

2025 Activity Report

RESEARCH CENTRE: Inria Paris Centre at Sorbonne University
IN PARTNERSHIP WITH: CNRS, Sorbonne Université


Project-Team

ANGE

Numerical Analysis, Geophysics and Environment



In collaboration with Laboratoire Jacques-Louis Lions (LJLL)



Project-Team ANGE

Creation of the Project-Team: 2014 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

- A6. – Modeling, simulation and control
 - A6.1. – Methods in mathematical modeling
 - A6.1.1. – Continuous Modeling (PDE, ODE)
 - A6.1.4. – Multiscale modeling
 - A6.1.5. – Multiphysics modeling
 - A6.2. – Scientific computing, Numerical Analysis & Optimization
 - A6.2.1. – Numerical analysis of PDE and ODE
 - A6.2.6. – Optimization
 - A6.3. – Computation-data interaction
 - A6.3.2. – Data assimilation
 - A6.3.4. – Model reduction
 - A6.3.5. – Uncertainty Quantification

Other research topics and application domains

- B3. – Environment and planet
 - B3.3. – Geosciences
 - B3.3.2. – Water: sea & ocean, lake & river
 - B3.3.3. – Nearshore
 - B3.4. – Risks
 - B3.4.1. – Natural risks
 - B3.4.3. – Pollution
- B4. – Energy
 - B4.3. – Renewable energy production
 - B4.3.1. – Biofuels
 - B4.3.2. – Hydro-energy

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1 Team members, visitors, external collaborators

Research Scientists

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- Marie-Odile Bristeau [SORBONNE UNIVERSITE]
- Jacques Sainte-Marie [INRIA, Senior Researcher, until Apr 2025, HDR]

Faculty Members

- Nina Aguilon [SORBONNE UNIVERSITE, Associate Professor]
- Emmanuel Audusse [UNIV PARIS XIII, Associate Professor Delegation, until Aug 2025]
- Nathalie Ayi [SORBONNE UNIVERSITE, Associate Professor]
- Anne-Laure Dalibard [SORBONNE UNIVERSITE, Professor, from Feb 2025]
- Bernard Di Martino [Université de Corse, Associate Professor, HDR]
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Post-Doctoral Fellows

- Etienne Meunier [INRIA, Post-Doctoral Fellow]
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- Marie Boussard [INRIA]
- Maya Janvier [CNRS, from Oct 2025]
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Technical Staff

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Interns and Apprentices

- Octave Litrico [INRIA, Intern, from Aug 2025]
- Adam Rozentalis [INRIA, Intern, from Jun 2025 until Sep 2025]
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Administrative Assistants

- Nelly Maloisel [INRIA]
- Abigail Palma [INRIA]

2 Overall objectives

2.1 Presentation

Among all aspects of geosciences, we mainly focus on gravity driven flows arising in many situations such as

- hazardous flows (flooding, rogue waves, landslides. . .),
- sustainable energies (hydrodynamics-biology coupling, biofuel production, marine energies. . .),
- risk management and land-use planning (morphodynamic evolutions, early warning systems. . .)

There exists a strong demand from scientists and engineers in fluid mechanics for models and numerical tools able to simulate not only the water depth and the velocity field but also the distribution and evolution of external quantities such as pollutants or biological species and the interaction between flows and structures (seashores, erosion processes. . .). The key point of the researches carried out within ANGE is to answer this demand by the development of efficient, robust and validated models and numerical tools.

2.2 Scientific challenges

Due to the variety of applications with a wide range of spatial scales, reduced-size models like the shallow water equations are generally required. From the modelling point of view, the main issue is to describe the behaviour of the flow with a reduced-size model taking into account several physical processes such as non-hydrostatic terms, biological species evolution, topography and structure interactions within the flow. The mathematical analysis of the resulting model do not enter the field of hyperbolic equations anymore and new strategies have to be proposed. Moreover, efficient numerical resolutions of reduced-size models require particular attention due to the different time scales of the processes and in order to recover physical properties such as positivity, conservativity, entropy dissipation and equilibria.

The models can remain subject to uncertainties that originate from incomplete description of the physical processes and from uncertain parameters. Further development of the models may rely on the assimilation of observational data and the uncertainty quantification of the resulting analyses or forecasts.

3 Research program

3.1 Overview

The research activities carried out within the ANGE team strongly couple the development of methodological tools with applications to real-life problems and the transfer of numerical codes. The main purpose is to obtain new models adapted to the physical phenomena at stake, identify the main properties that reflect the physical meaning of the models (uniqueness, conservativity, entropy dissipation, . . .), propose effective numerical methods to approximate their solution in complex configurations (multi-dimensional, unstructured meshes, well-balanced, . . .) and to assess the results with data in the purpose of potentially correcting the models.

The difficulties arising in gravity driven flow studies are threefold.

- Models and equations encountered in fluid mechanics (typically the free surface Navier-Stokes equations) are complex to analyze and solve.
- The underlying phenomena often take place over large domains with very heterogeneous length scales (size of the domain, mean depth, wave length, . . .) and distinct time scales, *e.g.* coastal erosion, propagation of a tsunami, . . .
- These problems are multi-physics with strong couplings and nonlinearities.

3.2 Modelling and analysis

Hazardous flows are complex physical phenomena that can hardly be represented by shallow water type systems of partial differential equations (PDEs). In this domain, the research program is devoted to the derivation and analysis of reduced complexity models compared to the Navier-Stokes equations, but relaxing the shallow water assumptions. The main purpose is then to obtain models well-adapted to the physical phenomena at stake.

Even if the resulting models do not strictly belong to the family of hyperbolic systems, they exhibit hyperbolic features: the analysis and discretisation techniques we intend to develop have connections with those used for hyperbolic conservation laws. It is worth noticing that the need for robust and efficient numerical procedures is reinforced by the smallness of dissipative effects in geophysical models which therefore generate singular solutions and instabilities.

On the one hand, the derivation of the Saint-Venant system from the Navier-Stokes equations is based on two approximations (the so-called shallow water assumptions), namely

- the horizontal fluid velocity is well approximated by its mean value along the vertical direction,
- the pressure is hydrostatic or equivalently the vertical acceleration of the fluid can be neglected compared to the gravitational effects.

As a consequence the objective is to get rid of these two assumptions, one after the other, in order to obtain models accurately approximating the incompressible Euler or Navier-Stokes equations.

On the other hand, many applications require the coupling with non-hydrodynamic equations, as in the case of micro-algae production or erosion processes. These new equations comprise non-hyperbolic features and a special analysis is needed.

Multilayer approach As for the first shallow water assumption, *multi-layer* systems were proposed to describe the flow as a superposition of Saint-Venant type systems [31, 34, 35]. Even if this approach has provided interesting results, layers are considered separate and non-miscible fluids, which implies strong limitations. That is why we proposed a slightly different approach [32, 33] based on a Galerkin type decomposition along the vertical axis of all variables and leading, both for the model and its discretisation, to more accurate results.

A kinetic representation of our multilayer model allows to derive robust numerical schemes endowed with crucial properties such as: consistency, conservativity, positivity, preservation of equilibria, . . . It is one of the major achievements of the team but it needs to be analyzed and extended in several directions namely:

- The convergence of the multilayer system towards the hydrostatic Euler system as the number of layers goes to infinity is a critical point. It is not fully satisfactory to have only formal estimates of the convergence and sharp estimates would provide an optimal number of layers.
- The introduction of several source terms due for instance to the Coriolis force or extra terms from changes of coordinates seems necessary. Their inclusion should lead to substantial modifications of the numerical scheme.
- Its hyperbolicity has not yet been proven and conversely the possible loss of hyperbolicity cannot be characterised. Similarly, the hyperbolic feature is essential in the propagation and generation of waves.

Non-hydrostatic models The hydrostatic assumption consists in neglecting the vertical acceleration of the fluid. It is considered valid for a large class of geophysical flows but is restrictive in various situations where the dispersive effects (like wave propagation) cannot be neglected. For instance, when a wave reaches the coast, bathymetry variations give a vertical acceleration to the fluid that strongly modifies the wave characteristics and especially its height.

Processing an asymptotic expansion (w.r.t. the aspect ratio for shallow water flows) into the Navier-Stokes equations, we obtain at the leading order the Saint-Venant system. Going one step further leads to a vertically averaged version of the Euler/Navier-Stokes equations involving some non-hydrostatic terms. This model has several advantages:

- it admits an energy balance law (that is not the case for most dispersive models available in the literature),
- it reduces to the Saint-Venant system when the non-hydrostatic pressure term vanishes,
- it consists in a set of conservation laws with source terms,
- it does not contain high order derivatives.

Multi-physics modelling The coupling of hydrodynamic equations with other equations in order to model interactions between complex systems represents an important part of the team research. More precisely, three multi-physics systems are investigated. More details about the industrial impact of these studies are presented in the following section.

- To estimate the risk for infrastructures in coastal zones or close to a river, the resolution of the shallow water equations with moving bathymetry is necessary. The first step consisted in the study of an additional equation largely used in engineering science: The Exner equation. The analysis enabled to exhibit drawbacks of the coupled model such as the lack of energy conservation or the strong variations of the solution from small perturbations. A new formulation is proposed to avoid these drawbacks. The new model consists in a coupling between conservation laws and an elliptic equation, like the Euler/Poisson system, suggesting to use well-known strategies for the analysis and the numerical resolution. In addition, the new formulation is derived from classical complex rheology models and allowed physical phenomena like threshold laws.
- Interaction between flows and floating structures is the challenge at the scale of the shallow water equations. This study requires a better understanding of the energy exchanges between the flow and the structure. The mathematical model of floating structures is very hard to solve numerically due to the non-penetration condition at the interface between the flow and the structure. It leads to infinite potential wave speeds that could not be solved with classical free surface numerical schemes. A relaxation model was derived to overcome this difficulty. It represents the interaction with the floating structure with a free surface model-type.
- If the interactions between hydrodynamics and biology phenomena are known through laboratory experiments, it is more difficult to predict the evolution, especially for the biological quantities, in a real and heterogeneous system. The objective is to model and reproduce the hydrodynamics modifications due to forcing term variations (in time and space). We are typically interested in phenomena such as eutrophication, development of harmful bacteria (cyanobacteria) and upwelling phenomena.

Data assimilation and inverse modelling In environmental applications, the most accurate numerical models remain subject to uncertainties that originate from their parameters and shortcomings in their physical formulations. It is often desirable to quantify the resulting uncertainties in a model forecast. The propagation of the uncertainties may require the generation of ensembles of simulations that ideally sample from the probability density function of the forecast variables. Classical approaches rely on multiple models and on Monte Carlo simulations. The applied perturbations need to be calibrated for the ensemble of simulations to properly sample the uncertainties. Calibrations involve ensemble scores that compare the consistency between the ensemble simulations and the observational data. The computational requirements are so high that designing fast surrogate models or metamodels is often required.

In order to reduce the uncertainties, the fixed or mobile observations of various origins and accuracies can be merged with the simulation results. The uncertainties in the observations and their representativeness also need to be quantified in the process. The assimilation strategy can be formulated in terms of state estimation or parameter estimation (also called inverse modelling). Different algorithms are employed for static and dynamic models, for analyses and forecasts. A challenging question lies in the optimization of the observational network for the assimilation to be the most efficient at a given observational cost.

3.3 Numerical analysis

Non-hydrostatic scheme The main challenge in the study of the non-hydrostatic model is to design a robust and efficient numerical scheme endowed with properties such as: positivity, wet/dry interfaces treatment, consistency. It must be noticed that even if the non-hydrostatic model looks like an extension of the Saint-Venant system, most of the known techniques used in the hydrostatic case are not efficient as we recover strong difficulties encountered in incompressible fluid mechanics due to the extra pressure term. These difficulties are reinforced by the absence of viscous/dissipative terms.

Space decomposition and adaptive scheme In the quest for a better balance between accuracy and efficiency, a strategy consists in the adaptation of models. Indeed, the systems of partial differential equations we consider result from a hierarchy of simplifying assumptions. However, some of these hypotheses may turn out to be irrelevant locally. The adaptation of models thus consists in determining areas where a simplified model (*e.g.* shallow water type) is valid and where it is not. In the latter case, we may go back to the “parent” model (*e.g.* Euler) in the corresponding area. This implies to know how to handle the coupling between the aforementioned models from both theoretical and numerical points of view. In particular, the numerical treatment of transmission conditions is a key point. It requires the estimation of characteristic values (Riemann invariant) which have to be determined according to the regime (torrential or fluvial).

Asymptotic-Preserving scheme for source terms Hydrodynamic models comprise advection and sources terms. The conservation of the balance between source terms, typically viscosity and friction, has a significant impact since the overall flow is generally a perturbation around an equilibrium. The design of numerical schemes able to preserve such balances is a challenge from both theoretical and industrial points of view. The concept of Asymptotic-Preserving (AP) methods is of great interest in order to overcome these issues.

Another difficulty occurs when a term, typically related to the pressure, becomes very large compared to the order of magnitude of the velocity. At this regime, namely the so-called *low Froude* (shallow water) or *low Mach* (Euler) regimes, the difference between the speed of the gravity waves and the physical velocity makes classical numerical schemes inefficient: firstly because of the error of truncation which is inversely proportional to the small parameters, secondly because of the time step governed by the largest speed of the gravity wave. AP methods made a breakthrough in the numerical resolution of asymptotic perturbations of partial-differential equations concerning the first point. The second one can be fixed using partially implicit scheme.

Multi-physics models Coupling problems also arise within the fluid when it contains pollutants, density variations or biological species. For most situations, the interactions are small enough to use a splitting strategy and the classical numerical scheme for each sub-model, whether it be hydrodynamic or non-hydrodynamic.

The sediment transport raises interesting issues from a numerical aspect. This is an example of coupling between the flow and another phenomenon, namely the deformation of the bottom of the basin that can be carried out either by bed load where the sediment has its own velocity or suspended load in which the particles are mostly driven by the flow. This phenomenon involves different time scales and nonlinear retroactions; hence the need for accurate mechanical models and very robust numerical methods. In collaboration with industrial partners (EDF–LNHE), the team already works on the improvement of numerical methods for existing (mostly empirical) models but our aim is also to propose new (quite) simple models that contain important features and satisfy some basic mechanical requirements. The extension of our 3D models to the transport of weighted particles can also be here of great interest.

Optimisation Numerical simulations are a very useful tool for the design of new processes, for instance in renewable energy or water decontamination. The optimisation of the process according to a well-defined objective such as the production of energy or the evaluation of a pollutant concentration is the logical upcoming challenge in order to propose competitive solutions in industrial context. First of all, the set of parameters that have a significant impact on the result and on which we can act in practice is identified. Then the optimal parameters can be obtained using the numerical codes produced by the team to estimate the performance for a given set of parameters with an additional loop such as gradient descent or Monte Carlo method. The optimisation is used in practice to determine the best profile for turbine pales, the best location for water turbine implantation, in particular for a farm.

4 Application domains

4.1 Overview

Sustainable development and environment preservation have a growing importance and scientists have to address difficult issues such as: management of water resources, renewable energy production, bio/geo-chemistry of oceans, resilience of society w.r.t. hazardous flows, urban pollutions, . . .

As mentioned above, the main issue is to propose models of reduced complexity, suitable for scientific computing and endowed with stability properties (continuous and/or discrete). In addition, models and their numerical approximations have to be confronted with experimental data, as analytical solutions are hardly accessible for these problems/models. A. Mangeney (IPGP) and N. Goutal (EDF) may provide useful data.

4.2 Geophysical flows

Reduced models like the shallow water equations are particularly well-adapted to the modelling of geophysical flows since they are characterized by large time or/and space scales. For long time simulations, the preservation of equilibria is essential as global solutions are a perturbation around them. The analysis and the numerical preservation of non-trivial equilibria, more precisely when the velocity does not vanish, are still a challenge. In the fields of oceanography and meteorology, the numerical preservation of the so-called geostrophic state, which is the balance between the gravity field and the Coriolis force, can significantly improve the forecasts. In addition, data assimilation is required to improve the simulations and correct the dissipative effect of the numerical scheme.

The sediment transport modelling is of major interest in terms of applications, in particular to estimate the sustainability of facilities with silt or scour, such as canals and bridges. Dredging or filling-up operations are expensive and generally not efficient in the long term. The objective is to determine a configuration almost stable for the facilities. In addition, it is also important to determine the impact of major events like emptying dam which is aimed at evacuating the sediments in the dam reservoir and requires a large discharge. However, the downstream impact should be measured in terms of turbidity, river morphology and flood.

4.3 Hydrological disasters

It is a violent, sudden and destructive flow. Between 1996 and 2005, nearly 80% of natural disasters in the world have meteorological or hydrological origins. The main interest of their study is to predict the areas in which they may occur most probably and to prevent damages by means of suitable amenities. In France, floods are the most recurring natural disasters and produce the worst damages. For example, it can be a cause or a consequence of a dam break. The large surface they cover and the long period they can last require the use of reduced models like the shallow water equations. In urban areas, the flow can be largely impacted by the debris, in particular cars, and this requires fluid/structure interactions be well understood. Moreover, underground flows, in particular in sewers, can accelerate and amplify the flow. To take them into account, the model and the numerical resolution should be able to treat the transition between free surface and underground flows.

Tsunamis are another hydrological disaster largely studied. Even if the propagation of the wave is globally well described by the shallow water model in oceans, it is no longer the case close to the epicenter and in the coastal zone where the bathymetry leads to vertical accretions and produces substantial dispersive effects. The non-hydrostatic terms have to be considered and an efficient numerical resolution should be induced.

While viscous effects can often be neglected in water flows, they have to be taken into account in situations such as avalanches, debris flows, pyroclastic flows, erosion processes, . . . *i.e.* when the fluid rheology becomes more complex. Gravity driven granular flows consist of solid particles commonly mixed with an interstitial lighter fluid (liquid or gas) that may interact with the grains and decrease the intensity of their contacts, thus reducing energy dissipation and favoring propagation. Examples include subaerial or subaqueous rock avalanches (e.g. landslides).

4.4 Biodiversity and culture

Nowadays, simulations of the hydrodynamic regime of a river, a lake or an estuary, are not restricted to the determination of the water depth and the fluid velocity. They have to predict the distribution and evolution of external quantities such as pollutants, biological species or sediment concentration.

The potential of micro-algae as a source of biofuel and as a technological solution for CO₂ fixation is the subject of intense academic and industrial research. Large-scale production of micro-algae has potential for biofuel applications owing to the high productivity that can be attained in high-rate raceway ponds. One of the key challenges in the production of micro-algae is to maximize algae growth with respect to the exogenous energy that must be used (paddlewheel, pumps, . . .). There is a large number of parameters that need to be optimized (characteristics of the biological species, raceway shape, stirring provided by the paddlewheel). Consequently our strategy is to develop efficient models and numerical tools to reproduce the flow induced by the paddlewheel and the evolution of the biological species within this flow. Here, mathematical models can greatly help us reduce experimental costs. Owing to the high heterogeneity of raceways due to gradients of temperature, light intensity and nutrient availability through water height, we cannot use depth-averaged models. We adopt instead more accurate multilayer models that have recently been proposed. However, it is clear that many complex physical phenomena have to be added to our model, such as the effect of sunlight on water temperature and density, evaporation and external forcing.

Many problems previously mentioned also arise in larger scale systems like lakes. Hydrodynamics of lakes is mainly governed by geophysical forcing terms: wind, temperature variations, . . .

4.5 Sustainable energy

One of the booming lines of business is the field of renewable and decarbonated energies. In particular in the marine realm, several processes have been proposed in order to produce electricity thanks to the recovering of wave, tidal and current energies. We may mention water-turbines, buoys turning variations of the water height into electricity or turbines motioned by currents. Although these processes produce an amount of energy which is less substantial than in thermal or nuclear power plants, they have smaller dimensions and can be set up more easily.

The fluid energy has kinetic and potential parts. The buoys use the potential energy whereas the water-turbines are activated by currents. To become economically relevant, these systems need to be optimized in order to improve their productivity. While for the construction of a harbour, the goal is to minimize swell, in our framework we intend to maximize the wave energy.

This is a complex and original issue which requires a fine model of energy exchanges and efficient numerical tools. In a second step, the optimisation of parameters that can be changed in real-life, such as bottom bathymetry and buoy shape, must be studied. Eventually, physical experiments will be necessary for the validation.

4.6 Urban environment

The urban environment is essentially studied for air and noise pollutions. Air pollution levels and noise pollution levels vary a lot from one street to next. The simulations are therefore carried out at street resolution and take into account the city geometry. The associated numerical models are subject to large uncertainties. Their input parameters, e.g. pollution emissions from road traffic, are also uncertain. Quantifying the simulation uncertainties is challenging because of the high computational costs of the numerical models. An appealing approach in this context is the use of metamodels, from which ensembles of simulations can be generated for uncertainty quantification.

The simulation uncertainties can be reduced by the assimilation of fixed and mobile sensors. High-quality fixed monitoring sensors are deployed in cities, and an increasing number of mobile sensors are added to the observational networks. Even smartphones can be used as noise sensors and dramatically increase the spatial coverage of the observations. The processing and assimilation of the observations raises many questions regarding the quality of the measurements and the design of the network of sensors.

4.7 SmartCity

There is a growing interest for environmental problems at city scale, where a large part of the population is concentrated and where major pollutions can occur. Numerical simulation is well established to study the urban environment, *e.g.* for road traffic modelling. As part of the smartcity movement, an increasing number of sensors collect measurements, at traditional fixed observation stations, but also on mobile devices, like smartphones. They must properly be taken into account given their number but also their potential low quality.

Practical applications include air pollution and noise pollution. These directly relate to road traffic. Data assimilation and uncertainty propagation are key topics in these applications.

5 Social and environmental responsibility

5.1 Footprint of research activities

Only few travels were done last year (including one flight) as a consequence of a will of the team to avoid this type of transportation.

5.2 Impact of research results

Part of ANGE activity is devoted to research on renewable energy. In this way, the team took part to the organization of the EMRSim 22 conference, which devoted to Marine Energy Techniques and Simulation.

6 Highlights of the year

The PEPR Maths-vives/ANR Project "ERRABL: Estimation de ressource dans le Raz Blanchard", including financial support for 2 PhD and a 1 post-doc has been accepted in September.

7 Latest software developments, platforms, open data

7.1 Latest software developments

7.1.1 Freshkiss

Name: FREe Surface Hydrodynamics using KInetic SchemeS

Keywords: Finite volume methods, Hydrostatic Navier-Stokes equations, Free surface flows

Functional Description: Freshkiss3D is a numerical code solving the 3D hydrostatic and incompressible Navier-Stokes equations with variable density.

Contact: Jacques Sainte Marie

Participants: Fabien Souillé, Emmanuel Audusse, Jacques Sainte Marie, Marie-Odile Bristeau

Partners: UPMC, CEREMA

7.1.2 TSUNAMATHS

Keywords: Modeling, Tsunamis

Functional Description: Tsunamaths is an educational platform aiming at simulating historical tsunamis. Real data and mathematical explanations are provided to enable people to better understand the overall process of tsunamis.

URL: <http://tsunamath.paris.inria.fr/>

Contact: Jacques Sainte Marie

Participants: Emmanuel Audusse, Jacques Sainte Marie, Raouf Hamouda

7.1.3 Freshkiss3D

Keywords: Python, Cython, Navier-Stokes

Functional Description: Tool for the numerical solution of free surface Navier-Stokes equations

Publication: [hal-01393147](#)

Contact: Jacques Sainte Marie

Participants: Cedric Doucet, Apolline El Baz, Jacques Sainte Marie

Partner: UPMC

8 New results

8.1 Numerical Methods for fluids

8.1.1 A comprehensive list of stationary solutions of shallow water models

Participants: Nina Aguillon, Emmanuel Audusse.

The shallow water equation of Barré de Saint-Venant describes the evolution of the water height and of the horizontal velocity of a column of water. It is valid when the horizontal length scale of the flow is much greater than its vertical length scale. This model is widely employed to model rivers and lake. It can be enriched to take into account a shear velocity along the vertical. In [21], we classify all the stationary solutions of the shallow water equation with a shear velocity on a bounded domain. Boundary conditions are fixed at the inlet and the outlet, and their number depends on whether the regime is supercritical (Froude number larger than 1) or subcritical. The stationary solutions consist of a succession of regular parts where the momentum and hydraulic head are constant, separated by discontinuity (also called hydraulic jumps) through which the hydraulic head decreases but the momentum and momentum flux are constant. We exhibit the form of the stationary solution and its conditions of existence for any set of boundary conditions on monotonic, bumped shaped and hollow shaped topographies. We find that in some cases and for supercritical flow at the inlet, two different stationary solutions can fulfilled the same set of boundary conditions. The solutions with shocks on increasing topography are sparsely documented and seem to be instable. Eventually we consider a topography made of a succession of N decreasing bumps and prove in the subcritical case that up to 2^{N-1} solutions with discontinuities on decreasing topography only may coexist.

8.1.2 Energy stable and linearly well-balanced numerical schemes for the non-linear Shallow Water equations with Coriolis force

Participants: Emmanuel Audusse.

In [6], we analyse a class of energy-stable and linearly well-balanced numerical schemes dedicated to the nonlinear Shallow Water equations with Coriolis force. The proposed algorithms rely on colocated finite-difference approximations formulated on cartesian geometries. They involve appropriate diffusion terms in the numerical fluxes, expressed as discrete versions of the linear geostrophic equilibrium. We show that the resulting methods ensure semi-discrete energy estimates. Among the proposed algorithms a colocated finite-volume scheme is described. Numerical results show a very clear improvement around the nonlinear geostrophic equilibrium when compared to those of classic Godunov-type schemes.

8.1.3 Hyperbolicity of a semi-Lagrangian formulation of the hydrostatic free-surface Euler system

Participants: Jacques Sainte-Marie, Bernard Di Martino, Edwige Godlewski, Julien Guillod.

In [9], using a semi-Lagrangian change of coordinates, the hydrostatic Euler equations describing free-surface sheared flows is rewritten as a system of quasilinear equations, where stability conditions can be determined by the analysis of its hyperbolic structure. The system one obtains can be written as a quasi linear system in time and horizontal variables and involves no more vertical derivatives. However, the coefficients in front of the horizontal derivatives include an integral operator acting on the new vertical variable. The spectrum of these operators is studied in detail, in particular it includes a continuous part. Riemann invariants are then determined as conserved quantities along the characteristic curves. Examples of solutions are provided, in particular stationary solutions and solutions blowing-up in finite time. Eventually, we propose an exact multilayer P0-discretization, which could be used to solve numerically this semi-Lagrangian system, and analyze the eigenvalues of the corresponding discretized operator to investigate the hyperbolic nature of the approximated system.

8.1.4 Implicit kinetic schemes for the Saint-Venant system

Participants: Jacques Sainte-Marie.

Explicit (in time) kinetic schemes applied to the nonlinear shallow water equations have been extensively studied in the past. The novelty of [10] is to investigate an implicit version of such methods in order to improve their stability properties. In the case of a flat bathymetry we obtain a fully implicit kinetic solver satisfying a discrete entropy inequality and keeping the water height non negative without any restriction on the time step. Remarkably, a simplified version of this nonlinear implicit scheme allows to express the update explicitly which we implement in practice. The case of varying bottoms is then dealt with through an iterative solver combined with the hydrostatic reconstruction technique. We show that this scheme preserves the water height non-negativity under a CFL condition and satisfies a discrete entropy inequality without error term, which is an improvement over its explicit version. An extension of the implicit and iterative methods to the two dimensional case is also discussed. Finally we perform some numerical validations underlining the advantages and the computational cost of our strategy.

8.1.5 Unconditionally stable numerical scheme for the 2D transport equation

Participants: Yohan Penel.

The main goal of [11] is to extend the numerical scheme for the transport equation described in previous works [Penel, 2012; Bernard et al., 2014] from one to two dimensional problems. It is based on the method of characteristics, which consists in solving two ordinary differential equations rather than a partial differential equation. Our scheme uses an adaptive 6-point stencil in order to reach second-order accuracy whenever it is possible, and preserves some essential physical properties of the equation, such as the maximum principle. The resulting scheme is proved to be unconditionally stable and to reach second-order accuracy. We show numerical examples with comparisons to the well known Essentially Non-Oscillatory (ENO) scheme [Shu, 1998], in order to illustrate the good properties of our scheme (order of convergence, unconditional stability, accuracy). Using a Gaussian initial condition, several test cases are considered, using a constant or a rotating velocity field, taking into account or not variable source terms. Also, a test is given that shows the possibility of applying the scheme in more realistic fluid mechanics case.

8.1.6 Barotropic-Baroclinic Splitting for Multilayer Shallow Water Models with Exchanges

Participants: Jacques Sainte-Marie, Nina Aguilon.

The paper [22] presents the numerical analysis of a barotropic-baroclinic splitting in a nonlinear multilayer framework with exchanges between the layers in terrain-following coordinates. The splitting is formulated as an exact operator splitting. The barotropic step handles free surface evolution and depth-averaged velocity via a well-balanced one-layer model, while the baroclinic step manages vertical exchanges between layers and adjusts velocities to their mean values. We show that the barotropic-baroclinic splitting preserves total energy conservation and meets both a discrete maximum principle and a discrete entropy inequality. Several numerical experiments are presented showing the gain in computational cost, particularly in low Froude simulations, and the benefits of using well-balancing strategies for the barotropic step.

8.1.7 Topography optimization for enhancing microalgal growth in raceway ponds

Participants: Jacques Sainte-Marie, Julien Salomon.

Modelling the evolution process for the growth of microalgae in an artificial pond is a huge challenge, given the complex interaction between hydrodynamics and biological processes occurring across various timescales. In [7], we consider a raceway, i.e., an oval pond where the water is set in motion by a paddle wheel. Our aim is to investigate theoretically and numerically the impact of bottom topography in such raceway ponds on microalgae growth. To achieve this goal, we consider a biological model based on the Han model, coupled with the Saint-Venant systems that model the fluid. We then formulate an optimization problem, for which we apply the weak maximum principle to characterize optimal topographies that maximize biomass production over one lap of the raceway pond or multiple laps with a paddle wheel. In contrast to a widespread belief in the field of microalgae, we show that a flat topography in a periodic regime satisfies the necessary optimality condition, and observe in the numerical experiments that the flat topography is actually optimal in this case. However, non-trivial topographies may be more advantageous in alternative scenarios, such as when considering the effects of mixing devices within the model. This study sheds light on the intricate relationship between bottom topography, fluid dynamics, and microalgae growth in raceway ponds, offering valuable insights into optimizing biomass production.

8.2 Fluids modelling

8.2.1 A linear model of separation for western boundary currents with bathymetry

Participants: Anne-Laure Dalibard, Corentin Gentil.

This paper [24] is devoted to the asymptotic analysis of strongly rotating and stratified fluids, under a β -plane approximation, and within a three-dimensional spatial domain with strong topography. Our purpose is to propose a linear idealized model, which is able to capture one of the key features of western boundary currents, in spite of its simplicity: the separation of the currents from the coast. Our simplified framework allows us to perform explicit computations, and to highlight the intricate links between rotation, stratification and bathymetry. In fact, we are able to construct approximate solutions at any order for our system, and to justify their validity. Each term in the asymptotic expansion is the sum of an interior part and of two boundary layer parts: a “Munk” type boundary layer, which is quasi-geostrophic, and an “Ekman part”, which is not. Even though the Munk part of the approximation bears some similarity with previously studied 2D models, the analysis of the Ekman part is completely new, and several of its properties differ strongly from the ones of classical Ekman layers. Our theoretical analysis is supplemented with numerical illustrations, which exhibit the desired separation behavior.

8.2.2 Long-time behavior of the Stokes-transport system in a channel

Participants: Anne-Laure Dalibard, Julien Guillod.

In [8], we consider here a two-dimensional incompressible fluid in a periodic channel, whose density is advected by pure transport, and whose velocity is given by the Stokes equation with gravity source term. Dirichlet boundary conditions are taken for the velocity field on the bottom and top of the channel and periodic conditions in the horizontal variable. We prove that the affine stratified density profile is stable under small perturbations in Sobolev spaces and prove convergence of the density to another limiting stratified density profile for large time with an explicit algebraic decay rate. Moreover, we are able to precisely identify the limiting profile as the decreasing vertical rearrangement of the initial density. Finally, we show that boundary layers are formed for large times in the vicinity of the upper and lower boundaries. These boundary layers, which had not been identified in previous works, are given by a self-similar ansatz and driven by a linear mechanism. This allows us to precisely characterize the long-time behavior beyond the constant limiting profile and reach more optimal decay rates.

8.2.3 Modeling gas flow in a looped thermosyphon with a 1 D low-Mach number expansion

Participants: Yohan Penel.

In [16], we provide numerical results for a laminar gas flow at small velocities in the "looped thermosyphon", or "natural circulation loop" : a closed configuration composed of two horizontal adiabatic pipes and two vertical pipes with different wall temperature. To this extent, following Paolucci, [39, 40] we construct a low-Mach number model capable of taking into account the periodicity and the discontinuities intrinsic to this configuration. This compressible model is richer than the Boussinesq model since it describes the pressure variation and is adapted to the description of flows driven by large temperature gradients. We settle averaged equations through the pipes of small radius compared to the length, this gives a one dimensional system of equations of mass, momentum and energy with two pressures, a dynamical one and a thermodynamical one only function of time. We construct a quasi-exact solution in a laminar and steady-state regime. We approach the low-Mach averaged 1D Model with a coupled numerical method based on the characteristics method considering the presence of the periodic conditions and the discontinuous gravity term with Dirac distributions as derivatives at the corners. The numerical results are confronted and validated by the aforementioned reference solution to determine their accuracy.

8.2.4 Theoretical and Numerical Study of the Convergence of Luenberger Observers for a Linearized Water Wave Model

Participants: Lucas Perrin.

In [27], we investigate the convergence properties of Luenberger observers applied to a linearized water wave model. The study is motivated by the challenge of estimating wave dynamics when only partial free surface measurements are available. We identify fundamental obstructions to convergence, showing that the classical Luenberger observer fails to achieve full-state reconstruction due to challenges associated with mean-value modes and high-frequency components. To overcome these limitations, we introduce modified observer schemes that incorporate frequency filtering and projection techniques. Our theoretical results are reinforced by numerical experiments that demonstrate the practical effectiveness of these observer-based estimation methods for water waves.

8.2.5 Forward self-similar solutions to the 2D Navier–Stokes equations

Participants: Julien Guillod.

In [23], we construct self-similar solutions to the 2D Navier–Stokes equations evolving from arbitrarily large -1 -homogeneous initial data and present numerical evidence for their non-uniqueness.

8.3 Acceleration techniques: parallelization, machine learning, model reduction

8.3.1 Parallel approximation of the exponential of semidefinite negative Hermitian matrices

Participants: Lucas Perrin, Julien Salomon.

The numerical solution of parabolic equations often involves calculating the exponential of Hermitian matrices. In [25], we consider a rational approximation of the exponential function to design an algorithm for computing the matrix exponential in the Hermitian case. Using partial fraction decomposition, we derive a parallelizable method, reducing the computation to independent resolutions of linear systems. We analyze the effects of rounding errors on the accuracy of our algorithm. This work is complemented by numerical tests that demonstrate the efficiency of our method and compare its performance with standard implementations.

8.3.2 Convergence of ParaOpt for general Runge-Kutta time discretizations

Participants: Norbert Tognon, Julien Salomon.

ParaOpt is a time parallel method based on Parareal for solving optimality systems arising in optimal control problems. The method was presented in [M.J. Gander, F. Kwok and J. Salomon, SIAM J. Sci. Comput., 42 (2020), A2773-A2802] together with a convergence analysis in the case where implicit Euler is used to discretize the differential equations governing the system dynamics. However, its convergence behaviour for higher order time discretizations has not been considered. In [26], we use an operator norm analysis to prove that the convergence rate of ParaOpt applied to a linear-quadratic optimal control problem has the same order as the Runge-Kutta time integration method used, provided that a few auxiliary order conditions are satisfied. We illustrate our theoretical results with numerical examples, before showing an additional test case not covered by our analysis, namely, a nonlinear optimal control problem involving a Schrödinger type system.

8.3.3 Learning to generate physical ocean states: Towards hybrid climate modeling

Participants: Etienne Meunier.

Ocean General Circulation Models require extensive computational resources to reach equilibrium states, while deep learning emulators, despite offering fast predictions, lack the physical interpretability and long-term stability necessary for climate scientists to understand climate sensitivity (to greenhouse gas emissions) and mechanisms of abrupt variability such as tipping points. In [28], we propose to take the best from both worlds by leveraging deep generative models to produce physically consistent oceanic states that can serve as initial conditions for climate projections. We assess the viability of this hybrid approach through both physical metrics and numerical experiments, and highlight the benefits of enforcing physical constraints during generation. Although we train here on ocean variables from idealized numerical simulations, we claim that this hybrid approach, combining the computational efficiency of deep learning with the physical accuracy of numerical models, can effectively reduce the computational burden of running climate models to equilibrium, and reduce uncertainties in climate projections by minimizing drifts in baseline simulations.

8.3.4 ParaOpt for unstable systems

Participants: Norbert Tognon.

ParaOpt is a two-level time-parallel method to solve the coupled forward/backward Euler-Lagrange system arising from partial differential equations (PDEs) constrained optimization. In [29], we present a convergence analysis of this algorithm in the case where the system under consideration is unstable. We complete this theoretical study with numerical experiments, where the properties of the algorithm are investigated on linear and nonlinear examples.

8.3.5 Towards fully differentiable neural ocean model with Veros

Participants: Etienne Meunier.

In [18], we present a differentiable extension of the VEROS ocean model, enabling automatic differentiation through its dynamical core. We describe the key modifications required to make the model fully compatible with JAX autodifferentiation framework and evaluate the numerical consistency of the resulting implementation. Two illustrative applications are then demonstrated: (i) the correction of an initial ocean state through gradient-based optimization, and (ii) the calibration of unknown physical parameters directly from model observations. These examples highlight how differentiable programming can facilitate end-to-end learning and parameter tuning in ocean modeling. Our implementation is available online.

8.4 Other results

8.4.1 Graph and Mean-Field Limits for Interacting Particle Systems

Participants: Nathalie Ayi.

Models of collective dynamics provide a powerful framework to analyze phenomena such as opinion formation in populations and flocking behaviors in animal groups. While the classic mean-field limit approach has provided valuable insights into indistinguishable particle systems, it fails to capture the influence of individual identities and specific interaction structures. Graph theory addresses this limitation and allows to study large-population limits of systems of interacting particles on weighted graphs. The lecture notes presented in [17] begin by exploring two approaches to large-population limits for non-exchangeable particle systems: the graph limit and the (non-exchangeable) mean-field limit. Rigorous convergence results are presented, emphasizing their interplay. Building on this foundation, we consider three variations: adaptive dynamical networks, which capture evolving interaction structures, random graphs, which provide realistic models for generating graphs, and hypergraphs, which extend analysis to higher-order interactions, crucial in systems where joint influences can be observed.

8.4.2 Humanity's Last Exam

Participants: Julien Guillod.

phan:hal-04915593, title = Humanity's Last Exam, Benchmarks are important tools for tracking the rapid advancements in large language model (LLM) capabilities. However, benchmarks are not keeping pace in difficulty: LLMs now achieve over 90% accuracy on popular benchmarks like MMLU, limiting informed measurement of state-of-the-art LLM capabilities. In response, we introduce Humanity's Last Exam (HLE,

see [15]) a multi-modal benchmark at the frontier of human knowledge, designed to be the final closed-ended academic benchmark of its kind with broad subject coverage. HLE consists of 3,000 questions across dozens of subjects, including mathematics, humanities, and the natural sciences. HLE is developed globally by subject-matter experts and consists of multiple-choice and short-answer questions suitable for automated grading. Each question has a known solution that is unambiguous and easily verifiable, but cannot be quickly answered via internet retrieval. State-of-the-art LLMs demonstrate low accuracy and calibration on HLE, highlighting a significant gap between current LLM capabilities and the expert human frontier on closed-ended academic questions. To inform research and policymaking upon a clear understanding of model capabilities, we publicly release HLE at .

8.4.3 Probing the partition function for temperature-dependent potentials with nested sampling

Participants: Julien Salomon.

Thermodynamic properties can be in principle derived from the partition function, which, in many-atom systems, is hard to evaluate as it involves a sum on the accessible microscopic states. Recently, the partition function has been computed via nested sampling, relying on Bayesian statistics, which is able to provide the density of states as a function of the energy in a single run, independently of the temperature. This appealing property is lost whenever the potential energy that appears in the partition function is temperature-dependent: for instance, mean-field effective potential energies or the quantum partition function in the path-integral formalism. For these cases, the nested sampling must be carried out at each temperature, which results in a massive increase of computational time. In [13], we introduce and implement a new method, that is based on an extended partition function where the temperature is considered as an additional parameter to be sampled. The extended partition function can be evaluated by nested sampling in a single run, so to restore this highly desirable property even for temperature-dependent effective potential energies. We apply this original method to compute the quantum partition function for harmonic potentials and Lennard-Jones clusters at low temperatures and show that it outperforms the straightforward application of nested sampling for each temperature within several temperature ranges.

8.4.4 Segmenting the motion components of a video: A long-term unsupervised model

Participants: Etienne Meunier.

Human beings have the ability to continuously analyze a video and immediately extract the motion components. We want to adopt this paradigm to provide a coherent and stable motion segmentation over the video sequence. In this perspective, we propose in [14] a novel long-term spatio-temporal model operating in a totally unsupervised way. It takes as input the volume of consecutive optical flow (OF) fields, and delivers a volume of segments of coherent motion over the video. More specifically, we have designed a transformer-based network, where we leverage a mathematically well-founded framework, the Evidence Lower Bound (ELBO), to derive the loss function. The loss function combines a flow reconstruction term involving spatio-temporal parametric motion models combining, in a novel way, polynomial (quadratic) motion models for the spatial dimensions and B-splines for the time dimension of the video sequence, and a regularization term enforcing temporal consistency on the segments. We report experiments on four VOS benchmarks, demonstrating competitive quantitative results while performing motion segmentation on a sequence in one go. We also highlight through visual results the key contributions on temporal consistency brought by our method.

8.4.5 Surrogate modeling of interactions in microbial communities through Physics-Informed Neural Networks

Participants: Lucas Perrin.

Microorganisms form complex communities known as microbiota, influencing various aspects of host well-being. The Generalized Lotka-Volterra (GLV) model is commonly used to understand microorganism population dynamics, but its application to the microbiota faces challenges due to limited bacterial data and complex interactions. The preliminary work [12] focuses on using a Physics-Informed Neural Network (PINN) and synthetic data to build a surrogate model of bacterial species evolution driven by a GLV model. The approach is calibrated and tested on several models differing in size and dynamic behavior.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Participation in other International Programs

Participants: Julien Salomon, Jacques Sainte-Marie.

OceanIA

Partner Institution(s): INRIA • INRIA Paris

- INRIA Saclay
- INRIA Sophia-Antipolis
- INRIA Chile

Date/Duration: 2020-2025

Additional info/keywords: OceanIA is a four-years project (11.2020–12.2025) involving Inria teams in Chile, Paris, Saclay, and Sophia-Antipolis, and the Fondation Tara Océan, the Center of Mathematical Modeling (CMM, U.Chile), the Pontificia Universidad Católica de Chile (PUC), the GO-SEE CNRS Federation, and the Laboratoire des Sciences du Numérique de Nantes (LS2N).

9.1.2 Visits of international scientists

Other international visits to the team

Felix Kwok

Status: researcher

Institution of origin: Université Laval

Country: Québec, Canada

Dates: 09.06-13.07

Context of the visit: Research on ParaOpt algorithm

Mobility program/type of mobility: research stay

9.1.3 Visits to international teams

Research stays abroad

Participants: Nathalie Ayi.

Visited institution: Stay at SLMath (Berkeley)

Country: USA

Dates: 03.10-27.11

Context of the visit: Research

Mobility program/type of mobility: research stay

Participants: Anne-Laure Dalibard.

Visited institution: Hausdorff Center for Mathematics (HCM), Bonn,

Country: Germany

Dates: 23.06-27.06

Mobility program/type of mobility: Lecture

Participants: Julien Salomon.

Visited institution: Mathematisches Forschungsinstitut Oberwolfach (MFO)

Country: Germany

Dates: 24.11-28.11

Mobility program/type of mobility: Lecture

9.1.4 Other european programs/initiatives

Participants: Anne-Laure Dalibard.

Visited institution: Mathematisches Forschungsinstitut Oberwolfach (MFO)

Country: Germany

Dates: 12.05-16.05

Mobility program/type of mobility: Organization of a workshop.

9.2 National initiatives

Projet Emergence (2023-2025)

Participants: Nathalie Ayi.

- Project acronym: Emergence
- Project title: Numerical studies of STOchastic Kinetic partial differential equations (STOCK)
- Coordinator: Nathalie Ayi (SU)
- Funding: 15 000 euros.

ANR NASSMOM (2024-2028)

Participants: Nina Aguillon, Julie Deshayes, Sybille Techené.

- Project acronym: NASSMOM
- Project title: Nondiffusive advection schemes and spurious mixing in ocean model
- Coordinator: Nina Aguillon
- Funding: 246 957 euros.

Water masses of given temperature and salinity are advected without much blending over long periods of time in the ocean. At the numerical level, the discretization of the equation creates a spurious mixing (or numerical diffusion) that artificially mixes the water masses. It can be of the same order of magnitude as the physical mixing. This is especially true in climate simulations where the grid is coarse and the time of integration is long. This project is concerned with two different aspects of the spurious mixing. First, we will study a numerical procedure to quantify precisely in space and time the spurious mixing. The method is both different from usual entropy inequality in maths that are limited to first order schemes, and from global diagnosis based on water mass transformation in oceanography. It should allow us to better understand the geography and effects of spurious mixing. It can be applied to any transported quantity or to the evolution of total energy. Second, we will develop antidiffusive advection schemes for the salinity and temperature in the European ocean general circulation model NEMO. This approach is different from the usual « higher order, finer grids » strategy and has been successfully employed for atmospheric pollution and biphasic flows. Preliminary results obtained by the principal investigator on a new second order antidiffusive scheme show a gain of accuracy in the smooth regions and a correct behavior in 2 space dimensions. This is a major improvement compared to the existing first order antidiffusive schemes, which should allow us to go beyond its use in the vertical direction only. In conclusion, this project proposes a mathematical approach on the question of spurious mixing in ocean general circulation models. The team gathers experts on numerical analysis and ocean modeling. We will collaborate closely together with the aim of having a direct contribution to NEMO.

ANR BOURGEONS (2023-2027)

Participant: Anne-Laure Dalibard.

- Project acronym: BOURGEONS
- Project title: Boundaries, Congestion and Vorticity in Fluids: A connection with environmental issues
- Coordinator: Anne-Laure DALIBARD
- Funding: 567301 euros.

The purpose of the BOURGEONS project is to investigate several aspects of fluid dynamics which all play an important role in geophysical flows and their environmental applications. It is organized around two main topics which strongly expanded in recent years, and for which we will address both fundamental and applied aspects: (i) the dynamics of floating objects, congested flows and extreme waves; and (ii) the analysis of boundary layers and vortices.

PEPR Climaths (2024-2029)

Participant: Anne-Laure Dalibard.

- Project acronym: CLIMATHS
- Project title: Fundamental advances in modelling key processes for reducing climate change impacts
- Coordinator: Anne-Laure DALIBARD
- Funding: 1 000 000 euros.

The CLIMATHS project targets fundamental developments required to reduce uncertainties in the study of the impacts of climate change. The climate and its main components - including the atmosphere and ocean - obey complex dynamics, some aspects of which are still poorly understood, despite their crucial importance for mankind in a context of climate disruption.

ANR Saphir (2022-2026)

Participants: Jacques Sainte-Marie, Bernard Di Martino.

- Project acronym: Saphir
- Project title: Sensor Augmented weather Prediction at high Resolution
- Coordinator: J-F. Muzy (Université de Toulouse Paul Sabatier)
- Funding: 296 000 euros.

Providing reliable forecasts of severe weather events is a major issue in many areas such as civil safety or renewable energy production. SAPHIR proposes to combine high-resolution (sub-km) atmospheric dynamics models and a set of direct measurements from weather stations, atmospheric monitoring programs or a dedicated sensor network within a «deep learning» architecture specifically optimized for improving forecasting accuracy. We plan to use this approach to improve the forecast (at horizons ranging from few hours to few days) of intense weather events including rainfalls and electrical activity with an application to river flooding forecasting. SAPHIR is also aiming for an application in the field of renewable energies by improving the forecast of cloudiness and wind strength, which are determining factors for the production of solar or wind power plants.

ANR DEEPNUM (2022-2026)

Participants: Julien Salomon, Jacques Sainte-Marie.

- Project acronym: DEEPNUM
- Project title: Algorithmes pour l'optimisation à grande échelle de problèmes de propagation d'ondes
- Coordinator: Julien Salomon
- Funding: 493 799,20 euros.

The project aims at developing the interplay between Deep Neural Networks (DNNs) and Differential Equations (DEs), with the goal of modeling complex dynamical systems arising from the observation of natural phenomena. Two application domains are targeted, environment and healthcare. We address three fundamental questions: how to adapt and apply numerical analysis theory to DNNs for analyzing them, providing theoretical guaranties and improving their robustness, how to combine simulation and data based models into hybrid systems, how could DNNs help solving DEs and complement numerical solvers. In addition, we evaluate our methods on simulation and real world data in the environment and health domains. DeepNuM gathers partners with complementary skills: DEs and Environment (INRIA-ANGE), Machine Learning and DNNs (Sorbonne – MLIA), DEs and Biophysics (INRIA-EPIONE).

ANR MEGA (2023-2028)

Participants: Bernard Di Martino, Jacques Sainte-Marie, Nina Aguillon.

- Project acronym: MEGA
- Project title: Giant submarine landslides in gas hydrate provinces: a comparison of the Nile and Amazon deep-sea fans
- Coordinator: Sébastien Mingeon
- Funding: 533,348 euros.

Giant submarine landslides (10-2000 km³) are found in the thick Quaternary sediment succession of passive continental margins. Their ages coincide with periods of sea-level fall and rise, but it is unclear how such vast failures can be triggered on low seafloor slopes (<2°) in the absence of a triggering factor such as seismicity. Key hypotheses involv. Beck, P. Bonneton, D. Bresch, C. Collot, A.-L. Dalibard, E. Dormy, I. Gallagher, Th. Gallay, D. Gérard-Varet, E. Grenier, M. Hillairet, M. Kazakova, C. Lacave, D. Lannes, F. Marbach, F. Marche, E. Miot, M. Parisot, C. Perrin, C. Prange, M. Rigal, F. Rousset, L. Saint-Raymond, F. Sueur, M. Tucsna, A. Venaille. e excess pore pressures linked to reductions in gas-hydrate stability, driven by changes either in climate or in subsurface fluid flow. The MEGA project wants to explore such hypotheses through the first modelling of linked changes in gas hydrate and slope stability in response to ocean pressure and temperature changes, using an innovative comparison of the Nile and Amazon deep-sea fans that experience different forms of climate forcing over glacial-interglacial timescales. As such megaslides have never triggered in historical times, MEGA will provide input for the first modelling of their tsunamogenic consequences on coastal zones.

ANR SMASH (2025-2029)

Participants: Julien Guillod.

- Project acronym: SMASH
- Project title: Emergent Small Scale behaviors in Hydrodynamic models
- Coordinator: F. Vigneron
- Funding: 315000 euros.

ANR HEAD (2024-2029)

Participants: Nathalie Ayi.

- Project acronym: HEAD
- Project title: Hyperbolic Evolutions, Approximations & Dynamics
- Coordinator: M. Rodrigues
- Funding: 422 820 euros.

Our project is focused on the analysis of the long-time dynamics of first-order hyperbolic systems of nonlinear partial differential equations and their approximations by numerical schemes, vanishing viscosity or in the dispersionless limit. It contributes to three general aims:

1. The development of a stability theory applicable to singular waves, including discontinuous and/or characteristic ones.
2. Uniform stability results when the long-time limit and the approximation process commute.
3. A refined description of obstructions when they do not.

Its concrete applications are focused on models from fluid mechanics and plasma dynamics.

RT "Terre & Énergies" (2023–)

Participants: Emmanuel Audusse, , Bernard di Martino, , Martin Parisot, Jacques Sainte-Marie.

The MathGeoPhy interdisciplinary research group was created in January 2022, for five years. It is funded by the French National Center for Scientific Research (CNRS), with the mission of animating the French scientific community around the theme of mathematics in interaction with the geophysics of fluid and solid envelopes. The members of the GdR are interested in mathematical modeling, scientific computing and the development of new numerical methods applied in particular to :

- offshore and coastal ocean dynamics, gravity waves, coastal erosion problems
- micro-macro approaches, granular and complex flows
- fluvial and torrential hydrodynamics, extreme events and environmental risks, landslides, avalanches, volcanic eruptions, glaciology, etc.

GdR EOL-EMR (2021–2026)

Participants: Julien Salomon, Jacques Sainte-Marie.

The objectives of this project are the following:

- To promote the dissemination of existing knowledge and expertise within and across disciplines.
- The GDR EMR is a forum for the exchange of expertise and know-how within and across disciplines.
- To promote the implementation of collaborations, between partners of the GDR and with the industrial fabric.

The GDR is an entry and orientation point. It provides a forum for the exchange of information concerning industrial needs and the skills of the academic community; and enables the bringing together of players. Valuing the national scientific community The GDR EMR gives visibility to the community, in particular through the development of a mapping of the actors and themes available on the web platform

10 Dissemination

10.1 Promoting scientific activities

Participants: Anne-Laure Dalibard.

2019- : Comité National Français des Mathématiques

Participants: Julien Salomon.

2021- : Redactor-in-chief of MATAPLI (French applied maths revue)

Participants: Emmanuel Audusse.

2020- : Responsible of a section of MATAPLI (French applied maths revue)

10.1.1 Seminar Organization

Participants: Julien Guillod.

- 2019- : Séminaire Analyse non-linéaire et EDP (DMA, ENS)
- 2021- : Séminaire Infomath

Participants: Anne-Laure Dalibard.

- 2016- : Comité d'organisation du séminaire du LJLL
- 2025- : Présidente du Comité scientifique du cycle "1 Texte une aventure mathématique"

Participants: Nathalie Ayi.

2021- : Journée interne du LJLL

10.1.2 Scientific events: organisation

General chair, scientific chair

Participants: Emmanuel Audusse.

NumHyp 2025, Darmstadt, Germany

Member of the organizing committees

Participants: Nathalie Ayi.

Conference Festum Pi, 2025, Creta, Greece.

Participants: Emmanuel Audusse.

Mathematical modelization for physics and learning : waves, quantum mechanics and neural networks.

10.1.3 Journal**Member of the editorial boards**

Participants: Anne-Laure Dalibard.

- Annales de l'Institut Henri Poincaré - Analyse non linéaire (Co-rédactrice-en-chef)
- SIAM Journal on Mathematical Analysis
- Communications in partial differential equations

Participants: Nathalie Ayi.

2025- :Kinetic and Related Model

Initials	Journal
JG	Annales scientifiques de l'ÉNS, SIAM Journal on Mathematical Analysis, Mathematical and Computational Applications, Nonlinearity, Applied Mathematical Letters
EA	SMAI journal of computational mathematics, JCP
NAgui	IMA Journal of Numerical Analysis
JS	Proc. of 29th Conference on Domain Decomposition

Reviewer - reviewing activities**10.1.4 Invited talks**

See Table 1.

10.1.5 Research administration

Participants: Nathalie Ayi.

Membre du comité de sélection pour les postes de Maître de conférences à l'IMJ.

Initiales	Nom de la conférence ou du laboratoire	Lieu	Date
JG	Fluid solid interactions and related problems	CIRM, Marseille	21-25.04.25
Nayi	CoGaDeL Webinar	Uni. of Buea, Cameroun	15.12.25
Nayi	SLMath Seminar	SLMath, Berkeley, USA	12-11-25
Nayi	Probability, PDE and App. Math. Seminar	Uni. of California, Davis, USA	06.11.25
Nayi	Tbilisi Analysis & PDE Seminar,	Uni. of Georgian Tbilisi (Online)	10.06.25
Nayi	Séminaire EDP	USVQ, Versailles	22.05.25
Nayi	Séminaire Analyse Non linéaire et EDP	école Normale Supérieure, Paris	08.04.25
Nayi	Groupe de Travail ANGE	Sorbonne Uni., Paris	05.03.25
Nayi	Séminaire Analyse Appliquée	Aix Marseille Uni., Marseille	14.01.25
ALD	Séminaire de mécanique des fluides numériques	IHP, Paris	27.01.25
ALD	Colloquium du CEREMADE	Uni. Paris-Dauphine	04.02.25
ALD	Journées annuelles de l'ANR BOURGEONS	Uni. Grenoble-Alpes	11.03.25
ALD	Amphi 0 de mathématiques	école polytechnique, Palaiseau	08.04.25
ALD	Phys. and maths. of hydrodyn. and wave turbulence	CIRM, Marseille	26-28.05.25
ALD	Séminaire SPIKE	IHP, Paris	10.6.25
ALD	Special Topic school "Particles in Flow"	HCM, Bonn, Allemagne	23-27.06.25
ALD	Paris-Seoul Joint Workshop on Fluid Dynamics	école Normale Supérieure, Paris	07-11.07.25
ALD	End of CRISIS	CIRM, Marseille	27-31.10.25
ALD	Theoretical challenges for ocean dynamics	ENS de Lyon, Lyon	17-21.11.25
EG	Colloquium du LAMFA	Uni. Picardie, Amiens	25.11.25
NAgui	Lancement de l'ANR HEAD	Uni. Rennes	18.02.25
EA	Conférence Climath	UNIV. BORDEAUX	25.11.25
JS	séminaire EHES	EHES	04.03.25
JS	Séminaire CEA, CEA-DIF, Bruyère-le-Chatel	CEA Bruyère-le-Chatel	18.03.25
JS	29th Domain Decomposition Method Conference	Milan, Italie	26.6.25
JS	Seminar: Time Parallel Time Integration	Oberwolfach, Allemagne	24.11.25
JS	workshop HyBOX	ENSTA, Saclay	04.12.25
JS	Journée ANR GdMod	Uni. de Pau	16.12.25
JS	25 workshop, Joint IFPEN-Inria laboratory	IFPEN, Rueil-Malmaison	10.12.25
JS	Workshop OCEANIA	INRIA Paris	18.12.25

Table 1: List of invited talks of team members.

Participants: Julien Salomon.

- Membre du comité de sélection pour 2 postes de Maître de conférences au LJLL
- Membre du comité de sélection pour les postes de CR/ISFP à l'INRIA-Bordeaux

Participants: Nina Aguillon.

- Membre du comité de sélection pour 2 postes de Maître de conférences au LJLL
- Membre du Comité de sélection pour 1 poste de Maître de conférences au LIP6, Sorbonne Uni.

Long term responsibilities are given in Table 2.

JS	Membre élu du CSA de l'INRIA	2023-
JS	Membre élu de la Commission d'évaluation	2023-
JSM	Membre du CS de l'institut des transformations numériques - SciencesPo	
JSM	Co-pilote du PEPR 'agroécologie et numérique'	2022-2028
JSM	Directeur du programme 'Numérique et environnement'	2022-
Nayi	Membre du conseil du laboratoire LJLL	2020 - ...
Nayi	Membre du comité scientifique de l'UFR 929	2020 - ...
EA	Membre CR et CAC de USPN	2020-2024
Nagui	Membre du CES	2023-
ALD	Membre du Conseil d'administration de la SMAI	2019-2025
ALD	Membre du CS de l'Institut Pascal	2022-...
ALD	Membre du CS et bureau du GDR "Défis théoriques pour les sciences du climat"	2020-...
ALD	Membre du CS du Réseau Thématique (anciennement GDR) Analyse des EDP	2021-...
ALD	Membre du comité de programme du PEPR Maths-Vives	2024-...
ALD	Conseil d'administration de la FSMP	2025-...
Nagui	Membre du conseil de département du cycle d'intégration	2022-...

Table 2: JS: J. Salomon, JG: J. Guillod, JSM: J. Sainte-Marie, Nayi: N. Ayi, Nagui: N. Aguillon, ALD: A-L. Dalibard.

10.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

10.2.1 Faculty responsibilities, committees

Participants: Julien Guillod.

- 2019- : Membre du conseil de la Licence de Mathématiques pour l'UFR 929, SU
- 2025 : Membre du comité d'attribution des primes, SU
- 2022 : Référent égalité et lutte contre les discriminations pour l'UFR 929, SU
- 2025 : Référent égalité du LJLL auprès du CNRS

Participants: Nathalie Ayi.

- 2022- : Membre du conseil de département du cycle d'intégration
- 2023- : Membre du CNU

Participants: Nina Aguillon.

- 2022- : Membre du conseil de l'UFR 929, SU
- 2022- : Comité de pilotage de CAPSULE (centre d'accompagnement à la pédagogie et support à l'expérimentation)

Participants: Anne-Laure Dalibard.

Pôle écoute du LJLL

10.2.2 Supervision

Supervision activities are given in Table 3.

Advisor ANGE	Ext. Co-advisors	Type	Name	Institution	Period
JS,NAgui		PhD	M. Boussard	SU	2024-2027
JS		PhD	N. D. Tognon	SU	2022-2025
JS,EM		PhD	M. Janvier	SU	2025-2028
ALD		PhD	C. Gentil	SU	2023-2026
N. Ayi, JSM	P. Ramaciotti Morales	PhD	F. Cornia	SU	2024-2027
JG,EM, JSM		PhD	B. Gorce	SU	2025-2028
Nayi		Stage L3	M. Sifferlin	Orsay	juin 2025
Nayi	F. Delebecque	Post-doc	A. Cotil	SU	2025-2026
ALD	D. Lannes	Post-doc	M. Rigal	SU	dec 2024-dec 2025
ALD	R. Bianchini, L. Saint-Raymond	Post-doc	I. Cristian	SU	2025-2027

Table 3: Doctoral and Post-doc. supervision activities.

10.2.3 Juries

Participation to committees is summarize in Table 4.

Initials	Mois	Type (PhD, HdR)	Role	Name	Institution
ALD	Décembre	PhD	Membre	Maissâ Boughrara	Uni. Sorbonne Paris-Nord
ALD	Septembre	PhD	Membre	Marguerite Champion	Sorbonne Uni.
ALD	Septembre	PhD	Membre	Alan Riquier	ENS Paris
ALD	Juin	HDR	Membre	Bérénice Grec	Uni. Paris-Cité
ALD	Juin	PhD	Membre	Haocheng Yang	ENS Paris-Saclay
JSM	Décembre	PhD	Président	Duncan Cassells	Sorbonne Uni.
JS	Décembre	HDR	Membre	Afaf Bouharguane	Uni. de bordeaux
JS	Juin	PhD	Dir. de thèse	Norbert D. Tognon	Sorbonne Uni.

Table 4: Participation to committees.

10.2.4 Teaching

Teaching activities are given in Table 5.

10.2.5 Educational and pedagogical outreach

Participants: Edwige Godlewski.

2019- : president of commission française pour l'enseignement des mathématiques (CFEM)

10.3 Popularization

Large audience events participations are summarized in Table 6

10.3.1 Others science outreach relevant activities

Initials	Title	Duration	Level	Inst.	Type
JS	Méthodes numériques pour les EDP	45	M2	Uni. Abomey-Calavi	CM
JSM	Modél. des écoulements gravitaires	40	M1	Univ. P.-Diderot,IPGP	
JSM	Méthodes num. en géosciences	50	M2	Univ. P.-Diderot, IPGP	
NAyi	Approximation des EDPs	36	M1	Sorbonne Uni.	CM
JD	Structures mathématiques	22	L3	Polytech Sorbonne	TD
NAGui	Approximation des EDPs	54	M1	Sorbonne Uni.	TD
NAGui	Dir. des études de L2 mathématiques	64	L2	Sorbonne Uni.	resp.
NAGui	Topologie et calcul différentiel 1	36	L2	Sorbonne Uni.	TD
NAGui, JSM	Modèles d'écoulements	10	M2	SU	CM
NAGui	Formation moniteurs en maths	8	D	SU	resp.
Nagui	EDP elliptiques	40	M1	SU	TD
BDM	Calcul différentiel	54	L3	Uni. de Corse	CM,TD
BDM	Analyse numérique matricielle	54	L3	Uni. de Corse	CM,TD,TP
BDM	Pratique d'Analyse	18	L1	Uni. de Corse	TP
BDM	Pratique d'Algèbre	18	L2	Uni. de Corse	TP
BDM	Pratique d'Analyse	18	L2	Uni. de Corse	TP
BDM	Modélisation	15	M2	Uni. de Corse	CM
EA	Calcul scientifique & Python	30	CP2I2	USPN	TD-TP
EA	Optimisation	30	ING2	USPN	TD-TP
EA	Calcul scientifique & Octave	15	ING1	USPN	CM-TD-TP
EA	Analyse numérique	15	L2	USPN	CM-TD-TP
JG	Programmation Python pour les maths.	113	L2	Sorbonne Uni.	TP/TD
JG	Fondements des méthodes numériques	58	M1	Sorbonne Uni.	TD
JG	Topologie et Calcul différentiel	63	L3	ENS Paris	CM

Table 5: Teaching activities of the team.

Participants: Jacques Sainte-Marie.

30.06.2025 : Colloque “Les données au service des territoires intelligents” - Sénat

11 Scientific production

11.1 Major publications

- [1] E. Audusse, M.-O. Bristeau, M. Pelanti and J. Sainte-Marie. ‘Approximation of the hydrostatic Navier-Stokes system for density stratified flows by a multilayer model. Kinetic interpretation and numerical validation’. In: *J. Comput. Phys.* 230 (2011), pp. 3453–3478. doi: [10.1016/j.jcp.2011.01.042](https://doi.org/10.1016/j.jcp.2011.01.042). URL: <http://dx.doi.org/10.1016/j.jcp.2011.01.042>.
- [2] E. Audusse, M.-O. Bristeau, B. Perthame and J. Sainte-Marie. ‘A multilayer Saint-Venant system with mass exchanges for Shallow Water flows. Derivation and numerical validation’. In: *ESAIM Math. Model. Numer. Anal.* 45 (2011), pp. 169–200. doi: [10.1051/m2an/2010036](https://doi.org/10.1051/m2an/2010036). URL: <http://dx.doi.org/10.1051/m2an/2010036>.
- [3] M.-O. Bristeau, A. Mangeney, J. Sainte-Marie and N. Seguin. ‘An energy-consistent depth-averaged Euler system: derivation and properties’. In: *Discrete and Continuous Dynamical Systems - Series B* 20.4 (2015), p. 28.
- [4] J. Ledoux, S. Rizzo and J. Salomon. ‘Analysis of the Blade Element Momentum Theory’. working paper or preprint. Apr. 2020. URL: <https://hal.archives-ouvertes.fr/hal-02550763>.

Initiales	Date	Détails
ALD, JG, EG	17-18.02.2025	Encadr. stage pour enseignant-es du 2aire (Maison pour la Science)
Nayi	11.12.2025	Exposé, Collège de Roissy en Brie
Nayi	avril 2025	Exposé, Lycée LPO du Nord, Mayotte (Online).
Nayi	10-04-2025	Séminaire "Aromaths", SU, Paris.
Nayi	04/2025	Exposé, Lycée Charlemagne, Paris.
Nayi	25-03-2025	Exposé, Lycée Jehan de Beauce, Chartres.
Nayi	mars 2025	Exposé, Festival "Le Printemps des Mathématiques", Castanet-Tolosan.
Nayi	mars 2025	Exposé, Collège du bois d'Aulne, Conflans Sainte Honorine.
ALD	octobre 2025	Orga. et anim. table ronde au FEM
ALD	1/4/2025	Conf. de rentrée des élèves 1ère année, Ecole polytechnique
JSM	Mai	Exposé, lycée Buffon, Paris
JSM	Février	Tribunal pour les Générations Futures - IA et environnement - Paris
JSM	Mars	Tribunal pour les Générations Futures - IA et environnement - Orléans
JSM	Octobre	Joint IFPEN-Inria laboratory,
JSM	Septembre	Foire agricole de Châlons en Champagne - Conférence 'IA et agriculture'
JSM	Novembre	Green Tech Forum - Table ronde 'AI Action Summit : neuf mois après'
JSM	Juin	Table ronde 'IA et démocratie' - Forum Place(s) de la Démocratie - Nancy
JSM	Février	AI action summit, Paris Rédacteur du position paper "Key challenges for environmental performance of AI"
NAGui	Décembre	speed-meeting métier RJMI ENS
NAYi + NAGui	Avril	organisation d'une JFMI (100 collégiennes)
NAGui	Octobre	atelier Fête de la science
NAYi+ NAGui	Mars	Table ronde "Femmes, Mathématiques et Informatique : échanges sur leur Parcours et Perspectives" bibliothèque MIR
Nagui	2024-...	Chroniqueuse dans le podcast "Tête à tête chercheuses"
Nayi	2022-...	Animation du podcast "Tête-à-tête Chercheuse(s)"
Nayi	05.2025	Enregistrement d'un épisode en public du podcast "Tête-à-tête Chercheuse(s)" dans le cadre de l'initiative "Ambassadrices de l'égalité", Lycée Edgar Morin, Douai.
Nayi	Septembre	Animation de la table ronde "Quelles réformes pour quels objectifs ?", Journée d'études sur la fusion des ENS de Sèvres et de Paris.
Nayi	Octobre	Participation à une vidéo pour les réseaux sociaux dans le cadre de la campagne "Toutes dans l'équation", Ministère de l'Éducation Nationale
Nayi	Juin	Participation au speed meeting "Maths C pour L", Sorbonne Uni., Paris.
Nayi	Avril	Conférence Master Class Lycéennes Sephora Berrebi, Institut Henri Poincaré, Paris.
Nayi	Mai	Echange, lycée Saint Joseph à Saint Ambroix (online)
Nayi	Mars	Echange, Lycée Charles Péguy, Orléans.

Table 6: Participation to large audience events.

- [5] J. Sainte-Marie. 'Vertically averaged models for the free surface Euler system. Derivation and kinetic interpretation'. In: *Math. Models Methods Appl. Sci. (M3AS)* 21.3 (2011), pp. 459–490. DOI: [10.1142/S0218202511005118](https://doi.org/10.1142/S0218202511005118). URL: <http://dx.doi.org/10.1142/S0218202511005118>.

11.2 Publications of the year

International journals

- [6] E. Audusse, V. Dubos, N. Gaveau and Y. Penel. 'Energy stable and linearly well-balanced numerical schemes for the non-linear Shallow Water equations with Coriolis force'. In: *SIAM Journal on Scientific Computing* 47.01 (7th Jan. 2025), A1–A23. DOI: [10.1137/22M1515707](https://doi.org/10.1137/22M1515707). URL: <https://hal.science/hal-03509990> (cit. on p. 13).

- [7] O. Bernard, L.-D. Lu, J. Sainte-Marie and J. Salomon. ‘Topography optimization for enhancing microalgal growth in raceway ponds’. In: *SIAM Journal on Control and Optimization* 63.4 (15th July 2025), pp. 2451–2471. DOI: [10.1137/23M1616297](https://doi.org/10.1137/23M1616297). URL: <https://hal.science/hal-02994713> (cit. on p. 15).
- [8] A.-L. Dalibard, J. Guilloid and A. Leblond. ‘Long-time behavior of the Stokes-transport system in a channel’. In: *Analysis & PDE* 18.8 (25th July 2025), pp. 1955–2032. DOI: [10.2140/apde.2025.18.1955](https://doi.org/10.2140/apde.2025.18.1955). URL: <https://hal.science/hal-04114516> (cit. on p. 16).
- [9] B. Di Martino, C. El Hassanieh, E. Godlewski, J. Guilloid and J. Sainte-Marie. ‘Hyperbolicity of a semi-Lagrangian formulation of the hydrostatic free-surface Euler system’. In: *Nonlinearity* 38.1 (2025), p. 015018. DOI: [10.1088/1361-6544/ad9b65](https://doi.org/10.1088/1361-6544/ad9b65). URL: <https://hal.science/hal-04190892>. In press (cit. on p. 14).
- [10] C. El Hassanieh, M. Rigal and J. Sainte-Marie. ‘Implicit kinetic schemes for the Saint-Venant system’. In: *ESAIM: Mathematical Modelling and Numerical Analysis* 59 (16th May 2025), pp. 1863–1908. DOI: [10.1051/m2an/2025038](https://doi.org/10.1051/m2an/2025038). URL: <https://hal.science/hal-04048832> (cit. on p. 14).
- [11] B. Grec, D. Kumozec and Y. Penel. ‘Unconditionally stable numerical scheme for the 2D transport equation’. In: *Computers & Mathematics with Applications* 182 (15th Mar. 2025), pp. 275–290. DOI: [10.1016/j.camwa.2025.02.003](https://doi.org/10.1016/j.camwa.2025.02.003). URL: <https://hal.science/hal-04974335> (cit. on p. 14).
- [12] P. J. Hossie, B. Laroche, T. Malou, L. Perrin, T. Saigre and L. Sala. ‘Surrogate modeling of interactions in microbial communities through Physics-Informed Neural Networks.’ In: *ESAIM: Proceedings and Surveys* 81 (10th Oct. 2025), pp. 104–122. DOI: [10.1051/proc/202581104](https://doi.org/10.1051/proc/202581104). URL: <https://hal.inrae.fr/hal-04440736> (cit. on p. 20).
- [13] L. Maillard, P. Depondt, F. Finocchi, S. Huppert, T. Plé, J. Salomon and M. Trassinelli. ‘Probing the partition function for temperature-dependent potentials with nested sampling’. In: *The Journal of Chemical Physics* 163.18 (13th Nov. 2025). DOI: [10.1063/5.0293473](https://doi.org/10.1063/5.0293473). URL: <https://hal.science/hal-05237277> (cit. on p. 19).
- [14] E. Meunier and P. Bouthemy. ‘Segmenting the motion components of a video: A long-term unsupervised model’. In: *IEEE Transactions on Pattern Analysis and Machine Intelligence* Early access (Sept. 2025), pp. 1–12. DOI: [10.1109/TPAMI.2025.3608065](https://doi.org/10.1109/TPAMI.2025.3608065). URL: <https://hal.science/hal-04937203> (cit. on p. 19).
- [15] L. Phan, A. Gatti, Z. Han, N. Li, J. Hu, H. Zhang, S. Shi, M. Choi, A. Agrawal, A. Chopra et al. ‘A benchmark of expert-level academic questions to assess AI capabilities’. In: *Nature* 649.8099 (28th Jan. 2026), pp. 1139–1146. DOI: [10.1038/s41586-025-09962-4](https://doi.org/10.1038/s41586-025-09962-4). URL: <https://hal.science/hal-04915593> (cit. on p. 19).
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Conferences without proceedings

- [17] N. Ayi. ‘Graph and Mean-Field Limits for Interacting Particle Systems’. In: Festum Pi 2024. La Canée, Crète, Greece, 2025. URL: <https://hal.science/hal-05054506> (cit. on p. 18).
- [18] E. Meunier, S. Ouala, H. Frezat, J. L. Sommer and R. Fablet. ‘Towards fully differentiable neural ocean model with Veros’. In: EurIPS 2025 - Differentiable Systems and Scientific Machine Learning - A workshop @. Copenhagen, Denmark, 21st Nov. 2025, pp. 1–8. URL: <https://hal.science/hal-05410440> (cit. on p. 18).

Scientific books

- [19] J. Guilloid. *Python Programming for Mathematics*. The Python Series. Chapman & Hall/CRC, Jan. 2025. DOI: [10.1201/9781003565451](https://doi.org/10.1201/9781003565451). URL: <https://hal.science/hal-04907674>.

Doctoral dissertations and habilitation theses

- [20] D. N. Tognon. ‘Time parallelization and machine learning for optimal control and inverse problems’. Sorbonne Université, 30th June 2025. URL: <https://theses.hal.science/tel-05262960>.

Reports & preprints

- [21] N. Aguillon, E. Audusse, N. Boulos and M. Parisot. *A comprehensive list of stationary solutions of shallow water models*. 8th Apr. 2025. URL: <https://hal.science/hal-05025901> (cit. on p. 13).
- [22] N. Aguillon and S. Hörnschemeyer. *Barotropic-Baroclinic Splitting for Multilayer Shallow Water Models with Exchanges*. 15th Jan. 2026. URL: <https://hal.science/hal-05483700> (cit. on p. 15).
- [23] D. Albritton, J. Guillod, M. Korobkov and X. Ren. *Forward self-similar solutions to the 2D Navier–Stokes equations*. 6th Jan. 2026. URL: <https://hal.science/hal-05458467> (cit. on p. 17).
- [24] A.-L. Dalibard and C. Gentil. *A linear model of separation for western boundary currents with bathymetry*. 30th Dec. 2025. URL: <https://hal.science/hal-05435740> (cit. on p. 15).
- [25] F. Hecht, S.-M. Kaber, L. Perrin, A. Plagne and J. Salomon. *Parallel approximation of the exponential of semidefinite negative Hermitian matrices*. 14th Feb. 2025. URL: <https://hal.science/hal-03948509> (cit. on p. 17).
- [26] F. Kwok, J. Salomon and D. N. Tognon. *Convergence of ParaOpt for general Runge-Kutta time discretizations*. 31st Mar. 2025. URL: <https://hal.science/hal-05014759> (cit. on p. 17).
- [27] P. Lissy and L. Perrin. *Theoretical and Numerical Study of the Convergence of Luenberger Observers for a Linearized Water Wave Model*. 4th Feb. 2025. URL: <https://hal.science/hal-04928698> (cit. on p. 16).
- [28] É. Meunier, D. Kamm, G. Gachon, R. Lguensat and J. Deshayes. *Learning to generate physical ocean states: Towards hybrid climate modeling*. 4th Feb. 2025. URL: <https://hal.science/hal-04937213> (cit. on p. 17).
- [29] D. N. Tognon. *ParaOpt for unstable systems*. 25th Feb. 2025. URL: <https://inria.hal.science/hal-04966081> (cit. on p. 18).

Software

- [30] [SW] O. Delestre, C. Lucas, P.-A. Ksinant Garcia, F. Darboux, C. Laguerre, A.-C. Boulanger, N. Gaveau, M. Rougier, M. Mancini, S. Cordier and F. James, *SWASHES: Shallow Water Analytic Solutions for Hydraulic and Environmental Studies* version 1.05.00, 22nd Apr. 2025. Université d’Orléans (UO), Orléans, FRA.; INRA Institut National de la Recherche Agronomique; CNRS - Centre National de la Recherche Scientifique. LIC: CeCILL Free Software License Agreement v2.0. HAL: [hal-02804975](https://hal.inrae.fr/hal-02804975), URL: <https://hal.inrae.fr/hal-02804975>, vcs: <https://sourcesup.renater.fr/projects/swashes/>, SWHID: [swh:1:dir:40a2735f1bcc3dcb8e45e9d45465b172fcb9247c;origin=https://subversion.renater.fr/anonscm/svn/swashes;visit=swh:1:snp:29938e5264b02bb66d84366347ae52a21e66acce;anchor=swh:1:rev:9a09e84f43eda07fec8a2cfdd0eb1b002237ffda;path=/tags/release-1.05.00/](https://subversion.renater.fr/anonscm/svn/swashes).

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