THE UNIVERSITY OF TEXAS AT AUSTIN

WHAT STARTS HERE CHANGES THE WORLD

Keys to Assuring Storage Permanence in Class VI Projects

Susan Hovorka
Gulf Coast Carbon Center
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Groundwater Protection Council 2023 Annual Forum

Looking Back, Moving Forward: 40 Years of Advancing Groundwater Protection and Sustainability

9/14/2023 Tampa Florida

BUREAU OF ECONOMIC GEOLOGY

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

GCCC GULF COAST CARBON CENTER

Class VI Tools to Assure Storage Permanence

- Models of CO_2 plume
- Model of the AOR
- Monitoring data to confirm correctness of model

How do we use these tools effectively?
Answer: Scientific method to test for and prove/disprove consequential missmatches

"All models are wrong but some are useful"

George E.P. Box 1976

- Example: Detailed characterization of flow system at Detailed Study Area Cranfield MS

Hossieni http://dx.doi.org/10.1016/j.ijggc.2012.11.009

  - Three wells with good log suites 300 ft apart, two complete cores, surface and cross well seismic
  - Of 100 model realizations only 3 matched single phase flow
  - None matched CO_2 flow perfectly

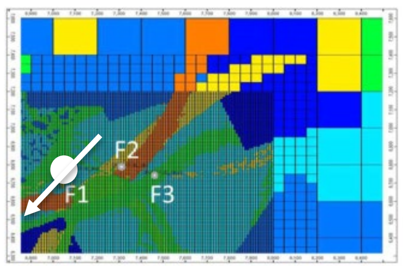


Fig. 11. In DAS, local grid refinement used for accurate study of fluid flow across wells and grids gradually coarsen outward. South to the top and West to the left of the map.

Map of complex fluvial facies

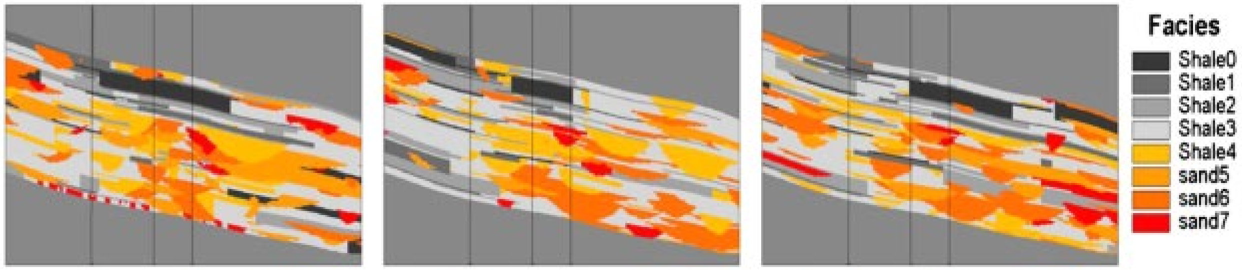
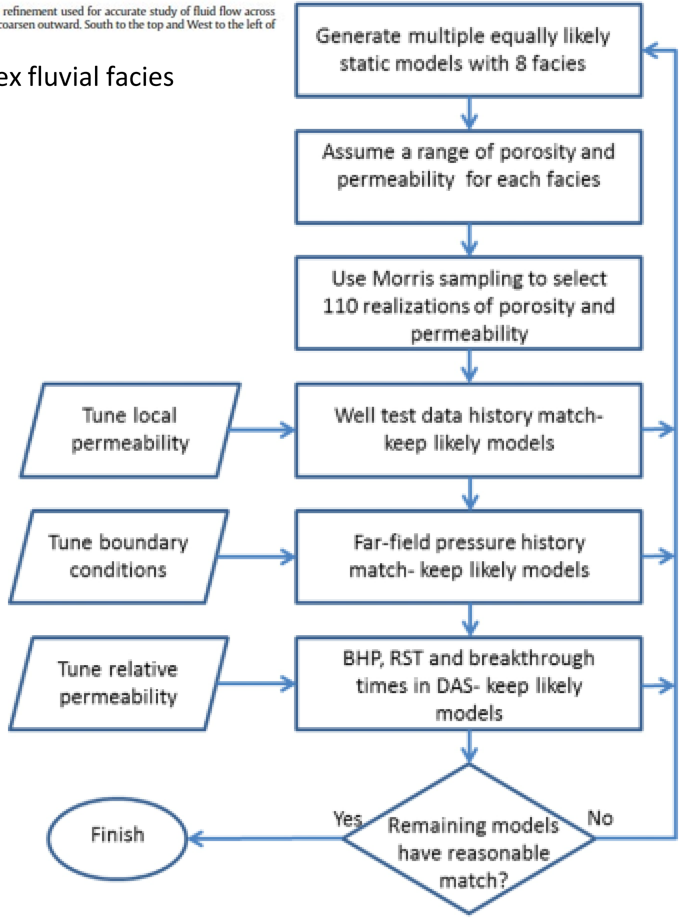
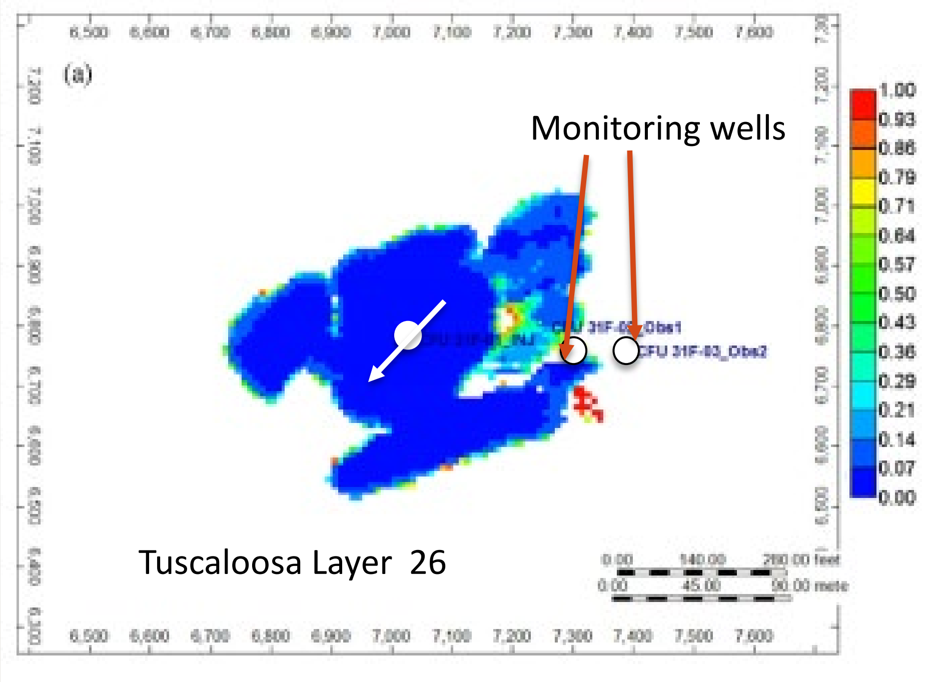
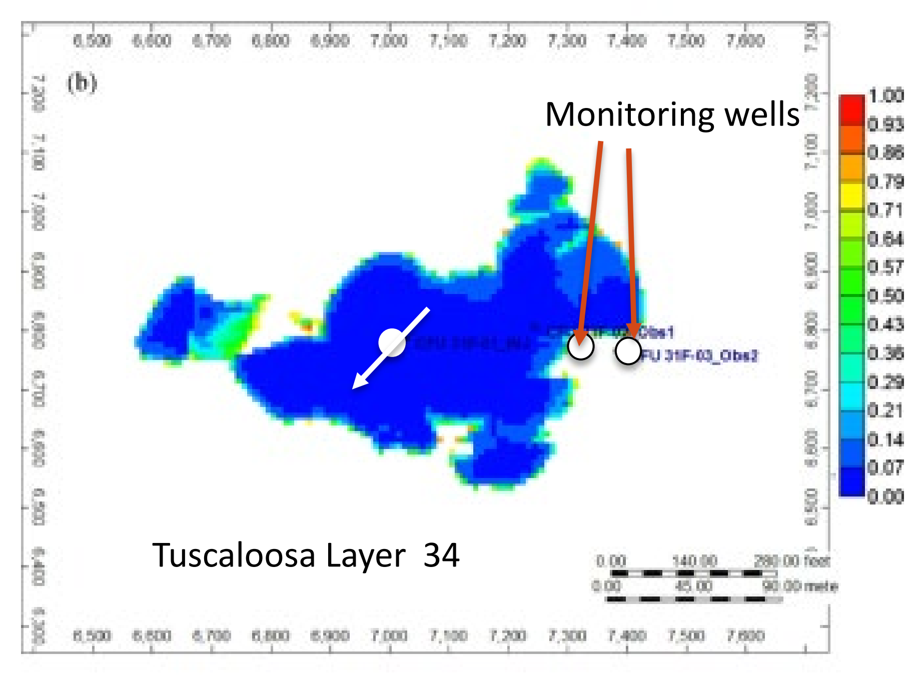


Fig. 10. Object modeling approach used to generate three equally likely static facies models conditioned to hard data at well locations: Left to right—DAS wells CFU 31F-1, CFU 31F-2, and CFU 31F-3.



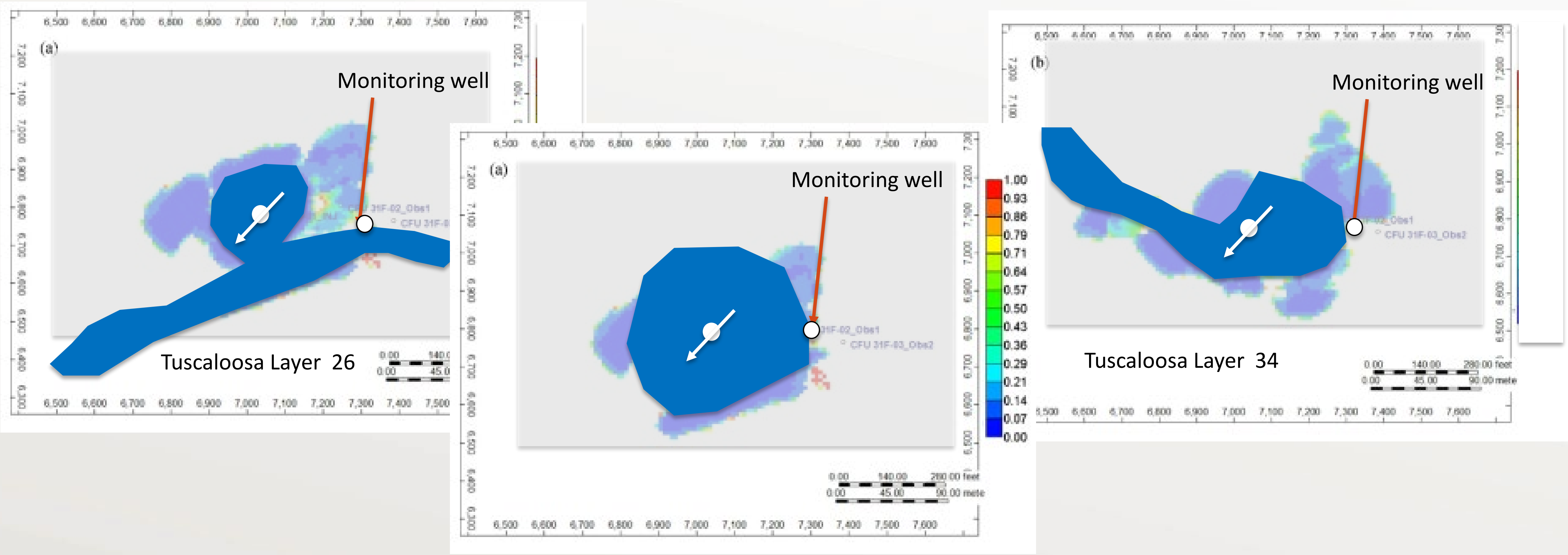
Cranfield plume front maps at early time





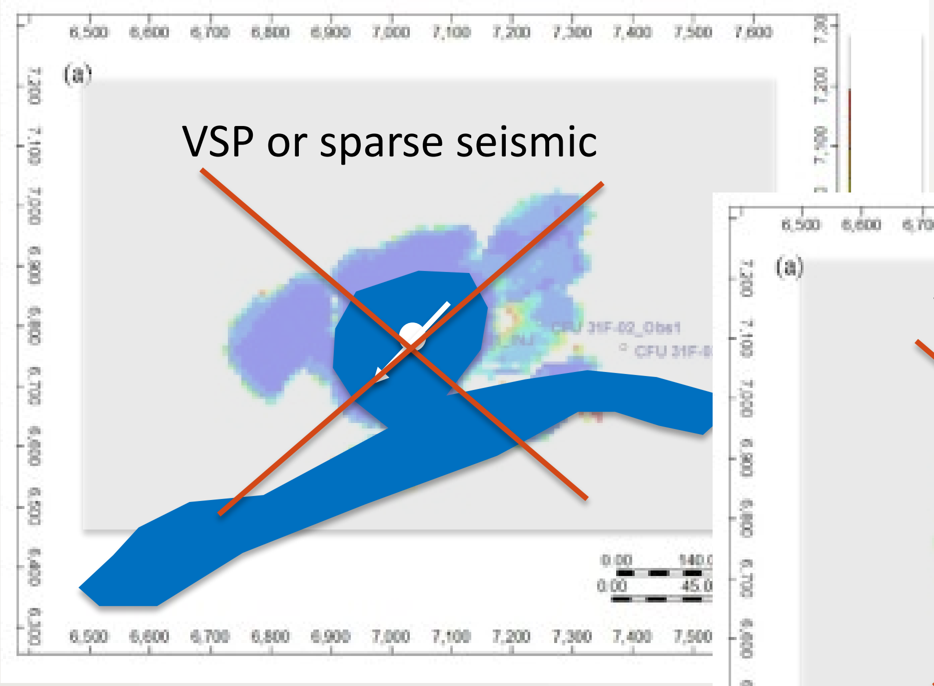
(Showing methane tracer concentrations)

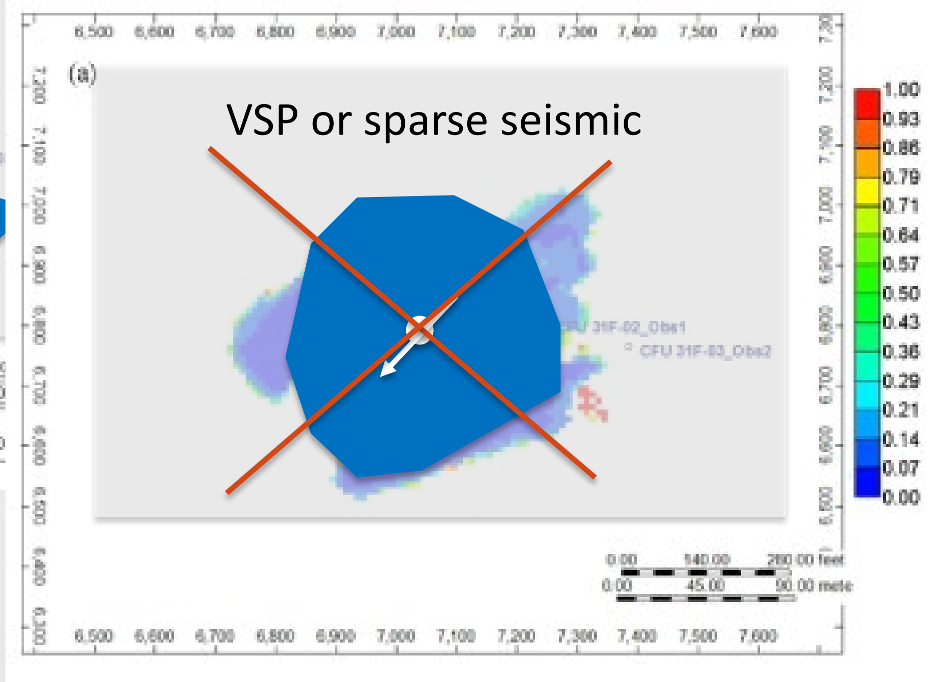
Make model "useful" (per Box) create possible plume front maps of unactable outcomes – risk of plume exceeding AoR

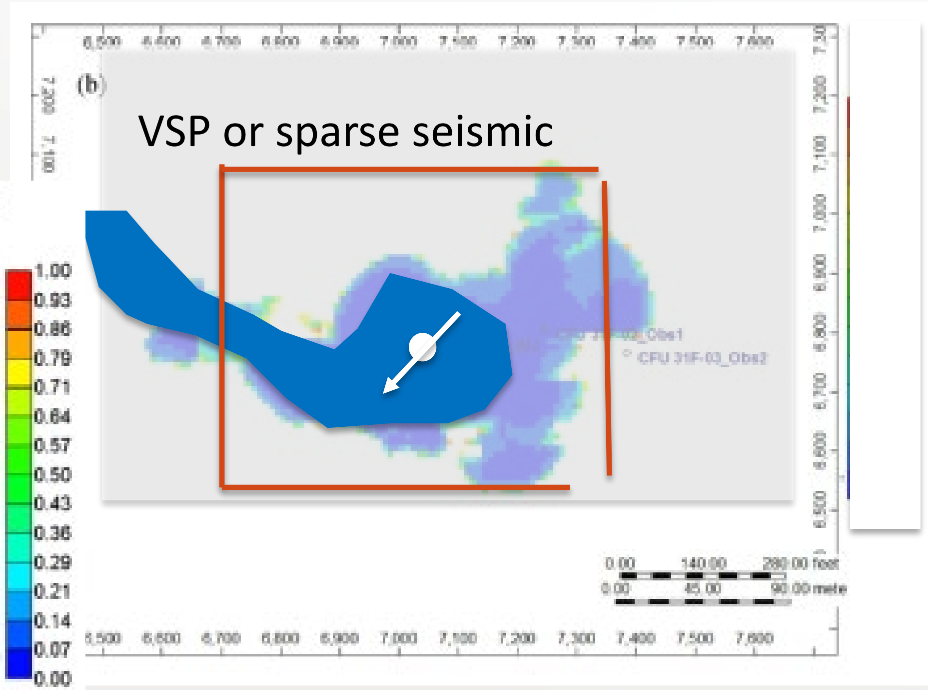


However observe that one monitoring well is not enough to make a unique history match

Collect targeted monitoring data that systematically reduces risk







Injection – fall off test looking at change in compression – distance to fluid change

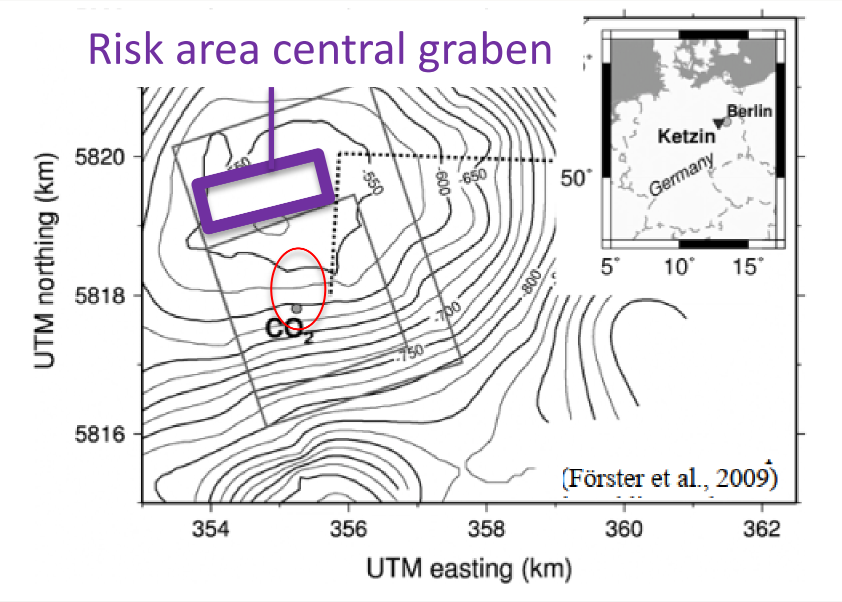
Several indicators however can separate cases

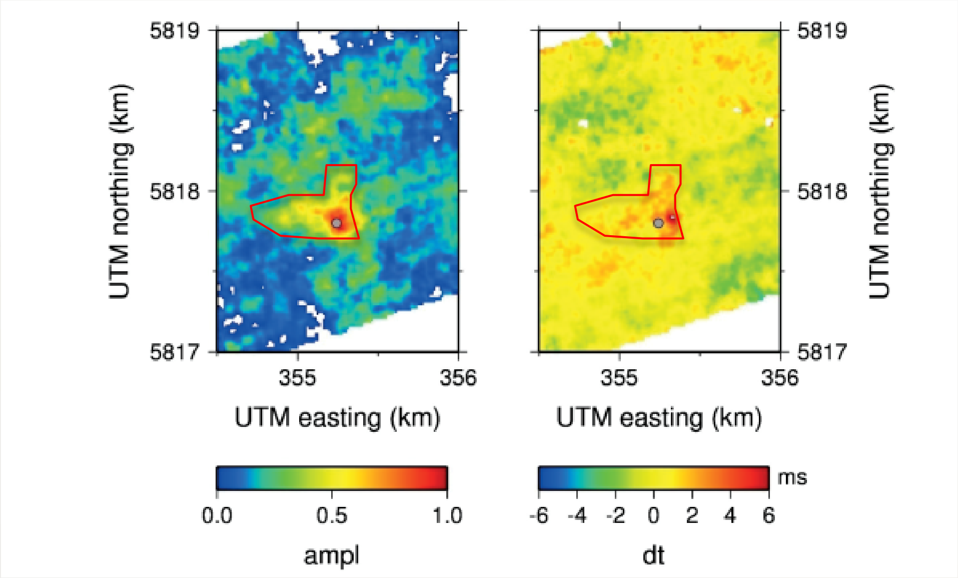
General Principal for validation of modeling by monitoring

- Scientific method approach in regulation:
  - Identify the discrepancies that might be consequential to the containment required
  - Design monitoring that will systematically probe for such anomalies (e.g. at 5 years).
  - Report detection of anomaly = need for remedial action
  - No anomaly = finding of conformant performance
  - No need for “perfect” history match

Eliminate need for endless modification of models

- Example from Ketzin CO_2 injection project, Germany 2008-2013





From Ivanova Univ Upsala PhD

The observed unexpected E-W plume elongation is not on the pathway to breakthrough at the area of increased risk

Pressure as model match

- Pressure is diffusive - somewhat less effected by reservoir heterogeneity
- Pressure is strongly linked to boundary conditions which are key in correct AoR calculation.
- Sparse far field pressure may be sufficient to de risk AoR

Examples of consequential impacts

- CO_2 plume has “thief zone” or unexpected barrier and expands asymmetrically
- CO_2 plume has lower than expected saturation and expands laterally faster than expected
- CO_2 preferentially accesses only part of the intended storage zone and both pressure and CO_2 plume are larger than expected
- Flaws (open penetrations?) in confining system are present and allow vertical migration of fluids

CO_2 plume meets unexpected barrier and expands asymmetrically

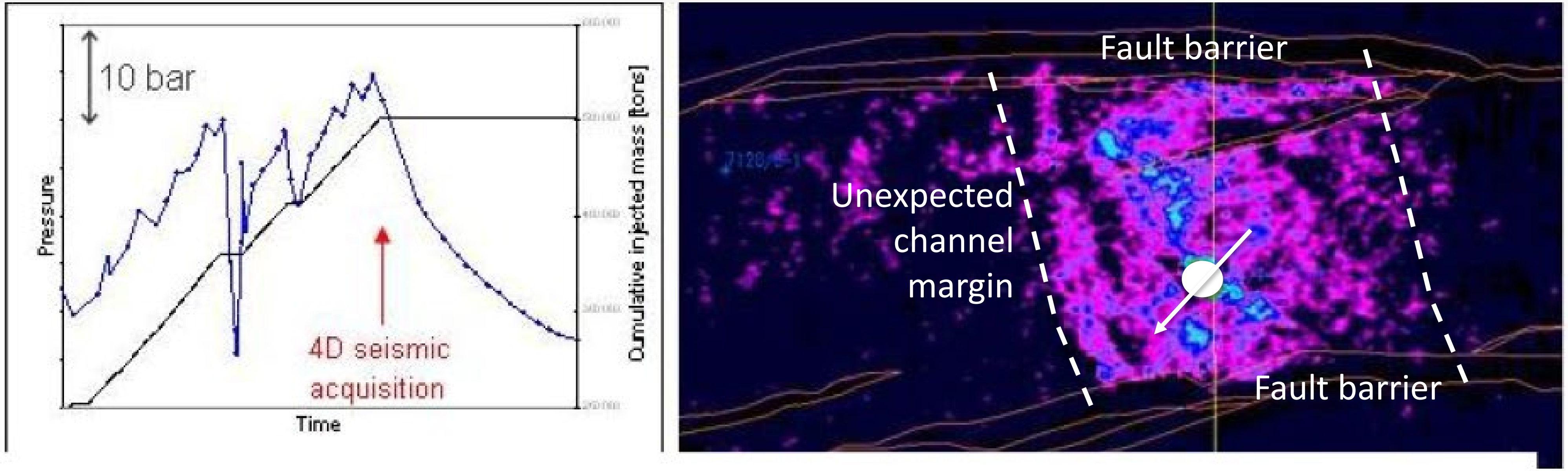


Figure 8: Portion of the injection and pressure data from Snøhvit spanning year 2009 (left), and 4D seismic difference amplitude map of the lowermost Tubåen Fm. level (right)..

Snøhvit saline injection 2009 in Barents sea encountered unexpected lateral barriers to flow pressure rose more quickly than expected. An offset well was drilled to assure continued injection below fracture pressure.

From Eiken et al, 2011

CO_2 plume has "thief zone" and expands asymmetrically

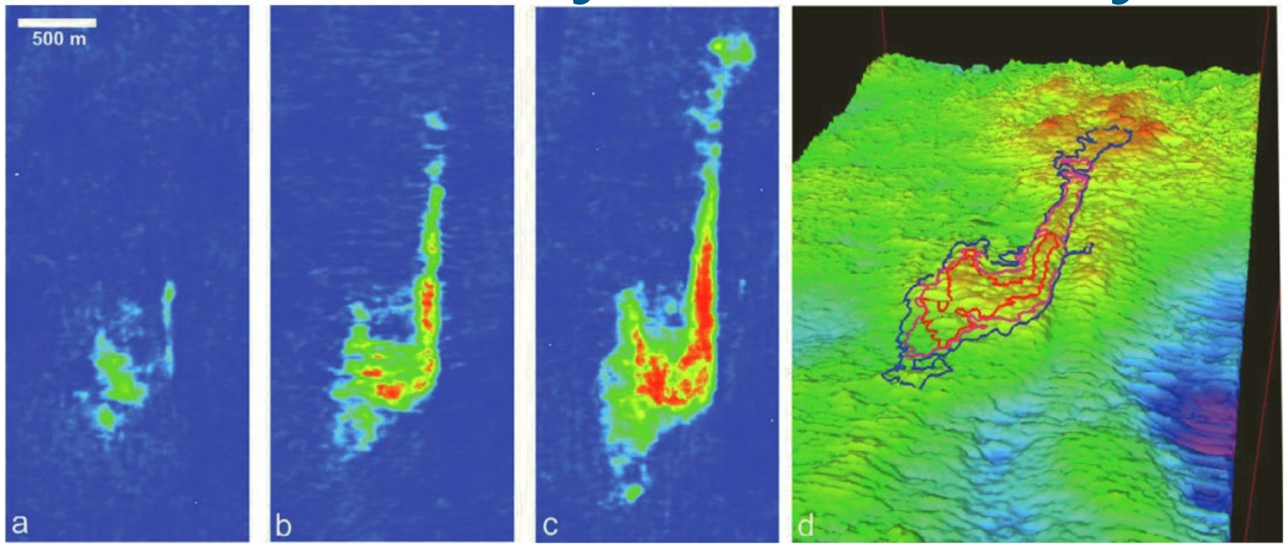
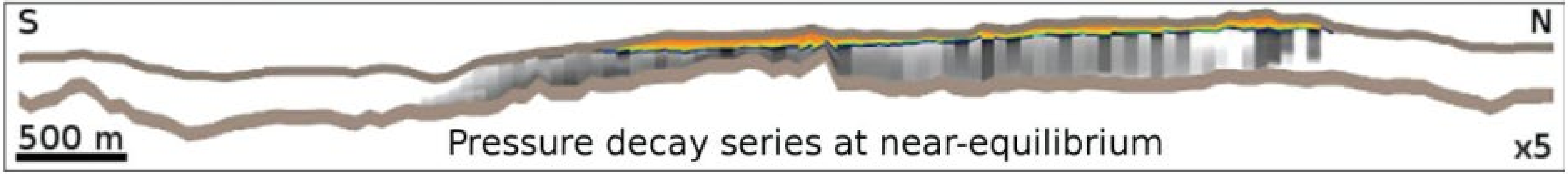


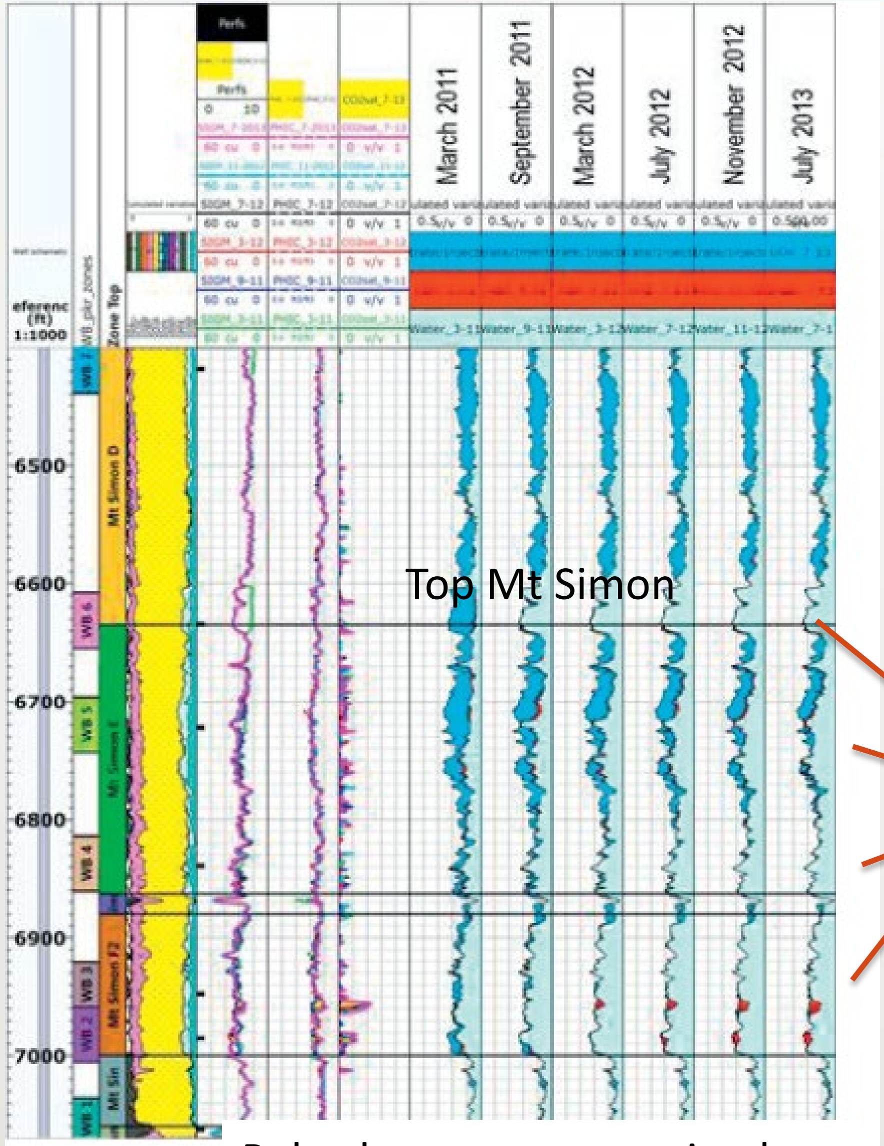
Figure 3 Growth of the topmost CO_2 layer mapped through difference amplitudes a) 2001 minus 1994 b) 2004 minus 1994 c) 2006 minus 1994 . d) 3D perspective view (looking north) of the top Utsira Sand surface (mapped on the baseline 1994 dataset) showing the CO_2 - water contacts in 2001 (red), 2004 (purple and 2006 (blue).

Chadwick et al
doi:10.1016/j.egypro.2009.01.274

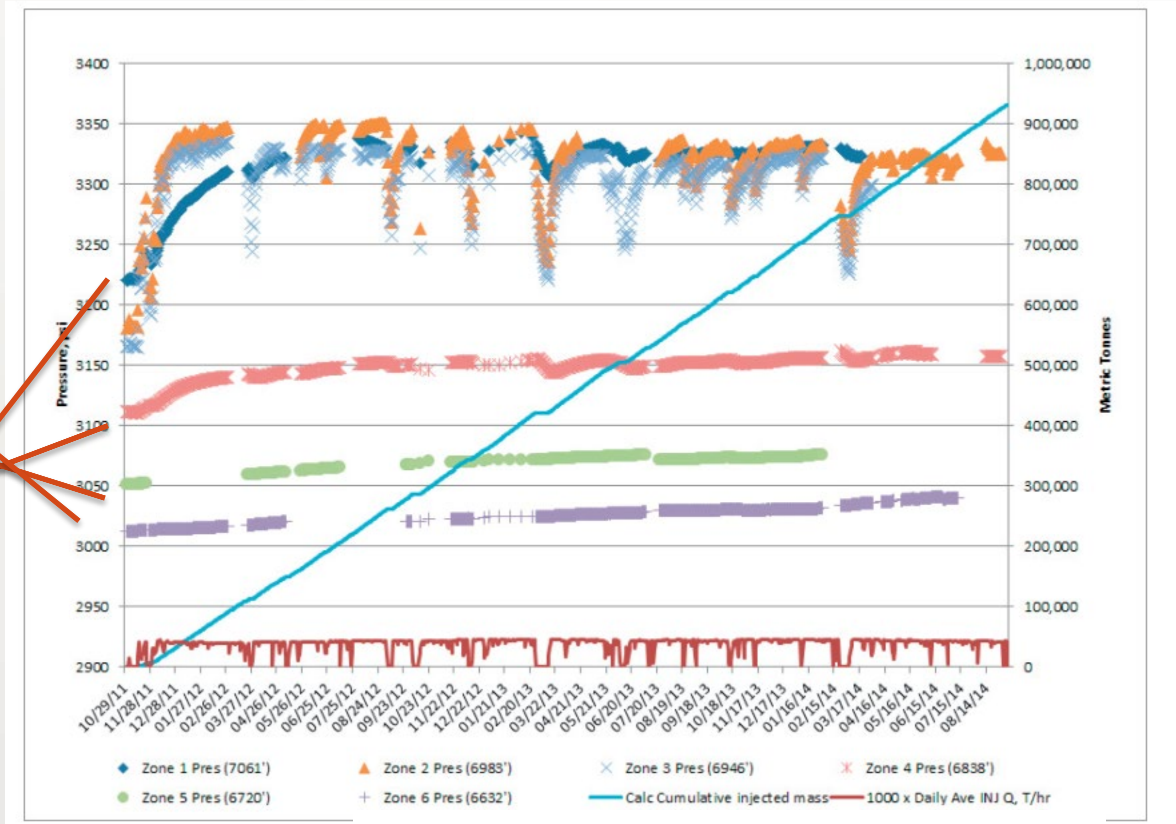


Cavanagh 2013

CO_2 preferentially accesses only part of the intended storage zone (are pressure and CO_2 plume are larger than expected?)



Pulsed neutron saturation logs

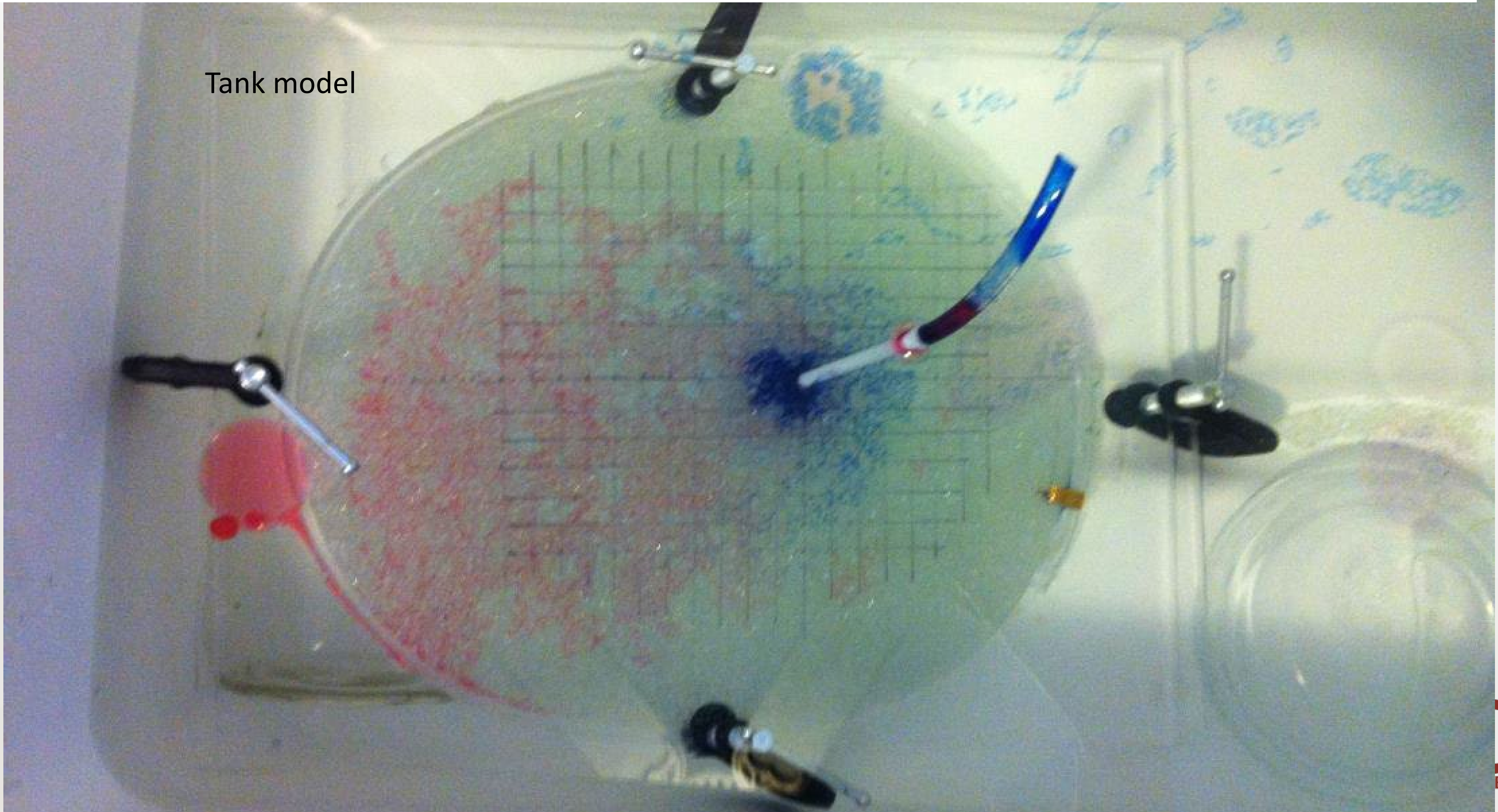


Pressure response plotted over time

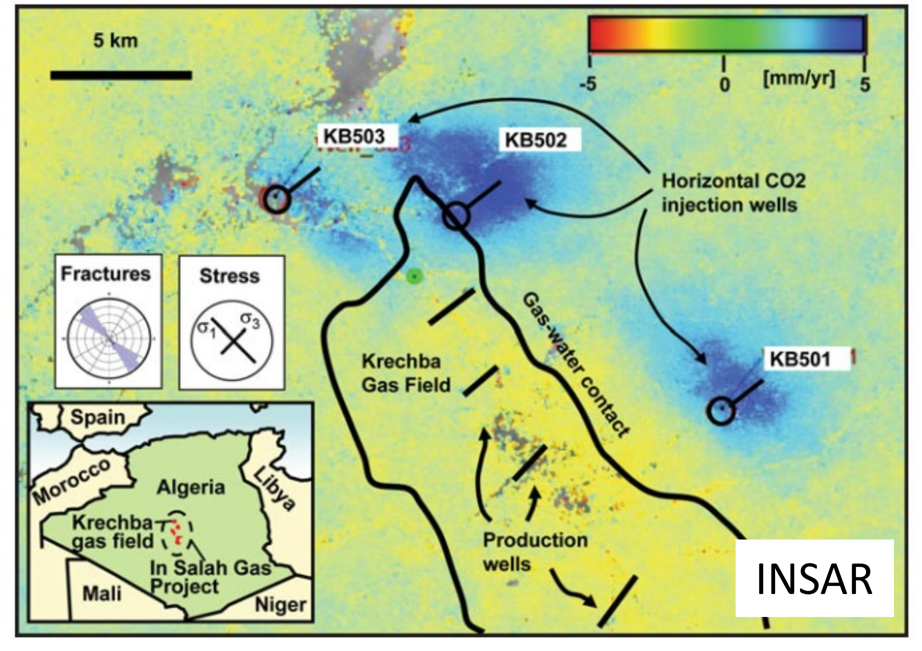
GCCC GULF COAST CARBON CENTER
BUREAU OF ECONOMIC GEOLOGY

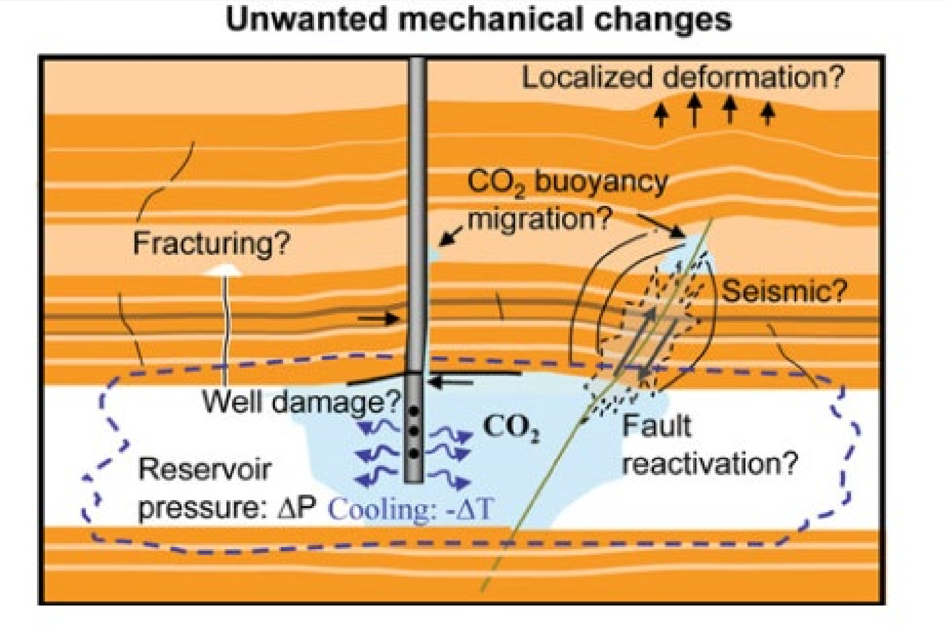
Couëslan et al 2014, Decatur

CO_2 plume has lower than expected saturation and expands laterally larger than expected



Flaws in confining system are present and allow vertical migration of fluids





- An error in pressure management caused geomechanical damage to a saline CO_2 injection site at In Salah, Algeria and out-of-zone fluid migration, which was detected with INSAR

Rutqvist, 2012 DOI 10.1007/s10706-011-9491-0

Scientific Method Monitoring Design (ALPMI)

Risk assessment method as usual

Quantify risks to define material impact

Specify magnitude, duration, location, rate of material impact

- Avoid subjective terms like safe and effective.
- E.g. : Specify mass of leakage at identified horizon or magnitude of seismicity.
- Specify certainty with which assurance is needed

Model material impact scenarios

Explicitly model unacceptable outcomes showing leakage cases.

ALPMI uses models differently than the typical history matching the expected performance

Identify signals in the earth system that indicate or preferably precede material impact

This method down selects to consider only signals that may indicate material impact is occurring or may occur.

Select monitoring tools that can detect these signals at required sensitivity

Approaches like those normally seismic survey design should be deployed for all modeling tools

Forward modeling tool response is essential to developing the expected negative finding: “No material impact was detected by a system that could detect this impact.”

Deploy tools and collected and analyze data

This activity as traditionally conducted. Include all the expected components, such as attribution, updating as needed, feedback , etc..

Report if material impact did/did not occur

Close !

Only via this ALPMI process can a finding that the material impact did not occur be robustly documented

Main points

- Routine matching sparse monitoring data to models is time consuming as well as ineffective in derisking projects
- Recommend: pre-plan monitoring to challenge models where outcomes have consequences. Site specific design with use of basic scientific method to disprove a failure hypothesis.

Thank You!

susan.hovorka@beg.utexas.edu
gulfcoastcarbon.org
University of Texas at Austin