Monitoring storage projects for permanence – case studies from North America

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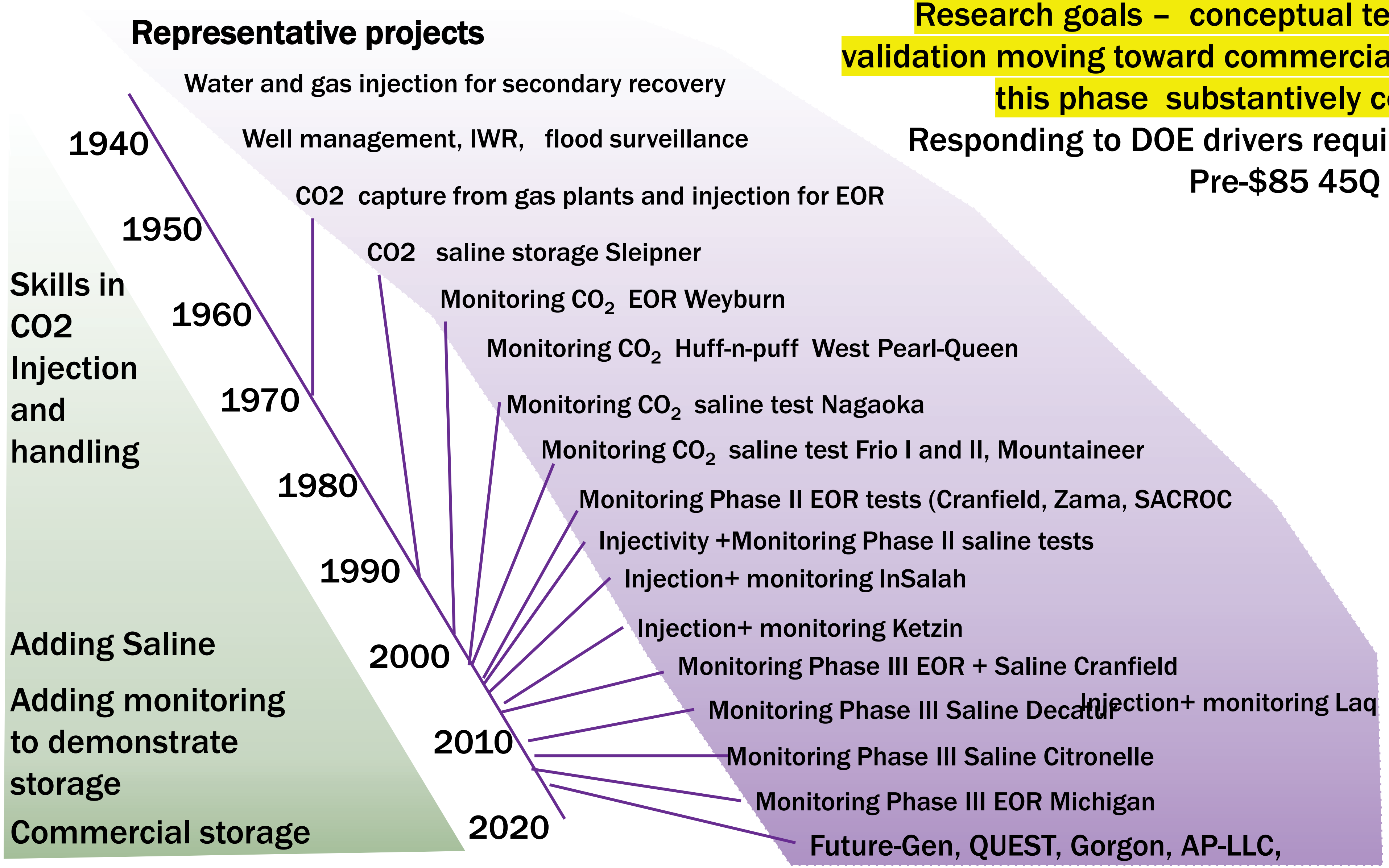
Looking back at research monitoring

Research goals – conceptual testing and validation moving toward commercialization – this phase substantively completed

Responding to DOE drivers requiring MMV

Pre-$85 45Q tax credit



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

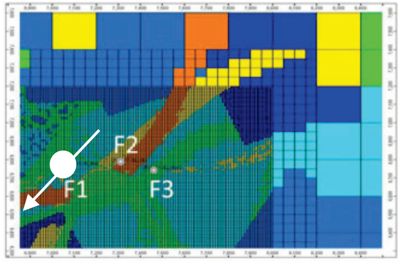
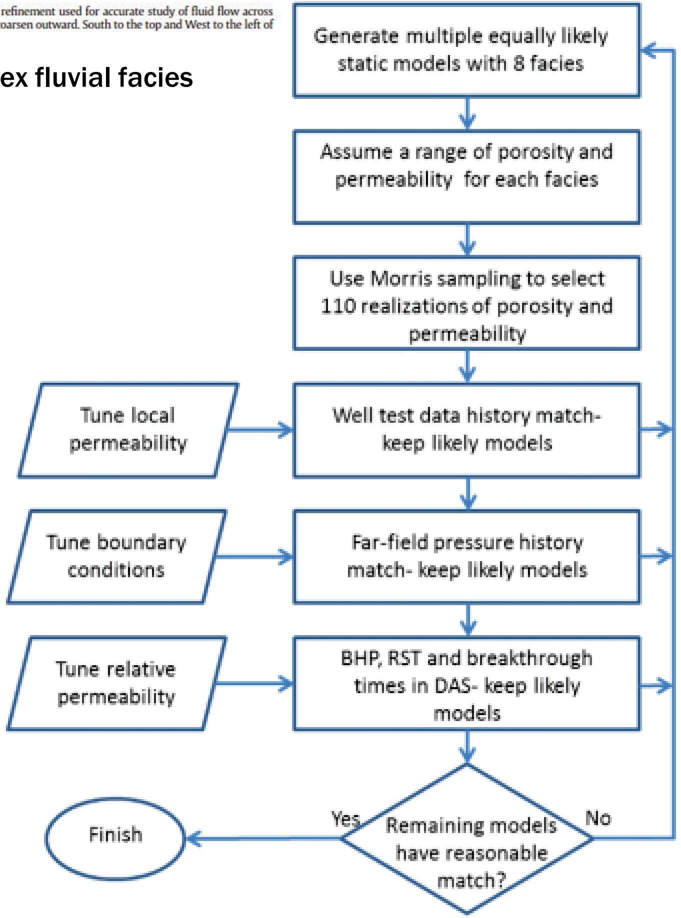


Fig. 11. In DAS, local grid refinement used for accurate study of fluid flow across wells and grids gradually coarsen outward. South to the top and West to the left of the map.

Map of complex fluvial facies



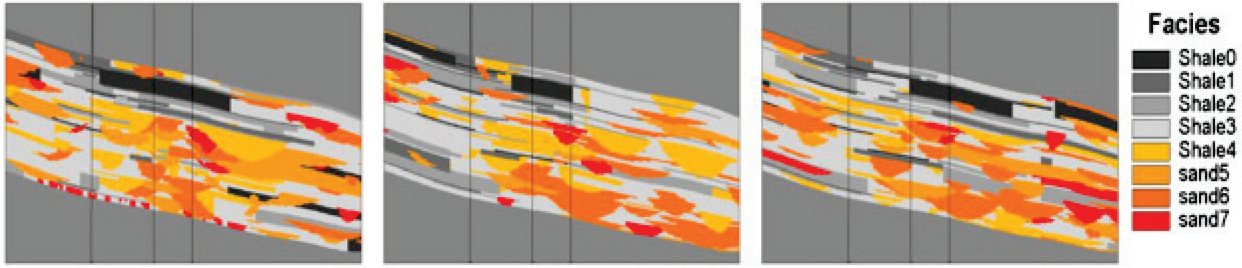
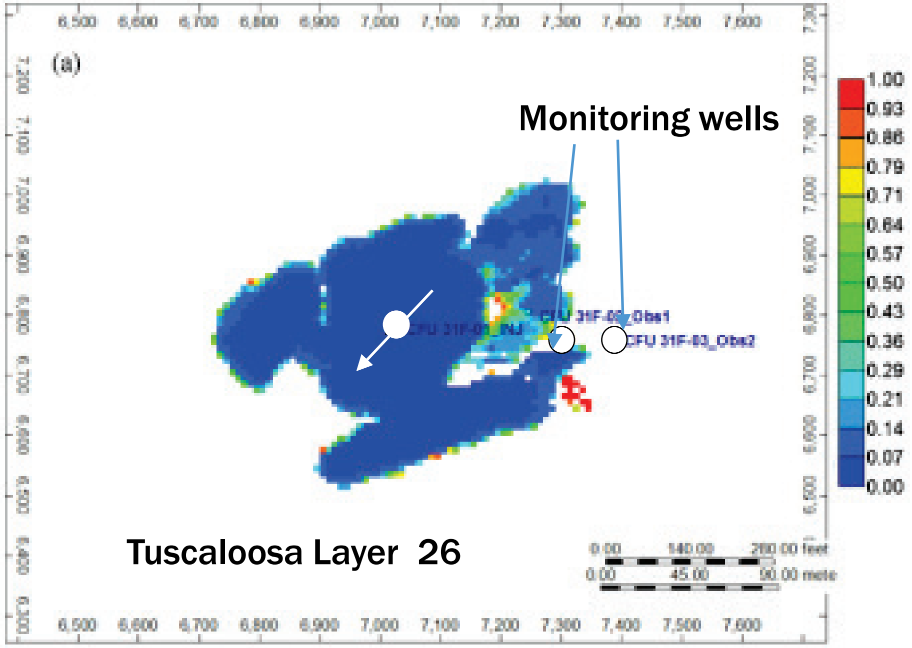
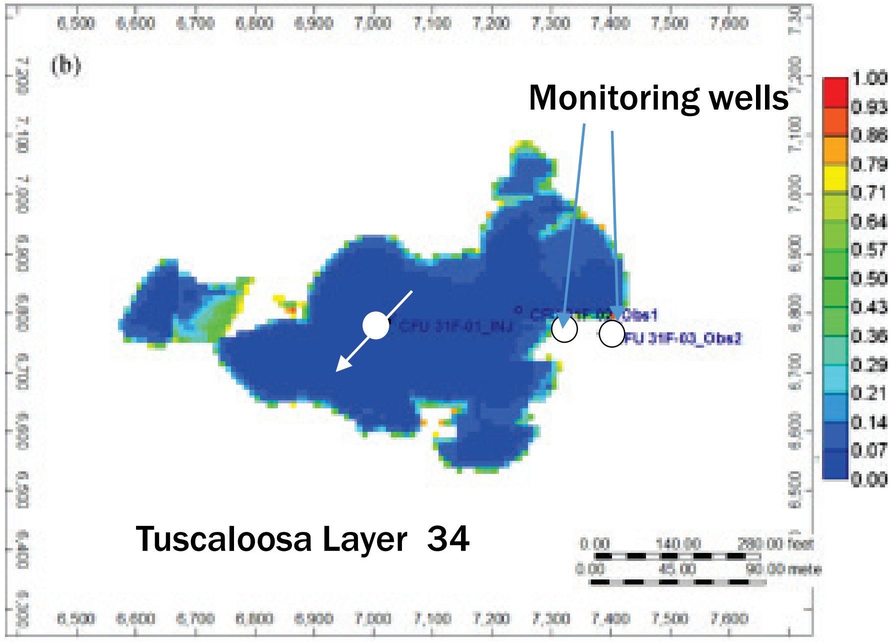


Fig. 10. Object modeling approach used to generate three equally likely static facies models conditioned to hard data at well locations: Left to right—DAS wells CFU 31F-1, CFU 31F-2, and CFU 31F-3.

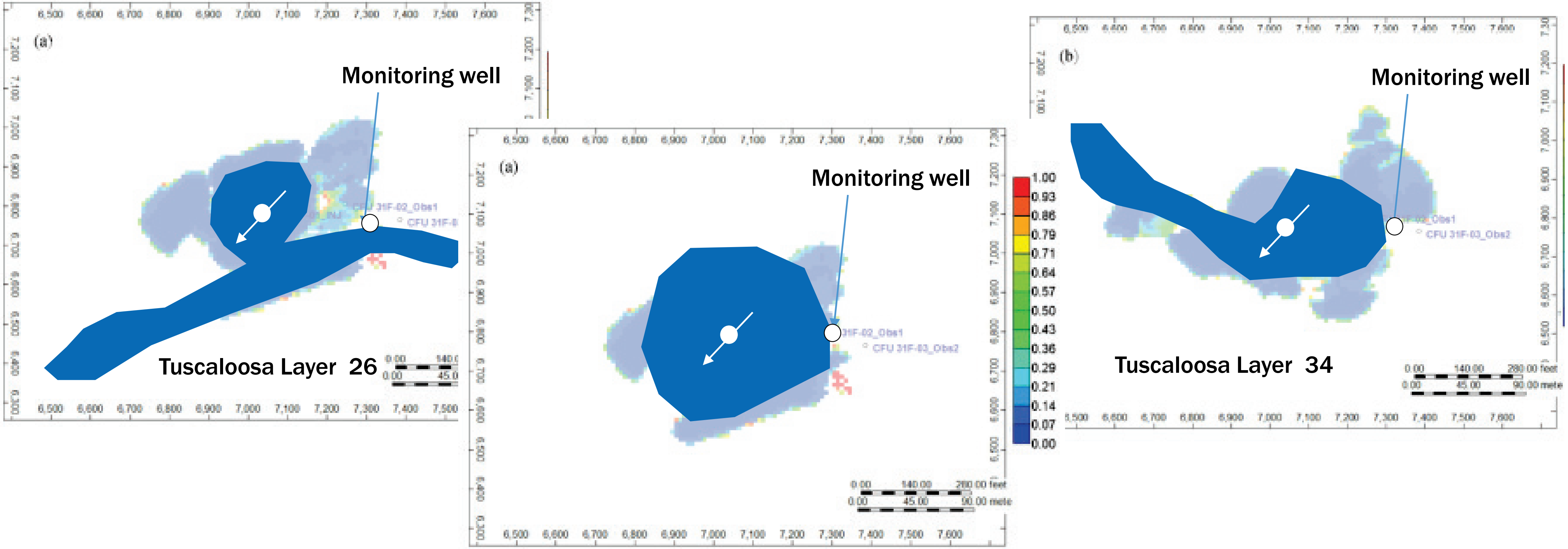
Cranfield plume front maps at early time





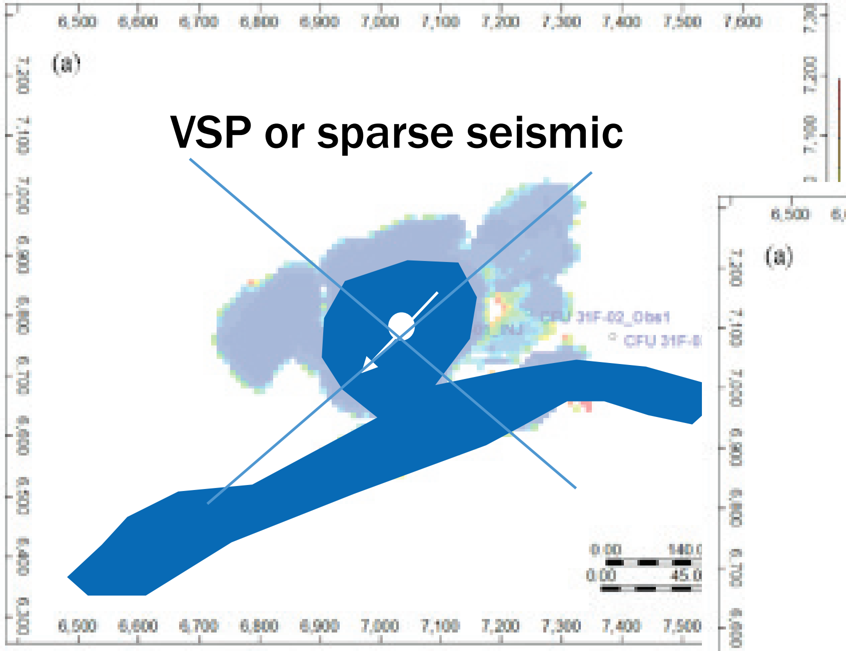
(Showing methane tracer concentrations)

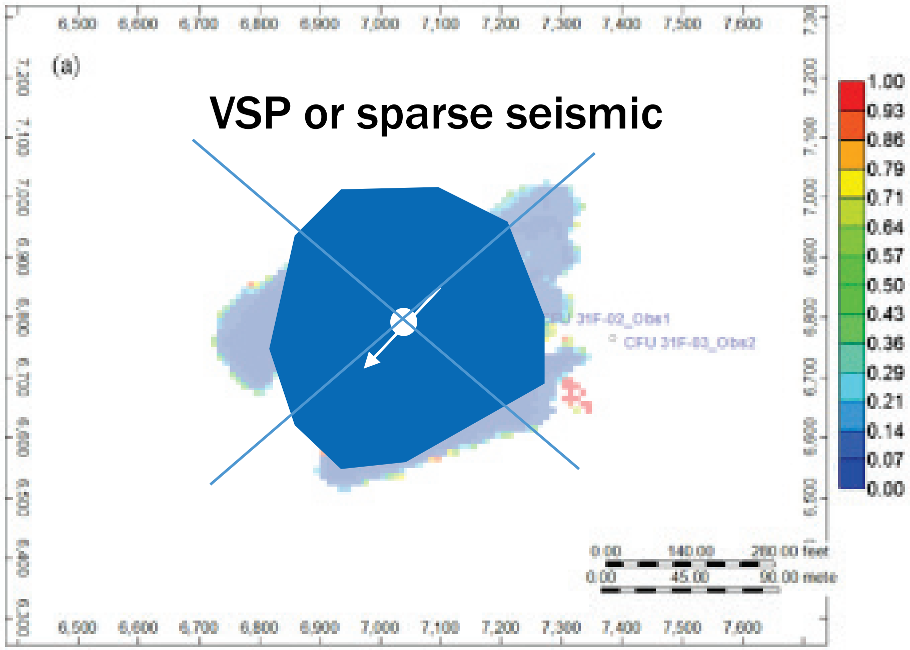
Make model "useful" (per Box) create possible plume front maps of unactable outcomes – risk of plume exceeding AoR

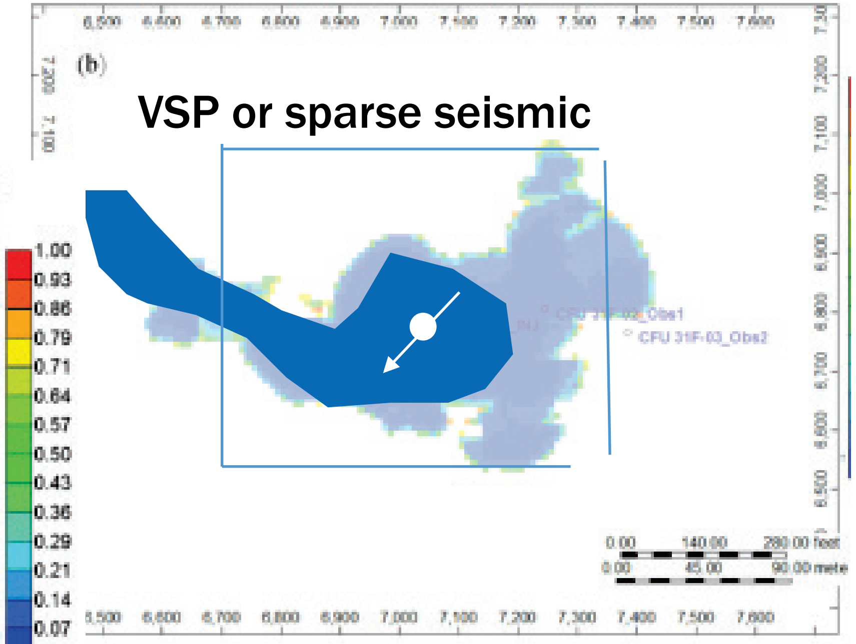


However observe that one monitoring well is not enough to make a unique history match

Collect targeted monitoring data that systematically reduces risk







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

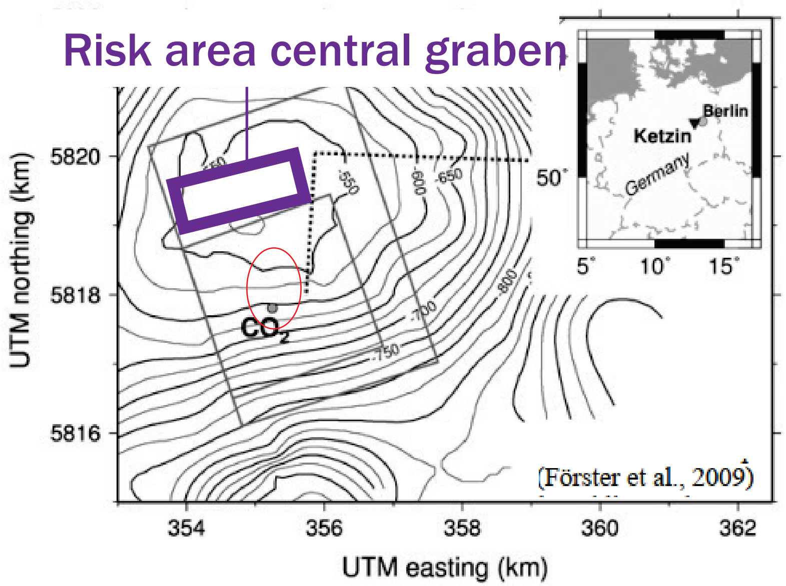
Several indicators however can separate cases

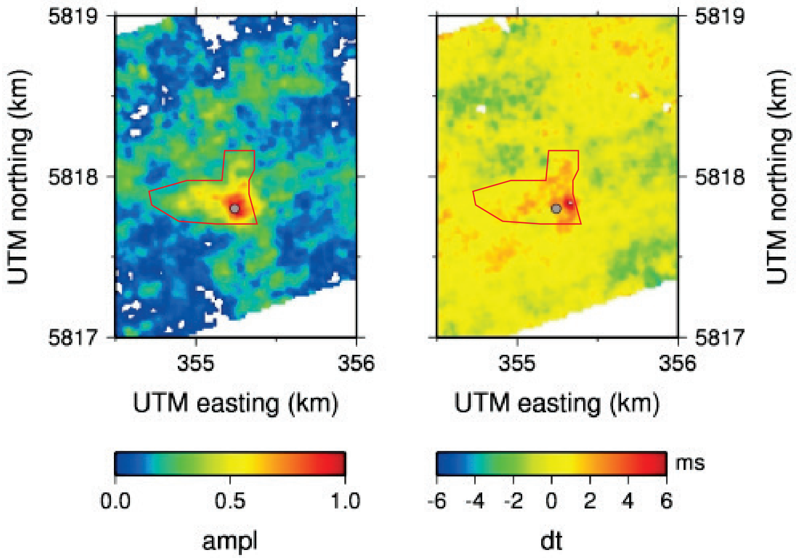
General Principal for validation of modeling by monitoring

- 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



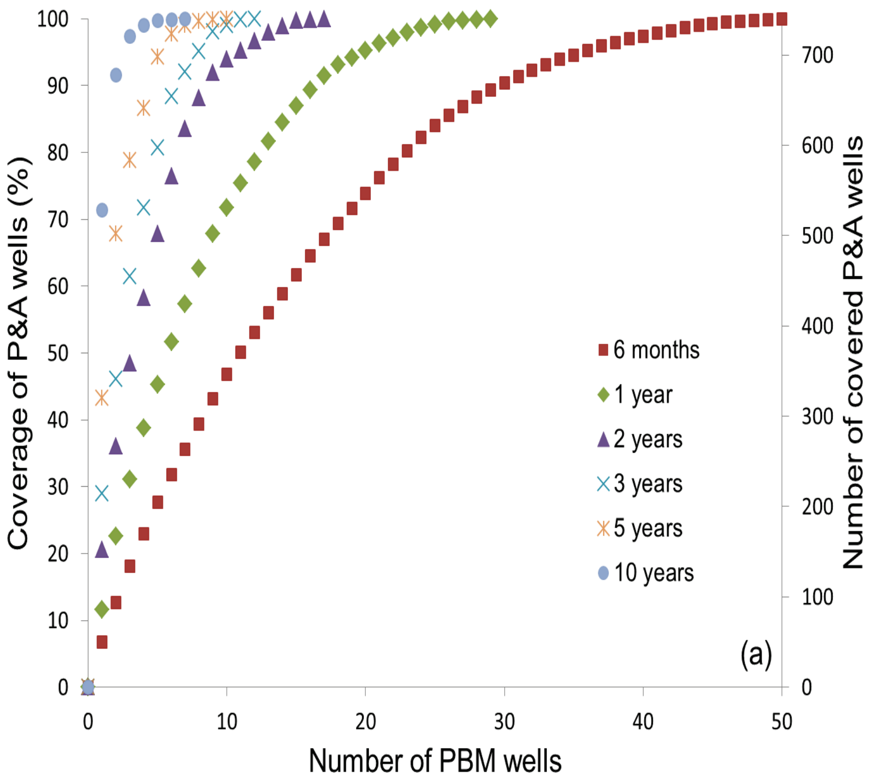


From Ivanova Univ Upsala PhD

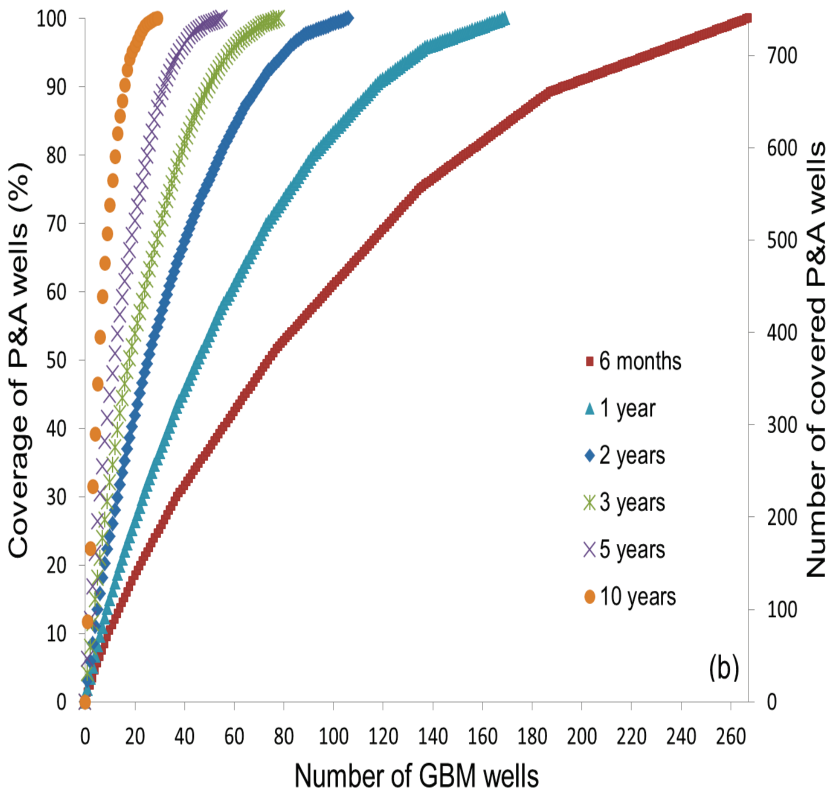
The observed unexpected E-W plume elongation is not on the pathway to breakthrough at the area of increased risk

Sensitivity analysis for above-zone leakage detection time in models

Detecting pressure signal



Detecting geochemical signal



Behni Bollhassani, UT MS thesis

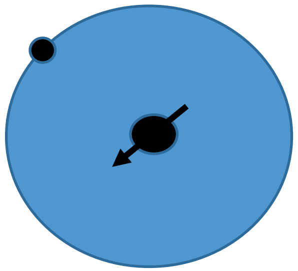
Pressure as model match

- Pressure is diffusive - somewhat less affected 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

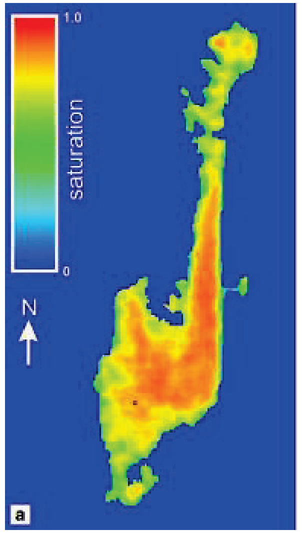
New version of EASi-tool for simple pressure and AOR evaluation to be released as freeware www.gulfcoastcarbon.org

Plume tracking

- Testing and monitoring to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure (*e.g.*, the pressure front) by using:
  - Direct methods in the injection zone(s); and,
  - (2) Indirect methods (*e.g.*, seismic, electrical, gravity, or electromagnetic surveys and/or down-hole carbon dioxide detection tools)
- Could required pressure fall-off test at injection well serve as direct monitoring per Bob VV?



Single monitoring well on predicted year 5 plume validates a model if high symmetry assumed



Unexpected asymmetry is expected in geologic settings

Williams and Chadwick 10.1190/GEO2011-0449.1

CO_2 plume meets unexpected barrier and expands asymmetrically

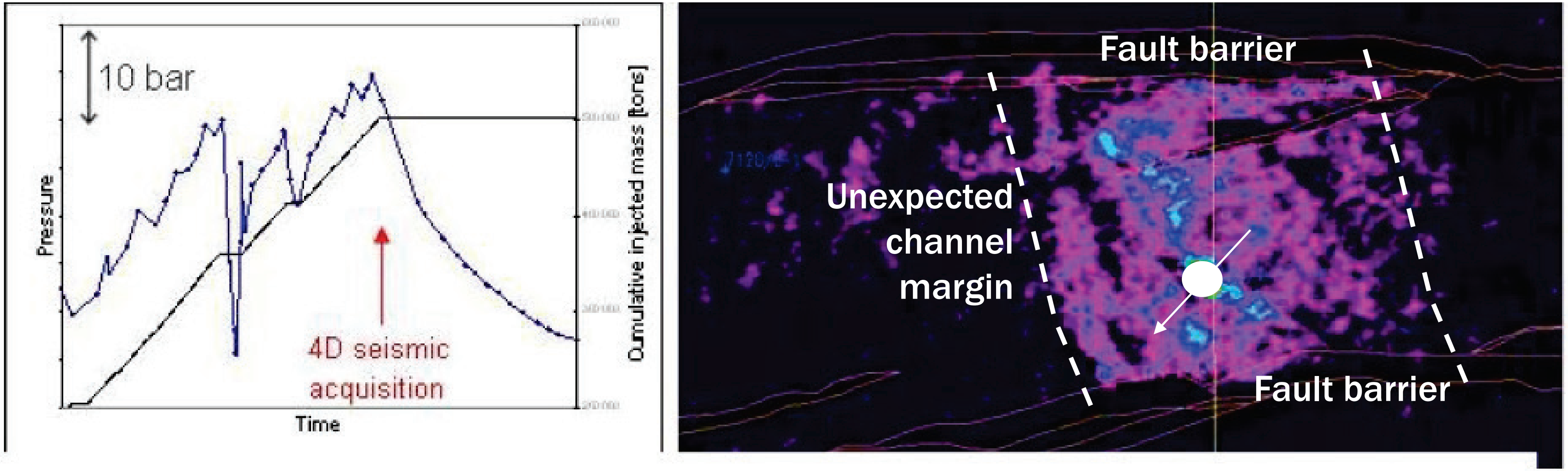
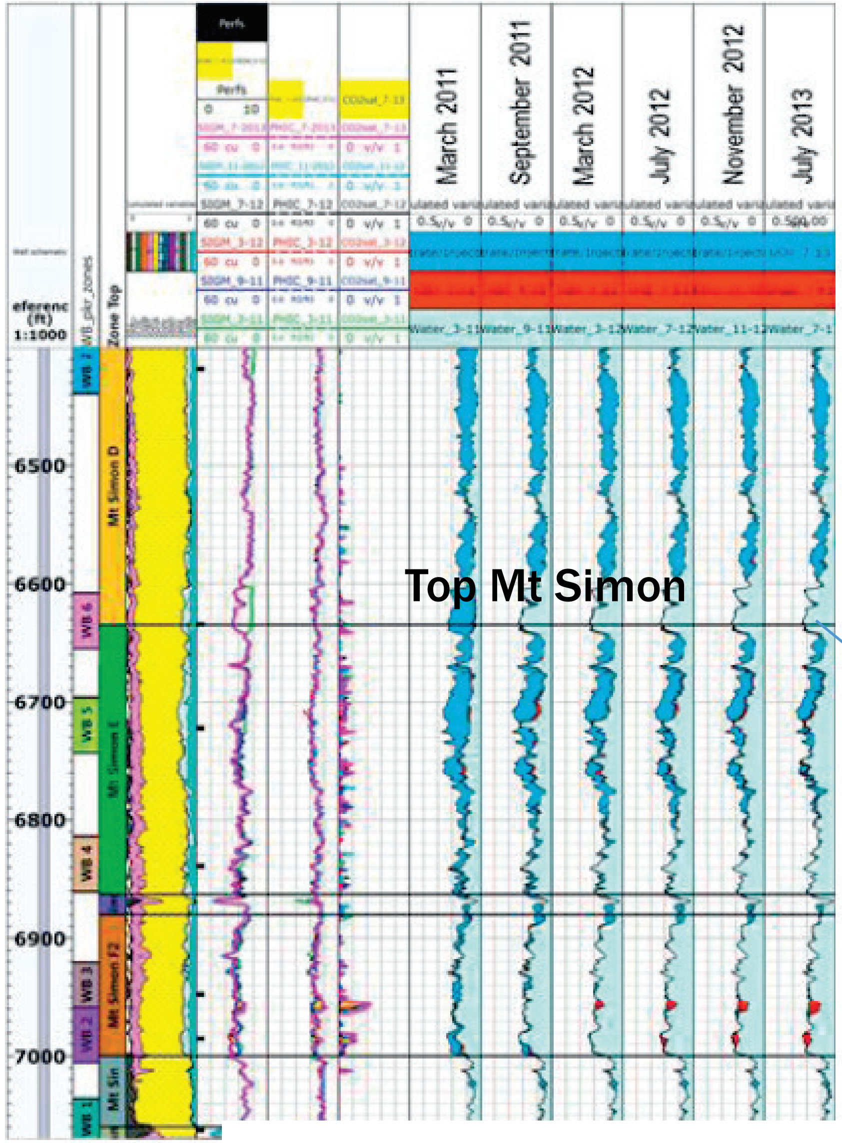


Figure 8: Portion of the injection and pressure data from Snøhvit spanning year 2009 (left), and 4D seismic difference amplitude map of the lowermost Tubåen Fm. level (right)..

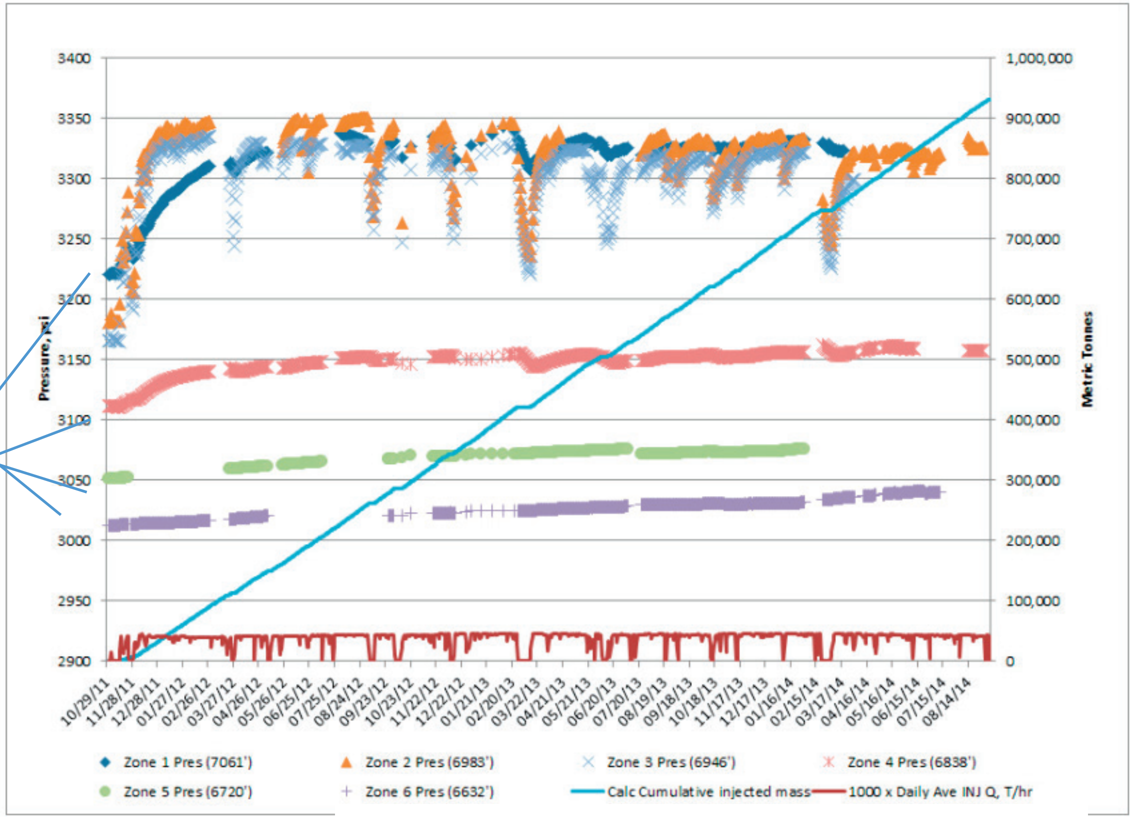
Snøhvit saline injection 2009 in Barents sea encountered unexpected lateral barriers to flow pressure rose more quickly than expected. An offset well was drilled to assure continued injection below fracture pressure.

From Eiken et al, 2011

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



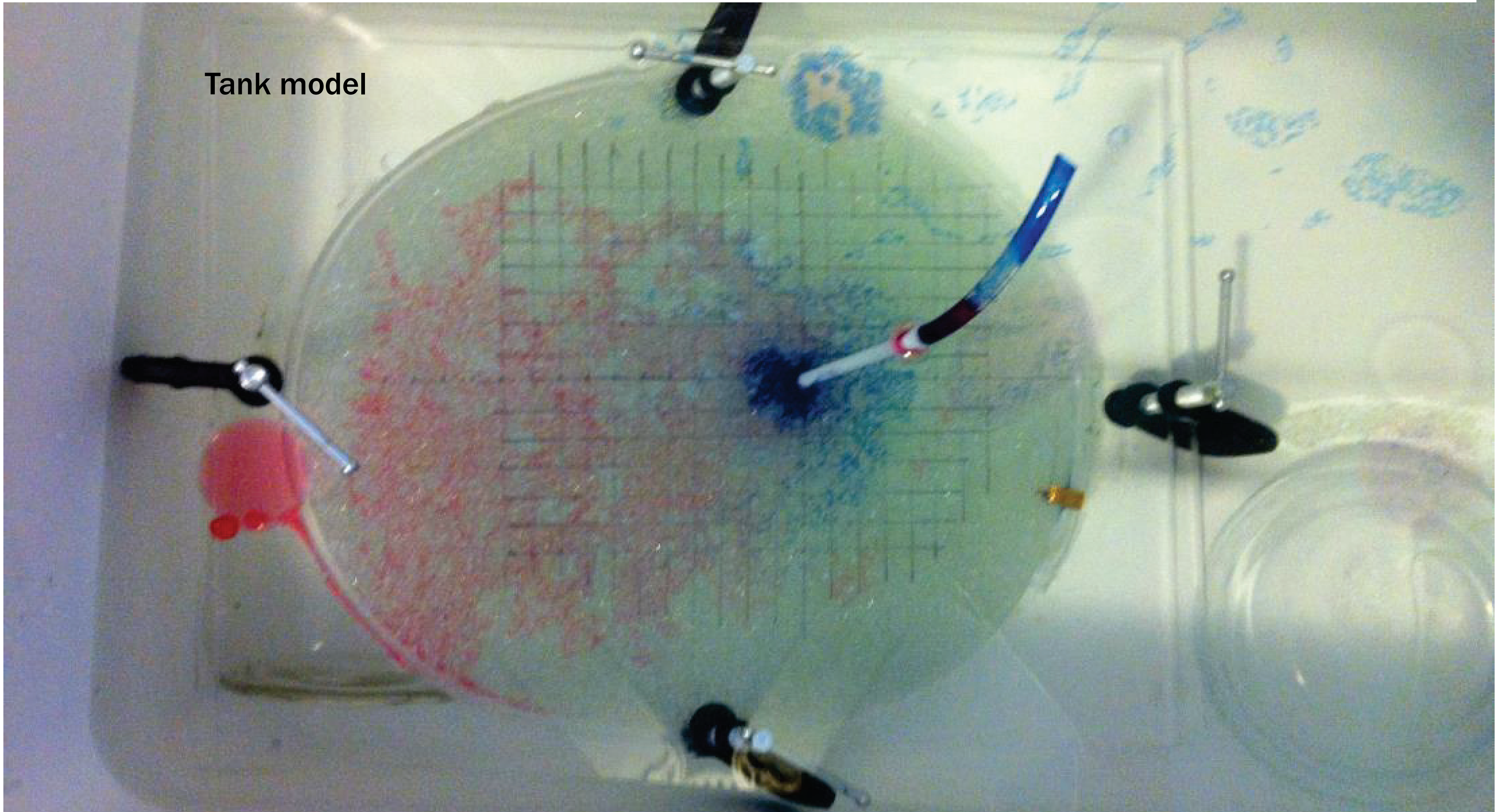
Pulsed neutron saturation logs



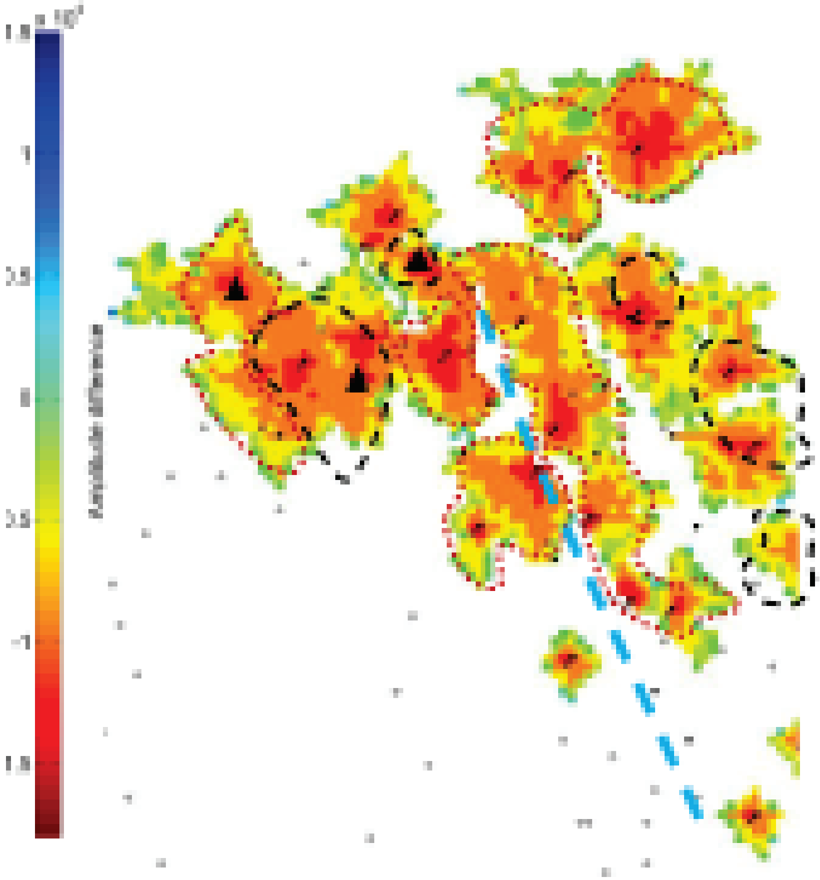
Pressure response plotted over time

Couëslan et al 2014, Decatur

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



CO_2 plume simulation history match with breakthrough



Simulation results

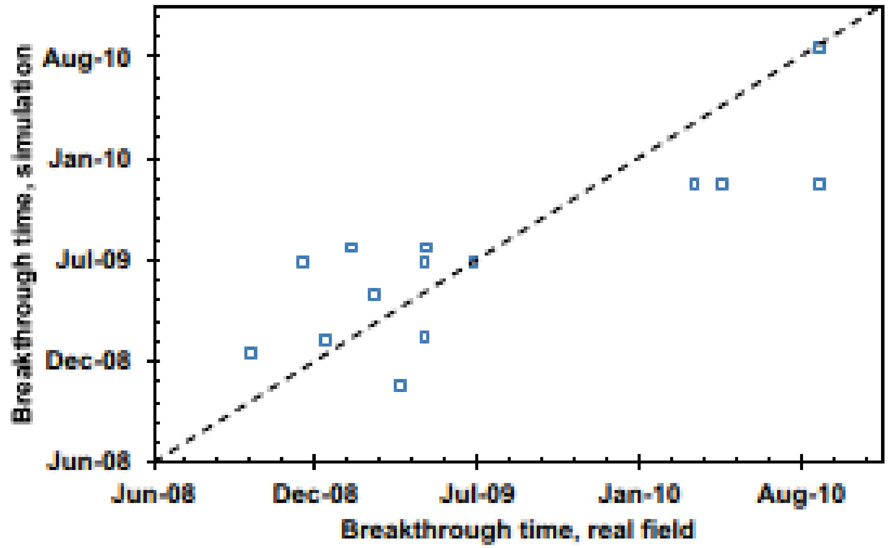


Figure 8: Comparison of actual and simulated CO_2 breakthrough times in production wells shows that current model performance is acceptable and has no bias toward underestimating or overestimating breakthrough times.

Title: Integration of reservoir simulation, history matching, and 4D seismic for CO2-EOR at Cranfield, Mississippi, USA

: Masoud Alfi; Seyyed Abolfazl Hosseini

GCCC 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

Explicitly model unacceptable outcomes showing leakage cases.

Model material impact scenarios

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.

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

Select monitoring tools that can detect these signals at required sensitivity

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.”

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

Deploy tools and collected and analyze data

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

Report if material impact did/did not occur

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.

The Gulf Coast Carbon Center

GULF COAST CARBON CENTER

We seek to impact global levels of atmospheric carbon dioxide (CO_2) by:

- conducting studies, often focusing on the Gulf of Mexico, in regard to geological storage, retention and monitoring of CO_2 in the deep subsurface;
- educating the public about the process of geological CO_2 storage; and
- enabling the private sector to develop an economically viable industry to store CO_2 in the Gulf of Mexico, across the U.S., and globally.

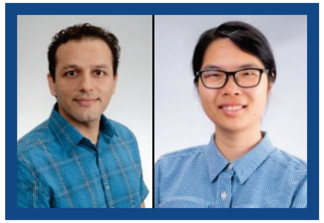
Geologic Characterization

Carlos Uroza | Alex Bump | Timothy Meckel | Mariana Olariu | Shuvajit Bhattacharya

Surface or Deep Monitoring

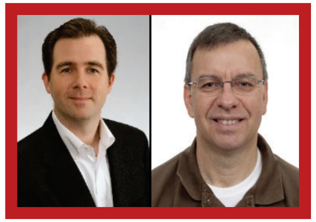
Susan Hovorka | Katherine Romanak

Fluid-Flow Modeling



Seyyed Hosseini | Hailun Ni

Seismic Interpretation



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