1. Improvements in the FRESHKISS3D code

Participants: Marie-Odile Bristeau, David Froger, Jacques Sainte-Marie, Fabien Souillé.

Several tasks have been achieved in the FRESHKISS3D software:

- Cython branch finalization (integration of second order in time and space numerical schemes)
- Project exportation on Gitlab.inria collaborative development platform
- New development tools set-up (Gitlab-ci, Git-lfs)
- Definition of new development rules and practices with gitlab
  - Use of the issue board
  - Review system and merge request rework
- Chlorides propagation in Vilaine river (Saur project)
  - Case definition in freshkiss3d
  - TracerSource class definition for floodgate modeling
  - VerticalDebit class definition for special boundary condition (siphon)
  - Simplified scenarios set-up (1day, 2days simulated)
  - First simulations and post processing
- New examples structure with introduction of two new cases to illustrate VerticalDebit and TracerSource class
- Various documentation updates

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

A contract has been made (120.000 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.

The ANR project Hyflo-Eflu relies on a collaboration with the company “HydroTube Energie”. It comprises the recruitment of a young engineer and regular meetings with industrial (Bordeaux) and academic partners (Nantes).

8.2. Bilateral Grants with Industry

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

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Plasticity of geophysical flows and seismic emissions (2013-2016)

Participant: Anne Mangeney.

This project is funded by Sorbonne Paris Cité (80.000 euros) and is a collaboration between IPGP and Univ. Paris 13.

9.1.2. LRC Manon (2014-2018)

Participants: Edwige Godlewski, Yohan Penel, Nicolas Seguin.

CEA and Laboratory Jacques-Louis Lions launched a collaboration in order to carry out studies about complex fluids (modelling, numerical simulations and optimisation), in particular about compressible two-phase flows. This includes the derivation of strategies for model coupling, for instance in the case of an asymptotic hierarchy of models.

9.2. National Initiatives

9.2.1. 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).

9.2.2. ANR Hyflo-Eflu (2016-2020)

Participants: Jérérmy 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 optimization, 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 horizontal 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.

9.2.3. CNRS CORSURF (2016)

Participants: Bernard Di Martino, Cindy Guichard, Anne Mangeney, Jacques Sainte-Marie.

CNRS project call: INSU-INSMI

Project acronym: CORSURF

Project title: COmplex Rheology SURface Flows

Coordinator: Cindy Guichard

In collaboration with E. Fernández-Nieto (Sevilla, Spain).

Geophysical flows like avalanches (mud, snow) or landslides involve surface flows with non-Newtonian fluids. The goal is to develop numerical models, both accurate with respect to the material behavior and industrially efficient.

9.2.4. CNRS MOCHA (2016)

Participant: Martin Parisot.

CNRS project call: PEPS

Project acronym: MOCHA

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

Coordinator: Martin Parisot

Multi-dimensionnal coupling in river hydrodynamics offers a convenient solution to properly model complex flow while limiting the computational cost and making the most of pre-existing models. The project aims to adapt the lateral interface coupling proposed in [37] to the implicit version and test it on real data for the Garonne River.

9.2.5. CNRS Moset (2016-2017)

Participants: Emmanuel Audusse, Martin Parisot.

CNRS project call: INSU Tellus

Project acronym: Moset

Project title: Modélisation des suspensions concentrées naturelles

Coordinator: Emmanuel Audusse

In collaboration with G. Antoine (EDF), S. Boyaval (LHSV), C. Le Bouteiller (Irstea), M. Jodeau (EDF).

Gathering mathematicians (numerical analysis) and geophysicists, this project focuses on the quantitative prediction of solid transport. This issue raises several questions about rheology when the sediment concentration is high enough. It is crucial for modelling the dynamics of suspension. The collaboration aims at assessing models by means of experimental data and at providing preliminary numerical results to evaluate the order of magnitude of constraints.

9.2.6. Inria Project Lab “Algae in Silico” (2015-2018)

Participants: Nora Aïssiouene, Marie-Odile Bristeau, David Froger, Yohan Penel, Jacques Sainte-Marie, Fabien Souille.

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”.

9.2.7. ANR MIMOSA (2014–2017)

Participants: Nora Aïssiouene, Marie-Odile Bristeau, Anne Mangeney, Bernard Di Martino, Jacques Sainte-Marie.

Program: ANR Défi 1 “Gestion sobre des ressources et adaptation au changement climatique”

Project acronym: MIMOSA

Project title: MIcroseism MOdeling and Seismic Applications

Coordinator: Eleonore Stutzmann (IPGP)

Seismic noise is recorded by broadband seismometers in the absence of earthquakes. It is generated by the atmosphere-ocean system with different mechanisms in the different frequency bands. Even though some mechanisms have been known for decades, an integrated understanding of the noise in the broadband period band 1-300sec is still missing. Using novel theoretical, numerical and signal processing methods, this project will provide a unified understanding of the noise sources and quantitative models for broadband noise. Conversely, we will be able to interpret seismic noise in terms of ocean wave properties. This first analysis step will lead to the identification and characterization of source events, which we will use to improve noise tomography, and seismic monitoring.

9.2.8. ANR LANDQUAKES (2012–2016)

Participant: Anne Mangeney.

Program: ANR Blanc “Mathématiques et interactions”

Project acronym: LANDQUAKES

Project title: Modélisation des glissements de terrain et des ondes sismiques générées pour détecter et comprendre les instabilités gravitaires

Coordinator: Anne Mangeney

Within the ANR domain “Mathematics and Interfaces”, this ANR project (between Univ. Paris-Est – LAMA, Univ. Denis Diderot Paris 7 – IPGP, Univ. Nantes – LPGN, Univ. Strasbourg EOST, 180.000 euros) deals with the mathematical and numerical modelling of landslides and generated seismic waves.

A. Mangeney is also involved in the CARIB ANR program (2014–2017) entitled “Comprendre les processus de construction et de destruction des volcans de l’Arc des Petites Antilles”.

9.2.9. GdR EGRIN (2013–2017)

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.

9.3. European Initiatives

9.3.1. 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.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

The collaboration with IMUS (Institute of Mathematics of the university of Sevilla, Spain) was informaly launched in 2016 through several visits in Spain of members of ANGE and the writing of a paper. To go further, a submission was made to create an Inria Associate Team.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

In the framework of the collaboration with researchers at the university of Sevilla (Spain), Enrique Fernández-Nieto spent two weeks (weeks n. 13 and 41) at Inria. IPGP hosted several researchers who work with A. Mangeney: Pere Roig (PhD, Departamento de Geodinámica i Geofísica, University of Barcelona, Spain), Giulia Bossi (postdoc, ETH, Zürich), Andrea Wolter and Margherita Spreafico (permanent positions, ETH, Zürich).

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Y. Penel spent three months (Jan.-Mar.) at the university of Sevilla (Spain) to collaborate with E. Fernández-Nieto.
- N. Aissiouene went to the university of Málaga for one month (Apr.) and was involved in the project EDANYA.
- C. Guichard, Y. Penel and J. Sainte-Marie were invited to the university of Sevilla for one week (week n. 42) to set up a forthcoming project.
- A. Mangeney went to Sevilla in November (week n. 47).

We also mention that M. Parisot spent one week (week n. 48) at the university of Toulouse (CERFACS).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

B. Di Martino, C. Guichard, A. Mangeney, Y. Penel and J. Sainte-Marie organised the workshop “Complex rheology for granular flows: challenges and deadlocks” that took place at IPGP on October 14th and that gathered 25 researchers.

M. Parisot organise’s the Working group (GdT) of the Ange team.

Moreover, L. Boittin co-organise’s the Junior Seminar at Inria–Paris.

10.1.2. Journal

10.1.2.1. Reviewer - Reviewing Activities

Member	Journal
E. Audusse	Advanced Water Resources, ESAIM:ProcS., SMAI Journal of Computational Mathematics
E. Godlewski	Computers and Fluids
C. Guichard	Numerische Mathematik, Mathematics and Computers in Simulation, Annali di Matematica Pura ed Applicata
B. Haspot	Analysis of PDE, JDE, JMAA, M3AS, ARMA, Siam Analysis, Mathematische Annalen, CMS, JFA, Acta Applicandae Mathematicae
A. Mangeney	J. Fluid Mech., J. Geophys. Res., Numeric. Analyt. Methods Geomech., Earth Surf. Processes and Landforms
M. Parisot	Continuum Mechanics and Thermodynamics, Hydrological Processes
Y. Penel	Hydrological Processes
J. Salomon	SIAM Journal on Numerical Analysis, M2AN, SIAM Journal of Scientific Computing
J. Sainte-Marie	M2AN, Nonlinearity, IJNMF, Applied mathematical modellling, Journal of Hydraulic Research, Computers and Fluids, European Journal of Applied Math, Numerische Mathematik

10.1.3. Invited Talks

Conference	Location	Month	Members involved
European Geosciences Union	Vienna (Austria)	April	A. Mangeney
Peril flood	Paris	May	M. Parisot
CANUM	Obernai	May	D. Kazerani
ECMI	Santiago de Compostela (Spain)	June	C. Guichard
CECAM	Lyon	June	A. Mangeney
Martian gullies and Earth analogues	London (UK)	June	A. Mangeney
Scientific computing and modelling	Amiens	June	J. Sainte-Marie
Asymptotic Behavior of systems of PDE	Lille	June	D. Kazerani
AIMS	Orlando (US)	July	N. Aissiouene
EGU FORM-OSE training school	Azores (Spain)	July	A. Mangeney
HYP	Aachen (Germany)	August	Y. Penel
Modelling of coastal hydrodynamics	Vannes	September	E. Audusse, J. Sainte-Marie
GDR Renewable marine energies	Nantes	October	J. Salomon
GDR Transnat	Roscoff	November	E. Audusse
Liquid-vapor interfaces in fluid flows	Paris	December	D. Kazerani

Seminars	Date	Member
IMUS (Sevilla, Spain)	February	Y. Penel
EDANYA (Málaga, Spain)	April	N. Aissiouene
Paris (LJLL)	May	M. Parisot
GIS HED[2]	June	D. Kazerani
Luminy (CEMRACS)	August	E. Audusse
Lille	September	M. Parisot

10.1.4. Leadership within the Scientific Community

Organisation	People	Duty
AMIES	E. Godlewski	Member of board
CFEM	E. Godlewski	Director
Comité d'Orientation Pour les Risques Naturels Majeurs du Ministère de l'Environnement	A. Mangeney	Member
EGRIN	E. Audusse B. di Martino N. Goutal C. Guichard A. Mangeney M. Parisot J. Sainte-Marie	Correspondent (Paris 13) Correspondent (Corse) Correspondent (EDF) Correspondent (UPMC) Member of board Correspondent (ANGE) Scientific head
HCERES	A. Mangeney	Expert
LJLL	E. Godlewski	Deputy director
Research commission of UPMC	D. Kazerani	Member
SMAI	Y. Penel	Member of board

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master's degree (M2) E. Godlewski and J. Sainte-Marie, Hyperbolic models for complex flows and energy applications, 25 hours (lectures), Univ. Pierre et Marie Curie Paris 6

Master's degree (M2) E. Godlewski, Numerical methods for nonstationary PDEs, 18 hours (example and programming classes), Univ. Pierre et Marie Curie Paris 6

Master's degree (M2) C. Guichard, Numerical methods for nonstationary PDEs, 6 hours (programming classes), Univ. Pierre et Marie Curie Paris 6

Master's degree (M2) H. Martin and J. Sainte-Marie, Numerical methods in fluid mechanics, 52 hours (lectures and programming classes), Univ. Paris Diderot Paris 7, IPGP

Master's degree (M2) B. Haspot, Linear partial differential equations, 15 hours (lectures), Univ. Paris Dauphine

Master's degree (M2) B. Di Martino, Mathematical modelling, 21 hours (lectures, example and programming classes), Univ. Corse

Master's degree (M2) J. Salomon, Scientific computing and numerical analysis, 30 hours (lectures, example and programming classes), Univ. Paris Dauphine

Engineering school (2nd year) E. Audusse, Hyperbolic systems, 30 hours (lectures and example classes), Univ. Paris 13

Engineering school (2nd year) E. Audusse, Finite difference method for PDEs, 30 hours (lectures and programming classes), Univ. Paris 13

Master's degree (M1) C. Guichard, Basis of numerical methods, 68 hours (programming classes), Univ. Pierre et Marie Curie Paris 6

Master's degree (M1) H. Martin and J. Sainte-Marie, Models in geosciences, 40 hours (lectures and programming classes), Univ. Paris Diderot Paris 7, IPGP

Master's degree (M1) B. Di Martino, Numerical methods, 27 hours (lectures and programming classes), Univ. Corse

Master's degree (M1) B. Di Martino, Mathematics, 33 hours (lectures, example and programming classes), Univ. Corse

Master's degree (M1) B. Haspot, Functional analysis, 85 hours (lectures and example classes), Univ. Paris Dauphine

Master's degree (M1) E. Godlewski, Numerical methods, 24 hours (lectures), Univ. Pierre et Marie Curie Paris 6

Engineering school (1st year) E. Audusse, Numerical analysis for differential equations, 30 hours (example classes), Univ. Paris 13

Bachelor's degree (L3) C. Guichard, Numerical linear algebra, 76.5 hours (example and programming classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L3) M. Parisot, Hilbert analysis, 30 hours (lectures and example classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L3) B. Di Martino, Numerical methods, 18 hours (lectures and programming classes), Univ. Corse

Bachelor's degree (L2) E. Audusse, Scientific computing, 36 hours (lectures), Univ. Paris 13

Bachelor's degree (L2) Y. Penel, Integration in 2 and 3 dimensions, 12 hours (lectures), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L1) F. Wahl, Linear algebra, 54 hours (example classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L1) F. Wahl, Analysis and algebra for sciences, 38.5 hours (example classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L1] E. Nayir, Mathematics, 72 hours (example classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L1) E. Godlewski and E. Nayir, Linear algebra, 48 hours (lectures and example classes), Univ. Pierre et Marie Curie Paris 6

Bachelor's degree (L1) L. Boittin, Calculus, 28 hours (example classes), Univ. Pierre et Marie Curie Paris 6

Some members are responsible of educational pathways:

- E. Audusse is the deputy director of the "Applied Mathematics and Scientific Computing" program of the SupGalilee engineering school.
- E. Godlewski is the head of the "Mathematics for Industry" M.Sc. program of Univ. Pierre et Marie Curie Paris 6.
- C. Guichard is the associated head of the "Mathematics and Programming" B. program of Univ. Pierre et Marie Curie Paris 6.
- A. Mangeney is the head of the "Telluric Natural Hazards" M. Sc. specialty of IPGP.

10.2.2. Supervision

PostDoc in progress El Hadji Kone, *Numerical modelling of shallow two-phase flows*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney, from 2016

PostDoc in progress Pierre-Olivier Lamarre, *Optimization of the hydrodynamic regime in a raceway and lagrangian trajectories of algae*, supervised by J. Sainte-Marie and N. Aïssiouene (in collaboration with O. Bernard, BIOCORE)

PhD Nora Aïssiouene, *Derivation and analysis of a non-hydrostatic Shallow water type model*, Univ. Pierre et Marie Curie Paris 6 (Inria grant), supervised by E. Godlewski and J. Sainte-Marie, defended on Dec. 16

PhD Dena Kazerani, *Simulation et modélisation de problèmes à frontière libre*, Univ. Pierre et Marie Curie Paris 6, supervised by N. Seguin (in collaboration with P. Frey and C. Audiard), defended on Nov. 16

PhD Clément Mifsud, *Analyse et approximation des systèmes de Friedrichs : application à la modélisation de l'élastoplasticité*, Univ. Pierre et Marie Curie Paris 6, supervised by N. Seguin (in collaboration with J.-F. Babadjian and B. Després), defended on Nov. 16

PhD Amandine Sergeant-Boy, *Detection and characterisation of seismic sources generated by glaciers: numerical modelling and analysis of seismic waves*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney (in collaboration with J.-P. Montagner, E. Stutzmann and O. Castelnau), defended on Nov. 16

PhD in progress Léa Boittin, *Modelling, analysis and efficient numerical resolution for erosion processes*, Univ. Pierre et Marie Curie Paris 6 (Inria grant), supervised by E. Audusse, M. Parisot and J. Sainte-Marie, from Jan. 16

PhD in progress Vincent Bachelet, *Granular flows and generated acoustic waves: a laboratory investigation*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney (in collaboration with J. De Rosny and R. Toussaint), from 2015

PhD in progress Do Minh Hieu, *Analyse mathématique et schémas volumes finis pour la simulation des écoulements quasi-géostrophiques à bas nombre de Froude*, Univ. Paris 13, supervised by E. Audusse and Y. Penel (in collaboration with S. Dellacherie and P. Omnes), from 2014

PhD in progress Virginie Durand, *Spatio-temporal measurement, analysis and simulation of gravitational flows and seismic signals*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney, from 2016

PhD in progress Julian Kühnert, *Simulation of high frequency seismic waves*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney, from 2016

PhD in progress Hugo Martin, *Simulation of the coupling between seismic waves and granular flows*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney (in collaboration with Y. Maday), from 2016

PhD in progress Hélène Miallot, *Numerical modelling of landquakes*, Institut de Physique du Globe (Univ. Paris 7), supervised by A. Mangeney (in collaboration with Y. Capdeville), from 2015

PhD in progress Ethem Nayir, *Approximation multi-vitesse des équations de Navier-Stokes hydrostatiques: Analyse mathématique et simulations numériques*, Univ. Pierre et Marie Curie Paris 6, supervised by E. Audusse, Y. Penel and J. Sainte-Marie, from 2014

PhD in progress Nourelhouda Omrane, *Mathematical analysis and control of free-surface flows in variable domains*, Univ. Corse, supervised by B. Di Martino, from 2016

PhD in progress Pierrick Quémar, *3D numerical simulations of environmental hydrolics: application to Telemac*, Univ. Paris 13, supervised by E. Audusse and N. Goutal (in collaboration with A. Decoene, O. Lafitte, A. Leroy and C. Tuân Phan), from 2016

PhD in progress Sebastian Reyes-Riffo, *Mathematical methods for recovering marine energies*, Univ. Paris Dauphine, supervised by J. Salomon, from 2016

PhD in progress Fabien Wahl, *Modelling and analysis of interactions between free surface flows and floating objects*, Univ. Pierre et Marie Curie Paris 6, supervised by C. Guichard, E. Godlewski, M. Parisot and J. Sainte-Marie, from 2015

M2 internship Marie Zehgdoudi, *Étude des flux de lave émis au Piton de la Fournaise à partir d'enregistrements sismiques*, IPGP, supervised by A. Mangeney, Summer 2016

L3 internship Albin Grataloup, *Perturbation theory applied to the shallow water equations*, Ecole Normale Supérieure de Lyon, supervised by E. Audusse and Y. Penel, Summer 2016

We also mention that N. Goutal and M. Parisot supervised a student during the 2016 session of CEMRACS during the summer.

10.2.3. Juries

Feb., PhD A. Mangeney (president): Antoine Frère (CEA, *Modélisation des tsunamis génér{es par écoulement gravitaire : application dans le golfe de Gascogne*)

Feb., PhD A. Mangeney (referee): Véronique Dansereau (Univ. Grenoble, *A Maxwell-Elasto-Brittle model for the drift of ice*)

July, PhD E. Godlewski: Khalil Haddaoui (Univ. Pierre et Marie Curie Paris 6, *Méthodes numériques de haute précision et calcul scientifique pour le couplage de modèles hyperboliques*)

Sept., PhD E. Godlewski (referee): Asma Toumi (Univ. Toulouse, *Méthode numérique asynchrone pour la modélisation de phénomènes multi-échelles*)

Oct., PhD E. Godlewski (referee): Hippolyte Lochon (Univ. Marseille, *Modélisation et simulation d'écoulements transitoires eau-vapeur en approche bi-fluide*)

Oct., PhD B. Di Martino (referee): Ralph Lteif (Univ. Chambéry, *Modélisation et analyse mathématique de modèles en océanographie*)

Nov., PhD J. Sainte-Marie (referee): Amina Nouhou-Bako (Univ. Orléans, *Modélisation numérique de l'érosion diffuse des sols. Interaction gouttes-ruissellement*)

Nov., PhD E. Godlewski and J. Sainte-Marie: Dena Kazerani (Univ. Pierre et Marie Curie Paris 6, *Études mathématiques de fluides à frontières libres en dynamique incompressible*)

Nov., PhD A. Mangeney: Amandine Sergeant-Boy (Univ. Paris 7, *Detection and characterisation of seismic sources generated by glaciers: numerical modelling and analysis of seismic waves*)

Nov., PhD A. Mangeney: Sébastien Lherminier (Univ. Lyon 1, *Dynamique des avalanches invariantes d'échelle*)

Dec., PhD E. Godlewski, A. Mangeney and J. Sainte-Marie: Nora Aïssiouene (Univ. Pierre et Marie Curie Paris 6, *A numerical method for a dispersive shallow water system*)

Dec., HdR J. Sainte-Marie: Carine Lucas (Univ. Orléans, *Analyse mathématique et numérique de quelques modèles d'érosion*)

M. Parisot participated to the intermediate evaluation of Cécile Taing's PhD thesis (Univ. Pierre et Marie Curie Paris 6). A. Mangeney was a member of the jury evaluating M2 internships at IPGP.

10.3. Popularization

March E. Audusse intervened in a middle school on the occasion of the French week of Maths. J. Salomon went to a high school at Limay.

May N. Aïssiouene, E. Audusse, E. Godlewski (organiser), Y. Penel and F. Wahl ran a stand on the occasion of the "salon de la culture et des jeux mathématiques".

July M. Parisot gave a vulgarisation talk at Inria ("demi-heure de la science").

October E. Audusse intervened in a high school on the occasion of Savantes Banlieues.

November E. Nayir, Y. Penel and F. Wahl ran a stand during the ONISEP exhibition.

December E. Godlewski managed a group of middle school students at the Jacques-Louis Lions lab.

December F. Wahl helped the organisation at the "Math. Employment" show.

A. Sergeant-Boy, A. Mangeney, E. Stutzmann, J.-P. Montagner, F. Walter, L. Moretti, and O. Castelnau wrote an article entitled "La sismologie pour ausculter les pertes des glaciers des calottes polaires, lors du vêlage d'icebergs" in the CNRS–INSU newspaper (Apr.).

A. Mangeney is coaching high-school students from disadvantaged areas to manage scientific projects.

11. Bibliography

Major publications by the team in recent years

[1] E. AUDUSSE, M.-O. BRISTEAU, M. PELANTI, J. SAINTE-MARIE. *Approximation of the hydrostatic Navier-Stokes system for density stratified flows by a multilayer model. Kinetic interpretation and numerical validation*, in "J. Comput. Phys.", 2011, vol. 230, pp. 3453-3478, http://dx.doi.org/10.1016/j.jcp.2011.01.042

[2] E. AUDUSSE, M.-O. BRISTEAU, B. PERTHAME, J. SAINTE-MARIE. *A multilayer Saint-Venant system with mass exchanges for Shallow Water flows. Derivation and numerical validation*, in "ESAIM Math. Model. Numer. Anal.", 2011, vol. 45, pp. 169-200, http://dx.doi.org/10.1051/m2an/2010036

[3] M.-O. BRISTEAU, B. DI MARTINO, C. GUICHARD, J. SAINTE-MARIE. *Layer-averaged Euler and Navier-Stokes equations*, Sep 2015, working paper or preprint, https://hal.inria.fr/hal-01202042

[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

Publications of the year

Doctoral Dissertations and Habilitation Theses

[5] N. AISSIOUENE. *Numerical analysis and discrete approximation of a dispersive shallow water model*, Pierre et Marie Curie, Paris VI, December 2016, https://hal.archives-ouvertes.fr/tel-01418676

Articles in International Peer-Reviewed Journals

[6] N. AISSIOUENE, M.-O. BRISTEAU, E. GODLEWSKI, J. SAINTE-MARIE. *A combined finite volume - finite element scheme for a dispersive shallow water system*, in "Networks and Heterogeneous Media (NHM)", January 2016, vol. 11, n° 1, pp. 1-27, https://hal.inria.fr/hal-01160718

[7] E. AUDUSSE, F. BOUCHUT, M.-O. BRISTEAU, J. SAINTE-MARIE. *Kinetic entropy inequality and hydrostatic reconstruction scheme for the Saint-Venant system*, in "Mathematics of Computation", November 2016, vol. 85, pp. 2815-2837 [*DOI :* 10.1090/MCOM/3099], https://hal.inria.fr/hal-01063577

[8] J.-F. BABADJIAN, C. MIFSUD, N. SEGUIN. *Relaxation approximation of Friedrich's systems under convex constraints*, in "Networks and Heterogeneous Media", 2016, vol. 11, n° 2, pp. 223 - 237 [*DOI :* 10.3934/NHM.2016.11.223], https://hal.archives-ouvertes.fr/hal-01157484

[9] F. BOUCHUT, I. R. IONESCU, A. MANGENEY. *An analytic approach for the evolution of the static/flowing interface in viscoplastic granular flows*, in "Communications in Mathematical Sciences", 2016, vol. 14, n° 8, pp. 2101-2126 [*DOI :* 10.4310/CMS.2016.V14.N8.A2], https://hal-upec-upem.archives-ouvertes.fr/hal-01081213

[10] C. CANCÈS, F. COQUEL, E. GODLEWSKI, H. MATHIS, N. SEGUIN. *Error analysis of a dynamic model adaptation procedure for nonlinear hyperbolic equations*, in "Communications in Mathematical Sciences", 2016, vol. 14, n° 1, pp. 1-30, https://hal.archives-ouvertes.fr/hal-00852101

[11] D. KAZERANI. *Global existence for small data of the viscous Green-Naghdi type equations*, in "Journal of Differential Equations", July 2016, vol. 261, n^{o} 1, pp. 762-796 [*DOI :* 10.1016/J.JDE.2016.03.022], https://hal.archives-ouvertes.fr/hal-01111941

[12] D. KAZERANI. *The symmetric structure of the Green-Naghdi type equations*, in "Communications in Mathematical Sciences", August 2016, vol. 14, n^{o} 7, pp. 1925-1946 [*DOI :* 10.4310/CMS.2016.V14.N7.A7], https://hal.archives-ouvertes.fr/hal-01074488

[13] M. LACHOWICZ, H. LESZCZYŃSKI, M. PARISOT. *A simple kinetic equation of swarm formation: blow–up and global existence*, in "Applied Mathematics Letters", January 2016 [*DOI :* 10.1016/J.AML.2016.01.008], https://hal.inria.fr/hal-01241998

[14] M. LACHOWICZ, M. PARISOT, Z. SZYMAŃSKA. *Intracellular protein dynamics as a mathematical problem*, in "Discrete and Continuous Dynamical Systems - Series B (DCDS-B)", February 2016, https://hal.inria.fr/hal-01152399

[15] C. MIFSUD, B. DESPRÉS, N. SEGUIN. *Dissipative formulation of initial boundary value problems for Friedrichs' systems*, in "Communications in Partial Differential Equations", January 2016, vol. 41, n^{o} 1 [*DOI :* 10.1080/03605302.2015.1103750], https://hal.archives-ouvertes.fr/hal-01074542

[16] M. PARISOT, M. LACHOWICZ. *A Kinetic Model for the formation of Swarms with nonlinear interactions*, in "Kinetic and Related Models ", March 2016, vol. 9, n^{o} 1, 33 p. [*DOI :* 10.3934/KRM.2016.9.131], https://hal.inria.fr/hal-01152397

[17] M. PARISOT, J.-P. VILA. *Centered-potential regularization for the advection upstream splitting method*, in "SIAM Journal on Numerical Analysis", 2016, https://hal.inria.fr/hal-01152395

Other Publications

[18] N. AISSIOUENE, T. AMTOUT, M. BRACHET, E. FRÉNOD, R. HILD, C. PRUD 'HOMME, A. ROUSSEAU, S. SALMON. *Hydromorpho: A coupled model for unsteady Stokes/Exner equations and numerical results with Feel++ library*, February 2016, working paper or preprint, https://hal.inria.fr/hal-01266223

[19] E. AUDUSSE, C. CHALONS, P. UNG. *A simple three-wave Approximate Riemann Solver for the Saint-Venant–Exner equations*, August 2016, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01204754

[20] M.-O. BRISTEAU, D. FROGER, R. HAMOUDA, A. MANGENEY, J. SAINTE-MARIE, M. VALLÉE. *Numerical simulations of 3d hydrostatic Navier-Stokes system with free surface*, November 2016, working paper or preprint, https://hal.inria.fr/hal-01393147

[21] C. CANCÈS, C. GUICHARD. *Numerical analysis of a robust free energy diminishing Finite Volume scheme for parabolic equations with gradient structure*, 2016, to appear in Foundations of Computational Mathematics, https://hal.archives-ouvertes.fr/hal-01119735

[22] B. DI MARTINO, B. HASPOT, Y. PENEL. *Global stability of weak solutions for a multilayer Saint-Venant model with interactions between the layers*, December 2016, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01407886

[23] J. DRONIOU, R. EYMARD, T. GALLOUËT, C. GUICHARD, R. HERBIN. *The gradient discretisation method : A framework for the discretisation and numerical analysis of linear and nonlinear elliptic and parabolic problems*, November 2016, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01382358

[24] R. EYMARD, P. FERON, C. GUICHARD. *Family of convergent numerical schemes for the incompressible Navier-Stokes equations*, October 2016, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01382924

[25] E. D. FERNANDEZ-NIETO, M. PARISOT, Y. PENEL, J. SAINTE-MARIE. *Layer-averaged approximations for inviscid flow models*, June 2016, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01324012

[26] E. GODLEWSKI, M. PARISOT, J. SAINTE-MARIE, F. WAHL. *Congested shallow water type model : roof modelling in free surface flow*, September 2016, working paper or preprint, https://hal.inria.fr/hal-01368075

[27] M. LACHOWICZ, H. LESZCZYŃSKI, M. PARISOT. *Blow-up and global existence for a kinetic equation of swarm formation*, 2016, working paper or preprint, https://hal.inria.fr/hal-01370006

[28] C. LUSSO, F. BOUCHUT, A. ERN, A. MANGENEY. *A free interface model for static/flowing dynamics in thin-layer flows of granular materials with yield: simple shear simulations and comparison to experiments*, December 2016, working paper or preprint, https://hal-upec-upem.archives-ouvertes.fr/hal-00992309

[29] C. LUSSO, F. BOUCHUT, A. ERN, A. MANGENEY. *Explicit solutions to a free interface model for the static/flowing transition in thin granular flows*, August 2016, working paper or preprint, https://hal-upec-upem.archives-ouvertes.fr/hal-01180686

[30] C. LUSSO, A. ERN, F. BOUCHUT, A. MANGENEY, M. FARIN, O. ROCHE. *Two-dimensional simulation by regularization of free surface viscoplastic flows with Drucker-Prager yield stress and application to granular collapse*, December 2016, working paper or preprint [*DOI :* 10.1016/J.JCP.2016.12.036], https://hal-upec-upem.archives-ouvertes.fr/hal-01133786

References in notes

[31] E. AUDUSSE. *A multilayer Saint-Venant model : Derivation and numerical validation*, in "Discrete Contin. Dyn. Syst. Ser. B", 2005, vol. 5, n^{o} 2, pp. 189-214

[32] F. BOUCHUT, J. SOMMER, V. ZEITLIN. *Frontal geostrophic adjustment and nonlinear wave phenomena in one-dimensional rotating shallow water. part 2. high-resolution numerical simulations*, in "J. Fluid Mech.", 2004, vol. 514, pp. 35–63

[33] F. BOUCHUT, V. ZEITLIN. *A robust well-balanced scheme for multi-layer shallow water equations*, in "Discrete Contin. Dyn. Syst. Ser. B", 2010, vol. 13, pp. 739-758

[34] M. CASTRO, J. GARCÍA-RODRÍGUEZ, J. GONZÁLEZ-VIDA, J. MACÍAS, C. PARÉS, M. VÁZQUEZ-CENDÓN. *Numerical simulation of two-layer shallow water flows through channels with irregular geometry*, in "J. Comput. Phys.", 2004, vol. 195, n^{o} 1, pp. 202–235

[35] S. DELLACHERIE. *Analysis of Godunov type schemes applied to the compressible Euler system at low Mach number*, in "J. Comput. Phys.", 2010, vol. 229, n^{o} 4, pp. 978–1016

[36] B. DESPRÉS, C. BUET. *The structure of well-balanced schemes for Friedrichs systems with linear relaxation*, in "Appl. Math. Comput.", 2016, vol. 272, pp. 440–459

[37] N. GOUTAL, M. PARISOT, F. ZAOUI. *A 2D reconstruction for the transverse coupling of shallow water models*, in "Int. J. Numer. Methods Fluids", 2014, vol. 75, n^{o} 11, pp. 775–799