Detection limits and quantitative conformance assessment

Experience from the Ketzin case

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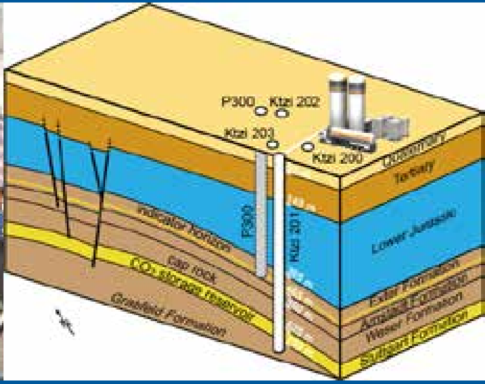

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Pre-ACT WP2 and WP3 Workshop
20-21 February 2018

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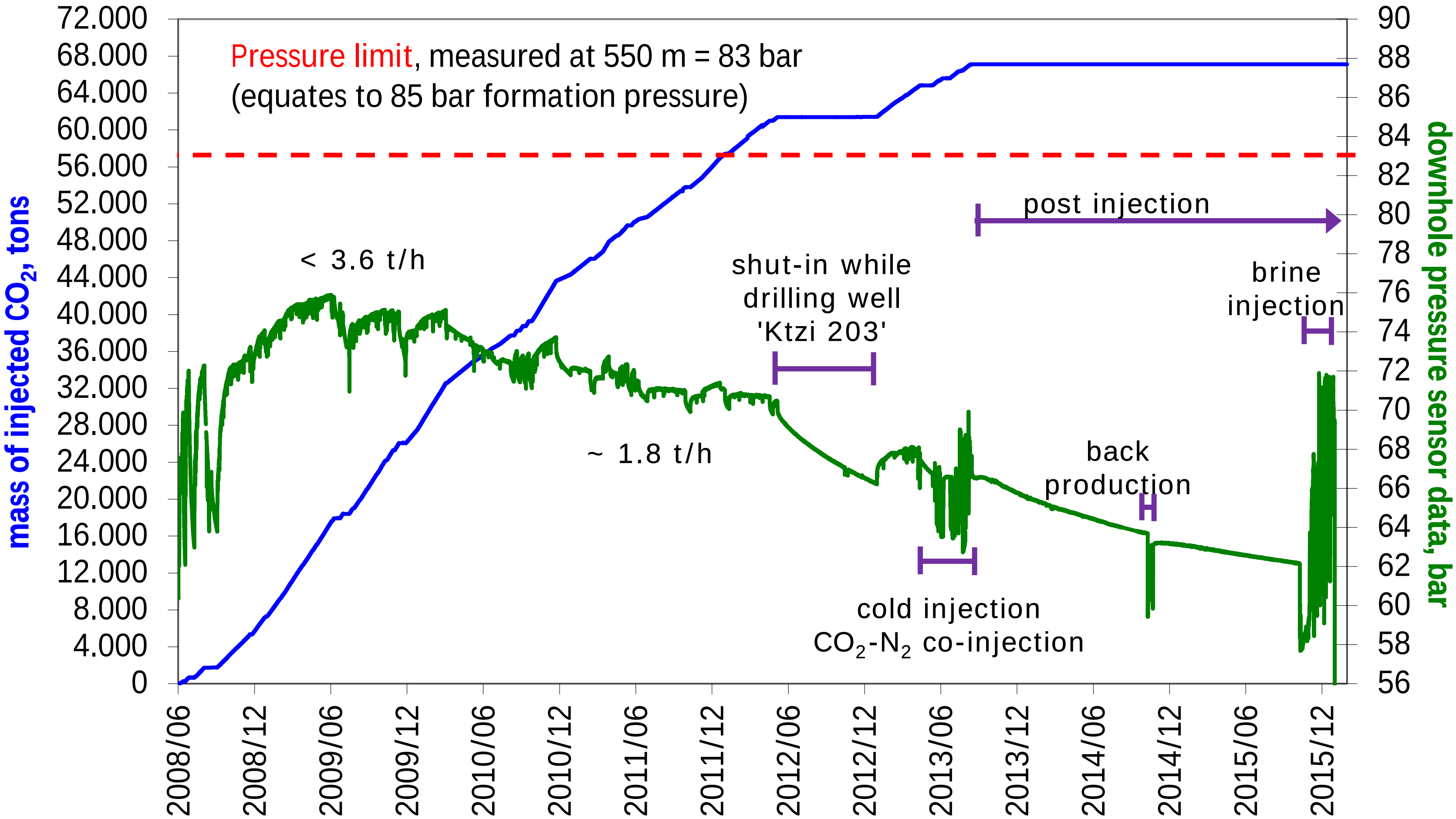
Motivation

- Pilot sites: focus on monitoring, research, often including all available methods.
- Large scale projects: need to put more focus on cost efficiency.

- Direct pressure monitoring: assuring reservoir pressure remains below damaging level.
- Indirect geophysical monitoring (seismic,...): providing images of plume extent and help to update reservoir model (3D permeability).

- Ketzin: Large range of monitoring methods applied, showing chances and limitations of quantitative conformance assessment.

CO_2 injection and pressure



- Active injektion June 2008 – August 2013.
- 67.000 tonnes.
- Pressure response follows injection rate.

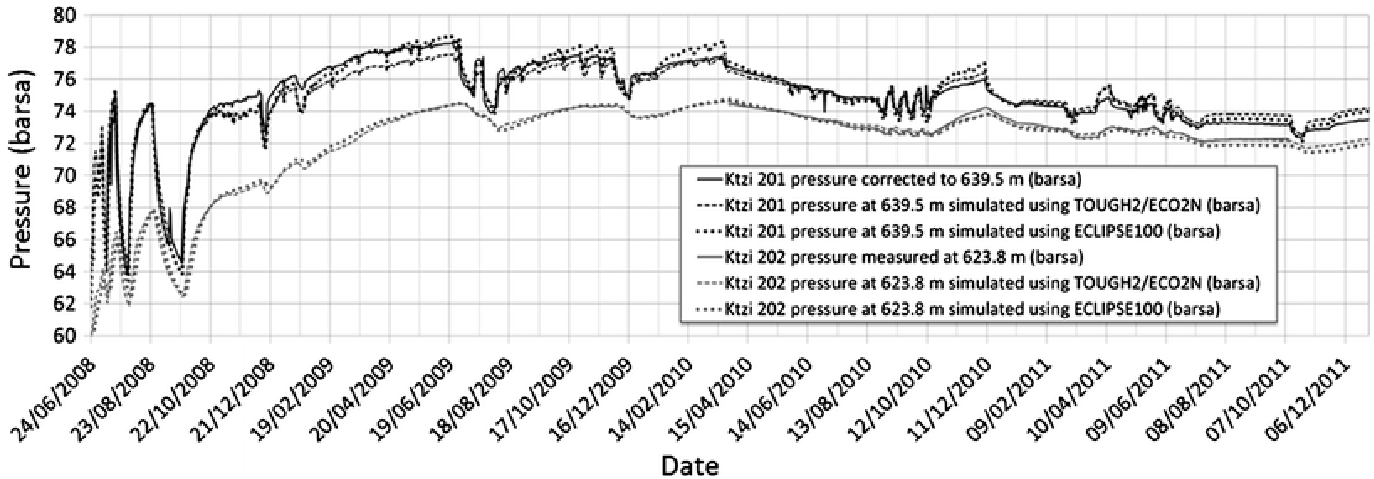
Performance criteria

CO_2 arrival at monitoring wells (e.g. Kempka & Kühn, 2013, Env. Earth Sci.)

Obs well	Phase	Observed (days)	Simulated TOUGH2 (days)	Simulated ECLIPSE (days)	Deviation TOUGH2 (%)	Deviation ECLIPSE (%)
CO2 Ktzi 200/2007 (45 m)	Dissolved CO_2	–	10.6	11.0	–	–
	Gaseous CO_2	21.7	19.3	20.3	11.1	6.4
CO2 Ktzi 202/2007 (112 m)	Dissolved CO_2	–	221.4	225.0	–	–
	Gaseous CO_2	271	229.8	256.0	15.2	5.5

Performance criteria

Pressure difference (e.g. Kempka & Kühn, 2013, Env. Earth Sci.)



- Match of pressure observations and simulations after application of 3D permeability modifyers.
- Demonstrating good quantitative model of average hydraulic properties around wells, but little control of conditions in far-field.
- No detection limit involved – exact match of observations and simulations desired.

Performance criteria

Plume shape matching

Based on simulated and observed plume shapes (seismic,…).

Geometrical parameters (effective reservoir properties):

- Plume footprint area
- Maximum lateral migration distance of CO_2 from the injection point
- Area of CO_2 accumulation trapped at top reservoir
- Volume of CO_2 accumulation trapped at top reservoir
- Area of all CO_2 layers summed
- Spreading coefficient

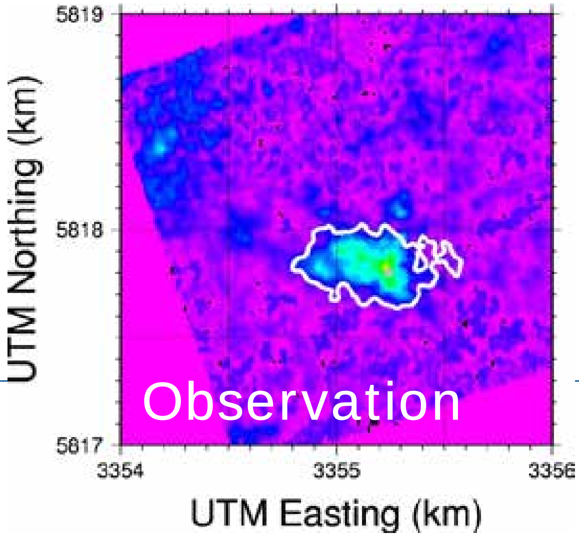
(Chadwick & Noy, 2015, Greenhouse Gases Science and Technology)

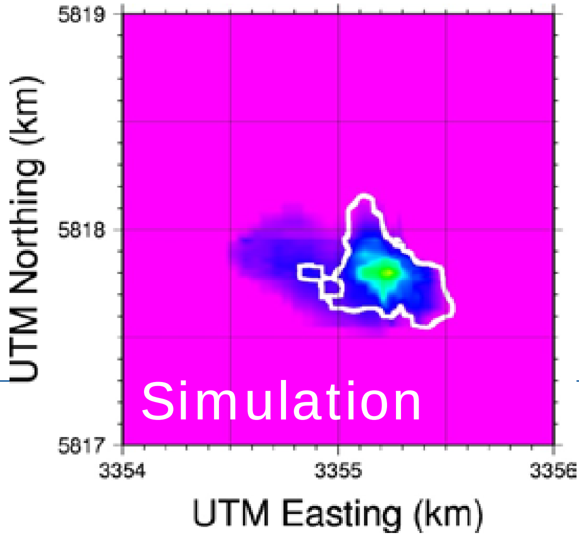
Simplified version of these parameters applied to Ketzin…

Uncertainties

- „Seismic plume“
  - Amplitude (or impedance) anomaly in difference data.
  - Affected by noise, not related to storage.
  - Amplitude threshold.
- „Simulated plume“
  - True reservoir heterogeneity unlikely to be fully described by the model.
  - Distribution of CO_2 partially goes into very thin layers.

--> Apply performance criteria to range of amplitude threshold and thickness values.





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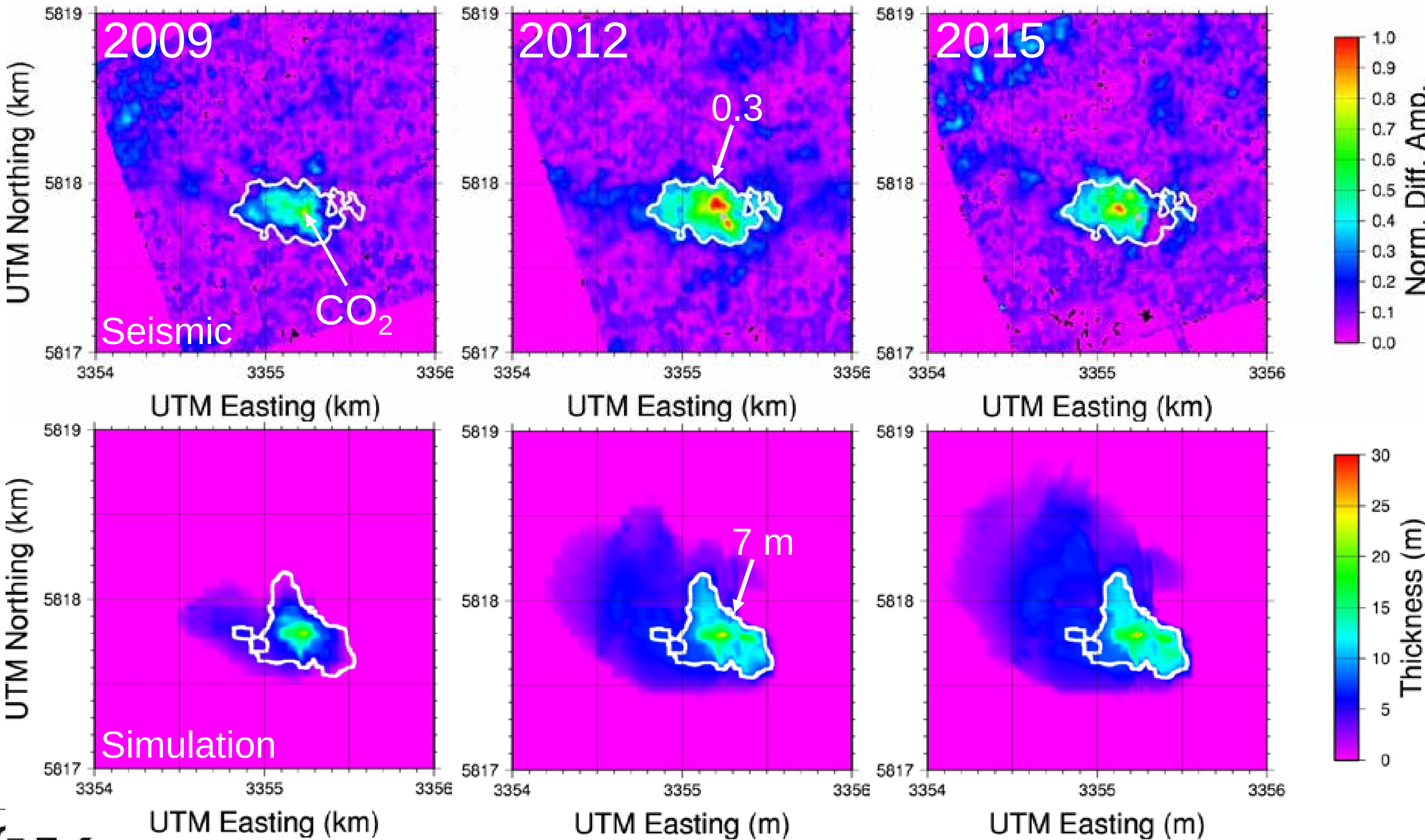
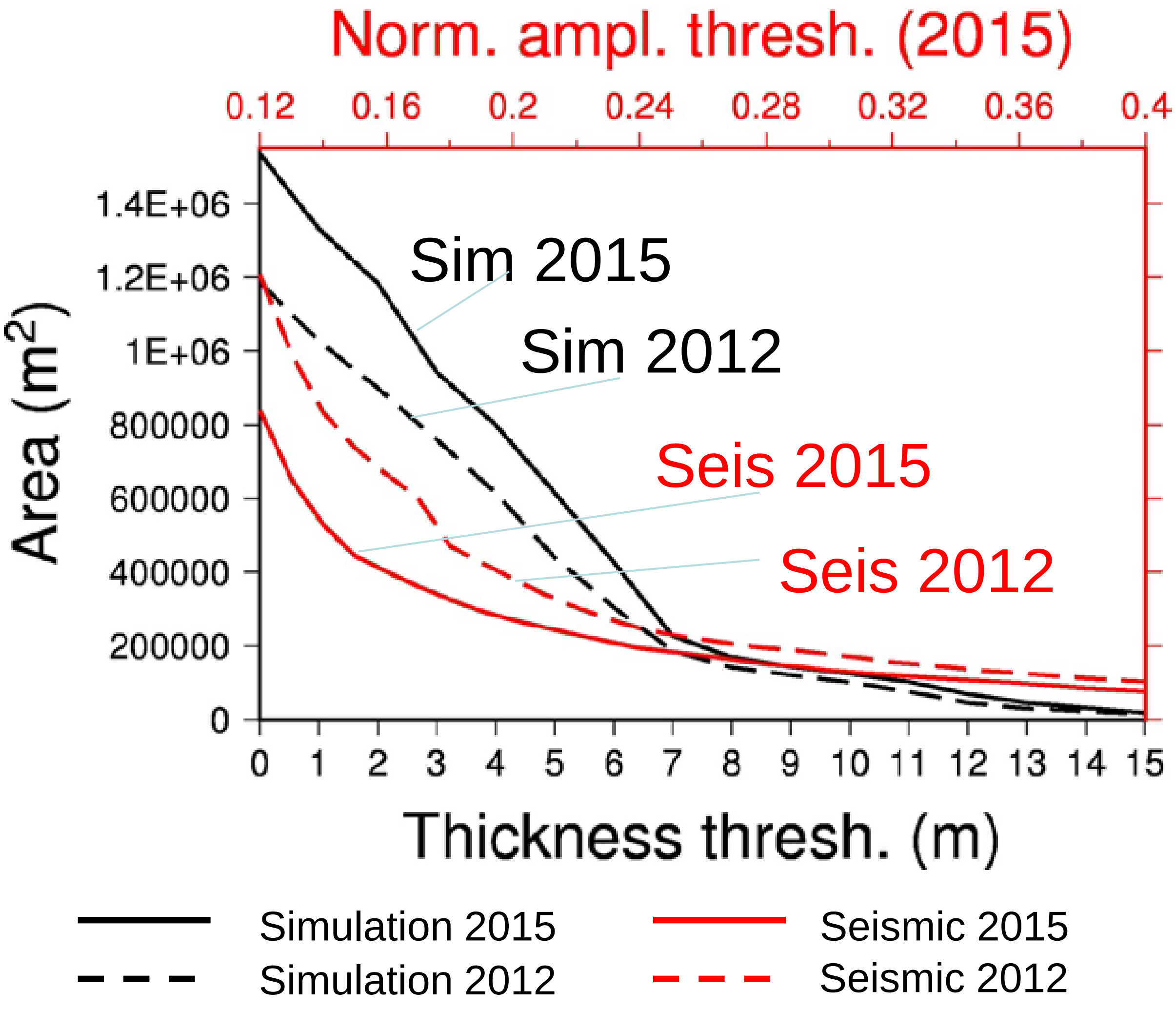
Ketzin: observed and simulated plume geometries



Plume footprint area 2012 and 2015



Simulated plume footprint with large share of „low-thickness“ (< 5 m).

Seismic plume footprint depending on amplitude threshold.

Simulated plume footprint has grown.
Seismic plume footprint has become smaller.

Dissolution and diffusion in thin layers well described?

May be less a problem in large scale storage sites.

(Lüth, Kempka, Ivanova, 2015, Int. J. GHG Contr.)

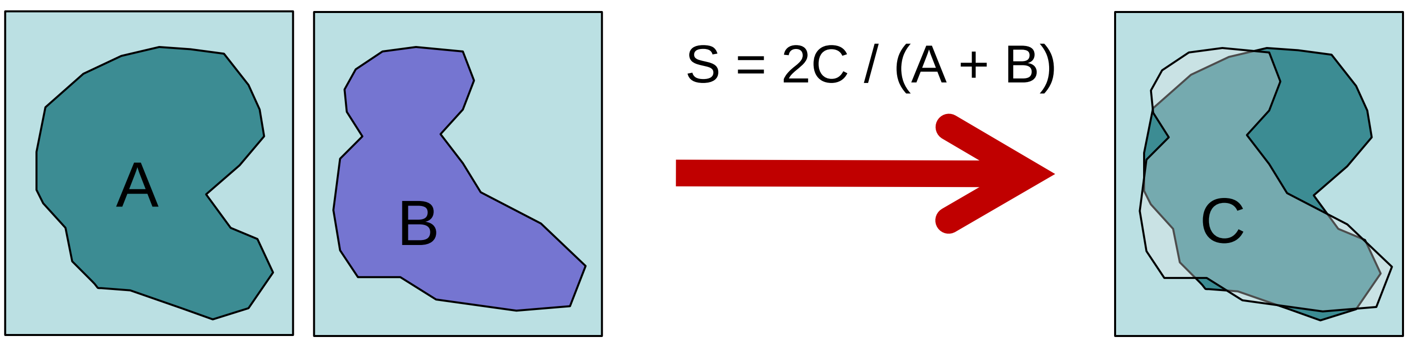
Performance criteria

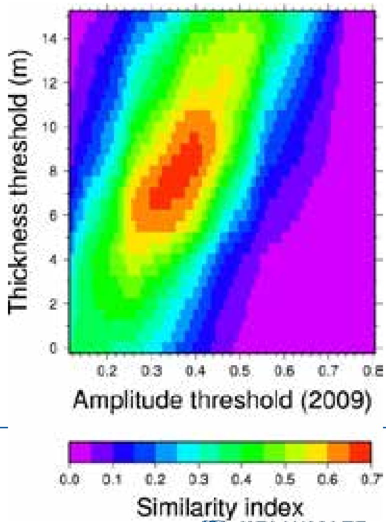
Plume shape matching

Based on simulated and observed plume shapes (seismic,…).

Plume shape geometries (3D permeability distribution):

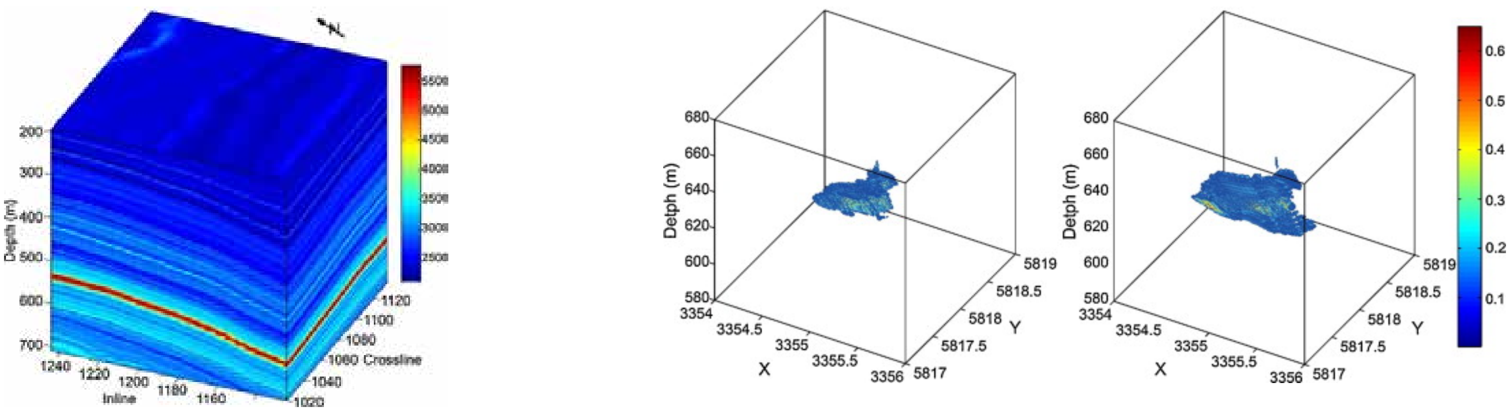
- Similarity index (e.g. Lüth et al., 2015)
- Euclidean distance
- Hausdorff distance (Jeong & Srinivasan, 2017, Int. J. of Greenhouse Gas Contr.)





Geophysical modelling and simulation

One step further: match geophysical observations and simulated geophysical signature from simulation:



Huang et al., 2015

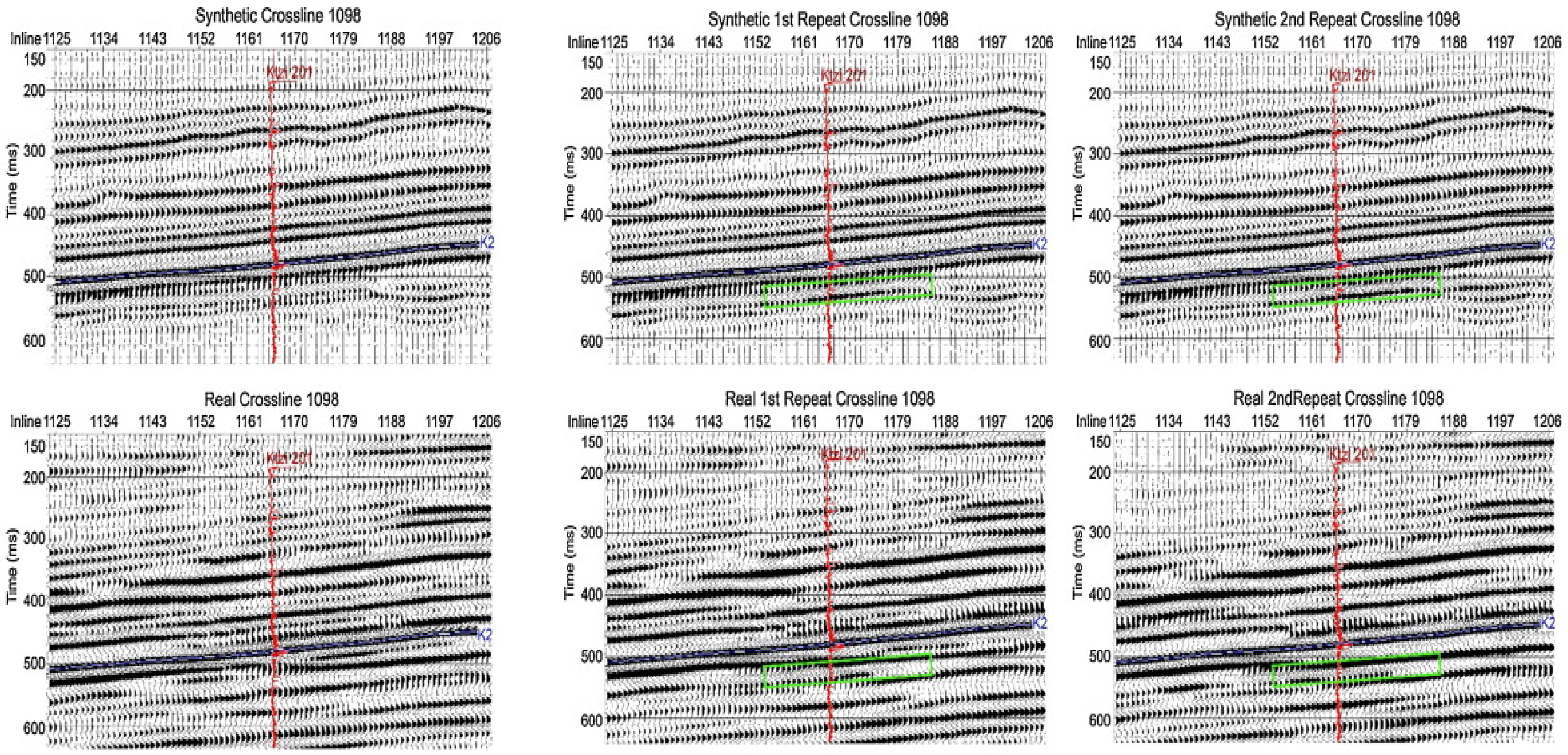
Elastic properties distribution (baseline)

Reservoir simulations (saturation changes)

Fluid substitution modelling – change of elastic properties

Geophysical modelling and simulation

Seismic forward modelling of baseline and repeat survey (convolution)



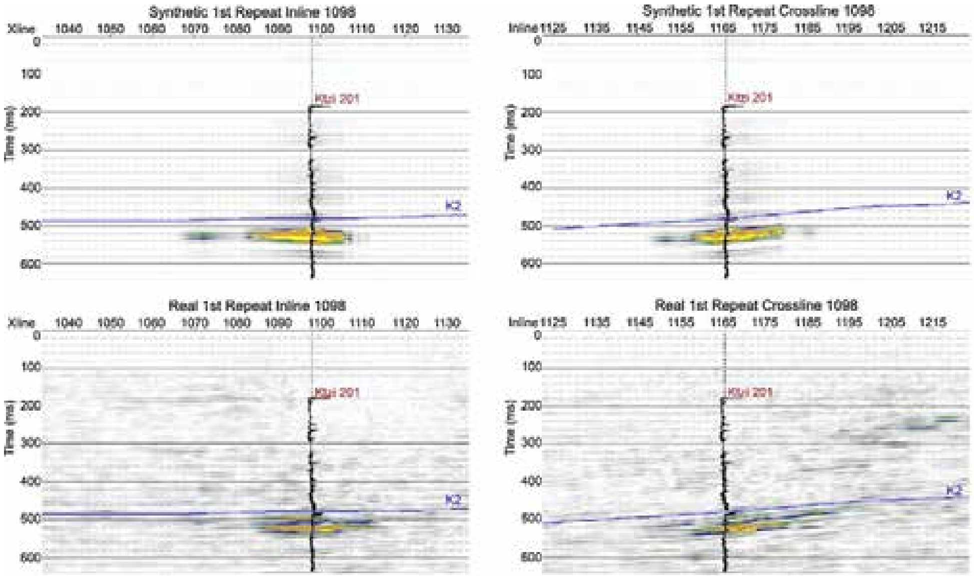
Baseline

1st repeat

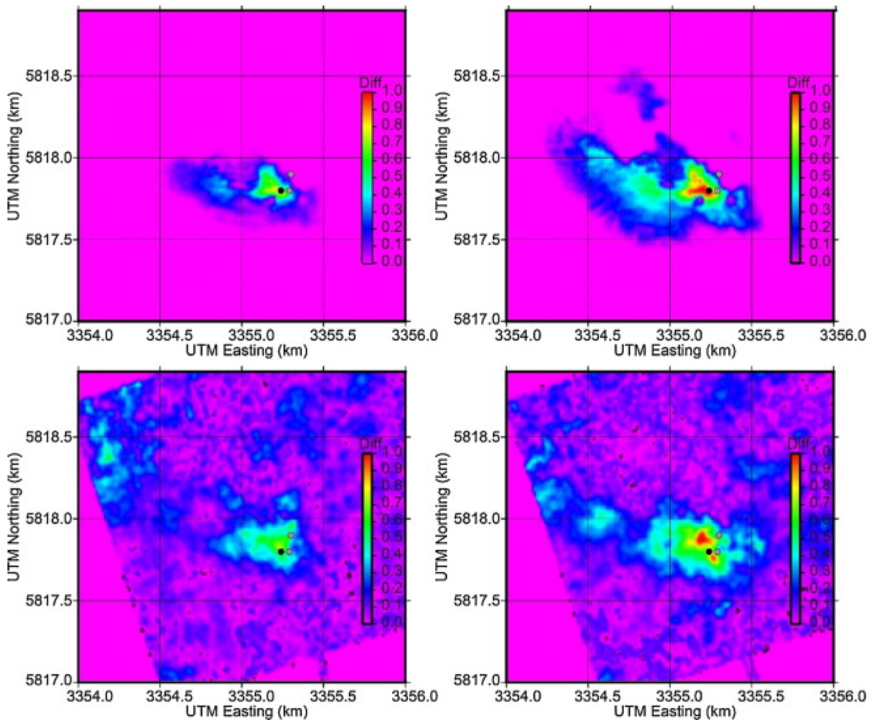
2nd repeat

Geophysical modelling and simulation

Time-lapse images of observations and simulations



Amplitude maps



Difference sections

Direct comparison of geophysical signatures, still affected by noise level.

Huang et al., 2015

Discussion

(Quantitative) conformance assessment

Aim: Ensure reservoir properties are sufficiently well known and reservoir processes are understood for reliable prediction of safe long-term behaviour.

Based on comparison of direct (or indirect) observations (pressure, seismic images, ...) and numerical simulations.

Indirect observations (seismic, ...) affected by detection threshold (saturation, thickness) depending on local conditions.

Quantitative conformance measures such as „plume footprint area" or „similarity index" must account for detection threshold, otherwise they are not useful.

Conformance assessment

During site operation (storage) and for transfer of storage liability from operator to public:

„Conformance of observed and simulated reservoir behaviour“ is one of high-level criteria.

How to define „conformance“ and „non-conformance“?

Numbers?

Description of expected behaviour, including range of numerical values for (relative) conformance?

Needed: benchmark studies on successful cases to define acceptable conformance range.