

Monitoring and Verification Issues for Carbon Storage

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Monitoring and Verification Issues for Carbon Storage Pilot Experiments

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Measurement, Monitoring and Verification

MM&V is defined as the capability to:

Measure the amount of CO₂ stored at a specific sequestration site,

Monitor the site for leaks or other deterioration of storage integrity over time,

Verify that the CO₂ is stored and unharmed to the host ecosystem

(some add **Model** and **Mitigate**)

www.netl.doe.gov

Ask: Why is MMV Needed at This Project?

- Health, Safety, and Environmental concerns
- Reservoir economics (ECBM, EOR, EGR)
- Required by regulators
- Credits/emissions trading/liability reduction
- Research objectives
- Public Acceptance
 - How does the public know that a project is safe?
 - How do investors know that a project is effective?



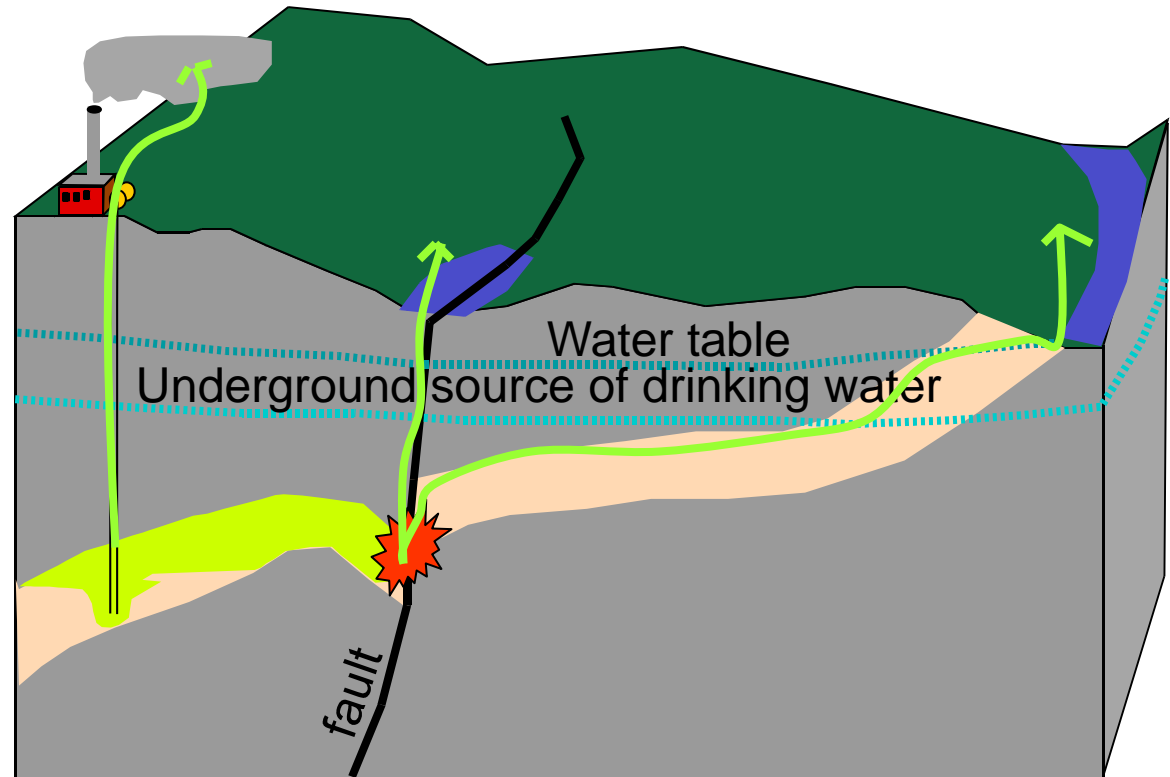
Substitute
underground
injection for air
release

Unexpected Results of Injection

Escape to
groundwater,
surface water,
or air via long
flowpath











Earthquake

Escape of CO₂
or brine to
groundwater,
surface water
or air through
flaws in the seal



Failure of well cement or
casing resulting in leakage

Major Impacts of Unexpected Result of Injection

Risk	Short term (during injection process)	Long term (after closure)
Seismicity		
Failure of well engineering	 	 
Leakage over a short path	 	 
Leakage over a long path		



Health and safety



Environment



Impact on atmosphere

MMV for CO₂ Already Exists: Use it

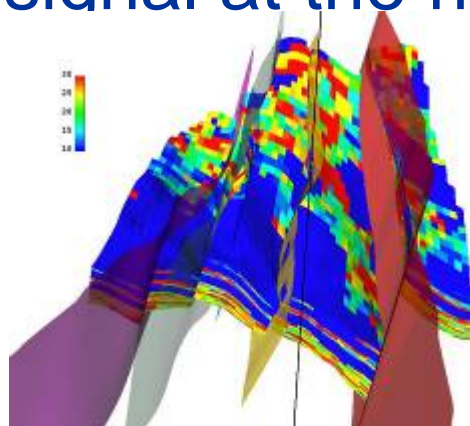
- Health and safety procedures for CO₂ pipelines, shipping, handling, and storing
- Pre-injection characterization and modeling
- Isolation of injectate from Underground Sources of Drinking Water (USDW)
- Maximum allowable surface injection pressure (MASIP)
- Mechanical integrity testing (MIT) of engineered system
- Standards for well completion and plug and abandonment in cone of influence and area of review around injection wells.
- Reservoir management; extensive experience in modeling and measuring location of fluids

Keys to Development of Successful Monitoring Program at an Experimental Injection

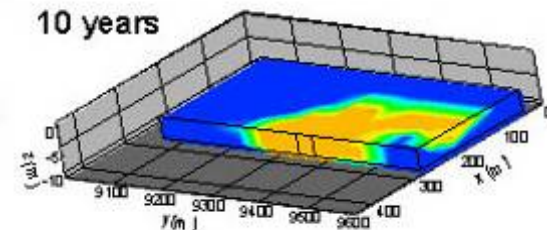
- Rigorous definition of objectives of monitoring
- Adequate pre-injection characterization and modeling of evolution of conditions post injection
- Sensitivity analysis to match tools to expected or possible signal at the right time



Sample analysis
(Core Lab)



Reservoir model
Knox/Yeh, BEG



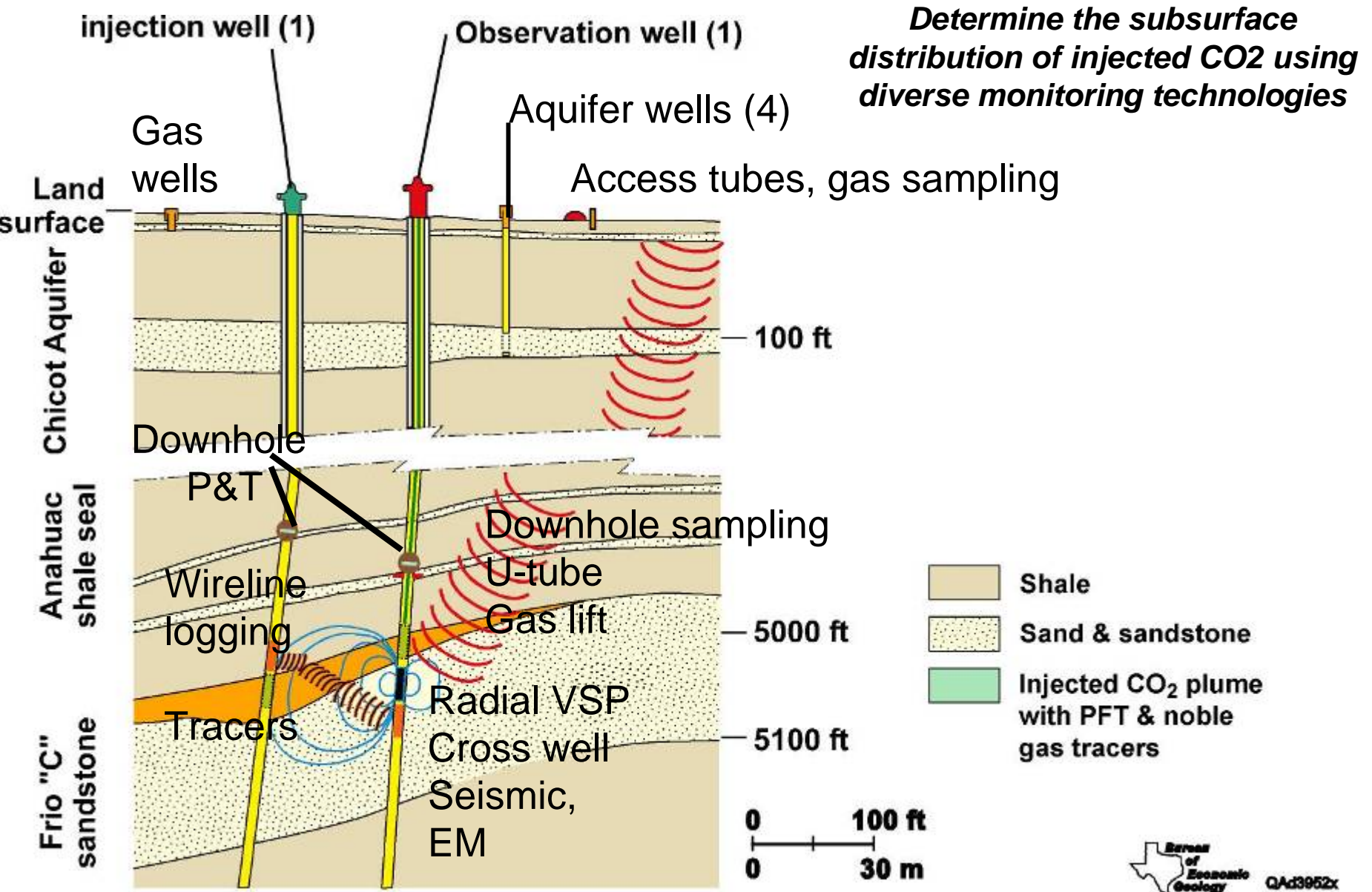
Flow Simulation
TOUGH2, Doughty, LBNL

Example of Goals: Frio Experiment: Monitoring CO₂ Storage in Brine- Bearing Formations

Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.

- **Demonstrate that CO₂ can be injected into a brine formation without adverse health, safety, or environmental effects**
- **Determine the subsurface distribution of injected CO₂ using diverse monitoring technologies**
- **Demonstrate validity of conceptual and numerical models**
- **Develop experience necessary for success of large-scale CO₂ injection experiments**

Monitoring at Frio Pilot



My Recommendations for Designing a MMV Program

- Characterization, modeling, sensitivity, and signal-to-noise analyses are essential
- Rank questions: no one tool is ideal for all questions; Impossible to optimize for all tools

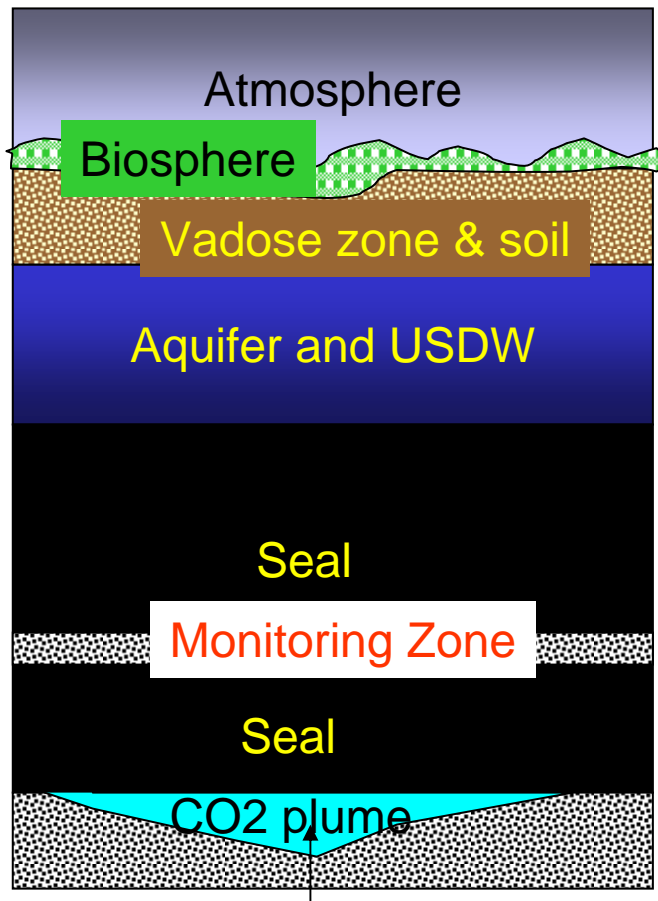


What is the best way to monitor for unexpected events?

MMV Technologies

- Intensive monitoring in pilot phases
- Effective monitoring during implementation
- The problem of monitoring slow leakage and long time frames is not yet solved
- See study by Benson on costs

Monitoring Zone Options



- Atmosphere
 - Ultimate integrator, dynamic
- Biosphere
 - Requires assurance of no damage, dynamic
- Soil and Vadose Zone
 - Integrator but dynamic
- Aquifer and USDW
 - Integrator, slightly isolated from ecological effects
- Above injection monitoring zone
 - First indicator, monitor small signals, more stable. May not integrate
- In-injection zone - plume
 - Oil-field type technologies. Will not find small leaks

Consider also lateral complexities, transport, focused flow paths

Atmospheric Monitoring

- Direct detection
- Many tools, from standard monitors to new tools in development
- Applied at many scales
- Detection is complicated because of high ambient CO₂ from atmosphere, soil, and vegetation – difficult to isolate small fluxes from subsurface



Real-time CO₂ atmospheric monitoring near Naples, Italy

Soil Gas Monitoring

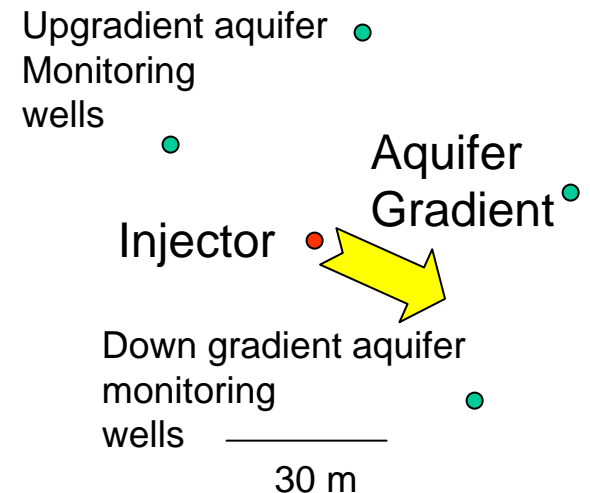
- Done at numerous sites volcanic sites, CO₂-EOR
- Relatively low cost, integrates seepage over a time period
- Escaped CO₂ is likely to be concentrated in vadose zone
- Like air, detection in soil is complicated because of high ambient CO₂
- Flux, composition, isotopes
- Coordinate with ecosystem monitoring



<http://volcanoes.usgs.gov/About/What/Monitor/Gas/soil.html>

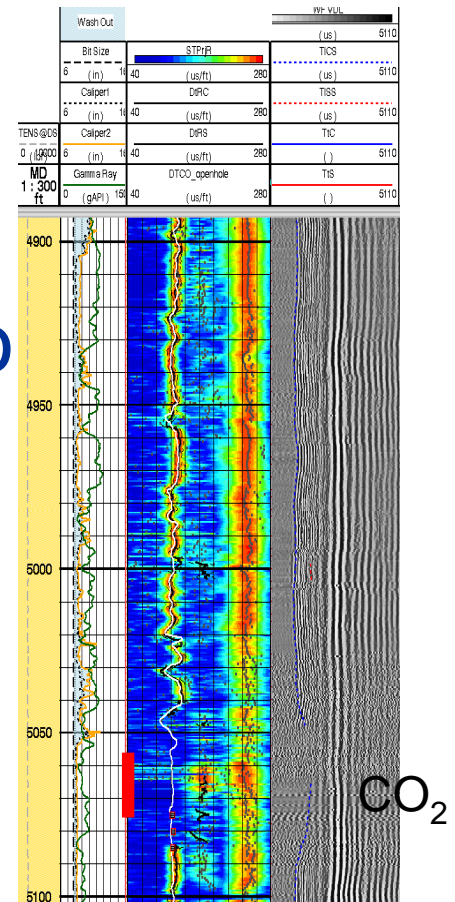
Groundwater Monitoring

- Standard technique in contaminated sites
- Good regional integrator
- Signal of leakage may be complex
- Might be used in combination with natural or introduced tracers



Wireline Well Logging

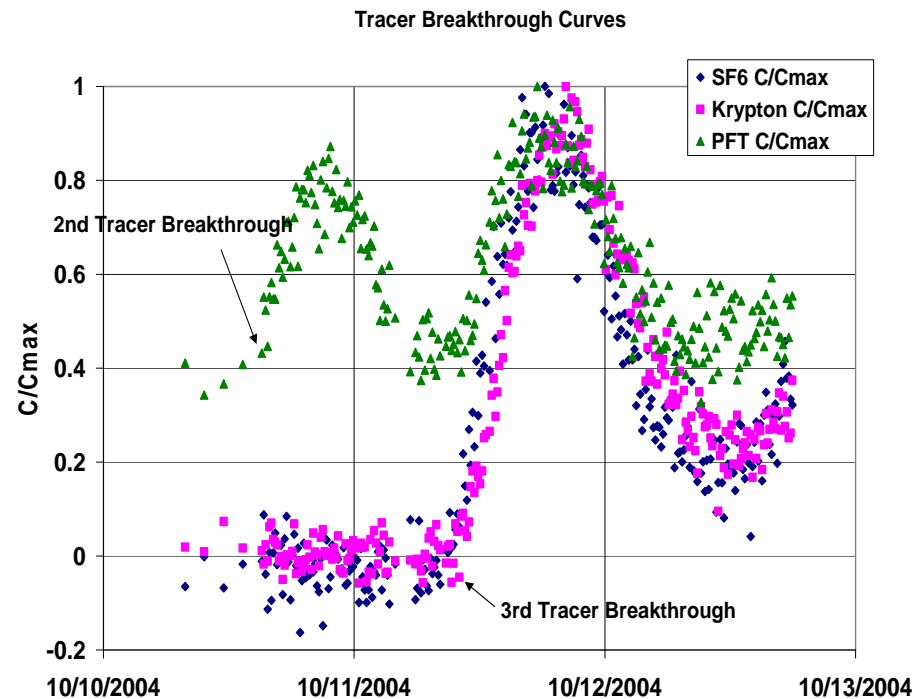
- Well-known oilfield activity
- Match tools to rock/fluid characteristics
- Typically good vertical resolution
- Quantitative, interpretable
- Well bore effects and damage may lead to errors
- Interpolate the interwell areas



Frio post injection cased hole sonic log,
Sakurai BEG/Mueller Schlumberger

Tracers and Geologic Inferences

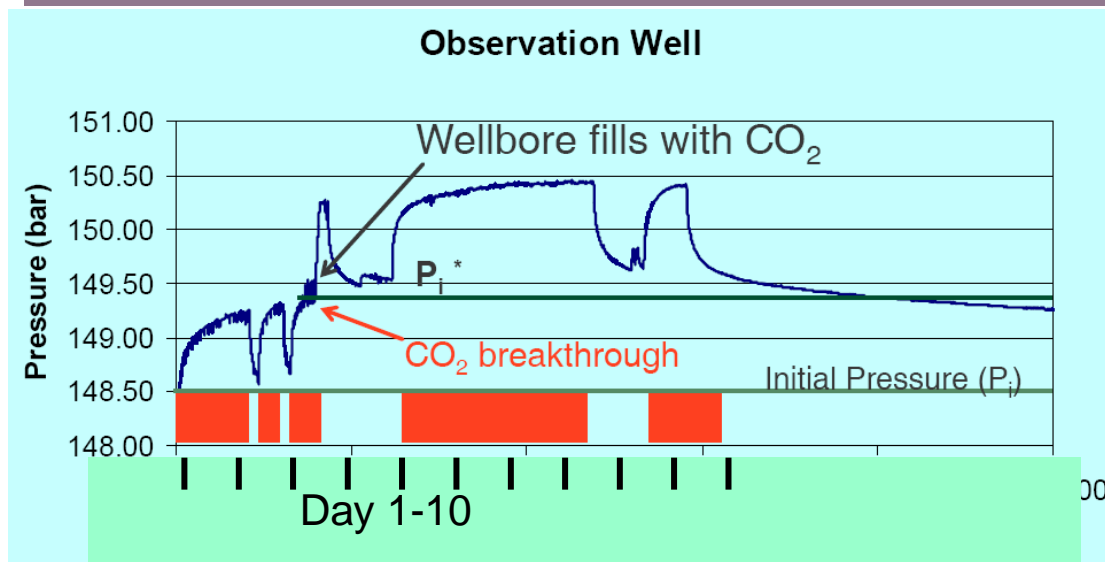
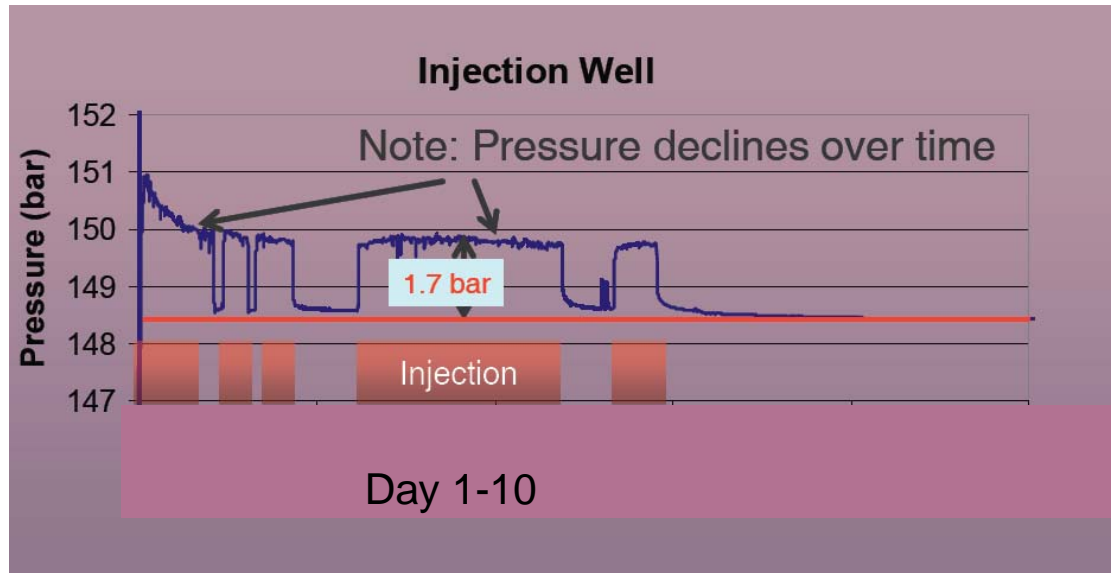
- Introduced materials that travel with CO₂ can uniquely fingerprint migration
 - Nobel gasses
 - PFT's and other chemically unique materials
 - Detection at very low concentrations
- CO₂ can be geochemically unique –
 - C isotopes
 - Impurities
- Hydrologic analysis to determine fractional saturation – Capacity assessment



Frio noble gas and PFT analysis, Barry Freifeld (LBNL) and Timmy Phelps (ORNL)

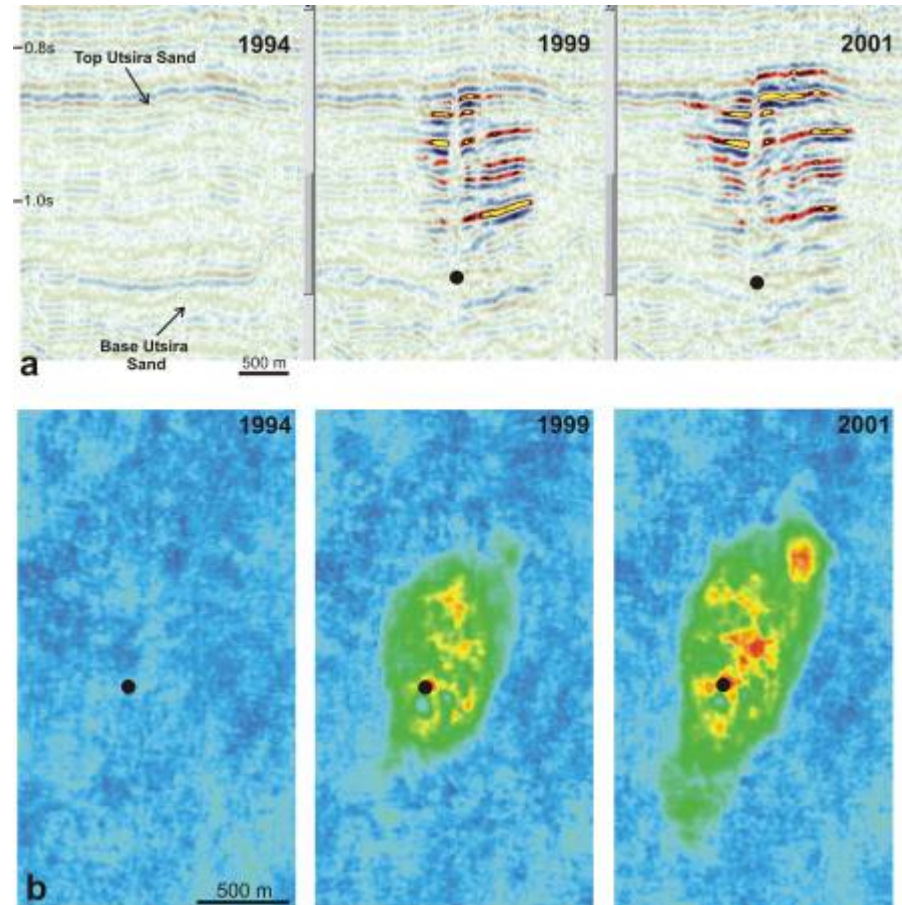
Reservoir Pressure and Temperature Responses

–Powerful and Inexpensive Tools



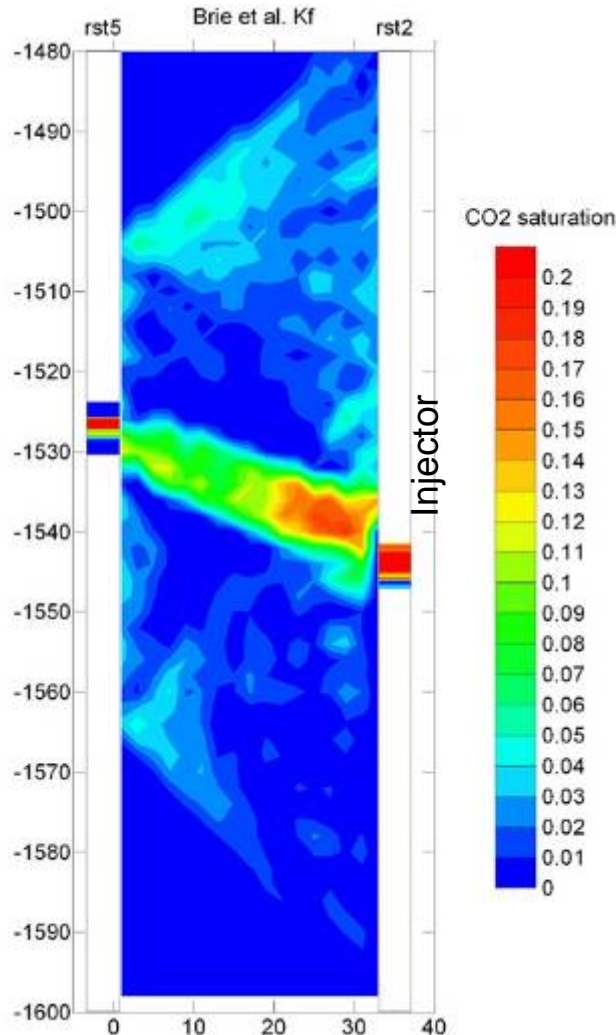
Surface Geophysics

- Surface seismic imaging – 2D, 3D, 4D
- Alternative methods
 - Electrical contrasts
 - Gravity
 - Passive Seismic
- Interferometry/tilt



Successful time lapse 3- at Sleipner (from Chadwick, 2004)

Time-laps Crosswell Seismic and Vertical Seismic Profiling



- Image host setting and CO₂
- Sensitivity to concentration is model dependent
- Resolution limits detection of small volumes
- May not detect slow leakage

Non-Seismic Geophysical Tools

- Electromagnetic: LBNL work
- Spontaneous Potential
- Gravity
- Tilt, Interferometry

Conclusions

- Monitoring and verification advances at pilots will benefit the future application of geologic storage of carbon
- Good design to select the right tool to meet the right need at the the right phase of the implementation is important

Information on MMV applied to geologic storage is available from many sources:

A few starters:

IPPC Special Report on Carbon Dioxide Capture and Storage, Sept 2005, esp. chapter 5 geologic storage.

<http://www.ipcc.ch/activity/srccs/index.htm>

CSLF discussion paper from task force for identifying gaps in CO₂ monitoring and verification of storage.

http://www.cslforum.org/documents/TaskForce_CO2_Monitoring_Verification.pdf

Frio Brine Pilot: www.beg.utexas.edu/co2

GEOSEQ: <http://www-esd.lbl.gov/GEOSEQ/index.html>

GHGT6, Gale and Kaya, 2003, Pergamon Press

GHGT 7, Rubin, Keith, Gilboy/Wilson, Morris, Gale, Thambimuthu, 2005, Elsevier

Princeton Carbon Mitigation Initiative <http://www.princeton.edu/~cmi/>

MIT Carbon Sequestration Initiative <http://sequestration.mit.edu>

Carbon Capture Project JIP <http://www.co2captureproject.org/index.htm>

IEA Greenhouse Gas R&D <http://www.ieagreen.org.uk>

DOE NETL: <http://www.fe.doe.gov/programs/sequestration/>