RESEARCH CENTRE

Inria Branch at the University of Montpellier

IN PARTNERSHIP WITH:

Université de Montpellier, CNRS

2023 ACTIVITY REPORT

Project-Team LEMON

Littoral Environment: M0dels and Numerics

IN COLLABORATION WITH: HydroSciences Montpellier (HSM), Institut Montpelliérain Alexander Grothendieck (IMAG)

DOMAIN

Digital Health, Biology and Earth

THEME

Earth, Environmental and Energy Sciences

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Project-Team LEMON

Creation of the Project-Team: 2019 January 01

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1 Team members, visitors, external collaborators

Research Scientists

- Antoine Rousseau [Team leader, INRIA, Researcher, until Sep 2023, HDR]
- Antoine Rousseau [Team leader, INRIA, Senior Researcher, from Oct 2023, HDR]

Faculty Members

- Carole Delenne [UNIV MONTPELLIER, Associate Professor, HDR]
- Pascal Finaud Guyot [UNIV MONTPELLIER, Associate Professor, HDR]
- Vincent Guinot [UNIV MONTPELLIER, Professor, HDR]
- Nicolas Meyer [UNIV MONTPELLIER, Associate Professor]
- Gwladys Toulemonde [UNIV MONTPELLIER, Professor, from Sep 2023, HDR]
- Gwladys Toulemonde [UNIV MONTPELLIER, Associate Professor, until Aug 2023, HDR]

Post-Doctoral Fellow

- Katia Ait Ameur [INRIA, Post-Doctoral Fellow, from Nov 2023]

PhD Students

- Fadil Boodoo [UNIV MONTPELLIER]
- Alexis Boulin [UNIV COTE D'AZUR]
- Cécile Choley [ENGEES, until Oct 2023]
- Omar Et Targuy [UNIV ARTOIS]
- Jose Daniel Galaz Mora [INRIA]
- Chloe Serre Combe [UNIV MONTPELLIER]
- Samuel Valiquette [CIRAD]

Interns and Apprentices

- Antoine Doize [INRIA, Intern, from Mar 2023 until Jun 2023]
- Marc Hetier [INRIA, Intern, from Mar 2023 until Aug 2023]
- Nadia Skifa [ENSIMAG, Intern, from Mar 2023 until Aug 2023]

Administrative Assistant

- Cathy Desseaux [INRIA]

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

Collaboration: Brett Sanders (UCI, USA), Sandra Soarez Frazao (UCL, Belgium).

Research program 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 [38] 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 [41]. It has led to the development of the Dual Integral Porosity model [39]. 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-less" methods are also used by the team for kinetic-relaxation approximation [40].

3.1.3 Street-buildings interactions during flood events

Participants: Pascal Finaud-Guyot, Cécile Choley.

The improvement of realistic flood scenarios also requires the addition of specific processes: we will continue the modeling of interaction with buildings (work initiated by Cécile Choley's PhD thesis) and 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, Jose Daniel Galaz Mora.

Collaboration: 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: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde, Katia Ait Ameur, Fadil Boodoo, Alexis Boulin, Cécile Choley, Omar Et Targuy, Jose Daniel Galaz Mora, Chloe Serre Combe, Samuel Valiquette.

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 Data fusion and parameter estimation

Participants: Carole Delenne.

Macroscopic models such as those developed by the team have advantages in terms of computational cost, but also in terms of time saved in the processing of the mesh which does not need to describe complex geometries. However, these models require new parameters that reflect the statistical properties of the domain geometry or the topography/bathymetry of the modeled area. The directional and connectivity properties of the environment have to be estimated from geographical data. In the continuity of Vita Ayoub's thesis [34], LEMON will work on the development of methods for the automatic estimation of these parameters from cartographic or Earth observation data. The objective will be to set up a methodology for continuous acquisition and automatic fusion of new information in order to improve the mapping of the study area as often as the hydrodynamic models require it.

3.2.2 Space-time variability of rainfalls

Participants: 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.

3.2.3 Multivariate dependence

Participants: Nicolas Meyer, Gwladys Toulemonde, Alexis Boulin, Samuel Valiquette.

Collaboration: Elena Di Bernardino (LJAD, UniCA), Thomas Laloé (LJAD, UniCA), Eric Marchand (Université de Sherbrooke), Frédéric Mortier (Cirad, Montpellier), Jean Peyhardi (IMAG, Université de Montpellier).

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.

3.2.4 Clustering and sparsity models for rainfall

Participants: Nicolas Meyer, Gwladys Toulemonde, Alexis Boulin.

Collaboration: Elena Di Bernardino (LJAD, UniCA), Thomas Laloé (LJAD, UniCA).

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: Carole Delenne, Pascal Finaud-Guyot, Vincent Guinot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde, Katia Ait Ameur, Fadil Boodoo, Cécile Choley, Omar Et Targuy, Jose Daniel Galaz Mora, 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. Since our recent publication [36], 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 explore the transfer of knowledge from configurations for which the data are numerous and of high quality (digital terrain model accurately known, good quality instrumentation) to more rudimentary computational domains.

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 2023 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 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 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 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 modeling 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

As for 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. 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 limit their professional air travel to 10.000km per year.

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

2023 was a year of evaluation for our project-team. This evaluation, coordinated by Inria's Evaluation Committee, is an important step in the team's life cycle. In particular, it enabled us to elaborate collectively on the future of all teams involved in the environmental sciences theme. We have produced a summary of this foresight, which raises more questions than it answers, but which reflects the topic's complexity and the debate that has opened up within the Institute itself.

7 New software, platforms, open data

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. It uses 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)

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, Marc Hetier

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.

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

Publications: hal-02112763, hal-03514473

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 Street-building exchange

Study and modeling of the physical processes controlling water exchanges between streets and buildings during an urban flood

Participants: Pascal Finaud-Guyot, Cécile Choley.

Cécile Choley's PhD [22] focuses on the modeling of urban floods and the consideration of buildings. Flood management provided by public services is based on two-dimensional numerical models. These models do not or only partially represent the exchanges between streets and buildings. However, feedback and photos report that water enters homes, threatening people and their property. While some buildings act as reservoirs and temporarily or even permanently store part of the volume of the flood, others are crossed by the flows if they are connected to several streets. To characterize the effect of buildings on flooding, a new numerical model is proposed, based on the integration of an additional source term in the 2D shallow water equations. The concept of the street-building model is inspired by compartment models, where street and building exchange a flow through openings, such as doors and windows. The transverse flow is controlled by discharge laws, developed from three-dimensional simulations of real-scale openings. The exchange laws are based on the weir and orifice laws from the literature, and the discharge coefficient is determined by limiting the error on the flow calculated numerically. Laws with a tolerance of 30% error on the discharge passing through an opening are established. The street-building model is applied in a synthetic street.

8.1.2 Porosity models for upscaled urban flood modeling

Single Porosity Model: Exploring the Spatial Resolution Limits in Complex Urban Patterns

Participants: Pascal Finaud-Guyot, Antoine Rousseau.

Collaboration: Cristián Escauriaza *(PUC Santiago, Chile)*, Sebastián Nash *(PUC Santiago, Chile)*.

When modeling large-scale urban floods, the use of porosity non-linear shallow water equations emerges as an interesting sub-grid approach for reducing computation time while preserving the structure of the solution. In such models, fine-scale topographic information is represented at a coarser scale through porosity parameters, enabling a speed-up in computations at the expense of losing accuracy while computing hydrodynamic variables. In [28], we use the Single Porosity model (SP) in Cartesian coordinates to simulate flows in both an idealized and a real-world urban area, while gradually increasing the spatial resolution. During such partial coarsening, in which we move from fine-scale to macro-scale, the porosity distribution changes within the urban zone from a highly heterogeneous field to a more uniform one. At an intermediate meso-scale, where the cell size is of the order of the street width and the reduction in computation time is still significant, the main preferential flow paths within the urban area can be captured by means of the porosity gradient. At such a scale, good agreement with refined classical model solutions is found for flow depth, flood extension, and hazard index, both in magnitude and spatial distribution. Numerical results highlight the importance of porosity models for quickly assessing flow properties during an event and improving real-txme decision-making through reliable information.

8.1.3 Large scale floods

Assimilation of flood maps into large scale hydraulic models to retrieve bathymetry information

Participants: Carole Delenne, Vita Ayoub.

Collaboration: Renaud Hostache *(UMR Espace-Dev, Montpellier)*.

Following the work of [35] in Vita Ayoub's PhD thesis, we are currently working on data assimilation using a tempered particle filter to retrieve an estimation of the river bathymetry. Indeed, a major challenge tied to the hydrodynamic modeling is the lack of hydraulic parameter data that are needed as inputs, such as the riverbed shape and elevation. While the knowledge of such information is critical for flood models, it is rarely available from remote sensing observations, digital elevation models (DEMs), or ground data measurements. Most studies have estimated river discharges and depths assuming the bathymetry and bed roughness to be known a priori. We propose to make use of Synthetic Aperture Radar (SAR) imagery due to its ability to provide frequent updates of flooded areas at a large scale, regardless of atmospheric conditions. The porosity functions of the SW2D-DDP hydraulic model enable a straightforward representation of the riverbed geometry using porosity parameters. Probabilistic flood maps derived from SAR data are thus assimilated using a Tempered Particle Filter into the SW2D-DDP model, in order to retrieve a simplified spatially distributed riverbed geometry (i.e., riverbed depth assuming trapezoidal shape). The first results presented in [5] are very encouraging as the model predictions reach water level errors below 0.5 m as a result of the assimilation although the retrieved river bottom elevation is not matching the real one.

Numerical modeling of large debris transport during floods

Participants: Pascal Finaud Guyot, Marc Hetier, Antoine Rousseau.

Collaboration: Vincent Acary *(Inria TRIPOP)*.

Flood risk is the natural phenomenon that affects the most people in the world, and climate change is likely to increase this trend. Floods, whether in rivers or in urban areas, carry debris that can have a significant impact on hydrodynamics and therefore on risk. Although numerical models are frequently used to anticipate the impacts of floods in order to improve land-use planning and facilitate crisis management, there are few models capable of representing accurately both the flood hydrodynamics and the associated debris transport process. Numerical models, when they exist, are generally based on simplifying assumptions. In [26], we propose a new operational model that is validated and compared with analytical results, other models and experimental data. The proposed model, implemented in the SW2D software, paves the way for a better representation of debris clogging on hydrodynamics, even with a large number of transported objects.

8.1.4 Coupling

Coupling dispersive and non-dispersive shallow water models

Participants: Antoine Rousseau, José Galaz.

Collaboration: Maria Kazolea *(Inria CARDAMOM)*.

The calculation of wave shoaling and breaking is essential in coastal applications like risk analysis. Due to the high cost of 3D models, 2D vertically averaged models are normally used. For the propagation and shoaling, higher order models are needed to describe the dispersion of waves with enough accuracy. For breaking some dissipation mechanism is normally introduced, of which the simple switch from the dispersive high order models to the first order Saint-Venant equations has been very popular for two reasons: the non parametric dissipation of energy of shock waves and its simple implementation. However, it has been shown that this model becomes unstable as the resolution is increased. In [32] we show how domain decomposition methods can propose a different way to "switch off" the dispersion by exchanging the information through boundary conditions and overlapping zones, obtaining different performances.

8.1.5 Numerical methods for hyperbolic systems of equations

Large CFL explicit scheme for hyperbolic systems

Participants: Vincent Guinot, Antoine Rousseau.

In [27], a large CFL algorithm is presented for the explicit, finite volume solution of hyperbolic systems of conservation laws. The Riemann problems used in the flux computation are determined using averaging kernels that extend over several computational cells. The usual Courant-Friedrichs-Lewy stability constraint is replaced with a constraint involving the kernel support size. This makes the method unconditionally stable with respect to the size of the computational cells, allowing the computational mesh to be refined locally to an arbitrary degree without altering solution stability. The practical implementation of the method is detailed for the shallow water equations with topographical source term. Computational examples report applications of the method to the linear advection, Burgers and shallow water equations. In the case of sharp bottom discontinuities, the need for improved, well-balanced discretizations of the geometric source term is acknowledged.

8.2 Data-driven models

8.2.1 Statistical approaches for extreme values

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

Participants: Gwladys Toulemonde, Alexis Boulin.

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

In the recent preprint [24], we adress both novel modeling techniques and practical algorithmic applications. In the first aspect of our contribution, we introduce a new class of models called Asymptotic Independent Block (AI-block) models. These models are based on a model-based approach to variable clustering, where clusters are delineated at the population level based on the independence of the extremes between these clusters. The second aspect of our contribution revolves around the development and rigorous evaluation of an algorithm specifically tailored for AI block models.

In addition, we situate our work in the context of multivariate stationary mixing random processes. To demonstrate the practical utility of our proposed AI block models and the associated algorithm, we present two compelling data analyses. These analyses are performed in neuroscience for the first one and in environmental sciences for the second one. This work has also been presented by Alexis Boulin three times in 2023 [21, 31, 6].

High-dimensional clustering of compound precipitation and wind extremes over Europe

Participants: Gwladys Toulemonde, Alexis Boulin.

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

Catastrophic climate events such as floods, forest fires and heat waves are often caused by the simultaneous extreme behavior of several interacting processes. Since in these compound events several spatio-temporal factors are jointly extreme and are inherently high dimensional, a proper understanding of them requires the development of dependence summary measures that are appropriate for extreme-value random vectors. The latter is a key component to propose spatial clustering of these temporal processes. Based on the recent development of an algorithm specifically tailored to asymptotic block models (see also [24]), we propose in this preprint [25] a clustering method adapted to compound extreme events. We illustrate this method by proposing a regionalization task. Specifically, we identify regions based on gridded data from observations and climate model ensembles over Europe. This approach uses daily precipitation sums and daily maximum wind speed data from from the ERA5 reanalysis dataset from 1979 to 2022. This work was also presented at ICSDS [4], at the JDS[12] and at a workshop on data science for coastal risk in Roscoff in November.

Multivariate sparse clustering for extremes

Participants: Nicolas Meyer.

Collaboration: Olivier Wintenberger *(Sorbonne University)*.

The concept of sparse regular variation introduced in [42] allows to infer the tail dependence of a random vector X. This approach relies on the Euclidean projection onto the simplex which, in comparison with standard methods, better exhibits the sparsity structure of the tail of X. We develop a procedure which enables to capture the clusters of extremal coordinates of this vector. This approach also includes the identification of the threshold above, where the values taken by X are considered as extreme. We provide an efficient and scalable algorithm called MUSCLE which is applied to numerical examples and real-world data, such as wind speed measurements.

Asymptotic tail properties of Poisson mixture distributions

Participants: Samuel Valiquette, Gwladys Toulemonde.

Collaboration: Jean Peyhardi *(Univ Montpellier)*, Eric Marchand *(Univ Sherbrooke, CA)*, Fredéric Mortier *(CIRAD)*.

Count data are omnipresent in many applied fields, often with overdispersion due to an excess of zeroes or extreme values. With mixtures of Poisson distributions representing an elegant and appealing modeling strategy, we focus in the published paper [2] on the study of how extreme value theory can be used in such a context. This work has also been presented in an international conference by the PhD student Samuel Valiquette, see [20].

Multivariate peaks-over-threshold with latent variable representations of generalized Pareto vectors

Participants: Gwladys Toulemonde.

Collaboration: Carlo Gaetan *(Venice)*, Thomas Opitz *(Inrae)*, Jean-Noël Bacro *(Univ Montpellier)*.

A flexible multivariate threshold exceedances modeling is defined based on component-wise ratios between any two independent random vectors with exponential and Gamma marginal distributions. This construction allows flexibility in terms of extremal bivariate dependence. More precisely, asymptotic dependence and independence are possible, as well as hybrid situations. Two useful parametric model classes will be presented. One of the two, based on Gamma convolution models, will be illustrated through a simulation study. Good performance is shown for likelihood-based estimation of summaries of bivariate extremal dependence for several scenarii. This work has been presented in an invited seminar in UCL and is submitted in [23].

8.2.2 Heterogeneous data

Data collection and representation for urban water networks

Participants: Carole Delenne, Omar Et-Targuy, Yassine Belghaddar.

Collaboration: Nanée Chahinian *(IRD)*, Salem Benferhat *(CRIL Lens)*, Ahlame Begdouri *(Université Sidi Mohamed Ben Abdellah)*.

A lot of work is currently being done in the framework of ANR CROQUIS[4] and European project STARWARS[5] to collect data of different nature/format on wastewater and stormwater networks. Problematic around these kind of heterogeneous, unprecise, uncertain geographical data have been presented in [3] and an automn school (IA[2]).

Concerning water network representation, even if geographic information systems (GIS) are powerful tools for geographical data, each type of elements: i.e. points, lines and polygons, are defined in separate files, so that pipes and manhole covers or devices are disconnected and linked through attributes in the associated database. One approach explored in Omar Et-Targuy's PhD is thus a graph-based approach that ensures connectivity and consistency [7].

Dealing with uncertain data Omar Et-Targuy's PhD concerns the practical fusion and heterogeneous conditioning of uncertain data, with an application to urban water data. Conditioning is an important task for updating and revising uncertain information when new information, often considered reliable, is added. This paper deals with the so-called Fagin and Halpern (FH-)conditioning within the framework of possibility theory [37]. In two conferences, Omar Et-Targuy presented his first work on the computation of FH-conditioning when it is applied to weighted knowledge bases. He also compared FH-conditioning with the two forms of standard possibilistic conditioning (min-based conditioning and product-based conditioning) [19] [7].

8.3 Hybrid models

8.3.1 Downscaling

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.
This work has been published in [36].

8.3.2 AI for flood forecasting

[4] Collecting, Representing, cOmpleting, merging and Querying heterogeneous and UncertaIn waStewater and stormwater network data, see Section 9.3

[5] STormwAteR and WastewAteR networkS heterogeneous data AI-driven management, see Section 9.2

Rainfall-runoff modeling with AI

Participants: Carole Delenne, Fadil Boodoo, Nadia Skifa.

The aim of Fadil Boodoo's PhD is to take advantage of new AI approaches to rapidly generate flood extent maps in view of flood forecasting. In the first part of the PhD, we focused on rainfall-runoff models, via a comparison of classical hydrological and Long Short Term Memory (LSTM) models [18], [29], [30].

The next step will be to generate flood extent maps with another kind of neural network (such as graph neural networks), that will be trained thanks to physical simulation of the flood with SW2D-DDP model.

9 Partnerships and cooperations

9.1 International initiatives

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

Participants: Pascal Finaud-Guyot, Antoine Rousseau, Katia Ait Ameur, Marc Hetier.

FLOTTE

Title: FLOod and TransporT Equations

Duration: 2023 ->

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 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

Papers [28] and [26] are related to this project.

9.1.2 Participation in other International Programs

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

- 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 modeling to better understand the agricultural practices-soil erosion interactions.

- Carole Delenne is a member of the project "Abidjan: eaux et ville en mutation"[6] funded by the UNESCO Center on water ICIREWARD, lead by Jean-Louis Perrin (HSM) in collaboration with Université Nangui Abrogoua. Abidjan, the economic capital of Côte d'Ivoire, is set to see its population double by 2050. Faced with the far-reaching changes observed over the last 10 years, this project aims to gain a better understanding of their impact on the urban water cycle, with major issues relating to flooding, domestic effluent management, resource pollution and the city's drinking water supply.

9.2 European initiatives

9.2.1 Horizon Europe

Participants: Carole Delenne, Omar Et-Targuy.

Carole Delenne is a member of the STARWARS European project steering committee: STormwAteR and WastewAteR networkS heterogeneous data AI-driven management (MSCA Staff Exchange program, Grant Number 101086252).

Public and private stakeholders of the wastewater and stormwater sectors are increasingly faced with large quantities and multiple sources of information/data of different nature: databases of factual data, geographical data, various types of images, digital and analogue maps, intervention reports, incomplete and imprecise data (on locations and the geometric features of networks), evolving and conflicting data (from different eras and sources), etc. The main objective of this multidisciplinary project is to provide novel proposals for the management of heterogeneous data with an application to stormwater and wastewater networks. The STARWARS project aims to bring together researchers from the AI and Water Sciences communities in order to enhance the emergence of new practical solutions for representing, managing, modeling, merging, completing, reasoning, explaining and query answering over data of different forms pertaining to stormwater and wastewater networks. The project is implemented through five work packages (WP):

- Data Collection and Data Completion
- Unreliable and Heterogeneous Data/Information Modeling
- Practical Merging, Inconsistency and Clustering
- Tractable Query-answering, Explainability, Algorithms
- Validations Project management, Communication, Dissemination and Training

The scheduled secondment plan is designed with the aim of maximizing knowledge transfer and training between the two fields of Water Sciences and AI and thus facilitating the achievement of the project objectives.

9.3 National initiatives

Participants: Carole Delenne, Pascal Finaud Guyot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde.

- Pascal Finaud-Guyot, Antoine Rousseau and Gwladys Toulemonde are members of ANR MUFFINS - MUltiscale Flood Forecasting with INnovating Solutions - 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

[6] Abidjan: water and the changing city

forecasting approaches, enabling the transfer of information between models (meteo-hydrology-hydraulic-damage) and scales (from local runoff generation over areas lesser than 1km2 to flood propagation on catchments of thousands km2), and taking advantage of innovative data (in situ, remote observation, opportunistic) to reduce forecasts uncertainties.

- 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 modeling. 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-18-CE02-0025 project GAMBAS - Generating Advances in Modeling Biodiversity And ecosystem Services - lead by Frédéric Mortier (CIRAD) and involving 6 partners (CIRAD, INRAE, LECA at Grenoble, IMAG at Montpellier, the Museum d'histoire naturelle and the LMO at Paris-Saclay) for a total of 569k€. GAMBAS gathers a collective comprised of quantitative ecologists and mathematicians with aspirations in ecology in order to expand Joint Species Distribution Models (JSDMs). The PhD grant of Samuel Valiquette is fully funded by this project.

- Gwladys Toulemonde is involved in the ANR project McLaren - Machine Learning and Risk Evaluation - under the grant ANR-20-CE23-0011 (289k€). The University of Côte d'Azur, the University of Montpellier, INRAE, Inria and the CNRS are involved in this project. The overall objective of the project is to bring significant innovations in these two areas of statistical learning and risk assessment. The PhD grant of Alexis Boulin is fully funded by this project.

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

- Nicolas Meyer obtained a PEPS grant on *Graphical models for extremes*. This project aims at using statistical tools developed for graphs to study the dependence structure of extreme events.

10 Dissemination

10.1 Promoting scientific activities

Participants: Carole Delenne, Pascal Finaud Guyot, Jose Daniel Galaz Mora, Vincent Guinot, Nicolas Meyer, Antoine Rousseau, Gwladys Toulemonde.

10.1.1 Scientific events: organisation

General chair, scientific chair

- Gwladys Toulemonde co-organized a BIRS workshop "Modern Statistical and Machine Learning Approaches for High-Dimensional Compound Spatial Extremes" at the University of Granada in Spain, from May 7 - 12, 2023.

Member of the organizing committees

- Nicolas Meyer, member of the organizing comittee of the workshop Statlearn2023
- Carole Delenne was member of the organizing comitee of the IA^2 school in Sete. The Autumn School in Artificial Intelligence (IA^2) aims to provide high-level courses in the various techniques used in artificial intelligence. This 2023 autumn school edition concerned the management of heterogeneous and imperfect information and data. The program of this school, spread over 5 days (from Monday, October 30 to Friday, November 3), was mainly composed of fundamental courses (mornings) supplemented by advanced presentations (afternoons) on specific research topics.

10.1.2 Scientific events: selection

Reviewer Carole Delenne was reviewer for ENIGMA workshop organized next to KR conference in Rhodes. AI-driven heterogeneous data management: Completing, merging, handling inconsistencies and query-answering 2023. Rhodes, Greece, September 3-4, 2023.

10.1.3 Journal

Member of the editorial boards

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

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).
- 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).

10.1.4 Invited talks

- Nicolas Meyer gave a talk at the one-day workshop *Événements extrêmes et risques*entitled "Tail inference for high-dimensional data"
- Antoine Rousseau gave a keynote [16] at the Rencontre annuelle 2023, GDR "Défis théoriques pour les sciences du climat", June 2023, Paris, France
- Antoine Rousseau gave a lecture [15] at the conference Numhyp23 - Numerical Methods for Hyperbolic Problems, June 2023, Bordeaux, France

- Gwladys Toulemonde gave a virtual lecture at UCL seminar in statistics, June 2023, London, UK.
- Carole Delenne gave a lecture at the Autumn Institute in Artificial Intelligence (IA2), co-organized in November 2023, Sete, France
- Gwladys Toulemonde gave an invited talk at the conference Data Science pour les risques côtiers, November 2023, Roscoff, France
- Antoine Rousseau gave a keynote [14] at the Journées Scientifiques Inria Chile, December 2023, Santiago, Chile
- Antoine Rousseau gave a lecture [13] at the hydraulic department of Pontificia Universidad Católica, December 2023, Santiago, Chile
- Gwladys Toulemonde gave an invited talk [4] at the IMS conference ICSDS 2023, December 2023, Lisbon, Portugal.

10.1.5 Leadership within the scientific community

- Gwladys Toulemonde is vice-president of the French Statistical Society (Société Française de Statistique, SFdS).

10.1.6 Scientific expertise

- Antoine Rousseau is member of the scientific board of Fondation Blaise Pascal.

10.1.7 Research administration

- 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 (6 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 until september 2023.
- 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).

10.2 Teaching - Supervision - Juries

10.2.1 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 2023:

- Carole Delenne is Program coordinator of the last year of "Eau et Génie Civil - EGC" (Water and Civil Engineering) and the penultimate year of "Sciences et technologies de l'eau" (water science and technology) of the engineering program at Polytech Montpellier.
- 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
- Vincent Guinot is Head of the EGC Academic department at Polytech Montpellier.
- Gwladys Toulemonde is Admissions office coordinator at Polytech Montpellier (500+ students/ year).

10.2.2 Supervision

PhD defended this year:

- Cécile Choley, "Numerical study of the street-building exchange during urban floods", Nov, Pascal Finaud-Guyot and R. Mosé (Université de Strabsourg), [22]

PhD in progress

- Fadil Boodoo, "Hydrodynamic model and artificial intelligence for a flood forecasting system", January 2021, supervised by Carole Delenne and Renaud Hostache (Université de Montpellier).
- Chloé Serre-Combe, *Stochastic generators of extreme precipitation and risk assessment of urban flooding at high spatiotemporal resolution*, October 2022, supervised by Gwladys Toulemonde, Nicolas Meyer, and T. Opitz (Inrae Avignon)
- Omar Et-Targuy, *practical fusion and heterogeneous conditioning of uncertain data*, October 2022, supervised by Salem Benferhat, Ahlame Begdouri, Carole Delenne.
- Alexis Boulin, Université de Côte d'Azur (UniCA) and Université de Montpellier, October 2021, supervised by Elena Di Bernadino, Thomas Laloé and Gwladys Toulemonde.
- Samuel Valiquette, PhD with Sherbrooke University, CIRAD and Université de Montpellier, October 2021(co-directed by Eric Marchand, Frédéric Mortier and Gwladys Toulemonde),

10.2.3 Juries

- Antoine Rousseau was reviewer for Rishabh Bbhatt's PhD (Univ. Grenoble Alpes, 2023)
- Antoine Rousseau was member of the Inria Junior Researcher (CRCN/ISFP) comittee in Grenoble
- Gwladys Toulemonde has participated in the PhD jury of Hela Hammami from University of Montpellier, defended in December, 2023.

10.3 Popularization

10.3.1 Internal or external Inria responsibilities

- Antoine Rousseau is co-editor of the national blog binaire, published by Le Monde.
- 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 Salon de la culture et des jeux mathématiques since 2020.
- In Montpellier, Gwladys Toulemonde and a humanities colleague set up the first local branch of the Collège des sociétés savantes. The creation was announced in June 2023 and the first action was a round table on "Science and Society" in 3 parts: Science and the media, Science and the socio-economic world, and Science and the general public, held during the Printemps des comédiens festival.

10.3.2 Education

- Carole Delenne participated several times in the reception of secondary school students in the framework of Digi'Filles (ISDM, Univ Montpellier): children's version of the “fresque du climat”, water cycle.
- Gwladys Toulemonde co-created the national programme Math C pour L, a mathematics research programme for female students in their first three years of university. The first edition was in CIRM, February 2023.
- Gwladys Toulemonde is involved in the board of the CFEM (commission française pour l'enseignement des mathématiques) since October, 2019, representing the SFdS.
- 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.
- Carole Delenne is part of OpenING and WidenING projects of the "Fondation Polytech", which aims to provide a series of educational 'seeds': these are a mixture of lectures and exercises on a particular concept, which students can complete independently (with guidance if required) in one or two hours. They are created using the H5P and Genially tools, e.g.
- Carole Delenne and Gwladys Toulemonde are part of Math'Start Project, that aims to provide a Moodle-based library of mathematical exercises to remedy, restore and consolidate numeracy skills at L1 level in mathematics. These deliverables will complement the resources already available in the form of educational 'seeds' of the OpenING project.

10.3.3 Interventions

- José Galaz gave a lecture "Tsunamilab, une plateforme numérique interactive pour créer des tsunamis" at the "Feria de la Ciencia" (Chile, 2023).

11 Scientific production

11.1 Publications of the year

International journals

[1] S. Majdalani and V. Guinot. 'Solute transport in heterogeneous model porous media under different flow rates: Experimental and modelling study'. In: *Journal of Hydrology* 616 (Jan. 2023), p. 128790. DOI: 10.1016/j.jhydrol.2022.128790. URL: https://hal.science/hal-03881729.

[2] S. Valiquette, G. Toulemonde, J. Peyhardi, É. Marchand and F. Mortier. 'Asymptotic tail properties of Poisson mixture distributions'. In: *Stat* 12.1 (2023), e622. DOI: 10.1002/sta4.622. URL: https://hal.science/hal-04107633.

Invited conferences

[3] N. Chahinian, B. Haydar, S. Conrad, S. Debard and C. Delenne. 'Everything You Always Wanted to Know About Urban Water Networks But Were Afraid to Ask -Extended Abstract'. In: *CEUR Workshop proceedings*. ENIGMA 2023 - 1st Workshop on AI-driven heterogeneous data management: Completing, merging, handling inconsistencies and query-answering, co-located with 20th International Conference on Principles of Knowledge Representation and Reasoning (KR 2023). Vol. 3495. Rhodes, Greece, 7th Oct. 2023, pp. 1–2. URL: https://hal.science/hal-04231966.

[4] G. Toulemonde, A. Boulin, E. Di Bernadino and T. Laloë. 'High dimensional clustering of coupound precipitation and wind extremes over Europe'. In: *Programm book*. ICSDS 2023 - IMS International Conference on Statistics and Data Science. 2023 IMS International Conference on Statistics and Data Science (ICSDS). Lisbon, Portugal, Dec. 2023. URL: https://inria.hal.science/hal-04373309.

International peer-reviewed conferences

[5] V. Ayoub, R. Hostache, M. Chini, R. Pelich, C. Delenne and P. Matgen. 'Assimilation of probabilistic flood maps into large scale hydraulic models to retrieve missing river geometry data using a tempered particle filter'. In: *IEEE Xplore*. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium. Pasadena, United States, 16th July 2023. URL: https://hal.science/hal-04378319.

[6] A. Boulin, E. D. Bernardino, T. Laloë and G. Toulemonde. 'High-dimensional clustering of sub-asymptotic maxima of a weakly dependent process'. In: *Proceedings of ICSDS 2023*. 2023 IMS International Conference on Statistics and Data Science (ICSDS). Lisbon, Portugal, 21st Dec. 2023. URL: https://hal.science/hal-04397145.

[7] O. Ettarguy, A. Begdouri, S. Benferhat and C. Delenne. 'Syntactic computation of Fagin-Halpern conditioning in possibility theory'. In: *EPiC Series in Computing*. LPAR 2023 - 24th International Conference on Logic for Programming, Artificial Intelligence and Reasoning. Vol. 94. Proceedings of 24th International Conference on Logic for Programming, Artificial Intelligence and Reasoning. Manizales, Colombia, 3rd June 2023, pp. 164–146. DOI: 10.29007/9pjn. URL: https://hal.science/hal-04377873.

[8] C. Peugeot, E. Le Roux, V. Wendling, G. Panthou, P.-A. Raynal, A. Ba, I. Bouzou Moussa, J.-M. Cohard, J. Demarty, F. Gangneron, M. Grippa, B. Hector, T. Lebel, P. Hiernaux, L. Kergoat, E. Lawin, J. D. Galaz Mora, É. Mougin, C. Pierre, J.-L. Rajot and T. Project. 'A drought-triggered hydrological tipping point in the central Sahel: an attribution study using system dynamics modelling'. In: 2nd conference internationale TERENO-OZCAR. Bonn, Germany, 2023. URL: https://imt-mines-ales.hal.science/hal-04286359.

[9] C. Serre-Combe, N. Meyer, T. Opitz and G. Toulemonde. 'Modélisation statistique de précipitations urbaines à fine échelle spatio-temporelle'. In: JDS 2023 - 54e Journées de Statistique de la SFds. Bruxelles, Belgium, 3rd July 2023. URL: https://hal.science/hal-04374113.

[10] C. Serre-Combe, N. Meyer, T. Opitz and G. Toulemonde. 'Towards statistical modelling of urban rainfall on a fine spatio-temporal scale'. In: RESSTE 2023 - Journée "Événements extrèmes et risques". Marseille, France, 1st June 2023. URL: https://hal.science/hal-04374066.

[11] O. Et-Targuy, A. Begdouri, S. Benferhat, C. Delenne, T.-N. Do and T.-T. Ma. 'A Graph-Based Approach for Representing Wastewater Networks from GIS Data: Ensuring Connectivity and Consistency'. In: *Communications in Computer and Information Science (to appear)*. ISDS 2023 - 1rst International Conference on Intelligent Systems and Data Science. Vol. 1949. Can Tho (Vietnam), Vietnam: Springer Nature Singapore, 31st Oct. 2023, pp. 243–257. DOI: 10.1007/978-981-99-7649-2_19. URL: https://hal.science/hal-04377851.

Conferences without proceedings

[12] A. Boulin, E. D. Bernardino, T. Laloë and G. Toulemonde. 'Identifying regions of concomitant compound precipitation and wind speed extremes over Europe'. In: 54es Journées de Statistique de la SFdS. Bruxelles, Belgium, 4th July 2023. URL: https://hal.science/hal-04397129.

[13] A. Rousseau. 'Frugal multi-scale flood modeling: new models and numerical tools'. In: Seminario del Departamento Ingeniería Hidráulica y Ambiental. Santiago, Chile, Dec. 2023. URL: https://inria.hal.science/hal-04396123.

[14] A. Rousseau. 'Multi-scale flood modeling with shallow water models'. In: Journée Scientifiques Inria Chile 2023. Santiago, Chile, 4th Dec. 2023. URL: https://inria.hal.science/hal-04372149.

[15] A. Rousseau and V. Guinot. 'Large CFL explicit scheme for nonlinear shallow water equations'. In: numhyp23 - Numerical Methods for Hyperbolic Problems. Bordeaux, France, 26th June 2023. URL: https://inria.hal.science/hal-04372201.

[16] A. Rousseau and V. Guinot. 'Upscaled models and large CFL time schemes for hydraulic modeling'. In: Rencontre annuelle 2023 GDR "Défis théoriques pour les sciences du climat". Paris, France, 5th June 2023. URL: https://inria.hal.science/hal-04117279.

[17] C. Serre-Combe, N. Meyer, T. Opitz and G. Toulemonde. 'Modélisation statistique de précipitations urbaines à fine échelle spatio-temporelle'. In: Workshop ANR MUFFINS. Aix-en -Provence, France, 28th Sept. 2023. URL: https://hal.science/hal-04374131.

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