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ACTIVITY REPORT

Project-Team
LEMON

Littoral Environment: M0dels and Numerics

DOMAIN

Digital Health, Biology and Earth

THEME

Earth, Environmental and Energy Sciences

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Project-Team LEMON

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1 Team members, visitors, external collaborators

Research Scientist

- Antoine Rousseau [Team leader, Inria, Researcher, HDR]

Faculty Members

- Carole Delenne [Univ de Montpellier, Associate Professor, HDR]
- Pascal Finaud-Guyot [Univ de Montpellier, Associate Professor, HDR]
- Vincent Guinot [Univ de Montpellier, Professor, HDR]
- Gwladys Toulemonde [Univ de Montpellier, Associate Professor, HDR]

PhD Students

- Vita Ayoub [Luxembourg Institute of Science and Technology, Univ. Montpellier]
- Yassine Bel Ghaddar [Berger-Levrault , CIFRE, Univ. Montpellier / USMBA]
- Joao Guilherme Caldas Steinstraesser [Inria, until Oct 2021]
- Cecile Choley [Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg]
- Jose Daniel Galaz Mora [Inria, from Feb 2021]
- Joseph Luis Kahn Casapia [Inria, until Aug 2021]
- Samuel Valiquette [Centre de coopération internationale en recherche agronomique, from Mar 2021]

Interns and Apprentices

- Killian Bakong [IRT Saint Exupéry, from Apr 2021 until Aug 2021]
- Marion Jicquel [Inria, from Jun 2021 until Aug 2021]
- Antoine Pfefer [Inria, from Apr 2021 until Aug 2021]

Administrative Assistant

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2 Overall objectives

Coastal areas are increasingly threatened by global warming-induced sea level rise. At the same time, 60% of the world population lives in a 100 km wide coastal strip (80% within 30 km from the shore in French Brittany). This is why coastlines are concerned with many issues of various types: economical, ecological, social, political, etc. Coastal areas are natural interfaces between various media (*e.g.* wind/sea/sand/land). The physical processes acting on these media have very different time scales, hence the need to build complex systems coupling nonlinear partial differential equations and random processes to describe them. To address these crucial issues, **LEMON is an interdisciplinary team working on the design, analysis and application of deterministic and stochastic models for inland and marine littoral processes, with an emphasis on both standalone models and hybrid systems.**

The spot of Montpellier offers large opportunities:

Important academic research community Additionally to IMAG[1] and HSM[2], we interact with several local academic research partners. To mention but a few examples, we collaborate with UMR MISTEA (pollution and remediation of water resources) and UMR LISAH (hydrology in agricultural areas). Regular contacts are also maintained with UMR Geosciences (morphodynamics), UMR G-Eau (hydraulics, data assimilation and flood economy), UMR MARBEC (lagoon environment).

NUMEV Labex and MUSE project The LEMON members are involved in projects funded by the current NUMEV Labex and actively participate in new initiatives pertaining to *sea and coast* modelling, both through the recently awarded MUSE project in Montpellier and through external (national, European, international) calls.

Industrial and economic community From the transfer & innovation viewpoint, the team members already interact with several local partners such as Cereg Ingénierie, IRT Saint-Exupéry, Tour du Valat, Predict Services, Artelia, Montpellier Métropole and Berger-Levrault.

The general scope of the LEMON project-team is to develop mathematical and computational methods for the modelling of hydraulic and hydrodynamic processes. The mathematical tools used are deterministic (PDEs, ODEs) and/or probabilistic (extreme value theory). Applications range from regional oceanography to coastal management, including risk assessment for natural hazards on the coastline (submersion and urban floods, tsunamis, pollution).

LEMON is a common research team between HSM (UM, CNRS, IRD), IMAG (UM, CNRS) and Inria, whose faculty members have never been associated to Inria groups in the past. All fellows share a strong background in mathematical modelling, together with a taste for applications to the littoral environment. As reflected in the team contributions, the research conducted by LEMON is interdisciplinary [3], thanks to the team members expertise (deterministic and stochastic modelling, computational and experimental aspects) and to regular collaborations with scientists from other domains. We believe this is both an originality and a strength for LEMON .

3 Research program

The team has three main scientific objectives. The first two are the development of new physical models and innovative mathematical methods for urban floods on the one hand and natural flows on the other hand. The third objective is to develop theoretical tools that can be used in the models serving the first two objectives. As mentioned above, the targeted applications cover PDE models and associated extreme events using a hierarchy of models of increasing complexity.

In each section, people involved in the project are listed in alphabetical order.

3.1 Urban Floods

In the context of climate change, the increase in urbanization, particularly in floodplains or near the seashore, could lead to an increase in vulnerability to flooding. Numerical models appear to be indispensable tools for predicting the impact of floods with different return periods and for evaluating mitigation and land-use planning policies [71].

Urban areas are characterized by significant variation in small-scale geometry and complex flows involving various phenomena [49, 50]. LEMON 's activities focus on the development of numerical models and methodologies, specifically designed for the urban context and for operational purposes.

3.1.1 Porosity models for upscaled urban flood modelling

[1] Institut Montpelliérain Alexander Grothendieck - UMR5149

[2] HydroSciences Montpellier - UMR 5569 - Note that HSM number changed from 5569 to 5151 in January 2021

[3] HSM UMR is a research unit affiliated to the National Institute for Sciences of the Universe (INSU) of CNRS, while the IMAG UMR is affiliated to the National Institute for Mathematical Sciences and their Interactions (INSMI).

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau.

State of the Art Simulating urban floods requires at least two-dimensional shallow water approaches and considerable computational power. Capturing the relevant hydraulic detail often requires computational cell sizes smaller than one meter. For instance, meshing a complete urban area with a sufficient accuracy would require 10^6 to 10^8 cells, and simulating one second often requires several CPU seconds. This makes the use of such model for crisis management impossible.

A new generation of models overcoming this issue has emerged over the last 20 years: porosity-based shallow water models. They are obtained by averaging the two-dimensional shallow water equations over large areas containing both water and a solid phase [45]. The size of a computational cell can be increased by a factor 10 to 50 compared to a 2D shallow water model, with CPU times reduced by 2 to 3 orders of magnitude [67]. While the research on porosity-based shallow water models has accelerated over the past decade [56, 82, 86, 57, 59, 67, 77, 78, 93, 94], a number of research issues remain pending.

Four year research objectives The research objectives are (i) to improve the upscaling of the flux and source term models to be embedded in porosity shallow water models and (ii) to validate these models against laboratory and in situ measurements. Improving the upscaled flux and source term models for urban applications requires that description of anisotropy in porosity models be improved to account for the preferential flows induced by building and street alignment. The description of the porosity embedded in the most widespread porosity approach, the so-called Integral Porosity model [82, 61], has been shown to provide an incomplete description of the connectivity properties of the urban medium. Firstly, the governing equations are strongly mesh-dependent because of consistency issues [61]. Secondly, the flux and source term models fail to reproduce the alignment with the main street axes in a number of situations [60]. Another path for improvement concerns the upscaling of obstacle-induced drag terms in the presence of complex geometries for which recent results suggest that the effects of microtopography on the flow cannot be upscaled using "classical" equation-of-state approaches, as done in most hydraulic models [58].

During this 4-year period, we will work to develop and validate improved flux and source term closures in the presence of strongly anisotropic urban geometries and in the presence of strongly variable topography. Validation will involve not only the comparison of porosity model outputs with refined flow simulation results, but also the validation against experimental data sets and real scale events. No experimental data set allowing for a sound validation of flux closures in porosity models can be found in the literature. Laboratory experiments will be developed specifically in view of the validation of porosity models. Such experiments will be set up and carried out in collaboration with the Université Catholique de Louvain (UCL), that has an excellent track record in experimental hydraulics and the development of flow monitoring and data acquisition equipment. These activities will take place in the framework of the PoroCity Associate International Laboratory (see next paragraph).

External collaborations

- University of California Irvine (B. Sanders): the collaboration with UCI started in 2014 with research on the representation of urban anisotropic features in integral porosity models [67]. It has led to the development of the Dual Integral Porosity model [62]. Ongoing research focuses on improved representations of urban anisotropy in urban flood modelling.

- Université Catholique de Louvain - UCL (S. Soares-Frazão): UCL is one of the few places with experimental facilities allowing for the systematic, detailed validation of porosity models. The collaboration with UCL started in 2005 and will continue with the PoroCity Associate International Laboratory proposal. In this proposal, a four year research program is set up for the validation, development and parametrization of shallow water models with porosity.

3.1.2 Downscaling

Participants: Joao Guilherme Caldas Steinstraesser, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

State of the Art The assessment of urban flood risk in urban areas requires the knowledge of the flow variables with a resolution of typically 1 meter or less. In practice, such High Resolution (HR) knowledge is not available because the existing modelling tools are too slow and require too much manpower for operational applications. To give but one example, simulating an urban flood using standard shallow water models over a 1 km × 1 km urban area typically requires 10 CPU seconds to simulate 1 second. This issue can be overcome by operating Low Resolution (LR) models (such as porosity models), that are three orders of magnitudes as fast as HR models. The LR results will then be downscaled onto HR grids. This path has been little explored (if at all) in the field of shallow water modelling.

Four year research objectives The team intends to explore two paths.

Scale coupling approaches A first approach consists in coupling the HR and LR models to achieve a faster computation by parallelizing the time stepping of the HR model, using the LR modelling results as a starting point for an iterative predictor-corrector procedure. This is the principle of para-real-based methods. Such methods are known to meet problems when hyperbolic problems (the class within which the shallow water equations fall) are dealt with. The research focuses on methods to improve the performance of para-real type approaches.

Statistical/learning-based approaches Coupling the LR and HR model is not a necessity. A second research path consists in training a data-driven method to reconstruct HR fields from LR fields using a number of precomputed scenarios. It can be expected that a method trained on a sufficiently wide range of hydraulic configurations will be able to downscale the flow variables even for flow configurations that have not been spanned in the training set. A number of research questions remain open.

- Can all flow configurations (e.g. smooth vs. discontinuous flows such as shocks) be handled with comparable accuracy by the downscaling method, or must some specific flow fields be treated by specific algorithms?
- Urban flood risk indicators are usually strongly nonlinear with respect to the flow variables. A research issue is: is it preferable to infer HR risk indicators directly from LR flow fields, or to downscale first the HR flow field from the LR flow field, then the HR risk indicator from the HR flow field?
- Do all upscaled models (e.g. a porosity-based model vs. a classical shallow water model) provide an equally good basis to downscaling?
- Different upscaled models are known to correctly represent different flow features (either the wave amplitude or the celerity). Do the HR inference from several upscaled models allow (i) to cope with bias in LR results; (ii) to infer the different features of the HR flow from the various upscaled models?

External collaborations

- Julie Carreau (HSM, IRD; now at Polytechnique Montreal) is coauthor with Vincent Guinot of [6].
- since late 2019, LEMON has started a collaboration with IRT Saint-Exupéry on the hybridization of models and large amounts of data for the modelling of urban floods. Neural network can be a promising way to realize the downscaling.

3.1.3 Street-building exchange

Participants: Pascal Finaud-Guyot, Cécile Choley, Antoine Rousseau.

State of art Classical practices for urban flood modelling consider the buildings as full or partial obstruction to the flow [84] but neglect in any case the street-building flow exchanges [89] although these exchanges can (i) create a flood retention within blocks and potential reduction of the peak discharge [53], (ii) produce secondary connection between streets through block and (iii) explain most part of the damages at the building scale [88, 34]. The lack of models to represent such a phenomenon forces, in coherence with an operational application for the classical approaches of management and characterization of flood risks, to assume that the water level inside the building is the same as in the immediate external neighborhood.

Four year research objectives In the context of the PhD thesis of Cécile Choley, new modelling approaches accounting for the street-building exchanges during flood event are developed. First milestones are reached with the determination of discharge law through the opening based on detailed 3D simulations and the implementation of such law in the 2D modelling software SW2D-LEMON (see section 7). A sensitivity analysis of the model answer to the building parameters should allow to define the required level of precision in the building data for an operational purpose.

This first research paves the way to coupling between deterministic and stochastic modelling approaches to represent with a probability law the undetermined building parameters (resistance of a door, room organization within the building, ...). Similar approaches might be applied to car-jam effect during urban flood event.

External collaborations

- Icube Laboratory (G. Dellinger): this partnership focuses on the 3D modelling street-building exchanges and the production of experimental data to validate the numerical development in the context of the Cécile Choley PhD Thesis.
- INRAE, UMR G-Eau (F. Grelot): F. Grelot is recognized as an expert in flood damage estimation. The potential of the flow dynamic inside building to better characterize damages and risk is assessed in the context of David Nortes Martinez (INRAE) post doctoral research.

3.2 Natural flows

The natural processes that take place in the coastal zone are numerous, complex and often integrate different space and time scales. They therefore require adapted models, both in terms of mathematical descriptions (based on differential equations) but also in terms of statistical processing.

3.2.1 Depth-Dependent Porosity model

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau.

State of the Art Simulating detailed free surface flows in wetlands requires considerable computational power and two-dimensional shallow water models are frequently needed. Typical issues arise when modelling wetlands and coastal lagoons, where large areas are often connected by an overwhelming number of narrow channels, obstructed by vegetation and a strongly variable bathymetry. Describing such channels with the level of detail required in a 2D model is impracticable.

A new generation of models overcoming this issue has emerged over the last 20 years: porosity-based shallow water models obtained by averaging the two-dimensional shallow water equations over large areas containing both water and a solid phase. In the specific fields of natural flows, Depth-Dependent Porosity (DDP) models have been designed to account for microtopography variation [45, 77, 78, 58].

Four year research objectives DDP models pave the way for various operational applications from local rainfall runoff on agricultural parcel to flood propagation in large catchment. However potential hyperbolicity loss can appear in the model for some particular parametrization [58].

The research objectives are:

- to generalize the DDP model for large scale modelling in which the parametrization may leads to hyperbolicity loss. The relationship between mesh and porosity fields have to be deeply investigated to determine either the mesh generation can avoid incoherent parametrization or numerical scheme have to be adapted to handle non-hyperbolic configurations.
- to adapt the DDP model for rainfall runoff on agricultural parcels. This implies to analyze the relationshis between topographical data, discretisation scale and hydrodynamic results but also to do the upscaling of complementary physical processes (infiltration, sheet flow, ...).
- to improve the upscaling of obstacle-induced drag terms in the presence of complex geometries. Indeed, recent upscaling research results obtained by the LEMON team in collaboration with Tour du Valat[4] suggest that the effects of microtopography on the flow cannot be upscaled using "classical" equation-of-state approaches, as done in most hydraulic models. A totally different approach must be proposed.

External collaborations

- Luxembourg Institute of Technology (R. Hostache): the collaboration with LIST started in 2018 with the project CASCADE funded by the Fond National de la Recherche du Luxembourg, and the co-direction of Vita Ayoub. The depth-dependent porosity model is applied to simulate the flooding of the Severn river (UK) during past events and validated against various measurements such as remotely sensed flood extents, and water levels at gauging stations.
- Tour du Valat (O. Boutron): the partnership with TdV focuses on the development and application of depth-dependent porosity models to the simulation of coastal lagoons, where the bathymetry and geometry is too complex to be represented using refined flow models.
- University of Tunis El Manar, Laboratory of Modelling in Hydraulics and Environment (M. Moussa): the partnership with M. Moussa focus on the co-supervision of tunisian PhD student for the use of DDP model to model rainfall-runoff on heavyly monitored agricultural catchement.
- UMR LISAH (D. Feurer): UMR LISAH is responsible for on field runoff data measurement on the Kamech catchment (Tunisia).

3.2.2 Transport

Participants: Céline Casenave (INRAE Montpellier), Joseph Luis Kahn Casapia, Antoine Rousseau.

State of the Art Water bodies such as lakes or coastal lagoons (possibly connected to the sea) located in high human activity areas are subject to various kinds of stress such as industrial pollution, high water demand or bacterial blooms caused by freshwater over-enrichment. For obvious environmental reasons, these water resources have to be protected, hence the need to better understand and possibly control such fragile ecosystems to eventually develop decision-making tools. From a modelling point of view, they share a common feature in that they all involve interacting biological and hydrological processes. According to [51], models may be classified into two main types: “minimal dynamic models”

[4] Institut de recherche pour la conservation des zones humides méditerranéennes

and “complex dynamic models”. These two model types do not have the same objectives. While the former are more heuristic and rather depict the likelihood of considered processes, the latter are usually derived from fundamental laws of biochemistry or fluid dynamics. Of course, the latter require much more computational resources than the former. In addition, controlling such complex systems (usually governed by PDEs) is by far more difficult that controlling the simpler ODE-driven command systems. LEMON has already contributed both to the reduction of PDE models for the simulation of water confinement in coastal lagoons [52, 32] and to the improvement of ODE models in order to account for space-heterogeneity of bioremediation processes in water resources [30].

Four year research objectives In collaboration with colleagues from the ANR-ANSWER project and colleagues from INRAE, our ambition is to improve existing models of lagoon/marine ecosystems by integrating both accurate and numerically affordable coupled hydrobiological systems. A major challenge is to find an optimal trade-off between the level of detail in the description of the ecosystem and the level of complexity in terms of number of parameters (in particular regarding the governing equations for inter-species reactions). The model(s) should be able to reproduce the inter-annual variability of the observed dynamics of the ecosystem in response to meteorological forcing. This will require the adaptation of hydrodynamics equations to such time scales (reduced/upscaled models such as porosity shallow water models (see Section 3.1.1) will have to be considered) together with the coupling with the ecological models. At short time scales (i.e. the weekly time scale), accurate (but possibly CPU-consuming) 3D hydrodynamic models processes (describing thermal stratification, mixing, current velocity, sediment resuspension, wind waves...) are needed. On the longer term, it is intended to develop reduced models accounting for spatial heterogeneity.
Over the 4-year period, the team will focus on two main application projects:

- the ANR ANSWER project (2017-2021, with INRAE Montpellier and LEESU) focusing on the cyanobacteria dynamics in lagoons and lakes. A PhD student is co-advised by Antoine Rousseau in collaboration with Céline Casenave (INRAE, Montpellier).

- the long term collaboration with Alain Rapaport (INRAE Montpellier) will continue both on the bioremediation of water resources such as the Tunquen lagoon in Chile and with a new ongoing project on water reuse (converting wastewater into water that can be reused for other purposes such as irrigation of agricultural fields). Several projects are submitted to the ANR and local funding structures in Montpellier.

External collaborations

- ANR ANSWER consortium: Céline Casenave (UMR MISTEA, INRAE Montpellier), Brigitte Vinçon-Leite (UM LEESU, ENPC), Jean-François Humbert (UMR IEES, UPMC). ANSWER is a French-Chinese collaborative project that focuses on the modelling and simulation of eutrophic lake ecosystems to study the impact of anthropogenic environmental changes on the proliferation of cyanobacteria. Worldwide the current environmental situation is preoccupying: man-driven water needs increase, while the quality of the available resources is deteriorating due to pollution of various kinds and to hydric stress. In particular, the eutrophication of lentic ecosystems due to excessive inputs of nutrients (phosphorus and nitrogen) has become a major problem because it promotes cyanobacteria blooms, which disrupt the functioning and the uses of the ecosystems.

- A. Rousseau has a long lasting collaboration with Alain Rapaport (UMR MISTEA, INRAE Montpellier) and Héctor Ramirez (CMM, Université du Chili).

3.2.3 Multiscale ocean models

Participants: Joao Guilherme Caldas Steinstraesser, Jose Daniel Galaz Mora, Antoine Rousseau.

The expertise of LEMON in this scientific domain is more in the introduction and analysis of new boundary conditions for ocean modelling systems, that can be tested on academical home-designed test cases. This is at the core of Antoine Rousseau's contributions over the past years. The real implementation, within operational ocean models, has to be done thanks to external collaborations which have already started with LEMON (see below).

State of the Art In physical oceanography, all operational models - regardless of the scale they apply to - are derived from the complete equations of geophysical fluid dynamics. Depending on the considered process properties (nonlinearity, scale) and the available computational power, the original equations are adapted with some simplifying hypotheses. The reader can refer to [81, 72] for a hierarchical presentation of such models.
In the shoaling zone, the hydrostatic approximation that is used in most large scales models (high sea) cannot be used without a massive loss of accuracy. In particular, shallow water models are inappropriate to describe the physical processes that occur in this zone (see Figure 1). This is why Boussinesq-type models are prefered [68]. They embed dispersive terms that allow for shoaling and other bathymetry effects. Since the pioneering works of Green and Naghdi [55], numerous theoretical and numerical studies have been delivered by the "mathematical oceanography" community, more specifically in France (see the works of Lannes, Marche, Sainte-Marie, Bresch, etc.). The corresponding numerical models (BOSZ, WaveBox) must thus be integrated in any reasonable nearshore modelling platform.

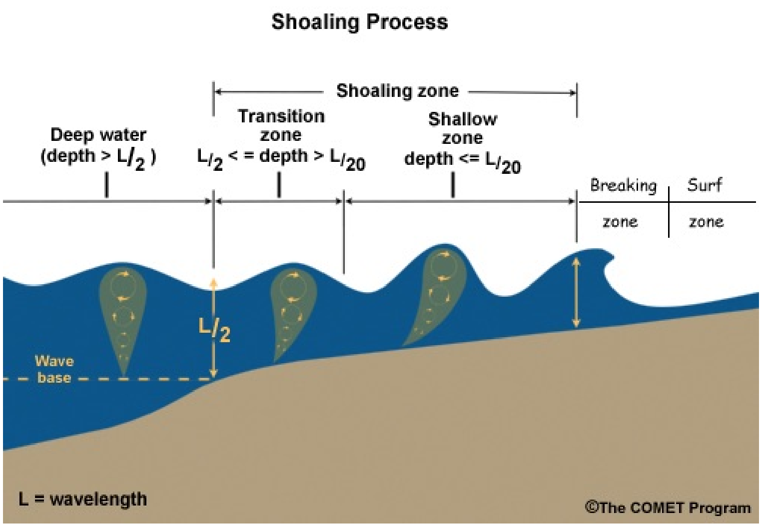

Figure 1: Deep sea, shoaling, and breaking zones.

However, these models cannot simply replace all previous models everywhere in the ocean: dispersive models are useless away from the shore and it is known that wave breaking cannot be simulated using Boussinesq-type equations. Hence the need to couple these models with others. Some work has been done in this direction with a multi-level nesting using software packages such as ROMS, but to the best of our knowledge, all the "boxes" rely on the same governing equations with different grid resolutions. A real coupling between different models is a more difficult task since different models may have different mathematical properties, as shown in the work by Eric Blayo and Antoine Rousseau on shallow water modelling [33].

Four year research objectives Starting from the knowledge acquired in the collaboration with Eric Blayo on model coupling using domain decomposition techniques, our ambition is to propose theoretical and numerical tools in order to incorporate nearshore ocean models into large complex systems including several space and time scales. This is one of the scientific objectives of the Inria challenge SURF, led by Arthur Vidard (Inria Grenoble). Two complementary research directions are considered:

Dispersive *vs* non-dispersive shallow water models As depicted in Figure 1, Boussinesq-type models (embedding dispersive effects) should be used in the so-called shoaling zone. The coupling with classical deep-sea / shallow water models has to be done such that all the processes in Figure 1 are correctly modelled (by different equations), with a reduced numerical cost. As a first guess, we think that Schwarz-type methods (widely used by the DDM community) could be good candidates, in particular when the interface locations are well-known. Moving interfaces (depending on the flow, the bathymetry and naturally the wind and all external forcings) is a more challenging objective that will be tackled after the first step (known interface) is achieved.

spectral *vs* time-domain models In the context of mathematical modelling and numerical simulation for the marine energy, we want to build a coupled numerical model that would be able to simulate wave propagation in domains covering both off-shore regions, where spectral models are used, and nearshore regions, better described by nonlinear dispersive (Boussinesq-type) models.
While spectral models work with a statistical and phase-averaged description of the waves, solving the evolution of its energy spectrum, Boussinesq-type models are phase-resolving and solves nonlinear dispersive shallow water equations for physical variables (surface elevation and velocity) in the time domain. Furthermore, the time and space scales are very different: they are much larger in the case of spectral models, which justifies their use for modelling off-shore propagation over large time frames. Moreover, important small scale phenomena in nearshore areas are better captured by Boussinesq models, in which the time step is limited by the CFL condition.
From a mathematical and modelling point of view, this task mainly consists in working on the boundary conditions of each model, managing the simultaneous use of spectral and time series data, while studying transparent boundary conditions for the models and developing domain decomposition approaches to improve the exchange of information.

External collaborations

- **Eric Blayo** is the former scientific leader of team MOISE in Grenoble, where Antoine Rousseau was first recruited. Eric Blayo and Antoine Rousseau have co-advised 3 PhDs and continue to work together on coupling methods in hydrodynamics, especially in the framework of the COMODO ANR network.
- In the framework of its collaboration with **MERIC**, Antoine Rousseau and Joao Guilherme Caldas Steinstraesser collaborate with the consortium DiMe (ANR-FEM project), and more particularly with Jean-François Filipot ans Volker Roeber for the coupling of spectral and time-domain methods.
- José Galaz's PhD is part of Inria's SURF challenge, which involves the AIRSEA, ANGE, CARDAMOM, FLUMINANCE and LEMON project teams. José's thesis is co-directed by Maria Kazolea (CARDAMOM).

3.3 Methodological developments

In addition to the application-driven sections, the team also works on the following theoretical questions. They are clearly connected to the above-mentioned scientific issues but do not correspond to a specific application or process.

3.3.1 Statistical approaches for extreme values

Participants: Gwladys Toulemonde, Samuel Valiquette.

State of the Art Max-stable random fields [85, 83, 65, 42, 75] are the natural limit models for spatial maximum data and have spawned a very rich literature. An overview of typical approaches to modelling maxima is due to [44]. Physical interpretation of simulated data from such models can be discussed. An alternative to the max-stable framework are models for threshold exceedances. Processes called

GPD processes, which appear as a generalization of the univariate formalism of the high thresholds exceeding a threshold based on the GPD, have been proposed [48, 91]. Strong advantages of these thresholding techniques are their capability to exploit more information from the data and explicitly model the original event data. However, the asymptotic dependence stability in these limiting processes for maximum and threshold exceedance tends to be overly restrictive when asymptotic dependence strength decreases at high levels and may ultimately vanish in the case of asymptotic independence. Such behaviors appear to be characteristic for many real-world data sets such as precipitation fields [43, 90]. This has motivated the development of more flexible dependence models such as max-mixtures of max-stable and asymptotically independent processes [96, 29] for maxima data, and Gaussian scale mixture processes [76, 64] for threshold exceedances. These models can accommodate asymptotic dependence, asymptotic independence and Gaussian dependence with a smooth transition.

Extreme events also generally present a temporal dependence [92]. Developing flexible space-time models for extremes is crucial for characterizing the temporal persistence of extreme events spanning several time steps; such models are important for short-term prediction in applications such as the forecasting of wind power and for extreme event scenario generators providing inputs to impact models, for instance in hydrology and agriculture. Currently, only few models are available from the statistical literature (see for instance [40, 41, 63]) and remain difficult to interpret.

Four year research objectives The objective is to extend state-of-the-art methodology with respect to three important aspects:

1. adapting well-studied spatial modelling techniques for extreme events based on asymptotically justified models for threshold exceedances to the space-time setup;
2. replacing restrictive parametric dependence modelling by semiparametric or nonparametric approaches;
3. proposing more flexible spatial models in terms of asymmetry or in terms of dependence. This means being able to capture the strength of potentially decreasing extremal dependence when moving towards higher values, which requires developing models that allow for so-called asymptotic independence.

External collaborations In a natural way, the Cerise and Fraise project[5] members are the main collaborators for developing and studying new stochastic models for extremes.

- More specifically, research with Jean-Noel Bacro (IMAG, UM), Carlo Gaetan (DAIS, Italy) and Thomas Opitz (BioSP, MIA, INRAE) focuses on relaxing dependence hypothesis.
- The asymmetry issue and generalization of some Copula-based models are studied with Julie Carreau (IRD, HydroSciences Montpellier; now at Polytechnique Montreal).

3.3.2 Stochastic methods for rainfall-forcing

Participants: Carole Delenne, Vincent Guinot, Gwladys Toulemonde.

State of the Art Reproducing optimally realistic spatio-temporal rainfall fields is of salient importance to the forcing of hydrodynamic models. This challenging task requires combining intense, usual and dry weather events. Far from being straightforward, this combination of extreme and non-extreme scenarii requires a realistic modelling of the transitions between normal and extreme periods. [73] have proposed, in a univariate framework, a statistical model that can serve as a generator and that takes into account low, moderate and intense precipitation. In the same vein, [95] developed a bivariate model. However, its extension to a spatial framework remains a challenge. Existing spatial precipitation stochastic generators

[5] Cerise (2016-2018) and Fraise (2019-2021) (see 10.3) are research program funded by LEFE MANU (MAthematical and Numerical methods) of the CNRS and led by Gwladys Toulemonde.

are generally based on Gaussian spatial processes [31, 69], that are not adapted to generate extreme rainfall events. Recent advances in spatio-temporal extremes modelling based on generalized Pareto processes [48, 91] and semi-parametric simulation techniques [36] are very promising and could form the base for relevant developments in our framework.

Four year research objectives The purpose is to develop stochastic methods for the simulation of realistic spatio-temporal processes integrating extreme events. Two steps are identified. The first one is about the simulation of extreme events and the second one concerns the combination of extreme and non extreme events in order to build complete, realistic precipitations time series. As far as the first step is concerned, a first task is to understand and to model the space-time structure of hydrological extremes such as those observed in the French Mediterranean basin, that is known for its intense rainfall events (Cevenol episodes), which have recently received increased attention. We will propose modelling approaches based on the exceedance, which allows the simulated fields to be interpreted as events. Parametric, semi-parametric and non-parametric approaches are currently under consideration. They would allow a number of scientific locks to be removed. Examples of such locks are e.g. accounting for the temporal dimension and for various dependence structures (asymptotic dependence or asymptotic independence possibly depending on the dimension and/or the distance considered). Methodological aspects are detailed in Section 3.3.1. The second step, which is not straightforward, consists in combining different spatio-temporal simulations in order to help to ultimately develop a stochastic precipitation generator capable of producing full precipitation fields, including dry and non-extreme wet periods.

External collaborations The Cerise (2016-2018) and Fraise (2019-2021) projects (see 10.3), led by Gwladys Toulemonde, are funded by the action MANU (MAthematical and Numerical methods) of the CNRS LEFE program [6]. Among others, they aim to propose methods for simulating scenarii integrating spatio-temporal extremes fields with a possible asymptotic independence for impact studies in environmental sciences. Among the members of this project, Jean-Noel Bacro (IMAG, UM), Carlo Gaetan (DAIS, Italy) and Thomas Opitz (BioSP, MIA, INRAE) are involved in the first step as identified in the research objectives of the present sub-section. Denis Allard (BioSP, MIA, INRAE), Julie Carreau (IRD, HSM; now at Polytechnique Montreal) and Philippe Naveau (CNRS, LSCE) will be involved in the second one.

3.3.3 Exploitation of heterogeneous data to improve model inputs

Numerical modelling requires data acquisition at several steps such as model validation, parameter assessment and practical implementation for operational use. The following two paths for research are devoted to data exploitation for hydraulic models: from data assimilation for model calibration to heterogeneous data fusion for a better knowledge of geometries and forcings.

a. Parametrization of shallow water models with porosity

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau.

State of the Art Model benchmarking against laboratory experiments is an essential step and is an integral part of the team's strategy. However, scale model experiments may have several drawbacks: (i) experiments are very expensive and extremely time-consuming, (ii) experiments cannot always be replicated, and measurement have precision and reliability limitations, (iii) dimensional similarity (in terms of geometry and flow characteristic variables such as Froude or Reynolds numbers) cannot always be preserved.

An ideal way to obtain data would be to carry out in situ measurements. But this would be too costly at the scale of studied systems, not to mention the fact that field may become impracticable during flood periods.

[6] Les Enveloppes Fluides et l'Environnement

Geographical and remote sensing data are becoming widely available with high spatial and temporal resolutions. Several recent studies have shown that flood extents can be extracted from optical or radar images [54], for example: to characterize the flood dynamics of great rivers [74], to monitor temporary ponds [87], but also to calibrate hydrodynamics models and assess roughness parameters (e.g. [97]).

Upscaled models developed in LEMON (see 3.1.1 and 3.2.1) embed new parameters that reflect the statistical properties of the medium geometry and the subgrid topography. New methods are thus to be developed to characterize such properties from remote sensing and geographical data.

Four year research objectives This research line consists in deriving methods and algorithms for the determination of upscaled model parameters from geodata.

For applications in urban areas, it is intended to extract information on the porosity parameters from National geographical survey databases largely available in developed countries. Such databases usually incorporate separate layers for roads, buildings, parking lots, yards, etc. Most of the information is stored in vector form, which can be expected to make the treatment of urban anisotropic properties easier than with a raster format. In developing countries, data is made increasingly available over the world thanks to crowdsourcing (e.g. OpenStreetMap) the required level of detail sometimes not available in vector format, especially in suburban areas, where lawns, parks and other vegetated areas, that may also contribute to flood propagation and storage, are not always mapped. In this context, the necessary information can be extracted from aerial and/or satellite images, that are widely available and the spatial resolution of which improves constantly, using supervised classification approaches.

For applications in great rivers the main objective is to develop an efficient framework for optimally integrating remote sensing derived flood information to compensate the lack of observation related to riverbed bathymetry and river discharge. The effective integration of such remote sensing-derived flood information into hydraulic models remains a critical issue. In partnership with R. Hostache (LIST), we will investigate new ways for making use of Satellite Earth Observation data (i.e. flooded areas and water level estimates derived from Synthetic Aperture Radar (SAR) data collections) for retrieving uncertain model parameters and boundary conditions. The method will be developed and validated using synthetically generated data sets as well as real-event data retrieved from the European Space Agency's archives. Extensive testing will be carried out in a number of high magnitude events recorded over the Severn (United Kingdom) and Zambezi (Mozambique) floodplain areas.

In wetlands applications, connectivity between different ponds is highly dependent on the free surface elevation, thus conditioning the presence of a flow. Characterizing such connectivity requires that topographical variations be known with high accuracy. Despite the increased availability of direct topographic measurements from LiDARS on riverine systems, data collection remains costly when wide areas are involved. Data acquisition may also be difficult when poorly accessible areas are dealt with. If the amount of topographic points is limited, information on elevation contour lines can be easily extracted from the flood dynamics visible in simple SAR or optical images. A challenge is thus to use such data in order to estimate continuous topography on the floodplain combining topographic sampling points and located contour lines the levels of which are unknown or uncertain.

External collaborations

- A first attempt for topography reconstruction in wetlands was done in collaboration with J.-S. Bailly (LISAH) in 2016 [46]. We have reactivated this research track within the 4-year period [7].
- Porosity model calibration for application on great rivers will be done in the framework of CASCADE project in collaboration with R. Hostache (LIST).

b. Data fusion and completion

Participants: Carole Delenne, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

State of the Art Assuming that a given hydrodynamic models is deemed to perform satisfactorily, this is far from being sufficient for its practical application. Accurate information is required concerning the overall geometry of the area under study and model parametrization is a necessary step towards the operational use. Moreover, the considered flow models are deterministic and must be conditioned by some forcings, such as rainfall events. When large areas are considered, data acquisition may turn out prohibitive in terms of cost and time, not to mention the fact that information is sometimes not accessible directly on the field. To give but one example, how can the roughness of an underground sewer pipe be measured? A strategy should be established to benefit from all the possible sources of information in order to gather data into a geographical database, along with confidence indexes.

The assumption is made that even hardly accessible information often exists. This stems from the increasing availability of remote-sensing data, to the crowd-sourcing of geographical databases, including the inexhaustible source of information provided by the Internet. However, information remains quite fragmented and stored in various formats: images, vector shapes, texts, etc.

This path of research began with the Cart'Eaux project (2015-2018), that aims to produce regular and complete mapping of urban wastewater system. Contrary to drinkable water networks, the knowledge of sewer pipe location is not straightforward, even in developed countries. Over the past century, it was common practice for public service providers to install, operate and repair their networks separately [80]. Now local authorities are confronted with the task of combining data produced by different parts, having distinct formats, variable precision and granularity [38].

Four year research objectives The overall objective of this research line is to develop methodologies to gather various types of data in the aim of producing an accurate mapping of the studied systems for hydrodynamics models.

Concerning wastewater networks, the methodology applied consists in inferring the shape of the network from a partial dataset of manhole covers that can be detected from aerial images [79, 39]. Since manhole covers positions are expected to be known with low accuracy (positional uncertainty, detection errors), a stochastic algorithm is set up to provide a set of probable network geometries [35]. As more information is required for hydraulic modelling than the simple mapping of the network (slopes, diameters, materials, etc.), text mining techniques such as used in [66] are particularly interesting to extract characteristics from data posted on the Web or available through governmental or specific databases. Using an appropriate keyword list, thematic entities are identified and linked to the surrounding spatial and temporal entities in order to ease the burden of data collection. It is clear at this stage that obtaining numerical values on specific pipes will be challenging. Thus, when no information is found, decision rules will be used to assign acceptable numerical values to enable the final hydraulic modelling.

Concerning rain inputs, instrumental configurations often present sparsity and do not correspond to the required spatiotemporal resolutions (on the order of km and hour, or even 100 meters and a few minutes in urban environments). To overcome this problem, LEMON contributes to the establishment of an urban observatory. This observatory creates a dense network of about twenty rain gauges on the Triolet campus of the University of Montpellier and surrounding areas at extremely fine spatial and temporal resolutions never achieved in the region until now. Other data sources can be used to complement the information provided by the observation network. Combining these heterogeneous, multi-source, multi spatial and temporal resolution data is a difficult task, rain being one of the most complex climatic processes due to (i) its binary nature (presence/absence), (ii) the importance of aggregation of strong values over space and time (floods), and (iii) the strong variations that can appear even at very small spatial and temporal scales. This data aggregation step is nevertheless essential because the quality and resolution of the data will determine the quality of the synthetic rainfall that can be simulated.

In any case, the confidence associated to each piece of data, be it directly measured or reached from a roundabout route, should be assessed and taken into account in the modelling process. This can be done by generating a set of probable inputs (geometry, boundary conditions, forcing, etc.) yielding simulation results along with the associated uncertainty.

Combining heterogeneous data for a better knowledge of studied systems raises the question of data fusion. What is the reality when contradictory information is collected from different sources? Dealing with spatial information, offset are quite frequent between different geographical data layers; pattern comparison approaches should be developed to judge whether two pieces of information represented by two elements close to each other are in reality identical, complementary, or contradictory.

3.3.4 Numerical methods for porosity models

Participants: Vincent Guinot, Pascal Finaud-Guyot.

State of the Art Porosity-based shallow water models are governed by hyperbolic systems of conservation laws. The most widespread method used to solve such systems is the finite volume approach. The fluxes are computed by solving Riemann problems at the cell interfaces. This requires that the wave propagation properties stemming from the governing equations be known with sufficient accuracy. Most porosity models, however, are governed by non-standard hyperbolic systems.

Firstly, the most recently developed Dual Integral Porosity (DIP) models include a momentum source term involving the divergence of the momentum fluxes [62]. This source term is not active in all situations but takes effect only when positive waves are involved [57, 60]. The consequence is a discontinuous flux tensor and discontinuous wave propagation properties. The consequences of this on the existence and uniqueness of solutions to initial value problems (especially the Riemann problem) are not known, or are the consequences for the accuracy of the numerical methods used to solve this new type of equations.

Secondly, most applications of these models involve anisotropic porosity fields [67, 82]. Such anisotropy can be modelled using 2×2 porosity tensors, with principal directions that are not aligned with those of the Riemann problems in two dimensions of space. The solution of such Riemann problems has not been investigated yet. Moreover, the governing equations not being invariant by rotation, their solution on unstructured grids is not straightforward.

Thirdly, the Riemann-based finite volume solution of the governing equations require that the Riemann problem be solved in the presence of a porosity discontinuity. While recent work [47] has addressed the issue for the single porosity equations, similar work remains to be done for integral- and multiple porosity-based models.

Four year research objectives The four year research objectives are the following:

- investigate the properties of the analytical solutions of the Riemann problem for a continuous, anisotropic porosity field,
- extend the properties of such analytical solutions to discontinuous porosity fields,
- derive accurate and CPU-efficient approximate Riemann solvers for the solution of the conservation form of the porosity equations.

External collaborations Owing to the limited staff of the LEMON team, external collaborations will be sought with researchers in applied mathematics. Examples of researchers working in the field are

- Minh Le, Saint Venant laboratory, Chatou (France): numerical methods for shallow water flows, experience with the 2D, finite element/finite volume-based Telemac2D system.
- M.E. Vazquez-Cendon, Univ. Santiago da Compostela (Spain): finite volume methods for shallow water hydrodynamics and transport, developed Riemann solvers for the single porosity equations.
- A. Ferrari, R. Vacondio, S. Dazzi, P. Mignosa, Univ. Parma (Italy): applied mathematics, Riemann solvers for the single porosity equations.
- O. Delestre, Univ. Côte d'Azur (France): development of numerical methods for shallow water flows (source term treatment, etc.)
- F. Benkhaldoun, Univ. Paris 13 (France): development of Riemann solvers for the porous shallow water equations.

4 Application domains

4.1 Overview

The protection of coastal areas around the world has become an important issue of concern, including within the scientific community. The coastline is defined as the physical separation between the sea or ocean on the one hand and the inland on the other, but these two worlds are in fact intertwined, which contributes to the difficulty of their modelling, both from a physical and statistical point of view.

4.2 Coastal Oceanography

Wave propagation models in the nearshore zone have evolved significantly over the last 15 years, with contributions that increasingly take into account effects related to variations of bathymetry, hence the non-hydrostatic nature of the flow. These models, very specific to the coastal zone, must be able to be coupled (together and with external models) so as to allow wave propagation numerical models to be integrated into numerical forecasting platforms, both in oceanography and in flood risk management.

4.3 Urban Floods

Due to climate change and rising sea levels, more and more cities are facing the risk of flooding. Whether they are in coastal areas or near rivers, these areas, which are inherently highly artificial and therefore poorly resistant to rising water levels, require different types of numerical models for flood risk: accurate (and potentially costly) models for land use planning, but also fast models, which can be run in real time, for crisis management.

4.4 Hasard and Risk Assessment

Modelling and risk assessment are at the heart of coastal science. Whether the events considered are of natural or anthropogenic origin, their economic, ecological or human impacts are too important to be neglected. By definition, the more extreme an event is, the lower its frequency of occurrence and therefore the less data available to characterize it. Hence the importance of using statistical tools dedicated to the modelling of extreme events, in order to provide risk management tools that are as safe and effective as possible.

5 Social and environmental responsibility

5.1 Footprint of research activities

Given the sanitary conditions endured throughout the year, we carried out few professional missions in 2021. Even students from South America did not have the opportunity to return to their families in the summer or during the holiday season.

Like all Inria teams, the many calculations we perform (on our personal computers or on dedicated clusters) do have an environmental cost. This cost is linked both to the resources needed to manufacture the machines we use, and to the energy consumed to run them.

LEMON members are aware of the climate emergency and are participating in actions on this subject. For example, Pascal Finaud-Guyot is involved in the "sustainable development and social responsibility" working group at Polytech Montpellier and in "energy footprint reduction" working group at HSM with Carole Delenne.

5.2 Impact of research results

Our research activities have a twofold impact in terms of environmental responsibility:

- the research carried out in the field of renewable energy contributes to the increase of decarbonized energy (especially through the team's activities in Chile, in collaboration with the MERIC center of excellence).
- in addition, given the climate change already underway, the team's work in environmental risk assessment and management contributes to better anticipation of natural hasards which, unfortunately, will continue to occur in the coming decades.

6 Highlights of the year

- A first version of the SW2D-LEMON platform (developed via with the SED team of engineers in Sophia-Anipolis) has been deployed at Polytech Montpellier (see Section 7). It will be used as a teaching tool within the Water Science & Technology engineering curriculum.
- 4 members of LEMON affiliated to the University of Montpellier undertook particularly significant academic responsibilties in 2021 (1 head of department, 2 programme coordinators and 1 head Admissions at Polytech Montpellier), for a total 1000 hrs.

7 New software and platforms

Let us describe new/updated software.

7.1 New software

7.1.1 SW2D-Lemon

Name: Shallow Water 2D - Lemon C++ software

Keywords: Numerical simulations, Shallow water equations, Upscaling, Finite volume methods

Scientific Description: SW2D-LEMON (SW2D for Shallow Water 2D) is developed by the LEMON research team in Montpellier. SW2D-LEMON is a multi-model software focusing on shallow water-based models. It includes an unprecedented collection of upscaled (porosity) models used for shallow water equations and transport- reaction processes. Porosity models are obtained by averaging the two-dimensional shallow water equations over large areas containing both a water and a solid phase. The size of a computational cell can be increased by a factor 10 to 50 compared to a 2D shallow water model, with CPU times reduced by 2 to 3 orders of magnitude. Applications include urban flood simulations as well as flows over complex topography. Besides the standard shallow water equations (the default model), several porosity models are included in the platform: (i) Single Porosity, (ii) Dual Integral Porosity, and (iii) Depth-dependent Porosity model. Various flow processes (friction, head losses, wind, momentum diffusion, precipitation/infiltration) can be included in a modular way by activating specific execution flags. Several examples are included to illustrate the potential of SW2D.

Functional Description: 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.

Release Contributions: - binary file for educational purposes (including documentation) first release - remove dependency with former package geo through mc.inria.fr ## version 0.8.1 - 04/02/2021 - now using dtk-forge (packages should be more homogeneous) (!220) - fixed frequency refresh for simulation (!246) - fixed using the control bar before finish breaking the results (!249) - fixed spurious call to close (!247) - added help menu (!238) - forbid loading settings during simulation (!244) ## version 0.8.0a - 28/01/2021 - logging now appears in the GUI sw2dModeler (!212) - you can extract values at chosen time using a dedicated text file (!217) - added various scripts and examples (!230 !229) - output file name changed (!224)

News of the Year: In 2021, some new features / tests have been included, and most of the work has consisted in some optimization in order to accelerate SW2D-LEMON. The software was also transfered to Polytech'Montpellier for educational purposes and to Tour du Valat (scientific fundation) for the numerical simulations of Camargue ponds.

URL: `https://sw2d.inria.fr/`

Publications: hal-01884110, hal-01878242, hal-01582224, hal-01541070, hal-01465071, hal-01118743, hal-02269526, hal-02269564, hal-03224056, hal-03224050, hal-02903282

Contact: Antoine Rousseau

Participants: Vincent Guinot, Antoine Rousseau, Carole Delenne, Pascal Finaud Guyot, Joao Guilherme Caldas Steinstraesser, Joseph Luis Kahn Casapia

Partner: Université de Montpellier

7.1.2 tsunamilab

Name: TsunamiLab

Keywords: Tsunamis, GPGPU, Dissemination, Web

Functional Description: TsunamiLab is an interactive tsunami simulation and visualization platform that teaches and raises awareness about tsunamis through interactive experiences. It allows science communicators, teachers, students and science enthusiasts to create virtual tsunamis or recreate historical tsunamis, and study their features in various digital and augmented reality formats.

TsunamiLab-Pool: Using cameras and projectors, the "pool" format allows children and adults to interact with their own hands, gathered around the circular screen. This allows the instructor to teach and engage several children simultaneously, in a way that is entertaining for all.

Web Platform: The platform's website allows anyone to simulate historical tsunamis, observe how they propagated in the ocean, and test what would have happened if they had been of greater or lesser magnitude.

Hologram: Through a prism, a holographic image makes it possible to observe the impact in different parts of the world at the same time.

Large Touch Screen: Support for large touch screens allows teachers to observe and explain phenomena in an engaging way in front of a group of students.

News of the Year: This year, TsunamiLab was used in several workshops at the "Fête de la Science" in France and in Chile.

URL: `http://www.tsunamilab.cl`

Publications: hal-02112763, hal-03514473

Contact: José Daniel Galaz Mora

Participants: José Daniel Galaz Mora, Antoine Rousseau

Partners: Cigiden, Inria Chile

8 New results

8.1 Urban Floods

8.1.1 Street-building exchange

Operational interest of the street-building exchange model

Participants: Pascal Finaud-Guyot, Cécile Choley.

Collaboration: Guilhem Dellinger (ENGEES, Icube Laboratory), André Paquier (INRAE Lyon).

Within the context of the Cécile Choley PhD Thesis, two milestones have been reached regarding the modelling of the street-building exchanges during an urban flood. First, the exchange law giving the discharge through an opening has been established on the basis of fine 3D hydrodynamic simulations. Over the tested range (representing floods with a water depth in the street up to 3.5m), the proposed law allow for a discharge estimation with an error of less than 20%.

A street-building exchange model is also implemented in sw2d allowing for simulation at larger scale than using a 3D approach. This model has been successfully applied to the 1988 Nîmes (Gard, France) flood in the Richelieu district (data provided by A. Paquier, INRAE Lyon) that leads to 11 fatalities. Comparing the results with and without buildings allow to highlight a significant modification of the street hydrodynamic with an increase of only 6% of the computational time. Over the range of the tested configurations, the street water is either increase or decrease of up to 60cm; subsequently, the flow velocity norm is modified of 1m/s.

The water depth evolution modeled in the building provides a new valuable information to better characterize the potential damages. Moreover, the comparison of the free surface elevation in both the building and the linked street highlights significant difference (either positive or negative) occurring up to 60% of the flood duration which invalidates the classical operational methodology.

This work has been presented at the 2021 SimHydro conference [13] and will be published in 2022.

8.1.2 Porosity models for upscaled urban flood modelling

SW2D-LEMON: a new software for upscaled shallow water modelling

Participants: Joao Guilherme Caldas Steinstraesser, Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Joseph Kahn Casapia, Antoine Rousseau.

In the international conferences Simhydro 2021 and EGU 2021, we presented in [11, 17] a new multi-OS platform named SW2D-LEMON (SW2D for Shallow Water 2D) developed by the LEMON research team in Montpellier. SW2D-LEMON is a multi-model software focusing on shallow water-based models. It includes an unprecedented collection of upscaled (porosity) models used for shallow water equations and transportreaction processes. Porosity models are obtained by averaging the two-dimensional shallow water equations over large areas containing both a water and a solid phase. The size of a computational cell can be increased by a factor 10 to 50 compared to a 2D shallow water model, with CPU times reduced by 2 to 3 orders of magnitude. Applications include urban flood simulations as well as flows over complex topography. Besides the standard shallow water equations (the default model), several porosity models are included in the platform: (i) Single Porosity, (ii) Dual Integral Porosity, and others are currently under development such as (iii) Depth-dependent Porosity model. Various flow processes (friction, head losses, wind, momentum diffusion, precipitation/infiltration) can be included in a modular way by activating specific execution flags. We recall here the governing equations as well as numerical aspects and present the software features. Several examples are presented to illustrate the potential of SW2D.

8.1.3 Downscaling

Modified parareal method for the nonlinear shallow water equations

Participants: Joao Guilherme Caldas Steinstraesser, Vincent Guinot, Antoine Rousseau.

The POD-DEIM-based parareal method introduced by [37] is implemented for solving the two-dimensional nonlinear shallow water equations using a finite volume scheme. This method is a variant of the traditional parareal method, first introduced by [70], that improves the stability and convergence for nonlinear hyperbolic problems, and uses reduced-order models constructed via the Proper Orthogonal Decomposition - Discrete Empirical Interpolation Method (POD-DEIM) applied to snapshots of the solution of the parareal iterations. We propose a modification of this parareal method for further stability and convergence improvements. It consists in enriching the snapshots set for the POD-DEIM procedure with extra snapshots whose computation does not require any additional computational cost. The performances of the classical parareal method, the POD-DEIM-based parareal method and our proposed modification are compared using numerical tests with increasing complexity. Our modified method shows a more stable behaviour and converges in fewer iterations than the other two methods. This work has been published in [5] and presented in the international conference Simhydro 2021 [12]. It was also part of Joao Guilherme Caldas Steinstraesser's PhD thesis [24].

Neural networks and boosted trees for multiscale shallow water equations

Participants: Kilian Bakong, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

During K. Bakong's internship, supported by IRT Saint-Exupery, we considered downscaling algorithms for shallow water flows thanks to artificial intelligence techniques. Neural networks and boosted trees are used for the simulation of high resolution flow variables computed from low resolution inputs. Various numerical configurations are addressed, with or without using principle component analysis to reduce the computational coast of training and forecasting steps.
A publication shall be submitted in early 2022.

8.2 Natural flows

8.2.1 Depth-Dependent Porosity model

DDP model for runoff modelling

Participants: Pascal Finaud-Guyot, Vincent Guinot.

Collaboration: Mahmoud Moussa (University of Tunis El Manar, Laboratory of Modelling in Hydraulics and Environment), Denis Feurer (UMR LISAH).

Modelling the runoff on cultivated parcels allow to characterize hydrodynamic fields (mainly water depth and velocity) during intense rainfall events that are responsible for soil erosion. For hydraulics, the relevant topographic detail has a characteristic size of the order of a decimeter or less which implies mesh with elements of few centimeters with a classical 2D shallow water model and unrealistic computational time.

The DDP model [58] has been designed to allow coarse grid simulation of shallow flows over complex topographies and geometries. This model has been compared to a fine classical 2D shallow water model on a synthetic runoff configuration [98]. In a steady-state configuration, the DDP model allows to successfully represent the free surface and average velocity distribution. With a 2500 times coarser mesh, the model allows for a reduction by 50000 of the computational time.

This work has been carried out during Yahyaoui Master thesis funded by the LMI Naïla that will continue in 2022 by a PhD thesis.

Efficient flood inundation modelling of the Severn River with DDP model

Participants: Carole Delenne, Vita Ayoub, Pascal Finaud-Guyot.

Collaboration: Renaud Hostache, Marco Chini, Patrick Matgen, Ramona Maria Pelich (LIST), David Mason (Univ. Reading).

Hydrodynamic models are powerful tools for flood hazard assessment but face numerous challenges, especially when operating at a large scale. The downside of discretising an area using a fine mesh yielding more accurate results, is the expensive computational cost of simulations. Moreover, critical input information such as bathymetry (i.e, riverbed geometry) are required but cannot be easily collected by field measurements or remote sensing observations. During the past few years, the development of sub grid models has gained a growing interest as these enable faster simulations by using coarser cells and, at the same time, preserve small-scale topography variations within the cell. In this study, we propose and evaluate a modelling framework based on the shallow water 2D model with depth-dependent porosity enabling to represent floodplain and riverbed topography through porosity functions. To enable a careful and meaningful evaluation of the model, we set up a 2D classical model and use it as a benchmark. We also exploit ground truth data and remote sensing derived flood inundation maps to evaluate the proposed modelling framework and use as test cases the 2007 and 2012 flood events of the river Severn (United Kingdom). The results, presented in Simhydro 2021 conference, [15] have been submitted for publication to Advances in Water Resources, demonstrate a high performance and low computational cost of the proposed model for fast flood simulations at a large scale.

8.3 Methodological developments

8.3.1 Statistical approaches for extreme values

On the use of Extreme value theory for the choice of mixture Poisson models

Participants: Gwladys Toulemonde, Samuel Valiquette.

Collaboration: Frédéric Mortier (Cirad), Jean Pehardi (Université de Montpellier).

Count data are widely observed in many applied fields like marine species. However, such data present overdispersion because excess of zeroes or extreme values. The use of the Poisson distribution fails to correctly fit such data. To overcome this limitation, mixture Poisson distribution is an elegant strategy to improve model performances. Such model supposes the Poisson's parameter is a positive random variable. But the choice of the distribution is tricky and the approach consisting of comparing models based on information criterion is computationally inefficient. In this work, based on extreme event theory, we propose an original strategy to select the most appropriate candidates belonging to three categories: Fréchet, Gumbel and pseudo-Gumbel. This approach is evaluated on simulations. This work involving two LEMON members was partially presented at the Journées de Statistique by Samuel Valiquette in June 2021 [14].

Non-parametric estimator of a multivariate madogram for missing-data and extreme value framework

Participants: Gwladys Toulemonde, Alexis Boulin.

Collaboration: Elena Di Bernardino (Université de Côte d'Azur), Thomas Laloé (Université de Côte d'Azur).

The modelling of dependence between maxima is an important subject in several applications in risk analysis. To this aim, the extreme value copula function, characterised via the madogram, can be used as a margin-free description of the dependence structure. From a practical point of view, the family of extreme value distributions is very rich and arise naturally as the limiting distribution of properly normalised component-wise maxima. We investigate the nonparametric estimation of the madogram where data are completely missing at random. We provide the functional central limit theorem for the considered multivariate madrogram correctly normalized, towards a tight Gaussian process for which the covariance function depends on the probabilities of missing. Explicit formula for the asymptotic variance is also given. Our results are illustrated in a finite sample setting with a simulation study. This work is presented in a preprint in 2021 [26].

8.3.2 Coupling

High-resolution modelling of nearshore circulation in an upwelling ecosystem

Participants: Antoine Rousseau.

While numerical modelling has proven successful at reproducing the physical, chemical, and biological processes associated with circulation over regional and mesoscales, challenges remain for modelling the coastal zone at sufficiently high resolution to resolve coastal flows and their interactions with larger-scale processes. Computational costs associated with grid resolution and limited observations for model validation are important concerns. This study evaluates a climatological hydrodynamic model off central Chile (28-38°S), which has three nested domains to reproduce both the regional and nearshore circulation patterns. To determine whether submesoscale processes propagate up to larger scales, results from the nested High-Resolution Model (HRM2, 32-34°S and 0.87 km resolution) and its parent (HRM0, 28-36°S and 7.4 km) were compared with those from a Low-resolution Model (LRM0) configured with the exact resolution as the HRM0. While both HRM0 and LRM0 reproduced well the climatological Sea

Surface Temperature (SST) and Salinity (SSS), as well as the general spatial patterns of kinetic energy, the annual transport of the Peru-Chile Undercurrent (PCUC) increased in the nested HRM0 (-0.7 to-1.3 Sv) compared to the LRMO (-0.58 to-0.95 Sv). Moreover, the Coastal Chilean Current (CCC) became up 2.16 faster in HRM2 than in LRM0, with a sharp shoreward decline in the maximum speed (down to 1 11 cm/s) nearshore, defining in this manner a coastal boundary layer (CBL), which was not reproduced by the LRM0. Also, the upwelling process in the HRMO was intensified by topographic features and was spatially consistent with ageostrophic circulation patterns. As expected, the most remarkable differences between model resolutions emerged nearshore, especially within the CBL, highlighting the importance of topographic effects on coastal circulation. Thus, although the low-resolution model can reproduce patterns of circulation in the coastal ocean fairly well, resolving submesoscale variability as in the HRMO imposes moderate to large changes in transport, current velocities, vorticity and topographic realism of the upwelling process. The extent to which variation in these processes affects biochemical processes, particle transports, and or larval dispersal must still be investigated. This work is presented in a preprint in 2021 [27].

8.3.3 Model parametrization

Endoreic waterbodies delineation from remote-sensing as a tool for immersed surface topography.

Participants: Carole Delenne, Antoine Rousseau.

Collaboration: Jean-Stephane Bailly (INRAE), Olivier Boutron (Tour du Valat), Renaud Hostache (LIST).

This path for research was initiated several years ago in collaboration with J. S. Bailly (LISAH). We recently came up with a methodology developed on synthetic data and published in Geosciences and Remote Sensing Letters [7]. Since several decades, it becomes possible to delineate waterbodies and their dynamics from optical or radar images, that are now available at high spatial and temporal resolutions. We present here an interpolation approach that takes benefits from this waterbodies delineation which consist in endoreic areas, in isovalue contourlines to improve topography estimation classically obtained from measurement points only. The approach, based on a minimisation problem, uses Thin Plate Splin interpolation functions, whose coefficient are determined along with the unknown water level of each curve. Results obtained on a generated topography show that this approach, applied with three contourline curves, yields a lower root mean square error with only one measurement point as the one obtained with nine points and the classical approach. The real-case application to the Rascaillan pond, was made possible by the collaboration with Olivier Boutron from Tour du Valat and Renaud Hostache from LIST. It shows that this approach can easily be implemented using widely available data such as Sentinel images, yielding a large decrease of the root mean square error between the interpolated topography and the reference Lidar acquisition, even using only two satellite images.

8.3.4 Heterogeneous data

Graph Convolutional Networks: Application to Database Completion of Wastewater Networks.

Participants: Carole Delenne, Yassine Belghaddar.

Collaboration: Nanée Chahinian (IRD), Ahlame Begdouri (FST Fes), Abderrahmane Seriai (Berger-Levrault).

Wastewater networks are mandatory for urbanisation. Their management, including the prediction and planning of repairs and expansion operations, requires precise information on their underground components (manhole covers, equipment, nodes, and pipes). However, due to their years of service and to the increasing number of maintenance operations they may have undergone over time, the attributes and characteristics associated with the various objects constituting a network are not all available at a given time. This is partly because (i) the multiple actors that carry out repairs and extensions are not necessarily the operators who ensure the continuous functioning of the network, and (ii) the undertaken changes are not properly tracked and reported. Therefore, databases related to wastewater networks may suffer from missing data. To overcome this problem, we aim to exploit the structure of wastewater networks in the learning process of machine learning approaches, using topology and the relationship between components, to complete the missing values of pipes. Our results show that Graph Convolutional Network (GCN) models yield better results than classical methods and represent a useful tool for missing data completion. This work has been published in [10] and presented to EGU General Assembly 2021 [23].

8.3.5 Numerical methods for porosity models

Downscaling of shallow water flows

Participants: Pascal Finaud-Guyot, Vincent Guinot.

Collaboration: Julie Carreau (IRD, HSM; now at Polytechnique Montreal).

An AI-based method (Principal Component Analysis [PCA] + Artificial Neural Networks [ANNs]) has been developed to infer high resolution flow fields from low resoltion, upscaled flow fields in urban areas. The feasibility of the approach has been tested under the assumption of perfect upscaling. It is applied to the downscaling of urban floods within synthetic and real-world urban areas. The work is presented in [6]. A simpler method, based on local downscaling and the fitting of power fuctions, has been presented at the SimHydro 2021 Conference [20]. It exhibits similar perfomance to the abovementioned PCA-ANN method.

8.4 Other contributions

8.4.1 Soil moisture modelling in context of climate change

Participants: Pascal Finaud-Guyot.

Collaboration: Yves Tremblay (IRD, HSM).

Soil moisture characterises agricultural droughts and plays a key role on runoff generation and thus on flood generation. Future soil moisture of the Mediterranean region is modelled under various climate scenarios to evaluate the impacts of changing precipitation patterns on extreme hydrological events such as droughts and floods.

This study focuses on 10 sites, located in southern France, with available soil moisture, temperature, and precipitation observations for a 10-year time period. Soil moisture is simulated at each site at the hourly time step using a model of soil water content. The sensitivity of the simulated soil moisture to different changes in precipitation and temperature is evaluated by simulating the soil moisture response to temperature and precipitation scenarios generated using a delta change method for temperature and a stochastic model (the Neyman–Scott rectangular pulse model) for precipitation.

Results show that soil moisture is more impacted by changes in precipitation intermittence than precipitation intensity and temperature. Overall, increased temperature and precipitation intensity associated with more intermittent precipitation leads to decreased soil moisture and an increase in the annual number of days with dry soil moisture conditions. In particular, a temperature increase of +4°C combined with a decrease of annual rainfall between 10% and 20%, corresponding to the current available climate scenarios for the Mediterranean, lead to a lengthening of the drought period from June to October with an average of +28days of soil moisture drought per year.

This work is published in Hydrology and Earth System Sciences [9].

8.4.2 BROWNI: a GPU powered tsunami simulation library

Participants: José Daniel Galaz Mora.

Collaboration: Inria Chile, CIGIDEN , MERIC .

Tsunami simulation software is essential in modern warning systems to characterize tsunami hazard, but its complexity discourages uses in risk management such as communication and public education. However, the ubiquity of web browsers and the appearance of web standards like WebGL that enable access to the Graphics Processing Unit (GPU), open the opportunity to reach other disciplines and communities. In this work, we developed an open source Javascript-WebGL library that enables users to run tsunami simulations that represent the propagation of long waves in the ocean efficiently on the web browser using the GPU. Through examples , it is demonstrated how Nami can produce results commonly seen in tsunami hazard assessment, and also other applications where the sim-ulator is tightly integrated with other web elements, data sources and sensors. The latter is demonstrated with TsunamiLab, a web platform for public education and tsunami awareness developed with BROWNI at its core. This has been published in [8].

9 Bilateral contracts and grants with industry

9.1 Bilateral Contracts with Industry

9.1.1 GERIMU

Participants: Vincent Guinot.

The GERIMU project entered its second phase in 2019. The industrial version of the SW2D computational code was parallelized and tested by ASA Company (subcontractor). Integration of all software components into the final software product took place in 2020.

9.1.2 IRT Saint-Exupéry

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

In late 2019, we started a new collaboration with IRT Saint-Exupéry for the hibridization of numerical models and large amount of data for the modelling of urban floods.

Financial difficulties and the health crisis unfortunately forced one of the partners to give up its participation, which necessitated a reformulation of the partnership project. The collaboration will only really start in 2021.

9.1.3 Berger-Levrault

Participants: Carole Delenne.

The research collaboration convention, signed with Berger-Levrault company in the framework of Yassine Belghaddar thesis (CIFRE ANRT France/Maroc), is ungoing until april 2022.

10 Partnerships and cooperations

10.1 International initiatives

Participants: Pascal Finaud-Guyot, Vincent Guinot, Gwladys Toulemonde.

10.1.1 Participation in other International Programs

- Gwladys Toulemonde is member of the PHC Utique project (with Tunisia) AMANDE (PI Julie Carreau, Polytechnique Montreal), 2019-2021. The project AMANDE focuses on stochastic and semi-parametric approaches combined to remote sensing for the study of the water stress.
- Pascal Finaud-Guyot and Vincent Guinot are members of the French-Tunisian International Laboratory Naïla, 2016-2023. The laboratory research focuses on the management of the water resources in agricultural Tunisian catchement. In this context, LEMON members develop DDP model for fine scale runoff modelling to better understand the agricultural practices-soil erosion interactions.

10.2 European initiatives

Participants: Carole Delenne.

- Carole Delenne is a member of the CASCADE project (Combining earth observation with a large scale model cascade for assessing flood hazard at high spatial resolution) lead by Renaud Hostache from (Luxembourg Institute of Science and Technology) and funded by Fonds National de la Recherche Luxembourg. The CASCADE project aims at developing a Satellite Earth Observation (SEO)-based modelling framework that enables an assessment of flood hazard at large scale and high spatial resolution. The project intends to unlock the potential offered by recent developments in terms of high performance computing, parsimonious and efficient hydrological and hydraulic models, as well as the availability of globally coherent remote sensing data. By using SEO data and other globally and freely available data sets as default data for driving and parameterizing the model, the project aims at developing a modelling solution that is no longer relying entirely on the availability of long records of reliable in situ observations. Such developments are considered a pre-requisite for hydrology-related disaster risk reduction worldwide.

10.3 National initiatives

Participants: Carole Delenne, Antoine Rousseau, Gwladys Toulemonde.

- Antoine Rousseau is member of the ANR ANSWER consortium lead by Céline Casenave (UMR MISTEA, INRAE Montpellier). ANSWER is a French-Chinese collaborative project that focuses on the **modelling and simulation of eutrophic lake ecosystems** to study the impact of anthropogenic environmental changes on the proliferation of cyanobacteria. Worldwide the current environmental situation is preoccupying: man-driven water needs increase, while the quality of the available resources is deteriorating due to pollution of various kinds and to hydric stress. In particular, the eutrophication of lentic ecosystems due to excessive inputs of nutrients (phosphorus and nitrogen) has become a major problem because it promotes cyanobacteria blooms, which disrupt the functioning and the uses of the ecosystems.
- Carole Delenne is a member (+co-leader of several tasks and a WP) of ANR CROQUIS - **Collecting, Representing, cOmpleting, merging and Querying heterogeneous and UncertaIn waStewater and stormwater network data** - led by Salem Benferhat (CRIL) and funded in 2022. In this project, we refer to data of different nature such as geographical databases, various types of images, digital/analogue maps, intervention reports, etc. Heterogeneity also refers to the imperfection of the available information where data may be unreliable, imprecise, incomplete, dynamic and conflicting. One of the objectives of CROQUIS is to answer the need for establishing a methodological framework to **collect, complete, centralize, update and archive data**. Approaches based on Machine Learning (ML) techniques enhanced with *basic additional knowledge* will be developed along with **knowledge-driven query answering and reasoning mechanisms** to infer new data needed for hydraulic modelling. In particular, we aim to develop an enhanced query answering tool that should be easily integrated into existing information systems in order to fully exploit available resources and to better exploit meta information such as uncertainty.
- Gwladys Toulemonde is member of the ANR project Gambas (PI Frédéric Mortier, Cirad), 2019-2023. The project GAMBAS focuses on joint species distribution models. These models can provide a better understanding and more accurate predictions of species distributions based on environmental variables while taking into account the effects of all other co-occurring species (e.g. competition).
- Gwladys Toulemonde is member of the ANR project McLaren (PI Thomas Laloé, Université Côte d'Azur), 2020-2024. The project McLaren focuses on Machine Learning and risk evaluation.
- Gwladys Toulemonde is head of a project (2019-2021) funded by INSU via the action MANU (MAthematical and NUmerical methods) of the LEFE program. This project, called Fraise, is focused on rainfall forcing by stochastic simulation for hydrological impact studies from dry periods to extreme events. The consortium involved in this project is larger than the Cerise one (14 researchers from 8 partners : AgroParisTech, CNRS, INRAE, Inria, IRD, Université de Lyon 1, Université de Montpellier and the University of Venise in Italy).

11 Dissemination

11.1 Promoting scientific activities

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

11.1.1 Scientific events: selection

Member of the conference program committees

- Gwladys Toulemonde is member of the scientific committee of the JdS (Journées de Statistique) 2021.
- Gwladys Toulemonde is member of the scientific committee of the CIMPA School "Probabilistic and statistical modelling with applications in epidemiology and environment", 2021-2022, Madagascar (partially virtual).

Reviewer

- Pascal Finaud-Guyot is reviewer for the conference "SHF, Colloque Hydrométrie 2021, Montpellier, 23-24 novembre 2021".

11.1.2 Journal

Reviewer - reviewing activities

- Carole Delenne is a reviewer for several Journals such as Journal of Hydraulic Research, Water, Computers Environment and Urban Systems (1 to 3 manuscripts/year).
- Vincent Guinot is a reviewer for Journal of Hydrology, Advances in Water Resources, Mathematical Problems in Engineering (3 manuscripts/year).
- Antoine Rousseau is a reviewer for Journal of Hydrology and Environmental Modelling & Assessment (2 manuscripts/year), DCDS-S (1 manuscript/year) and Mathematical Modelling and Numerical Analysis (ESAIM: M2AN, 1 manuscript/year).
- Pascal Finaud-Guyot is a reviewer for Journal of Hydroinformatics, Advances in Water Resources, Environmental Modelling and Software, Journal of Hydrology (2 manuscripts/year).
- Gwladys Toulemonde is a reviewer for Annals of applied statistics, Computational statistics and data analysis, Dependence modelling, Extremes, Journal of applied Statistics, Journal of Statistical Theory and Practice, Statistics and Computing, Water Ressources research (1 to 3 manuscripts/year).

11.1.3 Invited talks

- Carole Delenne was invited to give several seminars: at the MiDi Day (groupe de recherche sur les milieux divisés); to the aqua department of INRAE (online); to the research group Data and Knowledge Sharing and Integration of EspaceDev laboratory; to the Digiweek organised by Nîmes Métropole.
- Pascal Finaud-Guyot was invited to present LEMON activities on downscaling to the 'Water & Defense' journey.

11.1.4 Scientific expertise

- Gwladys Toulemonde is appointed by the Occitanie region to the scientific board in charge of innovation projects in the field of intelligent systems and digital data chain.
- Antoine Rousseau is member of the scientific board of Fondation Blaise Pascal.
- Antoine Rousseau is member of the international scientific board of the Climat-AmSud program.

11.1.5 Research administration

- Carole Delenne was elected member of the HSM board until march 2021.
- Carole Delenne is elected member of the Ecole Doctorale GAIA board.
- Vincent Guinot is head of the "Eau dans la Ville" cross-disciplinary research group at HSM (20 staff members) and of the Urban Observatory of HSM.

- Vincent Guinot is a member of the board for scientific strategy at HSM.
- Antoine Rousseau is head of the LEMON team at Inria CRI-SAM (5 staff members).
- Antoine Rousseau is a member of the Inria CRI-SAM steering board (Comité des Projets).
- Antoine Rousseau is a member of the Inria CRI-SAM scientific board (Bureau du Comité des Projets).
- Gwladys Toulemonde is elected member of a local committee (commission de section) relative to the CNU section 26.
- Gwladys Toulemonde is elected member of the MIPS Scientific Department (Mathematics, Computer Science, Physics and Systems), a component of the University of Montpellier.
- Gwladys Toulemonde is vice-president of the French Statistical Society (*Société Française de Statistique, SFdS*).
- Gwladys Toulemonde is elected member of the French Statistical Society board (*Société Française de Statistique, SFdS*).
- Gwladys Toulemonde is elected member of Environment group of the French Statistical Society board (*Société Française de Statistique, SFdS*).
- Gwladys Toulemonde is elected member of the liaison commitee of the MAS Group (*Modélisation Aléatoire et Statistique*), SMAI (*Société de Mathématiques Appliquées et Industrielles*).

11.2 Teaching - Supervision - Juries

Participants: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau, Gwladys Toulemonde.

11.2.1 Academic involvement / responsibilities

4 UM-affiliated members of LEMON are Academics, for a total teaching load of approximately 1000 hrs/year.

Moreover, these members undertook significant administrative duties (approx. 1000 hrs) in 2021:

- Carole Delenne became Program coordinator (Year 3) of the "Eau et Génie Civil - EGC" (Water & Civil Engineering) engineering program at Polytech Montpellier.
- Pascal Finaud-Guyot became Program coordinator (Year 2) and Sustainable Development coordinator for the EGC engineering program at Polytech Montpellier.
- Vincent Guinot became Head of the EGC Academic department at Polytech Montpellier.
- Gwladys Toulemonde was appointed Admissions office coordinator at Polytech Montpellier (300+ students/ year).

11.2.2 Supervision

- PhD in progress :
  - José Daniel Galaz Mora, "Coupling near shore wave models", Feb 2021, Antoine Rousseau and Maria Kazolea (Inria Bordeaux).
  - Vita Ayoub, "Assimilation of satellite derived flood information for better parameterizing and controlling large scale hydraulic models over data scarse areas", november 2018, Carole Delenne and R. Hostache (LIST, Luxembourg).

  - Yassine Belghaddar, "Data fusion for urban network mapping. Application to sanitation networks", may 2019, Carole Delenne and A. Begdouri (LSIA, Fès, Morocco).
  - Samuel Valiquette, "Modélisation multivariée de données de comptage en présence d'excès de zéros et de surdispersion", sept. 2020, Gwladys Toulemonde , F. Mortier, E. Marchand (Cirad, Université de Montpellier, Université de Sherbrooke).
  - Alexis Boulin, "Méthodes de clustering spatial de séries temporelles fondées sur une dépendance extrémale", sept 2021, Gwladys Toulemonde , T. Laloé, E. Di Bernadino (Université de Montpellier, Université Côte d'Azur).
  - Cécile Choley, "Numerical study of the street-building exchange during urban floods", november 2019, Pascal Finaud-Guyot and R. Mosé (Université de Strabsourg).

- Post doctoral position:

  - David Nortes Martinez (INRAE, UMR G-Eau), "Detailed flood damage and risk estimation within buildings", september 2021, F. Grelot (INRAE, UMR G-Eau) and Pascal Finaud-Guyot.

Being on an Inria delegation in spring 2021, Carole Delenne took advantage of the time freed up by teaching to supervise more trainees than usual: Antoine Pfefer (M2, Mathématiques appliquées CEPS, Univ. Aix Marseille), Fadil Boodoo (M2 mathématique: Statistique option Machine Learning, Sorbonne Université), Omar Et-Targuy (M2 Systèmes intelligents et réseaux, FST Fès) and Marion Jicquel (M1, Sciences et Technologies de l'Eau, Polytech Montpellier).

11.2.3 Juries

- Antoine Rousseau was member of the Inria Junior Researcher (CRCN/ISFP) comittee in Grenoble.
- Antoine Rousseau is member of the scientific committee for the SMAI-GAMNI PhD prize.
- Pascal Finaud-Guyot has participated to the recruitment jury in May 2021 for an associate professor at Montpellier University in CNU 35-36-60.
- Vincent Guinot has participated to the HDR jury of Pascal Finaud-Guyot defended in June 2021 at Montpellier University.
- Gwladys Toulemonde has participated to the HDR jury of Pierre Ribereau defended in January 2021 at Institut Camille Jordan, Lyon.
- Carole Delenne was reviewer of Yassine Kaddi's PhD, defended in October 2021 at Univ. Lyon, specialty: fluids mechanics.
- Carole Delenne is part of individual monitoring committee for the thesis of Suzanne Lapillonne (INRAE/Univ. Grenoble) and Cécile Choley.
- Antoine Rousseau is part of individual monitoring committee for the thesis of Emilie Duval (Inria / Univ. Grenoble).

11.3 Popularization

Participants: Carole Delenne, Antoine Rousseau, Gwladys Toulemonde.

11.3.1 Internal or external Inria responsibilities

- Gwladys Toulemonde is involved in the board of the CFEM (commission française pour l'enseignement des mathématiques) since october, 2019, representing the SFdS.
- Gwladys Toulemonde is involved in the board of Animath since october, 2019, representing the SFdS.
- Gwladys Toulemonde is a member of the organizing committee of the Forum Emploi Math (FEM 2020, virtual event).
- Gwladys Toulemonde is a member of the organizing committee of the *Salon de la culture et des jeux mathématiques*, 2020.
- Antoine Rousseau is member of the scientific board of Fondation Blaise Pascal.
- Antoine Rousseau is co-editor of the national blog binaire, published by Le Monde.
- Antoine Rousseau was appointed chair of the "Environment" round-table discussion in the Forum Emploi Math (FEM 2021, virtual event).

11.3.2 Interventions

- Carole Delenne participated twice in the reception of secondary school students ("stage de 3ieme"), in the framework of DigiFilles, organised by colleagues of ISDM (Institut des Sciences des Données de Montpellier).
- Antoine Rousseau gave a lecture "Tsunamilab, une plateforme numérique interactive pour créer des tsunamis" at the "Feria de la Ciencia" (Chile, 2021).
- Antoine Rousseau gave a lecture "Immersion au coeur d'un tsunami" at the national event "Science and You" 2021.
- Carole Delenne and Gwladys Toulemonde participated to the "Cahier Régional Occitanie sur les Changements Climatiques", available here.

12 Scientific production

12.1 Major publications

[1] V. Guinot, C. Delenne, A. Rousseau and O. Boutron. 'Flux closures and source term models for shallow water models with depth-dependent integral porosity'. In: *Advances in Water Resources* 122 (Sept. 2018), pp. 1–26. DOI: 10.1016/j.advwatres.2018.09.014. URL: https://hal.archives-ouvertes.fr/hal-01884110.

12.2 Publications of the year

International journals

[2] J. Aouni, J. N. Bacro, G. Toulemonde, P. Colin and L. Darchy. 'Utility-based dose selection for phase II dose-finding studies'. In: *Therapeutic Innovation & Regulatory Science* 55 (2021). DOI: 10.1007/s43441-021-00273-0. URL: https://hal.inria.fr/hal-02491551.

[3] J. Aouni, J. N. Bacro, G. Toulemonde, P. Colin, L. Darchy and B. Sébastien. 'On the use of utility functions for optimizing phase II/phase III seamless trial designs'. In: *Journal of clinical trials* 10.415 (24th June 2021). DOI: 10.35248/2167-0870.20.10.415. URL: https://hal.inria.fr/hal-02491531.

[4] V. Ayoub, C. Delenne, M. Chini, P. Finaud-Guyot, D. Mason, P. Matgen, R.-M. Pelich and R. Hostache. 'A porosity-based flood inundation modelling approach for enabling faster large scale simulations'. In: *Advances in Water Resources* 162 (Apr. 2022), p. 104141. DOI: 10.1016/j.advwatres.2022.104141. URL: https://hal.umontpellier.fr/hal-03558847.

[5] J. G. Caldas Steinstraesser, V. Guinot and A. Rousseau. 'Modified parareal method for solving the two-dimensional nonlinear shallow water equations using finite volumes'. In: *SMAI Journal of Computational Mathematics* 7 (2021), pp. 159–184. DOI: 10.5802/smai-jcm.75. URL: https://hal.inria.fr/hal-02894841.

[6] J. Carreau and V. Guinot. 'A PCA spatial pattern based artificial neural network downscaling model for urban flood hazard assessment'. In: *Advances in Water Resources* (Jan. 2021), p. 103821. DOI: 10.1016/j.advwatres.2020.103821. URL: https://hal.archives-ouvertes.fr/hal-02903282.

[7] C. Delenne, J.-S. Bailly, A. Rousseau, R. Hostache and O. Boutron. 'Endoreic waterbodies delineation from remote sensing as a tool for immersed surface topography'. In: *IEEE Geoscience and Remote Sensing Letters* 19 (2022), pp. 1–5. DOI: 10.1109/LGRS.2021.3079718. URL: https://hal.inria.fr/hal-03140413.

[8] J. Galaz, R. Cienfuegos, A. Echeverria, S. Pereira, C. Bertin, G. Prato and J.-C. Karich. 'Integrating tsunami simulations in web applications using BROWNI, an open source client side GPU powered tsunami simulation library'. In: *Computers and Geosciences* (Dec. 2021). DOI: 10.1016/j.cageo.2021.104976. URL: https://hal.inria.fr/hal-02112763.

[9] L. Mimeau, Y. Tramblay, L. Brocca, C. Massari, S. Camici and P. Finaud-Guyot. 'Modeling the response of soil moisture to climate variability in the Mediterranean region'. In: *Hydrology and Earth System Sciences* (11th Feb. 2021). DOI: 10.5194/hess-25-653-2021. URL: https://hal.archives-ouvertes.fr/hal-02884943.

[10] B. Yassine, N. Chahinian, A. Seriai, A. Begdouri, R. Abdou and C. Delenne. 'Graph Convolutional Networks: Application to Database Completion of Wastewater Networks'. In: *Water* 13.12 (June 2021), p. 1681. DOI: 10.3390/w13121681. URL: https://hal.archives-ouvertes.fr/hal-03264611.

International peer-reviewed conferences

[11] J. G. Caldas Steinstraesser, C. Delenne, P. Finaud-Guyot, V. Guinot, J. L. Kahn Casapia and A. Rousseau. 'SW2D-LEMON: a new software for upscaled shallow water modeling'. In: Simhydro 2021 - 6th International Conference Models for complex and global water issues - Practices and expectations. Sophia Antipolis, France, 16th June 2021. URL: https://hal.inria.fr/hal-03224050.

[12] J. G. Caldas Steinstraesser, V. Guinot and A. Rousseau. 'Application of a modified parareal method for speeding up the numerical resolution of the 2D shallow water equations'. In: Simhydro 2021 - 6th International Conference Models for complex and global water issues - Practices and expectations. Sophia Antipolis, France, 16th June 2021. URL: https://hal.inria.fr/hal-03224056.

[13] C. Choley, P. Finaud-Guyot, P.-A. Garambois and R. Mosé. 'An Effective Urban Flood Model Accounting for Street-Building Exchanges'. In: Simhydro 2021 - 6th International Conference Models for complex and global water issues - Practices and expectations. Sophia Antipolis, France, 16th June 2021. URL: https://hal.archives-ouvertes.fr/hal-03520964.

National peer-reviewed Conferences

[14] S. Valiquette, F. Mortier, J. Peyhardi and G. Toulemonde. 'Choix de mélange Poisson à l'aide de la théorie des valeurs extrêmes'. In: Journées de Statistique. Nice (distanciel), France, 7th June 2021. URL: https://hal.inria.fr/hal-03500505.

Conferences without proceedings

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