Activity Report 2015

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

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1. Members

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Mohsen Chebbi [ENIT Tunis, Tunisia, PhD Student, Jul 2015]
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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.

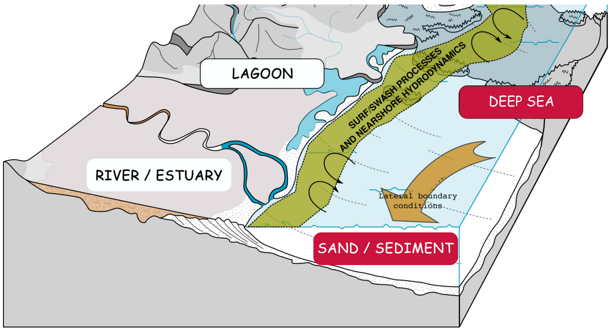

Figure 1. Examples of interacting nearshore processes. Courtesy F. Bouchette.

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 [29], [33], [60] are available in one dimensions, let alone in the multidimensional case. We can refer to [59], [36] for some linear dispersive equations, treated with finite-element methods, or to [33] for the first use of advanced high-order compact finite-volume methods for the Serre equations. Recent work undertaken during the ANR MathOCEAN [29] 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 [27] . 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 [30], or undular bores using Boussinesq-type models [40]. Let us also mention [38] for tsunami modeling and [37], [49] 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 [29], [57]. The SWASH project led by Zijlema at Delft [60] 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 [39] on transparent boundary conditions. Deep studies of these operators have been performed in the case of linear equations, [44], [28], [54]. 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 [50], 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 [41].

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 [26], [25], [53] 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 [26]. Unfortunately, the REV has been shown recently not to exist in urban areas [43]. 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 [35], [42], [45] and applied successfully to urban flood modeling scale experiments [42], [51], [56]. 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 [55] and multiple porosity [43] 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 [34]), Boussinesq-type dispersive models [27]), 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 [48], 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 [47]. 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 [39].

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 [41]) 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 [31], [32], [35], [42], [43], [45], [51], [55], [56] 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 [42], [43], [55], [58].
- 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 [43], [55]. 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 [46], [52]. 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 (5569up 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

- In 2015, the *Marine Energies Research International Center* (MERIC) was launched in Chile. 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 in partnership with DCNS and Enel.
- Antoine ROUSSEAU co-organized the CEMRACS 2015, in Marseilles: 6 weeks with more than 100 participants.
- Fabien MARCHE and Antoine ROUSSEAU co-organized the workshop Numerical Models for Coastal Hazards in Montpellier.

5.1.1. Awards

- Carole Delenne's project **Cart'Eaux** was selected in the Languedoc Roussillon *Chercheur d'avenir* competition.
- The GERIMU project has earned a distinction from the local Scientific Advisory Committee ("Coup de coeur du COSTI").

6. New Software and Platforms

6.1. 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.

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
- 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
- URL: http://vincentguinot.free.fr

6.2. WindPoS

Participant: Antoine Rousseau.

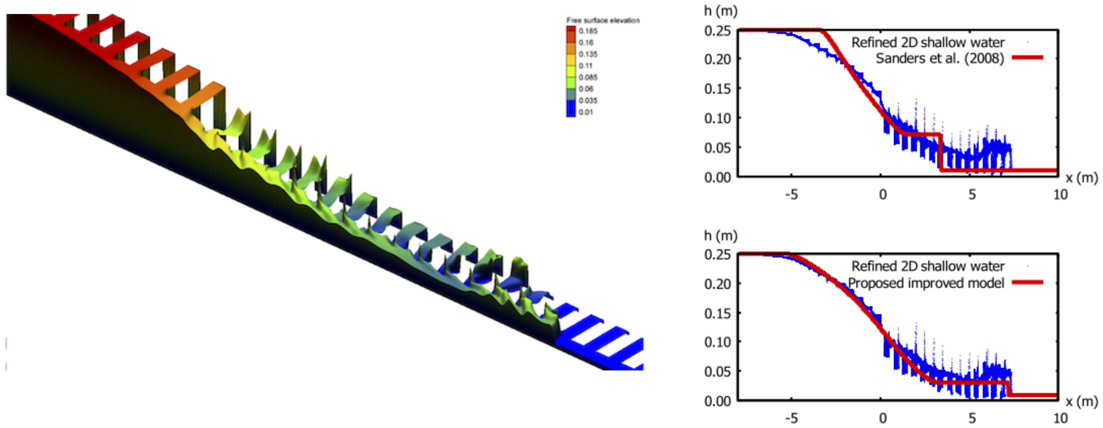

Figure 2. Propagation of a flood wave into a channel with lateral storage. Refined 2D simulation using the SW2D computational code

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.

- Contact: Antoine ROUSSEAU
- URL: http://windpos.inria.fr

7. New Results

7.1. Hydrodynamics of the Tunquen lagoon, Chile

Participant: Antoine Rousseau.

In this internship co-advised with Céline Acary-Robert (Inria Chile), Loïc Dagnas developed a numerical hydrodynamic model for a specific lagoon of the chilean costline. This kind of lagoon is characterized by an intermittent connection to the sea and a regular fresh water input coming from the Andean mountains. The hydrodynamic model consists in a two-dimensional shallow water model, including tracer equations for the time evolution of temperature and salinity. The hydrodynamic circulation of the lagoon has been simulated taking into account various external forcings such as water exchanges with the atmosphere, wind effects and external pumping.

7.2. Upscaled modeling of Vaccares lake in Camargue

Participants: Carole Delenne, Antoine Rousseau, Vincent Guinot.

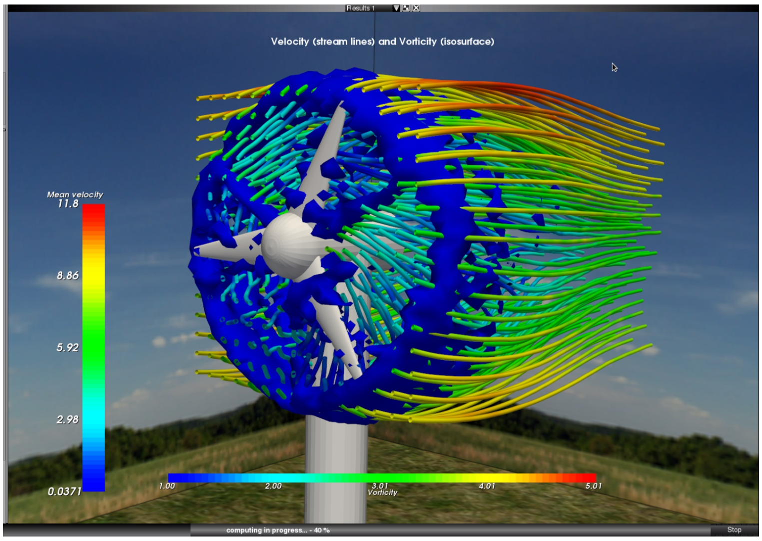

Figure 3. Velocity streamlines and vorticity around a wind mill (artistic view). WINDPOS Project.

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.

7.3. Numerical simulation of coastal flood made by Joanna storm (France, 2008)

Participant: Fabien Marche.

In collaboration with BRGM, a numerical platform based on Fabien Marche's numerical too WaveBox was developed in order to simulate coastal urban submersions associated with intense storms, see [22]. A nudging strategy is implemented with:

- a barotropic model at the regional scale,
- a spectral wave model with embeded meshes accounting for water level evolution and output from the large scale model,
- a free surface Shallow Water model (SURF2D, now called WaveBox) used at very high resolution for the submersion process.

7.4. Analysis of the inclusion of vorticity on fully nonlinear and weakly dispersive long wave models

Participant: Fabien Marche.

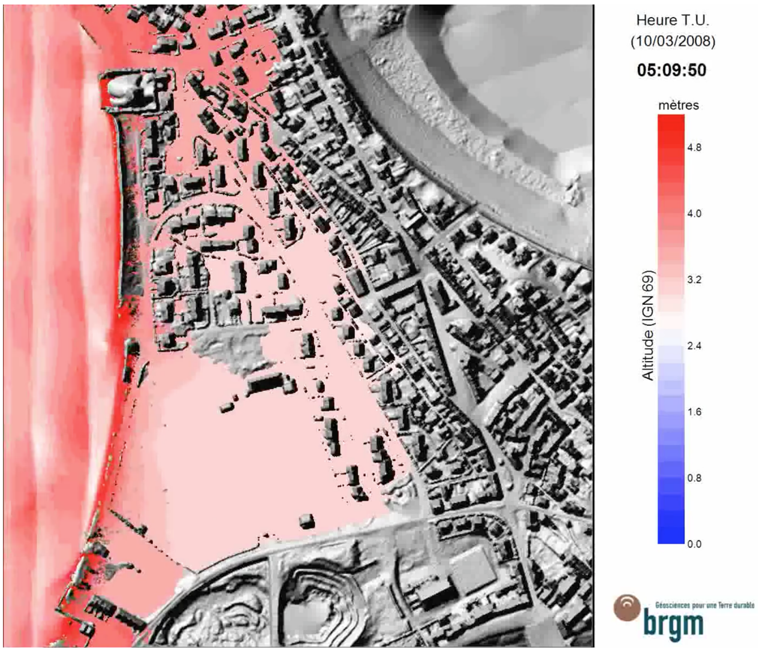

Figure 4. Simulation of Joanna storm (France, 2008). Snapshot of the movie made by BRGM, available on their Youtube page.

We study in [11] the propagation of long waves in the presence of vorticity. In the irrotational framework, the Green-Naghdi equations (also called Serre or fully nonlinear Boussinesq equations) are the standard model for the propagation of such waves. These equations couple the surface elevation to the vertically averaged horizontal velocity and are therefore independent of the vertical variable. In the presence of vorticity, the dependence on the vertical variable cannot be removed from the vorticity equation but it was however shown in [9] that the motion of the waves could be described using an extended Green-Naghdi system. In this paper we propose an analysis of these equations, and show that they can be used to get some new insight into wave-current interactions. We show in particular that solitary waves may have a drastically different behavior in the presence of vorticity and show the existence of solitary waves of maximal amplitude with a peak at their crest, whose angle depends on the vorticity. We also propose a robust and simple numerical scheme validated on several examples. Finally, we give some examples of wave-current interactions with a non trivial vorticity field and topography effects.

7.5. Multiscale aspects for confinement of coastal lagoons

Participant: Antoine Rousseau.

In [3] we expand a previous definition of paralic confinement (see [41]), and make it usable from the modeling slant, before implementing it in numerical tools. More specifically, we here deal with the multiscale aspect of the confinement. If a paralic environment is separated into two (or more) connected areas, we will show that is possible to split the confinement problem into two related problems, one for each area. We also focus on the importance of the interface length between the two subdomains.

7.6. Interface conditions for ocean models

Participant: Antoine Rousseau.

In [5] 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 [4] 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.

7.7. Use of remote sensing data for hydraulic modelling

Participant: Carole Delenne.

Wetlands provide a vital resource to ecosystem services and associated rural livelihoods; but their extent, geomorphological heterogeneity and flat topography make the representation of their hydrological functioning complex. The main objective of this area of research is to assess the relevance of remote sensing data for the monitoring and hydraulic modelling of different hydrosystems. In [14], a semi automated method exploiting 526 MODIS 8-day 500 m resolution images was developed to study the spatial and temporal dynamics of the annual flood across the Niger Inner Delta over the period 2000?2011. The flooded area is detected using band ratio indexes. Results were evaluated against classified Landsat images, previous studies and field stage data for a range of hydrological units: river stretches, lakes, floodplains and irrigated areas. Depending on the study area, its extent, and the objective to be reached, different kinds of remote sensing data may be interesting: RADAR, multispectral, high/low spatial/temporal resolution, etc. Several paths for research are currently considered to upgrade the use of remote-sensing data in hydrodynamic modelling:

- use of detected flooded area for model validation and for the calibration of parameters such as friction coefficient.
- topography assessment using the detection of the flooded area of a given wetland at different times.
- characterization of statistical properties of the geometry of the urban medium (useful for large-scale models): statistical, subgrid-scale properties of the topography, and information regarding the flow connectivity properties of the urban medium.

7.8. Lumped hydrological models with infinite characteristic time transfer functions

Participant: Vincent Guinot.

Karst and mountainous catchments usually exhibit rainfall-runoff transfer functions involving multiple time scales. In most existing conceptual, hydrological models of such catchments, multiple time scale response is achieved by introducing several reservoirs and non-linear transfer functions. In [9], multiple time scales are introduced by proposing a transfer function with an infinite characteristic time. The heavy-tailed transfer function behaves asymptotically as an inverse power of time. In the limit of long time scales, the governing equation for the system obeys a fractional differential equation. With a single reservoir, the proposed approach is shown to perform satisfactorily compared to other models of similar or more complex structure. The fractional differential equation is shown to be useless for usual time scales and should not be used in practice.

7.9. Upscaled models for urban floods

Participant: Vincent Guinot.

Shallow water models with porosity have arisen over the last two decades as a promising alternative to refined flow models for the simulation of urban floods. Several porosity-based models have been proposed in the literature. In [10], the integral porosity formalism developed at the University of California Irvine is validated against scale model experiments. A sudden dike breaching near an idealized city layout is simulated in the scale model. Comparison with numerical simulations shows the superiority of the integral porosity model over the single porosity model in reproducing the effects of urban layout anisotropy on flood wave propagation properties. This research has initiated a collaboration between the LEMON team and UC Irvine for the development of a new porosity formalism.

7.10. Models for dispersion in porous media

Participants: Carole Delenne, Vincent Guinot.

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 [13], a high-quality experimental device is built in the form of periodic heterogeneities of length 15 cm. Placing up to 10 periods in series allows the scaling properties of the dispersion model to be analyzed. Besides providing a high quality experimental database, the results in [13] 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 reproduces at all scales, (iii) this model is not the advection-dispersion model (even fractional).

7.11. Invasion in growth-fragmentation-death models

Participant: Fabien Campillo.

In collaboration with Nicolas Champagnat and Coralie Fritsch (Inria Nancy), we present in [20] two approaches to study invasion in growth-fragmentation-death models: one based on a stochastic individual based model and one based on an integro-differential model. The invasion of the population is described by the survival probability for the first model and by an eigenproblem for the second one. We study these two notions of invasion fitness, giving different characterizations of the growth of the population, and we make links between these two complementary points of view. We apply our work in the context of adaptive dynamics in a chemostat model.

7.12. Stochastic growth model with extinction

Participant: Fabien Campillo.

In collaboration with Marc Joannides and Irène Larramendy-Valverde (IMAG / Université de Montpellier), we consider in [6] a stochastic logistic growth model given by a stochastic differential equation featuring both birth and death rates in the drift and diffusion coefficients. Our aim is to infer these rates, based on discrete observations with possible extinction. Since extinction occurs eventually for the model, the density of the diffusion process is not absolutely continuous with respect to the Lebesgue measure; we established the associated Fokker-Planck equation together with appropriate numerical schemes. This formulation allows to design variants of the standard methods that can handle extinction.

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 (funded by Languedoc Roussillon region): in partnership with colleagues of LIRMM and HSM (Montpellier) Carole DELENNE will develop a new method to gather various types of data in order to produce a regular and complete mapping of urban assainissement, in order to allow sharp and complete hydrodynamical modeling of urban pipes.

- 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

9.3. International Initiatives

9.3.1. Inria International Labs

9.3.1.1. Nuwat / LIRIMA

With Moshen Chebbi (Phd student, ENIT, Tunis) we continue to explore the stochastic modeling for biotechnological problems. We proposed a framework that allows for both analysis and simulation of the models. This framework slightly generalized standard jump Markov processes on grids popularized by Tom Kurtz and co-workers. With Oussama Hadj-Abdelkader (Univ. Tlemcen) we continue to explore the nonlinear filtering techniques for the chemostat including unscented Kalman filtering and particle filtering.

9.3.1.2. Inria Chile

Antoine ROUSSEAU visited Inria Chile in January, 2015 (2 weeks) in order to prepare a long stay in Chile in 2016.

9.3.2. Inria International Partners

9.3.2.1. 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 *resource assessment & site characterization*.

9.3.2.2. Informal International Partners

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

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

Antoine ROUSSEAU and Fabien MARCHE collaborate with Rodrigo Cienfuegos and Cristián Escauriaza (CIGIDEN and PUC Chile, Santiago)

9.4. International Research Visitors

9.4.1. Visits of International Scientists

Carine Lucas (Université of Orléans, France) spent several months in LEMON to collaborate with Antoine ROUSSEAU on nontraditional models in oceanography.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events selection

10.1.1.1. Member of the conference program committee

Fabien MARCHE is member of the scientific committee of Advances in Numerical modeling of Hydrodynamics, 2015.

Fabien CAMPILLO is member of the scientific evaluation panels for the ANR's Generic Call for Proposals.

10.1.2. Journal

10.1.2.1. Member of the editorial board

Vincent GUINOT : Journal of Hydroinformatics.

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

10.1.2.2. 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.

10.2. 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.

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

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

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

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

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

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

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

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

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

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

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

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

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

10.2.2. Supervision

PhD in progress: Mehdi Pierre Daou, *Développement d'une méthodologie de couplage multi-modèles avec changements de dimension. Validation sur un cas-test réaliste en dynamique littorale*, May 2013, 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

Fabien CAMPILLO : President of the jury of the associate professor (Maitre de Conférence) at the university of Bordeaux (mathematics).

Fabien CAMPILLO : Referee and jury member: M. Étienne Descamps (AgroParisTech). *Approche de modélisation Monte-Carlo individu-centrée opérant par événements discrets appliquée à un procédé d?homogénéisation d?une émulsion laitière*

Antoine ROUSSEAU : CR2 competition in Inria Sophia-Antipolis, spring 2015.

10.3. Popularization

Antoine ROUSSEAU co-authored two outreach publications in Interstices, see [17] and [18].

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

Fête de la Science, Oct. 2015, Genopolys Montpellier

Fête de la Science, Oct. 2015, Centre International de Valbonne

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

Antoine ROUSSEAU gave several informal conferences in Grand Palais for the COP21 week (December 3-10, PAris)

11. Bibliography

Publications of the year

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Articles in International Peer-Reviewed Journals

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