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Developing numerical models for underground storage of synthetic natural gas
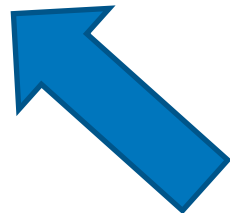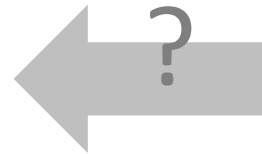
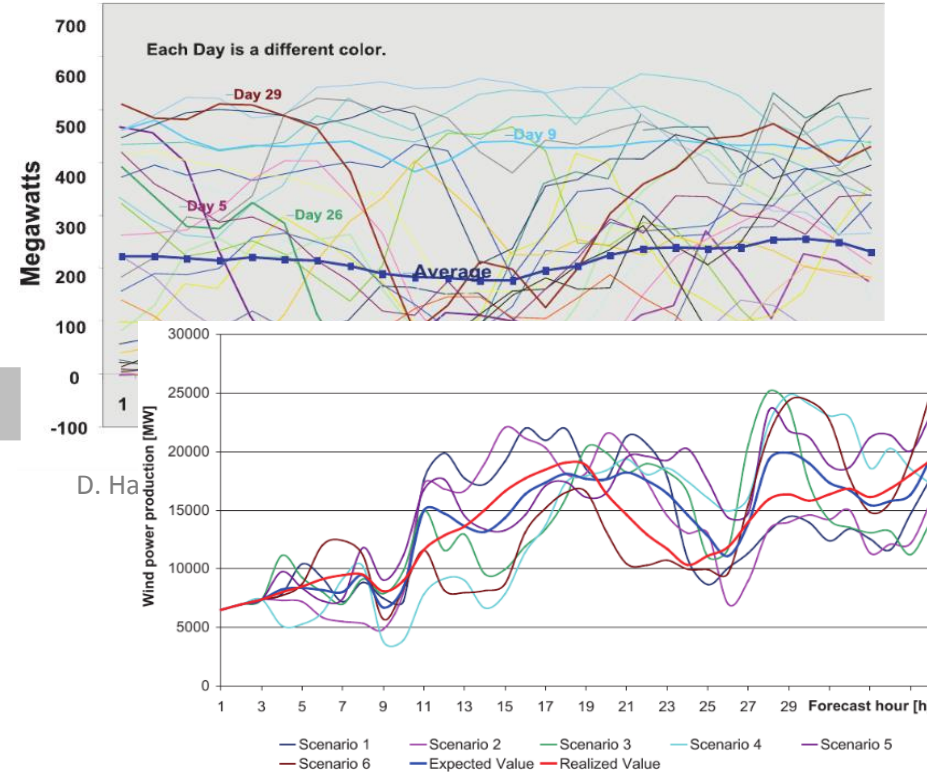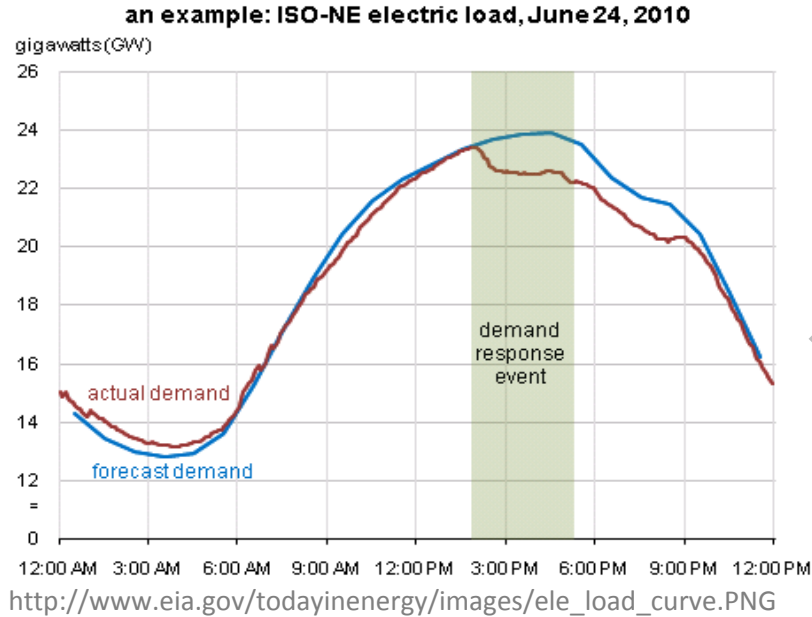**Beatrix Becker,** Bernd Flemisch, Rainer Helmig

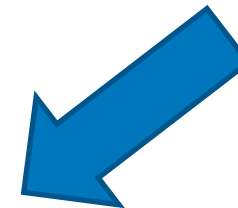University of Stuttgart

In cooperation with Bo Guo and Mike Celia

Princeton University

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Why energy storage?

an example: ISO-NE electric load, June 24, 2010

http://www.eia.gov/todayinenergy/images/ele_load_curve.PNG

D. Ha

P. Meibom, et al.

Energy storage

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General renewable energy storage concept

Conversion of electric energy

~40%

Power plant

Storage

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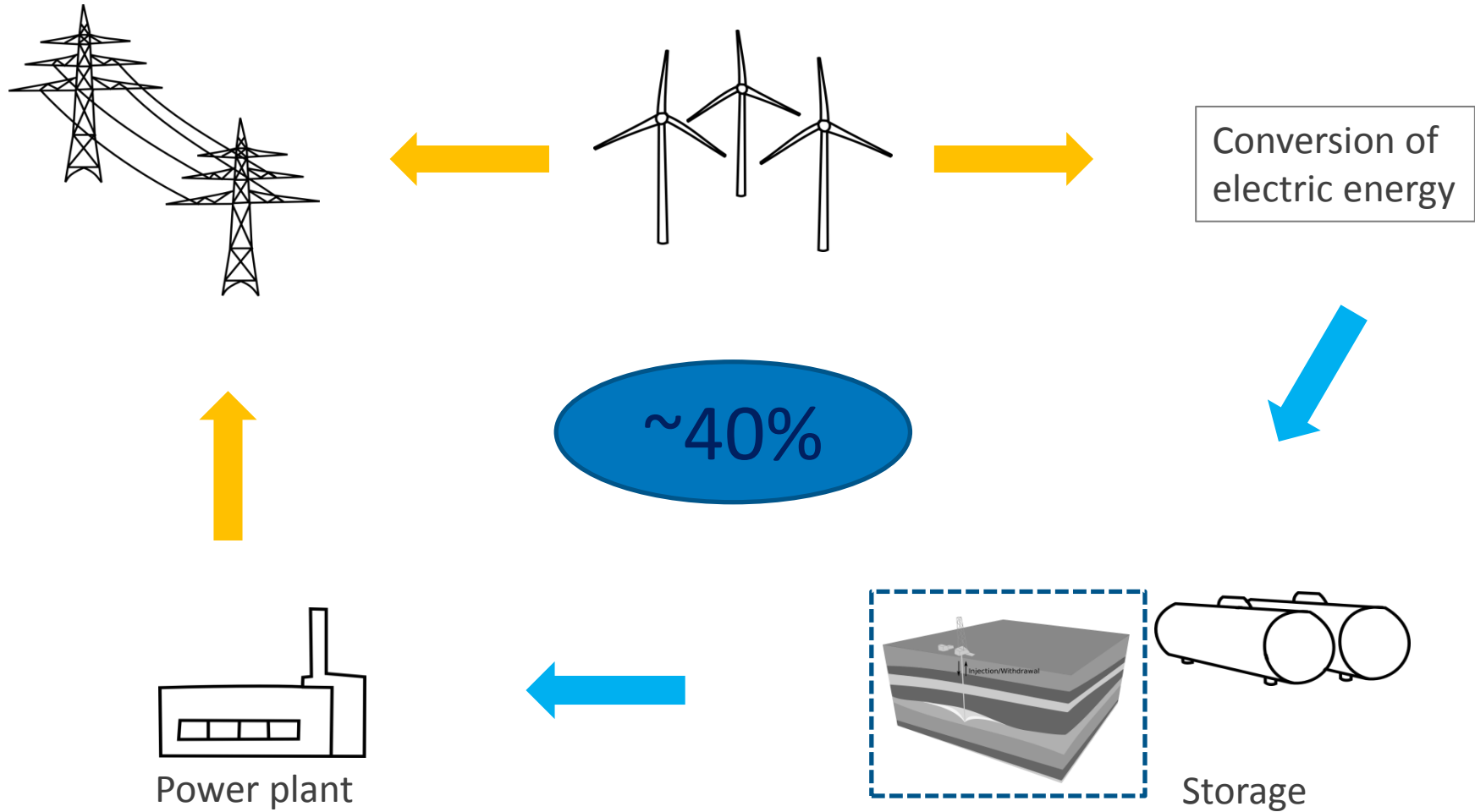
Subsurface energy storage options
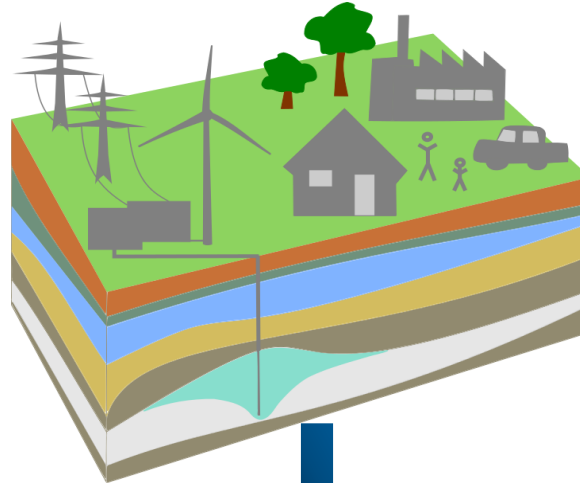
Mechanical	Chemical	Thermal
Compressed air energy storage	Hydrogen/SNG storage	Hot/cold water storage

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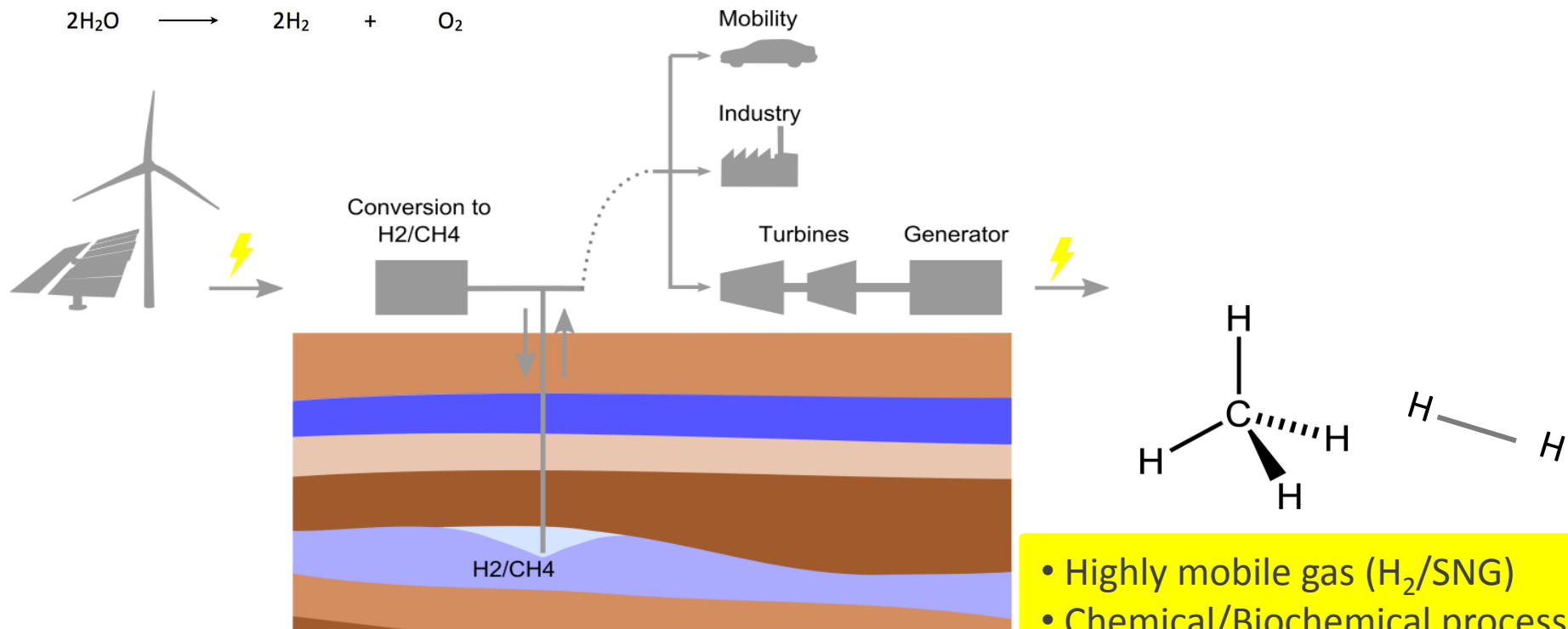Germany

Chemical underground energy storage

Electrolysis of water

Sabatier reaction

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$2H_2O \longrightarrow 2H_2 + O_2$$

Mobility

Industry

Conversion to
H2/CH4

Turbines   Generator

H2/CH4
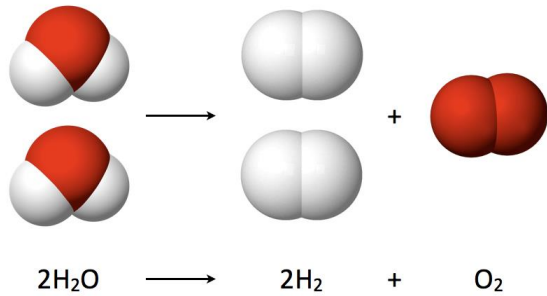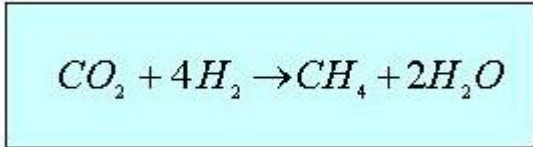
- Highly mobile gas (H_2/SNG)
- Chemical/Biochemical processes

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Subsurface storage facilities

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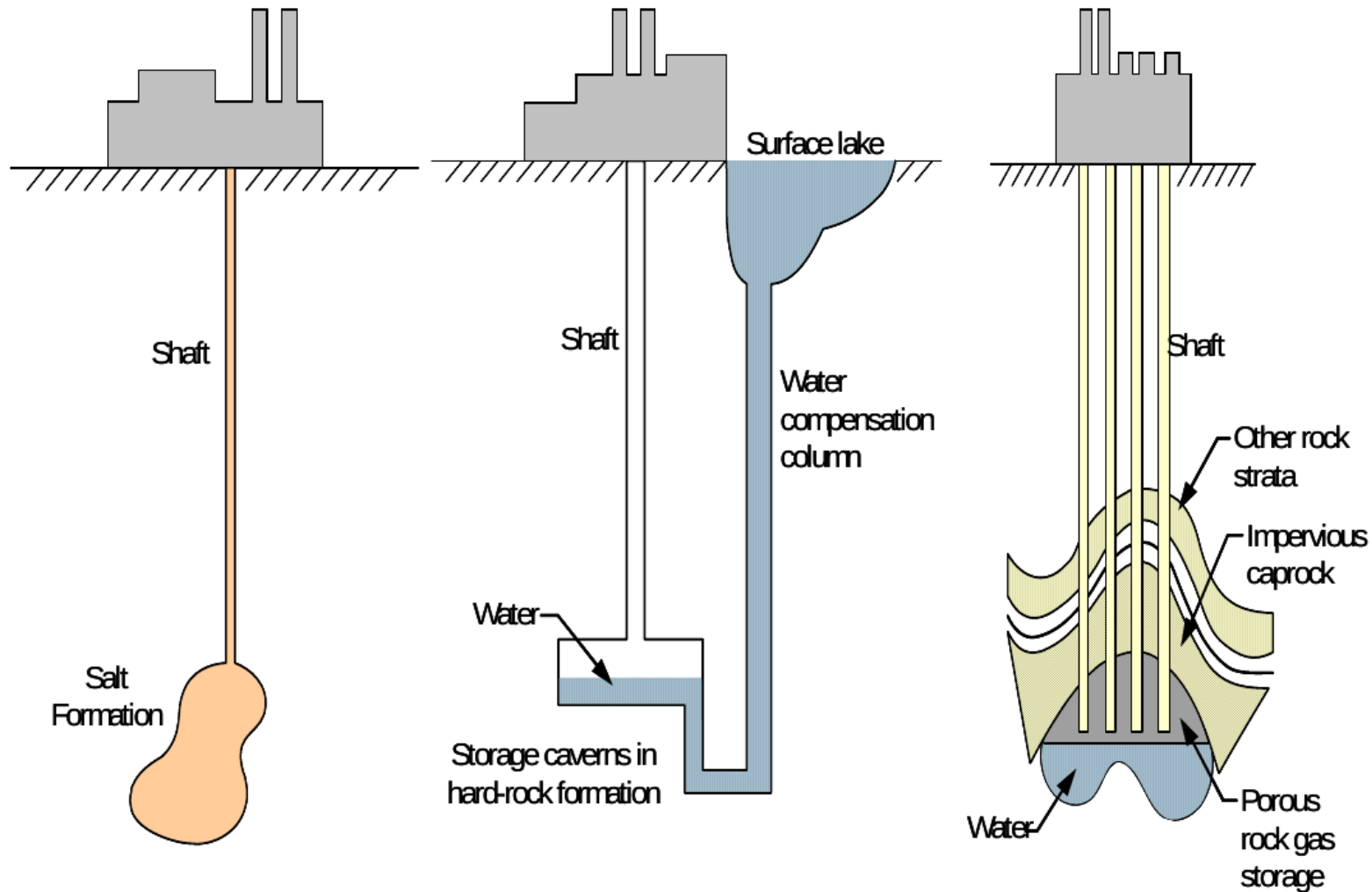
Why modeling energy storage?

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Leakage to surface

Influence groundwater flow pattern and quality

Leakage into groundwater

Mechanical stress

Groundwater contamination

Brine displacement

Structural failure

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Just a model…?

Faigle et al., 2013

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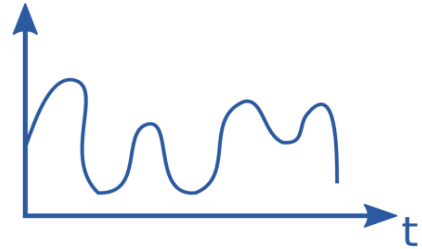
University of Stuttgart
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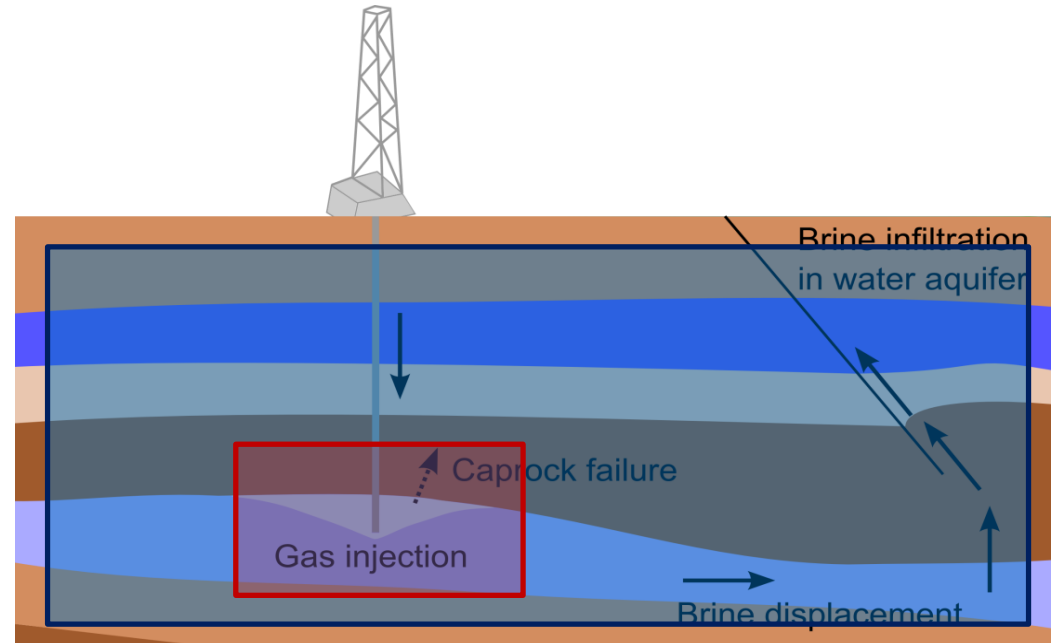# Modeling challenges

injection rate

t

Injection

Withdrawal

Fluctuations:
- daily
- weekly
- seasonally

Data:
- Limited data on geological parameters

Processes:
- Multi phase flow
- Compositional effects
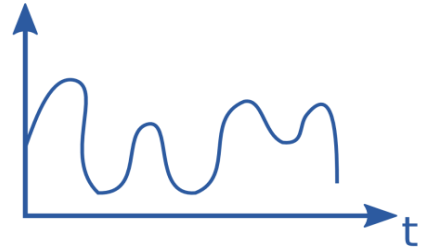- Non-isothermal
- Fingering
- Strongly hysteretic

Brine infiltration
in water aquifer

Caprock failure

Gas injection

Brine displacement

Highly complex   Less complex

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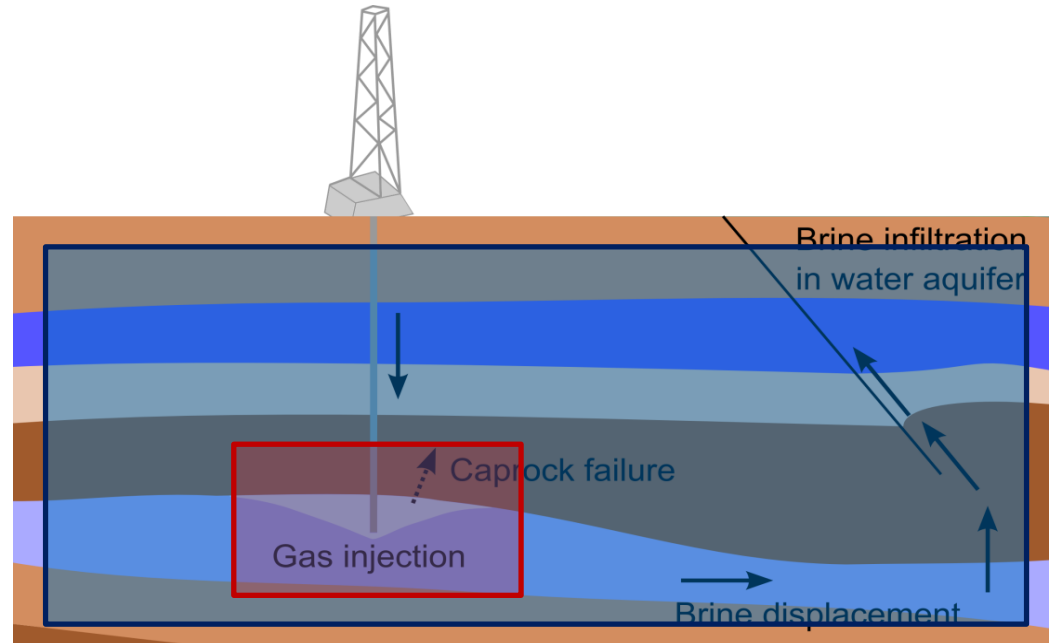
Modeling challenges

injection rate

t

Injection   Withdrawal

Fluctuations:
- daily
- weekly
- seasonally

Time and spatial scales:
• Dynamic boundary conditions
• Large domains, relatively large time scales
• Local features (fault zones, brine displacement zone...)
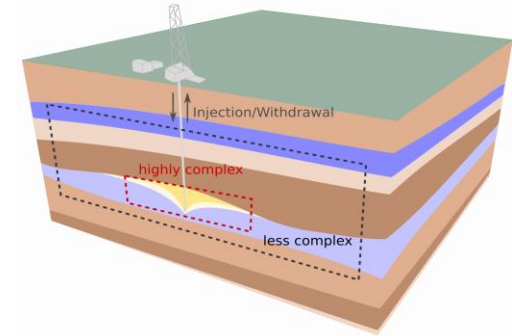• Locally highly complex processes, globally simple processes

Brine infiltration in water aquifer

Caprock failure

Gas injection

Brine displacement

Highly complex   Less complex

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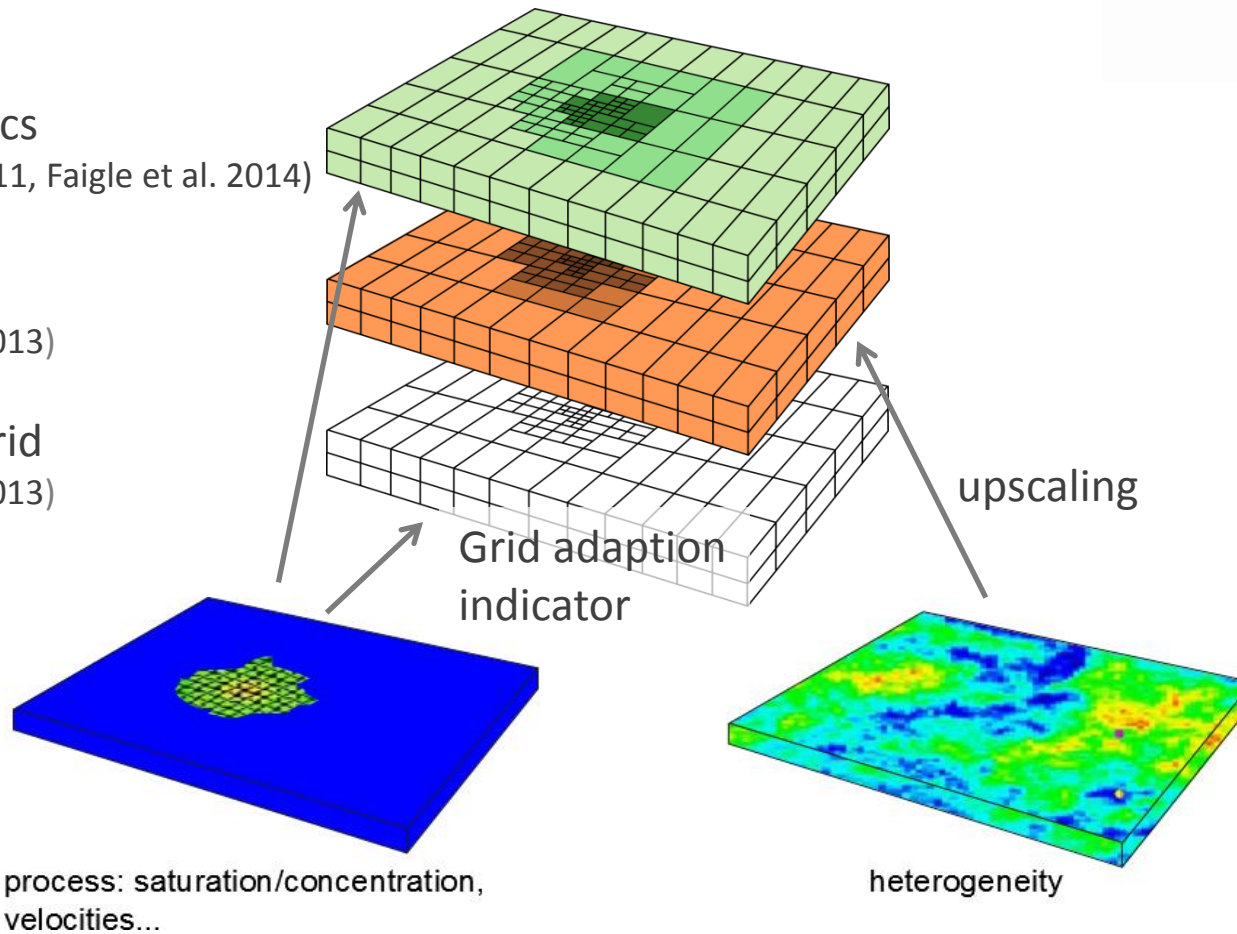Germany

Adaptive modeling

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Multi physics
(Fritz et al. 2011, Faigle et al. 2014)

Multi scale
(Wolff et al. 2013)

Adaptive grid
(Wolff et al. 2013)

Grid adaption
indicator

upscaling

process: saturation/concentration,
velocities...

heterogeneity

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Adaptive grid example: Nine-spot water flow

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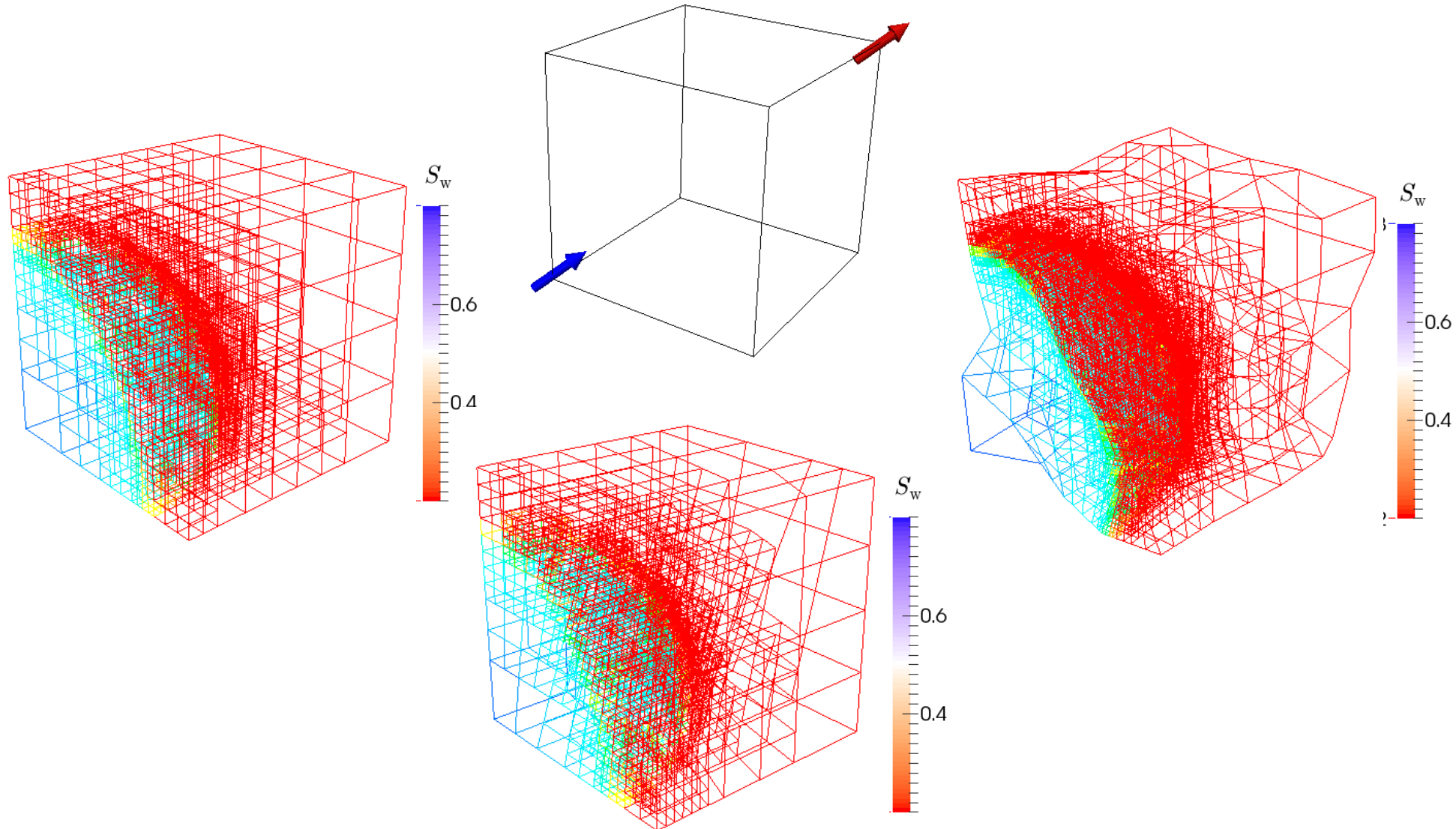
Multi-physics Modeling: Coupling (Fritz et al. 2011)
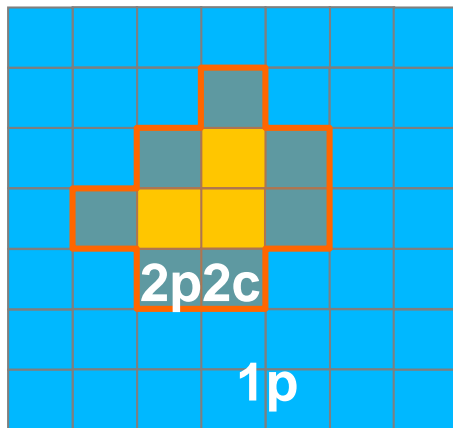
- Only one phase present in global rest domain.

- 2p2c processes only in subdomain.

- Only flux of one phase across subdomain border

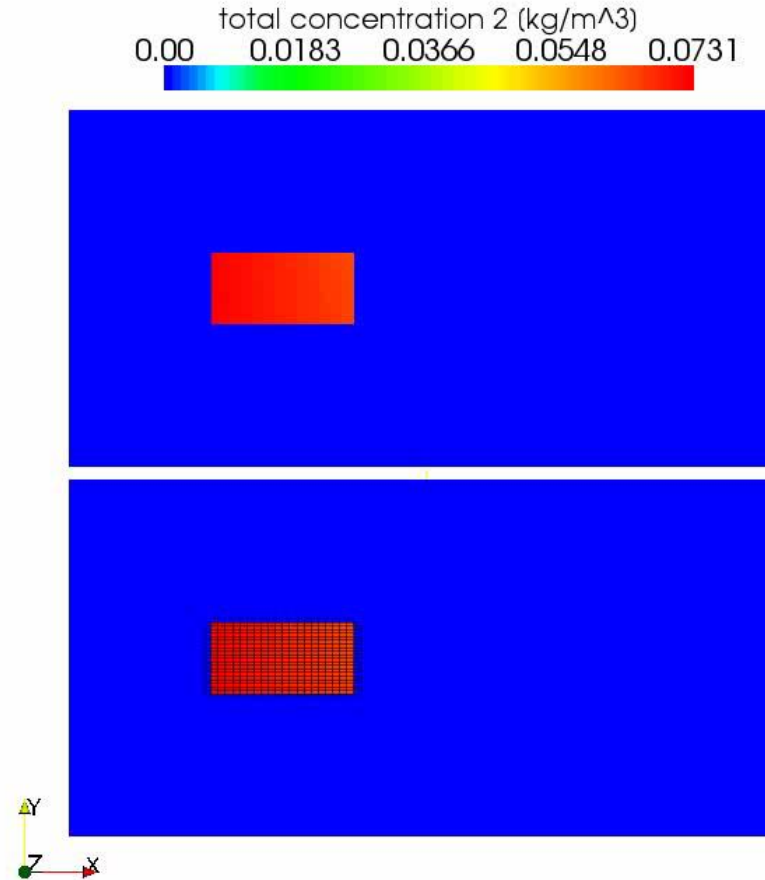- Dynamic subdomain: cell and all neighbors belong to subdomain if $S \neq 1$

- Easy coupling of transport equations:

$$\frac{\partial C^{\kappa}}{\partial t} = -\sum_{\alpha} \nabla \cdot (\mathbf{v}_{\alpha} \varrho_{\alpha} X_{\alpha}^{\kappa}) + q^{\kappa}$$

- 2p2c equation for a single phase equals:

$$\frac{\partial C^{\kappa}}{\partial t} = \nabla \cdot \left(\frac{\mathbf{v}}{\phi} C^{\kappa} \right)$$

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Example: Two-phase two componenent

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Multi-Multi results:
2D, injection of gas into a brine aquifer, 2phase-2component flow, isothermal

wetting saturation

1
0.8
0.6
0.4
0.278

Adaptive grid:

Multi-physics:

2p2c domain

1p domain
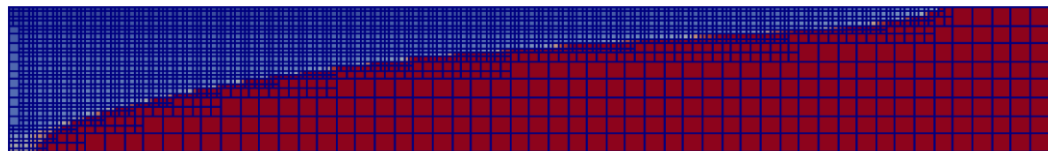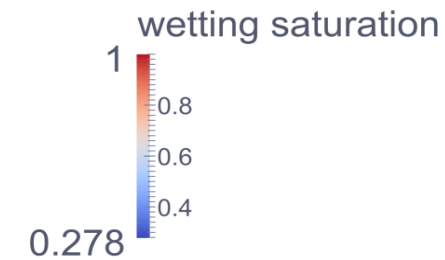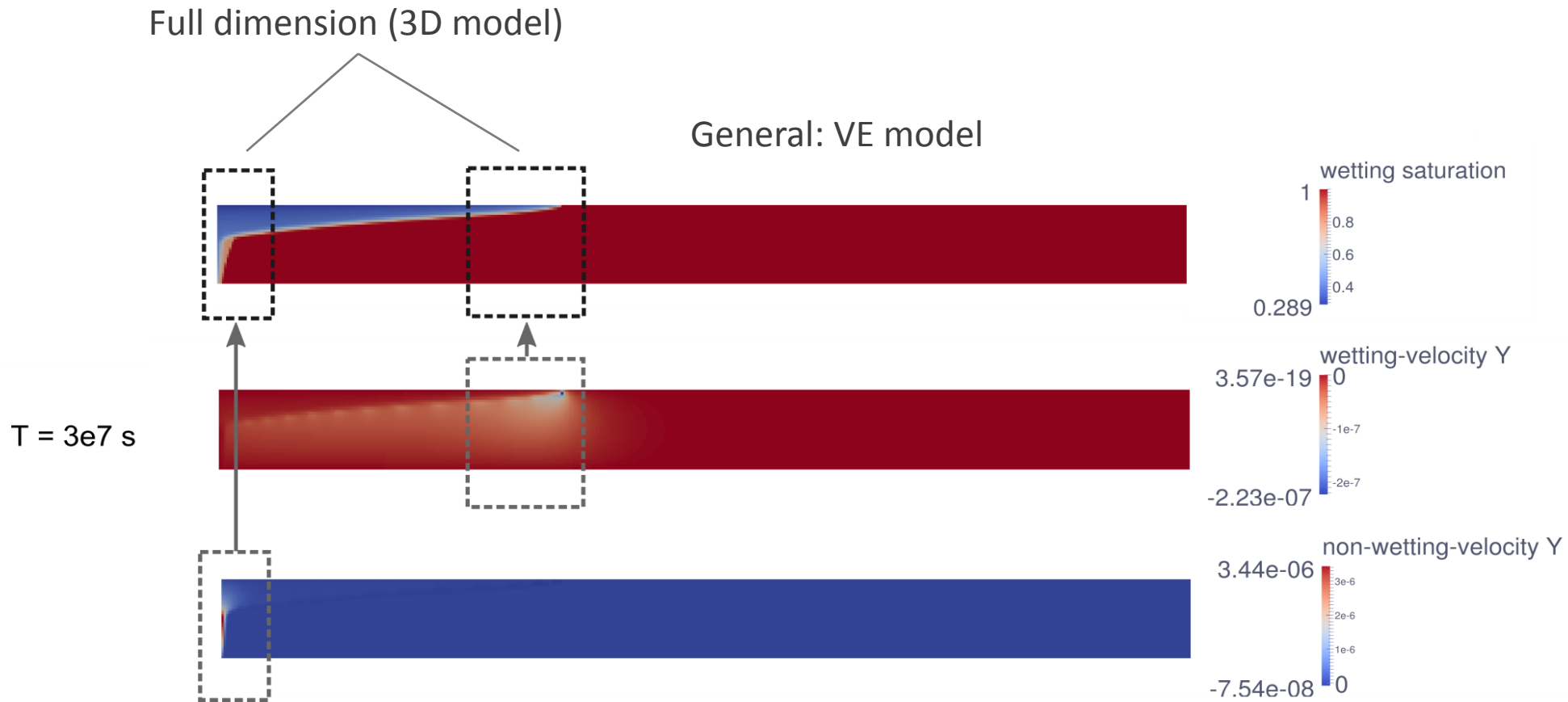
CPU time:
Fully Implicit: 100%
Impes: 14%
Impes+Multi physics: 11%
Impes+Adaptive: 2%

Coupling of a VE to a 3D model

Adaptive modeling

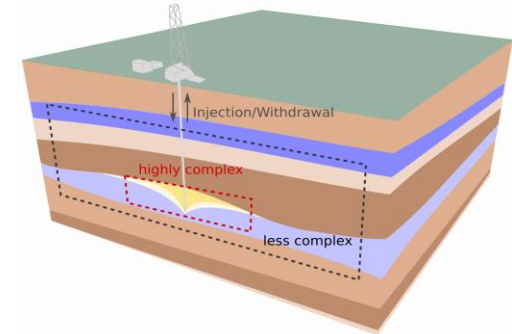

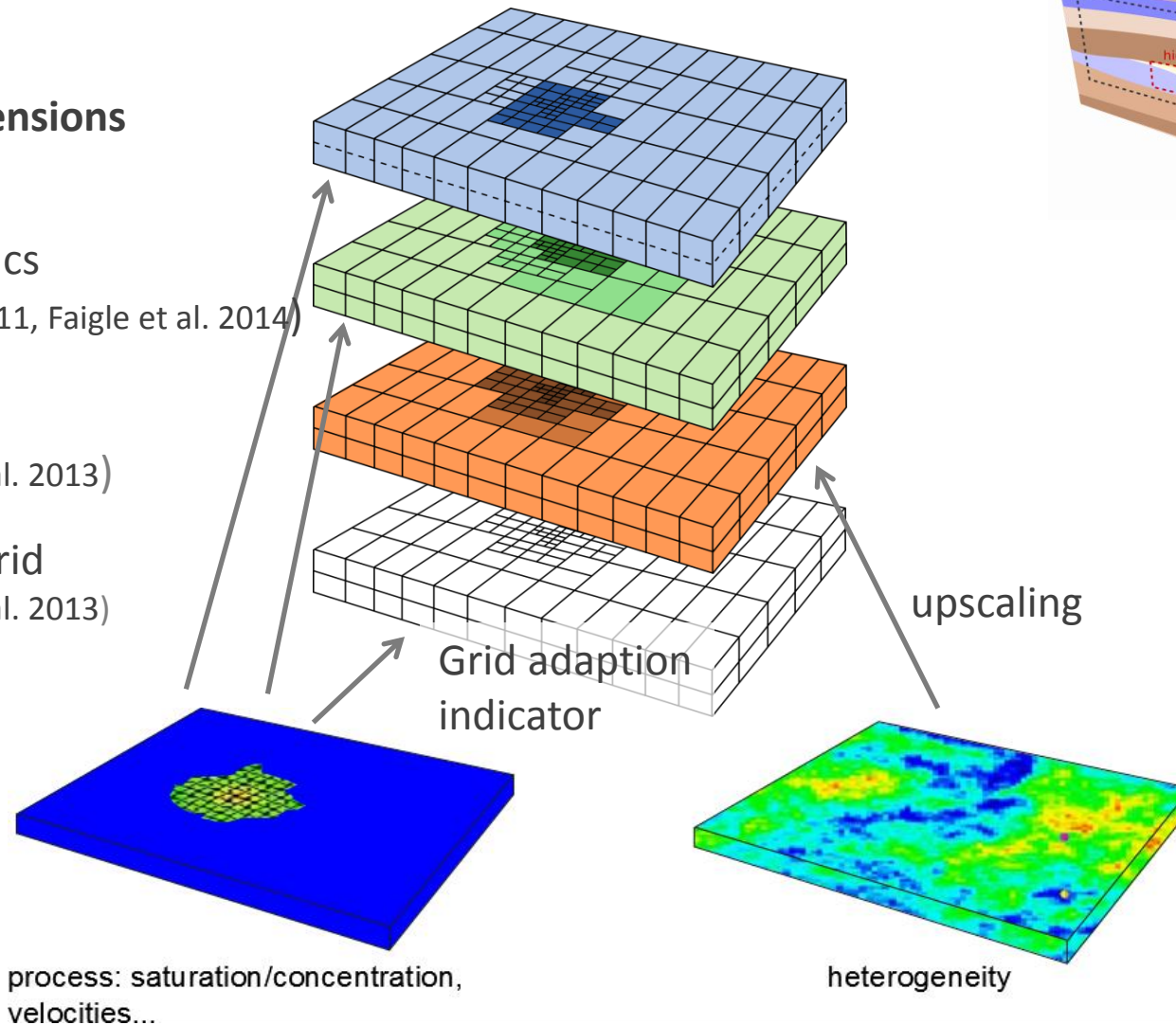**Multi dimensions**

Multi physics
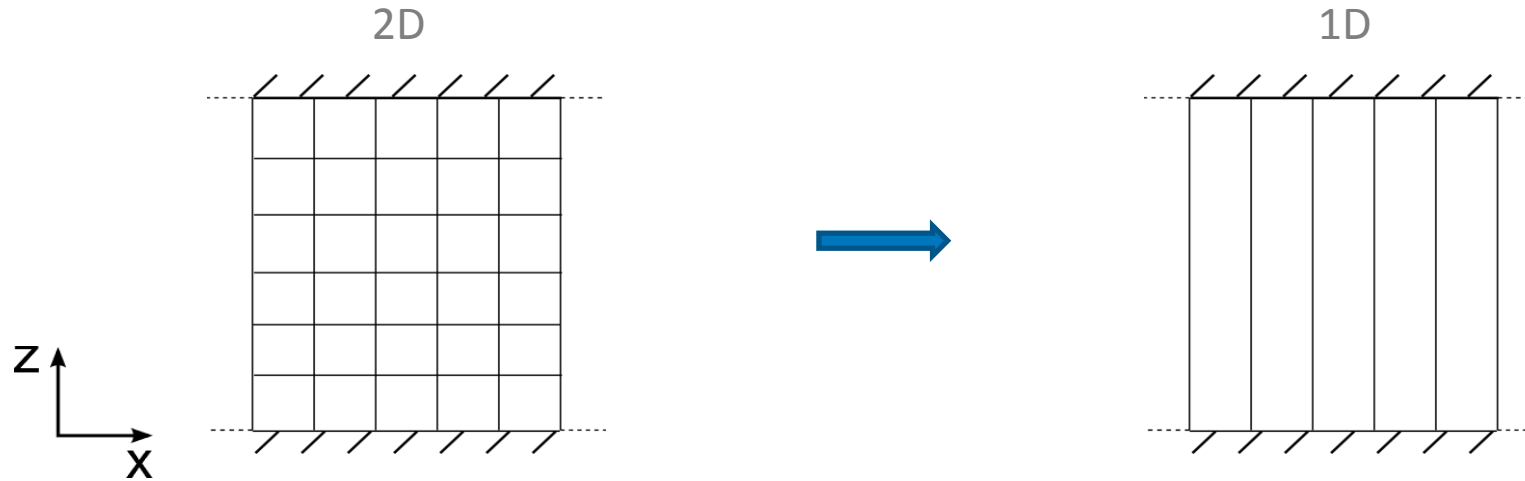(Fritz et al. 2011, Faigle et al. 2014)

Multi scale
(M. Wolff, et al. 2013)

Adaptive grid
(M. Wolff, et al. 2013)

Grid adaption indicator

upscaling

process: saturation/concentration, velocities...

heterogeneity

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VE model

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2D

1D

$$\frac{\partial}{\partial t}(\varrho_\alpha \phi s_\alpha) + \nabla \cdot (\varrho_\alpha \boldsymbol{u}_\alpha) = \varrho_\alpha \psi^\alpha \qquad \frac{\partial}{\partial t}(\varrho_\alpha \Phi S_\alpha) + \nabla \cdot (\varrho_\alpha \boldsymbol{U}_\alpha) = \varrho_\alpha \Psi^\alpha$$
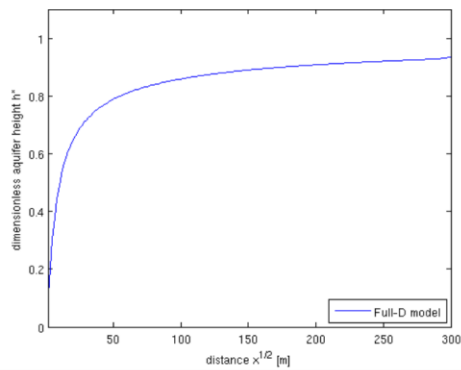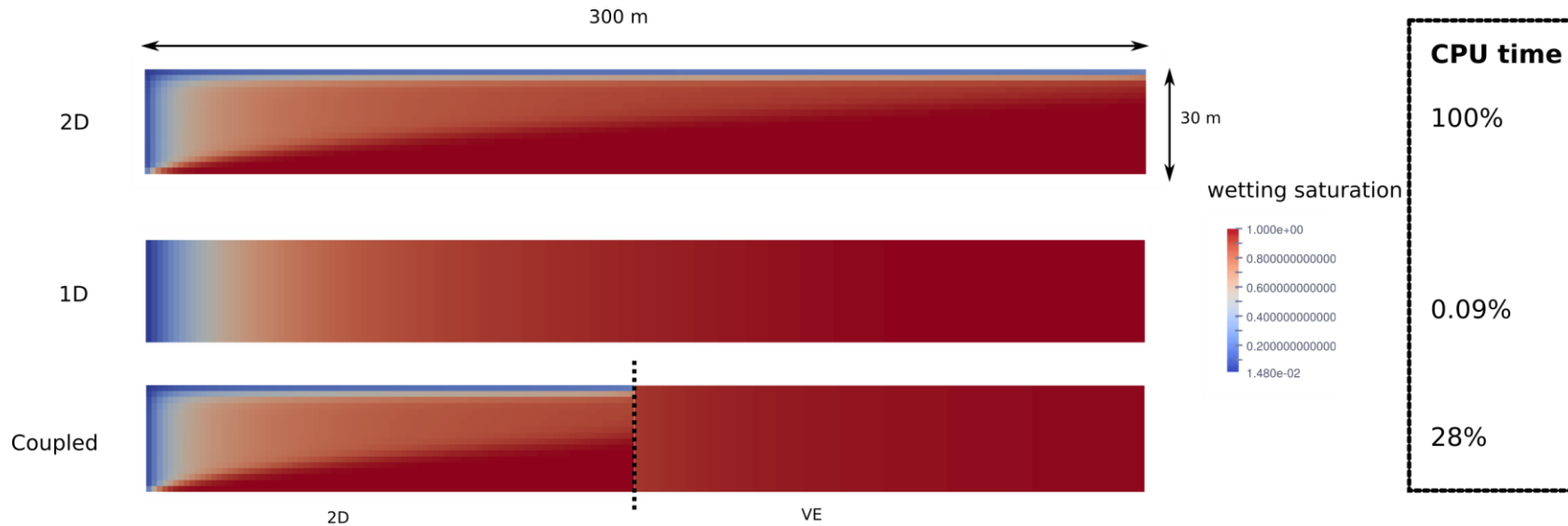
$$\boldsymbol{u}_\alpha = -\frac{k_{r,\alpha}\boldsymbol{k}}{\mu_\alpha}(\nabla p_\alpha - \varrho_\alpha \mathbf{g}) \qquad \boldsymbol{U}_\alpha = -\mathbf{K}\Lambda_\alpha(\nabla P_\alpha - \varrho_\alpha \mathbf{G})$$
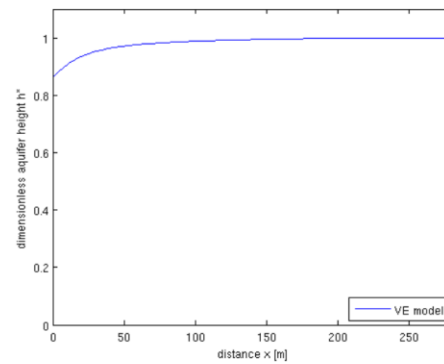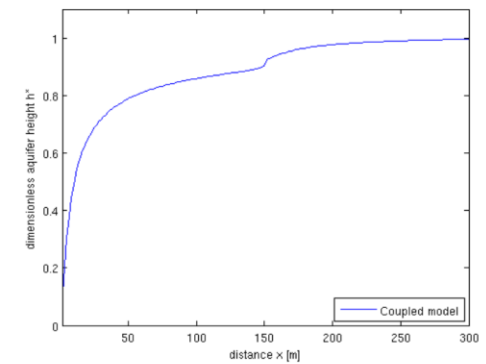
(B. Guo, et al. 2014)

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Preliminary results

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Summary and outlook

First steps:

  – Coupling of VE model to 3D model

  – Model switching criteria ➡ adaptive coupling

  – In cooperation with Bo Guo and Mike Celia, Princeton University

Including heterogeneity

Including hysteresis (Papafotiou, et al. 2010)

Including multi-physics

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