Predictive modelling ?

On matching arrival times and pressure data in Ketzin

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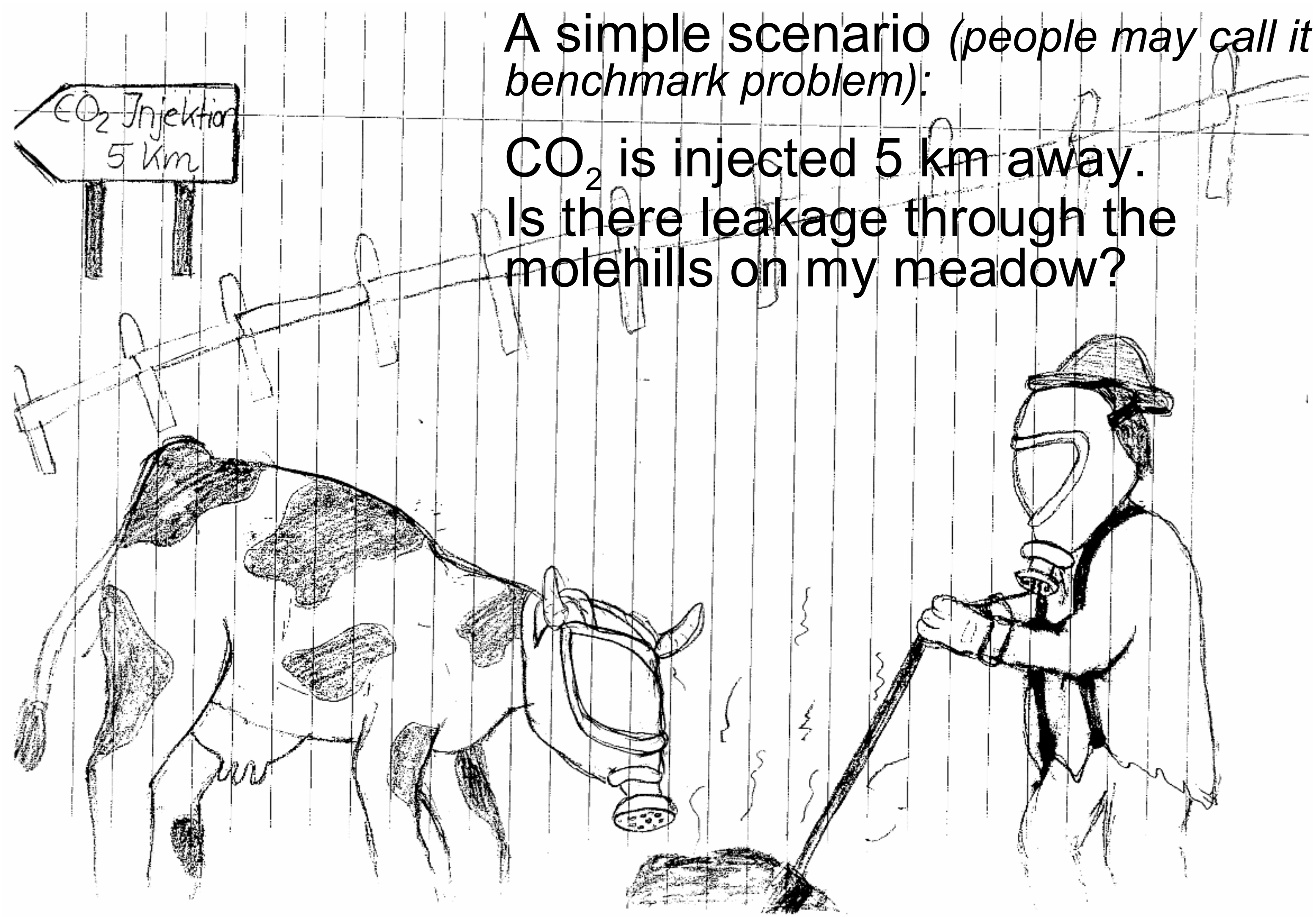
Can we predict CO_2 „whatever“, e.g. leakage ?

A simple scenario *(people may call it benchmark problem):*

CO_2 is injected 5 km away.
Is there leakage through the molehills on my meadow?



Why Predictions Can Differ

- The modeler
  - determines the size of the model domain
  - interprets the available hydrogeological information and accordingly assigns the boundary conditions
  - **(diligently gathers geologic data on subsurface structures, layers, heterogeneities, hydraulic properties, poro-perm data, etc.)**
  - **considers the uncertainties of the model input parameters**
  - chooses a simulator (code, model concept)
  - makes (no) mistakes

Why Predictions Differ

- The model concept
  - Which processes are really relevant? (must-have, nice-to-have, too costly?)
- Grid effects
  - Feasible grid resolutions depend on computational resources and the size of the model domain
  - Grid refinement in the vicinity of wells or below the cap-rock
- The code
  - E.g. TOUGH2, Dumux, MUFTE, Eclipse, etc.

Benchmark Studies 2008/2009 (Stuttgart and Svalbard)

- Fairly good agreement of model predictions in all cases
  - Available models capable of accounting for relevant processes, parameters, and properties with only minor quantitative deviations
  - **Uncertainties arising from geological input data are in general much larger than differences between simulation codes**
  - BUT: in parts strongly deviating results in the preliminary comparison at the benchmarks workshop in April 2008
    - Errors introduced by gridding
    - Wrong parameters, oversights
    - Different interpretations of problems leading, for example, to a different assignment of boundary conditions

Coming back to Ketzin …

Investigation on the Arrival Time

- Arrival at Ktzi 200: 15.07.2008 (21 days after injection started)
  → well predicted by the models
- Arrival at Ktzi 202: 20.03.2009 (269 days after injection started)
  → models predicted a much earlier arrival time

Question:

What can be the reason for this underestimation?

Answer:

We don’t know the geology well enough!

Model Setup

Geometry & Geology:

- According to Petrel Model by GEUS
- Model domain 5 km x 5 km
- Diameter of the wells: 0.22 m
- Ktzi 200 @ 355292.7 R, 5817801.6 H
- Ktzi 201 @ 355242.7 R, 5817803.7 H (injection interval - 46.2 meter)
- Ktzi 202 @ 355296.8 R, 5817901.4 H

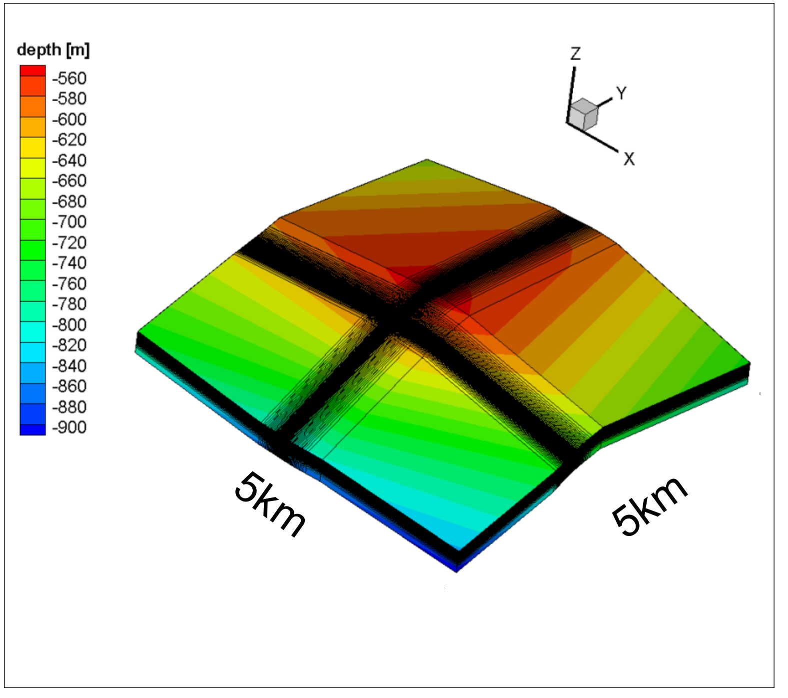
Outer boundary and Initial conditions

- Pressure 62 bar at 639.5m (SSTVD); hydrostatic
- Temperature according to interpolated temperature measurements in Ktzi163/69
- CO_2 saturation zero

CO_2 Injection boundary conditions

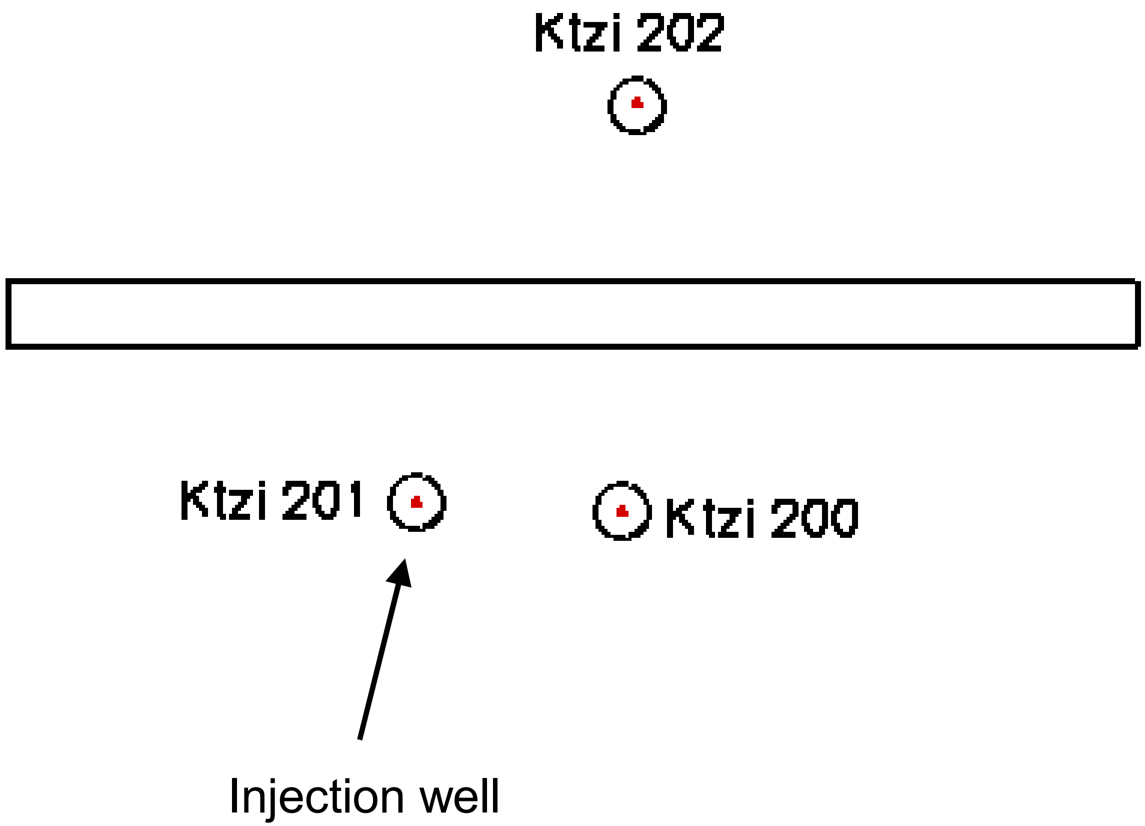
- Temperature: 31.5°C
- Mass flux: daily averaged injection regime (data from GFZ)
- No water injection

Model domain

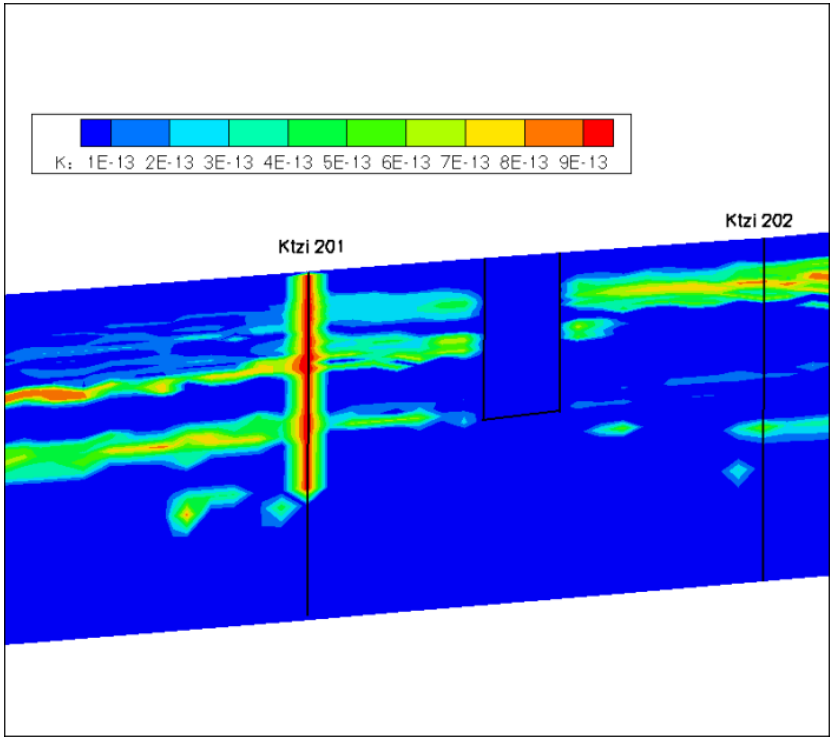


domain: 5km x5km

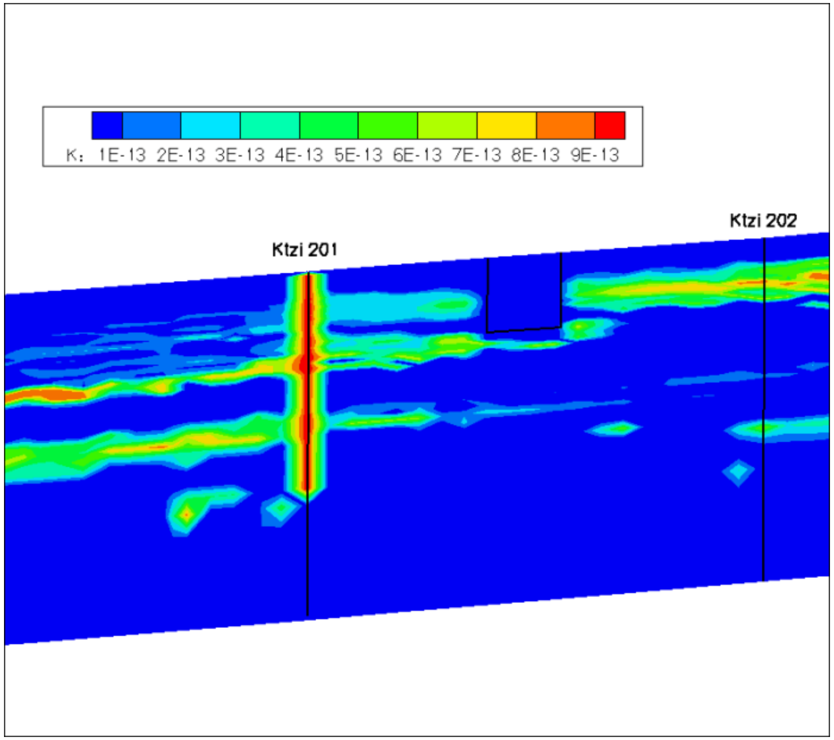
A simple-hearted question: Would a barrier help?



Permeability field for different barrier depth



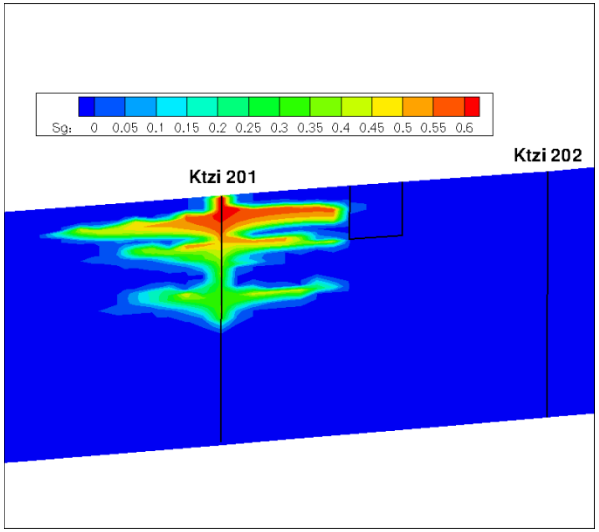
Deep barrier (2,3,4,5)



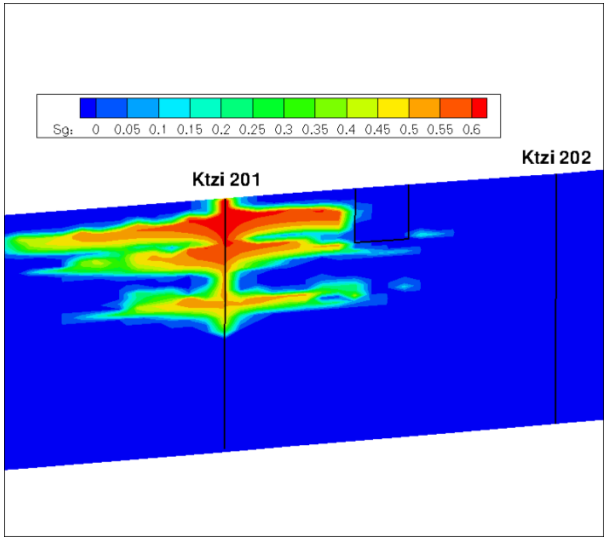
Flat barrier (15m deep) (6)

Scenario 6: flat barrier

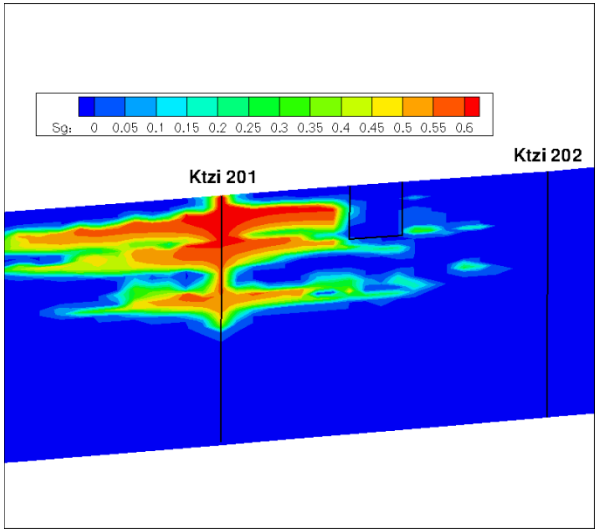
100 days



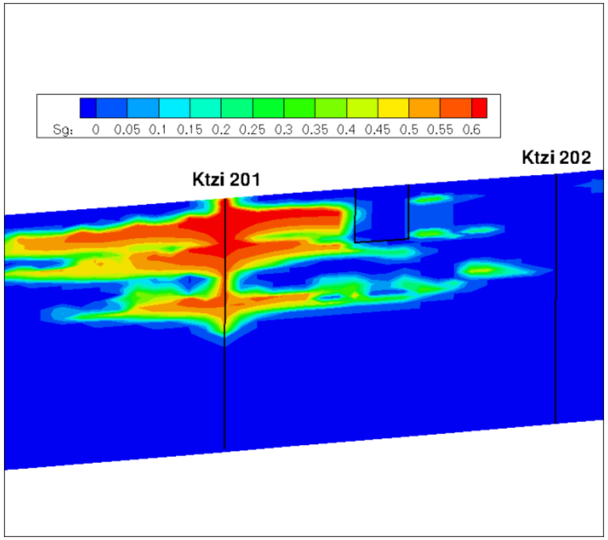
200 days



300 days

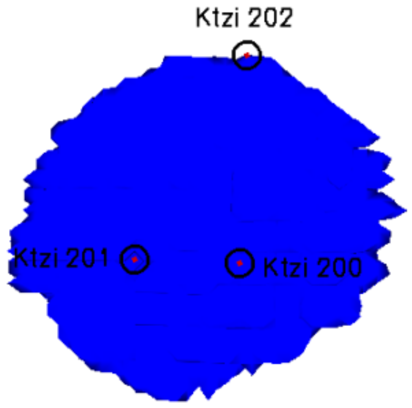


357days

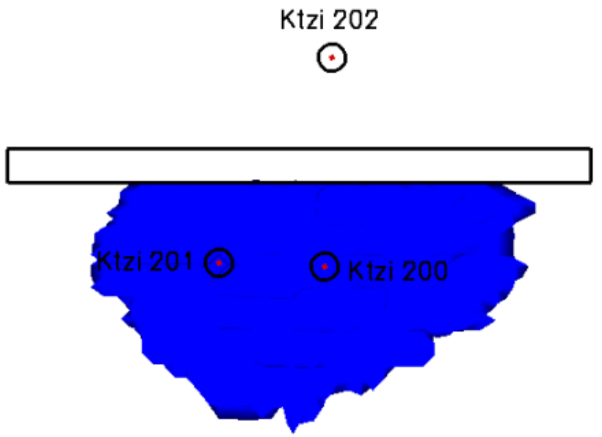


Different scenarios after 79 days of injection

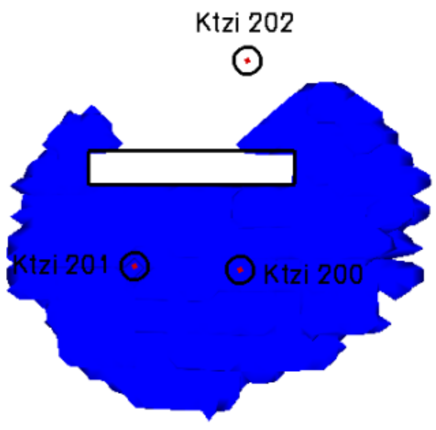
Reference scenario (1)



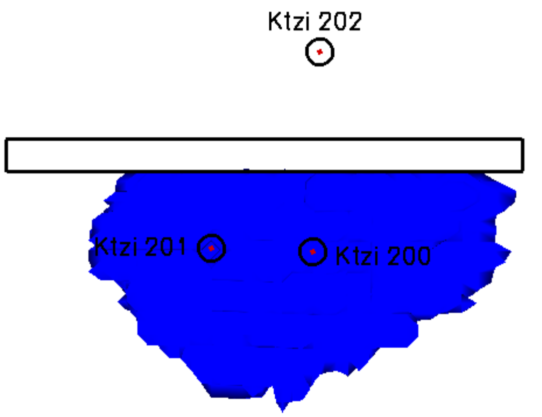
Long barrier (280 m) (2)



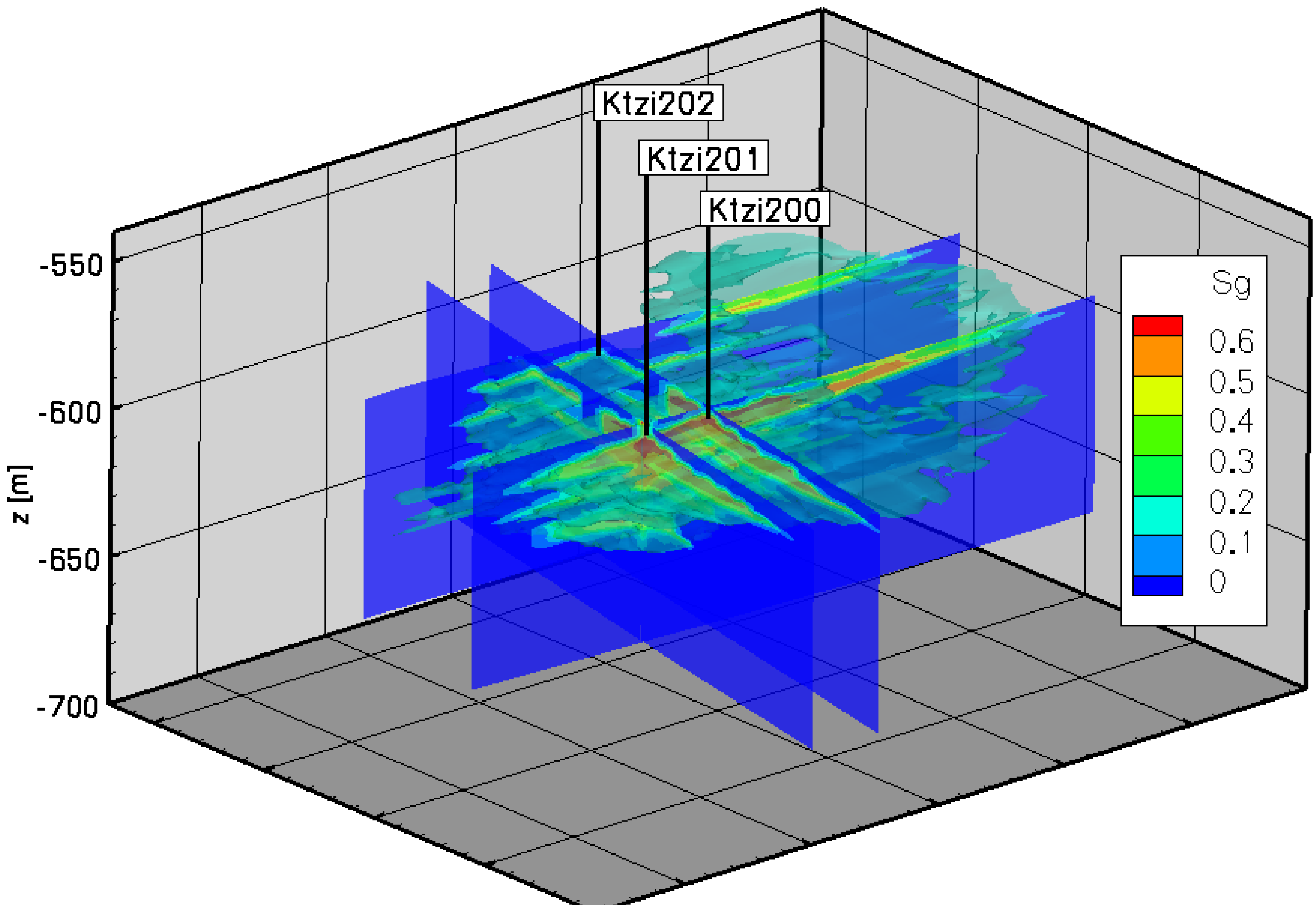
Short barrier (100 m) (3)



Middle barrier (260 m) (4)



3D view on the CO_2 plume



Arrival time of all scenarios

Scenario	Barrier	Arrival at Ktzi 202
1	no	79 days
2	Long (280m x 20m x 35m), K/1000	No arrival after 340 days
3	Short (100 m x 20m x 35m), K/1000	121 days
4	Middle (260 m x 20m x 35m), K/1000	303 days
5	Middle (240 m x 20m x 35m), K/1000	238 days
6	Flat (280m x 20m x 15m), K/1000	No arrival after 357 days
7	Varied permeability of the barrier: K/10	130 days
8	Varied permeability of the barrier: K/50	**258 days**
9	Varied permeability of the barrier: K/100	No arrival after 136 days

Some remarks on the history matching attempts

- Relation between geological model and plume shape evolution is evident

- History matching without having precise data on the real plume development is always arbitrary, no matter what approach to take.

- Therefore, we consider what-if scenarios, in this case: *“What if a barrier was there?”* as reasonable and sufficient for the moment to show that numerical modeling is in principle able to reproduce the processes in the reservoir

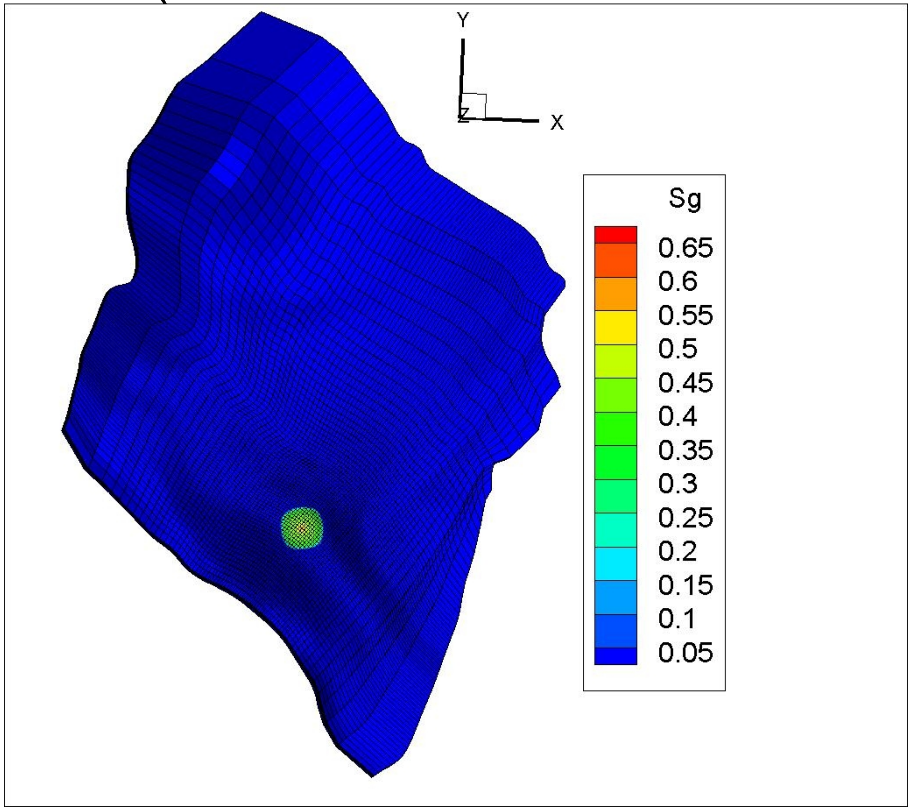
Some remarks on the history matching attempts

- History matching of the **pressure data** is another important task.
- Pressure response depends on permeability, injection rate, effects of compressibility of the fluids and the matrix,
- and the influence of constant head boundary conditions is very important for the simulated pressure response for a given injection rate.
- Depending on the distance between the injection well and the boundary, the constant head sooner or later limits the pressure increase in the domain since the pressure signal rapidly travels through the model domain.

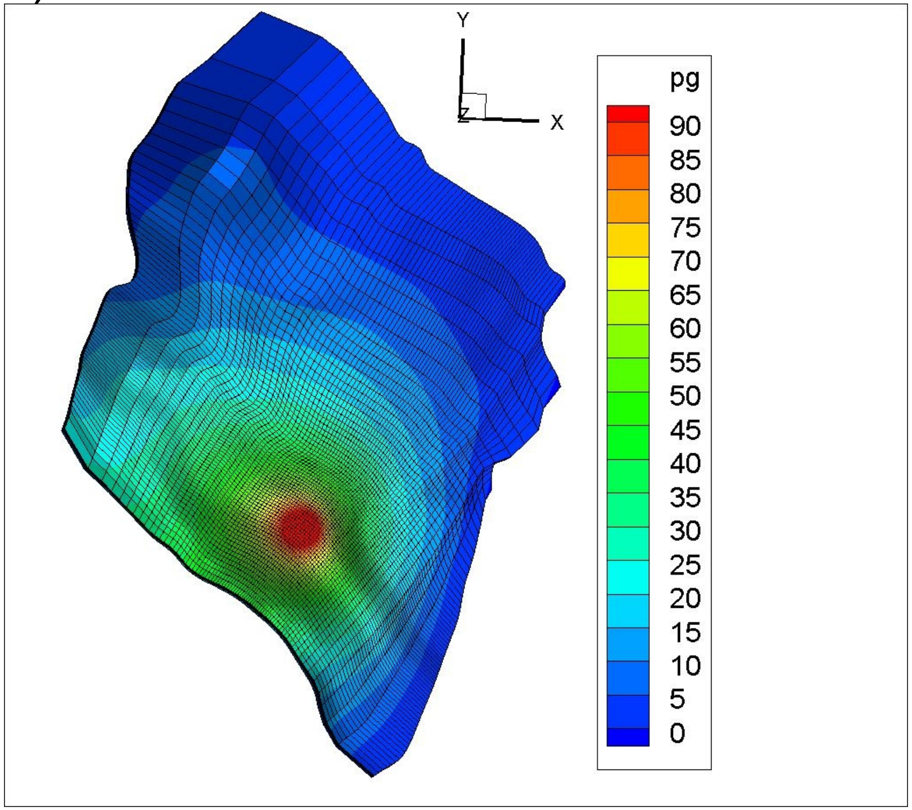
Different spatial scales for saturation and pressure

Example: area affected by CO_2 injection after 10 years of injection

(Note: this is not a Ketzin scenario)



saturation

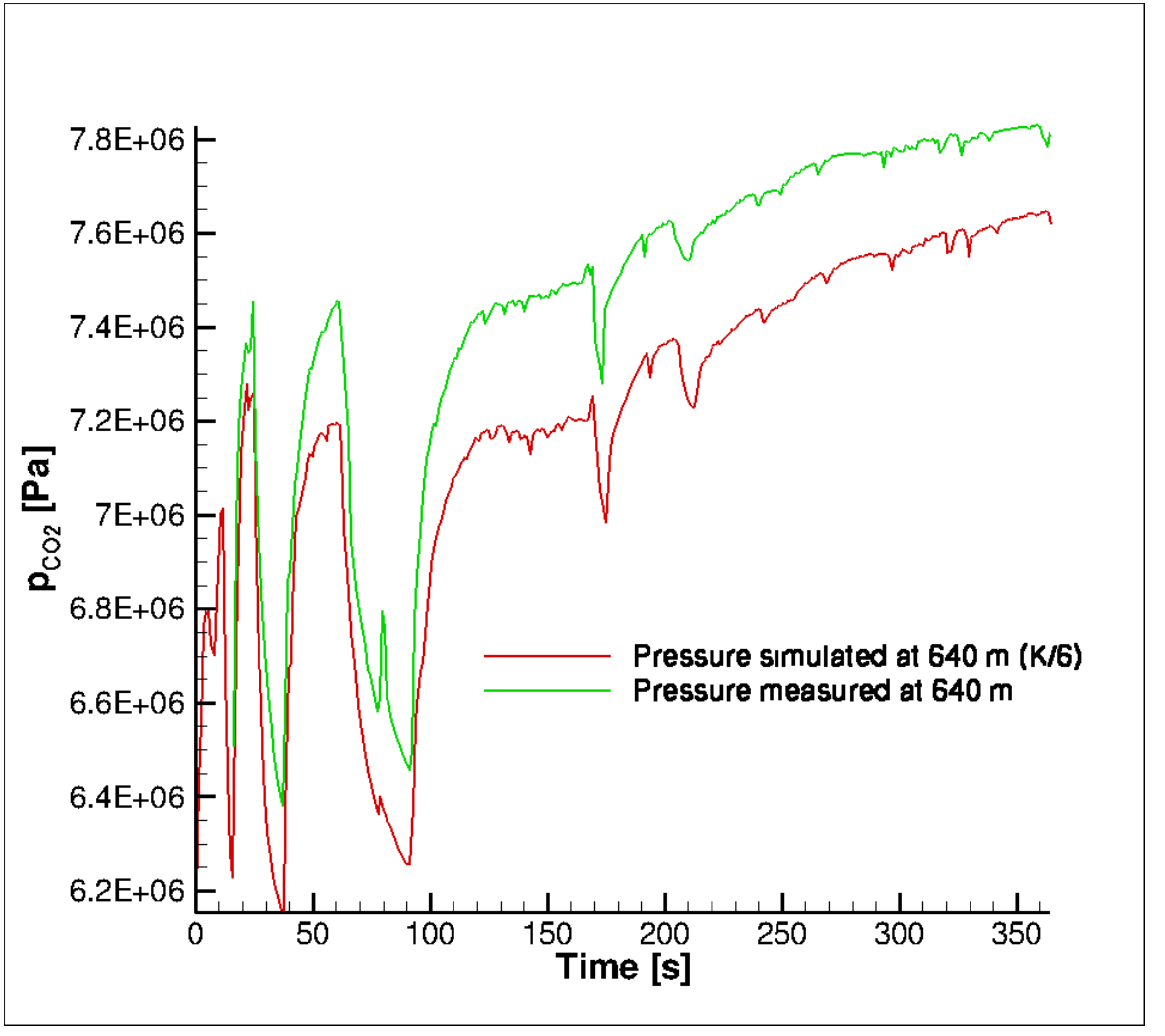


pressure

Matching the Ketzin pressure data

Matching the pressure data in the injection well by adapting the „background“ permeability

- Amplitudes of the peaks are reproduced well, while the absolute values deviate due to a differing reference pressure (needs to be checked)



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- History matching of the **pressure data** is another important task.
- Pressure response depends on permeability, injection rate, effects of compressibility of the fluids and the matrix,
- and the influence of constant head boundary conditions is very important for the simulated pressure response for a given injection rate.
- Depending on the distance between the injection well and the boundary, the constant head sooner or later limits the pressure increase in the domain since the pressure signal rapidly travels through the model domain.
- The question is how far a constant head boundary should be away from the injection so that the pressure increase is not affected by the boundary condition.
  - Choose careful!

Workshop on Numerical Models for Carbon Dioxide Storage in Geological Formations

Stuttgart, 2nd - 4th April, 2008

Full description of the benchmark problems available under:

http://www.iws.uni-stuttgart.de/co2-workshop

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Special Issue: Numerical Models for Carbon-Dioxide Storage in Geological Formations

Guest Edited by Holger Class, Helge K. Dahle and Rainer Helmig

Class, H., A. Ebigbo, R. Helmig, H. Dahle, J. M. Nordbotten, M. A. Celia, P. Audigane, M. Darcis, J. Ennis-King, Y. Fan, B. Flemisch, S. E. Gasda, S. Krug, D. Labregere, J. Min, A. Sbai, S. G. Thomas and L. Trenty (2009), A benchmark study on problems related to CO2 storage in geologic formations, Special issue of Computational Geosciences, 13(4), 409-434

Workshop:
Modeling and risk assessment of geological storage of CO_2

Longyearbyen/Svalbard, August 3-7, 2009

Non-Linearities and Upscaling in porous Media

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List of Norwegian projects related to NUPUS

- **N1** MatMoRA, Geological storage of CO_2: Mathematical modelling and risk assessment (**Dahle, Nordbotten, Lie**, Ehlers, Helmig, Class, Hassanizadeh)
- **N2** Modelling flow and transport in porous media over multiple scales (**Nordbotten**, Niessner, Pop, Hassanizadeh, Hilfer, Rohde)
- **N3** POGE, Assessing the potential for deep geothermal energy (**Berre, Nordbotten**, Schotting, Class)
- **N4** SUCCESS, Subsurface CO_2 storage - critical elements and superior strategy (Centre for environmental design of renewable energy) (**Aavatsmark**, Nordbotten, Dahle, Mannseth, Class, Helmig, Bruining, Ehlers)
- **N5** VAMP, Development and analysis of vertically averaged models in porous media (**Dahle, Nordbotten, Lie**, Pop, Helmig)