

Doctoral Programme in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 42nd cycle – first call

A mandatory attachment of the application is a description of the research project (approx. max 4 pages) relative to the research areas of the Doctoral Programme in Civil, Environmental and Mechanical Engineering on specific topics as described below.

Curriculum A - Civil and Environmental Engineering

- **Reference person: Marco Tubino (UNITN/DICAM)**

Participants: Guido Zolezzi (UNITN/DICAM), Niccolò Ragno (UNITN/DICAM), Gabriele Barile (ETH Zurich)

A1 - scholarship on reserved topics

Funded by: Department of Civil, Environmental and Mechanical Engineering.

Title: Sediment regime and evolutionary trajectories of riverine ecosystems

Rivers are among the most threatened ecosystems of the world and are impacted more and more by human activities. Rivers are strongly connected with other components of the earth system by exchanging water and sediment and by responding to alterations such as climate change, growth of vegetation, building of in-stream structures and gravel mining activities. This connectivity invariably leads to changing conditions on a multitude of temporal scales, from the daily scale (e.g., discharge variation due to precipitations or water releases), to the scales of decades or centuries (e.g., climate change, alterations of the sediment production in the basin). As a result, rivers are often out of equilibrium and follow morphodynamic trajectories, depending on intensity, duration, and nature of stressors. Their role as fundamental connecting agents of the evolving landscape is underpinned by the morphological dynamics, which results from the combined effect of processes acting at multiple scales, from the grain to the catchment. Channel geometry and patterns reflect the ongoing adjustment to fluctuating flow and sediment yields (bedload/suspended load) and, consequently, the balance of erosional and depositional processes.

Sediment management in fluvial and coastal environments is of crucial importance for environmental, productive and safety reasons. The loss of sediment connectivity along river networks is recognized as a major cause of habitat degradation and biodiversity loss, while erosion/deposition processes may severely contribute to flood hazards. Specifically, in alpine regions, the impact of sediment deficits is responsible for riverbed incision and related habitat degradation. At the same time, increase in sediment load and transport is a major problem in regions with soil erosion due to intensive agriculture. Consequences of sediment deficits and impacts on the river are decrease in habitat heterogeneity, risk of river bank erosion and of damage to infrastructure, increase in the risk of flood hazards, lack of spawning habitats for fish species and depauperate macroinvertebrate fauna, decrease in sediment turnover rates and river type-specific sediment quality, and risk of channel avulsion during extreme events.

In the last 40 years our understanding of morphodynamics has been remarkably advanced through mathematical theories and predictive models, which have received strong validation from laboratory scale experiments and more recently also from field observations. Theoretical models can now benefit from the remarkable support of satellite information, which provides an unprecedented capability of performing quantitative analyses of the spatial distributions of river and deltas characteristics and evolutionary trajectories. The morphodynamic processes that determine the shape of the river have been mainly studied under the assumption that the river system is in dynamic equilibrium. Furthermore, most of the existing morphodynamic models refer to the reach scale, i.e. a hydro-morphologically homogeneous portion of the channel, though processes at this scale are clearly conditioned by those occurring at hierarchically higher scales. Disequilibrium between sediment supply and transport capacity, the role of climate change and land use transitions on evolutionary trajectories, as well as the morphodynamical response to a variable flow regime, such as the hydrological cycle, are still to a large extent unexplored.

Research aims and methodology

Within the above framework, the aim of the project is to investigate non-equilibrium hydraulic and morphodynamic processes. With reference to projects currently underway at the Department of Civil, Environmental and Mechanical Engineering, the candidate will be able to develop his/her research with reference to one of the following topics:

a) Develop suitable quantitative, process-based tools to assess sediment production and transport processes of fine and coarse sediments at the river network scale in Alpine basins and detect the potential for restoration accounting for the operational and structural constraints set by the anthropic stressors. The project methodology envisages the integration of mathematical modelling approaches with the collection and analysis of field data in target case studies. Modelling will focus on the development and testing of a nested, multi-scale approach, where a chain of models will be used from the catchment to the reach scale. The field component will integrate the analysis of existing datasets available at public environmental agencies with those of remotely sensed data and with the collection and analysis of in situ field data.

b) Develop suitable quantitative, process-based tools to assess the morphodynamical response at the reach scale as well as flow and sediment distribution in multi-thread, anabranching river reaches, and analyse the role of changes of the external controlling variables. This will be accomplished by using a combination of numerical modelling, physical modelling at the Hydraulic laboratory of the Department of Civil Environmental and Mechanical Engineering, where a large experimental facility is available, field measurements and monitoring and statistical data analysis and interpretation of results on the basis of theoretical and conceptual models. Effectively tackling these questions is made possible by two key factors: (i) the recent theoretical development on bifurcations/confluences morphodynamics; (ii) the availability of specific case studies.

c) Develop suitable quantitative, process-based tools to assess morphodynamical trajectories in meandering rivers subjected to an alteration of sediment supply which can originate from climate variability, anthropogenic pressure, or geological adjustments. The project will place a particular emphasis in understanding the river response in terms of the channel geometry and planform evolution. This will be accomplished by the integration of mathematical modeling and field observations derived from satellite imagery. Quantitative analyses will be performed by extracting multi-spectral, high-resolution satellite data, which will be processed with an available process-based software.

The ideal candidate will have a background in Environmental Engineering, River Geomorphology or related fields. Candidates should also possess strong computer, scientific, and analytical expertise, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a good attitude for critical thinking. Since foreseen activities include model development, the candidate is required to have computational proficiency (or the will to pursue it) preferably in Fortran, R/python/Matlab and GIS products.

Suggested references:

Seminara et al. (2023a), Theoretical Morphodynamics: River Meandering

Seminara et al. (2023b), Theoretical Morphodynamics: Straight Channels

Monegaglia et al. (2017), Environmental Modeling & Software

Heckmann et al. (2018), Earth Science Review.

Morel et al. (2023), Nat. Hazard Earth Syst. Sci.

Redolfi et al. (2019), Earth Surface Processes and Landforms.

Ragno et al. (2021), Water Resources Research.

Barile et al. (2024), Earth Surface Dynamics.

Ragno & Tubino (2025), Earth Surface Processes and Landforms.

- Reference person: Marco Tubino (UNITN/DICAM)

Participants: Luca Adami (UNITN/DICAM), Gabriele Barile (ETH Zurich)

A2 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering.

Title: Transport processes in transitional environments

Water management is facing a growing number of challenges in many river basins worldwide, as the equal distribution of the available water resources is increasingly influenced by several, uncertain hydro-climatic and anthropogenic pressures. Within the current and projected water scarcity and drought scenario, such issue represents even a greater challenge in those basins that were massively regulated in the XX century, as water managers are asked to find balanced policies to stay ahead with multiple, interdependent and ever-increasing human water-related requirements. In this context, water conflict has become a recurring problem in many regulated systems, with the sole providers of the water benefits - the freshwater ecosystems - experiencing a severe alteration of their natural renewability and ecological integrity.

Among the water ecosystems most at risk, transitional wetlands stand out. Physical processes in lentic, transitional systems are driven by different forcings than those in lotic environments, where hydrodynamic actions are dominant. As the flow velocity gradually decreases, other processes begin to play a significant role, such as temperature gradients, wind forcing, and the presence of vegetation. Furthermore, the slowdown of the water velocity enhances the sedimentation of suspended particles. This is the case of the Mincio fluvial system near the city of Mantua (Lombardy, Northern Italy), where the morphology changes from a single-thread river to a fluvial lake complex, passing through a multiple-channel transitional wetland. The site is located downstream of a heavily human-altered environment with intensive agricultural use. As a result, it suffers from many environmental problems including eutrophication, siltation and spread of invasive macrophytes, further worsened by low discharge. The flow regime in the Mincio River is regulated by a complex system of hydraulic infrastructures, which was designed primarily for flood protection. In case of high discharge, the Mincio River is diverted into an artificial channel bypassing the wetland and the Mantua lake system to protect the city of Mantua. Concurrently, the incoming discharge from the river's tributaries is usually higher because of heavy rainfall. These tributaries collect water from agricultural drainages; as a result, they carry huge amounts of nutrients and fine sediments originating from surface runoff. This contribution to the Mincio River has a detrimental effect on water quality of the wetland, further worsened by the low incoming discharge of clear water that could dilute suspended sediments and nutrients input. As a consequence, most of the secondary channel network is threatened by terrestrialization, with a switch from hydrophytes to helophytes and ultimately terrestrial plants. This process leads to the loss of habitats of great ecological value, listed in the NATURA2000 European protected sites.

Research aims and methodology

Within the above framework, the aims of the project are as follows:

- i) develop a comprehensive analysis of various physical processes that are relevant to the case study of the River Mincio and to analogous freshwater ecosystems, such as sedimentation, anoxia, water mixing, and the role of aquatic vegetation;
- ii) develop a numerical model to compute the transport of suspended sediments within a multiple- channel transitional wetland, based on recent advances on river bifurcations dynamics, and take part in the development of a suite of models aimed at building a digital twin of the Mantua hydraulic network.

The project methodology envisages the integration of field measurements, remotely-sensed data and mathematical modelling. Field work will include bathymetric surveys, measurements of flow velocity and discharge partition at the network nodes, sediment sampling, dissolved oxygen monitoring and analysis of time series of suspended solid concentration from in situ instrumentation. Effectively tackling this project is made possible by two key factors: (i) the availability of an extensive dataset of field measurements, covering two years of observations, and of continuous measurements of turbidity; (ii) the availability of a hydrodynamical model of the wetland. The research is aimed at producing physically-based management guidelines that can be used by management agencies to plan future maintenance works and dredging operations and to predict the effects of different river regulation strategies.

The ideal candidate will have a background in Environmental Engineering or related fields. Candidates should also possess strong computer and scientific, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a good attitude for critical thinking. Since foreseen activities include model development and on-site measurements, the candidate is required to have (or the will to pursue them) computational proficiency (preferably in Fortran, R/python/Matlab and GIS products) and experience in experimental methodologies.

- Reference person: Marco Broccardo (UNITN/DICAM)

Participants: Davide Noè Gorini (UNITN/DICAM), Chiara Nardin (UNITN/DICAM), Alfio Viganò (Provincia Autonoma di Trento - PAT)

A3 - scholarship on reserved topics

Funded by: University of Trento – Department of Civil, Environmental and Mechanical Engineering within the project “Rischio sismico” CUP no. C65E24000330003 of the Provincia Autonoma di Trento

Title: Next-Generation High-Resolution Seismic Hazard Maps for Trentino with Site Amplification and Soil-Structure Interaction

This research project aims to develop a prototype for **next-generation, high-resolution seismic hazard maps** for the Trentino region by explicitly accounting for **site amplification** and **soil–structure interaction (SSI)** in a fully probabilistic setting. The project advances beyond conventional regional hazard products by coupling state-of-the-art regional PSHA with microzonation-informed local geology, physics-based (and computationally efficient) site-response modeling, and SSI-aware definitions of the input motion relevant to the built environment. The research outcomes are structured into three key contributions:

1. Probabilistic High-Resolution Hazard Downscaling and Microzonation Integration

- Development of a methodological framework to incorporate microzonation products (geological models, stratigraphic units, Vs profiles, basin geometry where available) into regional-scale PSHA, with explicit treatment of aleatory and epistemic uncertainties.
- Systematic comparison between national/regional hazard assessments and microzonation-informed hazard at finer resolution, quantifying where and why hazard levels change (amplification-prone sediments, topographic effects, impedance contrasts, basin edges).
- Production of hazard outputs consistent with engineering practice (hazard curves and uniform-hazard spectra) at map resolution compatible with regional planning and municipal decision-making.

2. Site Amplification and Nonlinear Site Response Embedded in Hazard Mapping

- Implementation of scalable site-response models that move beyond proxy-only approaches (e.g., single-parameter site classes), enabling frequency-dependent amplification and uncertainty propagation within the hazard calculation.
- Inclusion of nonlinear soil behavior where relevant, to avoid systematic bias in predicted spectral ordinates at short periods and moderate-to-strong shaking levels.
- Generation of spatially coherent amplification factors and period-dependent amplification maps, directly linked to the microzonation inputs and calibrated/validated against available local information (geotechnical, geophysical, and recorded motions where available).

3. SSI-Aware Hazard Metrics and GIS-Based Mapping for Trentino

- Extension of conventional “free-field” hazard to structure-relevant input motion incorporating SSI-aware transformations. This will be achieved by employing novel thermodynamic-based macroelement representations capable of capturing, in an efficient and rigorous manner, the multiaxial, nonlinear, frequency- and rate-dependent response of soil-foundation systems. Through their systematic application at the regional scale under consideration, this framework will enable: i) the computation of the effective translational-rotational input motions acting at the foundation level, and ii) the rigorous incorporation of SSI into the seismic assessment of the urban fabric.
- Development of a GIS-based pipeline that delivers high-resolution hazard layers (free-field and SSI-aware) suitable for integration into regional risk management workflows and for prioritizing detailed local studies.
- Demonstration on the Nord Garda Region with a systematic comparison against standard microzonation practice to identify i) contexts in which SSI effects are negligible, favourable, or detrimental, and ii) correlations enabling their systematic assessment, providing a valuable tool for preliminary design of new structures and large-scale evaluation of the existing urban fabric against expected natural hazards.

Overall, the project provides a replicable and scalable methodology for **high-resolution seismic hazard mapping** that better reflects the physical processes controlling ground motion in Trentino, strengthening the scientific basis for mitigation strategies and alignment with modern European hazard modeling practices.

Curriculum B - Mechanics, Materials, Chemistry and Energy

- **Reference person: Nicola M. Pugno (UNITN/DICAM)**

Participant: Giuseppe Puglisi (Politecnico di Bari)

B1 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: Fracture and Damage Mechanics of Snow from the Propagation Saw Test Scale to the Avalanche Scale under Changing Climate Conditions

This PhD project aims to investigate the mechanical mechanisms governing fracture initiation, crack propagation, and plastic collapse in weak layers of the snowpack, by integrating theoretical and numerical models of fracture and damage mechanics with controlled laboratory experiments and field measurements. Particular emphasis will be placed on the role of temperature and thermal gradients, which strongly influence the mechanical response, microstructural evolution, and stability of snow. The objective is to develop a multi-scale framework capable of linking processes observed at the scale of the *Propagation Saw Test* (PST) to fracture propagation dynamics at the slope scale, ultimately responsible for the release of slab avalanches.

The candidate will develop models based on quasi-brittle and cohesive fracture mechanics, coupled with continuum damage and plasticity formulations, incorporating the effects of microstructural heterogeneity, anisotropy, viscous rate-dependent behavior, and temperature-dependent constitutive properties of snow. Thermal effects will be explicitly considered, including their influence on bonding strength, creep, sintering, and weak-layer collapse. Particular attention will be devoted to the analysis of fracture initiation conditions, weak-layer collapse mechanisms, and critical crack propagation lengths through energetic formulations and instability criteria. From the PST scale to the avalanche scale, the models will be extended to account for scale effects, three-dimensional slope geometry, thermo-mechanical coupling, and the interaction between fracture in the weak layer and the mechanical response of the overlying slab.

The experimental program will include laboratory mechanical tests on natural and artificially prepared snow samples under controlled temperature conditions, enabling the characterization of elastic, viscous, plastic, and fracture properties as functions of temperature. These activities will be complemented by field campaigns involving instrumented PSTs and in situ measurements across different thermal regimes and real avalanches observations. The integration of modeling and experimental data will allow quantitative validation of propagation criteria and assessment of how changing thermal conditions affect snow stability.

In the broader context of global warming, rising air temperatures, altered snow metamorphism, and increasing frequency of melt-freeze cycles are expected to modify the mechanical behavior and failure modes of snowpacks. By explicitly addressing temperature effects across scales, the project will contribute to understanding how climate change may impact fracture processes and avalanche release conditions, from dry to wet.

The project is embedded within the framework of the ERC grant FRAMEGLOW of the PI, contributing to the development of a physically grounded, multi-scale, thermo-mechanically coupled description of fracture and damage in snow, and strengthening the link between fundamental mechanics and applications to avalanche hazard forecasting and mitigation in a changing climate.

- **Reference persons:** Eleonora Isotta (UNITN/DICAM, Max Planck Institute for Sustainable Materials), Narges Ataollahi (UNITN/DICAM)

Participant: Christina Scheu (Max Planck Institute for Sustainable Materials, Germany)

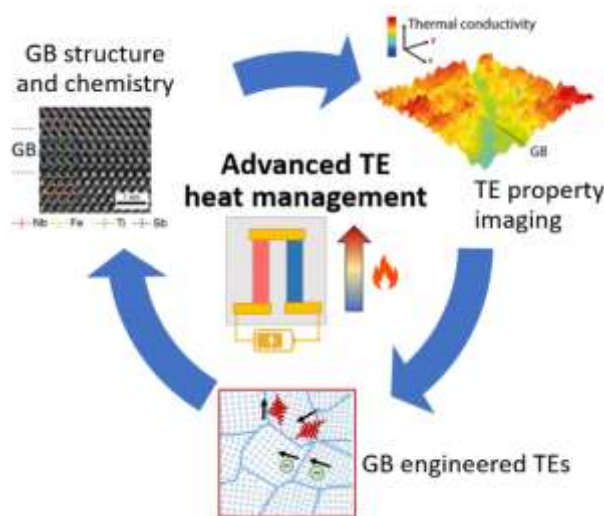
B2 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering within the project MUR FIS3, CUP n. E53C25002220001, FIS-2024-05016.

Title: Grain-boundary engineering for high performance thermoelectric devices via local-scale structure-property correlations

Thermoelectric (TE) devices are attractive for waste-heat energy harvesting, as well as for cooling and heating applications due to their versatile, reliable, and refrigerant-free operation. A particularly promising application of TEs is device-level heat management, which is increasingly critical for achieving high performance and efficiency in technologies such as batteries, advanced electronics, and hardware for computing and datacenters. The cooling performance of TE devices is linked to the materials figure of merit, zT , which is proportional to the ratio of electrical (σ) to thermal conductivity (κ). State-of-the-art TE materials typically reach $zT \sim 1.1\text{--}1.4$ near 300 K. Achieving reproducible zT s $\sim 1.3\text{--}1.7$ would render TEs technologically competitive, thus enabling their integration into heat management systems.

In this PhD thesis, we propose to achieve high zT via advanced grain-boundary engineering. GBs offer a compelling and novel material design space. In fact, recent literature suggests that: (i) GBs behave as ‘phases’ (called complexions) and can thus exist in multiple forms, with different local chemistry and structural arrangements; (ii) the type of GBs can have major impact on its thermal and electrical transport. TE research typically relies on macroscale measurements, incapable of identifying what GB types are beneficial among the many present in a sample. We recently demonstrated that measuring κ for individual GBs is possible (Figure). By leveraging local property measurements, we plan to comprehensively understand the behavior of individual GBs to guide GB engineering.



Proposed strategy to correlate TE properties via imaging (see <https://doi.org/10.1002/adma.202302777>) with analysis of GB structure and chemistry to achieve high zT materials.

The PhD researcher will develop a strong experimental background and will focus on (i) TE material synthesis and characterization, including with thermal conductivity imaging, local electrical measurements, and electron microscopy; (ii) data analysis and theoretical interpretation of results; (iii) TE device assembly and optimization. Outcomes will include publications in international scientific journals as well as presentations at national and international conferences.

This project will be carried out at the [Energy and Materials Laboratory](#). Electron microscopy investigations will be carried out in collaboration with the Max Planck Institute for Sustainable Materials, where the candidate will have the opportunity of spending a research stay.

Funded by:

Fondo Italiano per la Scienza FIS-3 Starting Grant – Project ‘HEAT’, FIS-2024-05016.



Funded by Ministero dell'Università e della ricerca according to D.D. no.18010 of November 12, 2025 – CALL FIS 3.

- **Reference persons:** Eleonora Isotta (UNITN/DICAM, Max Planck Institute for Sustainable Materials), Paolo Scardi (UNITN/DICAM)

Participants: Himanshu Jain (Lehigh University, USA), Rossana Dell'Anna (FBK), Elena Missale (FBK)

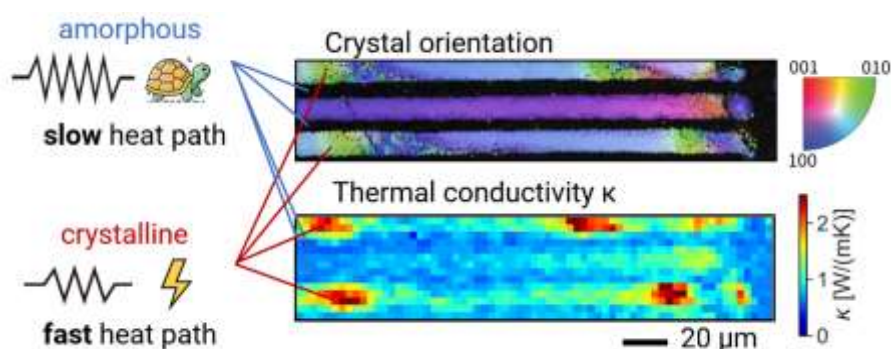
B3 - scholarship on reserved topics

Funded by: Department of Civil, Environmental and Mechanical Engineering within the project MUR FIS3, CUP n. E53C25002220001, FIS-2024-05016.

Title: Development of patternable heat guides for advanced thermal management in microelectronic and energy storage devices

The electrification of industrial, automotive, and domestic sectors plays a major role in the transition to a more sustainable society. Many technologies critical to this electrification, including electronics, computing, and energy storage devices, are limited by our ability to efficiently manage the heat they generate. As an additional challenge, these devices are increasingly miniaturized and must be able to dynamically respond to changes in their environment or operation, as well as cope with potentially failure-inducing events such as hotspots.

To meet the demands of next-generation technologies, new advanced solutions are needed to manage heat efficiently at localized and reconfigurable locations. One attractive opportunity for localized channeling of cooling and heating loads is laser patterning of semiconductor materials. Inducing phase changes in materials via lasers is commonly used for reversible memory storage. Laser processing was also recently used to write microscale crystal patterns in chalcogenides (Figure) and silicon.



Heat guides in Sb_2S_3 obtained via laser-induced crystallization. Thermal conductivity κ imaging with micron resolution shows a κ contrast between amorphous and crystalline areas. See: doi.org/10.1002/adfm.202517850

The goal of this PhD project is the development of laser-patterned heat guides to deliver heating and cooling loads at reconfigurable, submicron locations of a target battery or microelectronic device. The PhD researcher will work on laser-manufacturing methods to write and reconfigure heat-guide patterns, test their thermal conduction performance, and demonstrate the possibility of delivering heat at submicron locations by developing nanoscale patterning strategies.

The PhD researcher will develop a strong experimental background in advanced manufacturing of semiconductor materials, as well as characterization using scanning electron microscopy (SEM), temperature imaging, and thermal conductivity imaging via thermoreflectance (FDTR). Work will also focus on developing a theoretical interpretation of thermal transport results, with potential modelling integration. Outcomes will include publications in international scientific journals as well as presentations at national and international conferences. The candidate will develop an attractive profile for a career in industry R&D, as well as academia.

This project will be carried out at the [Energy and Materials Laboratory](#). The project is in collaboration with the Bruno Kessler Foundation, and the Materials Science Department. at Lehigh University, USA, where the PhD researcher will have the opportunity to spend a research stay.

Funded by:

Fondo Italiano per la Scienza FIS-3 Starting Grant – Project 'HEAT', FIS-2024-05016.



Funded by Ministero dell'Università e della ricerca according to D.D. no.18010 of November 12, 2025 – CALL FIS 3.

- Reference person: Nicola M. Pugno (UNITN/DICAM)

Participant: Massimiliano Fraldi (Università degli Studi di Napoli – Federico II)

B4 - scholarship on reserved topics

Funded by: University of Trento – Department of Civil, Environmental and Mechanical Engineering within the project HE ERC FRAMEGLOW – CUP E63C25001520006.

Title: Poroelastic quantized fracture mechanics of wet ice and snow

This PhD project aims to advance the theoretical and experimental understanding of fracture processes in wet ice and snow through the framework of Poroelastic Quantized Fracture Mechanics (PQFM). Within the context of the FRAMEGLOW project, the research focuses on the coupled interactions between fluid transport, microstructural evolution, and fracture propagation in partially saturated cryospheric materials.

Wet snow and temperate ice exhibit complex poroelastic behavior due to the coexistence of solid ice matrices and liquid water within interconnected pore networks. Traditional fracture mechanics approaches often fail to capture the discrete and scale-dependent nature of crack initiation and propagation in such heterogeneous media. By integrating quantized fracture mechanics with poroelastic theory, this project proposes a novel multiscale approach capable of describing fracture as a discontinuous, energy-driven process influenced by fluid pressure, permeability, and phase transitions.

The research will combine theoretical modeling, numerical simulations, and controlled laboratory experiments to: (i) characterize the role of liquid water content and pore pressure on fracture toughness and crack dynamics; (ii) develop predictive models for fracture initiation thresholds under varying thermal and hydraulic conditions; and (iii) validate these models against experimental data obtained from engineered snow/ice samples.

The outcomes are expected to significantly improve the understanding of failure mechanisms in wet cryospheric materials, with implications for avalanche release, glacier dynamics, and climate-sensitive geohazards. By embedding these findings within the broader objectives of FRAMEGLOW, the project will contribute to enhanced predictive capabilities and risk assessment tools in rapidly changing alpine and polar environments.

Curriculum C - Modelling and Simulation

- Reference person: Annunziato Siviglia (UNITN/DICAM)

Participant: Victor Chavarrias (DELTAIRES, Delft)

C1 - scholarship on reserved topics

Funded by: University of Trento – [Deltares](#)

Title: GPU-Accelerated Hydro-Morphodynamic Modeling: from Computational Performance to Flood Risk Applications

Climate change, sea-level rise, and increasing hydrological extremes are intensifying flood risk in riverine and deltaic systems. Ensuring flood safety and supporting climate adaptation require computationally efficient numerical models capable of simulating hydrodynamic and morphodynamic processes over large spatial and temporal scales. Physics-based models solving the Shallow Water-Exner equations are central to this effort, as they describe flow dynamics, sediment transport, and bed evolution processes that directly control flood hazard and long term system resilience.

State of the art hydro-morphodynamic models are widely used for flood risk assessment, infrastructure design, and adaptation planning. However, their high computational cost limits the exploration of uncertainties, the evaluation of alternative interventions, and the ability to perform large scenario ensembles under climate change. Established operational tools, such as Delft3D, illustrate both the robustness and the computational constraints of current modeling practice.

This PhD project investigates how GPU-accelerated computing can significantly enhance the performance of physics-based hydro-morphodynamic models. GPUs offer massively parallel architectures that differ fundamentally from traditional CPU systems, requiring adapted numerical strategies. In particular, implicit schemes, discontinuous formulations (e.g., wetting and drying), may hinder GPU efficiency, calling for a systematic redesign of algorithms.

The objective of this research is to explore the potential of GPU computing to significantly accelerate hydro-morphodynamic simulations for water management applications. Starting from simplified configurations and progressively increasing physical complexity, the project will identify computational bottlenecks and assess tradeoffs between alternative numerical formulations. Performance and scalability will be evaluated against established modeling approaches and benchmarks.

The expected outcome is a novel GPU-oriented numerical framework capable of substantially accelerating hydro-morphodynamic simulations in Delft3D while preserving physical consistency. By enabling faster scenario analysis and large-scale uncertainty quantification, the project will directly support improved flood risk assessment and climate adaptation strategies, contributing to next-generation operational modeling tools. Research outcomes will be published in high impact factor journals in the field of modeling of environmental science.

The candidate is expected to possess strong programming skills in high-level languages, as well as experience with GPU computing. A solid background in river hydraulics is required, together with a good command of the English language. Knowledge of sediment transport processes will be considered an advantage.

- Reference person: Massimo Cassiani (UNITN/DICAM)

Participants: Espen Sollum and Gabriela Sousa Santos at NILU, Norway

C2 - scholarship on reserved topics

Funded by: University of Trento – [Stiftelsen NILU](#).

Title: Advanced Lagrangian Modelling of Reactive Atmospheric Plumes from CO₂ Capture: Development, Validation and AI-Accelerated Prediction

One of the main unresolved concerns associated with amine-based CO₂ capture (CC) technology (https://climate.ec.europa.eu/eu-action/industrial-carbon-management/about-industrial-carbon-management_en) is the potential formation and release of nitrosamines (NSAs) and nitramines (NAs), compounds that are potentially carcinogenic. These substances may form in the atmosphere due to the degradation of volatile amines that inevitably escape from capture plants together with treated exhaust gases. Depending on the amines emitted, chemical reactions may occur in the presence of atmospheric oxidants and nitrogen oxides, leading to the formation of NSAs and NAs.

This project aims at the further development and validation of a physics- and chemistry-based model designed to evaluate atmospheric dispersion, chemical transformation, and deposition of substances emitted from CO₂ capture processes in large industrial and power generation plants. The model is developed at NILU and the University of Trento within the FuNitr project (Future Drinking Water Levels of Nitrosamines and Nitramines near a CO₂ Capture Plant), funded by the Research Council of Norway. It is based on a Lagrangian particle-based plume-in-grid approach known as the Volumetric Particle Approach (VPA), originally proposed by the PI (Cassiani, M., Bound-Layer Meteorology. 2013, 146, (2), 207-233). The VPA accurately and efficiently handles atmospheric dispersion, turbulent mixing, and nonlinear chemical reactions.

The PhD candidate will contribute to both the further development and the validation of the VPA model.

Model development:

- Advancing dry and wet deposition parameterizations.
- Enhancing three-dimensional wind-field reconstruction in complex terrain to better represent local flow conditions.
- Implementing automated coupling with a chemical kinetics pre-processor enabling flexible and scalable integration of evolving reaction mechanisms.
- Integrating a physically consistent online stack plume-rise module within the Lagrangian framework.

Model validation:

- Comparing VPA model results with experimental data collected during dedicated aerial measurement campaigns planned within the FuNitr project. These unique measurements will be based on PTR-MS-TOF instruments mounted on helicopters. The campaigns will be carried out in collaboration with the University of Oslo in 2026 and 2027, and the resulting datasets will be made available to the PhD candidate for analysis and model evaluation.
- Benchmarking VPA results against alternative computational fluid dynamics models (CFD) based on high-resolution Large Eddy Simulation (LES) of turbulence. The LES simulations will be carried out on massively parallel high-performance computing (HPC) platforms. Although high-resolution LES models are computationally demanding and not suitable for operational applications, they rely on fewer assumptions regarding atmospheric mixing processes and therefore provide a valuable reference for validating specific aspects of the VPA framework.

AI-based accelerated modelling

By generating an extensive database of simulations covering a wide range of initial and boundary conditions and model parameter variability, an AI-based surrogate modelling approach will be explored to reproduce VPA model outputs at a fraction of the computational cost.

The PhD programme will include a research stay of approximately six months at the NILU research institute in Kjeller, Norway (Oslo area).

The project is expected to result in at least three publications in international peer-reviewed journals: 1. A paper describing the improved model developments. 2. A paper presenting the comprehensive model validation. 3. A paper on the AI-based accelerated modelling approach.

We are looking for a highly motivated candidate with a background in physics, applied mathematics, environmental and atmospheric sciences, mechanical, environmental or chemical engineering.

The ideal candidate should have a solid knowledge of physics (ideally fluid dynamics), numerical methods, and computer programming (the core model codes are written in Fortran; AI components will likely utilize Python).