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Inria

2025 *Activity Report*

RESEARCH CENTRE: **Inria Branch at the University of Montpellier**

IN PARTNERSHIP WITH: **Université de Montpellier, CNRS**

Project-Team

LEMON

Littoral Environment: MOdels and Numerics

In collaboration with HydroSciences Montpellier (HSM), Institut Montpelliérain Alexander Grothendieck (IMAG)

Project-Team LEMON

Creation of the Project-Team: 2019 January 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A3.1.4. – Uncertain data
A3.1.10. – Heterogeneous data
A6.1.1. – Continuous Modeling (PDE, ODE)
A6.1.2. – Stochastic Modeling
A6.1.4. – Multiscale modeling
A6.1.5. – Multiphysics modeling
A6.2.1. – Numerical analysis of PDE and ODE
A6.2.2. – Numerical probability
A6.2.3. – Probabilistic methods
A6.2.4. – Statistical methods
A6.3.3. – Data processing
A6.3.4. – Model reduction
A6.3.5. – Uncertainty Quantification
A6.5.2. – Fluid mechanics
A6.5.3. – Transport
A6.5.4. – Waves
A9.2.1. – Supervised learning
A9.2.2. – Unsupervised learning
A9.6. – Decision support

Other research topics and application domains

B3.1. – Sustainable development
B3.2. – Climate and meteorology
B3.3.2. – Water: sea & ocean, lake & river
B3.3.3. – Nearshore
B3.4.1. – Natural risks
B3.4.3. – Pollution
B3.6. – Ecology
B3.6.1. – Biodiversity
B4.3.2. – Hydro-energy
B6.5. – Information systems
B8.3. – Urbanism and urban planning
B8.4. – Security and personal assistance
B8.4.1. – Crisis management
B9.11. – Risk management
B9.11.1. – Environmental risks

Contents

1 Team members, visitors, external collaborators

Research Scientist

- Antoine Rousseau [Team leader, INRIA, Senior Researcher, HDR]

Faculty Members

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- Vincent Guinot [UNIV MONTPELLIER, Professor, HDR]
- Nicolas Meyer [UNIV MONTPELLIER, Associate Professor]
- Gwladys Toulemonde [UNIV MONTPELLIER, Professor]

Post-Doctoral Fellow

- Katia Ait Ameur [INRIA, Post-Doctoral Fellow]

PhD Students

- Mitra Aelami [UNIV MONTPELLIER]
- Anne Bernard [UNIV MONTPELLIER]
- Fadil Boodoo [UNIV MONTPELLIER]
- Alexandre Capel [UNIV MONTPELLIER]
- Andrea Ferrero [UNIV MONTPELLIER, from Nov 2025]
- Chloe Serre Combe [UNIV MONTPELLIER]

Technical Staff

- Katia Ait Ameur [INRIA, Engineer, from Nov 2025]
- Lilas Bugeau [INRIA, Engineer, until Oct 2025]

Interns and Apprentices

- Andrea Ferrero [UGA, Intern, from Mar 2025 until Jul 2025]
- Marco Spadoni [INRIA, Intern, from Mar 2025 until Jun 2025]

Administrative Assistants

- Cathy Desseaux [INRIA, until Nov 2025]
- Anouk Renaud [INRIA, from Dec 2025]

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).

MIPS pole The LEMON members are involved in projects funded by the current MIPS pole at University of Montpellier and actively participate in new initiatives pertaining to *sea and coast* modeling, both 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 modeling 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 modeling, 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 modeling, 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

Foreword

Interdisciplinarity is a characteristic and a strength for LEMON. We want to build on this mix by developing two main research axes - physics-driven and data-driven models - applied to free-surface hydraulic processes and their coupling. These two axes will intersect through the hybridization of models and all this work will serve the development of the SW2D-LEMON software so that it remains both an operational easy to use software and a scientific reference of international standard.

[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).

3.1 Physics-driven models

3.1.1 Upscaled urban flood modeling

Participants: Lilas Bugeau, Pascal Finaud-Guyot, Vincent Guinot, Antoine Rousseau.

Collaboration: Carole Delenne *(Aix Marseille Univ)*, Brett Sanders *(UCI, USA)*, Sandra Soarez Frazao *(UCL, Belgium)*.

Concerning the physics-driven modeling axis, we will continue to work with porosity models, and more generally with upscaling mechanisms for free surface hydraulics. We know since [14] that each upscaled model is biased, which also eventually distorts downscaling operations. We wish to better identify these biases and take them into account in order to improve both the large-scale simulations (development of new models), and the small-scale ones (downscaling using compensation techniques between large-scale models). The collaboration with University California Irvine (UCI) started in 2014 with research on the representation of urban anisotropic features in integral porosity models [17]. It has led to the development of the Dual Integral Porosity model [15]. Ongoing research focuses on improved representations of urban anisotropy in urban flood modeling.
Université Catholique de Louvain (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 is still active.

3.1.2 Large time steps methods for hydraulic processes

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

Collaboration: Philippe Helluy *(Univ. Strasbourg & Inria TONUS)*.

In line with fast changes in the whole society, our scientific community is more and more sensitive to the environmental footprint of research. We already claim that porosity models can be valued for their sobriety, thanks to coarse space meshes and low computational cost simulations. We also wish to develop a time discretization strategy that will continue to lighten our algorithms. A first theoretical work has been carried out for 1D models, we wish to generalize it to 2D models and implement it into operational models.
Discussions have started with team TONUS in Strasbourg, as "CFL (Courant–Friedrichs–Lewy condition)-less" methods are also used by the team for kinetic-relaxation approximation [16].

3.1.3 Street-buildings interactions during flood events

Participants: Pascal Finaud-Guyot.

The improvement of realistic flood scenarios also requires the addition of specific processes: we will continue to model interactions with buildings (work initiated by Cécile Choley's PhD thesis) and to develop the transport of log jams in an urban flow, using the functionalities allowed by the concept of porosity to better take into account the feedback of log jams on the flow (crowding process).

3.1.4 Coupling coastal ocean and urban flood models

Participants: Antoine Rousseau.

Collaboration: Jose Daniel Galaz Mora *(PUC Santiago)*, Maria Kazolea *(Inria, team CARDAMOM)*.

Finally, we wish to continue to couple the numerical models developed by the team with other processes: relying on collaborations external to LEMON (as is currently the case with the SURF project of Inria for the Green-Naghdi / shallow water coupling) or recruiting new permanent members, we will use the team's strengths in free-surface hydraulics and in model coupling, to explore new fields of application.

3.2 Data-driven models

Participants: Pascal Finaud-Guyot, Vincent Guinot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde, Katia Ait Ameur, Mitra Aelami, Anne Bernard, Fadil Boodoo, Chloe Serre Combe.

One of the originality of LEMON is that we can count on a data-driven component that we wish to develop further. Data are indeed essential throughout the whole modeling/forecast process: providing source terms, bathymetric information, initial and boundary conditions; allowing model hybridization (using data assimilation or artificial intelligence methods); processing model outputs for risk measurements and decision making.

3.2.1 Space-time variability of rainfalls

Participants: Anne Bernard, Nicolas Meyer, Gwladys Toulemonde, Chloe Serre Combe.

Collaboration: Thomas Opitz *(INRAe, Avignon)*, Philippe Naveau *(LSCE, CNRS, Gif-sur-Yvette)*.

Understanding the spatial and temporal variability of rainfalls that can generate flash floods is a major challenge. This knowledge is essential to build stochastic methods for simulating scenarios integrating realistic spatiotemporal extreme rainfall fields. This modeling must be done keeping in mind the importance of the physical interpretation of data simulated with such models. We aim to develop, propose, study and implement models adapted to the presence of extreme values taking into account the associated complex dependencies. One difficulty lies in modeling the transitions (in time and space) between no rain, regular rainfall and extreme rainfall. Reproducing spatial or temporal non-stationarity in the intensities as well as in the dependency structure is also a challenge we wish to address.

3.2.2 Multivariate dependence

Participants: Nicolas Meyer, Gwladys Toulemonde, Alexandre Capel, Andrea Ferrero.

Collaboration: Alexis Boulin *(Ruhr-Universität Bochum)*, Samuel Valiquette *(Unvi Sherbrooke, Canada)*, Elena Di Bernardino *(LJAD, Univ. Côte d'Azur)*, Thomas Laloé *(LJAD, Univ. Côte d'Azur)*, Eric Marchand *(Université de Sherbrooke)*, Klaus Herrmann *(Université de Sherbrooke)*, Frédéric Mortier *(Cirad, Montpellier)*, Jean Peyhardi *(IMAG, Université de Montpellier)*, Marine Demangeaot *(IMAG, UMPV)*.

In the medium term, we want to develop appropriate risk measures that can then be used to assess the potential impacts of extreme rainfall events. Multivariate risk measures should be considered, as flood risk indicators are usually derived by combining different hydraulic variables. We would be interested in the estimation of risk sets, the idea being in the simplest framework to identify all the combinations of water height/velocity values which would lead to a risk higher than a fixed level. More generally, the question of modeling dependence in statistics, and in particular when we consider extremes, is one to which we want to contribute, as is the consideration of compound events.

3.2.3 Clustering and sparsity models for rainfall

Participants: Nicolas Meyer, Gwladys Toulemonde, Alexandre Capel.

Collaboration: Alexis Boulin *(Ruhr-Universität Bochum)*, Elena Di Bernardino *(LJAD, Univ. Côte d'Azur)*, Thomas Laloé *(LJAD, Univ. Côte d'Azur)*, Marine Demangeaot *(IMAG, UMPV)*.

Finally, our aim is to model forcing terms (rainfall, wind, etc.) for a large number of stations and with a small time scale. In addition, many covariates will be included in the models to better explain the phenomena. This means that we will deal with high dimensional data and with potentially many parameters. This is a limitation in terms of computation time and from a statistical point of view. We will therefore continue to propose methods to reduce the dimension: grouping stations for which the rainfall has a similar behavior (clustering) and highlighting a few significant parameters that are sufficient to explain the model (sparsity).

3.3 Hybrid modeling

Participants: Pascal Finaud-Guyot, Vincent Guinot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde, Katia Ait Ameur, Mitra Aelami, Fadil Boodoo, Chloe Serre Combe.

At the interface between these two main axes, we would like to continue working with hybrid models, in particular thanks to artificial intelligence techniques. Our team is interested in the techniques of physically informed neural networks (PINNs) in fluid mechanics and participates in several working groups on this subject. Keeping in mind that we are not experts on this topic and that the competition is intense, we will explore, notably in Fadil Boodoo's PhD, the use of AI methods for the simulation of rainfall-flood systems (together with rainfall-discharge and discharge-flood intermediate steps). We would also like to study, using configurations where data is abundant and of good quality (digital terrain model, external forcings, etc.), how to assess the potential impact of data scarcity in more rudimentary configurations.

To specify and carry out this work program, we hope that LEMON will be able to count on an Inria recruitment in the next 2 or 3 years (several candidates have already expressed interest in the 2025 and 2026 competition). We will also benefit from data from the Water in the City observatory, structured around the HSM laboratory and led by members of LEMON. The SW2D-LEMON software will of course be at the core of transfers operated by the team: we will continue to devote time of our permanent staff to its development, while willing to integrate this tool into a larger Inria platform in which engineering time (possibly shared with other teams) could be made available in order to enable us to focus on our primary research missions.

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 sea/ocean and inland, however these two worlds are in fact intertwined, which contributes to the difficulty of their modeling, 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 cities, 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

Modeling and risk assessment are at the heart of environmental science. Whether the considered events 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 modeling extreme events, in order to provide risk management tools that are better suited to the occurrence of rare (and potentially dangerous) events rather than to day-to-day management, for which other tools exist.

5 Social and environmental responsibility

5.1 Footprint of research activities

As for all Inria teams, the 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. Several members of the team also participate to the local group of Inria Montpellier Antenna dedicated to sustainable development and social responsibility.

Several LEMON members are committed to limiting their professional air travel to 10.000km per year. At least one member of the Lemon team is committed to never using air travel for professional activities.

5.2 Impact of research results

Our research activities have an indirect impact in terms of environmental responsibility:

- the research carried out by the team contributes to the seek of numerical frugality in numerical hydraulic modeling;
- 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

- In October, we released version 4.0.0 of SW2D software, the LEMON team's flagship product for several years. SW2D is open source software licensed under AGPL-3.0, designed for numerical modeling of hydraulic flows. It uses the Saint-Venant equations to model watercourses and flooding, including in urban areas. Its strengths compared to the state of the art:
  - No constraints on mesh structuring;
  - Low-tech models for rapid simulation of free surface flows (so-called 'porosity' models developed by the team);
  - Portability on Windows/macOS/Linux.
- In September, Antoine Rousseau completed his support mission with the management of the Inria Montpellier branch. The branch now has a new scientific head and a deputy scientific head, in line with the forthcoming creation of an Inria centre in Montpellier, to which Antoine will have contributed during 2 years.

7 Latest software developments, platforms, open data

7.1 Latest software developments

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: See Gitlab Changes tracking.

News of the Year:
- mentoring of Lilas Bugeau (code developer)
- code refactoring and loop optimization
- write more tests
- write user and developer doc
- In October, we released version 4.0.0. SW2D is open source software licensed under AGPL-3.0. Its strengths compared to the state of the art:
  - No constraints on mesh structuring
  - Low-tech models for rapid simulation of free surface flows (so-called 'porosity' models developed by the team)
  - Portability on Windows/macOS/Linux

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

Publications: hal-03882644, 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: Lilas Bugeau, Vincent Guinot, Antoine Rousseau, Pascal Finaud Guyot

Partners: Université de Montpellier, CNRS, IRD

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: - new device to detect finger movement - Tsunamilab workshop at Fête de la Science 2024 (Cité des Sciences, Paris)

URL: https://jgalazm.github.io/TsunamiLabTN/

Publications: hal-02112763, hal-03514473, hal-04912272

Contact: Jose Daniel Galaz Mora

Participants: Jose Daniel Galaz Mora, Antoine Rousseau

Partners: Cigiden, Inria Chile

8 New results

8.1 Physics-driven models

8.1.1 Assessing 3D and 2D hydrodynamic models for urban flood simulations: a district scale analysis with experimental street-level discharge, height and velocity

Participants: Pascal Finaud-Guyot.

Collaboration: Pierre-André Garambois *(RECOVER, INRAe)*.

Urban flood modeling is essential for understanding physical phenomena and enhancing flood forecasting. The relevance of these numerical tools must be assessed with flow measurements which are sparse for real floods. In [6], we assess the capability of state-of-the-art 2D (with or without $k - \varepsilon$ turbulence model) and 3D numerical models in reproducing the characteristics of urban flood flows within a realistic street network using an experimental dataset. The results show that all models can predict the flow discharge distribution and flow depths inside the district. The 3D model is always slightly more accurate, especially in zones where the flow is strongly perturbed. The comparison of numerical and experimental velocity profiles across streets highlights the need for a turbulence model to represent recirculation areas of finite length after crossroads and to obtain a more realistic velocity field and water elevation profile.

8.1.2 Numerical methods for hyperbolic systems of equations

Limitation strategies for high-order discontinuous Galerkin schemes applied to an Eulerian model of polydisperse sprays

Participants: Katia Ait Ameur.

Collaboration: Mohamed Essadki *(The MathWorks)*, Marc Massot *(CMAP, Ecole Polytechnique)*, Teddy Pichard *(CMAP, Ecole Polytechnique)*.

In [2], we tackle the modeling and numerical simulation of polydisperse sprays. Starting from a kinetic description for point particles, we focus on an Eulerian high-order geometric method of moment (GeoMOM) in size and consider a system of partial differential equations on a vector of successive fractional size moments of order 0 to N/2, N > 2, over a compact size interval. These moments correspond to physical quantities, which can be interpreted in terms of the geometry of the interface at small scale. There exists a stumbling block for the usual approaches using high-order moment methods resolved with high-order numerical methods: the transport algorithm does not naturally preserve the moment space. Indeed, reconstruction of moments by polynomials inside computational cells can create N-dimensional vectors which can fail to be moment vectors. We thus propose a new approach, as well as an algorithm, which is arbitrarily high-order in space and time with limited numerical diffusion, including at the boundaries of the state space, where a specific study is proposed. It allows to accurately describe the advection process and naturally preserves the moment space, at a reasonable computational cost.

8.1.3 Coupling methods

Analysis of linear Boussinesq-type models coupled with static interfaces

Participants: Antoine Rousseau.

Collaboration: José Galaz *(PUC Santiago, Chile)*, Maria Kazolea *(CARDAMOM, Inria)*.

In [11], we derive a new approach to analyze the coupling of linear Boussinesq and Saint-Venant shallow water wave equations in the case where the interface remains at a constant position in space. We propose a one-way coupling model as a reference, which allows us to obtain an analytical solution, to prove the well-posedness of the original coupled model and to compute what we call the coupling error - a quantity that depends solely on the choice of transmission conditions at the interface. We prove that this coupling error is asymptotically small for a certain class of data and discuss its role as a proxy for the full error with respect to the 3D water wave problem. Additionally, we highlight that this error can be easily computed in other scenarios. We show that the coupling error consists of reflected waves and argue that this explains some previously unexplained spurious oscillations reported in the literature. Finally, we prove the well-posedness of the half-line linear Boussinesq problem.

8.2 Data-driven models

Identifying regions of concomitant compound precipitation and wind speed extremes over Europe

Participants: Gwladys Toulemonde.

Collaboration: Alexis Boulin *(Ruhr-Universität Bochum)*, Elena Di Bernardino *(Univ. Côte d'Azur)*, Thomas Laloë *(Univ. Côte d'Azur)*.

The task of simplifying the complex spatio-temporal variables associated with climate modeling is of utmost importance and comes with significant challenges. In this work published in [5], our primary objective is to tailor clustering techniques to handle compound extreme events within grided climate data across Europe. Specifically, we intend to identify subregions that display asymptotic independence concerning compound precipitation and wind speed extremes. To achieve this, we utilize daily precipitation sums and daily maximum wind speed data derived from the ERA5 reanalysis dataset spanning from 1979 to 2022. In the process, we aim to elucidate the respective roles of extreme precipitation and wind speed in the resulting clusters. The proposed method is able to extract valuable information about extreme compound events while also significantly reducing the size of the dataset within reasonable computational timeframes.

High-dimensional variable clustering based on maxima of a weakly dependent random process

Participants: Gwladys Toulemonde.

Collaboration: Alexis Boulin *(Ruhr-Universität Bochum)*, Elena Di Bernardino *(Univ. Côte d'Azur)*, Thomas Laloë *(Univ. Côte d'Azur)*.

We propose a new class of models for variable clustering called Asymptotic Independent block (AI-block) models, which defines population-level clusters based on the independence of the maxima of a multivariate stationary mixing random process among clusters. This class of models is identifiable, meaning that there exists a maximal element with a partial order between partitions, allowing for statistical inference. We also present an algorithm for recovering the clusters of variables without specifying the number of clusters *a priori*. Our work [4] provides some theoretical insights into the consistency of our algorithm, demonstrating that under certain conditions it can effectively identify clusters in the data with a computational complexity that is polynomial in the dimension. This implies that groups can be learned nonparametrically: block maxima of a dependent process are only sub-asymptotic. To further illustrate the significance of our work, we applied our method to neuroscience and environmental real-datasets. These applications highlight the potential and versatility of the proposed approach.

Tree Pólya splitting distributions for multivariate count data

Participants: Gwladys Toulemonde.

Collaboration: Samuel Valiquette *(Univ Sherbrooke)*, Frédéric Mortier *(Cirad)*, Eric Marchand *(Univ Sherbrooke)*, Jean Pehardi *(IMAG, UM)*.

In [7], we develop a new class of multivariate distributions adapted for count data, called Tree Pólya Splitting. This class results from the combination of an univariate distribution and singular multivariate distributions along a fixed partition tree. Known distributions, including the Dirichlet-multinomial, the generalized Dirichlet-multinomial and the Dirichlet-tree multinomial, are particular cases within this class. As we demonstrate, these distributions are flexible, allowing for the modeling of complex dependence structures (positive, negative, or null) at the observation level. Specifically, we present the theoretical properties of Tree Pólya Splitting distributions by focusing primarily on marginal distributions, factorial moments, and dependence structures (covariance and correlations). A dataset of abundance of Trichoptera is used, on one hand, as a benchmark to illustrate the theoretical properties developed in this article, and on the other hand, to demonstrate the interest of these types of models, notably by comparing them to other approaches for fitting multivariate data, such as the Poisson-lognormal model in ecology or singular multivariate distributions used in microbiome.

Are LSTM and conceptual rainfall-runoff models able to cope with limited training datasets under diverse hydrometeorological conditions?

Participants: Fadil Boodoo.

Collaboration: Renaud Hostache *(Espace-Dev, IRD)*, Carole Delenne *(Aix Marseille Univ.)*.

As climate change exacerbates variability and non-stationarity in rainfall patterns, it is crucial to assess the predictive capabilities of forecasting models. Previous researches on rainfall-runoff modeling have focused on the impact of training dataset size on Artificial Neural Networks (ANNs) results, with limited consideration of hydrometeorological diversity. In [3] we first evaluate the influence of the training dataset length (1 to 15 years) on performance of a Long Short-Term Memory (LSTM) and a traditional conceptual model, Superflex, across 10 validation years. Next, training years are categorized based on hydrometeorological diversity (wetter, standard, drier). This clustering allows for experiments where models are trained on data from similar or different clusters, enhancing understanding of how data diversity, and therefore climate change, can affect model performance. Results indicate that the LSTM model is highly sensitive to training length: it shows poor performance with short datasets (below three years); it reaches similar performance to Superflex around six training years on average; finally it overperforms with 15 years of training. Conversely, Superflex maintains rather constant performance levels regardless of the dataset length. LSTM model benefits from diverse training data, achieving higher accuracy and reliability when trained on years with diverse hydrological typology.

9 Bilateral contracts and grants with industry

9.1 Bilateral grants with industry

AMIES grant with CEREG

Participants: Antoine Rousseau, Pascal Finaud Guyot, Vincent Guinot, Lilas Bugeau.

In 2024 we obtained a MATHéO grant from AMIES for a collaboration with CEREG on hydraulic modeling with SW2D-LEMON. Lias Bugeau has been hired by our team in this framework, until October 31, 2025.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

FLOTTE

Title: FLOod and TransporT Equations

Duration: 2023 -> 2025

Coordinator: Cristián Escauriaza (cescauri@ing.puc.cl)

Partners:

- Pontificia Universidad Católica de Chile Santiago (Chili)

Inria contact: Antoine Rousseau

Summary: The overall objective of the research program is to develop a numerical tool that is able to represent, in urban area, flood and transport (sediment, debris and vehicle) propagation as the potential feedback from transport to the flow. Several directions are identified:

- Shallow water and transport models coupling
- Upscaling of transport model
- Sensitivity analysis

MIX (Tandem Sherbrooke program at UM)

Participants: Nicolas Meyer, Gwladys Toulemonde, Andrea Ferrero.

Collaboration: Klaus Herrmann *(Université de Sherbrooke, Canada)*, Eric Marchand *(Université de Sherbrooke, Canada)*.

The aim of this thesis project is to develop frequentist and Bayesian inference techniques for estimating the limit distribution of the maximum under dependency assumptions.

10.2 European initiatives

10.2.1 ATLAS

Participants: Vincent Guinot.

Collaboration: Carole Delenne *(Univ. Aix Marseille)*, Nanée Chahinian *(IRD Montpellier)*.

The ATLAS project, funded by ANR in the framework of the European call ChistERA, officially started in June 2025. Taking full advantage of the wealth of geospatial data available nowadays is a major scientific and technological challenge, with significant societal and economic impacts. The multidisciplinary ATLAS project is set in this context and aims to augment the expressiveness and quality of geographic information systems (GIS) by integrating data from multiple sources, of different nature and quality, with urban flooding as a common thread application. Meeting a complex challenge such as this one requires a diverse range of expertise, including GIS, artificial intelligence and machine learning, image analysis, statistics, geographic alignment and many others. Bearing this in mind, this consortium was created to design innovative and practical solutions for collecting, organizing, extracting, selecting, transforming, combining and integrating multi-source geospatial data, of various nature and quality. This will enrich and augment GIS in various ways.
In 2026, a 6 month internship will be devoted to extracting the parameters for porosity-based shallow water models developed by the team from multi source features stored in urban databases. Part of the internship will also be devoted to validating porosity models using scale model experiments.

10.3 National initiatives

10.3.1 ANR MUFFINS

Participants: Antoine Rousseau, Pascal Finaud-Guyot, Gwladys Toulemonde.

Pascal Finaud Guyot, Antoine Rousseau and Gwladys Toulemonde are members of ANR MUFFINS (MUltiscale Flood Forecasting with INnovating Solutions), ending in 2025. The project is led by Pierre-André Garambois (INRAE) including the following partners: IMT, Univ Eiffel, Cerema IMFT, CCR, Météo/SPCME, SCHAPI. The objective of the MUFFINS project is to develop new accurate and computationally efficient flood forecasting approaches, enabling the transfer of information between models (meteo-hydrology-hydraulic-damage) and scales (from local runoff generation over areas lesser than 1 km^2 to flood propagation on catchments of thousands of km^2), and taking advantage of innovative data (in situ, remote observation, opportunistic) to reduce forecasts uncertainties.

10.3.2 ANR EXSTA

Participants: Nicolas Meyer.

Nicolas Meyer is member of the ANR project EXSTA (EXtremes, STatistical learning and Applications), led by Anne Sabourin, Université de Paris, 2024-2028. This project aims at developing machine learning techniques to study extreme values.

10.4 Regional initiatives

10.4.1 Eau-PiUM

Participants: Mitra Aelami, Anne Bernard, Gwladys Toulemonde, Vincent Guinot, Nicolas Meyer.

Collaboration: Renaud Hostache *(IRD, Montpellier)*, Carole Delenne *(Univ. Aix Marseille)*.

This is a project from the IDIL graduate program of the University of Montpellier, funding two doctoral contracts (ED GAIA and ED I2S) between 2024 and 2027.

Flooding is the leading natural hazard in France, with impacts particularly severe in urban and coastal areas. To improve our understanding and prediction of these extreme events, we are proposing several important extensions to the SW2D (Shallow water 2D) flow model, developed by the Inria-LEMON team in Montpellier. Firstly, we propose a high spatial and temporal resolution stochastic simulator for extreme precipitation forcing in urban and coastal environments (PhD 1, Mitra Aelami, *Urban flood risk modeling with neural networks and the impact of extreme spatio-temporal rainfall events*, doctoral school GAIA). This precipitation is a forcing term for the flow models studied in the second thesis. Indeed, the second axis of the project will consist in applying a hydraulic model for the simulation of urban flooding, which will serve as a learning base for an artificial intelligence model enabling the rapid estimation of flooded areas (PhD 2, Anne Bernard, *Stochastic rainfall generators and impact studies on flood risk in Montpellier*, doctoral school I2S). Secondly, we will develop spatialized sensitivity analysis methods to study how extreme values in the model's spatialized bivariate outputs (water heights and velocities) depend on the spatial patterns of extreme forcing. This impact study will be carried out at the intersection of the two thesis topics. The project aims to develop new generic methodological tools, as well as scenarios and maps of flood risk in the Montpellier region, taking into account the potential effects of climate change.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organization

General chair, scientific chair

- Gwladys Toulemonde served as Chair of the Scientific Committee for the "Journées de Statistique", June 2025, Marseille (France)

Member of the organizing committees

- Nicolas Meyer and Gwladys Toulemonde co-organized the Journées de Biostatistique in Montpellier, November 2025.

Member of the conference program committees

- Gwladys Toulemonde co-organized and partipated to the scientific program committee of the Conference on Stochastic Weather Generators « SWGEN » in December 2025, Grenoble (France).
- Gwladys Toulemonde and Antoine Rousseau co-chaired the scientific program committee and the organizing committee of the College's annual conference in February 2025, Montpellier (France). Sciences, responsabilité et engagement : quelles stratégies pour compter dans l'action publique ?

11.1.2 Journal

Member of the editorial boards

- Antoine Rousseau is associate editor of Discrete and Continuous Dynamical Systems - Series S.

Reviewer - reviewing activities

- Vincent Guinot is a reviewer for Journal of Hydrology, Advances in Water Resources, Mathematical Problems in Engineering (3 manuscripts/year).
- Nicolas Meyer is a reviewer for several journals, such as Extremes, Annals of Statistics, Bernoulli (1 to 3 manuscripts per year).
- Antoine Rousseau is a reviewer for Journal of Hydrology and Environmental Modelling and Assessment (2 manuscripts/year), DCDS-S (1 manuscript/year) and Computer Methods in Applied Mechanics and Engineering (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 statistical journals (like 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) and also Esaim or Water Ressources research (1 to 3 manuscripts/year).

11.1.3 Invited talks

- Nicolas Meyer was invited in the session "Recent advances in extreme value statistics", at EcoSta, Tokyo, August 2025
- Nicolas Meyer was invited in the session "Multivariate extremes", at CMStatistics, Londres, December 2025

- Gwladys Toulemonde was invited in the Workshop MISTRAL 2: Machine Learning in Insurance Sector Targeted to Risk Analysis and Losses, Climate change and insurability, CIRM, Marseille, November 2025
- Gwladys Toulemonde was invited in the session "Advances in applied probability" at IMS International Conference on Statistics and Data Science (ICSDS), Séville, December 2025

11.1.4 Leadership within the scientific community

- 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.

11.1.5 Scientific expertise

- Vincent Guinot is a member of the board for scientific strategy at HSM.
- Antoine Rousseau is a member of the Inria Center at Université Côte d'Azur scientific board (Bureau du Comité des Projets).
- Antoine Rousseau is a member of the scientific board of the MATH-AmSud program.
- Nicolas Meyer was en external reviewer for program CLIMAT-AmSud.
- Nicolas Meyer was member of the PhD committee of the Ecole Doctorale I2S.
- Gwladys Toulemonde was an external reviewer for ANRT (CIFRE PHD).

11.1.6 Research administration

- Antoine Rousseau is head of the LEMON team at Inria Branch at Université de Montpellier (6 staff members).
- Antoine Rousseau is a member of the Inria Center at Université Côte d'Azur steering board (Comité des Projets).
- Antoine Rousseau was deputy director of the Inria branch at the University of Montpellier until August 31.
- Gwladys Toulemonde is elected member of Environment group of the French Statistical Society board (Société Française de Statistique, SFdS).
- Gwladys Toulemonde was elected to the "commission de section 26" at Université de Montpellier.
- Gwladys Toulemonde is co-leader of the first local branch of the collège des sociétés savantes in Montpellier.
- Nicolas Meyer is elected member of the Ecole Doctorale I2S board.
- Anne Bernard organizes the PhD seminar of the whole local Inria branch.
- Katia Ait Ameur is strongly involved in the local AGOS group (works council/employee committee).

11.2 Teaching - Supervision - Juries

11.2.1 Academic involvement / responsibilities

5 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 2025:

- Pascal Finaud Guyot is Program coordinator (Year 2) and Sustainable Development coordinator for the EGC engineering program at Polytech Montpellier.

- Nicolas Meyer is head of Master 1 Statistics and Data Science at Université Montpellier.
- Vincent Guinot is responsible for internships for one whole Polytech programme (approx 100hrs/year).
- Gwladys Toulemonde is Admissions office coordinator at Polytech Montpellier (500+ students/ year).

11.2.2 Supervision

PhD defended this year

- Fadil Boodoo, Apport de l'intelligence artificielle pour la prévision spatio-temporelle des inondations, August 2025, [9] Supervision: Carole Delenne and Renaud Hostache.

PhD in progress

- Mitra Aelami, "Study of the risk of urban flooding using neural networks and the impact of extreme spatio-temporal rainfall events", since October 2024, supervised by Carole Delenne, Gwladys Toulemonde and Renaud Hostache.
- Flavien Baudu, "Assimilation de données d'observation de la Terre dans des modèles hydrauliques à surface libre pour améliorer la prévision des inondations à large échelle", since December 2024, supervised by Renaud Hostache and Carole Delenne.
- Anne Bernard, "Stochastic rainfall generators and impact studies on flood risk in Montpellier", since October 2024, supervised by Nicolas Meyer and Gwladys Toulemonde.
- Alexandre Capel, "Modèles graphiques pour les extrêmes", since October 2024, supervised by Nicolas Meyer and Gwladys Toulemonde with Marine Demangeot (Univ. Montpellier Paul Valery).
- Chloe Serre Combe, Stochastic generators of extreme precipitation and risk assessment of urban flooding at high spatiotemporal resolution, since October 2022, supervised by Gwladys Toulemonde, Nicolas Meyer, and Thomas Opitz (Inrae Avignon)
- Andrea Ferrero, Inference for extreme data in a univariate dependent setting, since November 2025, supervised by Nicolas Meyer, Gwladys Toulemonde, Klaus Herrmann (Université de Sherbrooke, Canada).

11.2.3 Juries

- Nicolas Meyer was member of an assistant professor (MCF) committee in Nancy.
- Gwladys Toulemonde was involved to three "comités de sélections" in 2025, for a professor in section CNU 27, a professor in section CNU 63 and a MCF in section CNU 26
- Gwladys Toulemonde was referee for the Ph.D of Manal Zeidan (Université Lyon 1) on "Apprentissage statistique pour processus spatio-temporels".
- Gwladys Toulemonde was jury member for the Ph.D. thesis of Philippe Ear (Université Nice Côte d'Azur) "Modèles distributionnels pour la correction de biais des précipitations journalières : un focus sur les évènements extrêmes".

11.3 Popularization

11.3.1 Specific official responsibilities in science outreach structures

- Antoine Rousseau is co-editor of the national blog binaire, initially published by Le Monde (moved to La Recherche).
- Gwladys Toulemonde co-organized for the SFdS (Société Française de Statistique) the national program "Math C pour L".

11.3.2 Participation in Live events

- Pascal Finaud-Guyot, Nicolas Meyer and Gwladys Toulemonde organized sessions of the “Fresque du climat” for the Master 1 students in Statistics and Data Science and for Polytech students, respectively.

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] K. Ait-Ameur, M. Essadki, M. Massot and T. Pichard. ‘Limitation strategies for high-order discontinuous Galerkin schemes applied to an Eulerian model of polydisperse sprays’. In: *ESAIM: Mathematical Modelling and Numerical Analysis* 59.5 (17th Sept. 2025), pp. 2349–2383. DOI: 10.1051/m2an/2025057. URL: https://hal.science/hal-04374640 (cit. on p. 14).

[3] F. Boodoo, R. Hostache, N. Skifa, J. Guerin and C. Delenne. ‘Are LSTM and conceptual rainfall-runoff models able to cope with limited training datasets under diverse hydrometeorological conditions?’ In: *Modeling Earth Systems and Environment* 11.2 (2025), p. 128. DOI: 10.1007/s40808-025-02316-z. URL: https://hal.science/hal-04965634 (cit. on p. 16).

[4] A. Boulin, E. Di Bernardino, T. Laloë and G. Toulemonde. ‘High-Dimensional Variable Clustering based on Maxima of a Weakly Dependent Random Process’. In: *Journal of the American Statistical Association* 120.551 (4th Apr. 2025), pp. 1933–1944. DOI: 10.1080/01621459.2025.2459443. URL: https://hal.science/hal-03969058 (cit. on p. 15).

[5] A. Boulin, E. Di Bernardino, T. Laloë and G. Toulemonde. ‘Identifying regions of concomitant compound precipitation and wind speed extremes over Europe’. In: *Journal of the Royal Statistical Society: Series C Applied Statistics* 74.4 (20th Nov. 2025), pp. 1057–1076. DOI: 10.1093/jrsssc/qlaf014. URL: https://hal.science/hal-04293894 (cit. on p. 15).

[6] G. Dellinger, L. Guiot, L. Pujol, F. Lawniczak, P. Francois, P. Finaud-Guyot, J. Vazquez and P.-A. Garambois. ‘Assessing 3D and 2D hydrodynamic models for urban flood simulations: a district scale analysis with experimental street-level discharge, height and velocity’. In: *Urban Water Journal* 22.9 (11th Aug. 2025), pp. 1084–1102. DOI: 10.1080/1573062X.2025.2531460. URL: https://hal.science/hal-05220799 (cit. on p. 13).

[7] S. Valiquette, J. Peyhardi, É. Marchand, G. Toulemonde and F. Mortier. ‘Tree Pólya Splitting distributions for multivariate count data’. In: *Journal of Multivariate Analysis* 211 (2026), p. 105507. DOI: 10.1016/j.jmva.2025.105507. URL: https://hal.science/hal-04563659 (cit. on p. 15).

Conferences without proceedings

[8] F. Boodoo, C. Delenne, F. Alberto, J. Guérin and R. Hostache. ‘Apport modélisation des hauteurs d’eau dans les plaines d’inondation avec les GNN’. In: Congrès Eau & Intelligence Artificielle 2026. Grenoble, France, 4th Mar. 2026. URL: https://hal.science/hal-05507025.

Doctoral dissertations and habilitation theses

[9] F. Boodoo. ‘Contribution of Artificial intelligence to spatio-temporal flood forecasting’. Université de montpellier, 25th Aug. 2025. URL: https://hal.science/tel-05532625 (cit. on p. 21).

Reports & preprints

[10] M. Castaño-Aguirre, A. F. López-Lopera, N. Bartoli, F. Massa and T. Lefebvre. *Scalable Sparse Co-Kriging for Multi-Fidelity Data Fusion: An Application to Aerodynamics*. 27th Feb. 2026. DOI: 10.1016/j.ress.2026.112485. URL: https://hal.science/hal-05530684.

[11] J. Galaz, M. Kazolea and A. Rousseau. *Analysis of linear Boussinesq-type models coupled with static interfaces*. 12th Mar. 2025. URL: https://inria.hal.science/hal-04988672 (cit. on p. 14).

[12] R. C. Sabi Gninkou, A. F. López-Lopera, F. Massa and R. Le Riche. *Scalable multitask Gaussian processes for complex mechanical systems with functional covariates*. 23rd Feb. 2026. URL: https://hal.science/hal-05524247.

[13] C. Serre-Combe, N. Meyer, T. Opitz and G. Toulemonde. *Spatio-temporal modeling of urban extreme rainfall events at high resolution*. 20th Feb. 2026. URL: https://hal.science/hal-05517816.

12.3 Cited publications

[14] V. Guinot, B. F. Sanders and J. E. Schubert. 'A critical assessment of flux and source term closures in shallow water models with porosity for urban flood simulations'. In: *Advances in Water Resources* 109 (2017), pp. 133–157 (cit. on p. 7).

[15] V. Guinot, B. F. Sanders and J. E. Schubert. 'Dual integral porosity shallow water model for urban flood modelling'. In: *Advances in Water Resources* 103 (2017), pp. 16–31 (cit. on p. 7).

[16] P. Helluy, P. Gerhard, V. Michel-Dansac and B. Weber. *Quasi-explicit, unconditionally stable, discontinuous galerkin solvers for conservation laws*. Research Report. IRMA (UMR 7501), May 2022. URL: https://hal.science/hal-03665248 (cit. on p. 7).

[17] B. Kim, B. F. Sanders, J. S. Famiglietti and V. Guinot. 'Urban flood modeling with porous shallow-water equations: A case study of model errors in the presence of anisotropic porosity'. In: *J. Hydrol.* 523 (2015), pp. 680–692. URL: http://dx.doi.org/10.1016/j.jhydrol.2015.01.059 (cit. on p. 7).