Activity Report 2016

Team LEMON

Littoral, Environnement : Méthodes et Outils Numériques

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Earth, Environmental and Energy Sciences

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Team LEMON

Creation of the Team: 2014 January 01

The team is located in Montpellier.

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1. Members

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2. Overall Objectives

2.1. Context

Coastal zones are the theatre for numerous interfaces. The main elements that come to mind are the sea/earth interface, saline/brackish/fresh water interfaces and sediment/biological world interfaces. These elements cause most of the phenomena met within coastal zones to be in fragile equilibrium or more often, in constant evolution. This is due to the evolving external pressures, such as anthropic activity or physical forces (tectonic features, tide, precipitations, storms, sea level rise, sediment transport, etc.). In order to illustrate the considerable importance of such a research project, let us underline the following figures:

- **60 % of the world population lives in a 100km wide coastal strip** (80% within 30km in Brittany),
- **current sea level rise** has occurred at a mean rate of 1.8 mm per year for the past century, and more recently at rates estimated near 2.8 ± 0.4 to 3.1 ± 0.7 mm per year (1993-2003). It is likely to rise in the future: IPCC recently anticipated a 1.5m sea level rise within the next century,

It results that **coastal management** requires the development of theoretical and applied models to facilitate the **decision process**. For example, a city that wants to develop a harbour needs to anticipate the time-evolution of urban floods. The construction of defense barriers to protect buildings and houses from natural hazards relies on the knowledge of potential submersion events, in a period where the impact of global climatic and anthropic changes on the coastal zone is expected to generate increased coastal risks (IPCC 2007 and 2013). One also needs to analyze *"what if"* scenarios for proposed changes in land use or land cover in coastal regions (such as French Mont Saint-Michel).
As a matter of fact, the software packages available for engineering applications are usually not satisfactory. More specifically, some modeling hypotheses (such as the hydrostatic approximation) should be weakened, and more appropriate numerical schemes should be implemented. What is proposed with LEMON is to **increase the quality of coastal engineering numerical tools**, thanks to better designed mathematical and numerical models.

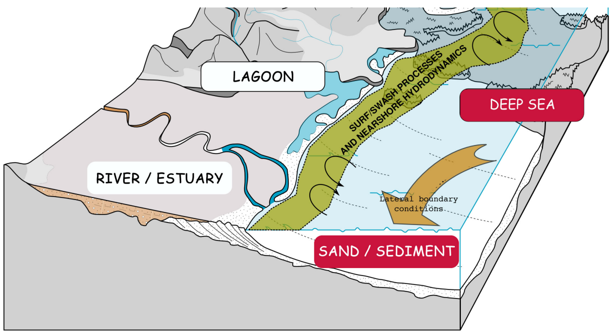

Figure 1. Examples of interacting nearshore processes. Courtesy F. Bouchette.

The mathematical modeling of the phenomena occurring within coastal zones and their interactions is currently a major scientific issue. If we want to model coastal zones, we have to consider the fact that they cover a very wide range of situations and that they are the result of several complex interacting phenomena (see Figure 1). More specifically, many time scales and space scales are involved and many physical and biological phenomena are in action. Moreover, within each zone, specific interactions between those phenomena make it an almost unique situation. Hence, we are far from having a database aggregating every possible situation. Modeling complex phenomena with the objective of building and improving management/decision tools requires the interaction of several models, each of them being dedicated to the simulation of a specific process. Such (mathematical and numerical) models usually exist but scarcely interact: therefore there is a need to understand how these bricks can be modified (forcing terms, boundary conditions) in order to be assembled. It will require a dialog with specialists of the application domain (geophysics, mechanical engineering, biology, hydrology, etc.) to help to develop new mathematical and numerical models for coastal engineering.
Developing more accurate and/or less CPU demanding models and coupling them together, LEMON will have a strong impact in the applications targeted and in coastal management.

3. Research Program

3.1. State of the Art

3.1.1. Shallow Water Models

Shallow Water (SW) wave dynamics and dissipation represent an important research field. This is because shallow water flows are the most common flows in geophysics. In shallow water regions, dispersive effects (non-hydrostatic pressure effects related to strong curvature in the flow streamlines) can become significant and affect wave transformations. The shoaling of the wave (the "steepening" that happens before the breaking) cannot be described with the usual Saint-Venant equations. To model such various evolutions, one has to use more sophisticated models (Boussinesq, Green-Naghdi...). Nowadays, the classical Saint-Venant equations can be solved numerically in an accurate way, allowing the generation of bores and the shoreline motion to be handled, using recent finite-volume or discontinuous-Galerkin schemes. In contrast, very few advanced works regarding the derivation and modern numerical solution of dispersive equations [23], [27], [56] are available in one dimensions, let alone in the multidimensional case. We can refer to [55], [30] for some linear dispersive equations, treated with finite-element methods, or to [27] for the first use of advanced high-order compact finite-volume methods for the Serre equations. Recent work undertaken during the ANR MathOCEAN [23] lead to some new 1D fully nonlinear and weakly dispersive models (Green-Naghdi like models) that allow to accurately handle the nonlinear waves transformations. High order accuracy numerical methods (based on a second-order splitting strategy) have been developed and implemented, raising a new and promising 1D numerical model. However, there is still a lack of new development regarding the multidimensional case.
In shallow water regions, depending on the complex balance between non-linear effects, dispersive effects and energy dissipation due to wave breaking, wave fronts can evolve into a large range of bore types, from purely breaking to purely undular bore. Boussinesq or Green-Naghdi models can handle these phenomena [21] . However, these models neglect the wave overturning and the associated dissipation, and the dispersive terms are not justified in the vicinity of the singularity. Previous numerical studies concerning bore dynamics using depth-averaged models have been devoted to either purely broken bores using NSW models [24], or undular bores using Boussinesq-type models [34]. Let us also mention [32] for tsunami modeling and [31], [43] for the dam-break problem. A model able to reproduce the various bore shapes, as well as the transition from one type of bore to another, is required. A first step has been made with the one-dimensional code [23], [53]. The SWASH project led by Zijlema at Delft [56] addresses the same issues.

3.1.2. Open boundary conditions and coupling algorithms

For every model set in a bounded domain, there is a need to consider boundary conditions. When the boundaries correspond to a modeling choice rather than to a physical reality, the corresponding boundary conditions should not create spurious oscillations or other unphysical behaviour at the artificial boundary. Such conditions are called **open boundary conditions** (OBC). They have been widely studied by applied mathematicians since the pionneering work of [33] on transparent boundary conditions. Deep studies of these operators have been performed in the case of linear equations, [38], [22], [50]. Unfortunately, in the case of geophysical fluid dynamics, this theory leads to nonlocal conditions (even in linear cases) that are not usable in numerical models. Most of current models (including high quality operational ones) modestly use a *no flux* condition (namely an homogeneous Neumann boundary condition) when a free boundary condition is required. But in many cases, Neumann homogeneous conditions are a very poor approximation of the exact transparent conditions. Hence the need to build higher order approximations of these conditions that remain numerically tractable.

Numerous physical processes are involved in coastal modeling, each of them depending on others (surface winds for coastal oceanography, sea currents for sandbars dynamics, etc.). Connecting two (or more) model solutions at their interface is a difficult task, that is often addressed in a simplified way from the mathematical viewpoint: this can be viewed as the one and only iteration of an iterative process. This results with a low quality coupled system, which could be improved either with additional iterations, and/or thanks to the improvement of interface boundary conditions and the use of OBC (see above). Promising results have been obtained in the framework of **ocean-atmosphere coupling** (in a simplified modeling context) in [44], where the use of advanced coupling techniques (based on domain decomposition algorithm) are introduced.

3.1.3. A need for upscaled shallow water models.

The mathematical modeling of **fluid-biology** coupled systems in lagoon ecosystems requires one or several water models. It is of course not necessary (and not numerically feasible) to use accurate non-hydrostatic turbulent models to force the biological processes over very long periods of time. There is a compromise to be reached between accurate (but untractable) fluid models such as the Navier-Stokes equations and simple (but imprecise) models such as [35].

In urbanized coastal zones, upscaling is also a key issue. This stems not only from the multi-scale aspects dealt with in the previous subsection, but also from modeling efficiency considerations.

The typical size of the relevant hydraulic feature in an urban area is between 0.1 m and 1.0 m, while the size of an urban area usually ranges from 10^3 m to 10^4 m. Refined flow computations (e.g. in simulating the impact of a tsunami) over entire coastal conurbations using a 2D horizontal model thus require 10^6 to 10^9 elements. From an engineering perspective, this makes both the CPU and man-supervised mesh design efforts unaffordable in the present state of technology.

Upscaling provides an answer to this problem by allowing macroscopic equations to be derived from the small-scale governing equations. The powerful, multiple scale expansion-based homogeneization technique [20], [19], [49] has been applied successfully to flow and transport upscaling in porous media, but its use is subordinated to the stringent assumptions of (i) the existence of a Representative Elementary Volume (REV), (ii) the scale separation principle, and (iii) the process is not purely hyperbolic at the microscopic scale, otherwise precluding the study of transient solutions [20]. Unfortunately, the REV has been shown recently not to exist in urban areas [37]. Besides, the scale separation principle is violated in the case of sharp transients (such as tsunami waves) impacting urban areas because the typical wavelength is of the same order of magnitude as the microscopic detail (the street/block size). Moreover, 2D shallow water equations are essentially hyperbolic, thus violating the third assumption.

These hurdles are overcome by averaging approaches. Single porosity-based, macroscopic shallow water models have been proposed [29], [36], [39] and applied successfully to urban flood modeling scale experiments [36], [45], [52]. They allow the CPU time to be divided by 10 to 100 compared to classical 2D shallow water models. Recent extensions of these models have been proposed in the form of integral porosity [51] and multiple porosity [37] shallow water models.

3.2. Scientific Objectives

Our main challenge is: build and couple elementary models in coastal areas to improve their capacity to simulate complex dynamics. This challenge consists of three principal scientific objectives. First of all, each of the elementary models has to be consistently developed (regardless of boundary conditions and interactions with other processes). Then open boundary conditions (for the simulation of physical processes in bounded domains) and links between the models (interface conditions) have to be identified and formalized. Finally, models and boundary conditions (*i.e.* coupled systems) should be proposed, analyzed and implemented in a common platform.

3.2.1. Single process models and boundary conditions

The time-evolution of a water flow in a three-dimensional computational domain is classically modeled by Navier-Stokes equations for incompressible fluids. Depending on the physical description of the considered domain, these equations can be simplified or enriched. Consequently, there are **numerous water dynamics models** that are derived from the original Navier-Stokes equations, such as primitive equations, shallow water equations (see [28]), Boussinesq-type dispersive models [21]), etc. The aforementioned models have **very different mathematical natures**: hyperbolic *vs* parabolic, hydrostatic *vs* non-hydrostatic, inviscid *vs* viscous, etc. They all carry nonlinearities that make their mathematical study (existence, uniqueness and regularity of weak and/or strong solutions) highly challenging (not to speak about the $1M Clay competition for the 3D Navier Stokes equations, which may remain open for some time).

The objective is to focus on the mathematical and numerical modeling of models adapted to **nearshore dynamics**, accounting for complicated wave processes. There exists a large range of models, from the shallow water equations (eventually weakly dispersive) to some fully dispersive deeper models. All these models can be obtained from a suitable asymptotic analysis of the water wave equations (Zakharov formulation) and if the theoretical study of these equations has been recently investigated [42], there is still some serious numerical challenges. So we plan to focus on the derivation and implementation of robust and high order discretization methods for suitable two dimensional models, including enhanced fully nonlinear dispersive models and fully dispersive models, like the Matsuno-generalized approach proposed in [41]. Another objective is to study the shallow water dispersive models without any irrotational flow assumption. Such a study would be of great interest for the study of nearshore circulation (wave induced rip currents).

For obvious physical and/or computational reasons, our models are set in bounded domains. Two types of boundaries are considered: physical and mathematical. Physical boundaries are materialized by an existing interface (atmosphere/ocean, ocean/sand, shoreline, etc.) whereas mathematical boundaries appear with the truncation of the domain of interest. In the latter case, **open boundary conditions** are mandatory in order not to create spurious reflexions at the boundaries. Such boundary conditions being nonlocal and impossible to use in practice, we shall look for approximations. We shall obtain them thanks to the asymptotic analysis of the (pseudo-differential) boundary operators with respect to small parameters (viscosity, domain aspect ratio, Rossby number, etc.). Naturally, we **will seek the boundary conditions leading to the best compromise** between mathematical well-posedness and physical consistency. This will make extensive use of the mathematical theory of **absorbing operators** and their approximations [33].

3.2.2. Coupled systems

The Green-Naghdi equations provide a correct description of the waves up to the breaking point while the Saint-Venant equations are more suitable for the description of the surf zone (i.e. after the breaking). Therefore, the challenge here is first to **design a coupling strategy** between these two systems of equations, first in a simplified one-dimensional case, then to the two-dimensional case both on cartesian and unstructured grids. High order accuracy should be achieved through the use of flexible Discontinuous-Galerkin methods.

Additionally, we will couple our weakly dispersive shallow water models to other fully dispersive deeper water models. We plan to mathematically analyze the coupling between these models. In a first step, we have to understand well the mixed problem (initial and boundary conditions) for these systems. In a second step, these new mathematical development have to be embedded within a numerically efficient strong coupling approach. The deep water model should be fully dispersive (solved using spectral methods, for instance) and the shallow-water model will be, in a first approach, the Saint-Venant equations. Then, when the 2D extension of the currently developped Green-Naghdi numerical code will be available, the improved coupling with a weakly dispersive shallow water model should be considered.

In the context of Schwarz relaxation methods, usual techniques can be seen as the first iteration (not converged) of an iterative algorithm. Thanks to the work performed on efficient boundary conditions, we shall **improve the quality of current coupling algorithms**, allowing for qualitatively satisfying solutions **with a reduced computational cost** (small number of iterations).
We are also willing to explore the role of geophysical processes on some biological ones. For example, the design of optimal shellfish farms relies on confinement maps and plankton dynamics, which strongly depend on long-time averaged currents. Equations that model the time evolution of species in a coastal ecosystem are relatively simple from a modeling viewpoint: they mainly consist of ODEs, and possibly advection-diffusion equations. The issue we want to tackle is the choice of the fluid model that should be coupled to them, accounting for the important time scales discrepancy between biological (evolution) processes and coastal fluid dynamics. Discrimination criteria between refined models (such as turbulent Navier-Stokes) and cheap ones (see [35]) will be proposed.

Coastal processes evolve at very different time scales: atmosphere (seconds/minutes), ocean (hours), sediment (months/years) and species evolution (years/decades). Their coupling can be seen as a *slow-fast* dynamical system, and a naïve way to couple them would be to pick the smallest time-step and run the two models together: but the computational cost would then be way too large. Consequently **homogenization techniques or other upscaling methods** should be used in order to account for these various time scales at an affordable computational cost. The research objectives are the following:

- So far, the proposed upscaled models have been validated against theoretical results obtained from refined 2D shallow water models and/or very limited data sets from scale model experiments. The various approaches proposed in the literature [25], [26], [29], [36], [37], [39], [45], [51], [52] have not been compared over the same data sets. Part of the research effort will focus on the extensive validation of the models on the basis of scale model experiments. Active cooperation will be sought with a number of national and international Academic partners involved in urban hydraulics (UCL Louvain-la-Neuve, IMFS Strasbourg, Irvine University California) with operational experimental facilities.
- Upscaling of source terms. Two types of source terms play a key role in shallow water models: geometry-induced source terms (arising from the irregular bathymetry) and friction/turbulence-induced energy loss terms. In all the upscaled shallow water models presented so far, only the large scale effects of topographical variations have been upscaled. In the case of wetting/drying phenomena and small depths (e.g. the *Camargue* tidal flats), however, it is forseen that subgrid-scale topographic variations may play a predominant role. Research on the integration of subgrid-scale topography into macrosocopic shallow water models is thus needed. Upscaling of friction/turbulence-induced head loss terms is also a subject for research, with a number of competing approaches available from the literature [36], [37], [51], [54].
- Upscaling of transport processes. The upscaling of surface pollutant transport processes in the urban environment has not been addressed so far in the literature. Free surface flows in urban areas are characterized by strongly variable (in both time and space) flow fields. Dead/swirling zones have been shown to play a predominant role in the upscaling of the flow equations [37], [51]. Their role is expected to be even stronger in the upscaling of contaminant transport. While numerical experiments indicate that the microscopic hydrodynamic time scales are small compared to the macroscopic time scales, theoretical considerations indicate that this may not be the case with scalar

transport. Trapping phenomena at the microscopic scale are well-known to be upscaled in the form of fractional dynamics models in the long time limit [40], [47]. The difficulty in the present research is that upscaling is not sought only for the long time limit but also for all time scales. Fractional dynamics will thus probably not suffice to a proper upscaling of the transport equations at all time scales.

3.2.3. Numerical platform

As a long term objective, the team shall create a common architecture for existing codes, and also the future codes developed by the project members, to offer a simplified management of various evolutions and a single and well documented tool for our partners. It will aim to be self-contained including pre and post-processing tools (efficient meshing approaches, GMT and VTK libraries), but must of course also be opened to user's suggestions, and account for existing tools inside and outside Inria. This numerical platform will be dedicated to the simulation of all the phenomena of interest, including flow propagation, sediment evolution, model coupling on large scales, from deep water to the shoreline, including swell propagation, shoaling, breaking and run-up. This numerical platform clearly aims at becoming a reference software in the community. It should be used to **develop a specific test case** around Montpellier which embeds many processes and their mutual interactions: from the *Camargue* (where the Rhône river flows into the Mediterranean sea) to the *Étang de Thau* (a wide lagoon where shellfishes are plentiful), **all the processes studied in the project occur in a 100km wide region**, including of course the various hydrodynamics regimes (from the deep sea to the shoaling, surf and swash zones) and crucial morphodynamic issues (*e.g.* in the town of Sete).

4. Application Domains

4.1. Coastal Oceanography

Participants: Fabien Marche, Antoine Rousseau.

Saint-Venant and Boussinesq equations have been widely applied until recently to model and simulate the propagation and transformations of waves in the nearshore area, over rapidly varying topography. However, the first equations do not include dispersive effects, and consequently have a domain of validity limited to the surf zone. The second set of equations overcome the limitations of the SV equations but relies on a "small amplitude assumption" and is therefore unable to model the whole range of waves transformations. This is the reason why they are usually called "weakly nonlinear Boussinesq equations". A better suited set of equations is known as the Green-Naghdi equations, but until recently, they have received far less attention, both from the theoretical and numerical point of view. In particular, there is no available numerical method of arbitrary ordre for 2d simulations on unstructured meshes. Additionally, the construction of rigorous positive preserving schemes is a paramount for the study of waves run-up.

4.2. Urban Floods

Participants: Carole Delenne, Vincent Guinot, Antoine Rousseau.

Floods have been identified by the National Accounting Authority (Cour des Comptes) to represent up to 1% of the GNP in terms of damage cost. For crisis management purposes, modeling urban floods at the scale of the conurbation is highly desirable. This however cannot be achieved in the current state of technology because of the meshing and computational cost (up to one billion cells being needed to mesh an entire urban area). This can be overcome by upscaling the shallow water equations so as to obtain large scale models that can operate three orders of magnitude faster than refined 2D models. Various upscaled versions of the upscaled 2D Shallow Water Equations have been proposed in the literature, some of which by members of the Lemon team. Further developments are being carried out, including the subgrid-scale description of topography variations and a better representation of energy dissipation terms. Laboratory experiments are also needed to discriminate between the various existing models.

4.3. River Hydraulics

Participants: Vincent Guinot, Antoine Rousseau.

Shallow Water (SW) models are widely used for the numerical modeling of river flows. Depending on the geometry of the domain, of the flow regime, and of required accuracy, either 1D or 2D SW models are implemented. It is thus necessary to couple 1D models with 2D models when both models are used to represent different portions of the same river. Moreover, when a river flows into the sea/ocean (e.g. the Rhône river in the Mediterranean), one may need to couple a 2D SW with a full 3D model (such as the Navier-Stokes equations) of the estuary. These issues have been widely addressed by the river-engineering community, but often with somehow crude approaches in terms of coupling algorithms. This may be improved thanks to more advanced boundary conditions, and with the use of Schwarz iterative methods for example.

5. Highlights of the Year

5.1. Highlights of the Year

- Antoine ROUSSEAU spent 9 months in the office of Inria Chile (Santiago, Chile) from February to October 2016 to collaborate on the new project on *Marine Energies Research International Center* (MERIC) in Chile. Antoine is the scientific coordinator of the research line “Advanced modeling for marine energy”, and several members of LEMON, CARDAMOM and TOSCA research teams will be involved in this 8 years project in partnership with DCNS and Enel.

6. New Software and Platforms

6.1. TsunamiLab

Participant: Antoine Rousseau.

Tsunami-Lab is an educational platform enabling simulation and visualization of tsunami effects in real time, with several historical scenarios and the possibility to build your own one. The target of this project is to provide students as well as general audience with an educational tool, intended to reduce tsunamis impact in Chile and help sparing human lives.
Tsunami-Lab was initated by José Galaz, engineer in mathematics and civil ingeneering, when he was working at the National Research Center for Integrated Gestion of Natural Hazards (CIGIDEN). The app is born with the match of a need - teach general audience more efficient methods to decrease tsunamis impact and spare human lives - and the use of new technologies. Later, a collaboration came up between CIGIDEN, Inria Chile and Inria (team LEMON) in order to optimize this project development.

- Participant: Antoine Rousseau
- Contact: José Galaz, jdgalazm@gmail.com
- URL: https://tsunamilab.inria.fr/

6.2. SW2D

Participants: Carole Delenne, Vincent Guinot.

Urban floods are usually simulated using two-dimensional shallow water models. A correct representation of the urban geometry and hydraulics would require that the average computational cell size be between 0.1 m and 1 m. The meshing and computation costs make the simulation of entire districts/conurbations impracticable in the current state of computer technology.

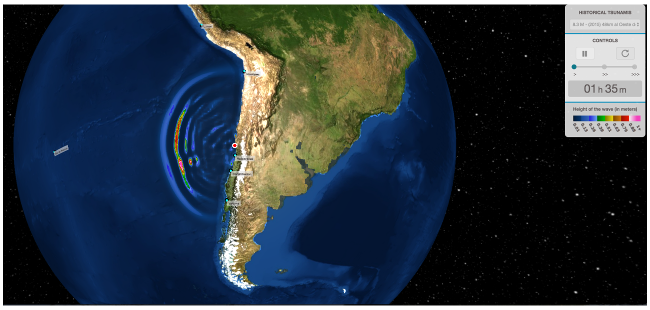

Figure 2. Propagation of a tsunami wave created by the a 8.3M earthquake in Chile (2015) using the TsunamiLab platform.

An alternative approach consists in upscaling the shallow water equations using averaging techniques. This leads to introducing storage and conveyance porosities, as well as additional source terms, in the mass and momentum balance equations. Various versions of porosity-based shallow water models have been proposed in the literature. The Shallow Water 2 Dimensions (SW2D) computational code embeds various finite volume discretizations of these models. Ituses fully unstructured meshes with arbitrary numbers of edges. The key features of the models and numerical techniques embedded in SW2D are

- specific momentum/energy dissipation models that are active only under transient conditions. Such models, that are not present in classical shallow water models, stem from the upscaling of the shallow water equations and prove essential in modeling the features of fast urban flow transients accurately
- three different closure relationships between the averaged flow variables and porosity-based fluxes
- modified HLLC solvers for an improved discretization of the momentum source terms stemming from porosity gradients
- higher-order reconstruction techniques that allow for faster and more stable calculations in the presence of wetting/drying fronts.
- Contact: Vincent Guinot
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6.3. WindPoS

Participant: Antoine Rousseau.

The computation of the wind at small scale and the estimation of its uncertainties is of particular importance for applications such as wind energy resource estimation. To this aim, starting in 2005, we have developed a new method based on the combination of an existing Numerical Weather Prediction model providing a coarse prediction, and a Lagrangian Stochastic Model for turbulent flows. This Stochastic Downscaling Method (SDM) requires a specific modeling of the turbulence closure, and involves various simulation techniques whose combination is totally original (such as Poisson solvers, optimal transportation mass algorithm, original Euler scheme for confined Langevin stochastic processes, and stochastic particle methods).

In 2013, WindPoS became the kernel of the wind farm modeling of the Fundacion Inria Chile. In France, its development is going on through the collaborative Modéol project on the evaluation of wind potential.

This is a joint work with Mireille Bossy from the team TOSCA.

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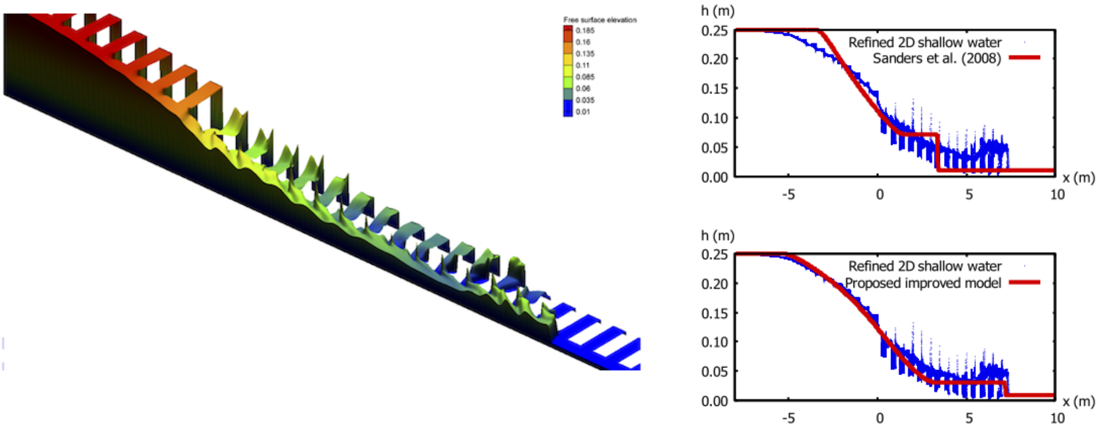

Figure 3. Propagation of a flood wave into a channel with lateral storage. Refined 2D simulation using the SW2D computational code

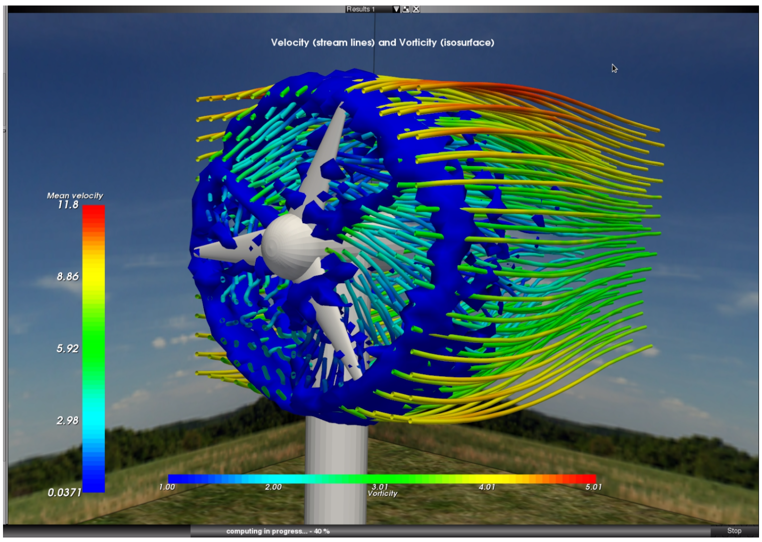

Figure 4. Velocity streamlines and vorticity around a wind mill (artistic view). WINDPOS Project.

7. New Results

7.1. Ocean modeling

Participants: Fabien Marche, Antoine Rousseau.

7.1.1. A first discrete formulation for Green-Naghdi equations on unstructured general meshes

We introduce in [17] the first numerical method available in the literature to approximate the solutions of the Green-Naghdi equations on fairly general unstructured meshes. The method relies on coupled elliptic and hyperbolic problems, the first one accounting for a dispersive correction of the free surface flow description provided by the second one, and on discontinuous polynomial approximations of arbitrary order and the construction of discrete differential operators suitable for such non-conforming approximations. It allows to handle general meshes and nonconforming interfaces. A nonlinear stability result is proved, together with the preservation at the discrete level of motionless steady states. Several test cases highlight the accuracy of this discrete formulation.

7.1.2. Quasi-hydrostatic ocean models

In [9], we work on nontraditional models where the so-called traditional approximation on the Coriolis force is removed. In the derivation of the quasi-geostrophic equations, we obtain new terms in δ/ε, where the domain aspect ratio and the Rossby number are both small numbers. We provide here some rigorous crossed-asymptotics with regards to these parameters , prove some mathematical and physical results on the nontraditional models, and situate them among traditional ones. This was also published as lecture notes given by Antoine ROUSSEAU in 2014: see [8].

7.1.3. Interface conditions for ocean models

In [4] we are interested in the search of interface conditions to couple hydrostatic and nonhydrostatic ocean models. To this aim, we consider simplified systems and use a time discretization to handle linear equations. We recall the links between the two models (with the particular role of the aspect ratio $\delta = H/L$) and introduce an iterative method based on the Schwarz algorithm (widely used in domain decomposition methods). The convergence of this method depends strongly on the choice of interface conditions: this is why we look for exact absorbing conditions and their approximations in order to provide tractable and efficient coupling algorithms.
In [3] we present a study of optimized Schwarz domain decomposition methods for Navier-Stokes equations. Once discretized in time, optimal transparent boundary conditions are derived for the resulting Stokes equations, and a series of local approximations for these nonlocal conditions are proposed. Their convergence properties are studied, and numerical simulations are conducted on the test case of the driven cavity. It is shown that conditions involving one or two degrees of freedom can improve the convergence properties of the original algorithm.

7.2. Renewable energies

Participant: Antoine Rousseau.

7.2.1. Wind circulation around mills

In [5] we present a new methodology, together with numerical studies, related to a Lagrangian stochastic approach applied to the computation of the wind circulation around mills. We present our numerical method and numerical experiments in the case of non rotating and rotating actuator disc models. First, for validation purpose we compare some numerical experiments against wind tunnel measurements. Second we perform some numerical experiments at the atmospheric scale and present some features of our numerical method, in particular the computation of the probability distribution of the wind in the wake zone, as a byproduct of the fluid particle model and the associated PDF method.

7.3. Multiscale modeling for environmental issues

Participants: Mathieu Dartevelle, Carole Delenne, Vincent Guinot, Antoine Rousseau.

7.3.1. Upscaled modeling of a coastal lagoon in Camargue

In 2015, Sélim Cornet developed a numerical model for the hydrodynamics of Vaccares system in Camargue. The data and reference simulations (made with TELEMAC-2D) were provided by Tour du Valat (contact O. Boutron). Sélim's work consisted in the implementation and validation of the porosity shallow water model developped by Vincent GUINOT , in order to obtain accurate but inexpensive simulations of the Vaccares hydrosystem. In 2016, we identified inconsistencies in the porosity closure model. These modeling issues have been analysed and a new theoretical approach, including new energy principles in the derivation of the porosity model, are under investigation.

7.3.2. Feedback strategies for decontamination of water resources

In [2] we show how to couple systems of ODEs and PDEs to provide efficient feedback strategies for the biological decontamination of water resources. For natural resources, we impose not to introduce any bacteria in the resource and to treat it aside preserving a constant volume of the resource at any time. The feedback strategies are derived from the minimal time synthesis of the system of ODEs.

7.3.3. Dispersion in porous media

Solute dispersion in porous media is usually modelled using Fick's law or fractional variations of the solute dispersion equation. The Fickian model, however, is known to exhibit a number of drawbacks, such as poor scaling properties. This is also true for its fractional counterparts, that perform with limited success when compared to experimental data sets. In [46], a high-quality experimental device is built in the form of periodic heterogeneities (Model Heterogeneous Porous Medium) of length 15 cm. Placing up to 10 MHPM in series allows the scaling properties of the dispersion model to be analyzed. Besides providing a high quality experimental database, the results in [46] indicate that (i) previously identified scaling trends for the dispersion coefficient may easily be explained by experiment variability, (ii) there exists a linear transport model that allows the experimental behaviour to be reproduced at all scales, (iii) this model is not the advection-dispersion model (even fractional). More experiments have been performed this year with a different connexion between each MHPM. More experiments have been performed this year with a different connexion between each MHPM. The benchmarking of various numerical models is currently under process; it includes classical models such as Advection-Diffusion, Mobile-Immobile, Multi Rate . . . as well as a proposed Purely Advective Multi Region model.

7.3.4. Modeling and identification for environmental applications

In collaboration with Mohsen Chebbi (ENIT, Tunis) and Salwa Toumi (ENIT, Tunis), we propose stochastic models of anaerobic membrane bioreactors [10]. These biotechnology processes are usually described as differential equations valid at large population scale. We propose model at different scales. At the microscopic scale, we consider a pure jump stochastic model that can be exactly simulated. However, when the size of the population is large that type of exact simulation is not feasible, hence we propose approximated simulation methods in discrete time, of the Poisson type or of the diffusive type. We establish the law of large numbers and the central limit theorem of the functional type.

We also consider different problems of simultaneous filtering and parameter estimation for hidden Markov models: in collaboration with Samuel Nyobe Som (University of Yaoundé 1) we study natural ressources examples; in collaboration with Oussama Hadj-Abdelkader (University of Tlemcen) we study applications in biotechnology. In both cases the fact that the frequency of data acquisition is slow enough to improve classical techniques.

7.4. Other results

Participants: Fabien Campillo, Carole Delenne, Antoine Rousseau.

7.4.1. Topography assessment from ordinal and continuous information

Hydrodynamic models in two dimensions require a precise knowledge of the domain topography, but data acquisition (field surveys, RADAR, etc.) remains difficult to set up at a large scale. Progress in remote sensing data now allows the automatic monitoring of water surfaces delineation from areal or satellite images (e.g. [48]); and flood dynamics from remote sensing data are known to be informative on floodplain topography for long. The idea is thus to combine sparse punctual information (obtained from ground survey) with continuous contour lines (obtained from image treatment) to better assess the domain topography. Two different approaches have been tested during Mathieu Dartevelle's internship (3 months): the first one is based on geostatistical considerations (kriging and conditional simulations) and the second one, deterministic, uses spline functions obtained from a minimisation process. The main challenge stands in the fact that, if the contour line is known to be an isovalue curve, its elevation is not known. First results have been presented in [12] but work is still needed especially to retrieve a precise estimation of curve elevation from very few data points. This work is done in collaboration with Jean-Stéphane Bailly (Lisah, AgroParisTech Montpellier).

7.4.2. Growth-fragmentation-death models

In collaboration with Coralie Fritsch (Inria Nancy) and Otso Ovaskainen (University of Helsinki), we propose a numerical approach that can be used to study the invasion fitness of a mutant in evolutionary models and to determine evolutionary singular strategies when the competitive exclusion principle holds [18]. Though the method is general, we illustrate this method with a mass-structured individual-based chemostat model. We assume that the mutations are rare and that the resident population is large, in which case the mutant population can be viewed, on a short time scale, as evolving in a constant environment. Both deterministic and stochastic models can be proposed to describe such a problem. We exploit a previously derived mathematical relationship between these models [7] to derive a general method for analyzing the invasion fitness of stochastic models.

In collaboration with Nicolas Champagnat and Coralie Fritsch (Inria Nancy), we studied the variations of the principal eigenvalue associated to a growth-fragmentation-death equation with respect to a parameter [16]. We use the probabilistic individual-based interpretation of the model. We study the variations of the survival probability of the stochastic model, using a generation by generation approach. Then, making use of the link between the survival probability and the principal eigenvalue established in a previous work, we deduce the variations of the eigenvalue with respect to the parameter of the model.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Free surface hydraulics

The finite volume-based, SW2D computational code (see Software section) is used by Cereg Ingénierie and Enveo (Montpellier Lavérune location) on a regular basis to carry out flood risk assessment studies. The code is constantly being developed on a work-for-hire basis depending on the company needs. The developments mostly concern pre- and post-processing functionalities, as well as specific hydraulic modules.

8.1.2. Hydrodynamics of coastal lagoons with porosity models

A two-dimensional shallow water with depth-variable porosity has been developed. The depth-variable porosity allows the subgrid-scale variations of the topography and hydraulic connectivity to be accounted for. The governing equations are written in conservation form and solved using a finite volume scheme. This allows the CPU time of the computational code to be divided by 2 to 3 orders of magnitude. The model is currently being tested against in situ measurements in the Vaccarès system in collaboration with Tour du Valat.

8.2. Bilateral Grants with Industry

Antoine ROUSSEAU collaborates with ARTELIA in the framework of M-P Daou's PhD thesis (CIFRE).

9. Partnerships and Cooperations

9.1. Regional Initiatives

- **Cart'Eaux** project (European Regional Development Fund (ERDF)): in partnership with colleagues of LIRMM and HSM (Montpellier) and with Berger-Levrault company, Carole DELENNE and Benjamin COMMANDRE are developing a methodology that will collect and merge multi-sources data in the aim of mapping urban drainage networks for hydraulic modeling purpose. This chain of treatment includes: i) detection of manhole covers from remote sensing data (aerial images, numerical elevation models…), 2) development of an algorithm to retrieve the network from the detected points and other information such as roads or topography, 3) data manning to extract useful characteristics for the hydraulic model, from various databases available or from documents automatically gathered from the web. A confidence index will be given to each characteristic assessed and a sensitivity analysis will enable the software to propose a hydraulic model together with an associated uncertainty.
- The GeRIMU project (Gestion du Risque d'Inondation en Milieu Urbain) counts 3 partners: Cerec Ingénierie, HSM and Predict Services. In this porject, the upscaled shallow water model with porosity SW2D developed at HSM is embedded in a software chain that will allow fast uran flood computations from forecasted precisiptation fields. The project is funded under the Feder scheme. It has earned a distinction from the local Scientific Advisory Committee ("Coup de coeur du COSTI").

9.2. National Initiatives

9.2.1. ANR

Fabien MARCHE is member of the ANR project BonD (PI Sylvie Benzoni), 2013-2017

Fabien MARCHE is member of the ANR project ACHYLLES (PI Rodolphe Turpault), 2014-2017

Fabien CAMPILLO is member of the ANR project Slofadybio, 2015-2016

Antoine ROUSSEAU is member of the ANR project ANSWER (PI Céline Casenave), 2016-2019

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

Vincent GUINOT was the main investigator of an International Training Network (ITN) proposal in 2016. The proposal was not accepted and will be submitted again in 2017, accounting for the remarks made by the reviewers.

9.4. International Initiatives

9.4.1. Inria International Labs

9.4.1.1. Inria Chile

Antoine ROUSSEAU spent 9 months at Inria Chile from January to October 2016.

9.4.2. Inria International Partners

9.4.2.1. Declared Inria International Partners

In 2015, the *Marine Energies Research International Center* (MERIC) was launched in Chile by CORFO. Antoine ROUSSEAU will be the scientific coordinator for Inria, and several members of LEMON, CARDAMOM and TOSCA research teams will be involved in this 8 years project driven by DCNS. Antoine ROUSSEAU and Fabien MARCHE are involved in the research line *advanced modeling for marine energy*.

9.4.2.2. Informal International Partners

Vincent GUINOT collaborates with B.F. Sanders (Irvine University, Californie, USA)

Carole DELENNE and Vincent GUINOT collaborates with S. Soares-Frazao (Unité de Génie Civil, Université catholique de Louvain, Belgium)

Antoine ROUSSEAU continues to collaborate with H. Ramirez (CMM, Santiago) and P. Gajardo (UTFSM, Valparaiso) after the end of the Inria associated team Dymecos (2015).

9.5. International Research Visitors

9.5.1. Research Stays Abroad

Antoine ROUSSEAU spent 9 months at Inria Chile from January to October 2016. He co-advised 2 master students and 1 research engineer in the framework of the MERIC project in Chile. Antoine ROUSSEAU also participated to the Tsunamilab project between Inria Chile and CIGIDEN.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Journal

10.1.1.1. Member of the editorial board

Vincent GUINOT : Journal of Hydroinformatics.

Antoine ROUSSEAU : Discrete and Continuous Dynamical Systems, Series S.

10.1.1.2. Reviewer

Fabien MARCHE : Advances in Applied Mathematics and Mechanics, International Journal for Numerical Methods in Fluids, Journal of Applied and Computational Mathematics, Journal of Computational Physics, Journal of Scientific Computing and SIAM Journal on Scientific Computing.

Vincent GUINOT : Journal of Hydrology and Journal of Hydroinformatics.

Antoine ROUSSEAU : Applied Numerical Mathematics, International Journal for Numerical Methods in Fluids.

10.1.2. Invited talks

Carole DELENNE workshop « Modelling the flood peril » Paris, May 30th and 31st, Université Pierre et Marie Curie

Antoine ROUSSEAU : Café Scientifique (Institut Français de Santiago, Ambassade de France), August 6th, 2016

Antoine ROUSSEAU : 4th French-Chilean workshop on Bioprocess Modeling, Santiago, Sept. 2016

10.1.3. Research administration

Antoine ROUSSEAU belongs to the workgroup dedicated to the development of SELECT, an Inria internal software to manage scientific recruitment. Carole DELENNE responsable d'année EGC3, direction des études EGC et tutorat de 5 apprentis (je sais pas où ca se met. . .)

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

F. Campillo, Stochastic modelling of ecosystems, 20 h, M2R Biostatistics, Univ. Montpellier

F. Campillo, Object oriented programming: probabilistic modeling and statistical numerics for biology, 20 h, Doctoral lectures, Univ. Montpellier

C. Delenne, Méthodes mathématiques pour l'ingénieur, 10.5H CM, 22.5hTD, L3, Polytech Montpellier

C. Delenne, Hydraulique, 60hTP, M1, Polytech Montpellier

C. Delenne, Hydraulic transients, 27hTD, M1, Polytech Montpellier

C. Delenne, Modélisation hydraulique à surface libre 2D, 6h TD, M2, Polytech Montpellier

C. Delenne, Tutorat de stages et projets, 77hETD, L3-M2, Polytech Montpellier

C. Delenne, Mathématiques, 15h CM, 15hTD, L3 (apprentissage), Polytech Montpellier

C. Delenne, Hydraulique, 28hTD, L1, IUT Génie Civil, Nîmes

V. Guinot, Mécanique des fluides, 72h ETD, L3, Polytech'Montpellier

V. Guinot, Hydraulique à surface libre, 60h ETD, L3, Polytech'Montpellier

V. Guinot, Méthodes Mathématiques pour l'Ingénieur, 18h ETD, M1, Polytech'Montpellier

V. Guinot, Hydraulique des Réseaux, 30h ETD, M1, Polytech'Montpellier

V. Guinot, Mécanique des Fluides, Master SPAE, 36h ETD, M1, UMontpellier

V. Guinot, Transitoires hydrauliques, 54 h ETD, M1, Polytech'Montpellier

V. Guinot, tutorat de stages ingénieur, 15h ETD, M1, Polytech'Montpellier

V. Guinot, Modélisation hydraulique à surface libre 2D, 6h ETD, M2, Polytech'Montpellier

V. Guinot, Projet Industriel de Fin d'Etudes (PIFE), 30h ETD, M2, Polytech'Montpellier

V. Guinot, Tutorat de Stage de fin d'études ingénieur, 18h ETD, M2, Polytech'Montpellier

F. Marche, Biomaths, 72h TD., L1, Université Montpellier

F. Marche, Analyse numérique des EDP, 24H CM, 12H TD, 15H TP., M1, Université Montpellier

F. Marche, Calcul scientifique avancé, 26H CM, M2R, Université Montpellier

A. Rousseau, Towards Coupling Coastal and Large Ocean Models, 6h, Master, PUC, Santiago, Chile

A. Rousseau, Introduction to numerical methods in CFD, 6h, Master, Inria Chile, Santiago, Chile

A. Rousseau, Introduction to ROMS, 12h, Master, Inria Chile and CIGIDEN, Santiago, Chile

10.2.2. Supervision

PhD: Mehdi Pierre Daou, *Développement d'une méthodologie de couplage multi-modèles avec changements de dimension. Validation sur un cas-test réaliste en dynamique littorale*, Univ. Grenoble, Sept. 2016, Eric Blayo (EPI MOISE) and Antoine Rousseau

PhD in progress: Mohsen Chebbi, Modélisation stochastique de procédés membranaires de traitement des eaux usées. September 2014, S. Toumi (ENIT, Tunis) and F. Campillo

PhD in progress: Oussama Hadj-Abdelkader, Filtrage particulaire pour le chemostat. September 2014, A. Hadj-Abdelkader (Univ. Tlemcen) and F. Campillo

10.2.3. Juries

Carole DELENNE : Jury member: Andriarimina Daniel Rakotonirina, *Fluid-solid interactions in a non-convex granular media: application to rotating drums and packed bed reactors*, december 2016, ENS Lyon

Antoine ROUSSEAU : Referee and jury member: Mrs Souad Khiari, *Problèmes Inverses de Points Sources dans les Modèles de Transport Dispersif de Contaminants Identifiabilité et Observabilité*, October 2016, Université de Technologie de Compiègne & Université de Tunis El-Manar / ENIT

Antoine ROUSSEAU : Jury member: M. Mehdi Pierre Daou, *Développement d'une méthodologie de couplage multi-modèles avec changements de dimension. Validation sur un cas-test réaliste en dynamique littorale*, September 2016, Univ. Grenoble

Antoine ROUSSEAU : Jury member: M. Victor Riquelme, *Problemas de control óptimo para la bioremediación de recursos acuíferos*, September 2016, Univ. de Chile, Santiago & Univ. Montpellier

Fabien MARCHE : Jury member: Mrs Nora Aissiouene, *Analyse numérique et approximation discrète d'un modèle dispersif en eau peu profonde*, December 2016, Univ. Pierre et Marie Curie, Paris

Antoine ROUSSEAU : Jury member: Mrs Carine Lucas, *Modélisation de problèmes de me´canique des fluides : approches théoriques et numériques*, December 2016, Université d'Orléans

Teaching manager of the department "Water and Civil Engineering", Polytech Montpellier, in charge of the first year of the training. Academic supervisor of 5 apprentices.

10.3. Popularization

Antoine ROUSSEAU gave several conferences for highschool students and their teachers in France and Chile, on the topics of mathematical modeling for environmental sciences:

Fête de la Science, Oct. 2016, Genopolys Montpellier

Café Cientificó, Aug. 2016, Instituto Francés, Santiago, Chile

Antoine ROUSSEAU is member of the national Inria network for scientific outreach *Médiation scientifique*

Antoine ROUSSEAU is member of the editorial board of Interstices

Antoine ROUSSEAU co-authored the Calendrier Mathématique 2017

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Articles in International Peer-Reviewed Journals

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