Modelling Network

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Joint Network Meeting

Santa Fe, June 2012

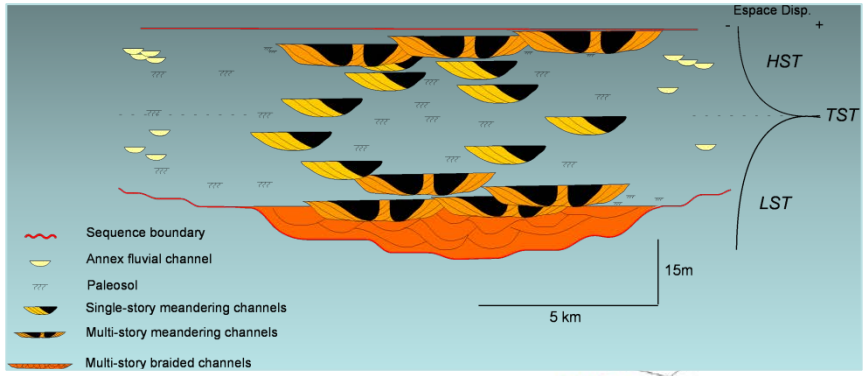
Network Proposal

- JNM 2008, New York
- Recognition of predictive model significance in emerging CCS regulations
- Concerns expressed:
  - Overlap with risk network
  - Bias towards ‘academic’ thinking
  - Sales platform for model developers
- Decision: hold first workshop

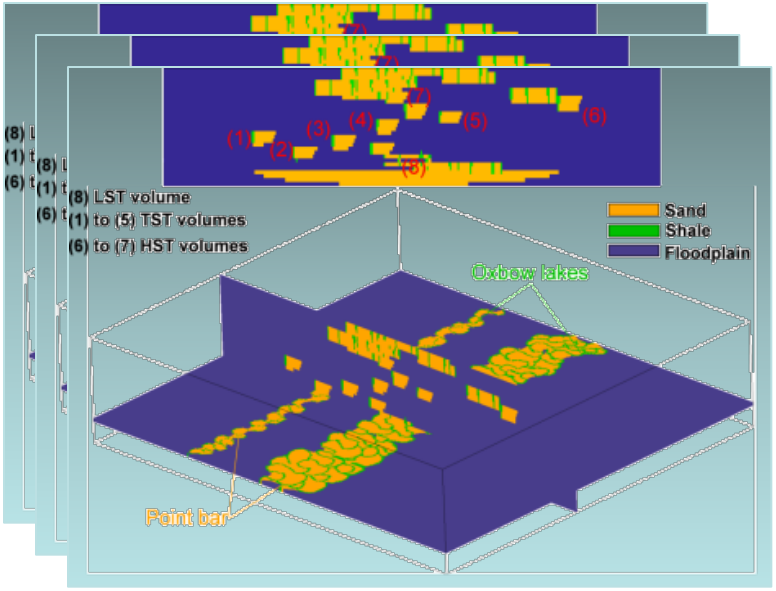
Topic n°1
Modeling and complexity of the underground

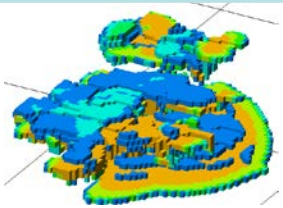
At the reservoir scale – complex hydrofacies architecture

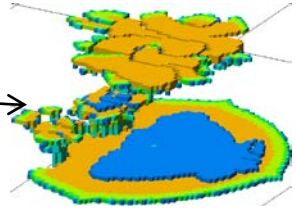
From the geological concept (for ex. fluvial deposit)

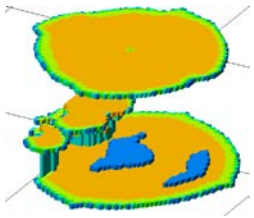


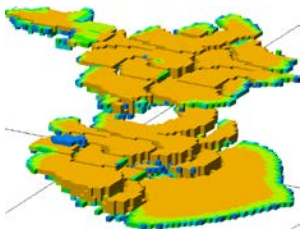
To the multiple geo-statistical realizations









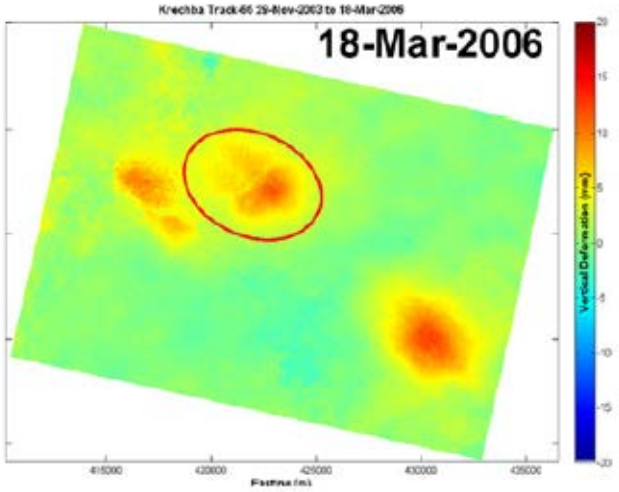


Will impact on the gas plume shape using the same initial concept

Difference in the compartmentalisation of the reservoir

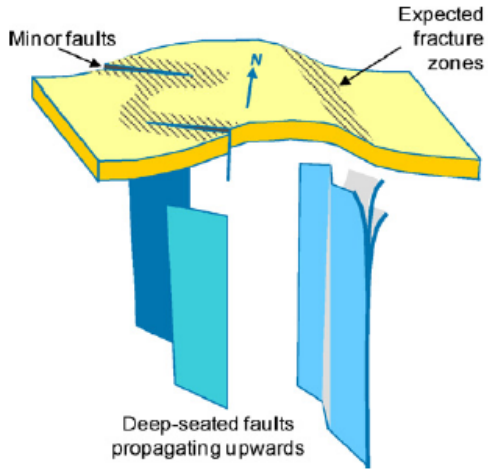
Issautier et al, 2011

At the reservoir scale – fracture network / fault



Two-lobed surface uplift pattern observed over KB-502 ?

➔ Dynamic behaviour of the fault (zone) transmissibility assessed through history matching



Two mechanisms seem to be involved:

- tensile opening of a 4km long pre-existing fault + volumetric expansion ;

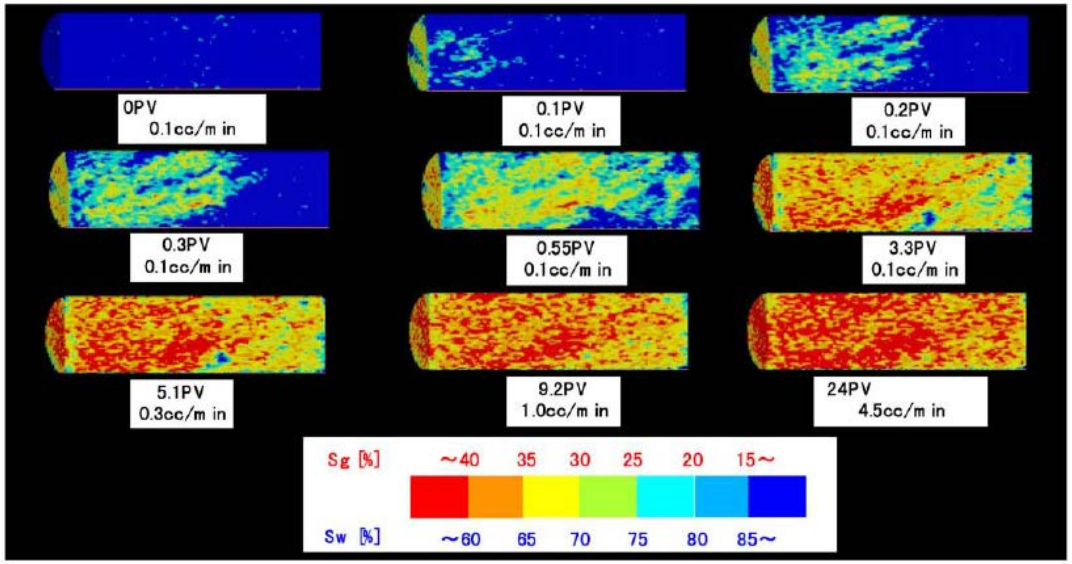
- pressure inflation of a 50m fracture zone extending 200-m into the lower caprock from the injection zone

J.-Q. Shi et al. / International Journal of Greenhouse Gas Control 7 (2012) 115–126

At the core scale: CO2 core flooding

J.-Q. Shi et al. / International Journal of Greenhouse Gas Control 5 (2011) 75–87

Tako sandstone



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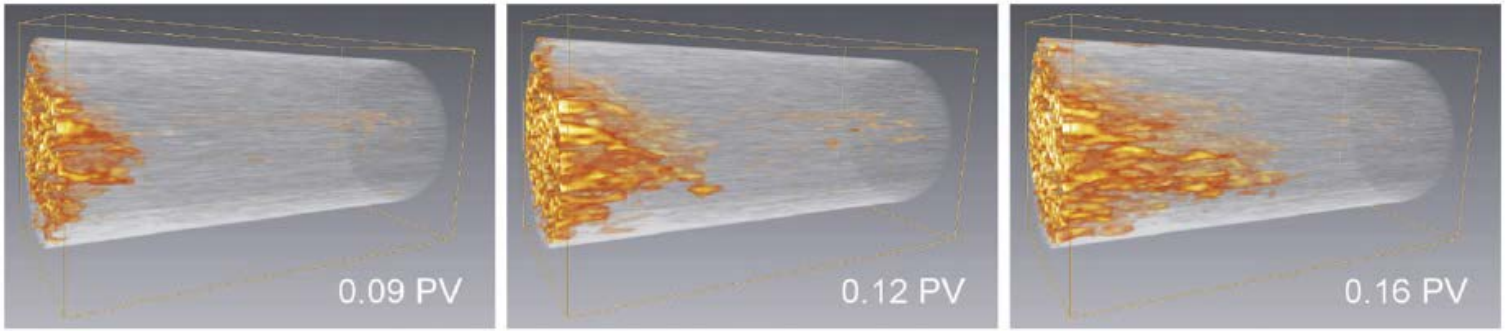
Berea sandstone



Topic n°2
Validating against observations

History matching – at lab scales

J.-Q. Shi et al. / International Journal of Greenhouse Gas Control 5 (2011) 75–87

- Experiments using Tako sandstone **with high heterogeneity**;
- **Not adequately described** by using a single capillary pressure curve in a 1D model;
- Conclusions similar to Perrin and Benson, 2009, TIPM.

S. Berg et al. / International Journal of Greenhouse Gas Control xxx (2012) xxx–xxx

- Experiments using Berea sandstone **with low heterogeneity;**
- **Well described** with 2D homogeneous numerical model;
- Little impact of heteregeneity (for this specific lab test).

History matching – at large scale

SLEIPNER

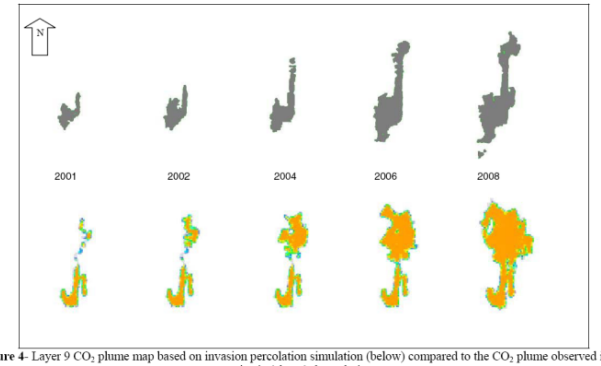


Figure 4- Layer 9 CO_2 plume map based on invasion percolation simulation (below) compared to the CO_2 plume observed in 4D seismic (above) through time.

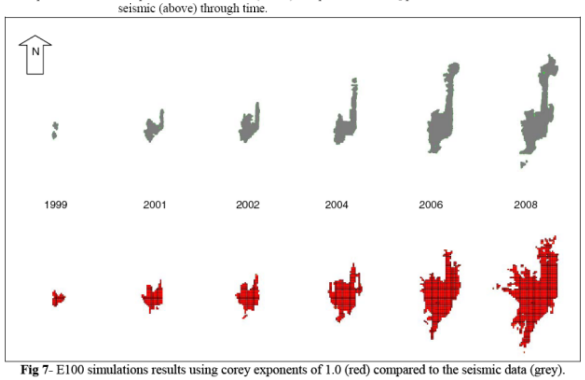


Fig 7- E100 simulations results using corey exponents of 1.0 (red) compared to the seismic data (grey).

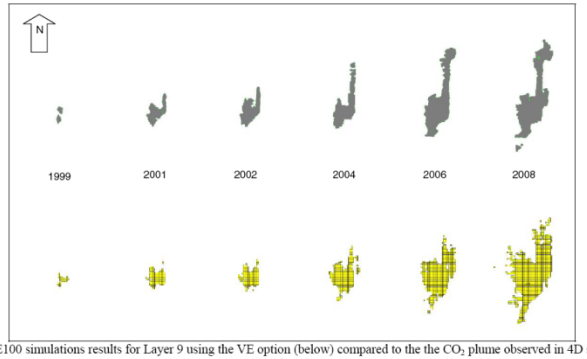
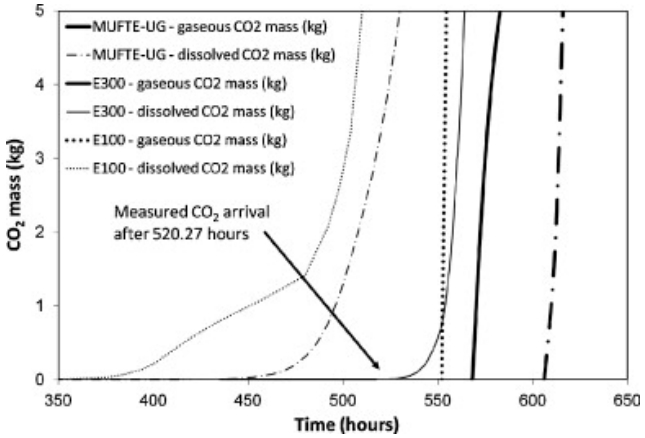


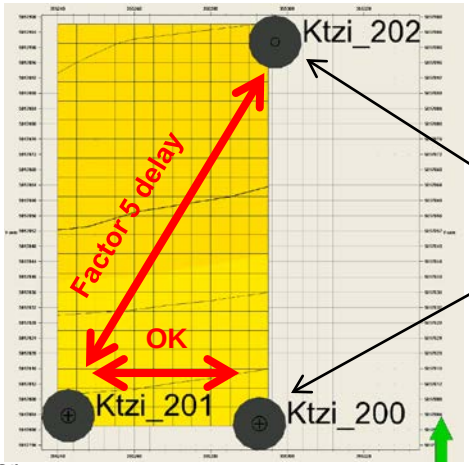
Fig 6- E100 simulations results for Layer 9 using the VE option (below) compared to the the CO_2 plume observed in 4D seismic (above).

Singh et al.,2010 SPE 134891

KETZIN

Kempka,et al., 2010, history matching at Ketzin, first well





Frykman et al., 2010

Topic n°3
Treatment of uncertainties

European Directive 2009/31/EC on the geological storage of carbon dioxide

ANNEX I - Step 3.2: Sensitivity characterisation

"**Multiple** simulations shall be undertaken to identify the **sensitivity** of the assessment to assumptions made about particular parameters. The simulations shall be based on altering **parameters** in the static geological earth model(s), and changing rate functions and assumptions in the dynamic modelling exercise. Any significant sensitivity shall be taken into account in the risk assessment".

Multiple simulations versus Multi-million gridblock model ?

Crucial need for a large scale basin model assessment combined with smale scale features and physics

Birkholzer et al., GHGT10:

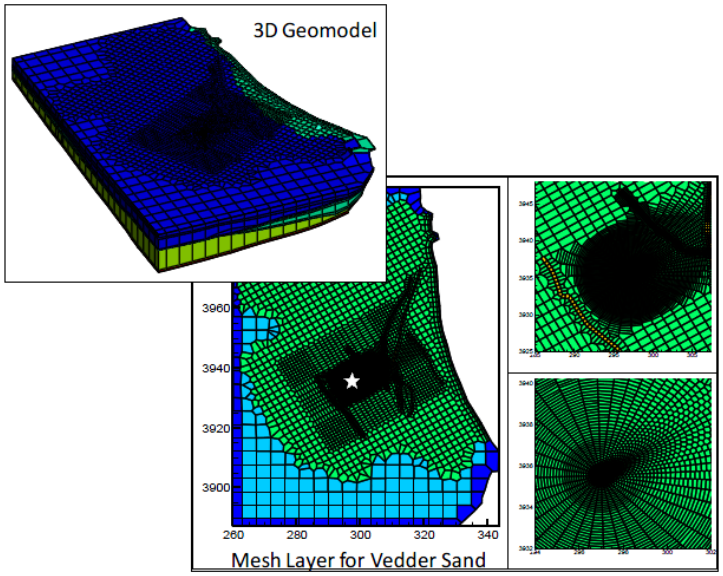
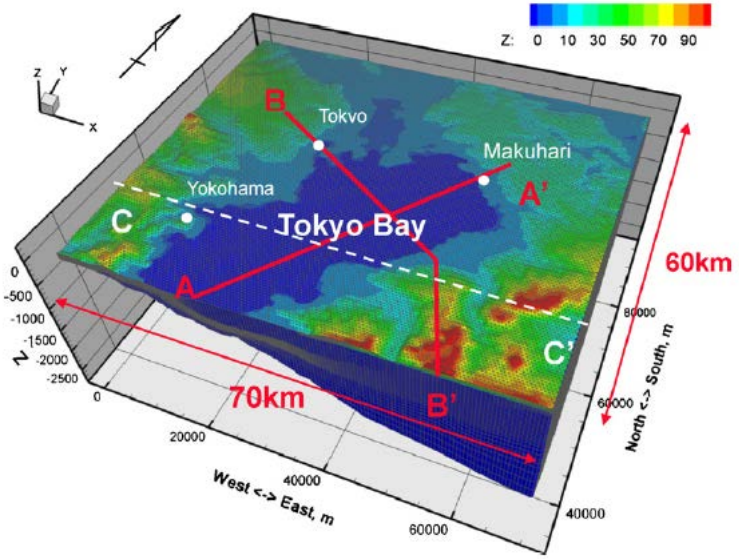
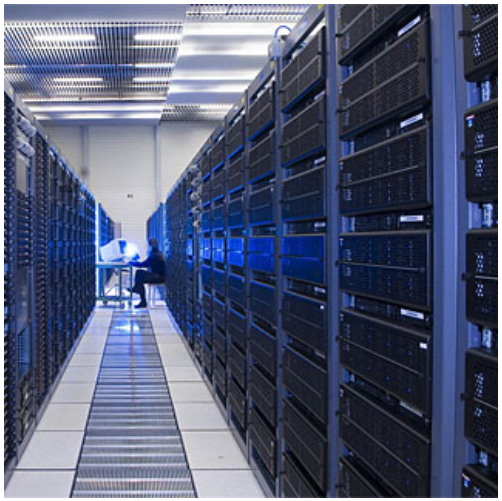


Figure 1. 3D geological model (top) and discretization in a 2D planview for one of the Vedder Sand layers (bottom). White star shows injection location. The green color represents the region with presence of the Vedder Sand. Yellow color represents faults. Boundary elements are in blue.

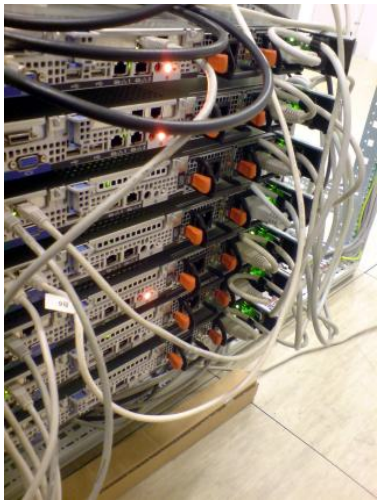


Yamamoto et al., 2009, IJGGC:

Option 1: massively parallelized simulator ?



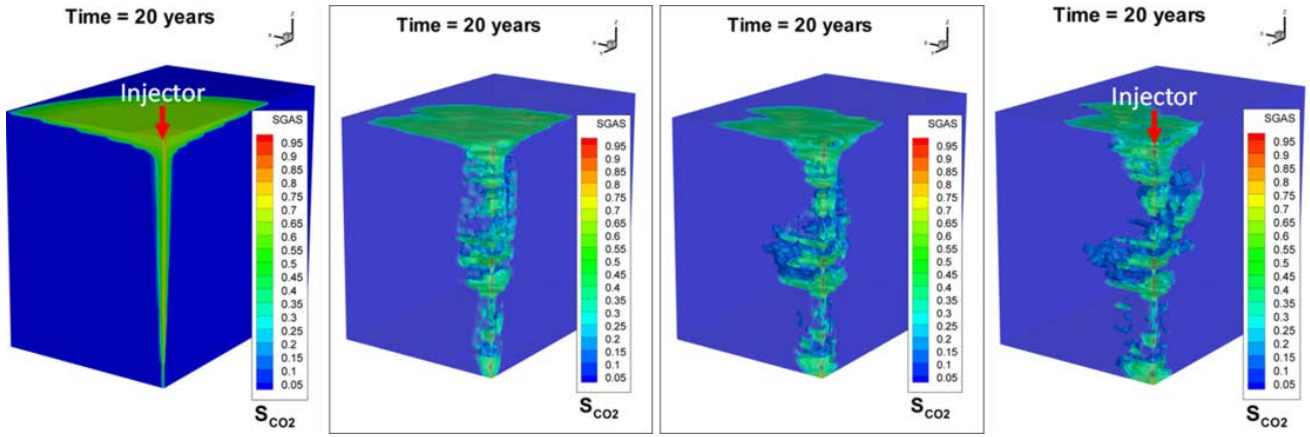
http://www.science.tamu.edu/articles/617



http://www.gridguide.org/

Example of parallel computation with TOUGH2-MP

- Impact of heterogeneity resolution on gas plume shape;
- on a **1 million grid** block model (SPE 10th model) ;
- run on the Earth Simulator in Tokyo ;
- **3 weeks of simulation** for the most complex case.



Yamamoto et al., 2011

Option 2: simplify the models ?

Physical-based approach:

- **Multiphase flow :**

Gasda et al., 2012, IJGCC; Manceau and Rohmer, 2011, TIPM, Mathias et al., 2009, TIPM, etc.

- **Geomechanics:**

Soltanzadeh and Hawkes, 2012, IJGGC; Mathias et al., 2009, IJGGC, etc.

« Computer experiments » approach:

- **Multiphase flow :** Reduced Order model (Brown et al., 2012, CCUS)
- **Geomechanics :** Response surface (Rohmer and Bouc, 2010, IJGGC)
- Etc.

Impact of Model uncertainty ?

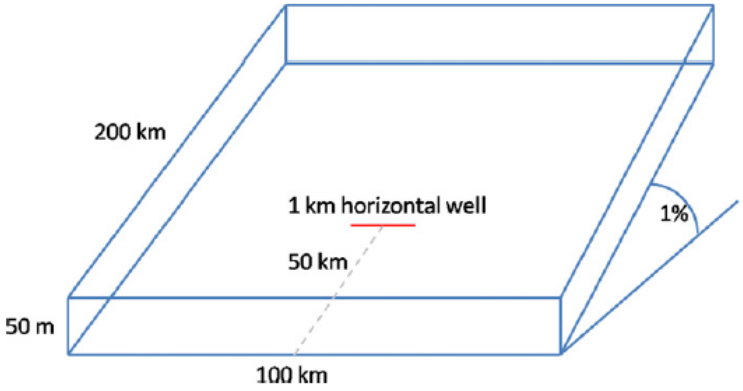


Fig. 1. Domain for benchmark problem.

20 y of injection and long term evolution (see Dahle et al., 2008)

Sources of model uncertainty:

- Specific physical processes modeled;
- Numerical modeling;
- Upscaling approach;
- Interpretation of the problem and metrics

Table 1
Participants of the benchmark study. Colors reflect the colors used to identify the different participants in the subsequent figures.

Participant	Simulator	Approach	Max. # cells	Indicator
U. Stuttgart	DuMu^x	3D, IMPEC	45,760	Stu-X-Y
SINTEF ICT	Inhouse	3D, IMPES+O.S.	1,200,000	Sintef
U. North Carolina	Inhouse	Vert. upsc. + IMPES	40,000	UNC-X
GFZ-Potsdam	E-100	3D, FIM	1,000,000	Pot-X
Heriot-Watt U.	E-100, GEM	3D, AIM	190,000	HWU
Stanford U.	GPRS	3D, FIM	300,000	Stanford

Impact of Model uncertainty ?

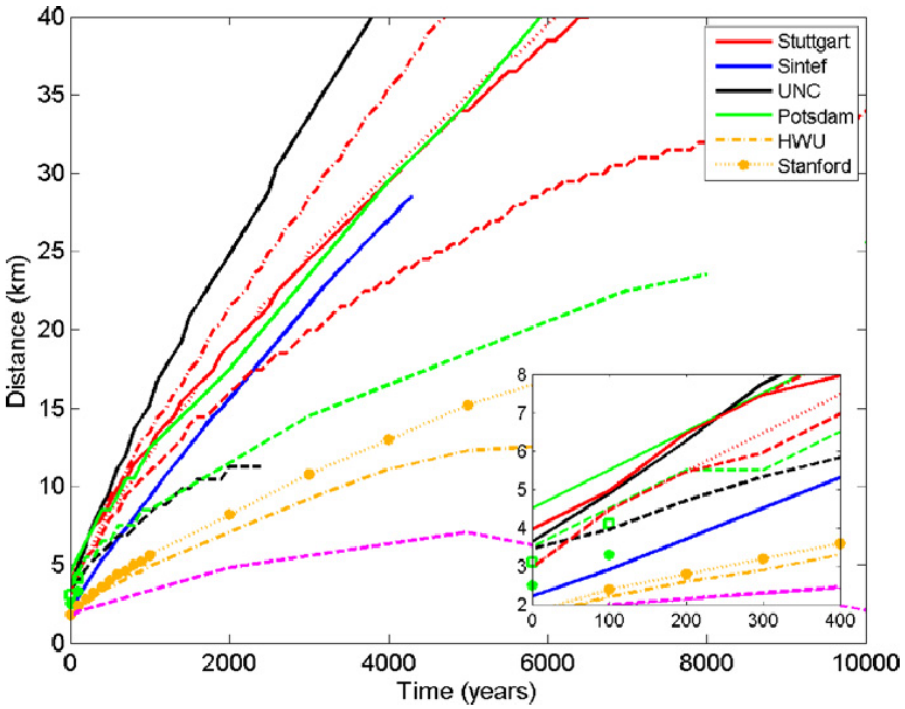


Fig. 3. Updip extent of the center of mass of mobile CO_2 measured from the injection point, as a function of time since injection stop. Colors represent different participating groups, while different lines styles represent different runs within the same group. Solid lines refer to common base case. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

- **All types of uncertainty have an influence**
- **Approaches of each team = valid, but lead to divergent solutions**

Note:

- Large impacts emphasized by the simplicity of the problem
- In more realistic problem, uncertainties on properties might dominate

J.M. Nordbotten et al. / International Journal of Greenhouse Gas Control 9 (2012) 234–242

Role of modeling ?

According to the authors:

« This does not imply that modelling is a useless exercise. On the contrary, models for CO2 are valuable tools for **increasing our understanding, providing first estimates, giving qualitative insight**

…

They should **not** be mistaken for **accurate prognostic tools** »

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Next steps

Sleipner Benchmark Model

- Users are provided with:
  - The Grid Coordinates.
  - The injection rates for Layer 9.
  - The permeability in X direction for the grid.
  - The permeability in Z direction for the grid.
  - The injection point is at I=61; J=126, K=7.
- Currently 33 people from 30 organisations have the dataset
- Planned session in next modelling network meeting to consider what work has been done

Ongoing Modelling Issues

- Adequate geological characterisation
- Effects of heterogeneity
- Model complexity
- Process coupling
- Calibration with monitoring
- Potential role with respect to permit surrender/liability issues