ETH zürich

Lagrangian transport modelling

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BASEMENT Users Meeting 2024

Outline

- Lagrangian modelling: motivation & background
- Applications: focus on eco-hydraulics
- Implementation within BASEMENT
- Modelling showcase

Introduction and Motivation

- Transport processes in rivers include
  - Pollutant
  - Sediments
  - Plastic
  - Organic material
  - Wood
  - …

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https://x.com/IEEPennState/status/1704532118808752350?s=20
https://x.com/LeicesterGeog/status/1269915845893017600?s=20

Introduction and Motivation

Understanding mechanism of transport (and deposition) is key to quantify **fluxes** and **budgets**

Large wood dynamics

Organism migration

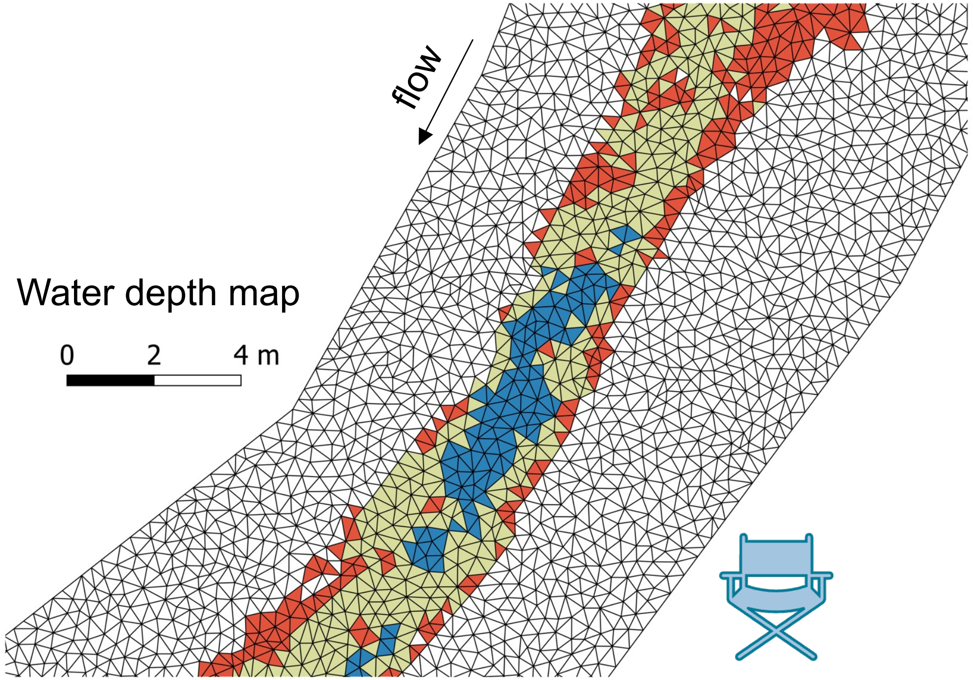
Eulerian vs Lagrangian approaches

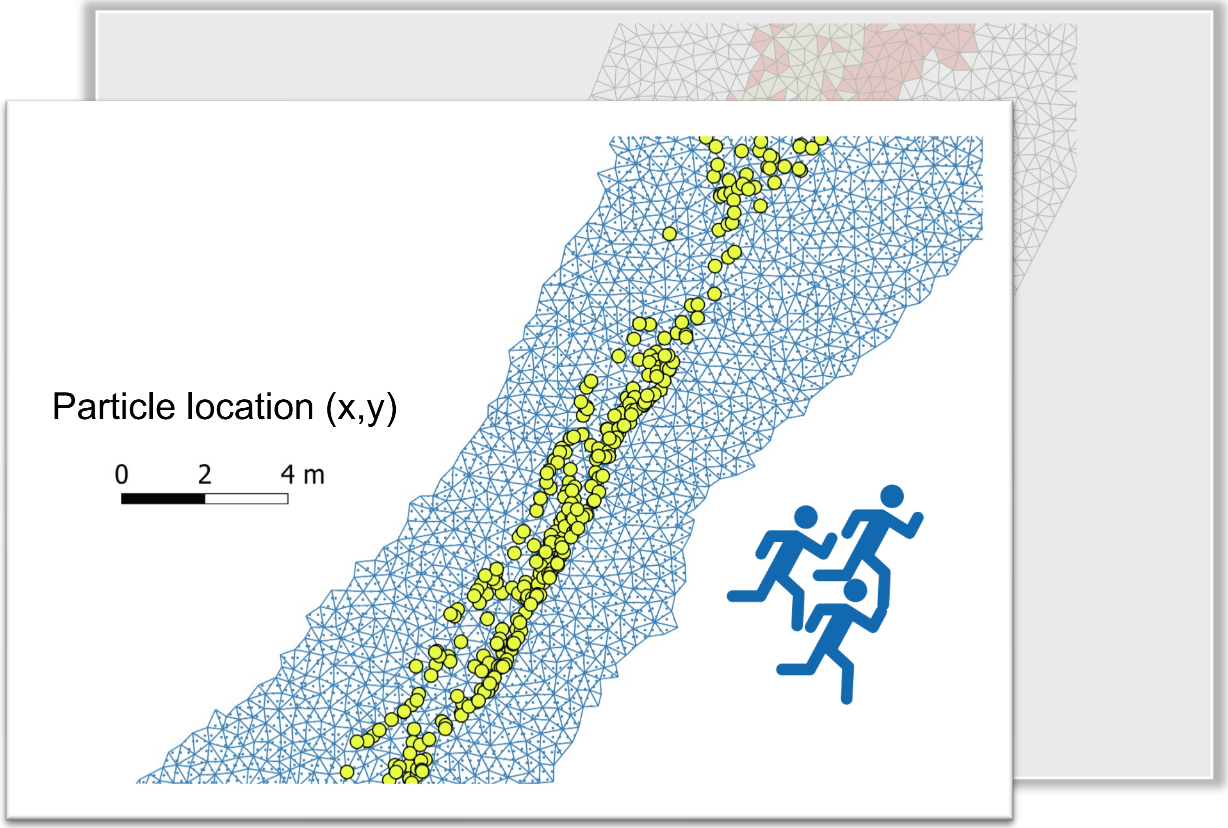
Eulerian approach

→ Flow field cell-wise

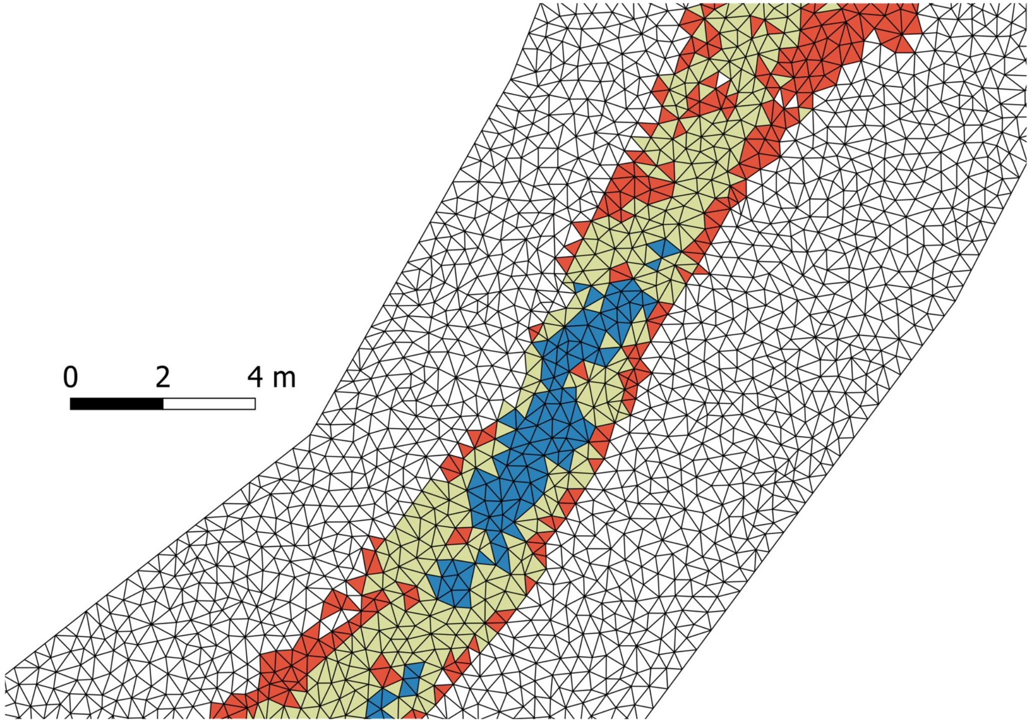
Lagrangian approach

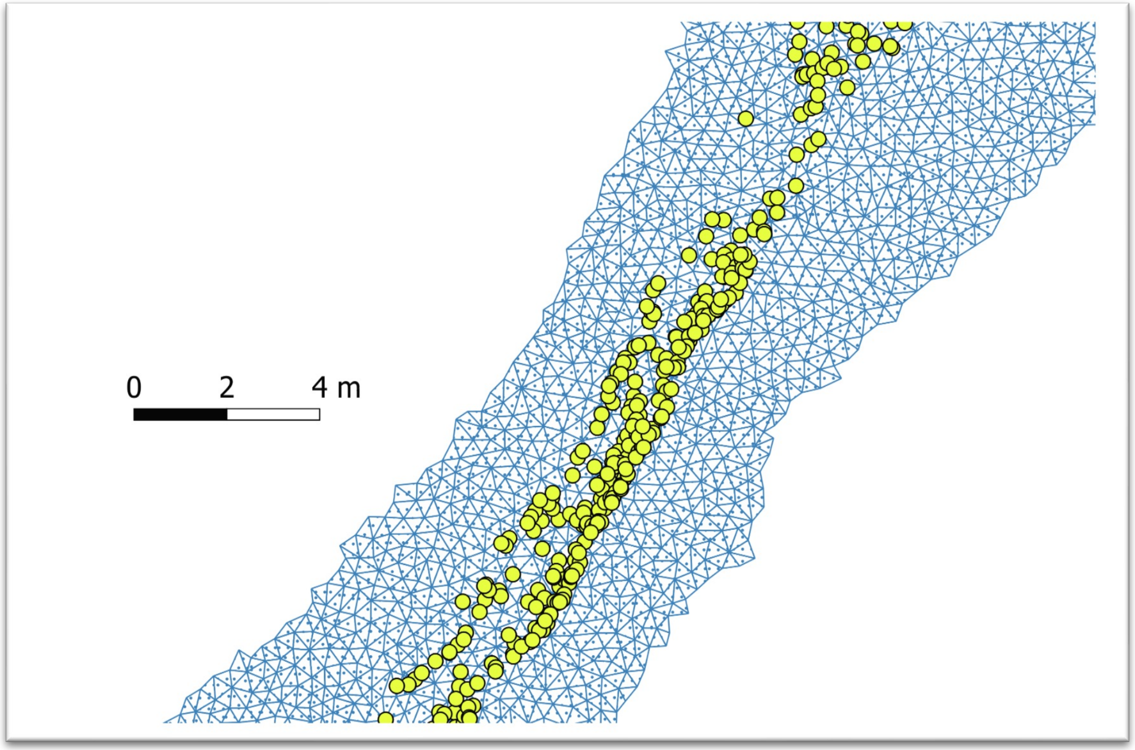
→ single particles motion through a flow field





Eulerian vs Lagrangian approaches





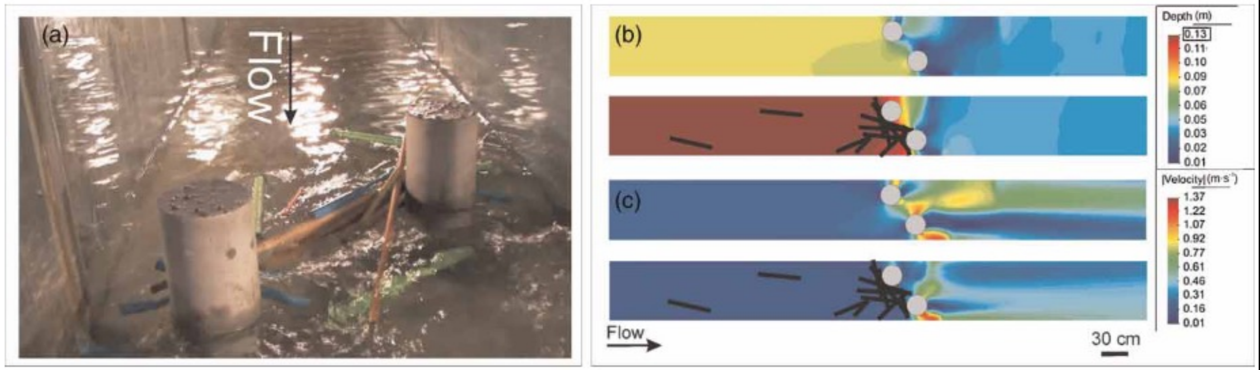
- Calculate budget and fluxes ✓
- Spatially-explicit variables ✓

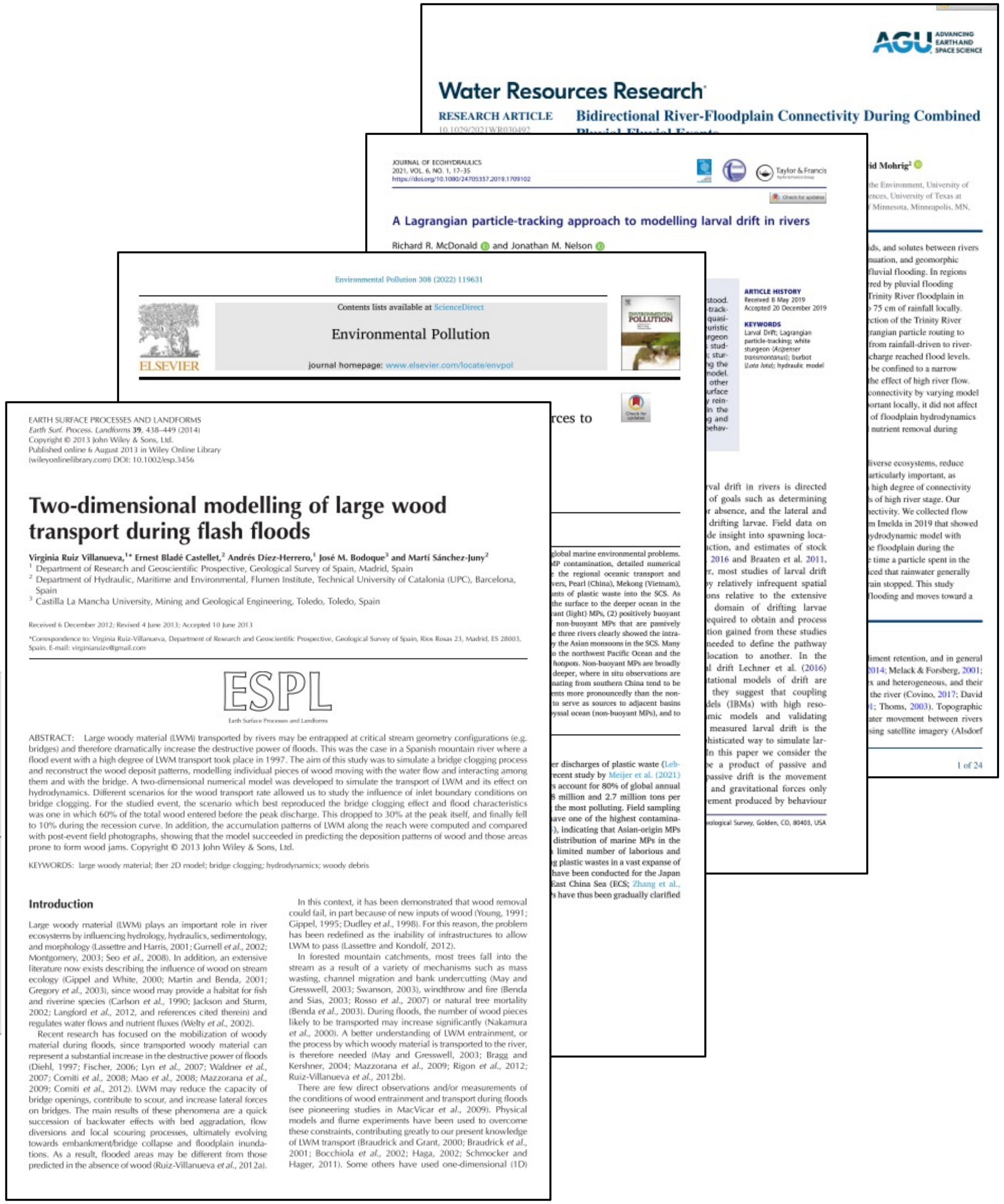
→ ✗

- Residence times
- Calculate trajectories
  – 3D motion of particle with interactions

Some applications

- Use of Lagrangian approaches find applications in
  - River-floodplain connectivity
  - Organism (e.g. larval) drift
  - Macro- and micro-plastic transport
  - Wood transport and accumulation





Plant dispersal by water

- Key mechanism for maintaining **plant biodiversity** in freshwater systems
- It allows plant to colonize new areas and connect distant communities

- Seeds as of *Tamarix* and *Salix* are adapted to be transported in water

They can be modelled as tracer or very small particles

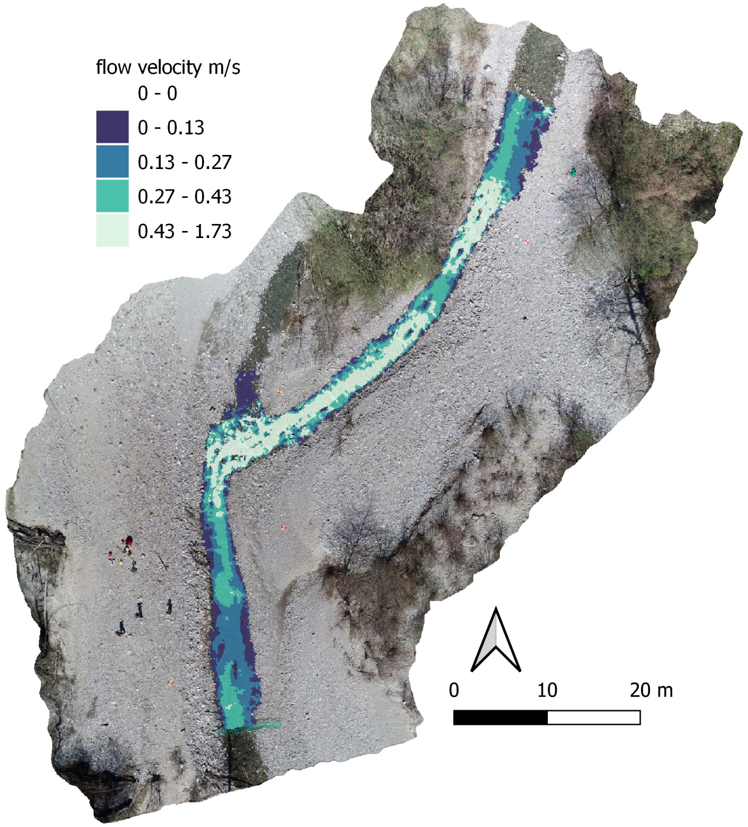
Floodpain vegetation at Moesa river, Graubünden (photo: Sabine F.)

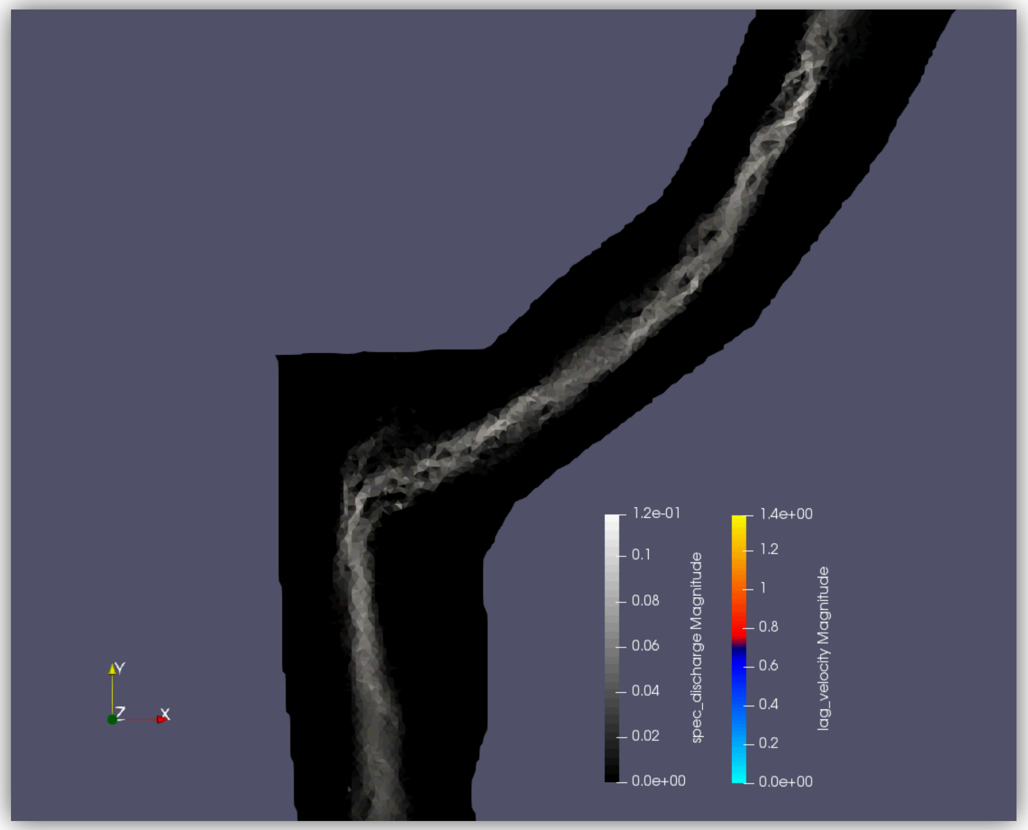
Modelling plant seed dispersal

BASEMENT v3.2
(Eulerian)

+

Lagrangian module





Implementation in BASEMENT and showcase

Daniel A. S. Conde

Implementation in BASEMENT

- Governing equations:

  - **One-way coupling**: size is low enough to disregard momentum transfers between them and the surrounding fluid

  - **Tracer approach**: particles advected according to the fluid velocity field (2DH)

$$\dot{\vec{x}}_p = \vec{u}_f$$

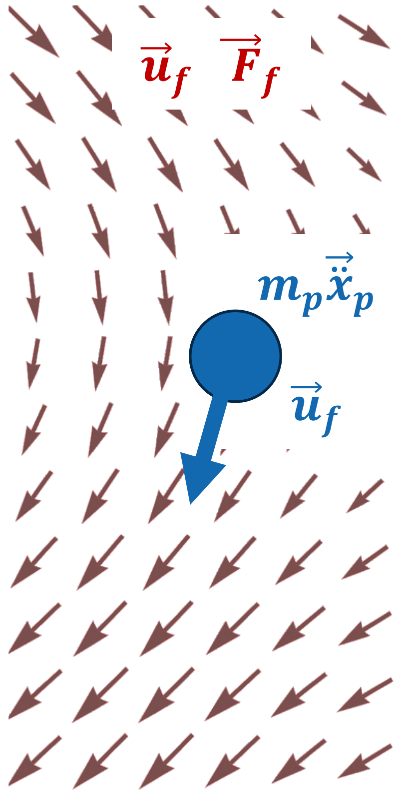
Lagrangian Eulerian

  - **Particle approach**: particles with momentum conservation (2DH + 1DV)

$$m_p \ddot{\vec{x}}_p = \vec{F}_{p,g} + \vec{F}_f$$

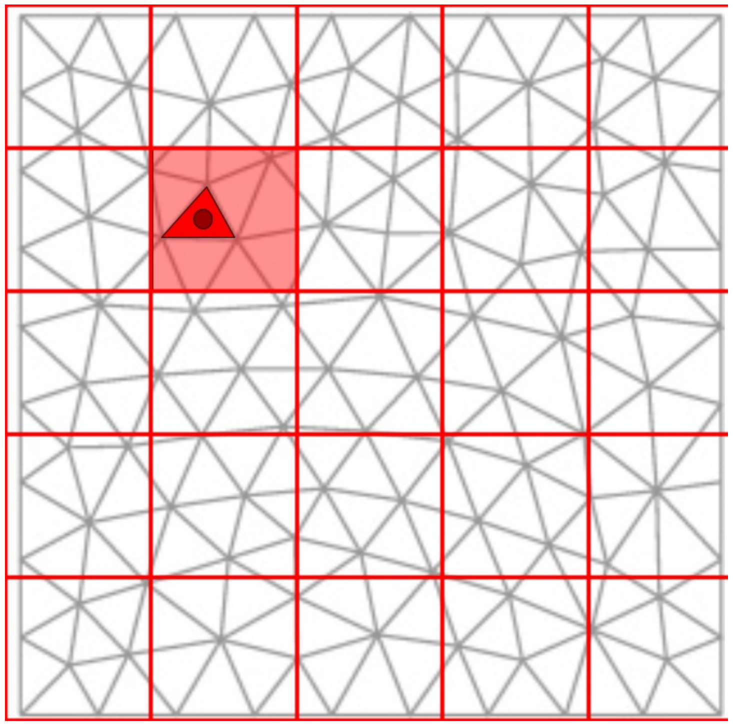
  - **Vertical motion**: computed from settling and suspension closures (1DV)

$$\dot{z}_p = w_s + r_s$$



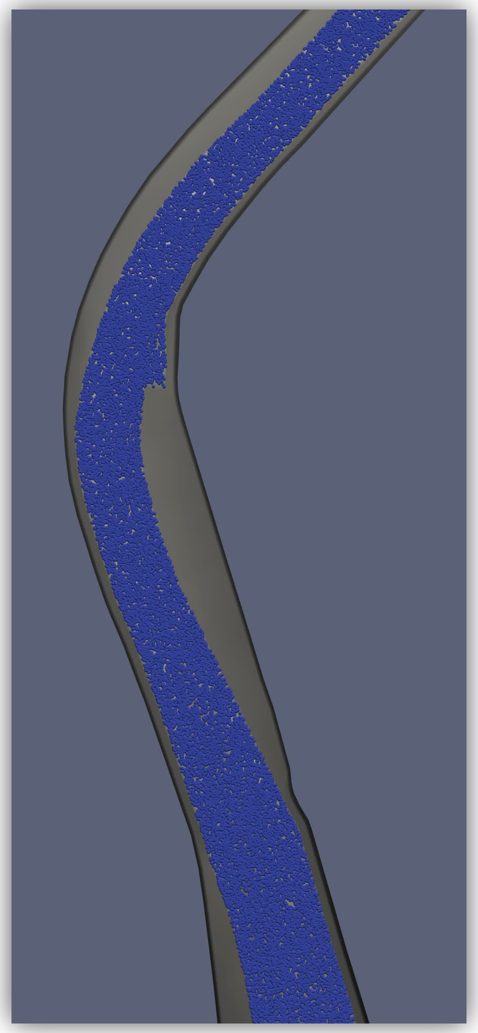
Implementation in BASEMENT

- Technical implementation:
  - BASEMENT is an **unstructured mesh solver**: including **meshless** methods requires considerable adaptation of the existing code base
  - A **structured 'virtual' mesh** is used in order to index the underlying triangular mesh, acting as a **proxy** between the **Lagrangian kernels** and **Eulerian data**
  - Lagrangian **particle position** can be **directly** mapped to the structured mesh, then a geometrical search algorithm probes the **triangular cell** for flow data



Implementation in BASEMENT

- Technical implementation:
  - **Fully parallelized** in all backends of BMv3
  - **Low memory requirement**, thousands of particles can be used with <1GB of additional memory
  - **Low computational overhead**, less than 25% increase in CPU simulations and less than 20% increase for GPU (comparable number of particles and cells)
  - **Dedicated output** (xdmf) for particle-based results



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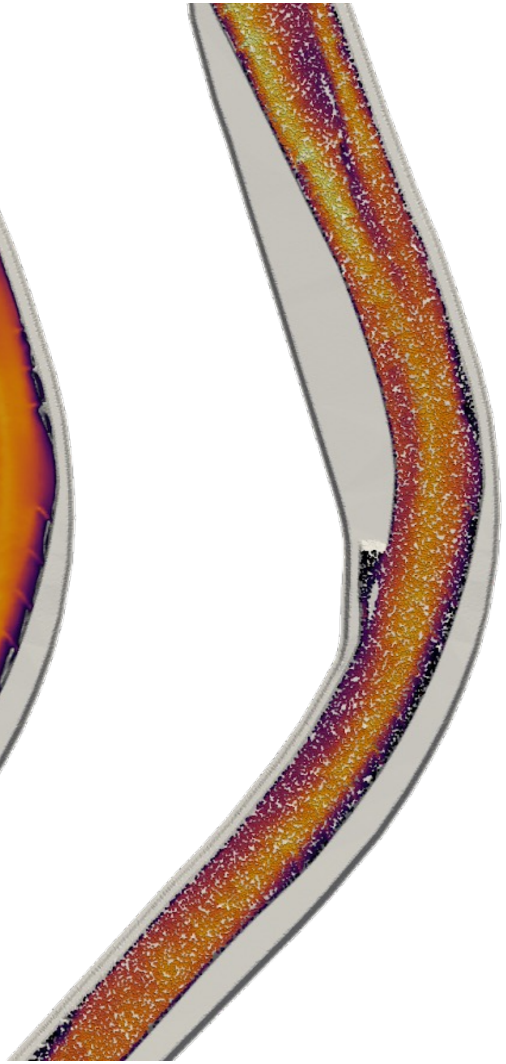
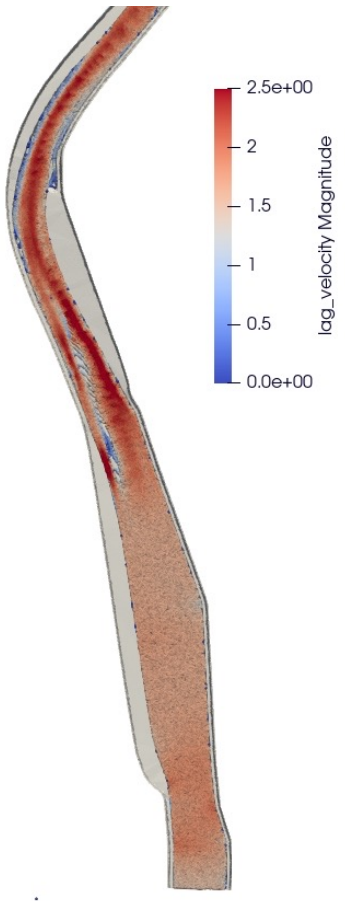
Eulerian velocity field



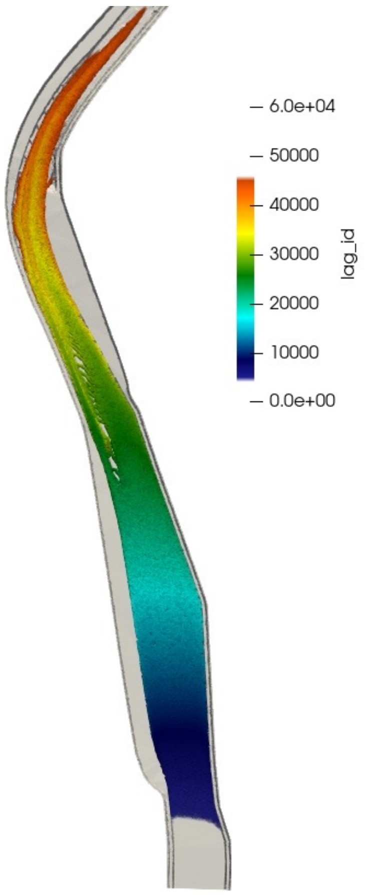
Lagrangian velocity field

Alpine Rhine case

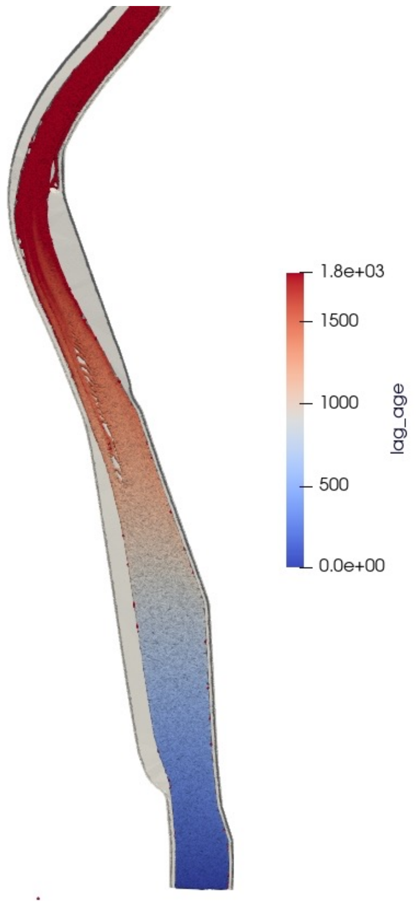
Alpine Rhine case – output quantities



particle velocity (m/s)



unique particle ID



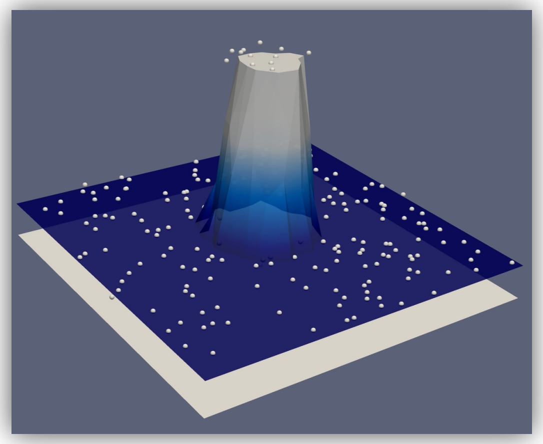
particle age (s)
since insertion

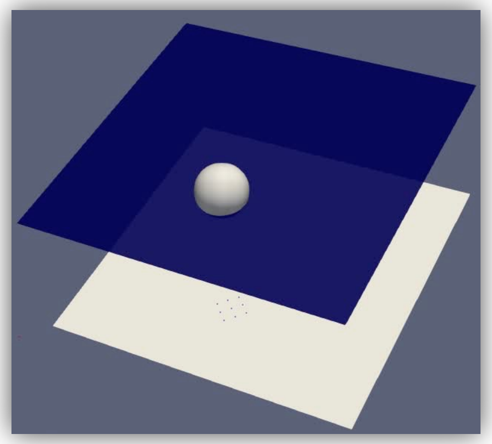
Conclusion and outlook

- Combination of **Eulerian and Lagrangian** approaches
- Generalizable for **several particle types**
- **Low computational overhead**, normally less than 10% increase in compute time
- **Dedicated output** format for particles (e.g. in ParaView)

- The implementation of a Lagrangian framework in BMv3 will bring **advanced capabilities for fluvial debris modelling**:

small particles
one-way coupling





large debris
two-way coupling
(early tests)

Thank you for your attention!

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