RESEARCH CENTRE

Inria Center
at Université Côte d'Azur

IN PARTNERSHIP WITH:

CNRS, Université Côte d'Azur

2022
ACTIVITY REPORT

Project-Team
COFFEE

COmplex Flows For Energy and Environment

IN COLLABORATION WITH: Laboratoire Jean-Alexandre Dieudonné (JAD)

DOMAIN

Digital Health, Biology and Earth

THEME

Earth, Environmental and Energy Sciences

Contents

Project-Team COFFEE

Creation of the Project-Team: 2013 January 01

Keywords

Computer sciences and digital sciences

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A6.1.5. – Multiphysics modeling

A6.2.1. – Numerical analysis of PDE and ODE

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B7.1. – Traffic management

1 Team members, visitors, external collaborators

Research Scientists

- Thierry Goudon [Team leader, INRIA, Senior Researcher, HDR]
- Laurent Monasse [INRIA, Researcher]

Faculty Members

- Florent Berthelin [UNIV COTE D'AZUR, Associate Professor, HDR]
- Konstantin Brenner [Univ. Côte d'zur, Associate Professor]
- Remi Catellier [Univ. Côte d'Azur, Associate Professor]
- Stéphane Junca [Univ. Côte d'Azur, Associate Professor, HDR]
- Stella Krell [UNIV COTE D'AZUR, Associate Professor]
- Roland Masson [UNIV COTE D'AZUR, Professor, HDR]

Post-Doctoral Fellows

- Maryam Al Zohbi [Univ. Côte d'Azur]
- Daniel Castanon-Quiroz [Inria]
- Florent Chave [CNRS]
- Ali Haidar [Inria]

PhD Students

- Sebastian Baudelet [UNIV COTE D'AZUR]
- Miranda Boutillier [Univ. Côte d'Azur]
- Nadine Dirani [UNIV COTE D'AZUR, ATER]
- Charbel Ghosn [Univ. Côte d'Azur]
- Mohamed Laazari [Univ. Côte d'Azur]
- Paul Paragot [UNIV COTE D'AZUR]
- Christian Tayou Fotso [CNRS]

Administrative Assistant

- Marie-Cecile Lafont [INRIA]

2 Overall objectives

The project aims at studying mathematical models issued from environmental and energy management questions. We consider systems of PDEs of hydrodynamic type or hybrid fluid/kinetic systems. The problems we have in mind involve unusual coupling, which in turn leads to challenging difficulties for mathematical analysis and the need of original numerical solutions. By nature many different scales arise in the problems, which allows to seek hierarchies of reduced models based on asymptotic arguments. The topics require a deep understanding of the modeling issues and, as far as possible boosted by the mathematical analysis of the equations and the identification of key structure properties, we wish to propose innovative and performing numerical schemes. To this end, the development of innovative Finite Volumes schemes with unstructured meshes on complex geometries will be a leading topic of the team activity.

3 Research program

Mathematical modeling and computer simulation are among the main research tools for environmental management, risks evaluation and sustainable development policy. Many aspects of the computer codes as well as the PDEs systems on which these codes are based can be considered as questionable regarding the established standards of applied mathematical modeling and numerical analysis. This is due to the intricate multiscale nature and tremendous complexity of those phenomena that require to set up new and appropriate tools. Our research group aims to contribute to bridging the gap by developing advanced abstract mathematical models as well as related computational techniques.

The scientific basis of the proposal is two–fold. On the one hand, the project is “technically–driven”: it has a strong content of mathematical analysis and design of general methodology tools. On the other hand, the project is also “application–driven”: we have identified a set of relevant problems motivated by environmental issues, which share, sometimes in a unexpected fashion, many common features. The proposal is precisely based on the conviction that these subjects can mutually cross-fertilize and that they will both be a source of general technical developments, and a relevant way to demonstrate the skills of the methods we wish to design.

To be more specific:

- We consider evolution problems describing highly heterogeneous flows (with different phases or with high density ratio). In turn, we are led to deal with non linear systems of PDEs of convection and/or convection–diffusion type.
- The nature of the coupling between the equations can be two–fold, which leads to different difficulties, both in terms of analysis and conception of numerical methods. For instance, the system can couple several equations of different types (elliptic/parabolic, parabolic/hyperbolic, parabolic or elliptic with algebraic constraints, parabolic with degenerate coefficients....). Furthermore, the unknowns can depend on different sets of variables, a typical example being the fluid/kinetic models for particulate flows. In turn, the simulation cannot use a single numerical approach to treat all the equations. Instead, hybrid methods have to be designed which raise the question of fitting them in an appropriate way, both in terms of consistency of the discretization and in terms of stability of the whole computation. For the problems under consideration, the coupling can also arises through interface conditions. It naturally occurs when the physical conditions are highly different in subdomains of the physical domain in which the flows takes place. Hence interface conditions are intended to describe the exchange (of mass, energy...) between the domains. Again it gives rise to rather unexplored mathematical questions, and for numerics it yields the question of defining a suitable matching at the discrete level, that is requested to preserve the properties of the continuous model.
- By nature the problems we wish to consider involve many different scales (of time or length basically). It raises two families of mathematical questions. In terms of numerical schemes, the multiscale feature induces the presence of stiff terms within the equations, which naturally leads to stability issues. A clear understanding of scale separation helps in designing efficient methods, based on suitable splitting techniques for instance. On the other hand asymptotic arguments can

be used to derive hierarchy of models and to identify physical regimes in which a reduced set of equations can be used.

We can distinguish the following fields of expertise

- Numerical Analysis: Finite Volume Schemes, Well-Balanced and Asymptotic-Preserving Methods
  - Finite Volume Schemes for Diffusion Equations and Viscous Flows
  - Finite Volume Schemes for Conservation Laws
  - Well-Balanced and Asymptotic-Preserving Methods
  - Domain Decomposition Methods
- Modeling and Analysis of PDEs
  - Kinetic equations and hyperbolic systems
  - PDEs in random media
  - Interface problems

4 Application domains

4.1 Multiphase porous media flows and multi-physics coupling

Our research focuses on the numerical modeling of multiphase porous media flows accounting for complex geology and for nonlinear and multi-physics couplings. It is applied to various problems in the field of energy such as the simulation of geothermal systems in collaboration with BRGM, of nuclear waste repositories in collaboration with Andra, and of oil and gas recovery in collaboration with Total. We are starting a new program through the Inria-IFPEN initiative. Our research directions include the development of advanced numerical schemes adapted to polyhedral meshes and highly heterogeneous media in order to represent more accurately complex geologies. A special focus is made on the modeling of multiphase flows in network of faults or fractures represented as interfaces of co-dimension one coupled to the surrounding matrix. We also investigate nonlinear solvers adapted to the nonlinear couplings between gravity, capillary and viscous forces in highly heterogeneous porous media. In the same line, we study new domain decomposition algorithms to couple non-isothermal compositional liquid gas flows in a porous medium with free gas flows occurring at the interface between the ventilation gallery and the nuclear waste repository or between a geothermal reservoir and the atmosphere. We are exploring the coupling between the multiphase flow in the porous matrix and the solid mechanics involved in opening fractures.

4.2 Particulate and mixture flows

We investigate fluid mechanics models referred to as “multi–fluids” flows. A large part of our activity is more specifically concerned with the case where a disperse phase interacts with a dense phase. Such flows arise in numerous applications, like for pollutant transport and dispersion, the combustion of fuel particles in air, the modelling of fluidized beds, the dynamic of sprays and in particular biosprays with medical applications, engine fine particles emission... There are many possible modelings of such flows: microscopic models where the two phases occupy distinct domains and where the coupling arises through intricate interface conditions; macroscopic models which are of hydrodynamic (multiphase) type, involving non standard state laws, possibly with non conservative terms, and the so–called mesoscopic models. The latter are based on Eulerian–Lagrangian description where the disperse phase is described by a particle distribution function in phase space. Following this path we are led to a Vlasov-like equation coupled to a system describing the evolution of the dense phase that is either the Euler or the Navier-Stokes equations. It turns out that the leading effect in such models is the drag force. However, the role of other terms, of more or less phenomenological nature, deserves to be discussed (close packing terms, lift term, Basset force...). Of course the fluid/kinetic model is interesting in itself and needs further analysis and dedicated numerical schemes. In particular, in collaboration with the Atomic Energy Commission

(CEA), we have proposed a semi-Lagrangian scheme for the simulation of particulate flows, extending the framework established in plasma physics to such flows.

We also think it is worthwhile to identify hydrodynamic regimes: it leads to discuss hierarchies of coupled hydrodynamic systems, the nature of which could be quite intriguing and original, while they share some common features of the porous media problems. We are particularly interested in revisiting the modeling of mixture flows through the viewpoint of kinetic models and hydrodynamic regimes. We propose to revisit the derivation of new mixture models, generalizing Kazhikov-Smagulov equations, through hydrodynamic asymptotics. The model is of "hybrid" type in the sense that the constraint reduces to the standard incompressibility condition when the disperse phase is absent, while it involves derivatives of the particle volume fraction when the disperse phase is present.

4.3 Fluid-structure interactions

The simulation of motions of solid bodies in a fluid, as well as fracturation, fissuration phenomena leads to numerical difficulties: they can undergo deformations, fragmentation and contact which deform dramatically the fluid domain, rendering remeshing techniques less effective. The numerical suite Mka2d/Mka3d/Celia2d/Celia3d/Precis addresses this issue. On the solid side, the adopted discrete element discretization works on general polyhedral meshes, and again uses different types of degree of freedom, stored at the cell and face centers, with suitable reconstruction procedures in order to guaranty the conservation properties. On the fluid side, we use a cut-cell approach designed in order to preserve exactly the discrete mass and energy conservations for general Finite Volume methods. This approach is an alternative to ALE methods which would require costly remeshing and can induce severe stability conditions due to mesh deformations. It is particularly adapted to manage fragmentation events, which lead to changes in the topology of the fluid domain. The delicate geometrical issues are handled by using robust, efficient and fast geometric intersection procedures. Such issues are also investigated for the modeling of urban floods; our methodologies on finite volume schemes on complex geometries and domain decomposition methods are reinvested on such problems through the ANR project Top-up (exploiting formal analogies between Shallow-Water equations and Richard's equation in the regimes of interest).

4.4 Neurosciences

The NeuroMod Institute for Modeling in Neuroscience and Cognition aims at promoting modeling as an approach for integrating brain mechanisms and cognitive functions. It has selected the project proposed by C. Guerrier and S. Krell about the modeling and simulation of the variations of the electric field in the dendritic tree of neurons as well as the electrodiffusion of ions in the neuronal cytoplasm, considered as an electrolyte (P. Paragot's PhD thesis). Thus, the model is based on the Nernst-Planck equation coupled to the Poisson equation; it has many similarities with convection-diffusion models arising for flows in porous media. Difficulties arise from the multi-scale configuration, and the presence of boundary layers between the cytoplasm, the membrane, and the external neuron's environment. This leads to new developments for the DDFV framework and its application with domain decomposition approaches.

4.5 Fungal network growth

Members of the team have started an original research program devoted to fungal network growth. We started working on this subject through a collaboration with biologists and physicists at LIED (Université Paris Diderot) and probabilists in CMAP (Ecole Polytechnique) and Université Paris Sud, involving Rémi Catellier and Yves D'Angelo (team Atlantis). The motivation is to understand branching networks as an efficient space exploration strategy, with fungus *Podospora Anserina* being the biological model considered. This research is submitted as an ANR-project and has been supported by various local fundings.

4.6 Tumor growth and immune response

We have developed a size and space structured model describing interaction of tumor cells with immune cells based on a system of partial differential equations. This model is intended to describe the earliest stages of this interaction and takes into account the migration of the tumor antigen-specific cytotoxic effectors cells towards the tumor microenvironment by a chemotactic mechanism. This study reveals cancer persistent equilibrium states as expected by biologists, as well as escape phases when protumoral immune responses are activated. This effect which leads to persistent tumors at a controlled level was inferred from clinical observations and demonstrations using mouse model. Therefore, the maintenance of cancer in a viable equilibrium state represents a relevant goal of cancer immunotherapy. The mathematical interpretation of the equilibrium state by means of eigenvalue problems and constrained equations, has permitted us to develop new numerical algorithms in order to predict at low numerical cost the main features of the equilibrium and to discriminate, in biologically relevant cases, the parameters that are the most influential on the equilibrium.

4.7 Self organization in population dynamics

This topic is addressed mainly with Paulo Amorim (Univ. Federal Rio de Janeiro) and Fernando Peruani (Lab. de Physique Théorique et Modélisation, Cergy Paris Université).

We are interested in the mathematical modeling of physico-biological phenomena that drive towards a self-organization of a population of individuals reacting to external signals. It might lead to the formation of remarkable patterns or the following of traveling external signal. We develop microscopic and hydrodynamic models for such phenomena, with a specific interest in the modeling of ant foraging.

5 New software and platforms

5.1 New software

5.1.1 AP_PartFlow

Functional Description: We are developing experimental codes, mainly based on Finite Differences, for the simulation of particulate flows. A particular attention is paid to guaranty the asymptotic properties of the scheme, with respect to relaxation parameters.

Contact: Thierry Goudon

5.1.2 Mka3d

Name: Mka3d

Keywords: Scientific computing, Elasticity, Elastodynamic equations

Functional Description: The Mka3d method simulates an elastic solid by discretizing the solid into rigid particles. An adequate choice of forces and torques between particles allows to recover the equations of elastodynamics.

URL: http://cermics.enpc.fr/~monassel/Mka3D/

Contact: Laurent Monasse

Partners: Ecole des Ponts ParisTech, CEA

5.1.3 Compass

Name: Computing Architecture to Speed up Simulation

Keywords: Finite volume methods, Porous media, High performance computing

Functional Description: Compass is a parallel code initiated in 2012 and co-developed by LJAD-Inria Coffee and BRGM since 2015. It is devoted to the simulation of multiphase flows in porous media, it accounts for non isothermal and compositional flows and includes complex network of fractures or faults represented as interfaces of co-dimension one coupled to the surrounding matrix. The discretization is based on vertex and cell unknowns and is adapted to polyhedral meshes and heterogeneous media. The ComPASS code is co-developed since december 2016 by the partners of the ANR CHARMS project including BGRM, LJAD-Inria Coffee, Storengy, MdS and LJLL with the objective to develop a new generation simulator for geothermal systems focusing on fluids and accounting for complex fault networks and wells.

URL: http://www.anr-charms.org/page/compass-code

Contact: Roland Masson

Participants: Simon Lopez, Farid Smai, Michel Kern, Yacine Ould Rouis, Nabil Birgle, Laurence Beaude, Konstantin Brenner, Roland Masson

Partners: BRGM, Université Côte d'Azur (UCA)

5.1.4 NS2DDV-M

Name: 2D Navier-Stokes equations with variable density

Keywords: Partial differential equation, Finite volume methods, Finite element modelling

Functional Description: The NS2DDV Matlab toolbox is an open-source program written in Matlab for simulating 2D viscous, incompressible and inhomogeneous flows. The computation kernel of the code is based on Finite Elements - Finite Volumes hybrid methods applied on the 2D Navier-Stokes equations. It works on unstructured meshes and can include mesh refinements strategies. We develop and freely distribute a new version of the Matlab code NS2DDV-M (equipped with a graphic interface and an accurate documentation) to promote new collaborations in the domain, allow some easy comparisons with concurrent codes on the same benchmark cases, and compare alternative numerical solution methods.

URL: https://wikis.univ-lille.fr/painleve/ns2ddv/download

Contact: Caterina Calgaro

Partner: Laboratoire Paul Painlevé

5.1.5 SimBiof

Keywords: Bioinformatics, Chemistry

Functional Description: We are developing numerical methods, currently by using Finite Differences approaches, for the simulation of biofilms growth. The underlying system of PDEs takes the form of multiphase flows equations with conservation constraints and vanishing phases. The numerical experiments have permitted to bring out the influence of physical parameters on the multidimensional growth dynamics.

Contact: Thierry Goudon

5.1.6 CELIA3D

Name: CELIA3D

Keywords: Fluid mechanics, Multi-physics simulation

Functional Description: The CELIA3D code simulates the coupling between a compressible fluid flow and a deformable structure. The fluid is handled by a Finite Volume method on a structured Cartesian grid. The solid is handled by a Discrete Element method (Mka3d scheme). The solid overlaps the fluid grid and the coupling is carried out with immersed boundaries (cut cells) in a conservative way.

URL: http://cermics.enpc.fr/~monassel/CELIA3D/

Contact: Laurent Monasse

Partners: Ecole des Ponts ParisTech, CEA

5.2 New platforms

Participants: Roland Masson , Konstantin Brenner , Florent Chave , Ali Haidar , Mohamed Laazari , Konstantin Brenner , Thierry Goudon , Miranda Boutilier , Paul Paragot , Charbel Ghosn , Sebastian Baudelet , Laurent Monasse , Christian Tayou Fotso .

- Our main software achievement is the code `ComPASS`. It is developped since 2013 through several collaborations, by means of PhD and postdocs, with BRGM, ANDRA, MdS, Storengy, LJLL and has benefitted from the support of Carnot Institute and ANR through the project Charms. (The project has not been fortunate enough to receive an engineer support from Inria, though.) The objective is to propose an alternative to commercial codes, like `Tough2`, which faces limitations, at least for some specific situations. The code is an open source parallel code, it works on complex geometry, with complex unstructured meshes, it accounts for faults, fractures and deals with polyphasic and compositional flows. It applies in particular to geothermal flows.

  Since 2021, both ANDRA and BRGM are committed to the partnership and the development of `ComPASS`. The management of the code is shared with S. Lopez and L. Beaude from BRGM. The common ANDRA/BRGM roadmap explicitly refers to `ComPASS` in the simulation strategy of these organisms. The code is distributed from the Inria Gitlab platform under the opensource license CeCILL2.1/GPLv3. It has been effectively used for several user-cases:

  – for ANDRA to study the evolution of the repository site and the desaturation of the walls of the aeration galleries, in the framework of the Donut-Eurad project;

  – for BRGM for geothermal applications like Géodenergies Reflet, Heatstore, the modeling of Paris bassin de Paris, Lamentine Bay, Bouillante, simulation of Le Teil seismic event...

  Further information available on the Compass website.

- The numerical suite Mka2d/Mka3d/Celia2d/Celia3d/Precis simulates an elastic solid by discretizing the solid into rigid particles in 2d or 3d configurations. An adequate choice of forces and torques between particles allows to recover the equations of elastodynamics. The code Celia2d-3d is devoted to fluid-structure interactions. The code Precis is a more mature version of these softwares, with further visualization procedures. The codes are on a GitLab plateform, with the objective of a diffusion beyond our circle of close collaborators. Moreover, a part of our methodologies aim at being reinvested in industrial collaborations (in discussion).

  Further information available on the website: Mka3d and Celia3d

- We are also developing several prototype codes, for internal use. For instance we have a quite well advanced Scilab code for the simulation of Euler systems, with Cartesian and unstructured meshes, and a fortran DDFV code for the simulation of Navier-Stokes equations, including domain decomposition functionalities. In the same category falls the Python code based on nonlinear diffusive equations for urban floods modeling. They are regularly improved; in particular through the commitment of PhD students. We develop also specific simulation tools for the applications of our academic partners.

6 New results

New results are concerned with

- Analysis and development of Finite Volume Methods for polyphasic flows in porous media with fractures
- Analysis and development of Finite Volume Methods for complex flows
- Domain decomposition methods for DDFV schemes
- Analysis of PDEs describing the behavior of classical and quantum particles interacting with their environment: Landau damping and dissipation mechanisms
- Analysis of systems of conservation laws: stochastic source terms and regularity analysis by means of fractional BV spaces.
- Simulation of fluid-structure interactions
- Modeling of tumor-immune system interactions

7 Bilateral contracts and grants with industry

The research of the team is regularly supported by several contracts with industrial partners: BRGM, Storengy, IFP-EN, on scientific computing issues in geosciences. This has permitted to welcome many PhD and postdocs. The transfer strategy is built on the development of the opensource code `ComPASS`, specifically oriented towards the simulation of mass and heat transfers in fractured media. The code is identified by the consortium Andra/BRGM as an alternative of the commercial code Tough2 for security simulations of transient hydraulic-gas flows.

- BRGM-Andra (2022-2025) funding of Mohamed Laaziri's PhD thesis
- IFPEN/Inria initiative (2022-2023) funding of Ali Haidar's postdoctoral fellowship
- BRGM (2020-2023) for a participation to the PhD thesis of Sabrine Ben Rhouma, Univ. Orléans
- european project EURAD, WP DONUTS, funding of Florent Chave's postdoctoral fellowship
- BRGM/Storengy (2019-2022) funding of Daniel Castanon-Quiroz postdoctoral fellowship

We are currently in touch with the company Altair for the development of simulation tools fro fluid structure ineractions problems.

8 Partnerships and cooperations

8.1 International initiatives

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

HDTHM

Title: Mathematical and numerical methods for thermo-hydro-mechanical models in porous media with discontinuities

Duration: 2019 ->

Coordinator: Jérome Droniou (jerome.droniou@monash.edu) and Roland Masson

Partners:

- Monash University (Australie)

Inria contact: Roland Masson

Summary: The objective of this project is to extend a recent successful joint work between the two project leaders into a tight collaboration between the Monash and the Coffee teams involving several permanent members and students. The present project focuses on challenging directions of research related to the numerical simulation of thermo-hydro-mechanical models in fractured porous media that take advantage of the complementarity of both teams' expertise. It is an opportunity to extend our collaborations with the Coffee team industrial partners in geosciences.

Participants: Konstantin Brenner , Roland Masson .

8.2 International research visitors

8.2.1 Visits of international scientists

Inria International Chair The on-going project, supported by ANR, about the modeling of urban floods, involves Frédéric Valentin from LNCC in Brazil who benefits from a INRIA International Chair at the Inria research centre Université Côte d'Azur.

Other international visits to the team The collaboration with J. Droniou is supported by the Inria associated team HDTHM; it has also been supported by Univ. Côte d'Azur chairs (chaire Montel). J. Droniou visits the team for a couple of month in Fall 2022.

We have benefitted from several visits of M. Gander from Geneva Univ.

8.3 European initiatives

8.3.1 Other european programs/initiatives

LJAD-Inria and BRGM are the French partners of the Norvegian-German-French project In- SPiRE (for International Open Source Simulation Software Partnership in Research and Education) supported by the Research Council of Norway with the code `ComPASS` as one of the softwares of this project together with Dune, Dumux and OPM.

We are member of the European Research Consortium Eurad, the European Joint Program on Radioactive Waste Management. It gathers 51 organisations across 23 EU Member States having received a mandate by their official National Programme owner for radioactive waste management and nationally funded Research Entities. ComPASS is part of the program Development and Improvement Of Numerical methods and Tools for modelling coupled processes (Donut), see for instance on a mixed-dimensional 3D-2D-1D applied to the simulation of the desaturation of the fractured excavated damaged zone at the interface with ventilated tunnels in Andra nuclear waste storage facilities. We are also member of the European Consortium Nupus (Interdisciplinary Union of Porous Media Research) led by the University of Stuttgart.

8.4 National initiatives

8.4.1 ANR

- ANR JCJC PRECIS (Effect of a shock wave on a structure with contact using mesh refinement and parallelism), Laurent Monasse: april 2018 - april 2021, partners Inria (leader), Ecole des Ponts, CEA, Université Paris-Est. The project funded in particular N. Dirani's PhD thesis, defended December 2022.

- ANR TOP-UP (2020-2024), Konstantin Brenner, Roland Masson: LJLL CNRS-Sorbonne Univ., Ecole des Ponts, LNCC Brazil. The project is devoted to the numerical modeling of urban floods, helping to size and position protective systems including dams, dikes or rainwater drainage network. This project gives raise to a PhD thesis and it involves a collaboration with F. Valentin, International Inria Chair.

- ANR JCJC GeoFun (ANR-19-CE46-0010, 2020-2024) The project GEOphysical Flows with UNified models is coordinated by Martin Parisot, member of the team CARDAMOM, from Inria Bordeaux, CNRS and University of Bordeaux. This project explores geophysical flows and the modeling of aquifers, wishing to propose a unified numerical library for the coupling between shallow free surface flows and the underground flow in porous medium.

- ANR JCJC COMODO (2019–2023) led by V. Ehrlacher (Ecole des Ponts), fosters the collaboration with C. Cancès (Inria Lille), M. Burger (FAU Erlangen), J. Frederik Pietschmann (TU Chemnitz). It is concerned with the simulation of cross-diffusion systems set on moving geometries, with on-going collaborations.

- ANR JCJC NEMO (2021–2025) led by L. Giraldi (PI, Centre Inria d'Université Côte d'Azur), with M. Binois (Centre Inria d'Université Côte d'Azur), C. Prud'homme (Univ. Strasbourg), S. Régnier (Sorbonne Univ.) is concerned with the development of fictious domain methods for models of micro-swimmers. We are concerned by the development of fluid-structure methodologies for the simulation of micro-swimmers. The project has supported a master internship and a PhD is supposed to start in 2023.

- ANR PRC NEMATIC (2021–2025): led by researchers of the Laboratoire Interdisciplinaire des Energies de Demain, this project is concerned with the developpement of models and methods for studying hyphal networks. We propose a derivation from branching processes of kinetic-like and hydrodynamic models, and numerical procedures in order to capture accurately the propagating front. Starting from a microscopic description of the Spitzenkörper (vesicules in hyphal cells which drive the growth of the cellular membrane), we intend to propose a chemically and physically informed model for branching rates. One PhD thesis is concerned with this project, and another one is going to start.

8.4.2 National and European networks

- GdR MathGeoPhy

  The research group MathGeoPhy has activities centered around scientific computing, design of new numerical schemes and mathematical modelling (upscaling, homogenization, sensitivity studies, inverse problems,...). Its goal is to coordinate research in this area, as well as to promote the emergence of focused groups around specific projects

- GdR Mamovi

  The team is involved in the activities of the research group dedicated to applications to life sciences.

- S. Junca is involved in GdR 3437 DYNOLIN "Dynamique non linéaire" and GdR MecaWave.

- LJAD-Inria and BRGM are the French partners of the Norvergian, German French project InSPiRE "International Open Source Simulation Software Partnership in Research and Education" which has just been accepted by the Research Council of Norway with the code ComPASS as one of the softwares of this project together with Dune, Dumux and OPM.

9 Dissemination

9.1 Promoting scientific activities

9.1.1 Scientific events: organisation

- K. Brenner organizes a symposium "Advances in modeling and simulation of multiphase and multicomponent flow in porous media" at the SIAM Geosciences Conference, June 19-22 2023, at Bergen.
- K. Brenner organized the INSPIRE project workshop, May 9-13 2022, Porquerolles, see Inspire project
- K. Brenner is member of the orgnaizing committee of the forthcoming edition of CEMRACS on Scientific Machine Learning.
- S. Krell participated to events of the 2022 Jean Morlet chair awarded to Martin Gander.

9.1.2 Journal

Member of the editorial boards T. Goudon is founding editor and Co-Editor in chief of SMAI Journal of Computational Mathematics SMAI-JCM

T. Goudon is academic editor at PlosOne.

Reviewer - reviewing activities We are regularly committed to review research papers for journals in applied mathematical analysis (ARMA, SIMA, Ann. PDE, ANN. ENS...), numerical analysis (SINUM, Numerische, JCP...), scientific computing (SISC), geosciences (SIAM Geosc.), life sciences (JTB, NHM,...)...

9.1.3 Scientific expertise

T. Goudon is Scientific officer for Mathematics at the General Directorate for Research and Innovation of the Ministry of Higher Education and Research. As such, he is member of the Board of IHP, CIMPA, CIRM, IHES and gives advices on any subject that concerns research in mathematics. He is responsible of the follow-up of mathematics in initiatives with national funding (Labex, Equipex, PEPR, IA national plan), and of the "Assises des Mathématiques".

T. Goudon is regularly expert for funding agencies (France, Switzerland, Belgium, Chile, Hong-Kong, Slovakia...). He serves as expert for the Marie Skłodowska-Curie call.

9.1.4 Research administration

- The team is strongly involved in the life of the Math. Department and the Univ. Côte d'Azur J. A. Dieudonné where members of the team have several responsibilities (member of the Board of the research unit, organization of the PDE-Numerical Analysis seminar, teaching responsibilities...). We are also committed to the institutions of Univ. Côte d'Azur: Inria depends on the Graduate School Spectrum and L. Monasse is member of the Scientific Board; T. Goudon chairs the Scientific Board of the Math. Department, S. Krell is member of the Steering Committee of the research unit J. A. Dieudonné, T. Goudon, S. Krell. L. Monasse were members of the Committee in charge of the scientific prospective 2018-2022, R. Masson is head of the Numerical analysis & PDE team of the J. A. Dieudonné research unit.
- S. Krell is member of the CNRS "Comité National" in Mathematics since 2020
- S. Krell is member of the Scientific Board of GdR Math-GeoPhy.
- K. Brenner serves in the scientific board of the newly established Water Observatory of Département des Alpes-Maritimes.
- T. Goudon is member of the Scientific Board of CIRM (Centre International de Rencontres Mathématiques)

- R. Masson is member of the scientific committee of CERFACS

9.2 Teaching - Supervision - Juries

9.2.1 Teaching

- Florent Berthelin, Master 2 Mathématiques fondamentales, Univ Côte d'Azur, 120h.
- Florent Berthelin, Chair of the Master 2 Mathématiques fondamentales, Univ Côte d'Azur.
- Florent Berthelin, Analysis, L2, Univ Côte d'Azur, 72h.
- Laurent Monasse, Introduction to continuum mechanics, M1, 30h., Univ Côte d'Azur
- Thierry Goudon is a member of the jury of the national competition to hire teachers (agregation de mathematiques).
- Thierry Goudon: CliMaths program. Lecture on traffic flows modeling, Ecole Centrale de Marseille
- Thierry Goudon: Master, lectures on signal processing, Univ Côte d'Azur
- Thierry Goudon: Master, lecture on PDEs, Univ. Côte d'Azur
- Stella Krell: Master, Finite Volume methods, Univ Côte d'Azur

9.2.2 Supervision

Beyond mentoring PhD thesis and postdoctoral fellowships, we also supervise masters internships, and apprenticeship with companies.

9.2.3 Juries

Team members are regularly invited to serve as reviewers of PhD thesis and habilitation to conduct research, in France, abroad and also on connected disciplines.

9.3 Popularization

9.3.1 Education

Stella Krell has participated to the creation and organisation of "mathematical rallyes" devoted to K-grades students. The objective is to develop the pleasure to practice mathematics, around clever games, see the website of the Académie de Nice.

Laurent Monasse participated to the program "Regards de géomètre" with speeches to K-grades in high-schools about mathematics, origamis and illusions. He participated to the "Cordées de la réussite" with a project on origamis for dress-production.

The team also regularly welcomes students from 4ème/3ème for short internships.

10 Scientific production

10.1 Publications of the year

International journals

[1] K. Atsou, S. Khou, F. Anjuère, V. Braud and T. Goudon. 'Analysis of the Equilibrium Phase in Immune-Controlled Tumors Provides Hints for Designing Better Strategies for Cancer Treatment'. In: *Frontiers in Oncology* 12 (2022), p. 878827. DOI: 10.3389/fonc.2022.878827. URL: https://hal.archives-ouvertes.fr/hal-03768113.

[2] F. Bonaldi, J. Droniou, R. Masson and A. Pasteau. 'Energy-stable discretization of two-phase flows in deformable porous media with frictional contact at matrix–fracture interfaces'. In: *Journal of Computational Physics* 455 (2022). DOI: 10.1016/j.jcp.2022.110984. URL: https://hal.archives-ouvertes.fr/hal-03349229.

[3] C. Bourdarias, A. P. Choudhury, B. Guelmame and S. Junca. 'Entropy solutions in BV^s for a class of triangular systems involving a transport equation'. In: *SIAM Journal on Mathematical Analysis* 54.1 (2022), pp. 791–817. DOI: 10.1137/20M1351783. URL: https://hal.archives-ouvertes.fr/hal-02895603.

[4] T. Goudon, J. Llobell and S. Minjeaud. 'An explicit finite volume scheme on staggered grids for the Euler equations: Unstructured meshes, stability analysis, and energy conservation'. In: *International Journal for Numerical Methods in Fluids* 94.1 (2022), pp. 76–119. DOI: 10.1002/fld.5048. URL: https://hal.archives-ouvertes.fr/hal-03428367.

[5] B. Guelmame. 'On the blow-up scenario for some modified Serre–Green–Naghdi equations'. In: *Nonlinear Analysis: Theory, Methods and Applications* (Nov. 2022). DOI: 10.1016/j.na.2022.113084. URL: https://hal.archives-ouvertes.fr/hal-03264688.

[6] B. Guelmame, D. Clamond and S. Junca. 'Hamiltonian regularisation of the unidimensional barotropic Euler equations'. In: *Nonlinear Analysis: Real World Applications* 64 (2022), 22p. DOI: 10.1016/j.nonrwa.2021.103455. URL: https://hal.archives-ouvertes.fr/hal-02907304.

[7] B. Guelmame, D. Clamond and S. Junca. 'Local well-posedness of a Hamiltonian regularisation of the Saint-Venant system with uneven bottom'. In: *Methods and Applications of Analysis* (2022). URL: https://hal.archives-ouvertes.fr/hal-02915262.

[8] B. Guelmame, S. Junca, D. Clamond and R. L. Pego. 'Global weak solutions of a Hamiltonian regularised Burgers equation'. In: *Journal of Dynamics and Differential Equations* (2022). DOI: 10.1007/s10884-022-10171-0. URL: https://hal.archives-ouvertes.fr/hal-02478872.

[9] H. Le Thi, S. Junca and M. Legrand. 'First return time to the contact hyperplane for n-degree-of-freedom vibro-impact systems'. In: *Discrete and Continuous Dynamical Systems - Series B* 27.1 (2022), pp. 1–44. DOI: 10.3934/dcdsb.2021031. URL: https://hal.archives-ouvertes.fr/hal-01957546.

Conferences without proceedings

[10] M. Al Zohbi and S. Junca. 'Existence of entropy solutions in BVs for a non-conservative and non-strictly hyperbolic diagonal system modelling 2 dislocations in cristallography'. In: Canum 2022 - 45eme Congrès National d'Analyse Numérique. Evian, France, 13th June 2022. URL: https://hal.archives-ouvertes.fr/hal-03704699.

Reports & preprints

[11] F. Bonaldi, J. Droniou and R. Masson. *Numerical analysis of a mixed-dimensional poromechanical model with frictionless contact at matrix–fracture interfaces.* 24th Jan. 2022. URL: https://hal.archives-ouvertes.fr/hal-03541096.

[12] K. Brenner. *On global and monotone convergence of the preconditioned Newton's method for some mildly nonlinear systems.* 28th Nov. 2022. URL: https://hal.archives-ouvertes.fr/hal-03876457.

[13] K. Brenner, N. Chorfi and R. Masson. *Algebraic flux correction finite element method with semi-implicit time stepping for solute transport in fractured porous media.* 10th May 2022. URL: https://hal.archives-ouvertes.fr/hal-03664380.

[14] D. Castanon Quiroz and D. Di Pietro. *A pressure-robust HHO method for the solution of the incompressible Navier-Stokes equations on general meshes.* 11th Oct. 2022. URL: https://hal.archives-ouvertes.fr/hal-03608248.

[15] N. Dirani and L. Monasse. *An explicit pseudo-energy conservative scheme for contact between deformable solids.* 30th Nov. 2022. URL: https://hal.archives-ouvertes.fr/hal-03879345.

[16] N. Dirani and L. Monasse. *Conservative coupling method between an inviscid compressible fluid flow and a deformable structure with contact*. 6th Dec. 2022. URL: https://hal.archives-ouvertes.fr/hal-03887085.

[17] B. Guelmame. *Global weak solutions of the Serre–Green–Naghdi equations with surface tension*. 23rd Feb. 2022. URL: https://hal.archives-ouvertes.fr/hal-03585433.

[18] B. Haspot and S. Junca. *Fractional BV solutions for* 2×2 *systems of conservation laws with a genuinely nonlinear field and a linearly degenerate field*. 29th Mar. 2022. URL: https://hal.archives-ouvertes.fr/hal-02532444.