Digital twin of a laboratory-scale porous medium

Jakub W. Both, B. Benali, E. Keilegavlen, J.M. Nordbotten, M. Fernø
University of Bergen, Norway

T. Kvamsdal, A. Rasheed
NTNU Trondheim, Norway

E. Fonn, K. Johannessen
SINTEF Digital, Norway

InterPore2022, Abu Dhabi, 30 May – 2 June 2022

Conference on Mathematical & Computational Issues in the Geosciences

June 19 - 22, 2023
Bergen, Norway

Important Deadlines

November 21, 2022
Submission of Minisymposium Proposals

December 6, 2022
SIAM Student Travel Award Applications and Early Career Travel Award Applications

December 19, 2022
Contributed Lecture, Poster, and Minisymposium Presentation Abstracts

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University of Bergen, Norway

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Learn more: go.siam.org/gs23

PhD positions (mathematics) in Bergen

1. Solvers for coupled problems involving ML and PBM; deadline June 9
2. Dynamic poromechanics; deadline June 1
3. Data assimilation and optimization; deadline June 15

1. 

2. 

3. 

Or visit jobbnorge.no, or get in touch with me

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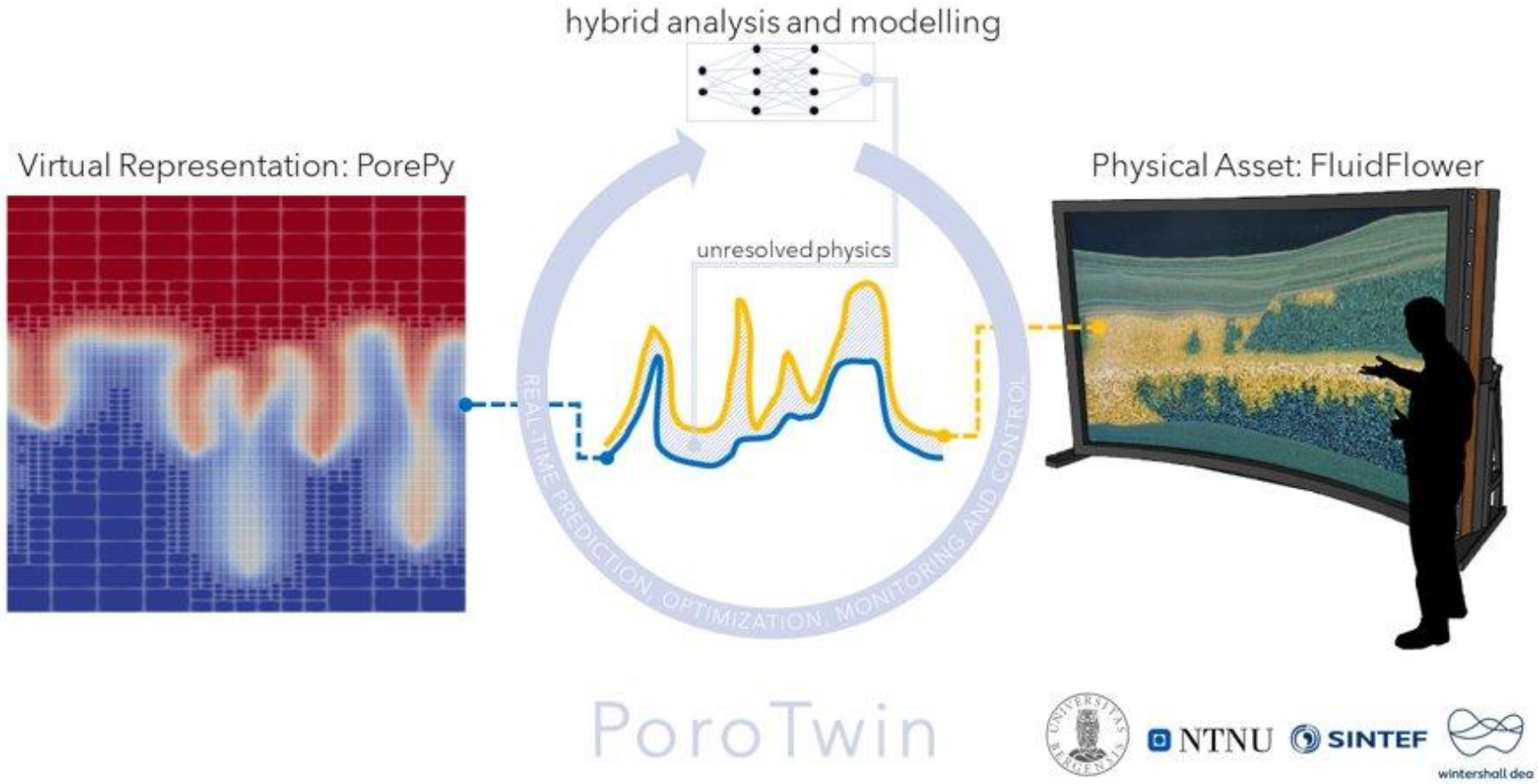
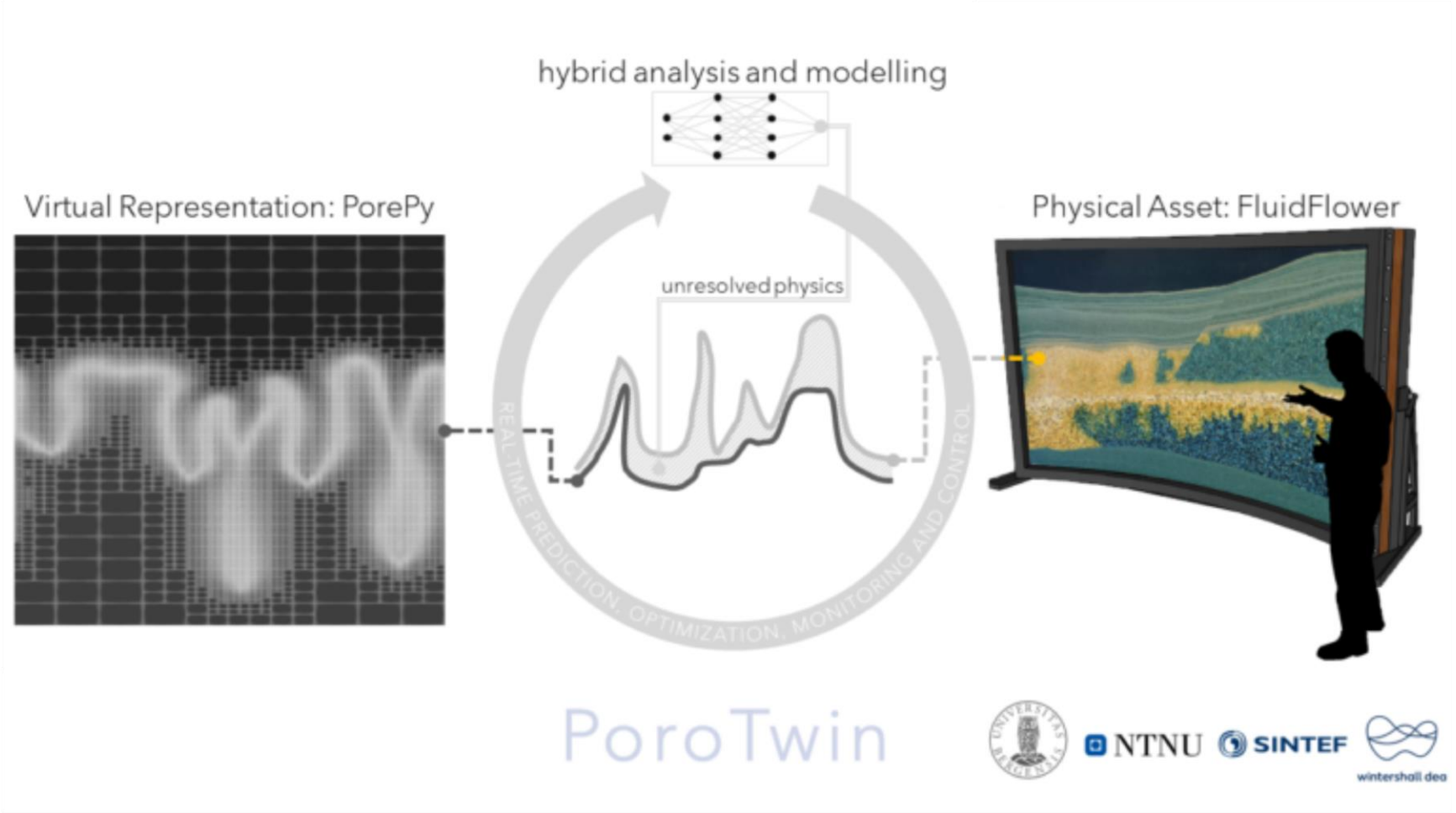
Digital twin concept



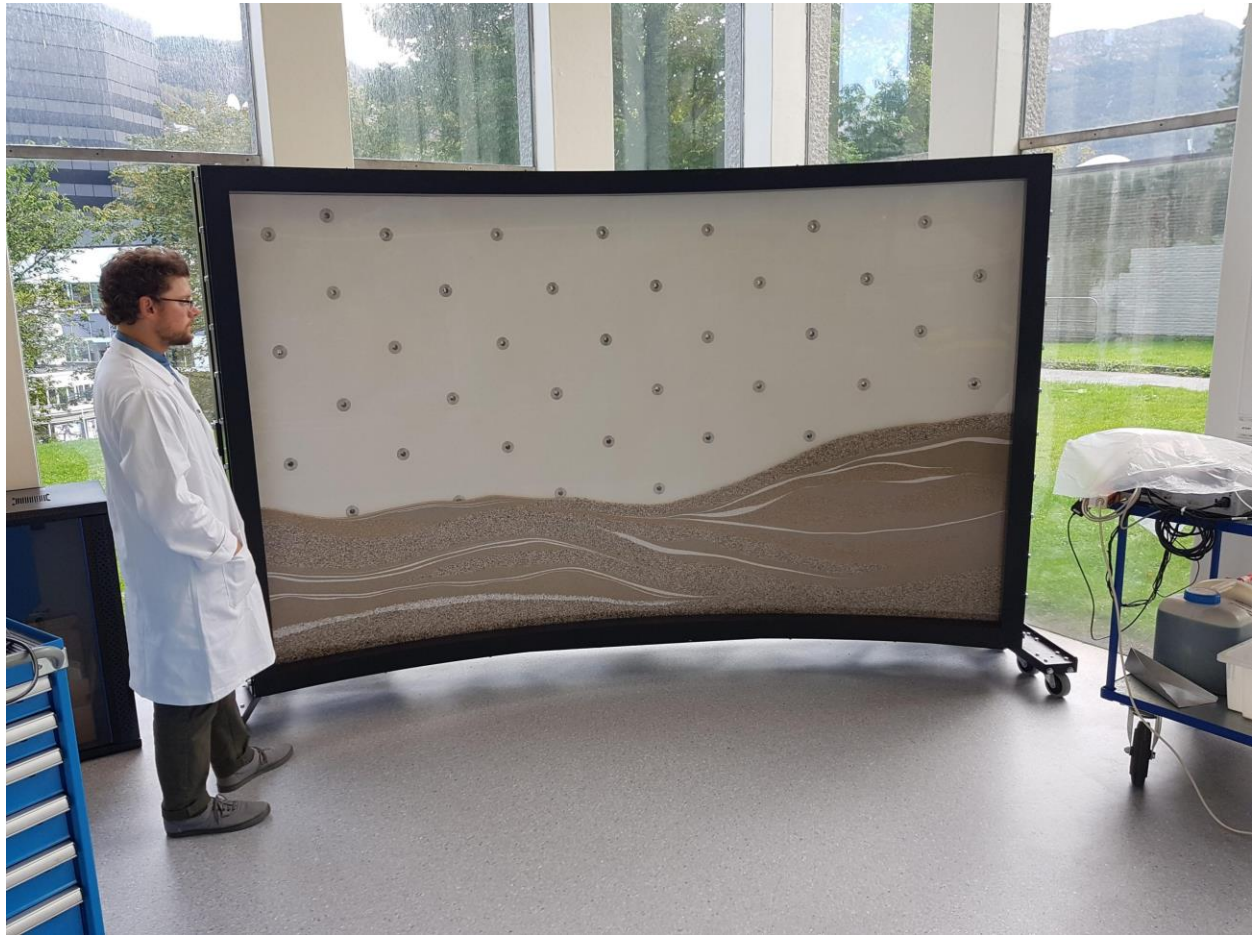
Long-term goal: Digital twin of a reservoir

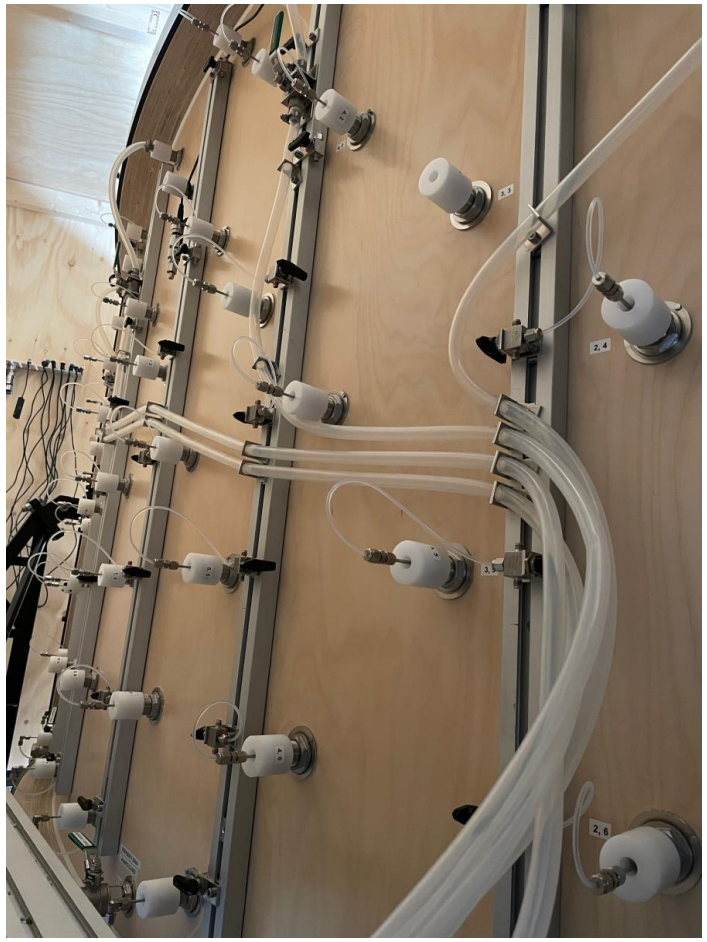
The physical asset



Long-term goal: Digital twin of a reservoir

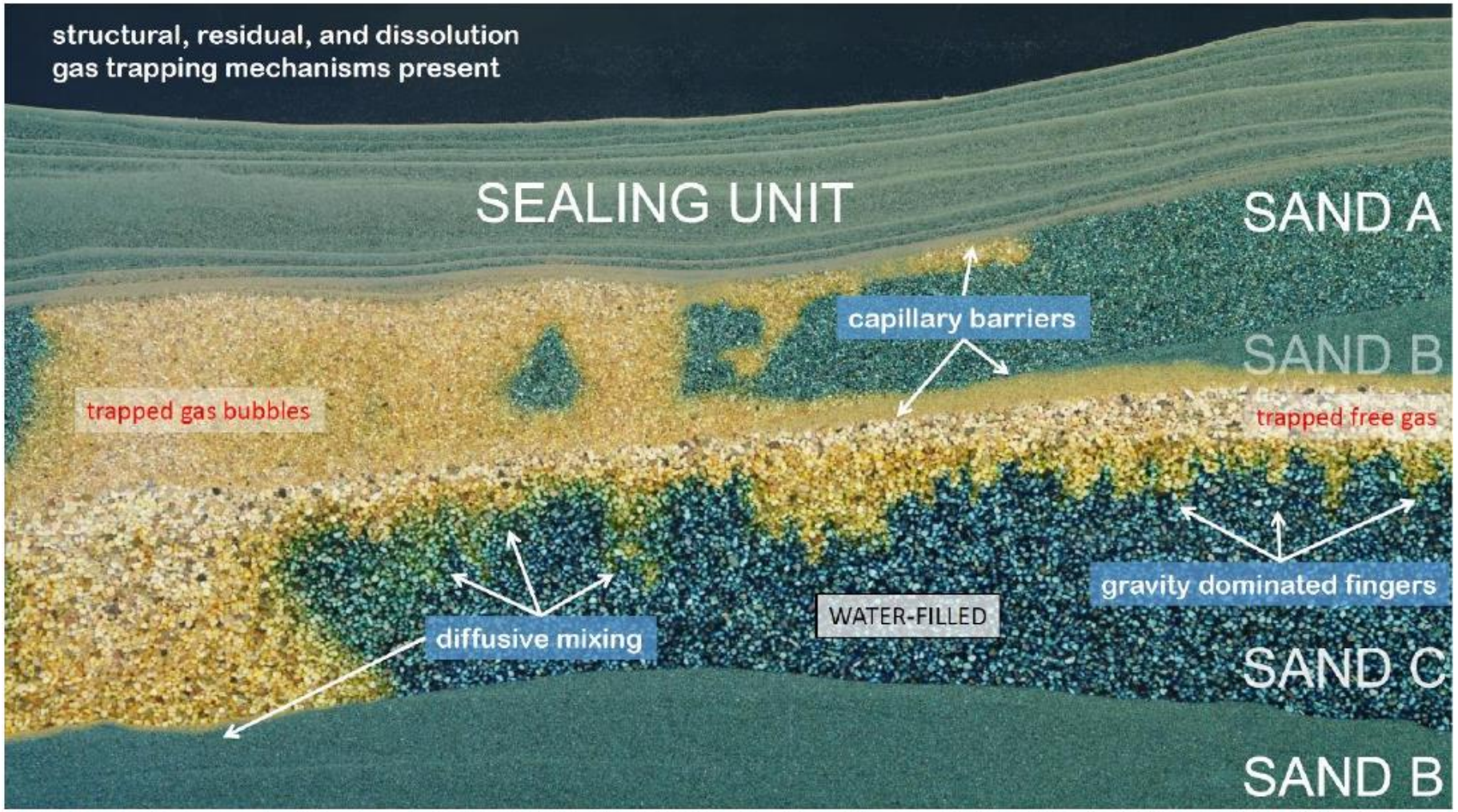
FluidFlower





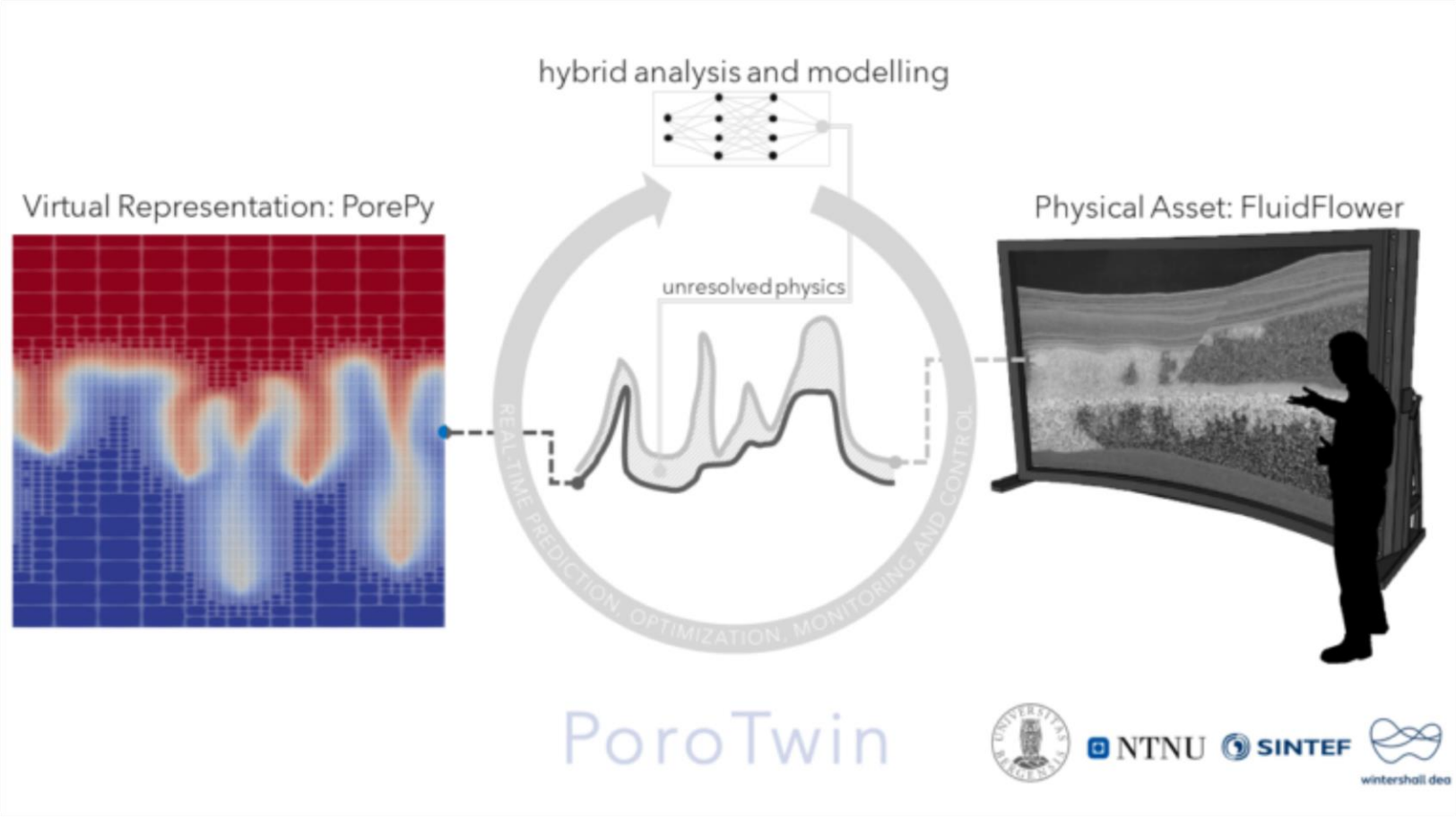
fluidflower.w.uib.no

CO2 storage experiments in the FluidFlower



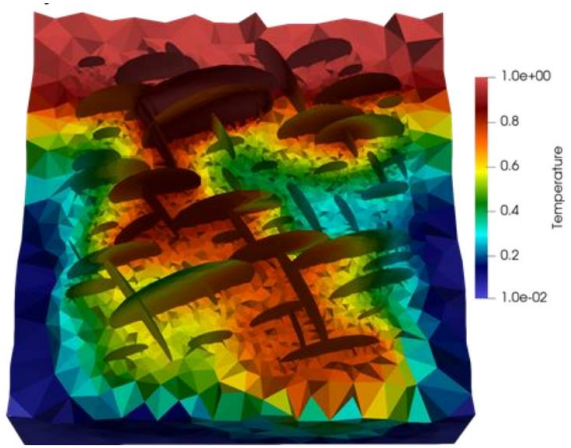
fluidflower.w.uib.no

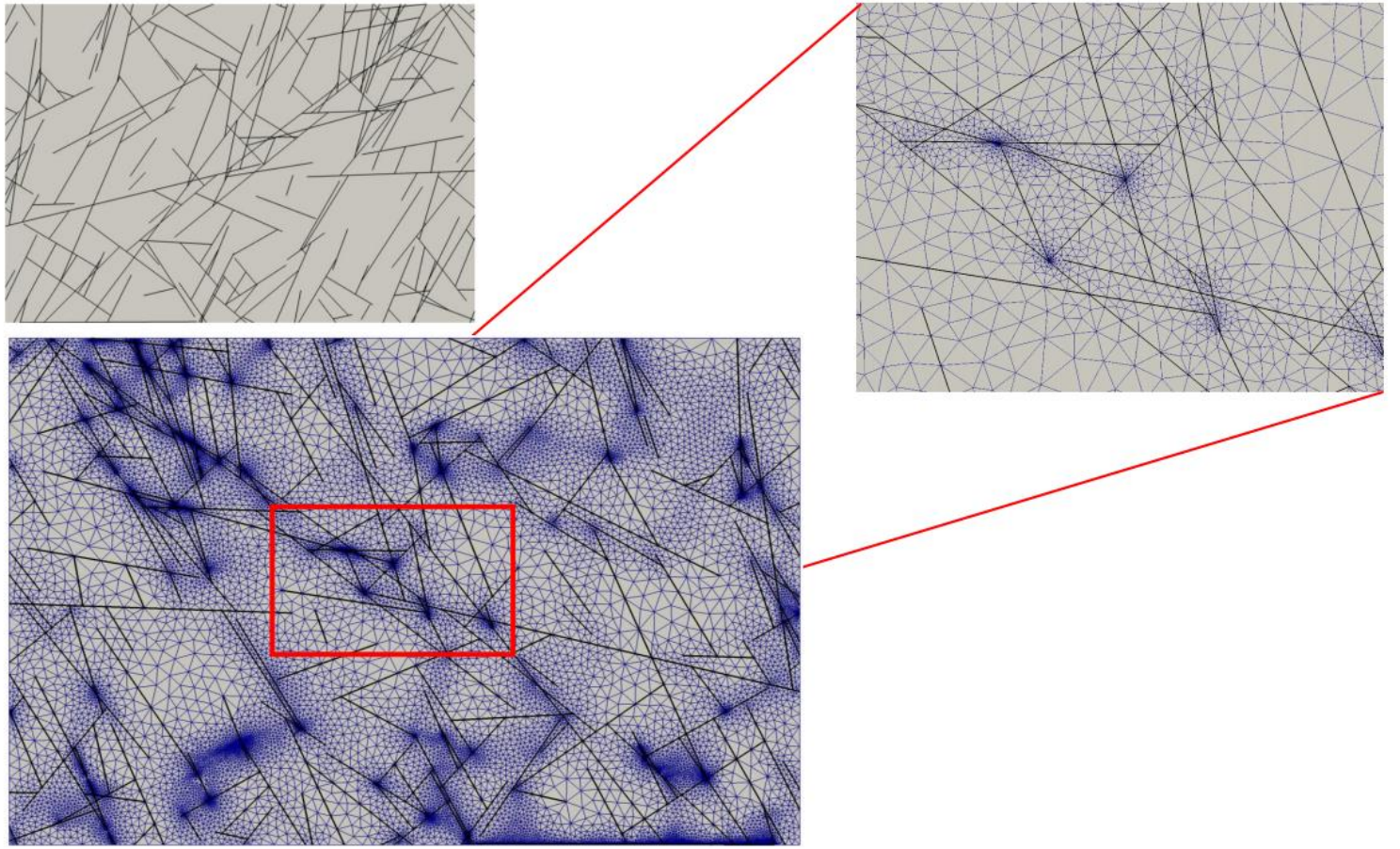
The virtual representation



PorePy: Physics based simulator

- Multi-physics FV simulator
- Flow, transport, geomechanics
- Tailored to fractured media
- Open-source





Keilegavlen *et al.* PorePy: an open-source software for simulation of multiphysics processes in fractured porous media. *Comput Geosci* (2021)

PorePy: github.com/pmgbergen/porepy

PBM: Flow and passive transport

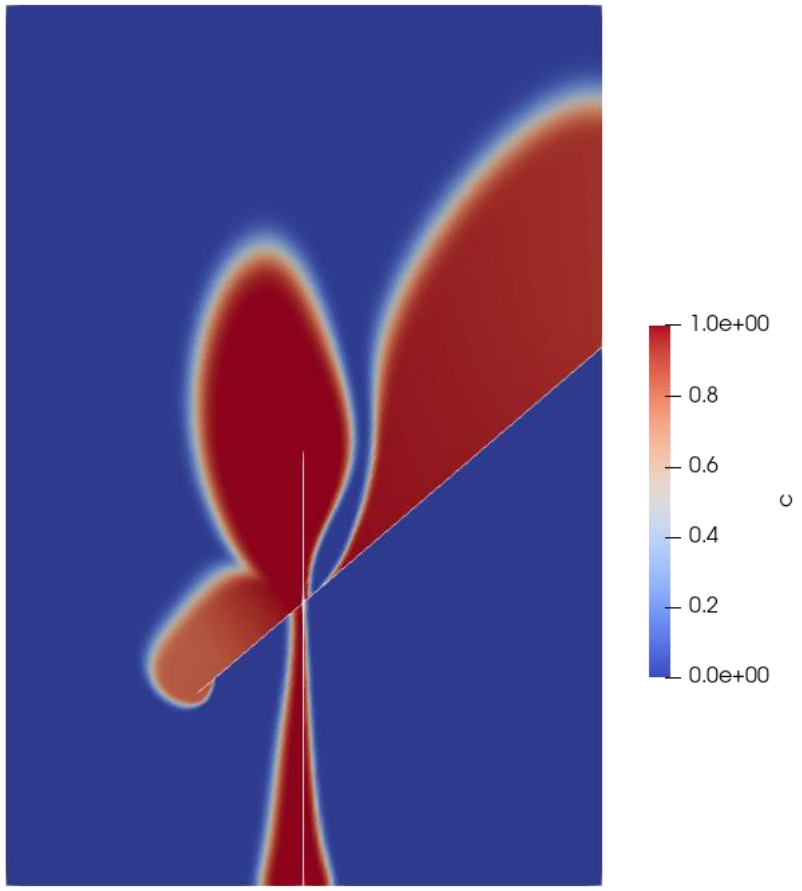
Incompressible, single-phase flow:

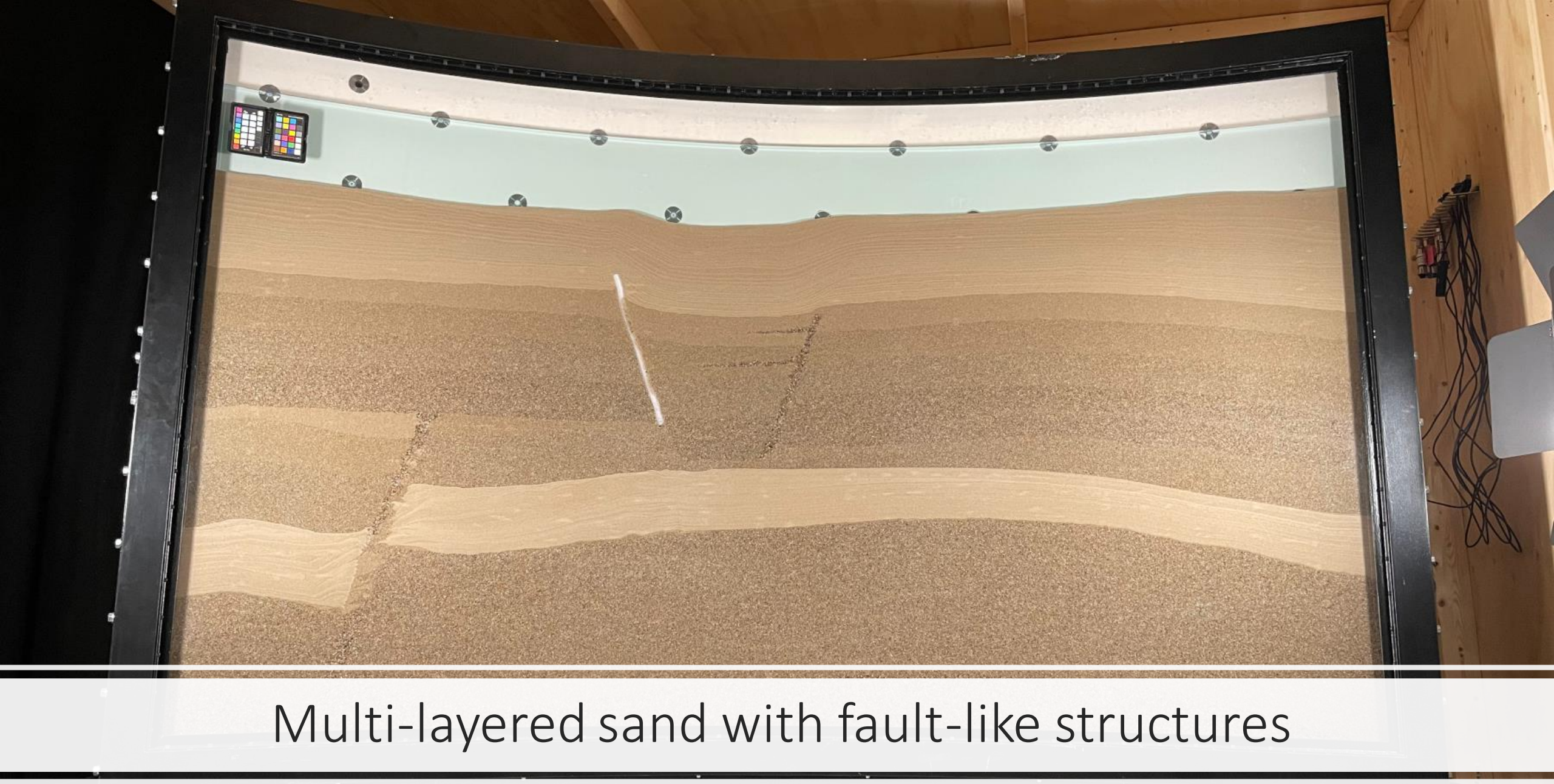
$$\nabla \cdot \boldsymbol{q} = h$$
$$\boldsymbol{q} = -\kappa \nabla p$$

Transport with dispersion:

$$\phi \partial_t c + \nabla \cdot (c\boldsymbol{q} - D\nabla c) = 0$$

Example: Injection in fracture

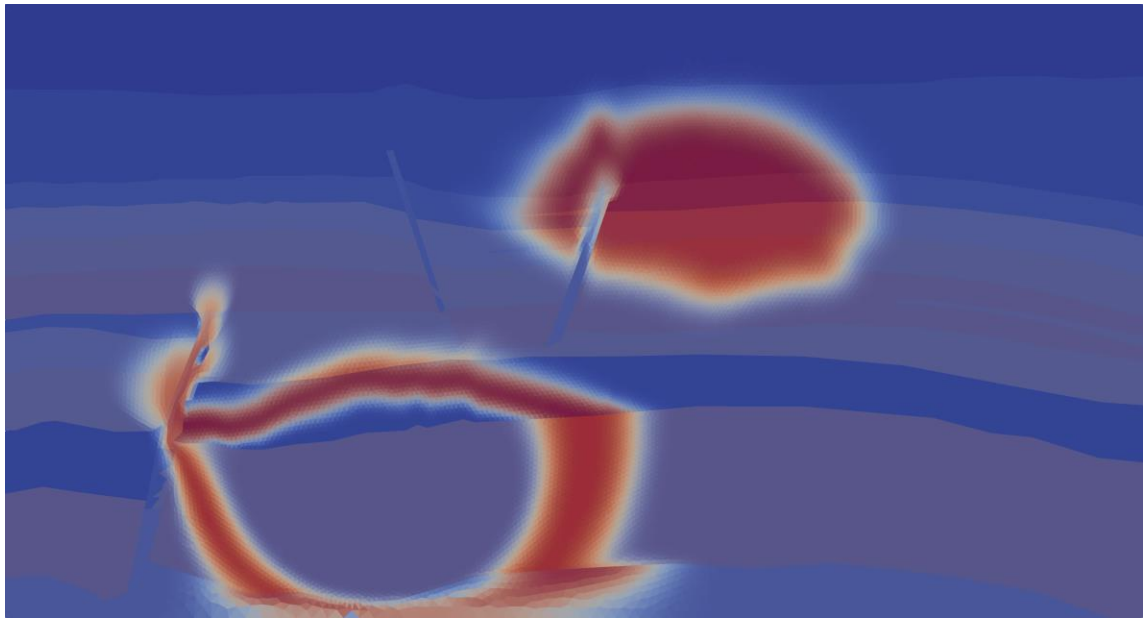




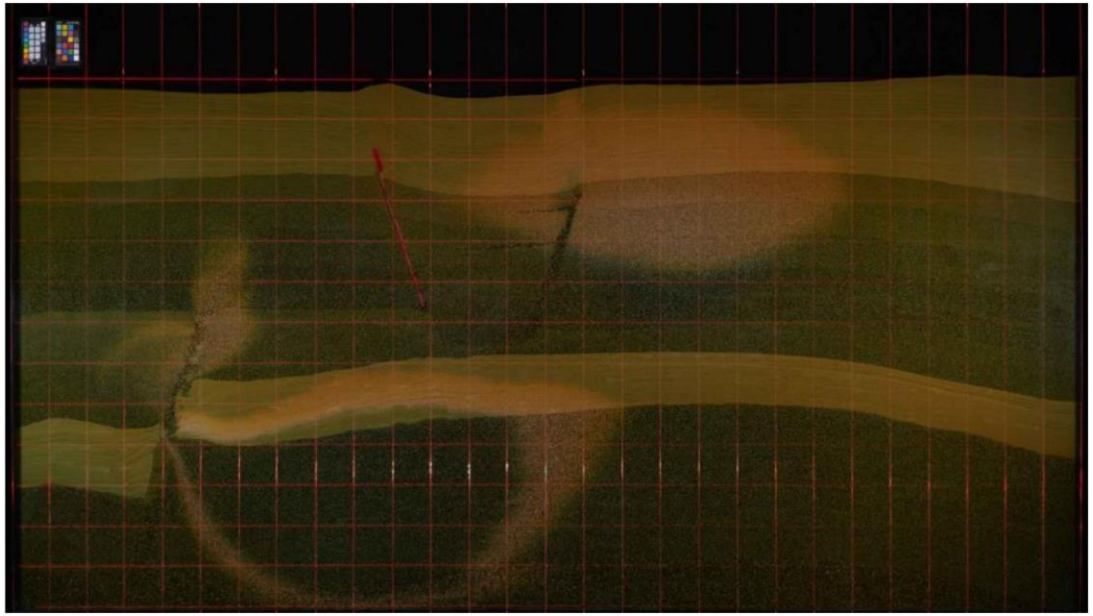
Multi-layered sand with fault-like structures

Tracer test in multi-layered sand

PorePy Simulation



FluidFlower experiment



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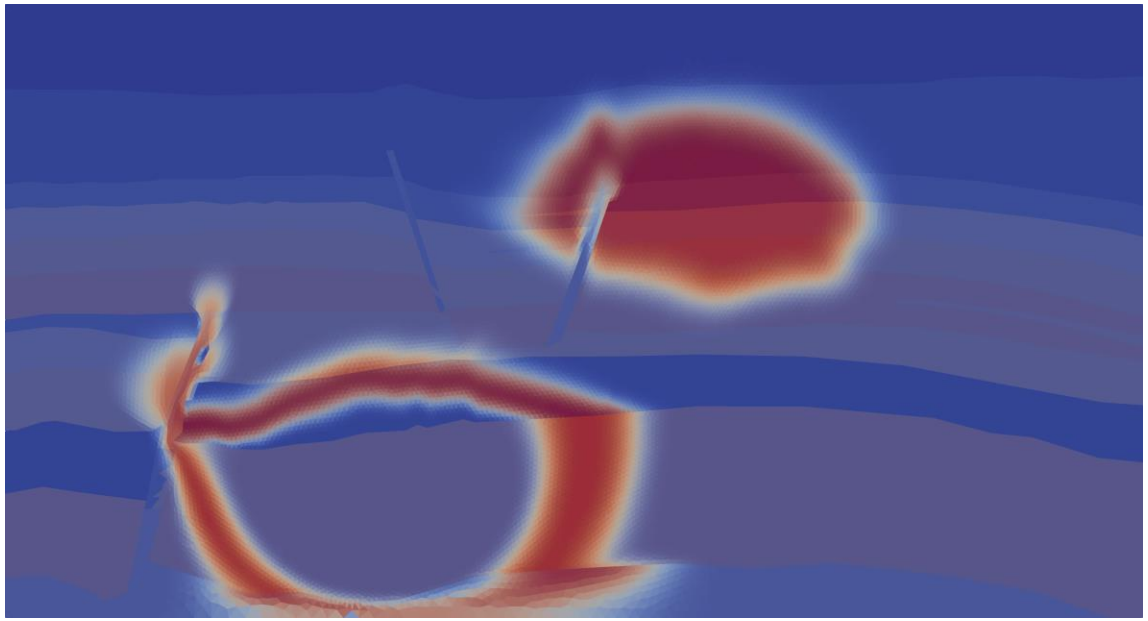

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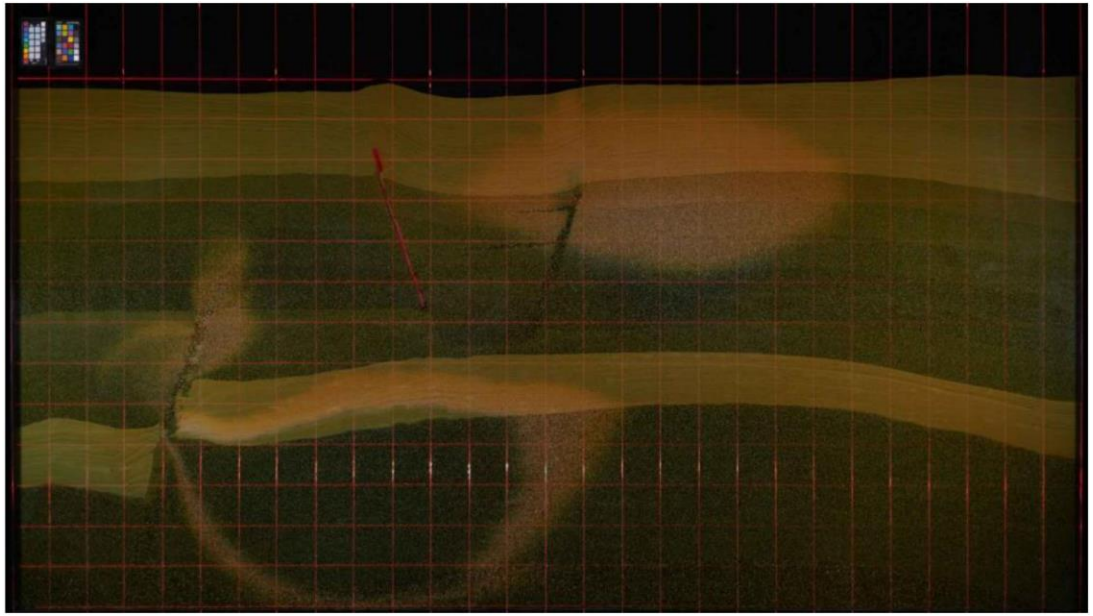
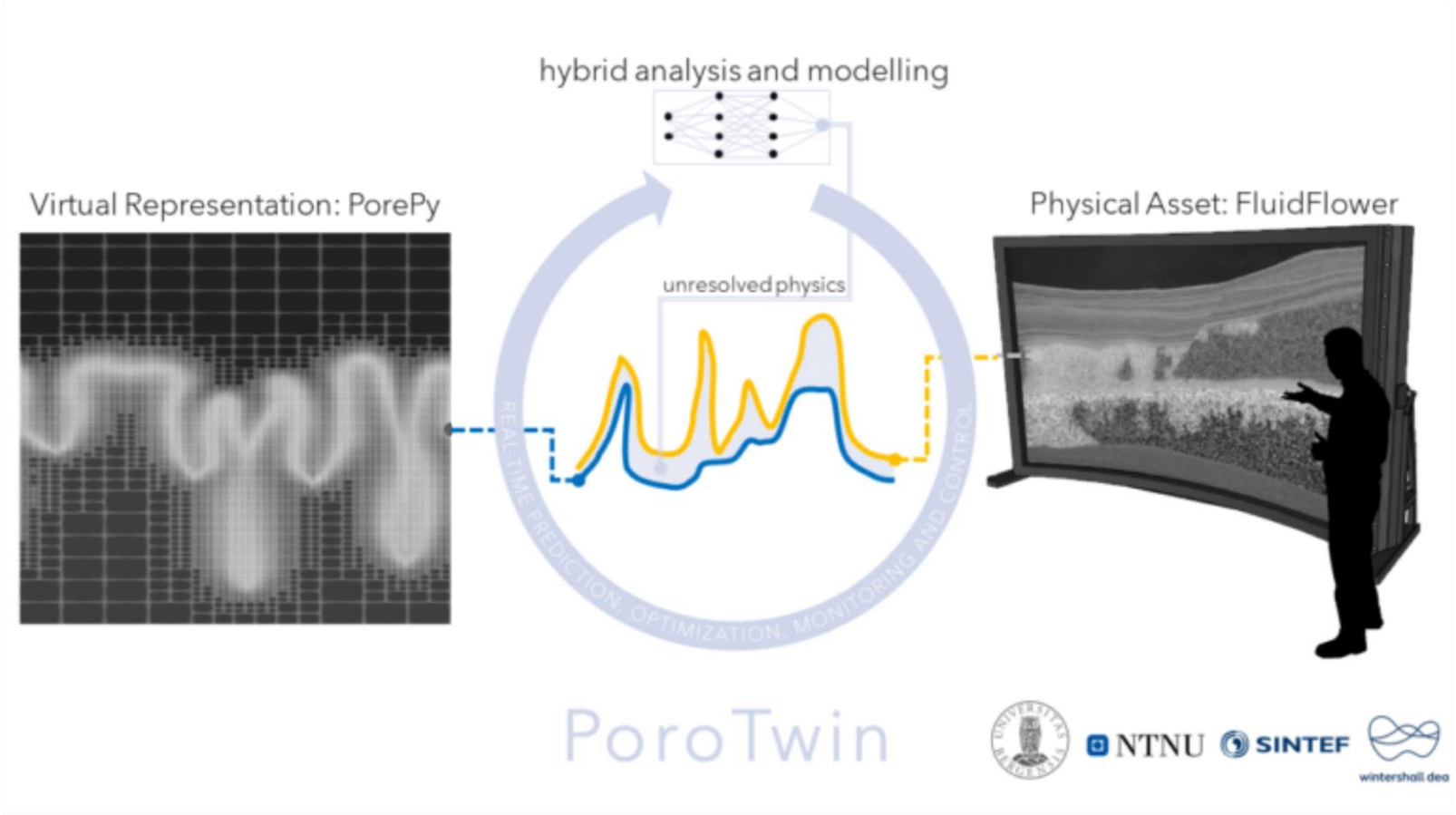
FluidFlower experiment



Missing physics: Inaccurate material parameters, density variation (tracer vs. water), ...

Hybrid analysis and modeling



Rasheed *et al,* Digital twin: Values, challenges and enablers from a modeling perspective, IEEE Access (2020)

Hybrid modeling approach

True model:

$$\mathcal{L}u_{\mathrm{TRUE}} = f$$

Blakseth *et al.* Deep neural network enabled corrective source term approach to hybrid analysis and modeling, Neural Networks (2022)

Hybrid modeling approach

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True solution

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PBM: Assumed physics

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Hybrid modeling approach

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Resulting RHS

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PBM model:

$$\mathcal{L}u_{\mathrm{PBM}} = f_{\mathrm{PBM}}$$

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RHS: Assumed physics

PBM solution

PBM: Assumed physics

Corrective source term approach:

$$\mathcal{L}u_{\mathrm{COSTA}} \overset{!}{=} \mathcal{L}u_{\mathrm{TRUE}}$$

Remark: Theoretically no modelling error.

Blakseth *et al.* Deep neural network enabled corrective source term approach to hybrid analysis and modeling, Neural Networks (2022)

Hybrid modeling approach

True model:

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Resulting RHS

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RHS: Assumed physics

PBM solution

PBM: Assumed physics

Corrective source term approach:

$$\begin{aligned}\mathcal{L}u_{\mathrm{COSTA}} &\overset{!}{=} \mathcal{L}u_{\mathrm{TRUE}} \\ &= \mathcal{L}u_{\mathrm{PBM}} + \mathcal{L}(u_{\mathrm{TRUE}} - u_{\mathrm{PBM}}) \\ &= f_{\mathrm{PBM}} + r\end{aligned}$$

Remark: Theoretically no modelling error.

Blakseth *et al.* Deep neural network enabled corrective source term approach to hybrid analysis and modeling, Neural Networks (2022)

Hybrid modeling approach

True model:

$$\mathcal{L}u_{\text{TRUE}} = f$$

Resulting RHS

True solution

PBM: Assumed physics

PBM model:

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RHS: Assumed physics

PBM solution

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Unknown residual

Remark: Theoretically no modelling error.

Hence, learn the residual from incorrect solution using deep neural networks.

Blakseth *et al.* Deep neural network enabled corrective source term approach to hybrid analysis and modeling, Neural Networks (2022)

Hybrid modeling approach

1. Compute PBM:

$$\mathcal{L}u_{\mathrm{PBM}} = f_{\mathrm{PBM}}$$

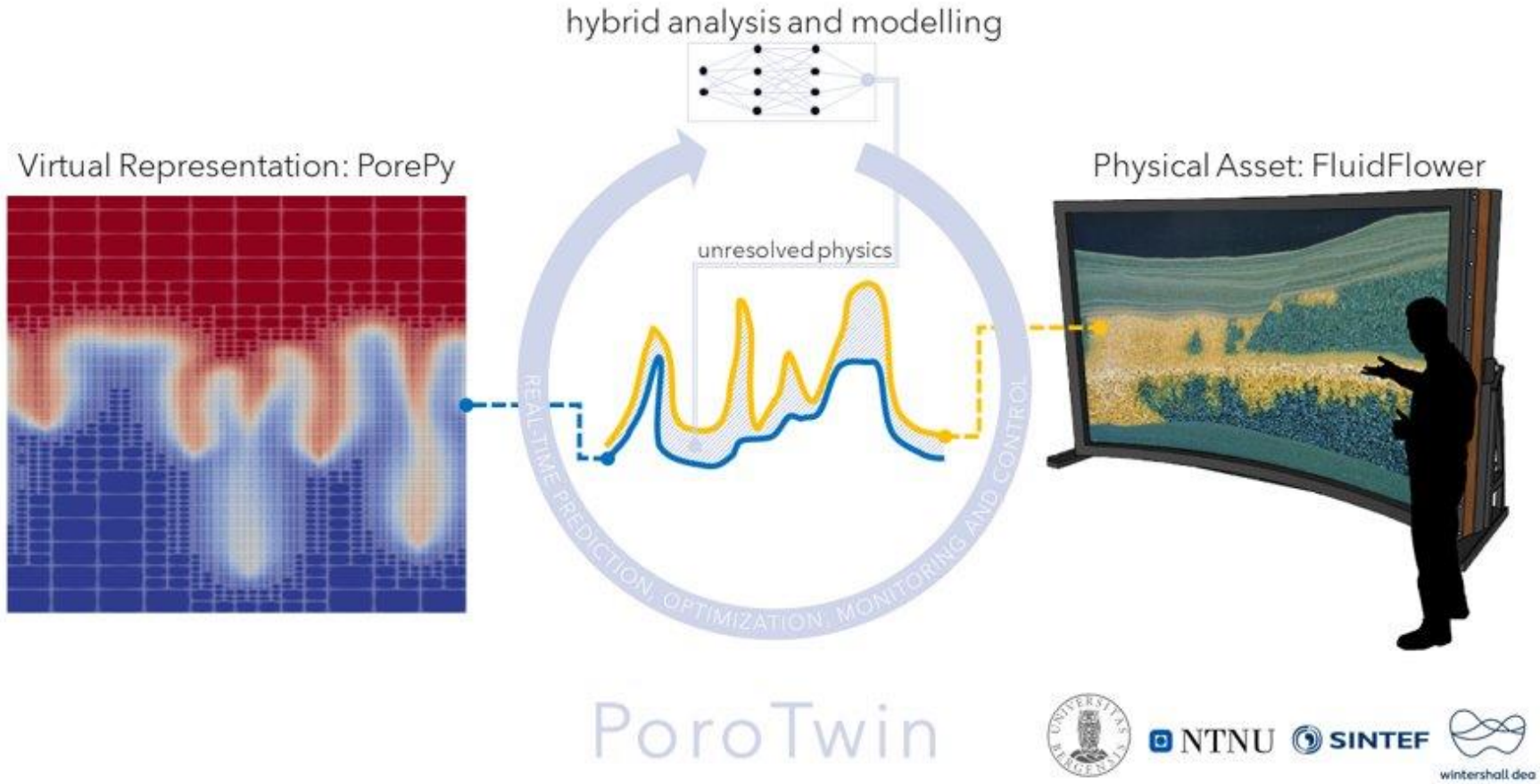
2. Determine the corrective source:

$$r = \mathrm{DDM}(u_{\mathrm{PBM}})$$

3. Compute the PBM with corrected physics:

$$\mathcal{L}u_{\mathrm{COSTA}} = f_{\mathrm{PBM}} + r$$

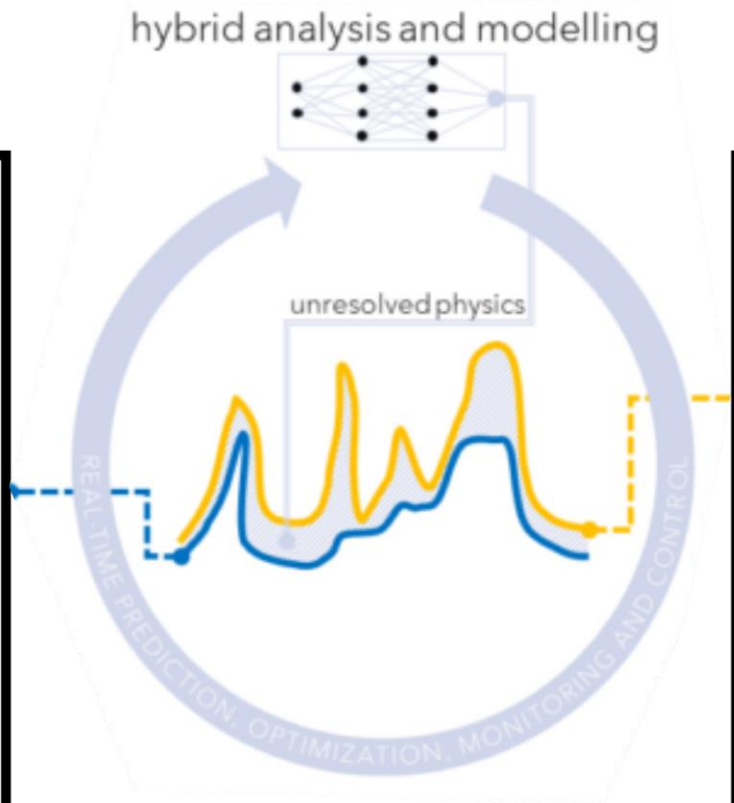
Digital twin concept



Proof-of-concept

Virtual representation:
IFEM (FEM)

Flow and transport without density contrast



IoT communication

"Physical asset":
PorePy (FVM) + Coarsening

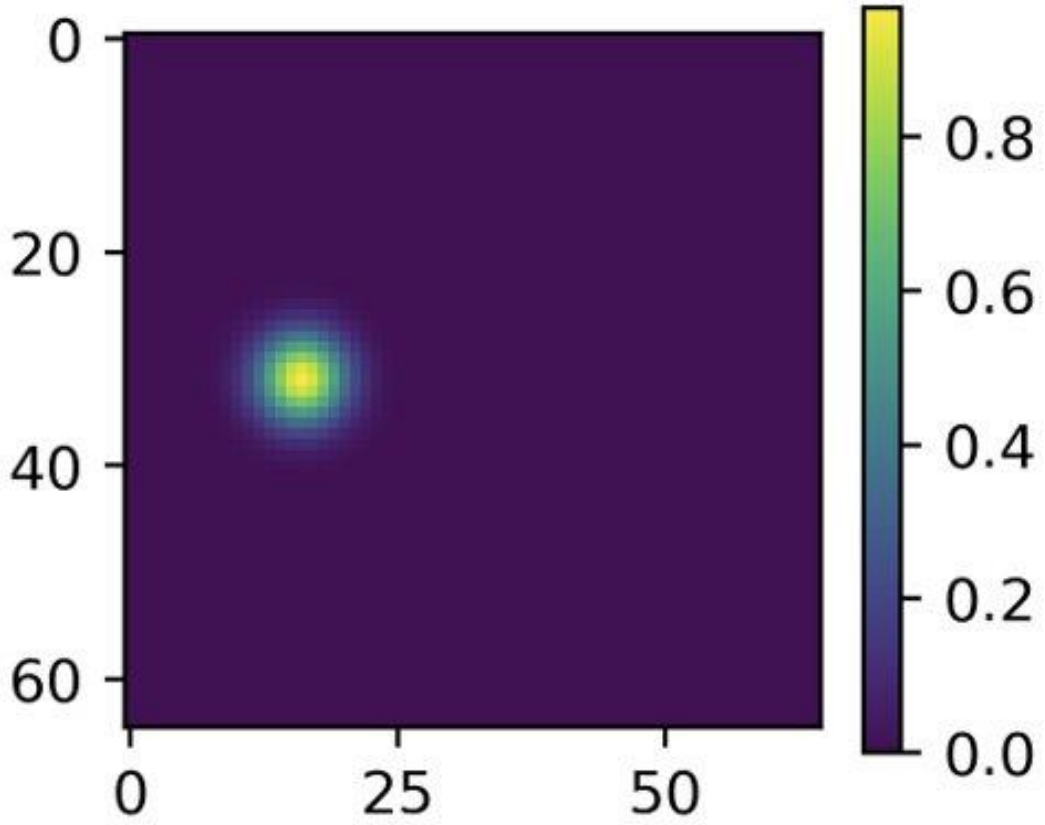
Flow and Transport with density contrast

Test case setup

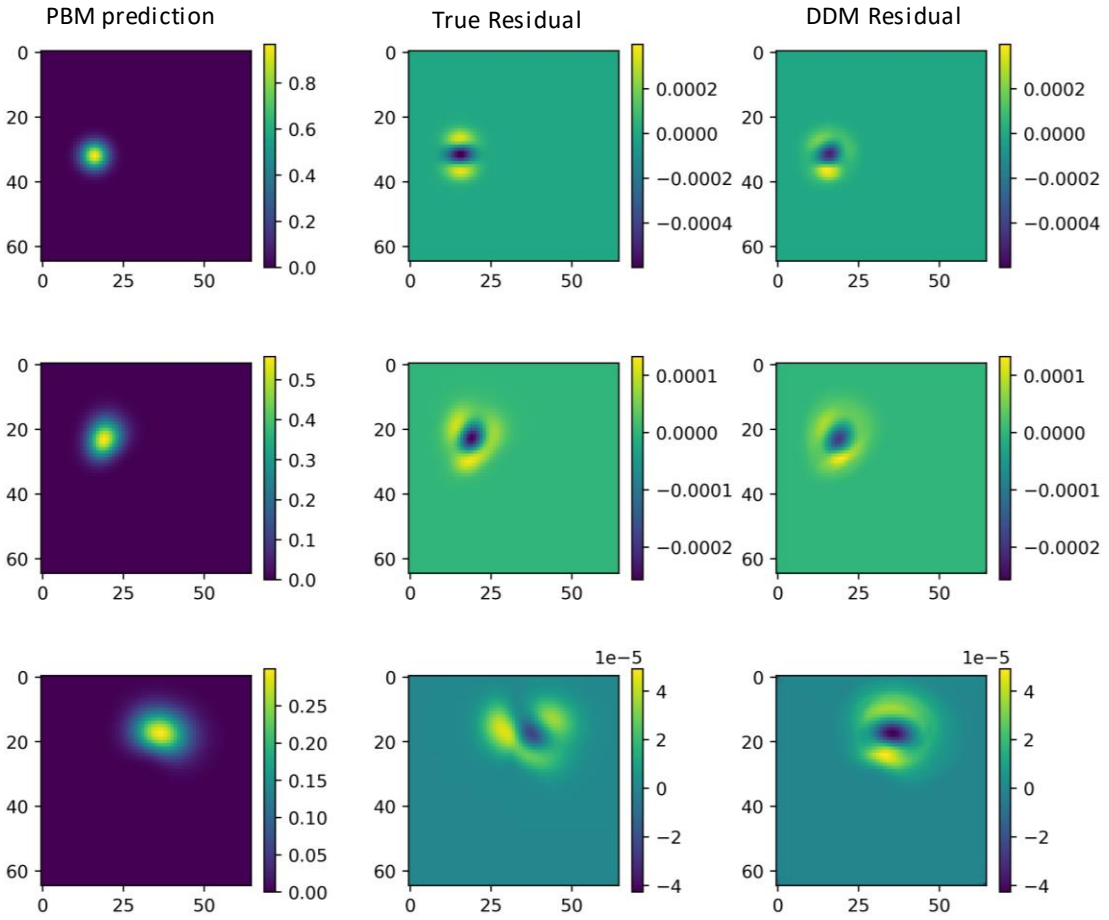
- Transport problem without dispersion

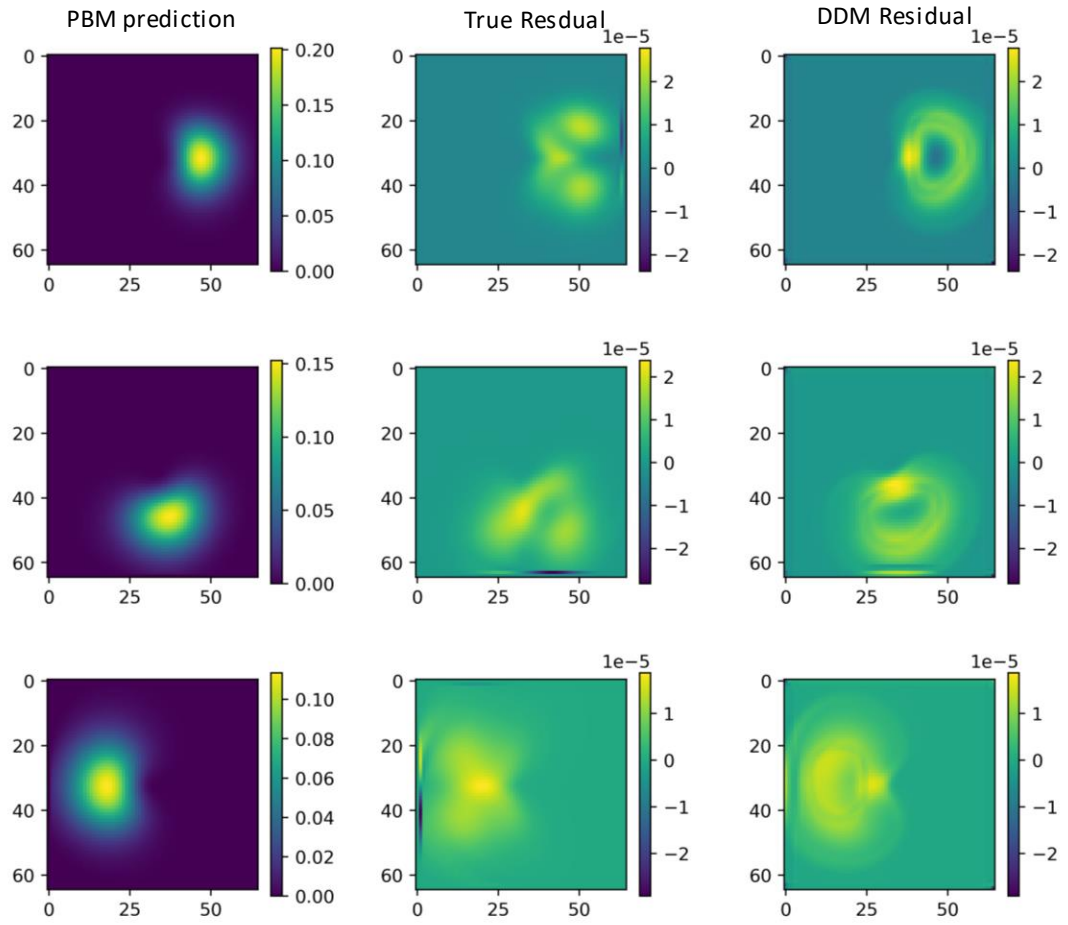
$$\partial_t c + \nabla \cdot (cq) = 0$$

- Flux prescribed as circular
- Initial tracer concentration to the right
- Simulate one rotation
- (Density contrast effects only in the "physical asset")



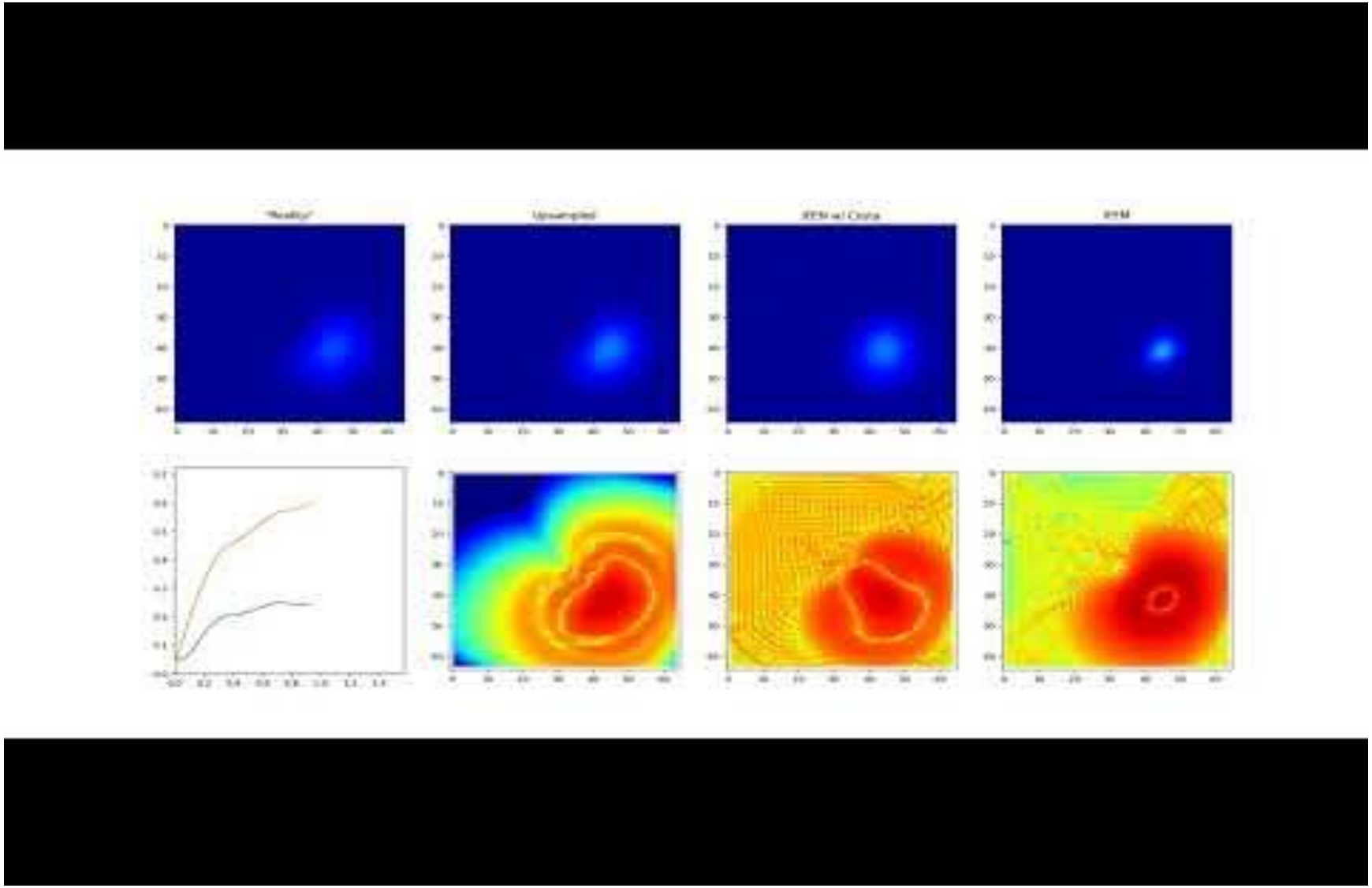
Test case I without hidden physics



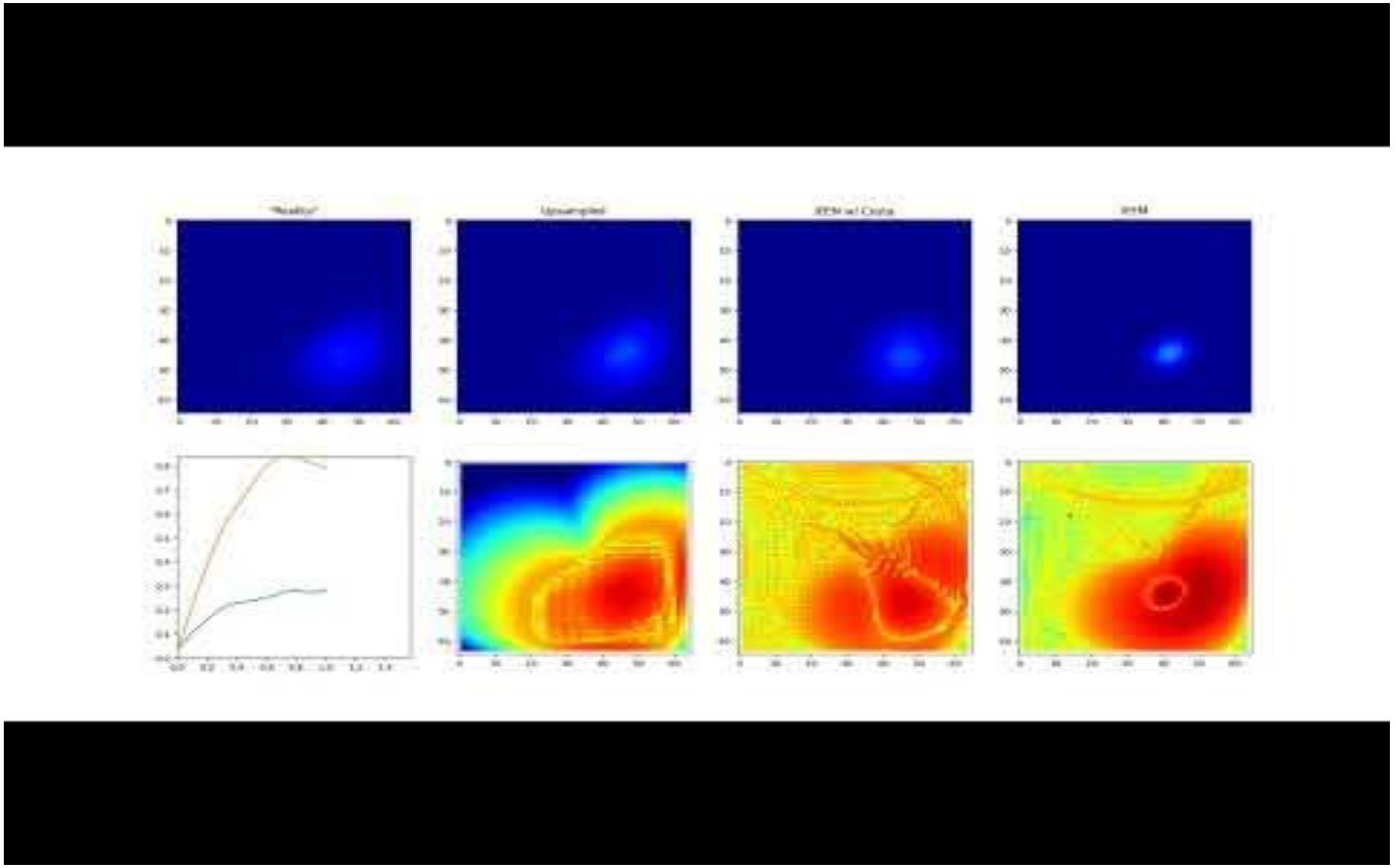


DDM makes FE-code learn FV.

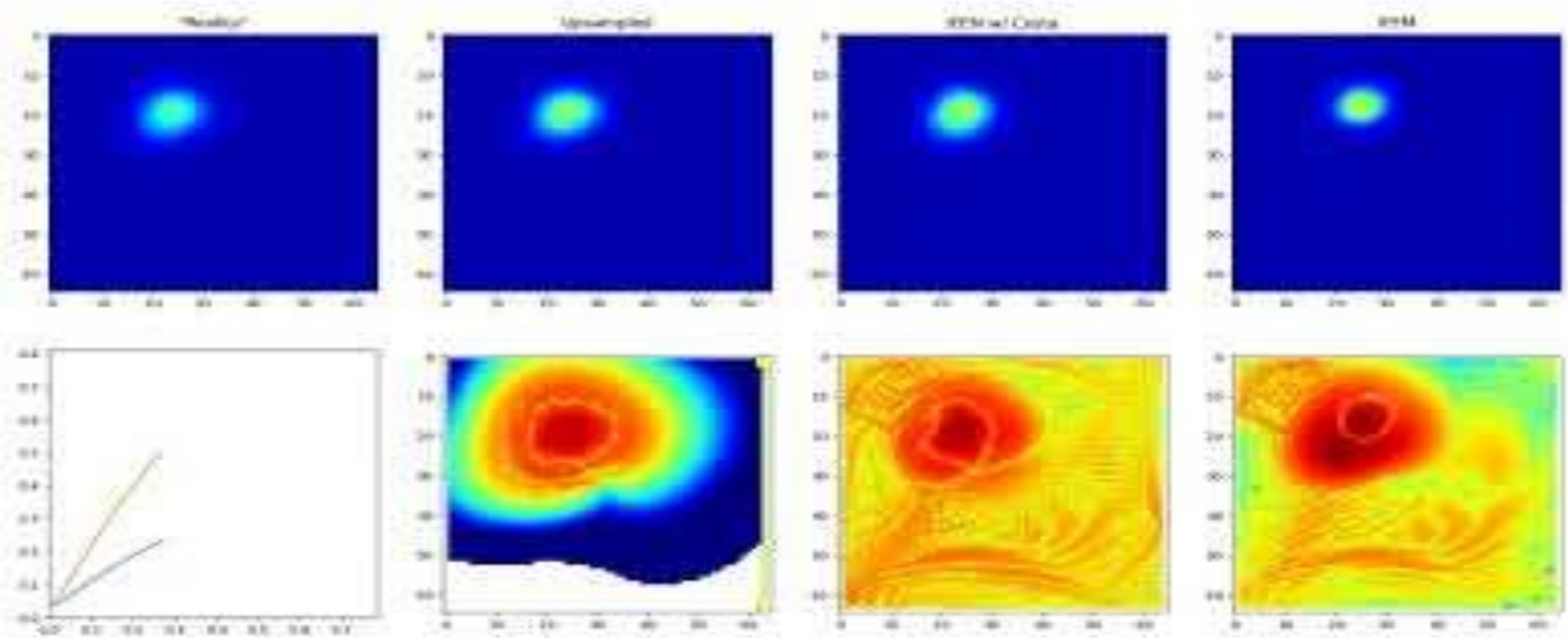
Test case I without hidden physics



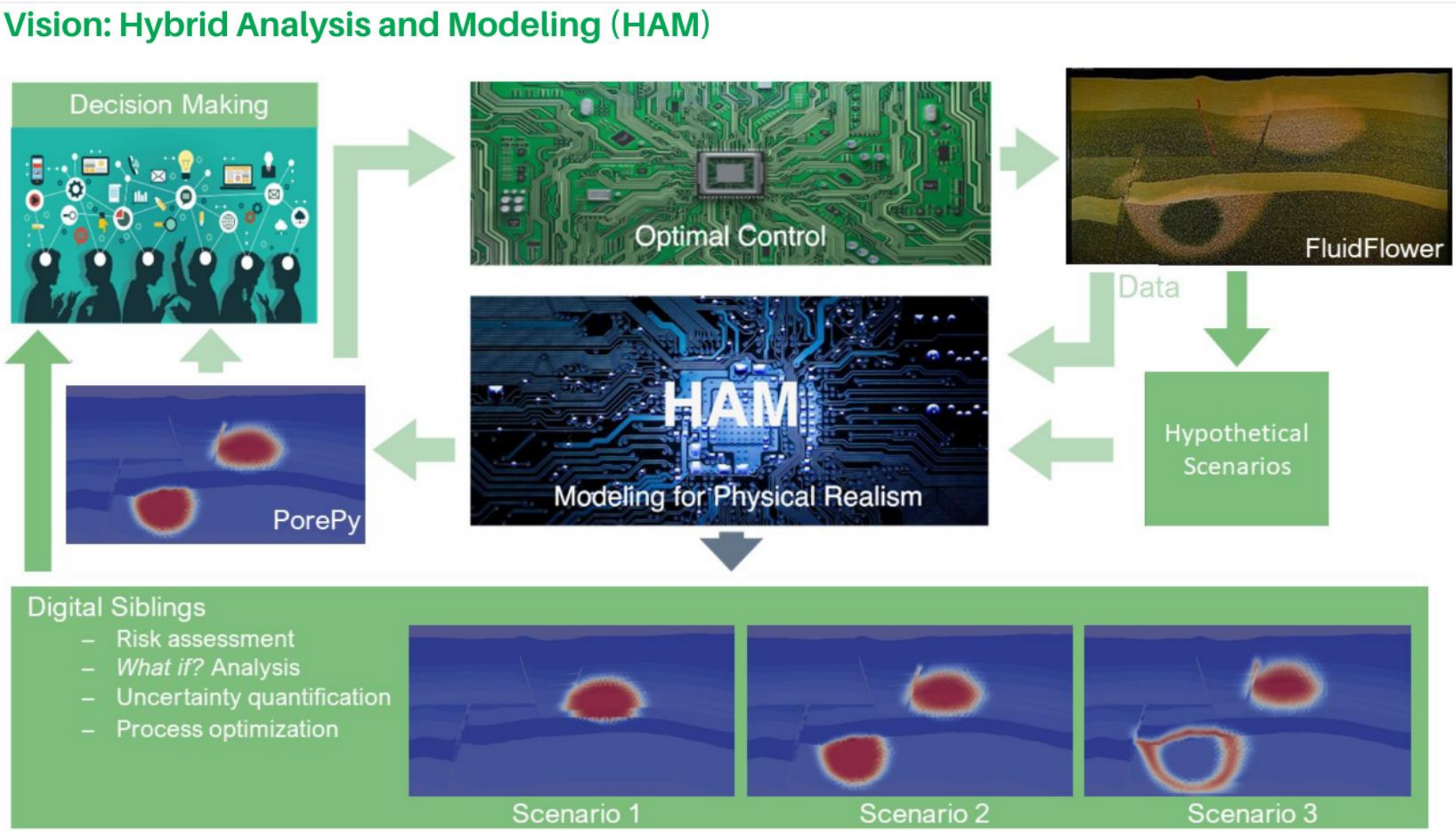
Test case II with hidden physics (lighter tracer)



Test case III with hidden physics (heavier tracer)



Outlook


Vision: Hybrid Analysis and Modeling (HAM)
Decision Making
Optimal Control
FluidFlower
Data
HAM
Modeling for Physical Realism
Hypothetical Scenarios
PorePy
Digital Siblings
– Risk assessment
– What if? Analysis
– Uncertainty quantification
– Process optimization
Scenario 1
Scenario 2
Scenario 3