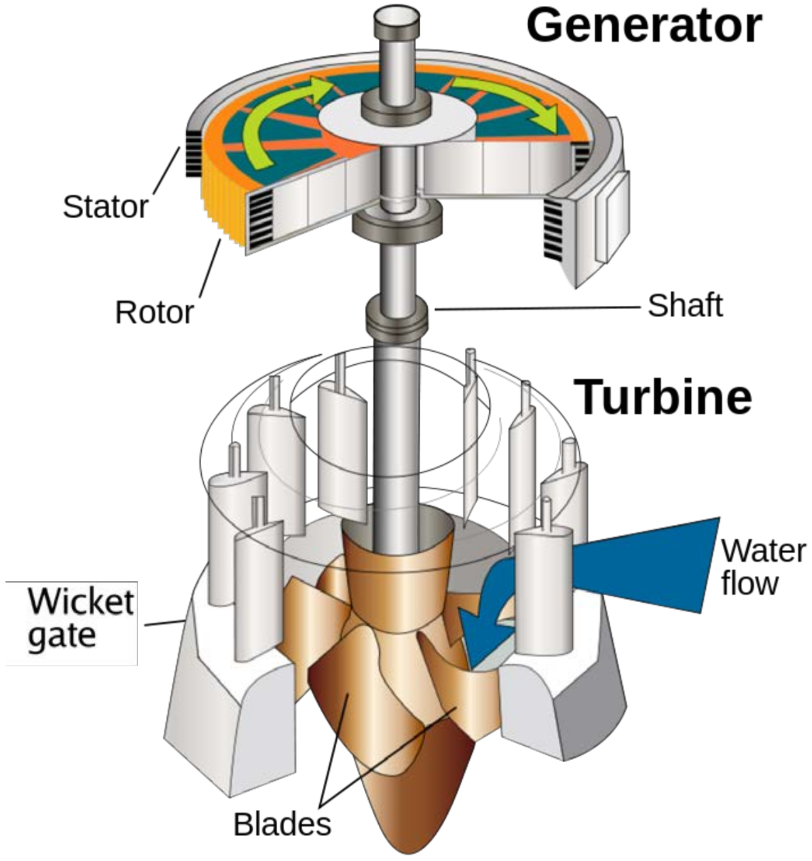
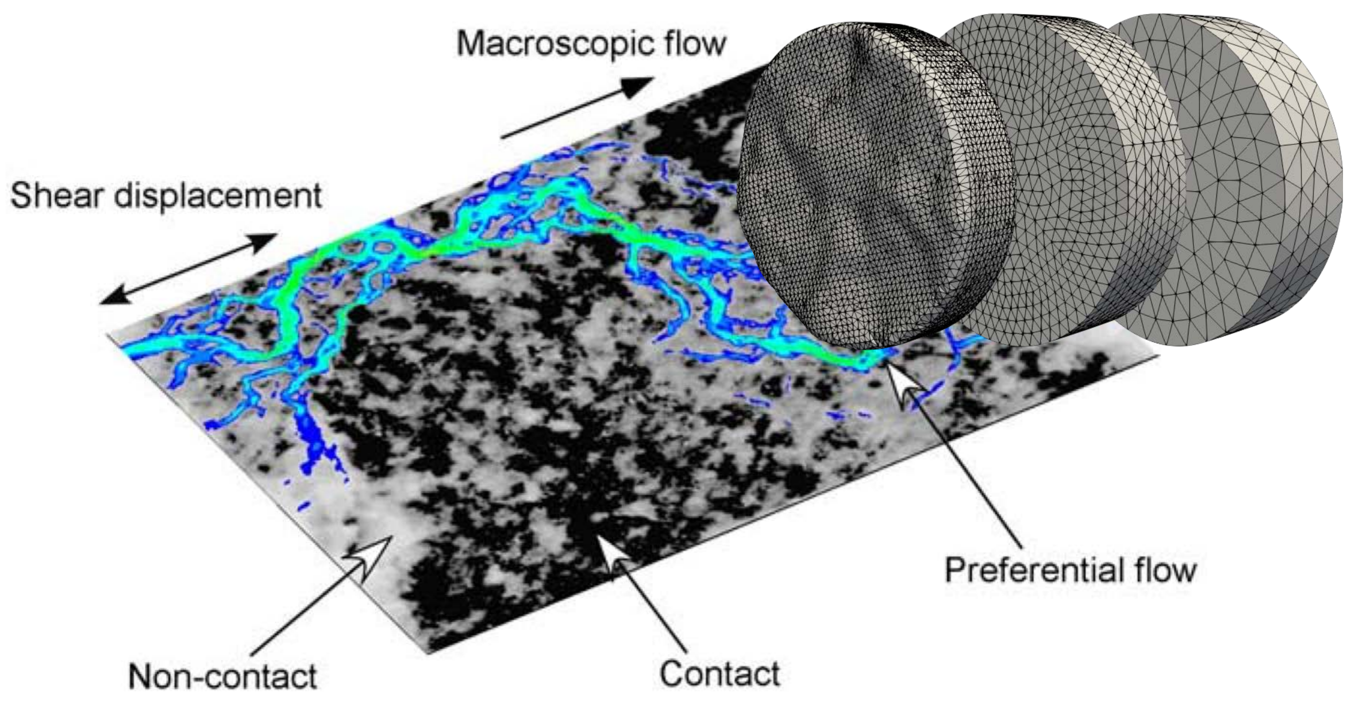
T 3.2 Computational Energy Innovation

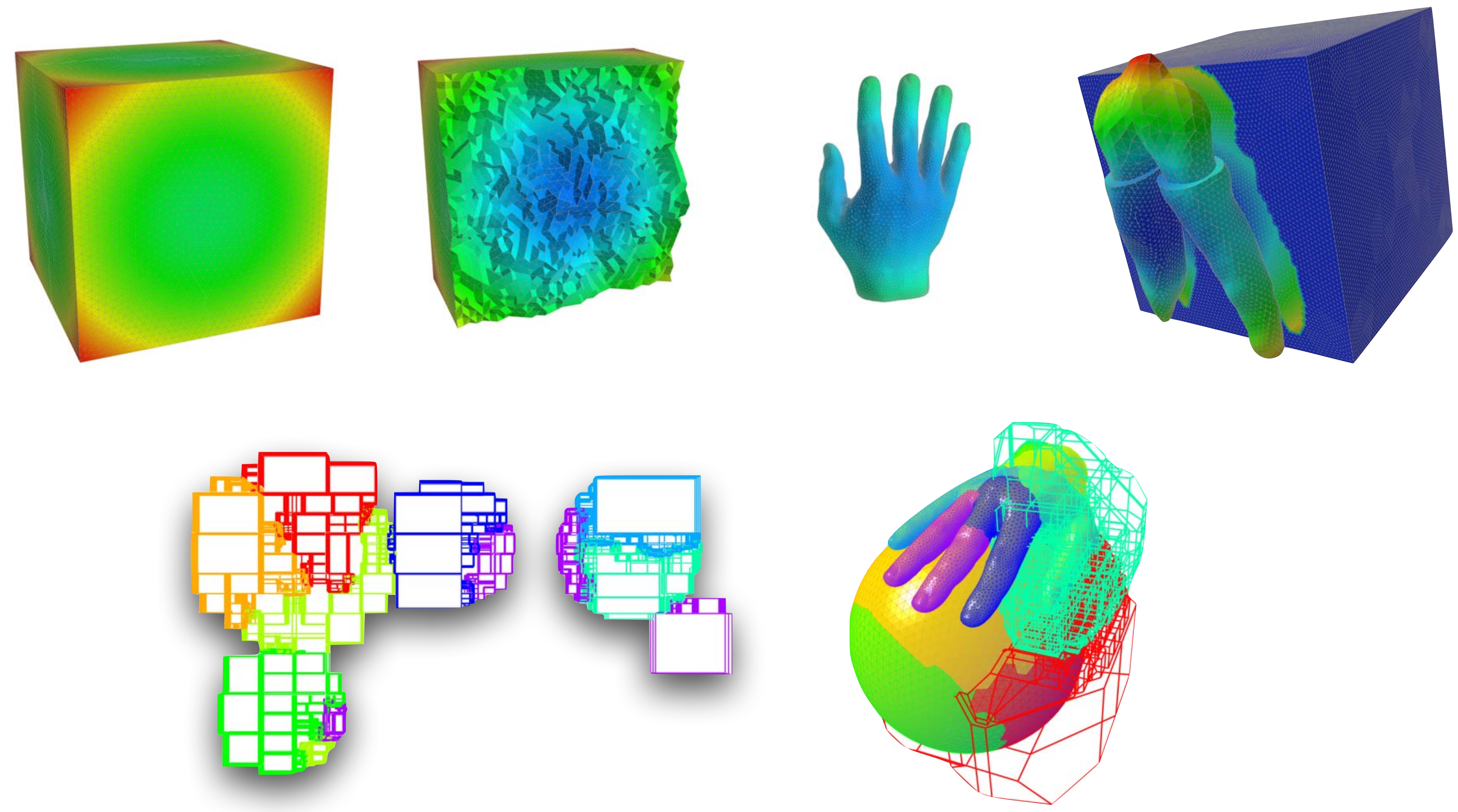


Water turbines



Computational Geophysics

Information transfer algorithm



- **L^2—transfer** between unstructured finite element meshes
- Arbirarily distributed
- https://bitbucket.org/zulianp/par_moonolith

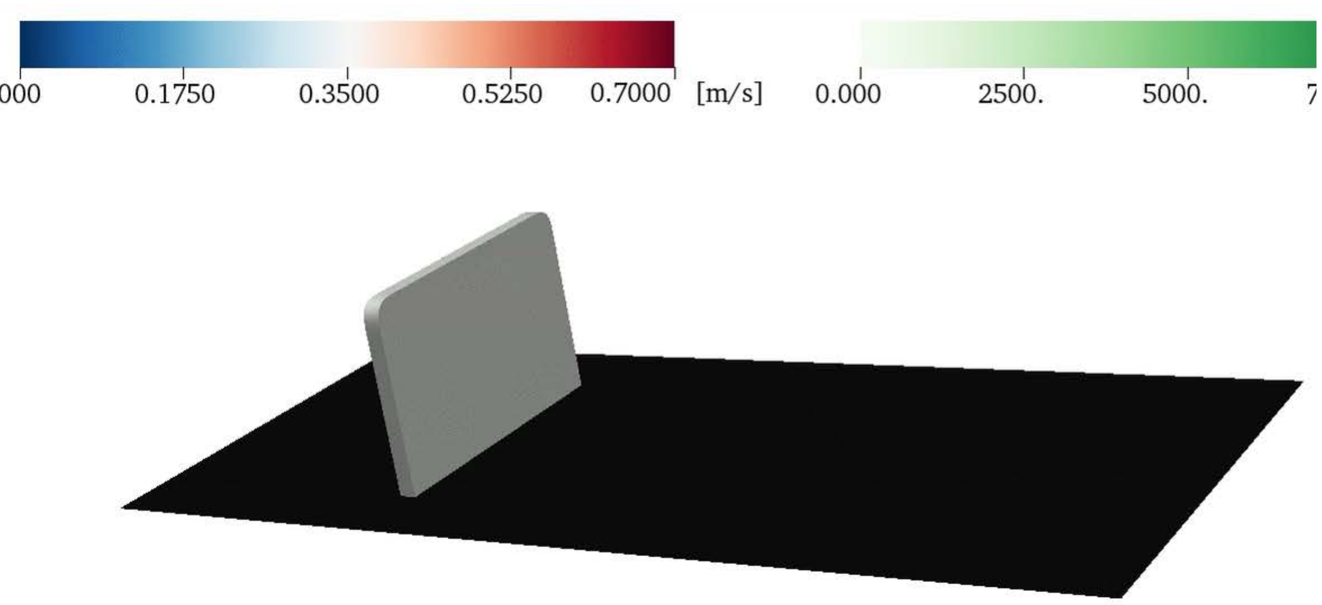
Embedded boundary method

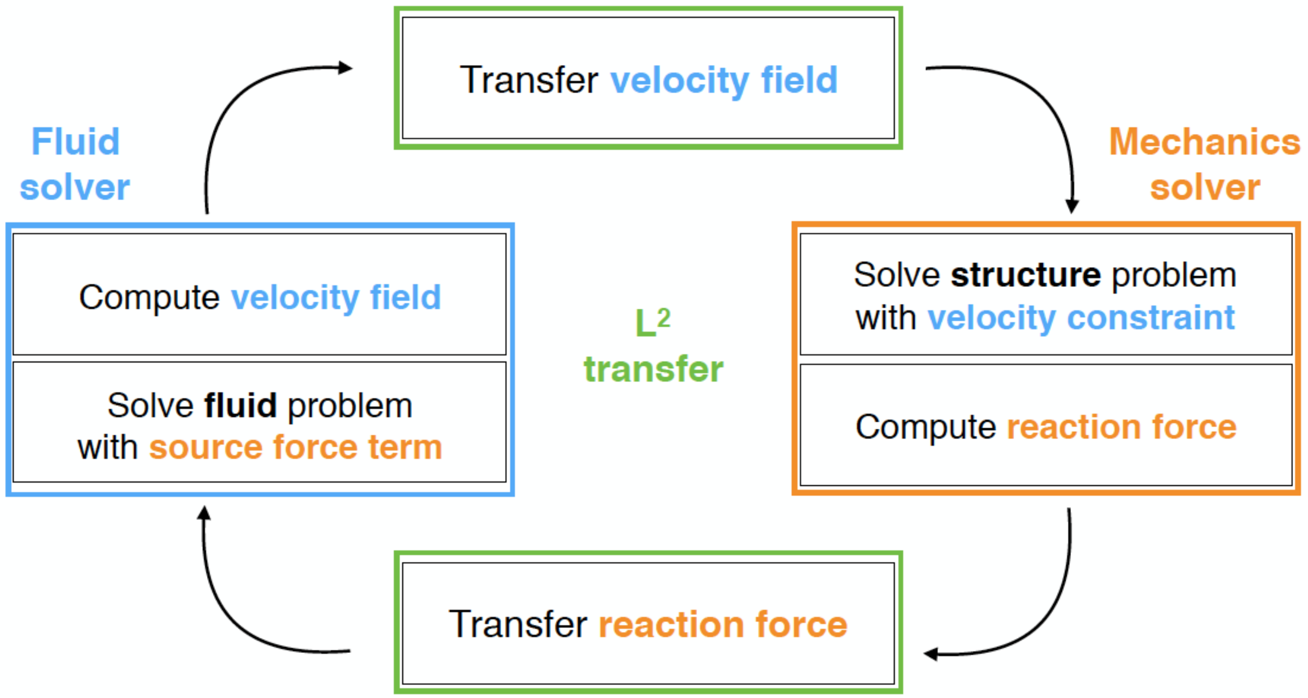
- Variational the transfer of the data

Assignment of a partition of unity to each point of the fluid grid

The solid motion is modelled by solving the elastodynamics equations in a FE framework

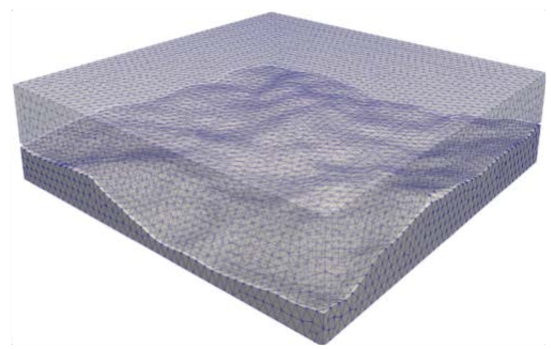
High-order FD Navier-Stokes solver for the numerical simulation of laminar, transitional and turbulent flows

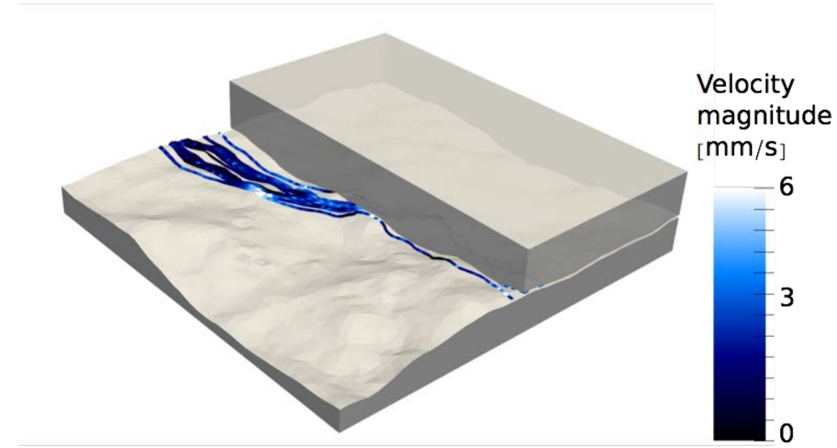


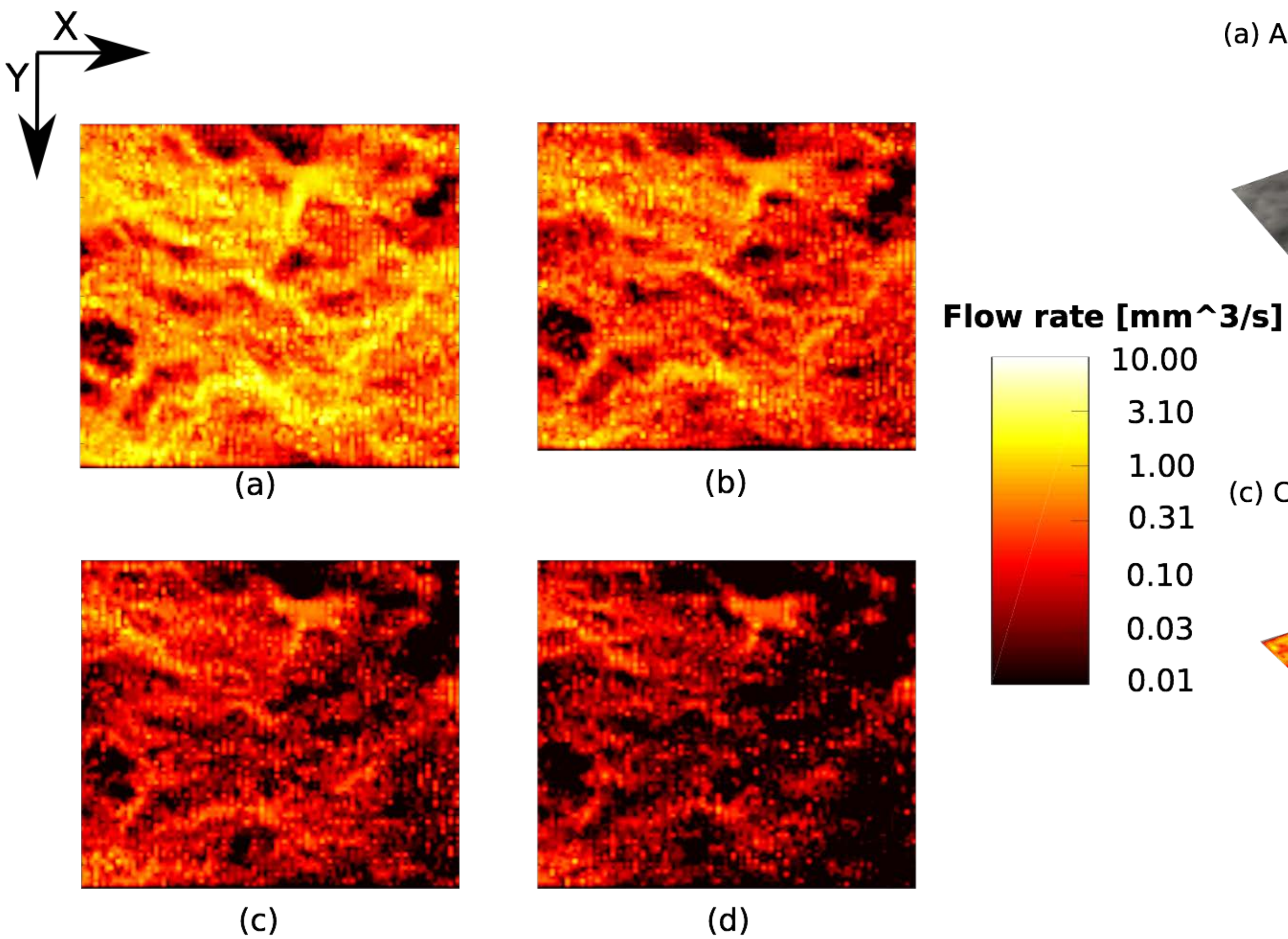


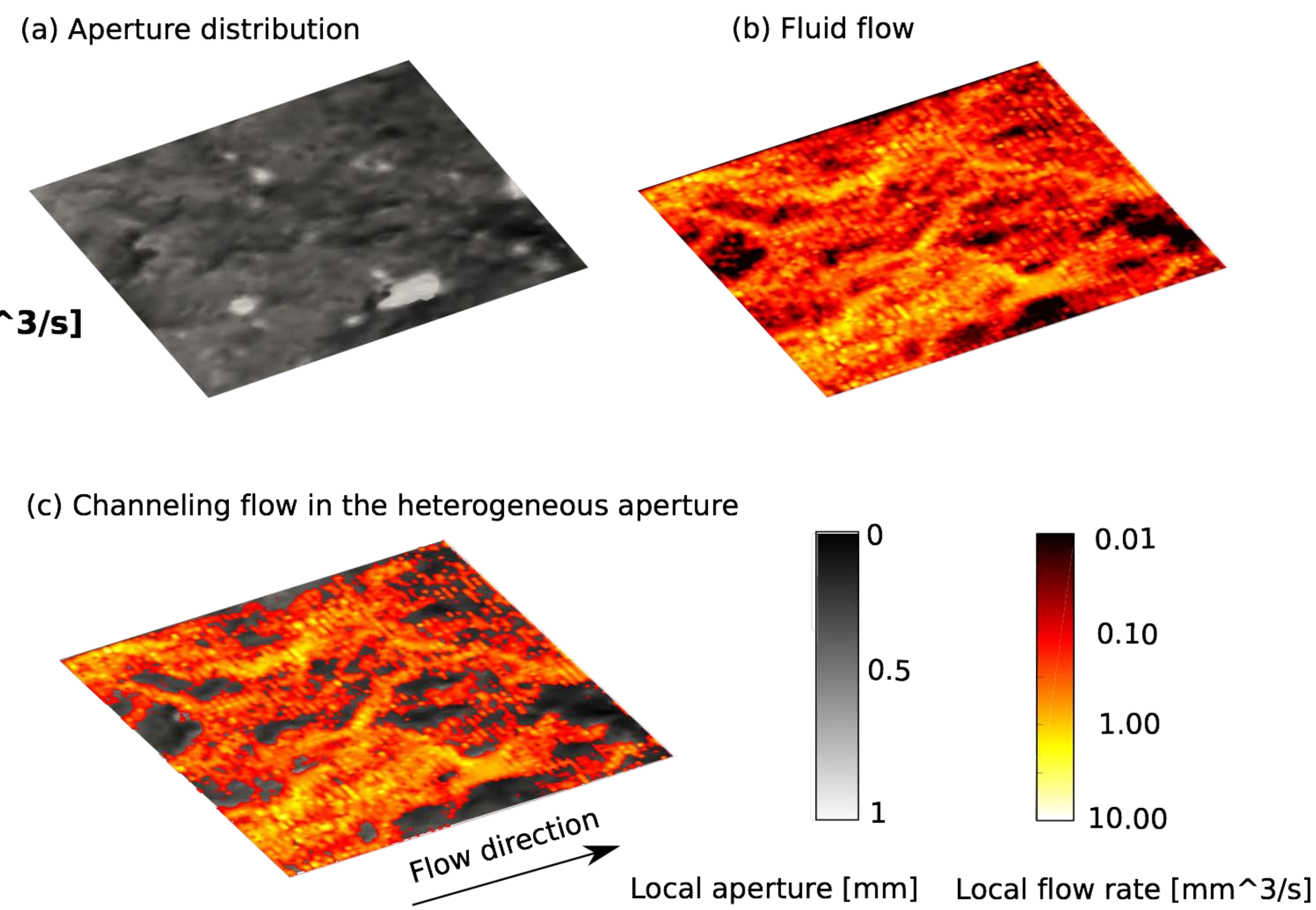
Maria GC Nestola, Barna Becseck, Hadi Zolfaghari Patrick Zulian, Dario De Marinis, Dominik Obrist, Rolf Krause

FSI in rough rock fractures





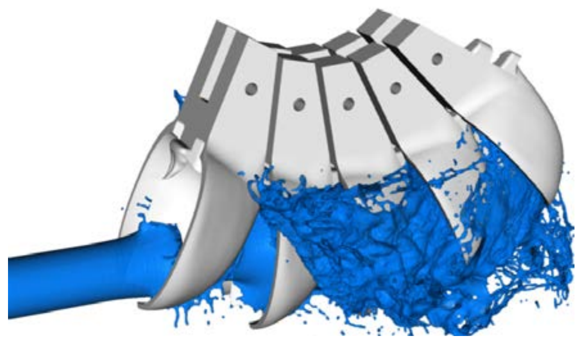




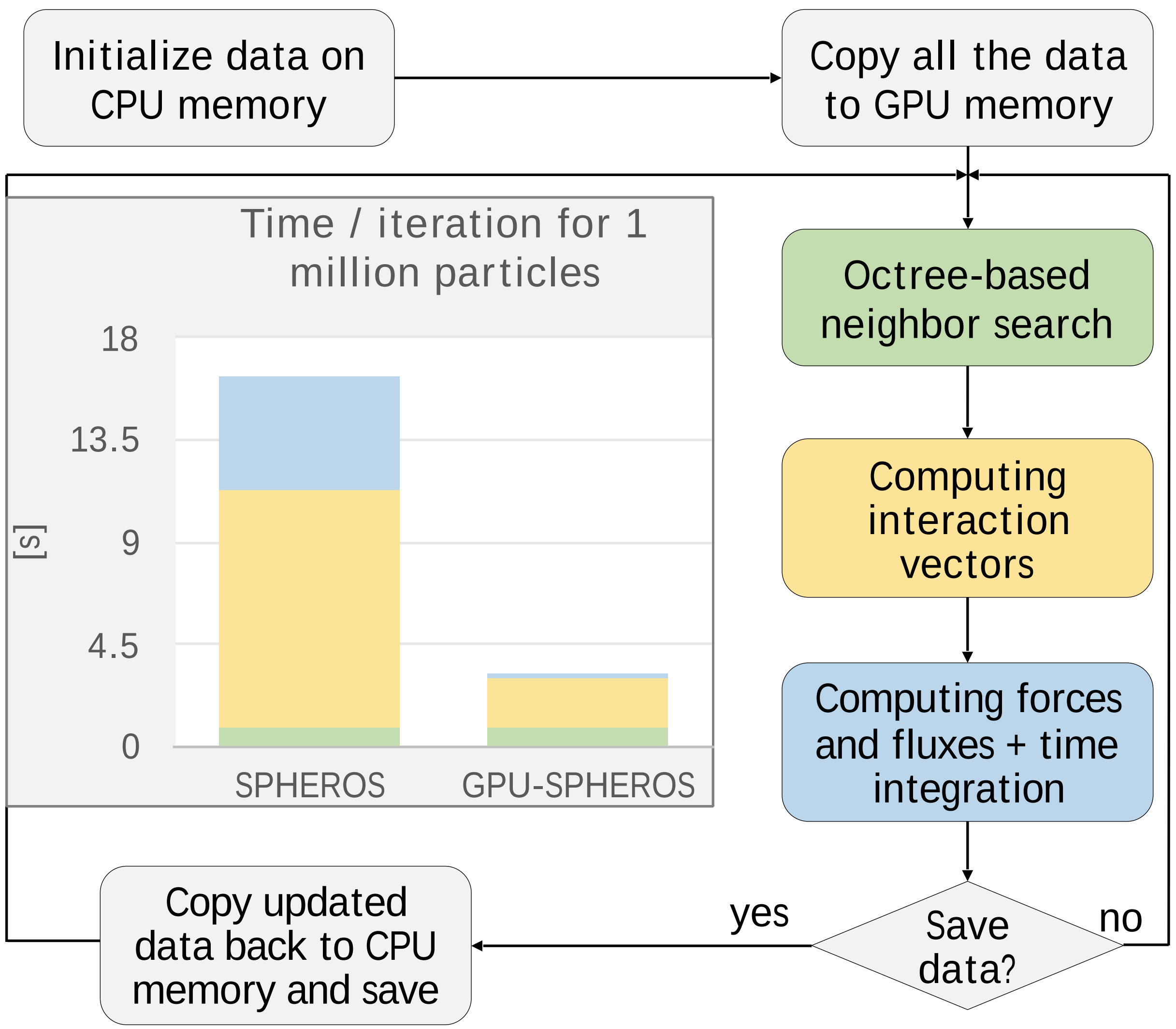
A. Numerical simulation of silt laden flow erosion

SCCER SoE

Pr. F. Avellan, EPFL



CTI GPU-SPHEROS: GPU



- Project : 3 years / start 7. 2015
- Status : GPU-SPHEROS (on single GPU) 6x faster than SPHEROS (on node with 2 CPUs). GPU-SPHEROS with Adaptive Domain Decomposition validated on up to 256 Tesla P100 GPUs in parallel. For simulation of a large scale problem, a Production Project proposal has been submitted to CSCS.
- Academic partner : EPFL LMH
- Industrial partners : Alstom Renewable CH
- Funding : KTI
- TRL : 4

LMH Laboratory for Hydraulic Machines

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

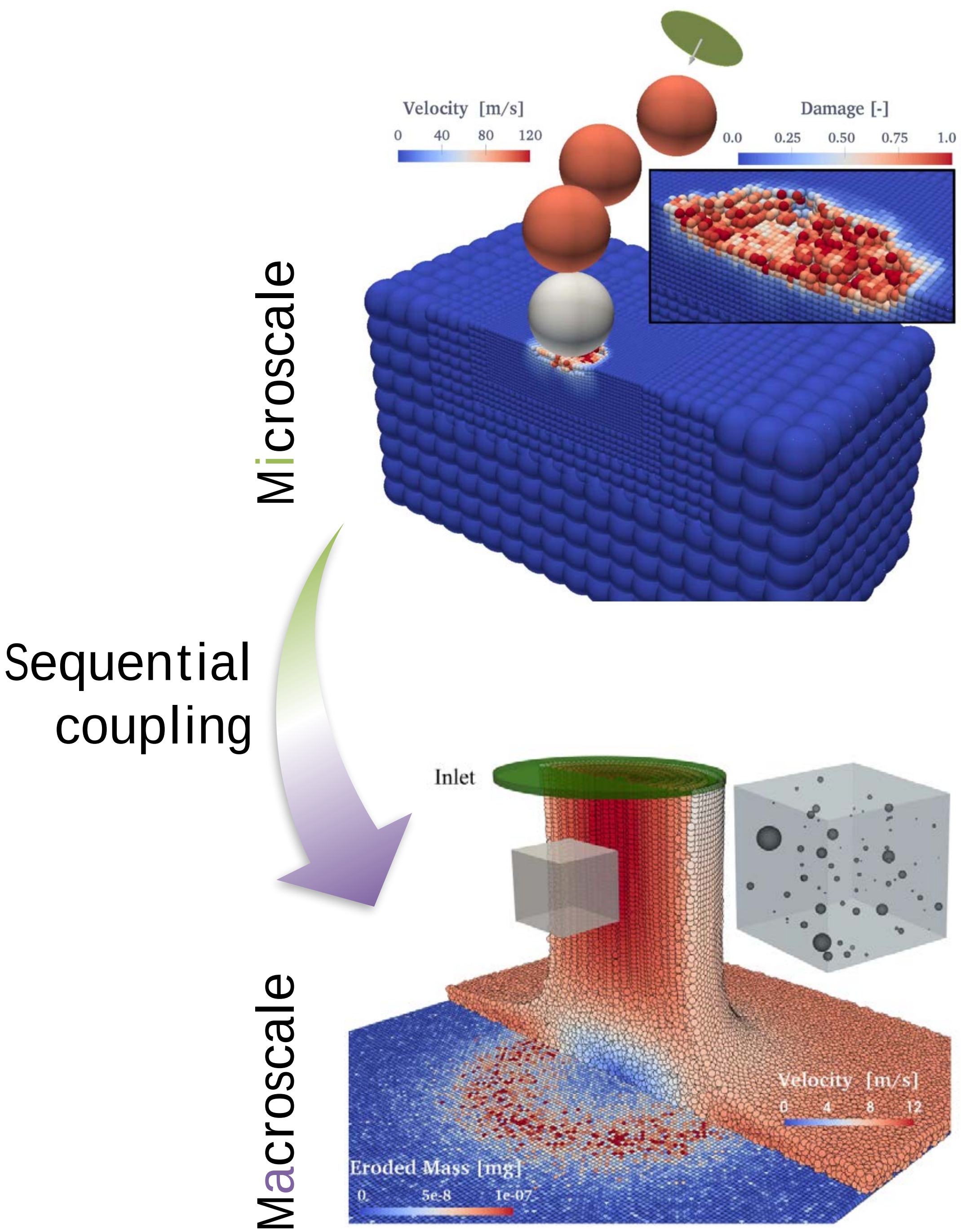
KTI/CTI DIE FÖRDERAGENTUR FÜR INNOVATION L'AGENCE POUR LA PROMOTION DE L'INNOVATION L'AGENZIA PER LA PROMOZIONE DELL'INNOVAZIONE THE INNOVATION PROMOTION AGENCY

A. Numerical simulation of silt laden flow erosion

SCCER SoE

Pr. F. Avellan, EPFL

CTI GPU-SPHEROS: erosion



- Project : 3 years / start 7. 2015
- Status : Implementation of physical models: elasto-plastic material, damage, thermoplastic and Hertz contact. Multiscale model for sediment impact erosion simulation validated for flat copper plate. Porting of the models to GPU in progress.
- Academic partner : EPFL LMH
- Industrial partners : Alstom Renewable CH
- Funding : CTI
- TRL : 4

LMH Laboratory for Hydraulic Machines

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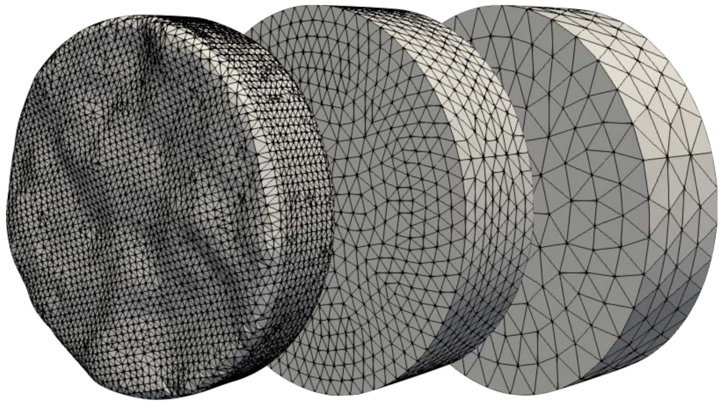
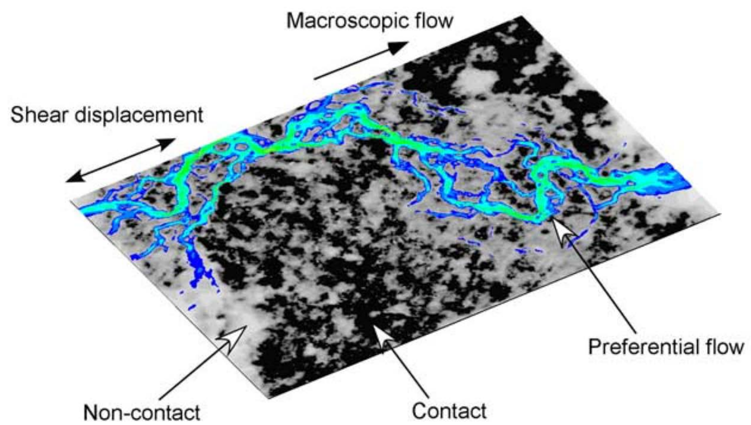
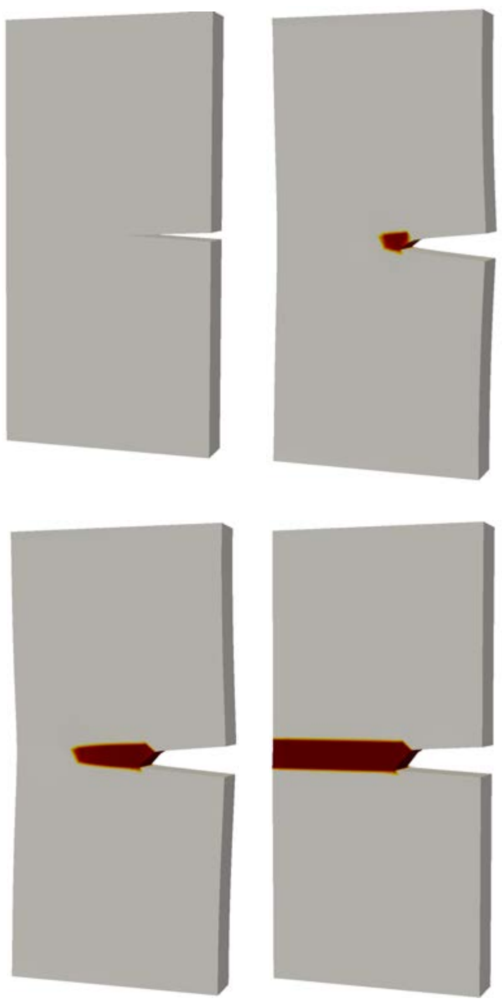
THE INNOVATION PROMOTION AGENCY

Multigrid solvers for geophysics problems







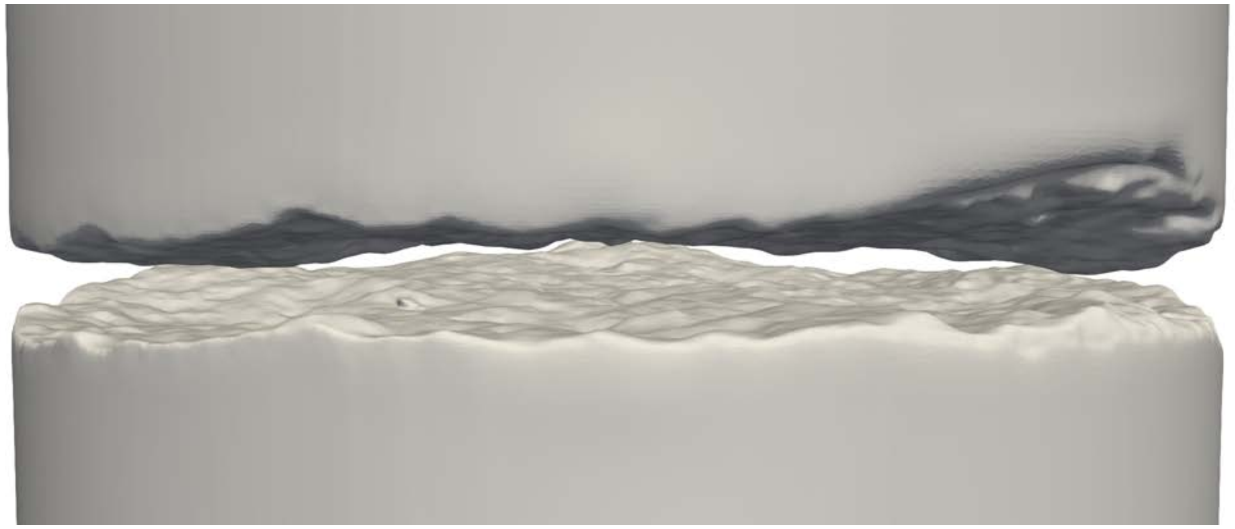
Multigrid solver for **Contact between fracture rocks**
(C. Von Planta)

Multigrid solver for **crack simulations** with XFEM[1]
(H. Kothari)

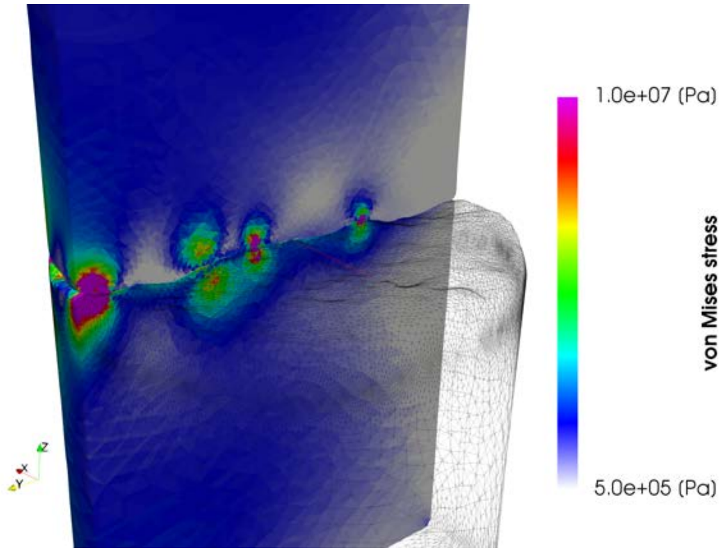
Multigrid solver for **Phase-field method**[2]
(A. Kopaničáková)

Literature: **1** Z. Goangseup, and T. Belytschko, 2003.
2 C. Miehe, F. Welschinger, and M. Hofacker, 2010.

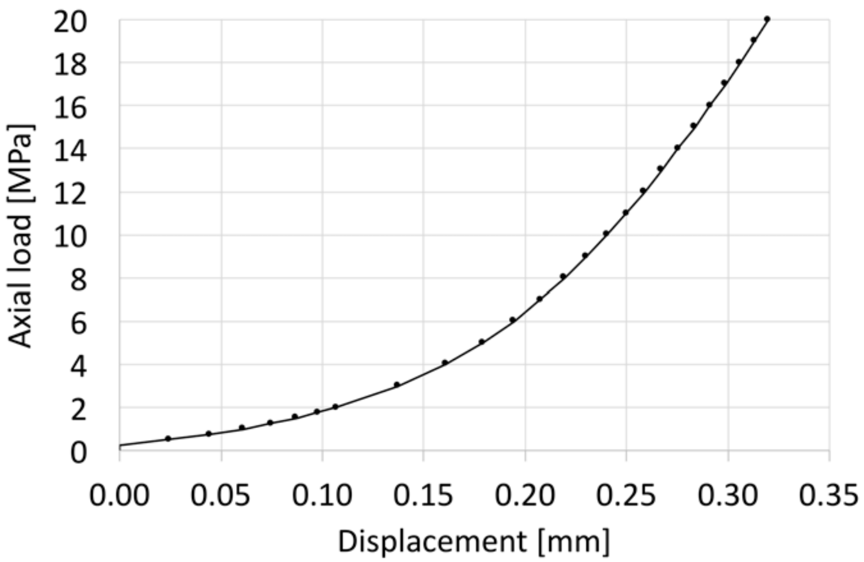
Contact between rough fractures



- Highly heterogenous aperture field
- Two-body problem
- Nonlinear problem
- Non-matching surface meshes



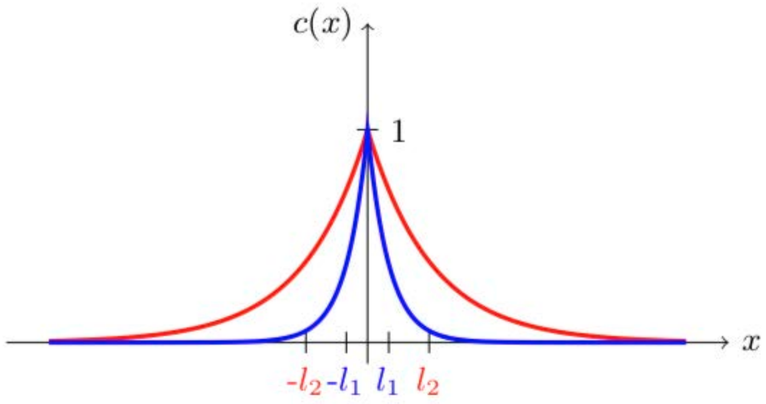
Induced internal stresses



Loading curve

Solution of contact problems between rough body surfaces with non matching meshes using a parallel mortar method,
Cyrill von Planta, Daniel Vogler, Patrick Zulian, Martin O. Saar, Rolf Krause, 2018, submitted

Phase Field Examples

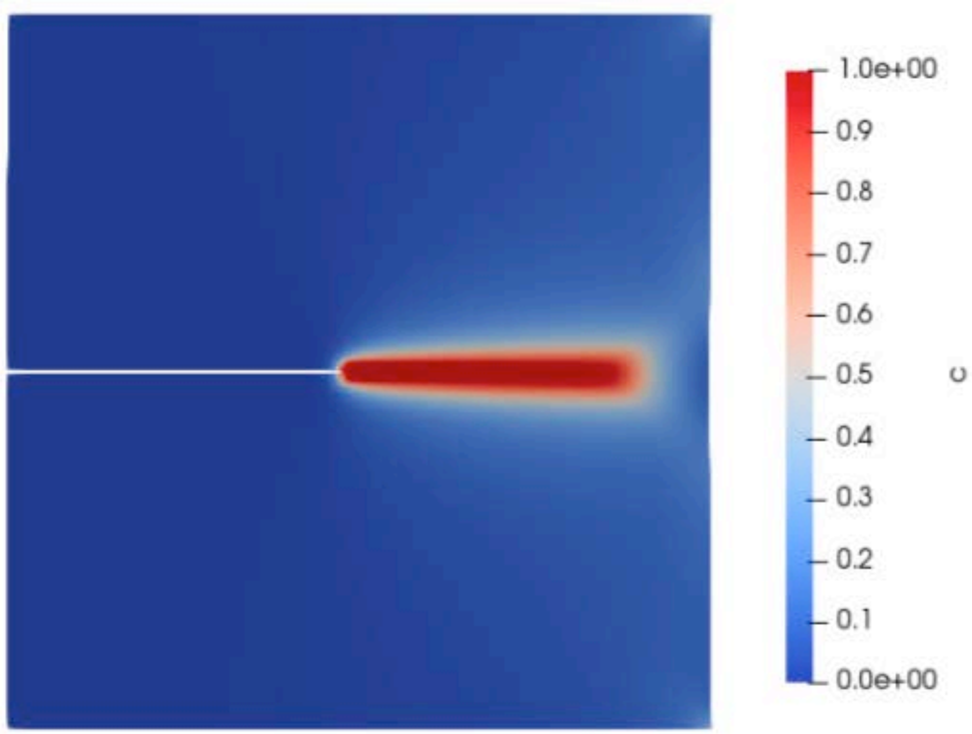


Phase field parameter:

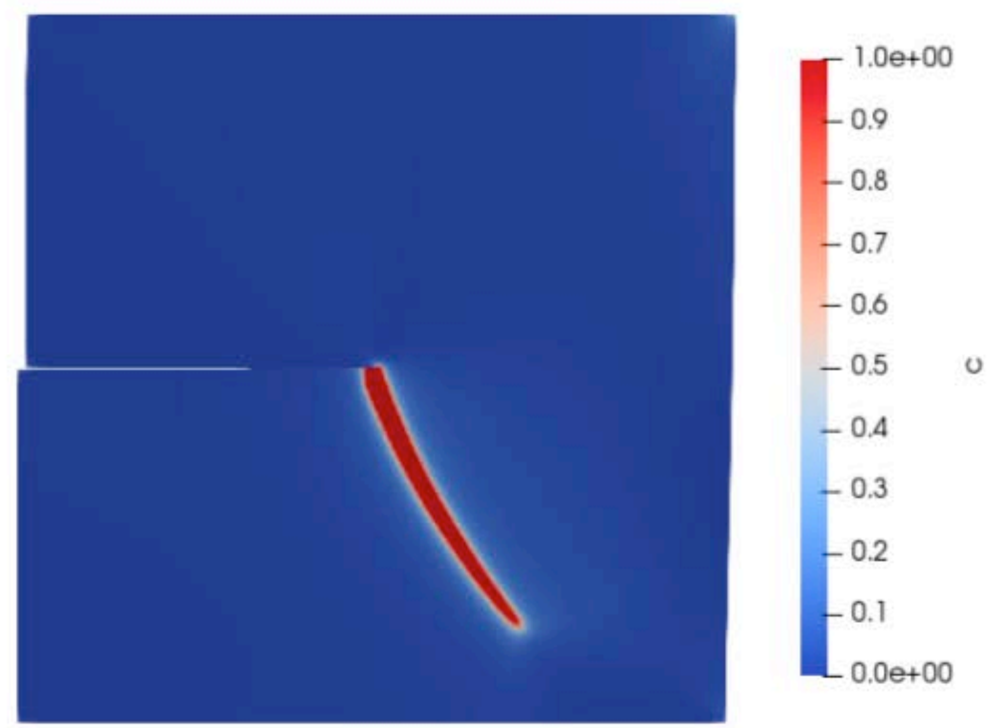
$$c(\boldsymbol{x}, t) = e^{-|\boldsymbol{x}|/l}$$

Energy formulation:

$$\Psi(\boldsymbol{u}, c) = \int_\Omega (((1-c)^2 + k)\Psi^+(\boldsymbol{u}) + \Psi^-(\boldsymbol{u})\, d\Omega) + \int_\Omega G_c \left(\frac{1}{2l} c^2 + \frac{l}{2} \mid \nabla c \mid^2 \right) d\Omega$$



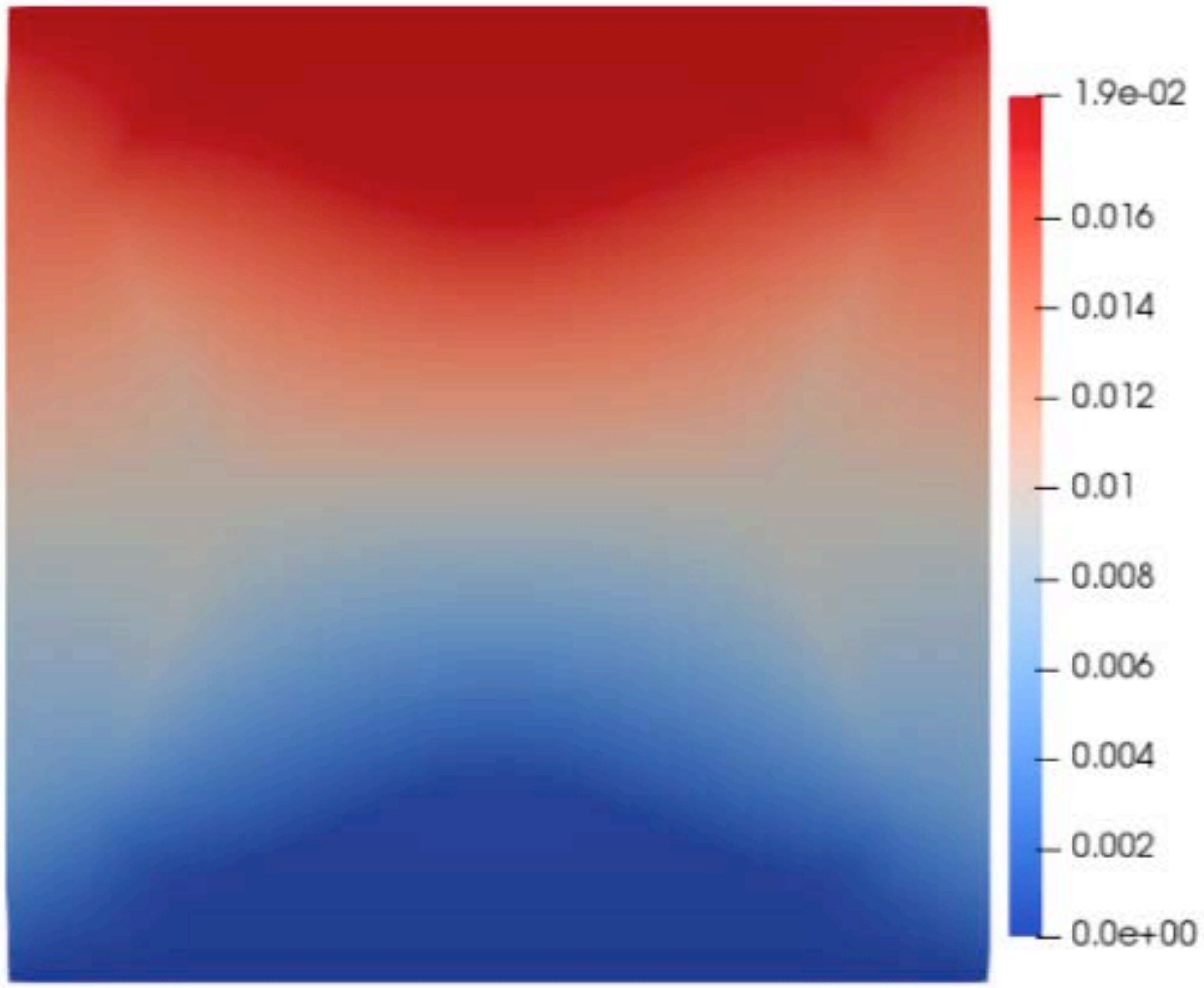
Fracture Mode 1



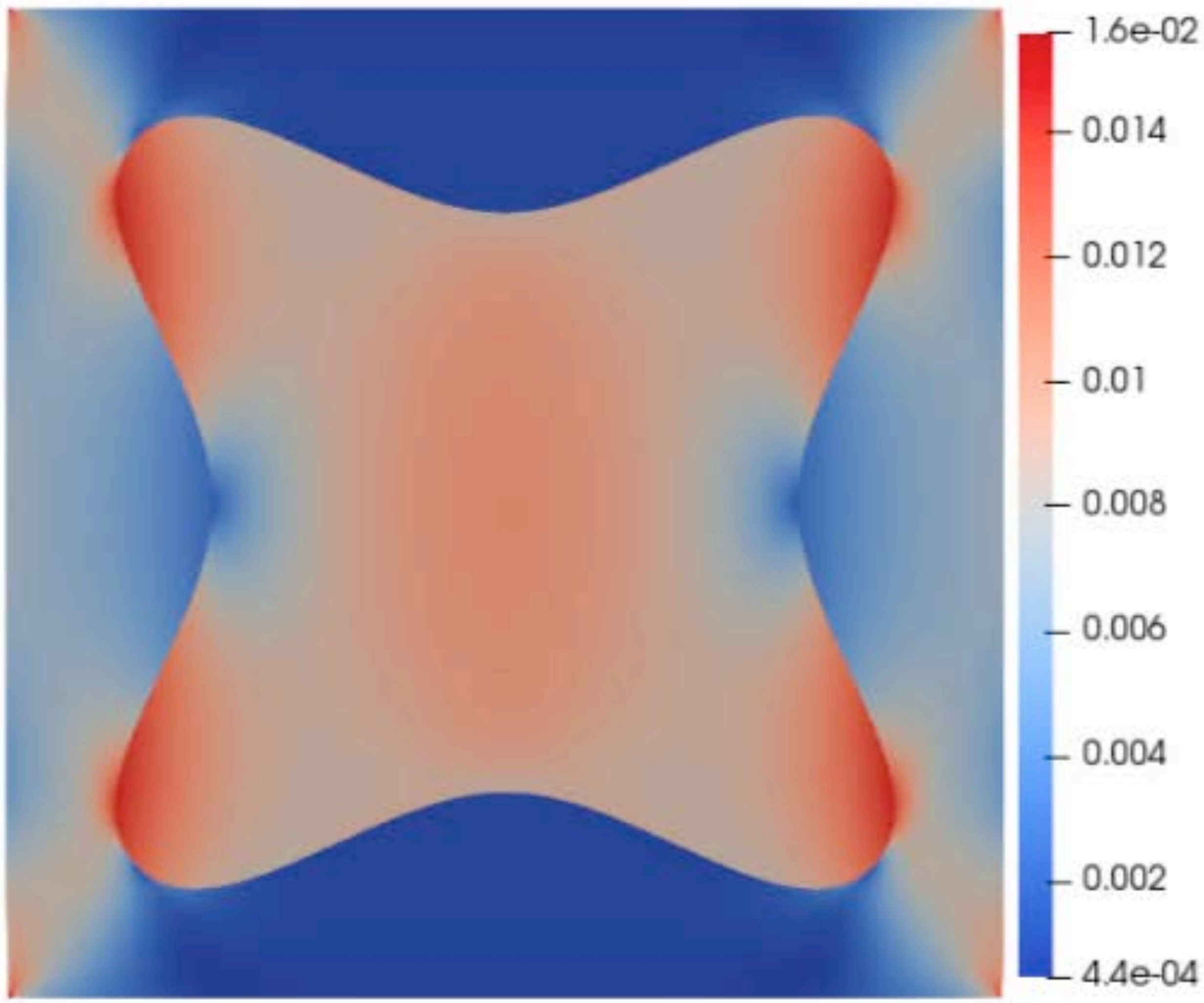
Fracture Mode 2

Contact-XFEM Examples

Glued contact- with embedded bodies
Material with Young's modulus $= 10^6, 10^8$, and Poisson ratio $= 0.3$



Displacements

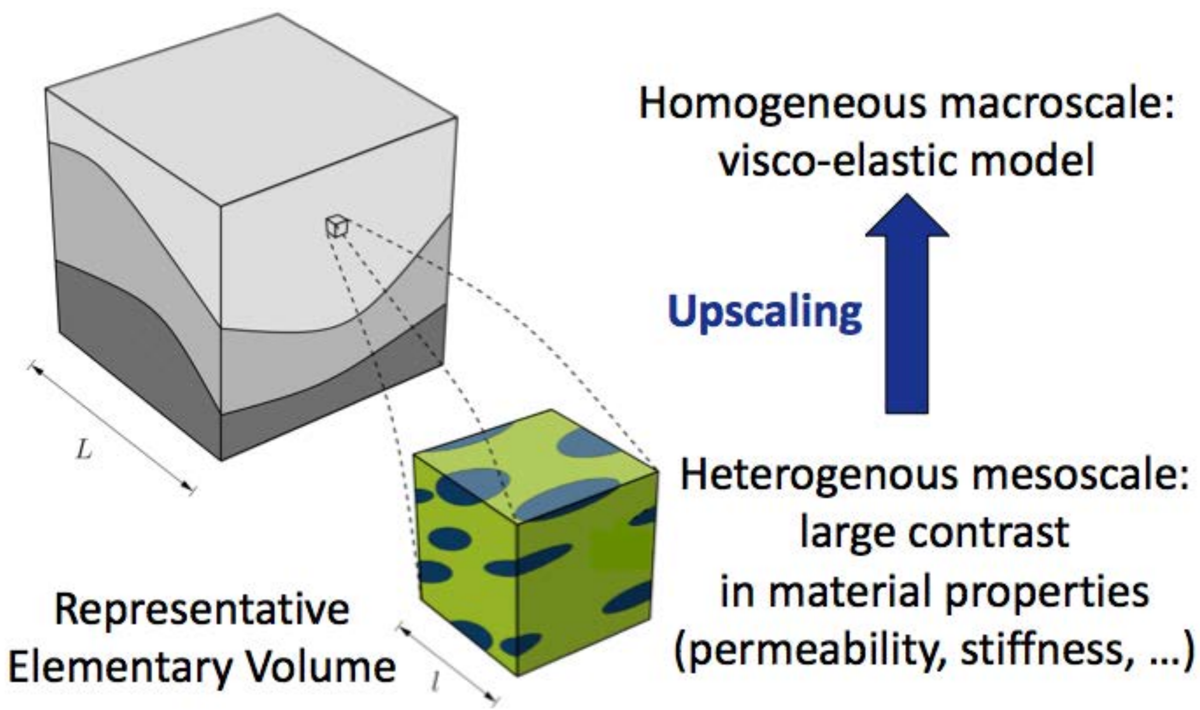


Vonmises stress

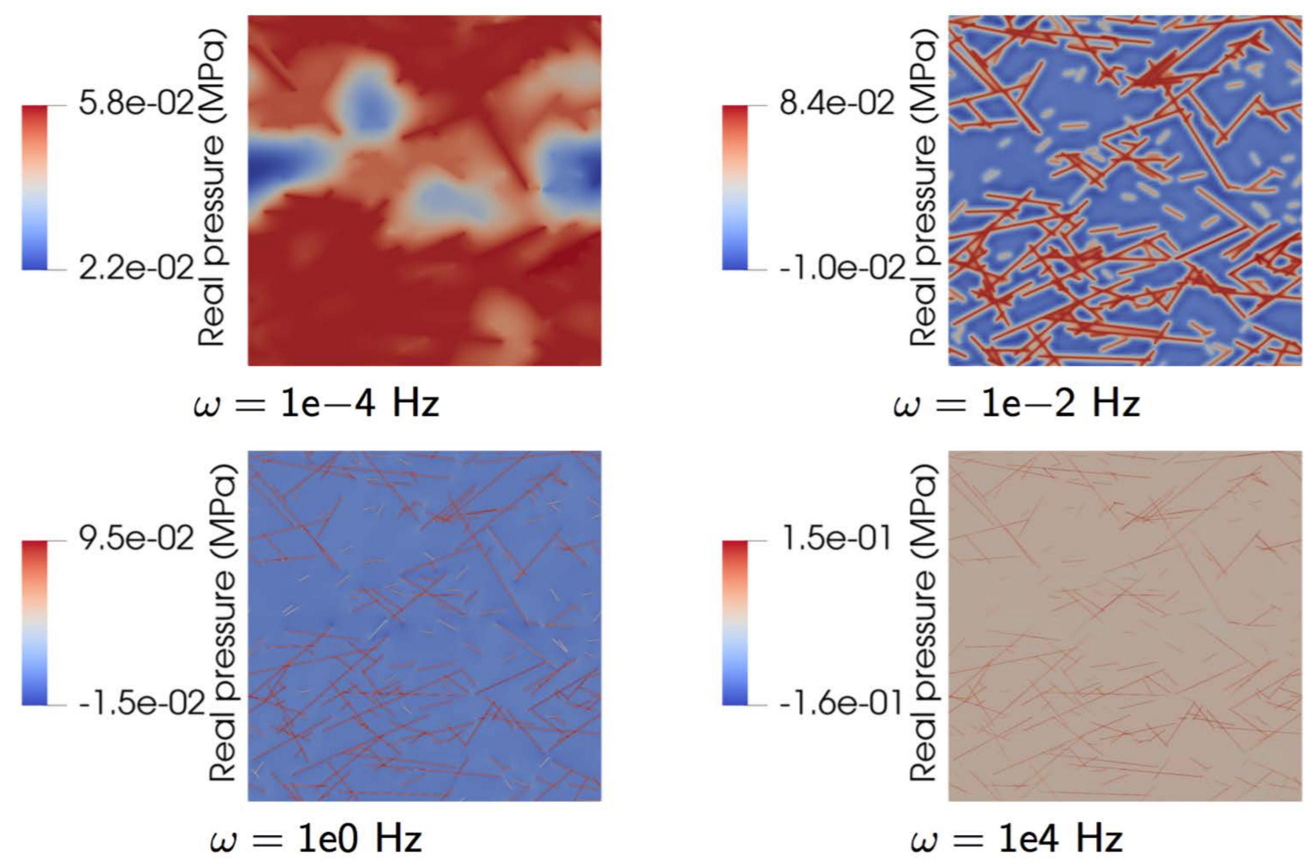
Models with fracture networks 1)

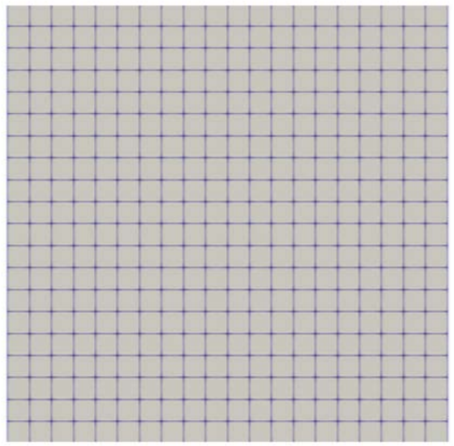
Computational bottlenecks:

- meshing for complicated networks
  Adaptive Mesh Refinement
- solution of large linear systems
- large number of stochastic samples

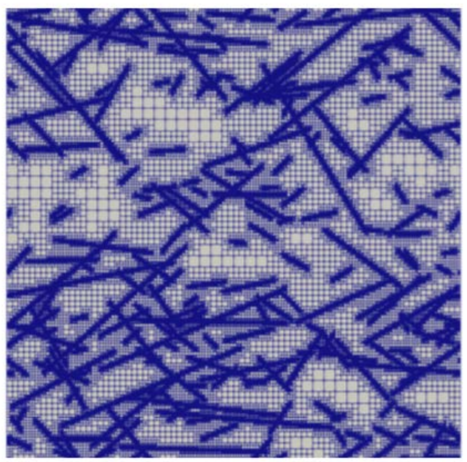


Adapted from Jänicke et al. (2015)





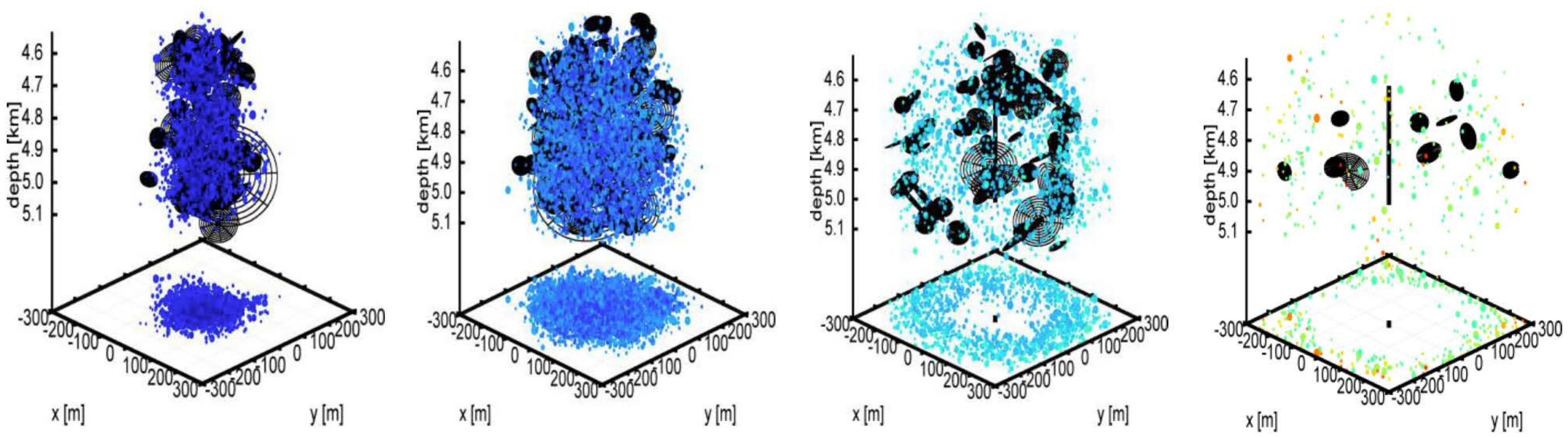
Initial mesh (uniform)



7 refinement steps

Validation: Favino et al. (2018), J. Comp. Phys.
First stochastic simulations: Hunziker, Favino, et al. (2017), J. Geophys. Res.

Macroscopic models:
- hybrid dimensional models
- fractures as 2D manifolds

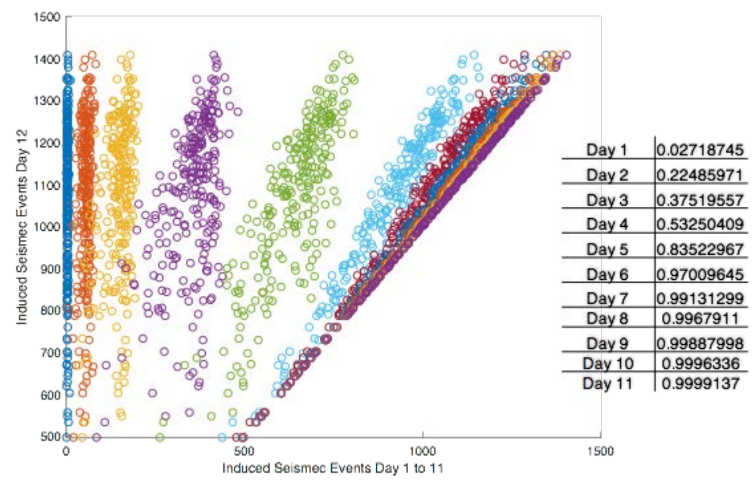


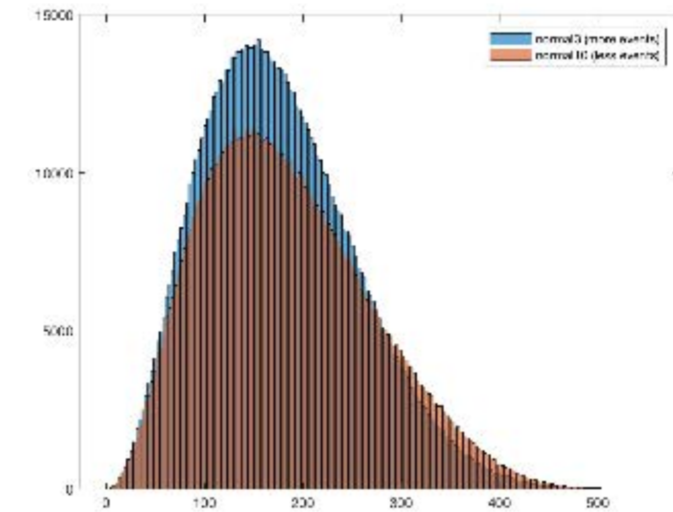
(i) 0-2 days (j) 2-4 days (k) 4-6 days (l) 6-14 days

Computational bottlenecks:
- large number of stochastic samples
- time limited to 6 hours

Surrogate models

1) shorter final time
2) space-time coarsening
3) 0D models

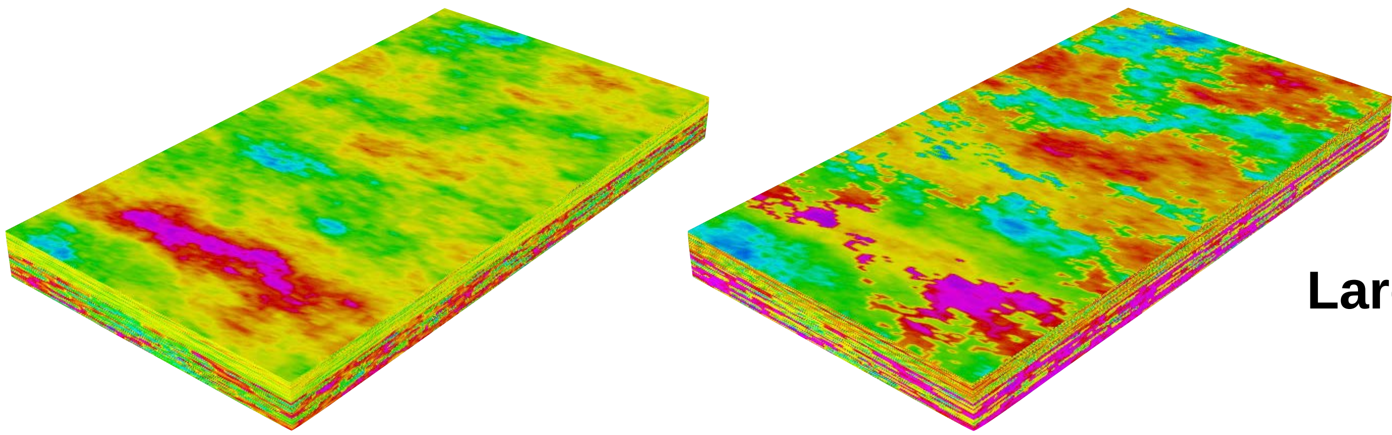




- SNF-Ambizione project of Marco Favino:
- *FASTER*, PASC project USI/ETHZ/SEB

Spatially correlated random fields for porous media

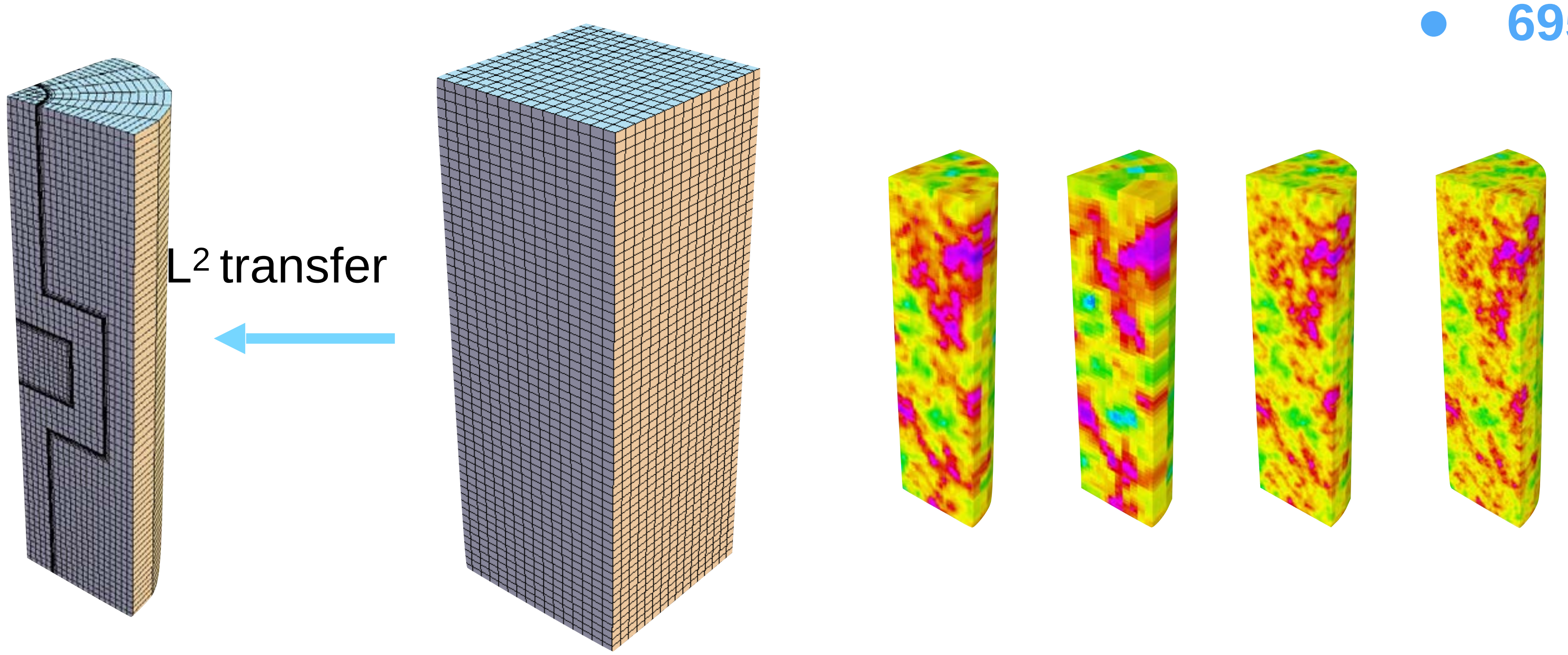
Estimation of the **impact of uncertainty on the results** of a groundwater flow simulation in porous media



Uncertain permeability field

Largest experiment

- **~8** hours of computation on **18432** processes
- **1.62 billion** degrees of freedom
- **228** fine level samples
- **69539** total samples



Gauss-Markov random field sampling on **arbitrary geometries**

In collaboration with
Lawrence Livermore National Laboratory

Capacity Building - Publications

- Tenure Track Professorship in Computational Energy (USI/ICS/SoE). Numerics of PDEs and Data Assimilation. **Michael Multerer** since 1.9.2018
- snf ambizione grant “Unraveling the attenuation and velocity dispersion of seismic waves in complex fractured media by means of multilevel simulations”.

Marco Favino (ICS/USI/ETH). Host institution: Uni Lausanne. Start 1.12.2018

[1] **An immersed boundary method based on the L2-projection approach**. Nestola, Maria Giuseppina Chiara, Barna Becsek, Hadi Zolfaghari, Patrick Zulian, Obrist Dominik, and Krause Rolf. Proceedings of the 24rd International Conference on Domain Decomposition Methods in Longyearbyen, Svalbard. Springer-Verlag, 2018.

[2] **Variational Parallel Information Transfer between Unstructured Grids in Geophysics - Applications and Solutions Methods.** Cyrill Planta, Daniel Vogler, Nestola, Maria Giuseppina Chiara, Patrick Zulian, and Rolf Krause. PROCEEDINGS, 43rd Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, 2018.

[3] **An immersed boundary method for fluid-structure interaction based on overlapping domain decompositions.** Nestola, Maria Giuseppina Chiara, Barna Becsek, Hadi Zolfaghari, Patrick Zulian, Dominik Obrist, and Krause Rolf. Journal of Computational Physics (2018). under review.

[4] **High-order accurate simulation of incompressible turbulent flows on many parallel GPUs of a hybrid-node supercomputers.** Hadi Zolfaghari, Barna Becsek, Nestola, Maria Giuseppina Chiara, Rolf Krause, and Obrist Dominik .Journal of Computational Science (2018). under review.

[5] **A parallel approach to the variational transfer of discrete fields between arbitrarily distributed unstructured finite element meshes**, R. Krause and P. Zulian. SIAM Journal of Scientific Computing 2016

[6] **Scalable hierarchical PDE sampler for generating spatially correlated random fields using non-matching meshes.** S. Osborn, P. Zulian, T. Benson, U. Villa, R. Krause, P, Vassilevski, Copper special issue of the journal of *Numerical Linear Algebra with Applications, 2018*

[7] *Seismic Attenuation in Realistic Fracture Networks*. Jürg Hunziker; Marco Favino; Eva Caspari; Beatriz Quintal; J. Germán Rubino; Rolf Krause; and Klaus Holliger. Sixth Biot Conference on Poromechanics, 2017.

[8] ***Seismic Attenuation and Stiffness Modulus Dispersion in Porous Rocks Containing Stochastic Fracture Networks*.** Jürg Hunziker, Marco Favino, Eva Caspari, Beatriz Quintal, J. Germán Rubino, Rolf Krause, and Klaus Holliger. Journal of Geophysical Research, 2018.

[9] ***Fully-Automated Adaptive Mesh Refinement for the Simulation of Fluid Pressure Diffusion in Strongly Heterogeneous Poroelastic Media*.** Jurg Hunziker, Eva Caspari, Beatriz Quintal, Klaus Holliger, and Rolf Krause. Journal of Computational Physics (2018). under review.

Università della Svizzera italiana — CARDIOCENTROTICINO
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Faculty of Informatics

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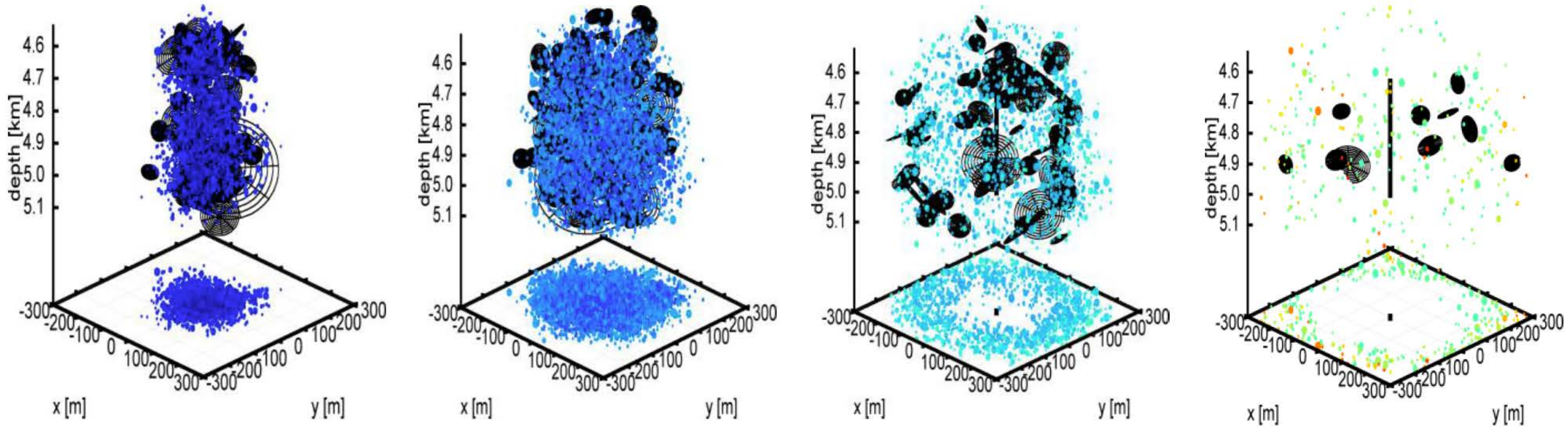
Innosuisse – Schweizerische Agentur für Innovationsförderung

Toward a Multifidelity Method for Estimating the Influence of Overpressure on Induced Seismicity

Alessio Quaglino, *Marco Favino*, Dimitrios Karvounis,
Claudio Tomasi, Stefan Wiemer, Thomas Driesner, Rolf Krause



(i) 0-2 days (j) 2-4 days (k) 4-6 days (l) 6-14 days

Large number of stochastic simulations to evaluate number of seismic events and magnitude: Monte Carlo method is dimension independent but slow in convergence

Multifidelity Monte Carlo

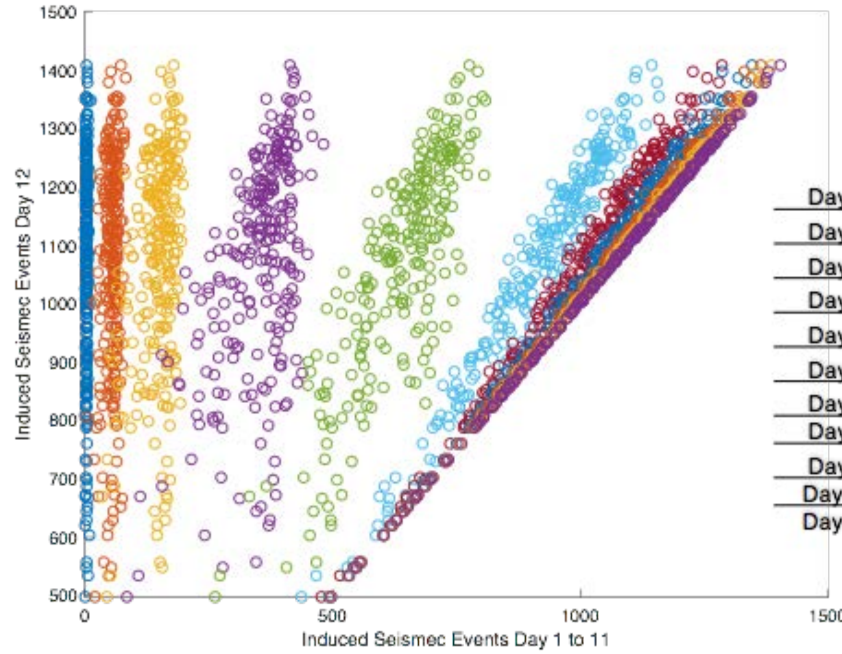
Employ surrogate models

to accelerate the computation of mean values evaluated for detailed models

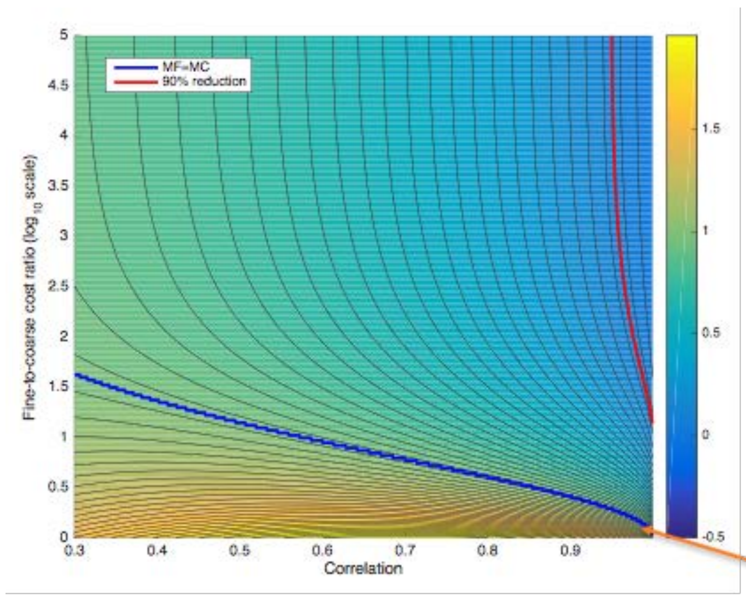
1) shorter final time

2) space-time coarsening

3) 0D models



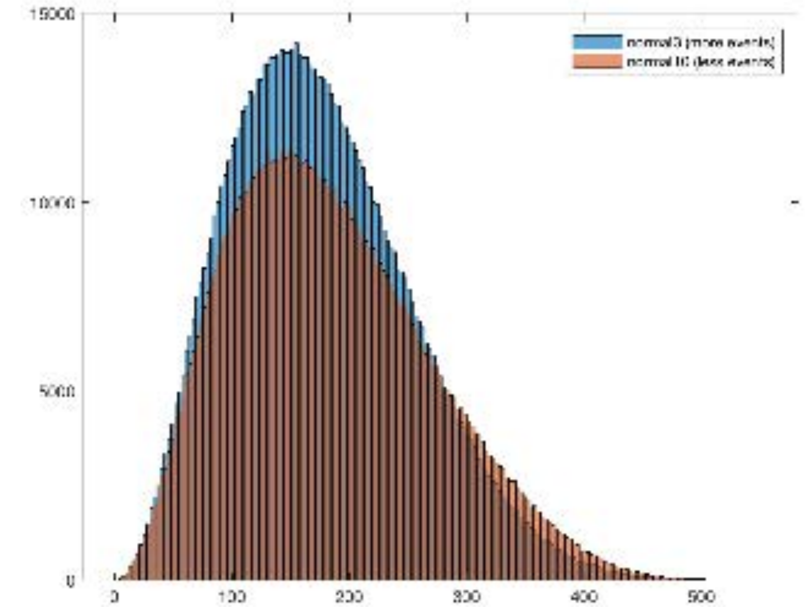
Day 1	0.02718745
Day 2	0.22485971
Day 3	0.37519557
Day 4	0.53250409
Day 5	0.83522967
Day 6	0.97009645
Day 7	0.99131299
Day 8	0.9967911
Day 9	0.99887998
Day 10	0.9996336
Day 11	0.9999137

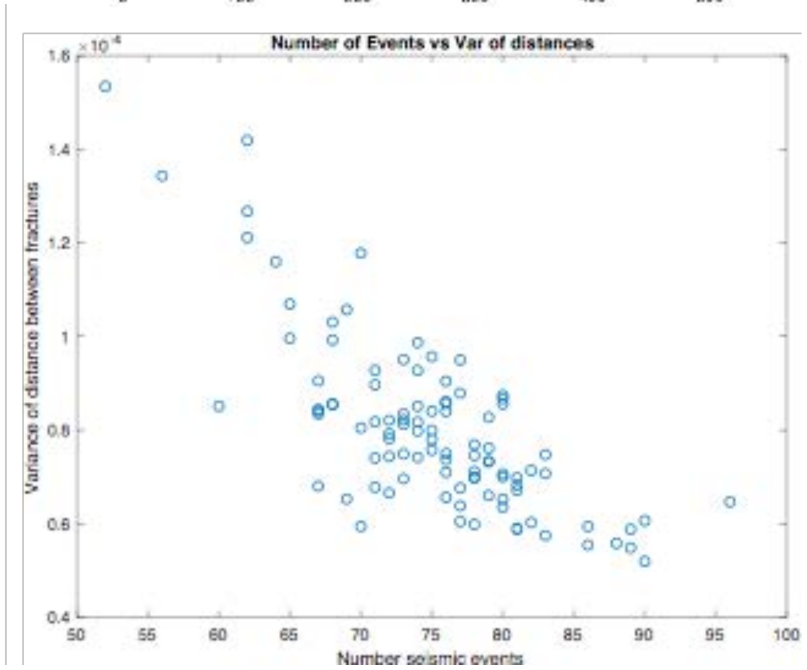


Contours of MF/MC error ratio

$$\frac{e(\hat{s}^*(Z))}{e(\overline{y}_n^{(1)}(Z))} = \left(\sum_{i=1}^{k} \sqrt{\frac{w_i}{w_1}(\rho_{1,i}^2 - \rho_{1,i+1}^2)}\right)^2$$

Day 6 lies about here





Surrogate models have to be **cheap** and **well-correlated** to gain with respect to Monte Carlo