DARTS workshop

Operator-Based Linearization approach: general idea and implementation

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Motivation

Increasing need for a fast simulation:

- High resolution models
- History-matching
- Optimization
- Uncertainty quantification
- More complex physics

How to improve performance?

- Decrease complexity
  - Physics
  - Upscale
  - Multiscale

- Increase computational power
  - Multicore systems with shared memory
  - Clusters with distributed memory
  - Manycore architectures (GPU, Xeon Phi)

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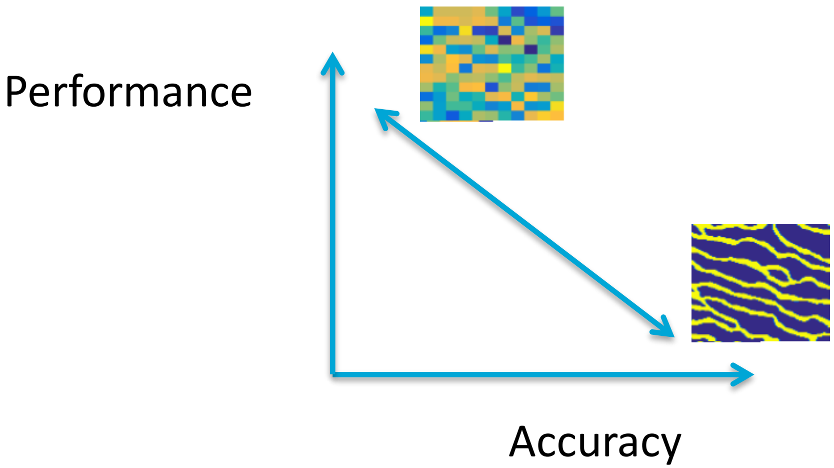
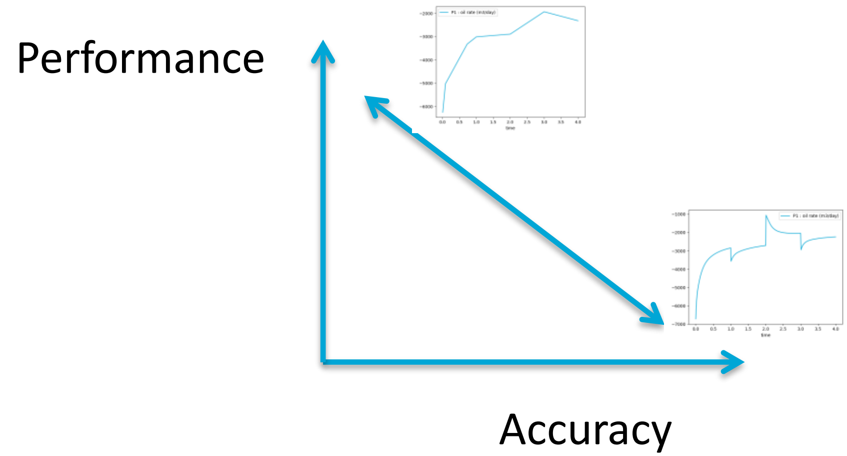
Discretization in reservoir simulation

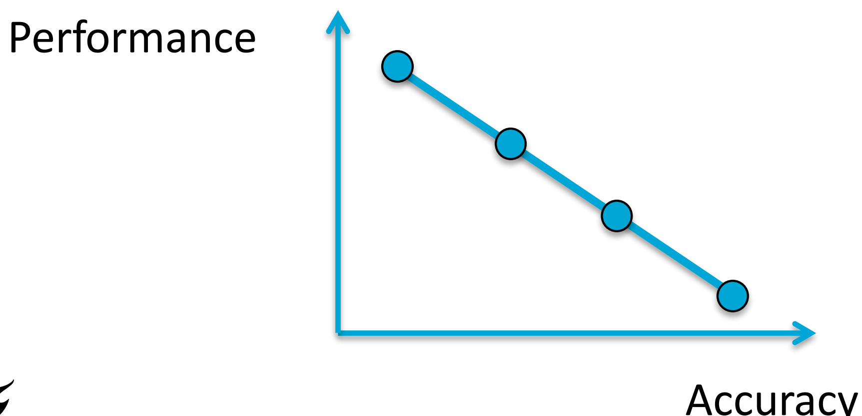
Space

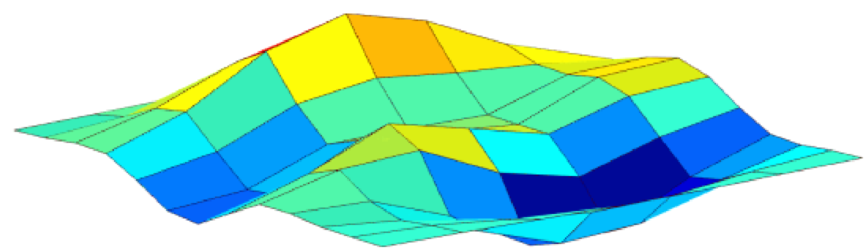


Time



Physical properties





Forward simulation requirements

Robustness - Fully Implicit Method

- is unconditionally stable
- results in highly nonlinear equations

Efficiency - nonlinear solution

- advanced nonlinear solvers
- physics-based linear solvers
- implementation on advanced architectures

The linearization procedure is important

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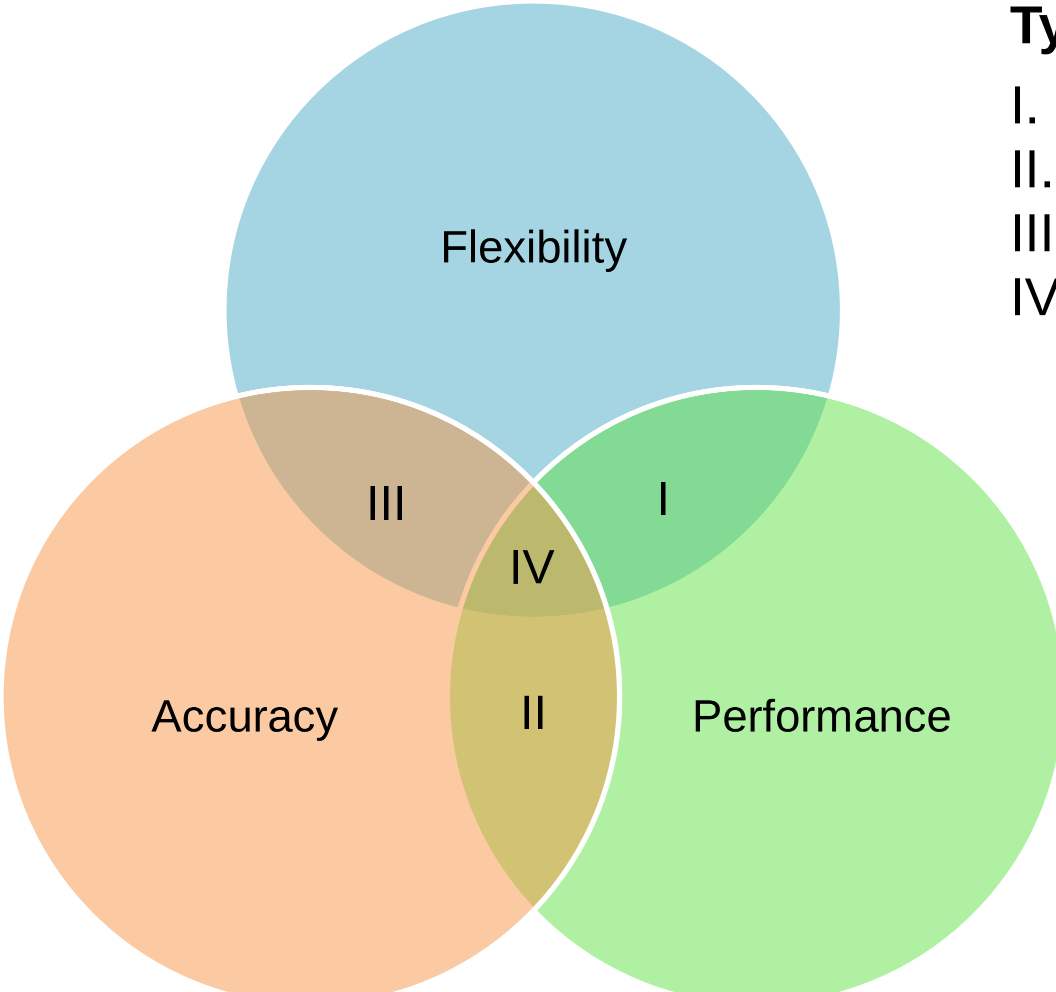
Fully implicit: how to linearize equations?



Types of linearization:

I. Numerical
II. Analytical
III. Automatic Differentiation
IV. Operator-Based Linearization (OBL)

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Operator form of equations

$$V\phi\left[\left(\sum x_{cj}\rho_j s_j\right)^{n+1}-\left(\sum x_{cj}\rho_j s_j\right)^{n}\right]-\Delta t\sum_{k\in L}\sum_{j=1}^{n_p}\left(x_{cj}\rho_j\lambda_j\Gamma\right)^l\left(p-p^l\right)=0$$

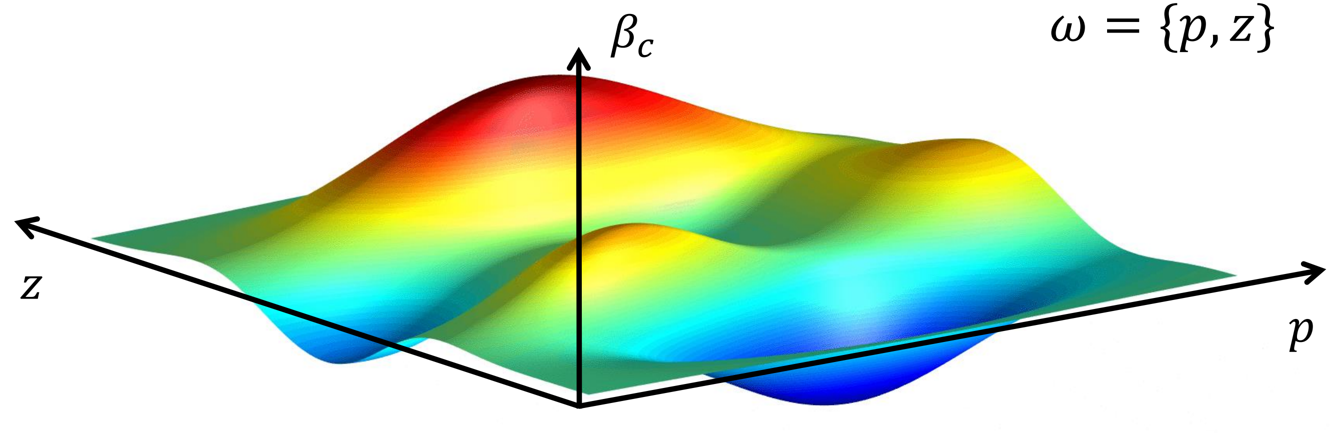
$$\phi_0 V[\alpha_c(\omega)-\alpha_c(\omega_n)]+\sum_k \Delta t\Gamma^l(\omega_1^l-\omega_1\ )\beta_c(\omega)=0$$

$\omega=\{p,z_1,\ldots,z_{n_c-1}\}$ (can include *T* or *h* for thermal)

$\alpha_c(\omega)=c(p)\ \sum_{j=1}^{n_p} x_{cj}\rho_j s_j,\qquad \beta_c(\omega)=\sum_{j=1}^{n_p} x_{cj}^l\rho_j^l\frac{k_{rj}^l}{\mu_j^l}$

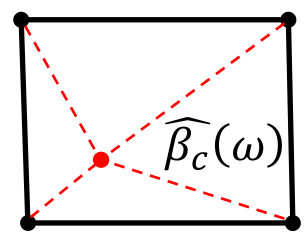
Operator-Based Linearization

$$\omega = \{p, z\}$$



$$\beta_c(\omega^1) = \sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\beta_c(\omega^2) = \sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$



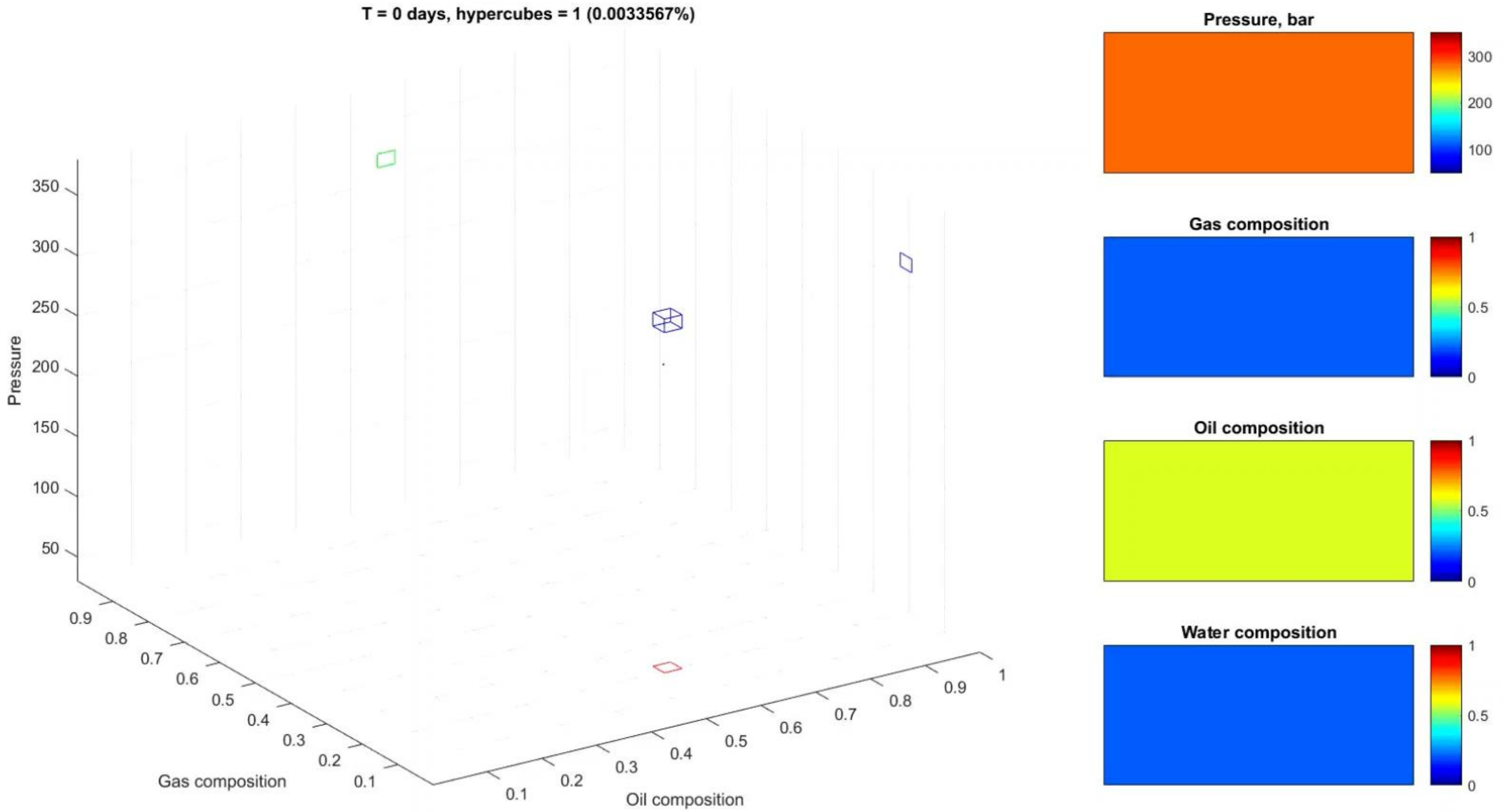
$$\beta_c(\omega^3) = \sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\beta_c(\omega^4) = \sum_{j=1}^{n_p} x_{cj}^l \rho_j^l \frac{k_{rj}^l}{\mu_j^l}$$

$$\left|\widehat{\beta_c} - \beta_c\right| \leq cV^2 \sup_{\omega} \left|\nabla^2 \beta_c\right|$$

Voskov (2017)

Adaptive parametrization



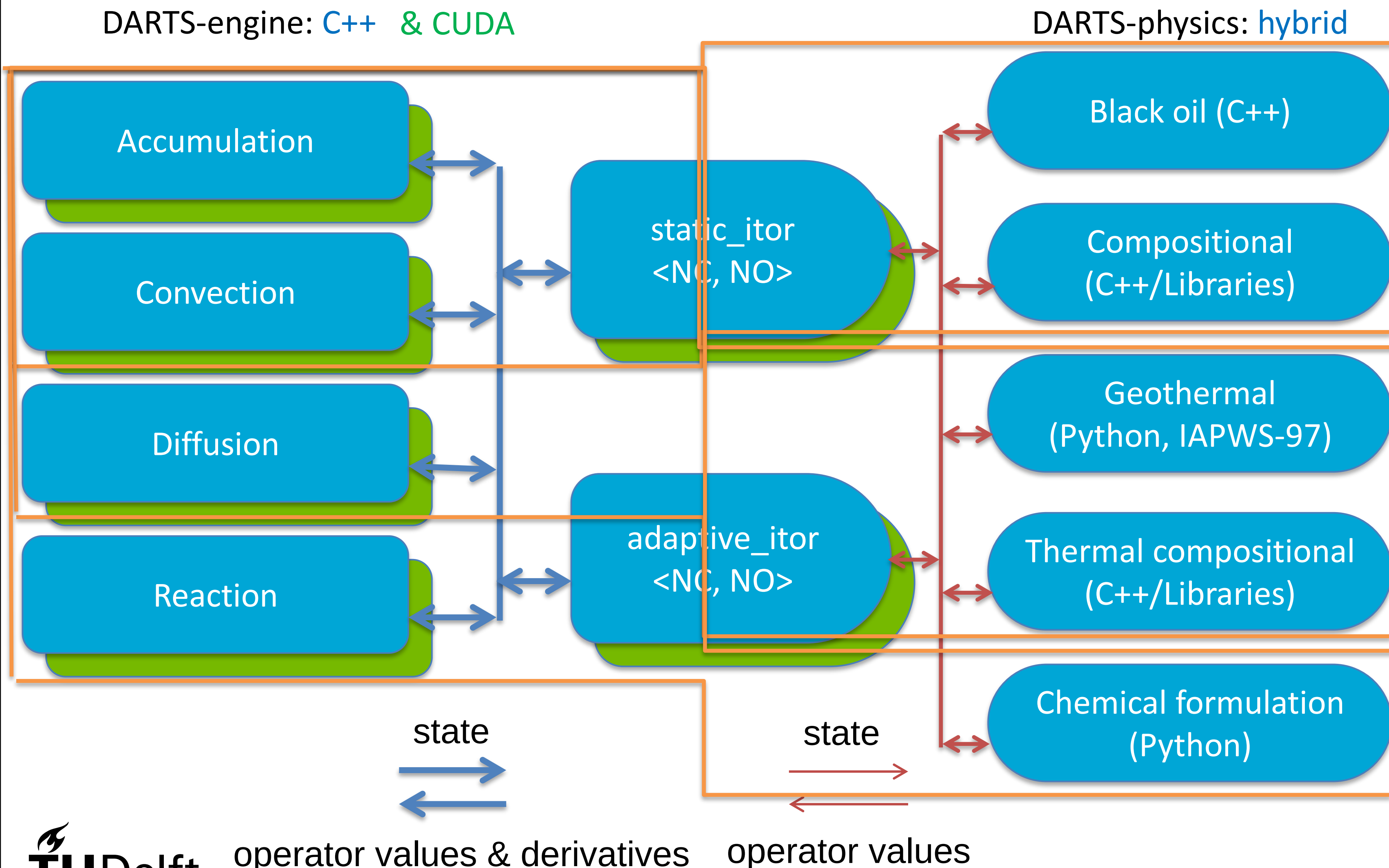
Khait and Voskov (2018)

Delft Advanced Research Terra Simulator in numbers

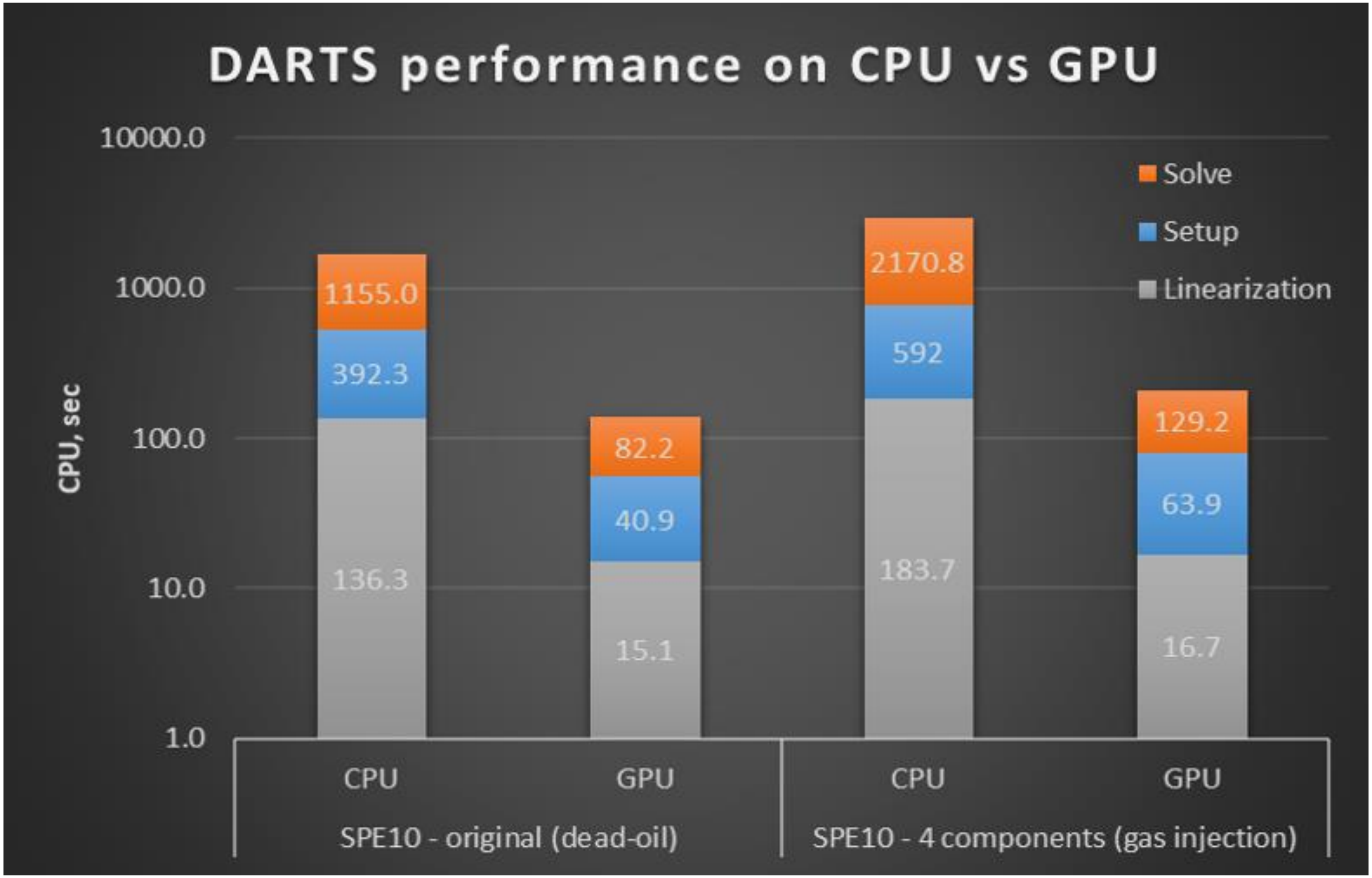
- 6 PhD and 1 PD projects
- 9 MSc projects defended so far
- Advance performance of simulation:
  - Around 100 times faster than average COMSOL model,
  - 3-5 times faster vs. state-of-the-art research simulators (ADGPRS, TOUGH2),
  - Close to performance of commercial simulators,
  - Fully GPU version is ready (6-15 times faster).
- Various physics included: convection, thermal conduction, diffusion, gravity, capillarity, chemistry (kinetic and equilibrium)
- Variety of applications: geothermal, black-oil, thermal-compositional, EOR, gas storage, hydrates etc.

https://darts.citg.tudelft.nl/

DARTS architecture



DARTS-GPU



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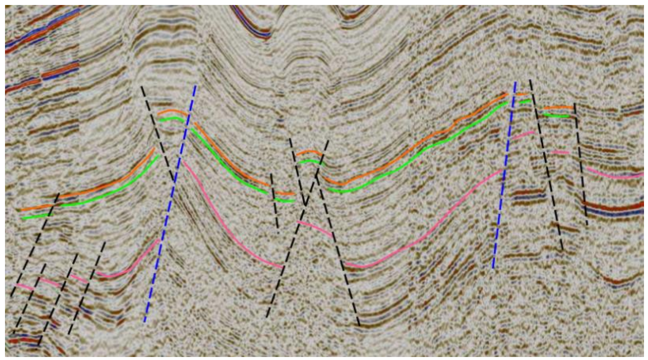
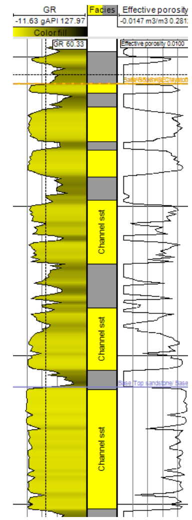
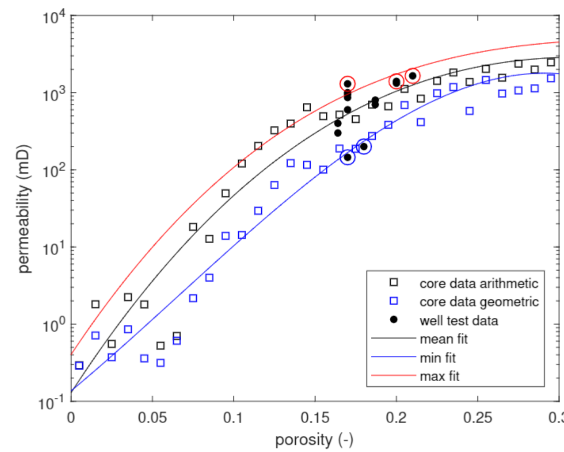
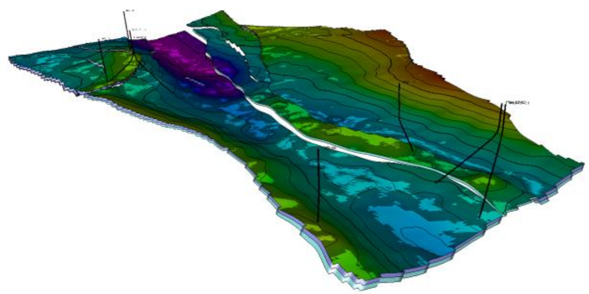
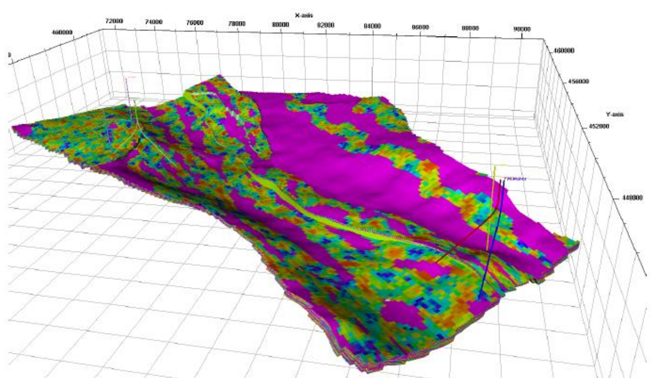
Den Haag project: sensitivity study

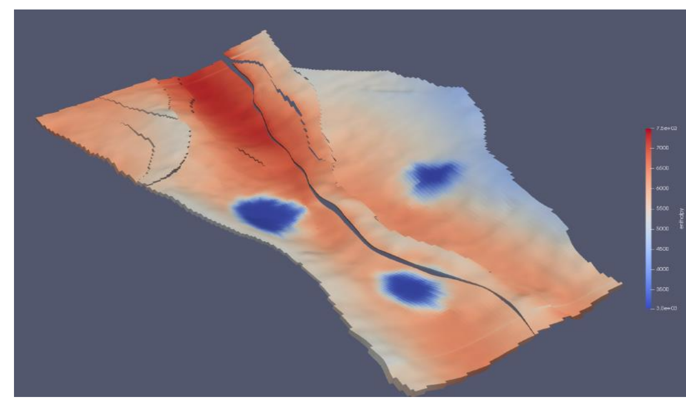












Perkins (2019)

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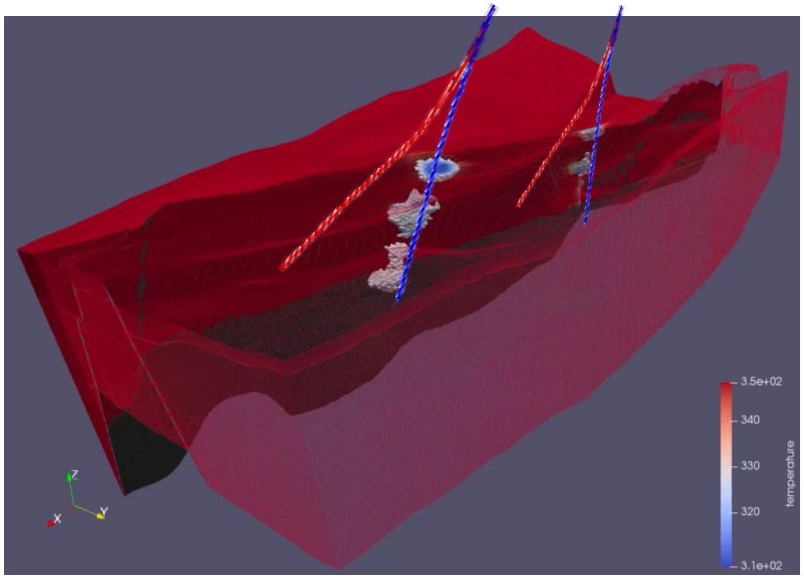
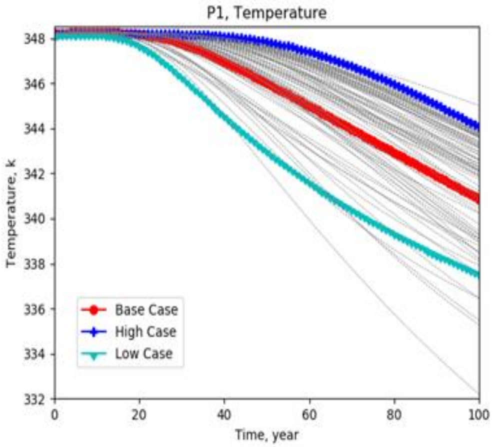
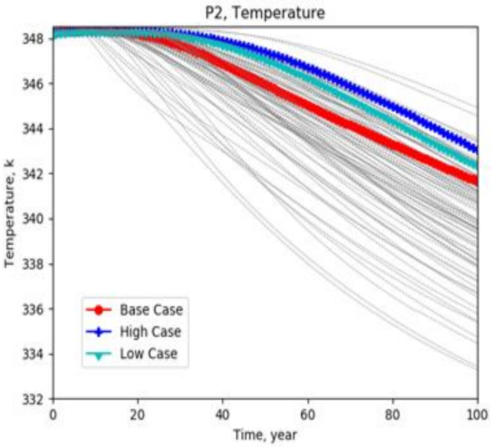
CRECCIT project: sensitivity

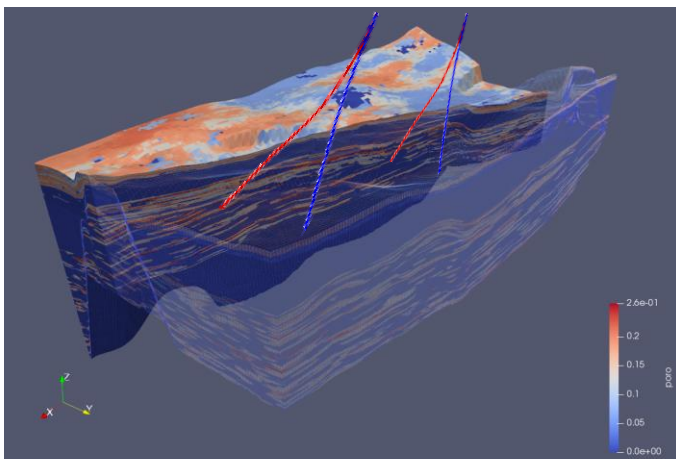
- One doublet has been drilled
- High uncertainty: well logs from the production well are only available
- Second doublet has been planned based on P50 case of first doublet
- We showed that use P50 scenario based only on one well data is misleading

3.2M grid blocks, 100 years of simulation



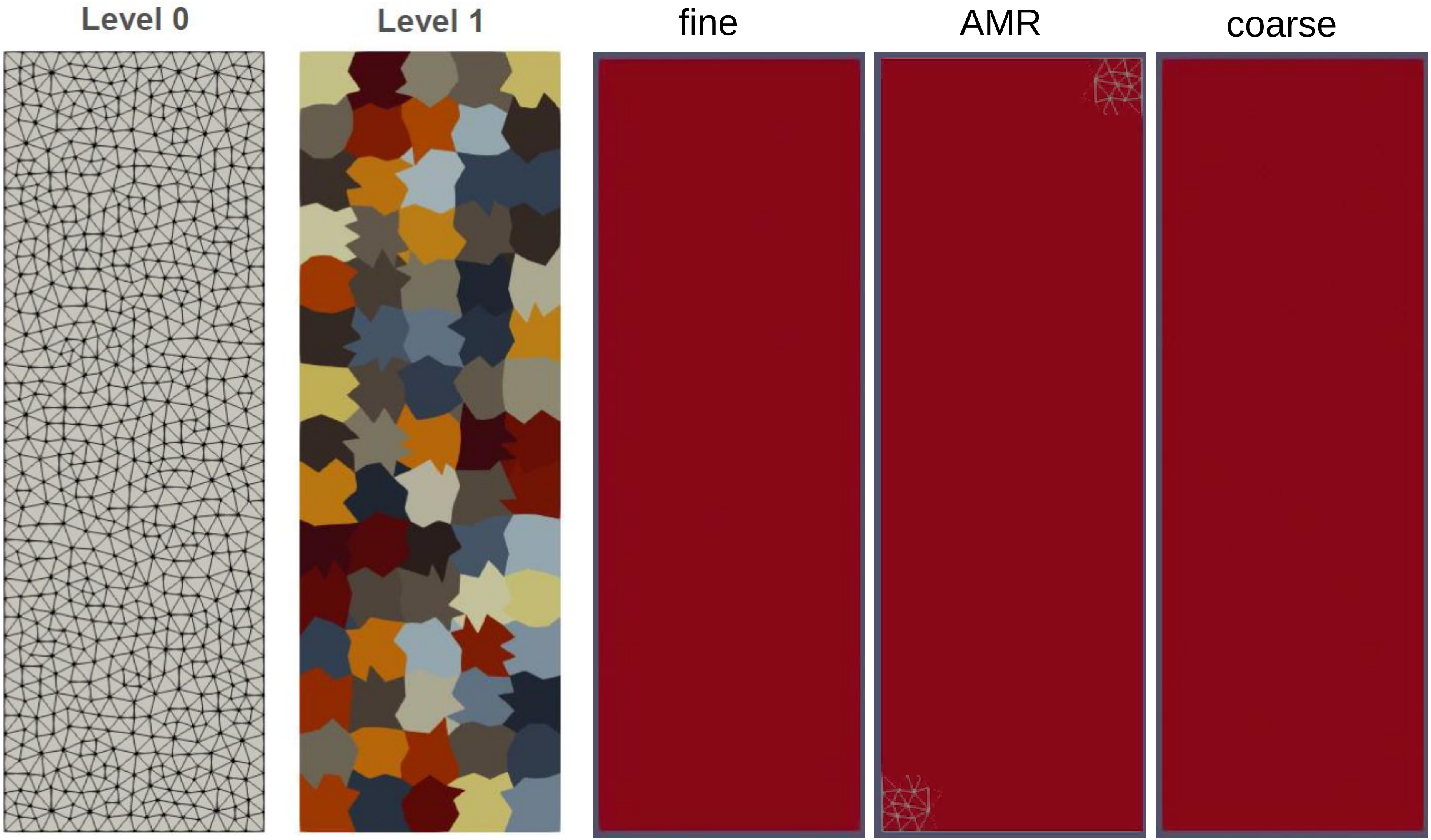






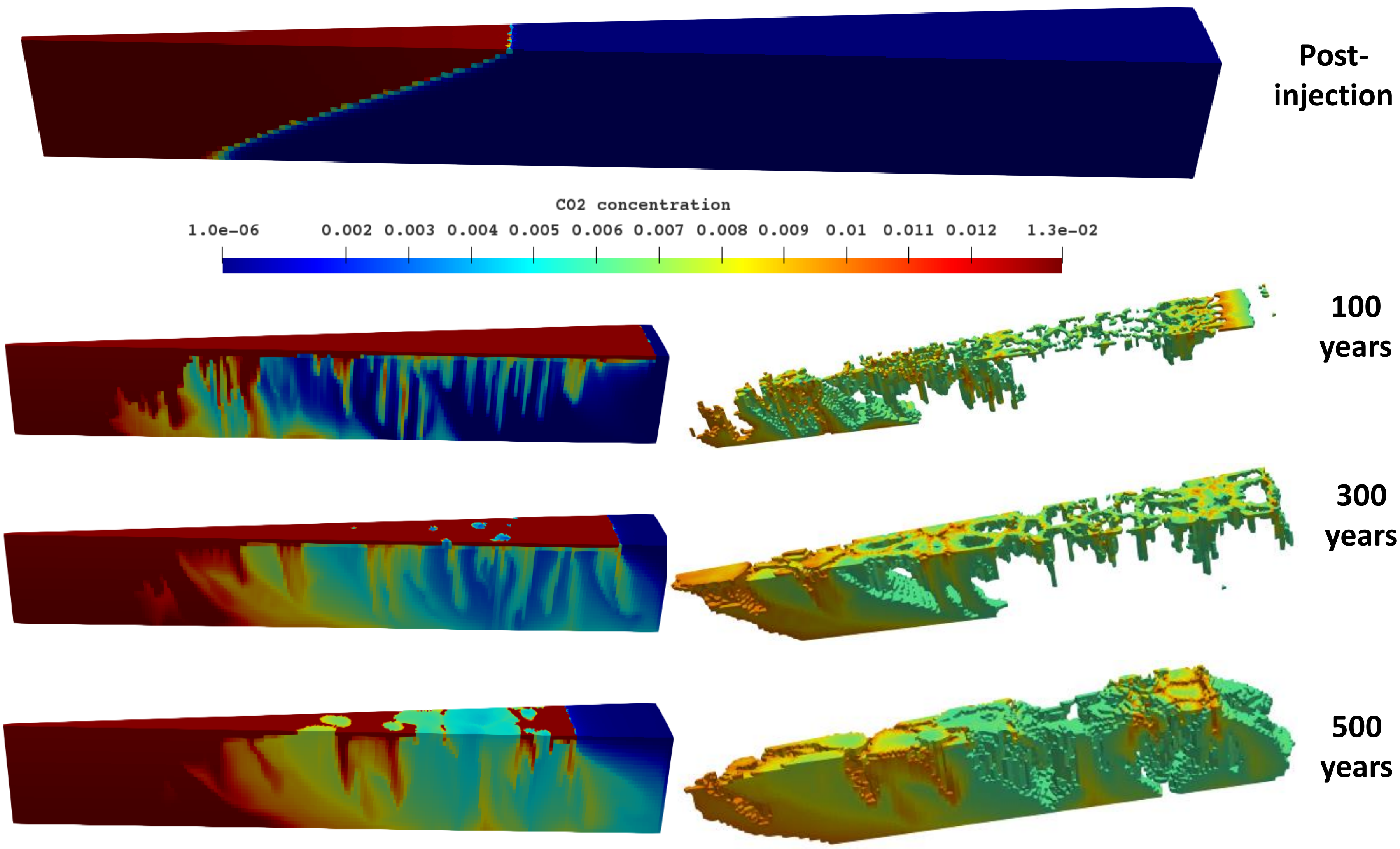
Saied et al. (2020)

Adaptive Mesh Refinement



Jones (2019)

Supercritical CO2 dissolution in aqueous brine



Morshuis (2019)

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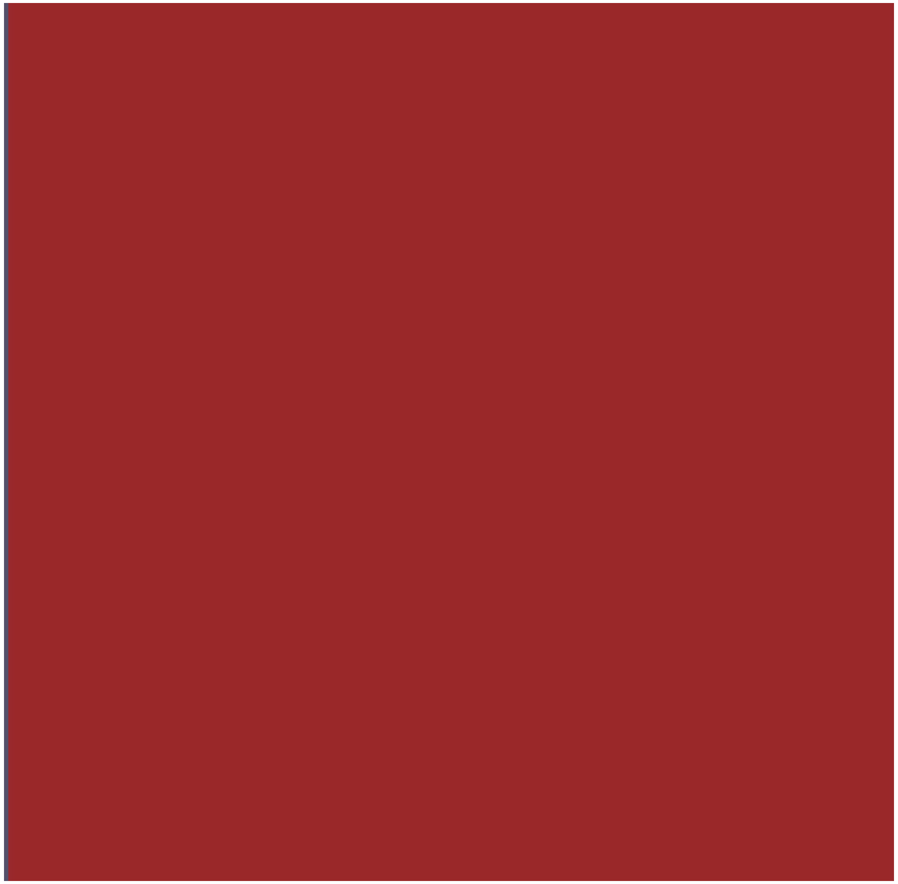
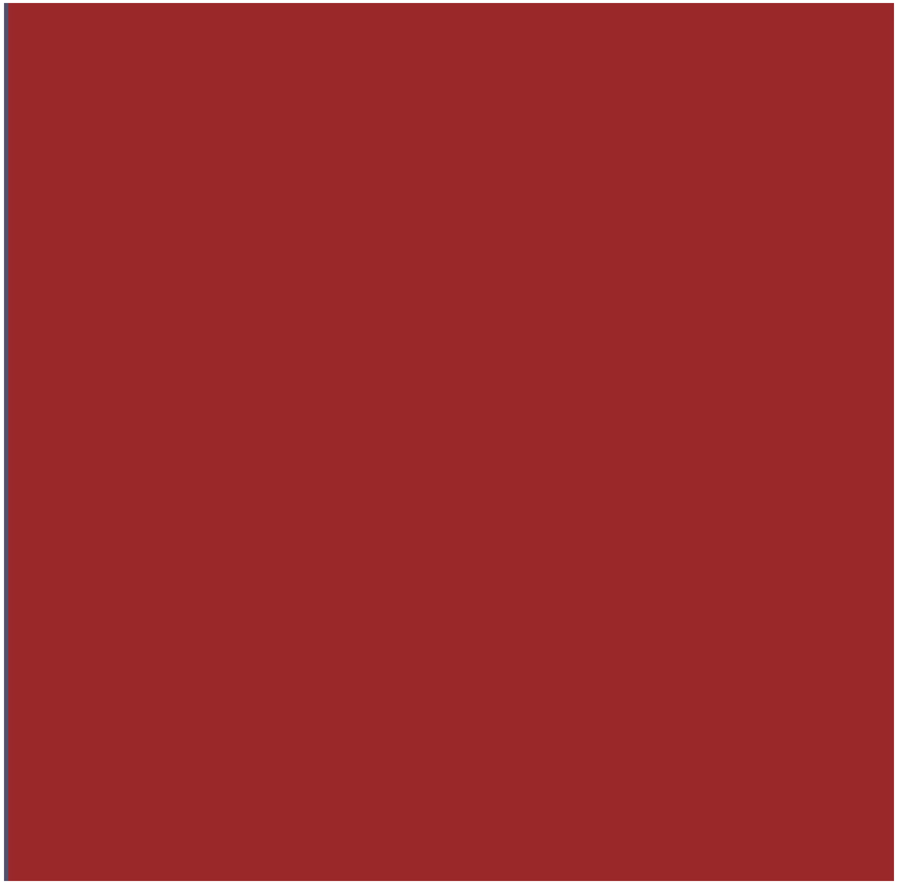
Carbonate dissolution

Fast kinetic



k_{rate} = 0.005 [1/day] → Da = 12.5

Slow kinetic



k_{rate} = 5e-7 [1/day] → Da = 1.25e-3

de Hoop and Voskov (2018)

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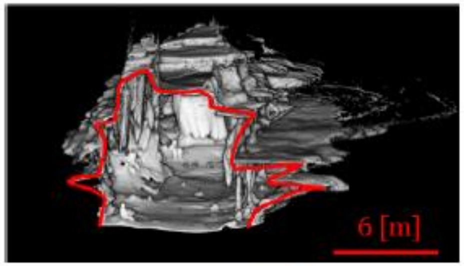
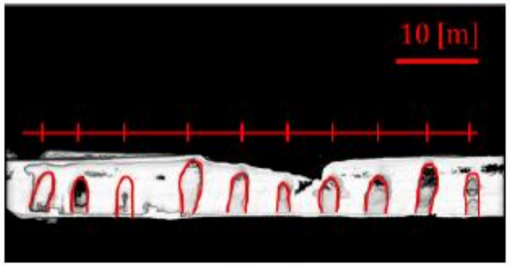
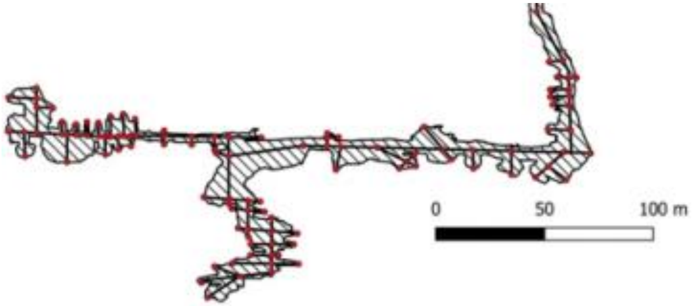
Modeling of dissolution in fractured networks

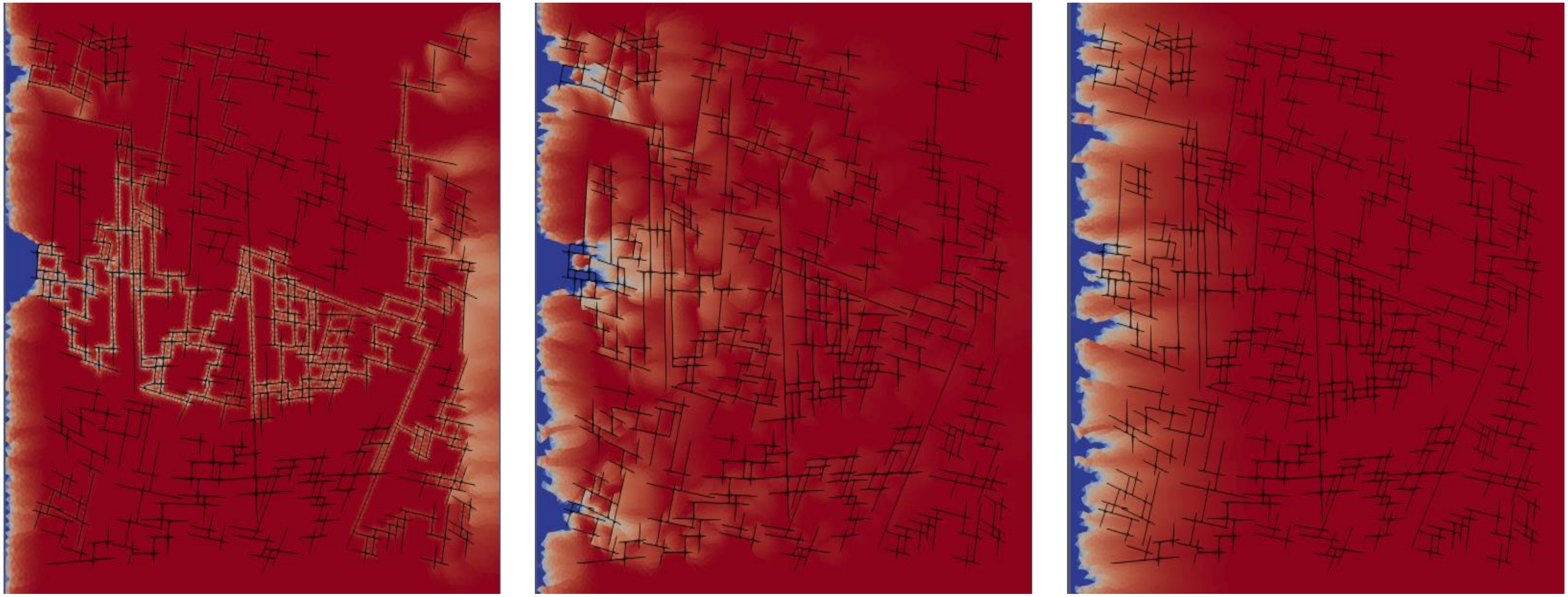


Cave "Ioio"



Cave "Torrinha"

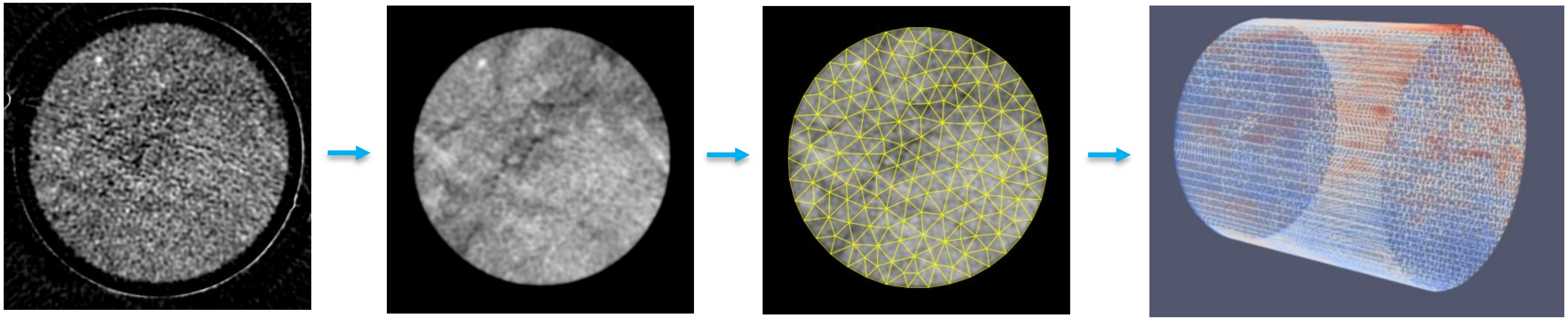




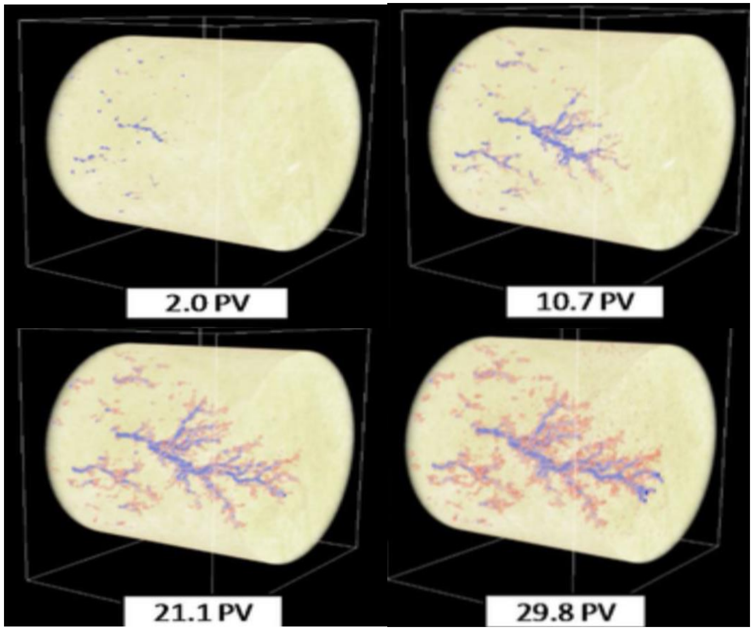
Decrease fracture aperture

Modeling of dissolution in core

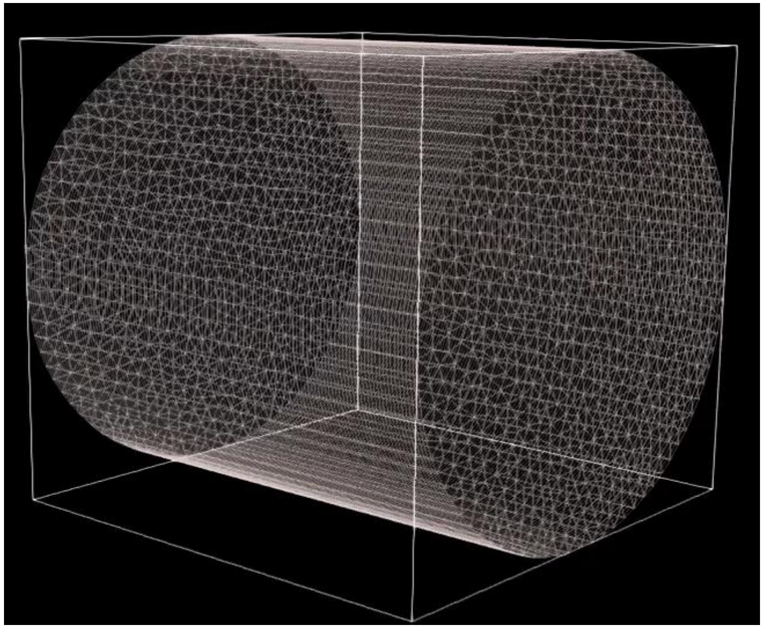
Step 1: porosity interpretation (image subtraction, filtering, gridding)



Step 2: modeling of dissolution (combination of DARTS + PHREEQC)

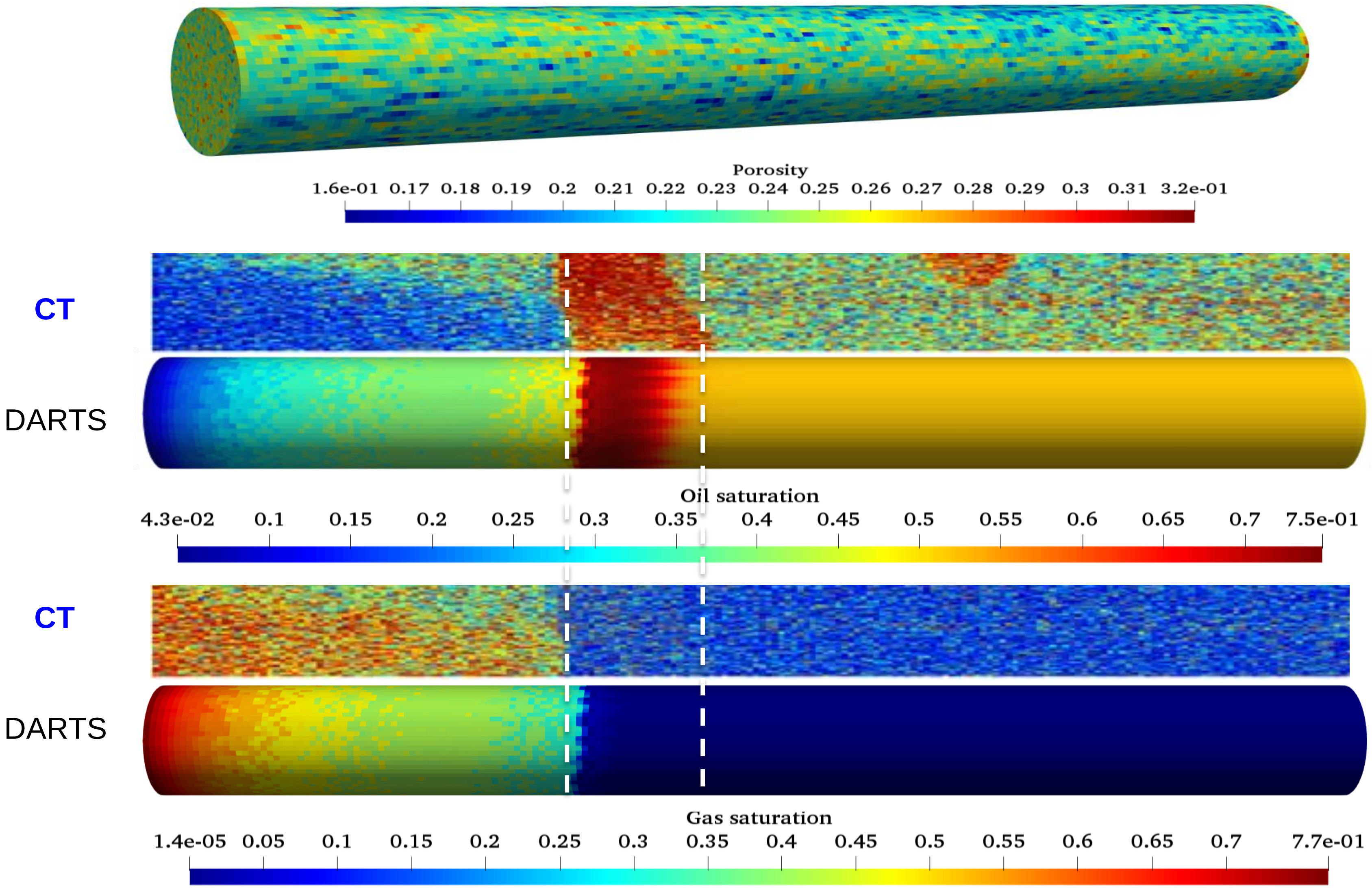


Snippe et al., 2019



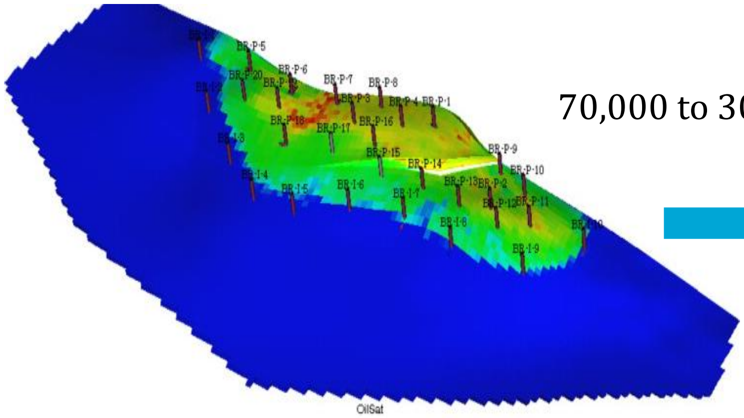
Margert, 2019

Modeling of foam CT experiments

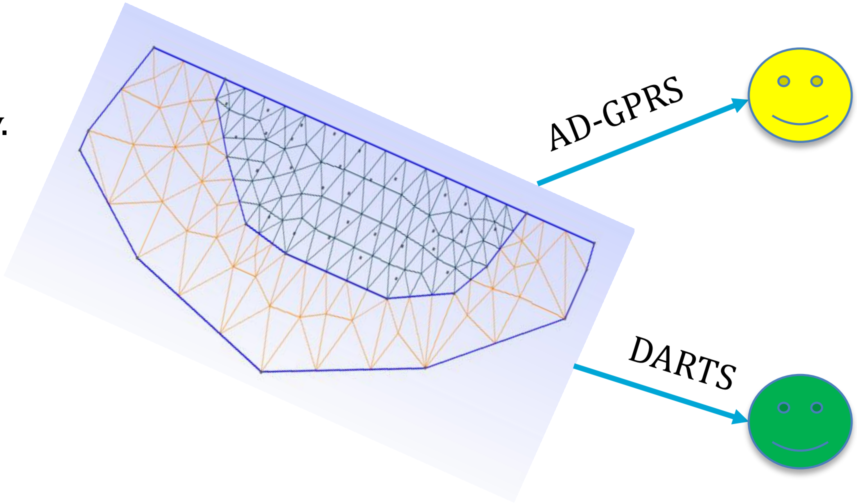


Tang et al. (2019)

Physics-based data-driven proxy model



70,000 to 300 c.v.



	High fidelity model	Proxy Model
Control volumes	~70 thousand	~300
Reservoir properties	Realization #73	Regressed to the data
Production data	20*120 days	20*120 days + coarsening
Simulation time (AD-GPRS)	645 seconds	8.3 seconds
Simulation time (DARTS)	97 seconds	0.46 -> 0.03 seconds

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Blinovs, 2019

Conclusion

- OBL framework proves to be
  - Accurate for various applications,
  - Flexible for complex extensions,
  - Highly efficient in terms of CPU,
  - Extendable to advanced architectures.
- New generation research code DARTS
  - New release will be delivered soon,
  - Easy to work with, but knowledge of reservoir simulation and Python is required.

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