# Monitoring and Verification Issues for Carbon Storage

**GCCC Digital Publication Series #06-01**

**Susan D. Hovorka**

Gulf Coast Carbon Center

**Keywords**:
**Measurement Monitoring and Verification (MMV), Injection Zone- Risks, MMV Technologies, Monitoring Zone Options, Surface Geophysics**

**Cited as:**
**Hovorka, S.D., Monitoring and verification issues for carbon storage: presented as online lecture to Regional Sequestration Partnerships Outreach and Geologic Working Groups, Austin, Texas, 2006. GCCC Digital Publication Series #06-01.**

# Monitoring and Verification Issues for Carbon Storage Pilot Experiments

Susan D. Hovorka
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

# Measurement, Monitoring and Verification

MM&V is defined as the capability to:

Measure the amount of $CO_2$ stored at a specific sequestration site,

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

Verify that the $CO_2$ is stored and unharmful 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?

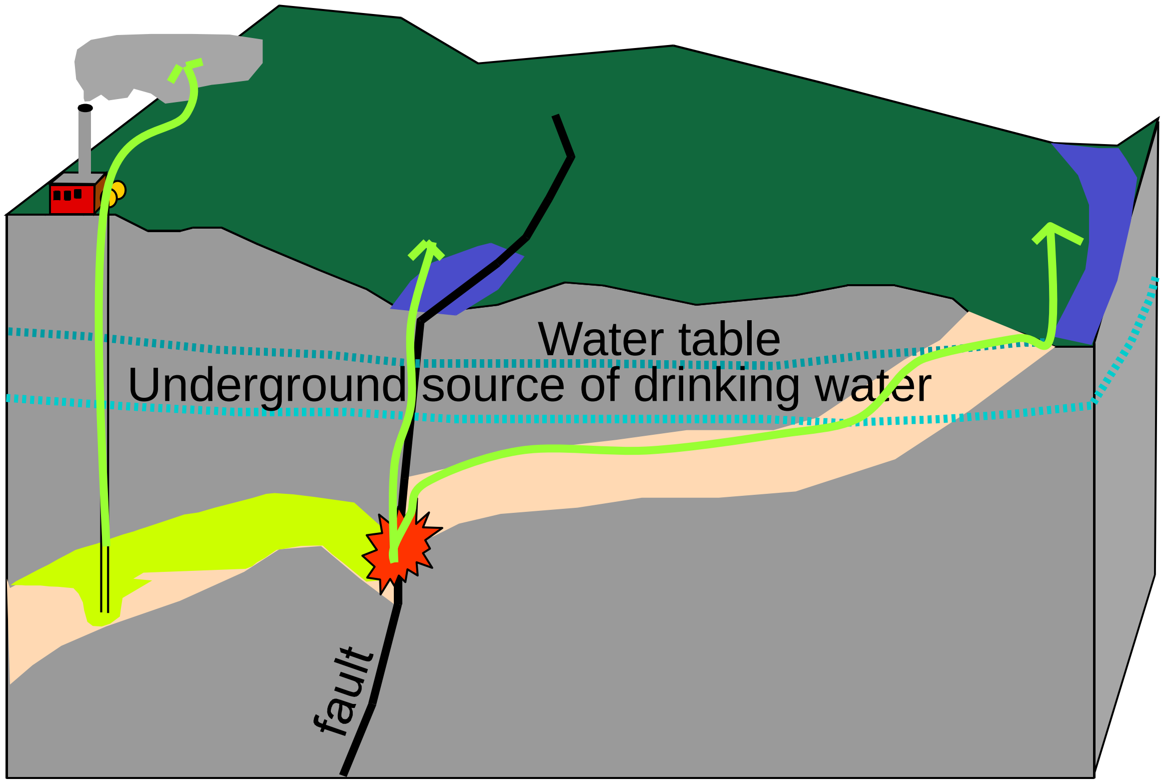
# Unexpected Results of Injection

Substitute underground injection for air release

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

Earthquake

Escape of $CO_2$ 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) |
|---|---|---|
| Seismisity | ✚ | |
| Failure of well engineering | ✚ ● | ★ ● |
| Leakage over a short path | ✚ ● | ★ ● |
| Leakage over a long path | | ★ |

✚ Health and safety ● Environment ★ Impact on atmosphere

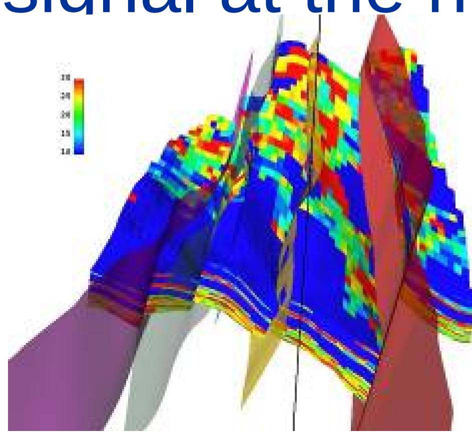
# MMV for $CO_2$ Already Exists: Use it

- Health and safety procedures for $CO_2$ 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

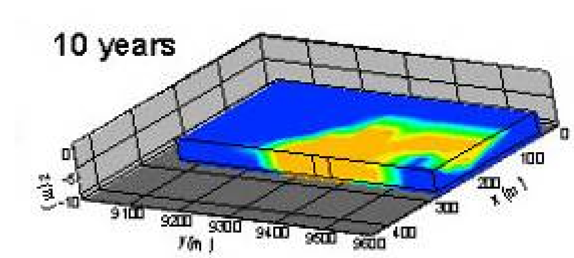
# Keys to Development of Successful Monitoring Program at an Experimental Injection

- 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

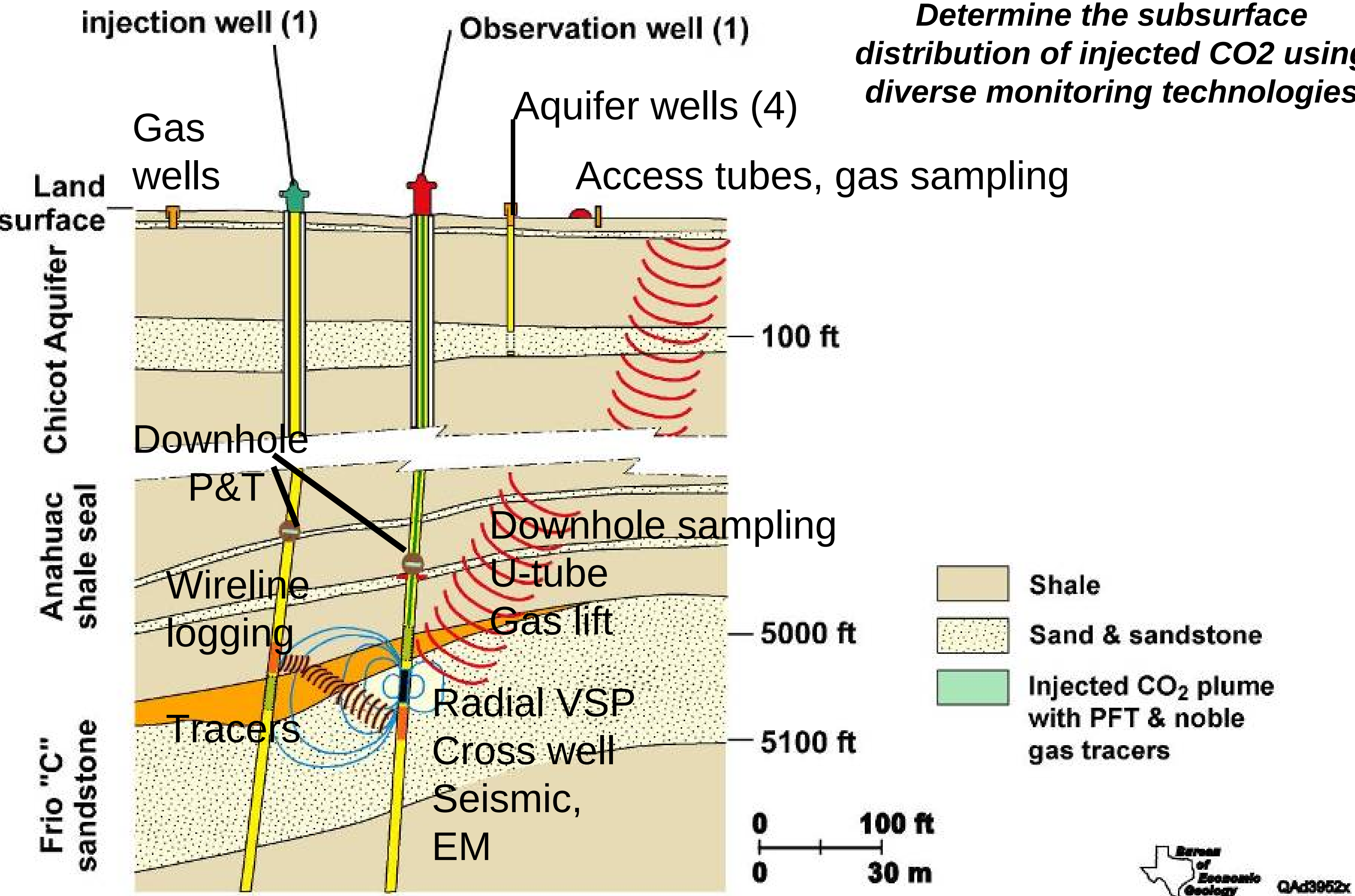
# Example of Goals: Frio Experiment: Monitoring $CO_2$ Storage in Brine-Bearing Formations

***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 $CO_2$ can be injected into a brine formation without adverse health, safety, or environmental effects**
- **Determine the subsurface distribution of injected $CO_2$ using diverse monitoring technologies**
- **Demonstrate validity of conceptual and numerical models**
- **Develop experience necessary for success of large-scale $CO_2$ injection experiments**

# Monitoring at Frio Pilot

***Determine the subsurface distribution of injected CO2 using diverse monitoring technologies***



# My Recommendations for Designing a MMV Program

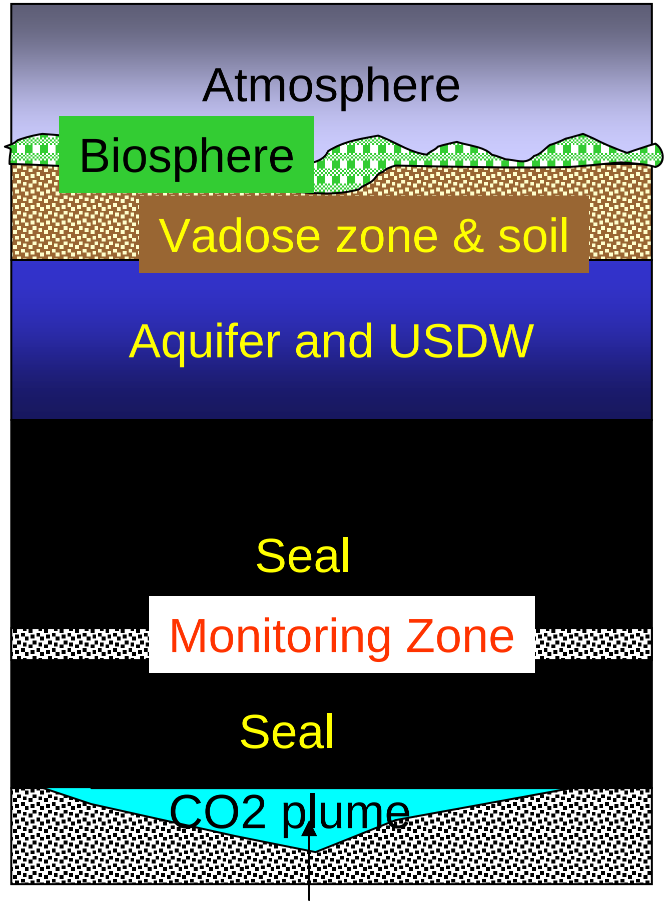
- Characterization, modeling, sensitivity, and signal-to-noise analyses are essential
- Rank questions: no one tool is ideal for all questions; Impossible to optimize for all tools


**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

Real-time $CO_2$ atmospheric monitoring near Naples, Italy

- Detection is complicated because of high ambient $CO_2$ from atmosphere, soil, and vegetation – difficult to isolate small fluxes from subsurface

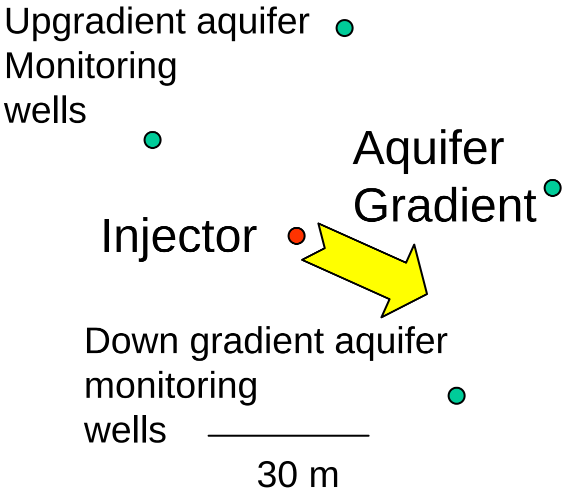
# Soil Gas Monitoring

- Done at numerous sites volcanic sites, $CO_2$-EOR
- Relatively low cost, integrates seepage over a time period
- Escaped $CO_2$ is likely to be concentrated in vadose zone
- Like air, detection in soil is complicated because of high ambient $CO_2$
- Flux, composition, isotopes
- Coordinate with ecosystem monitoring

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

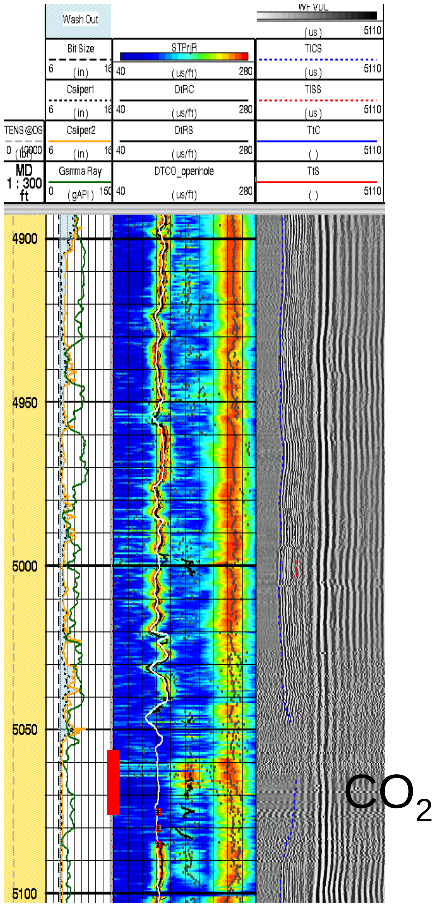
# Groundwater Monitoring

- 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

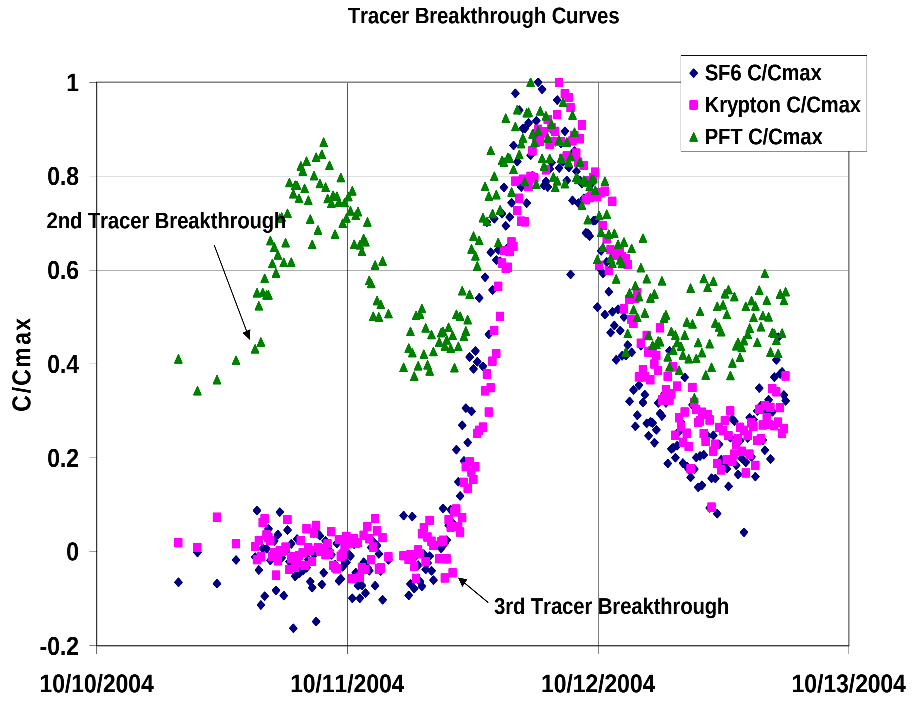
- Well-known oilfield activity
- Match tools to rock/fluid characteristics
- Typically good vertical resolutio quantitative, interpretable
- Well bore effects and damage may lead to errors
- Interpolate the interwell areas




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

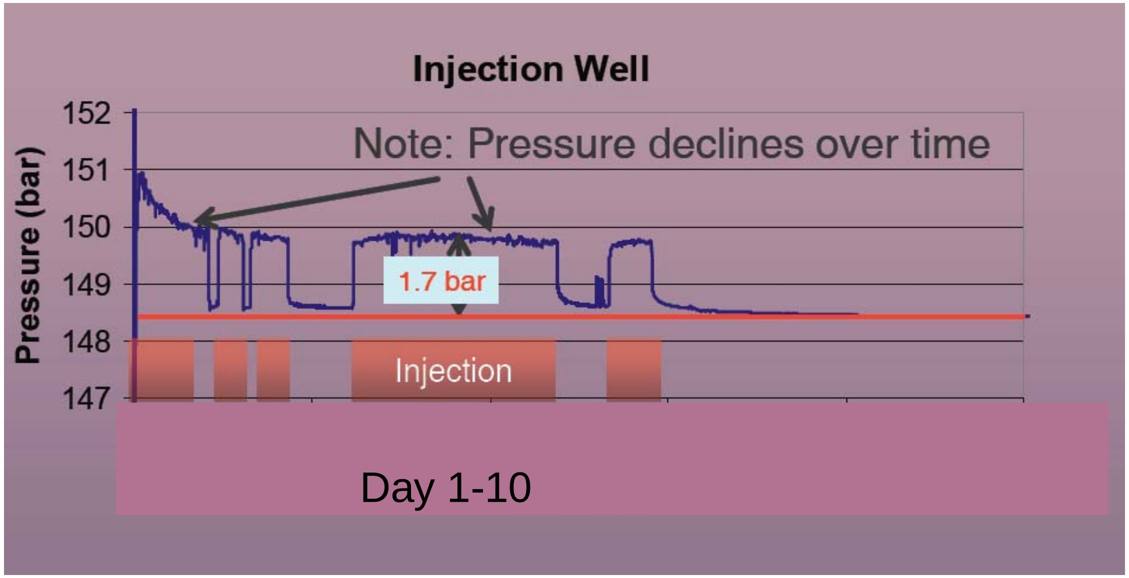
# Tracers and Geologic Inferences

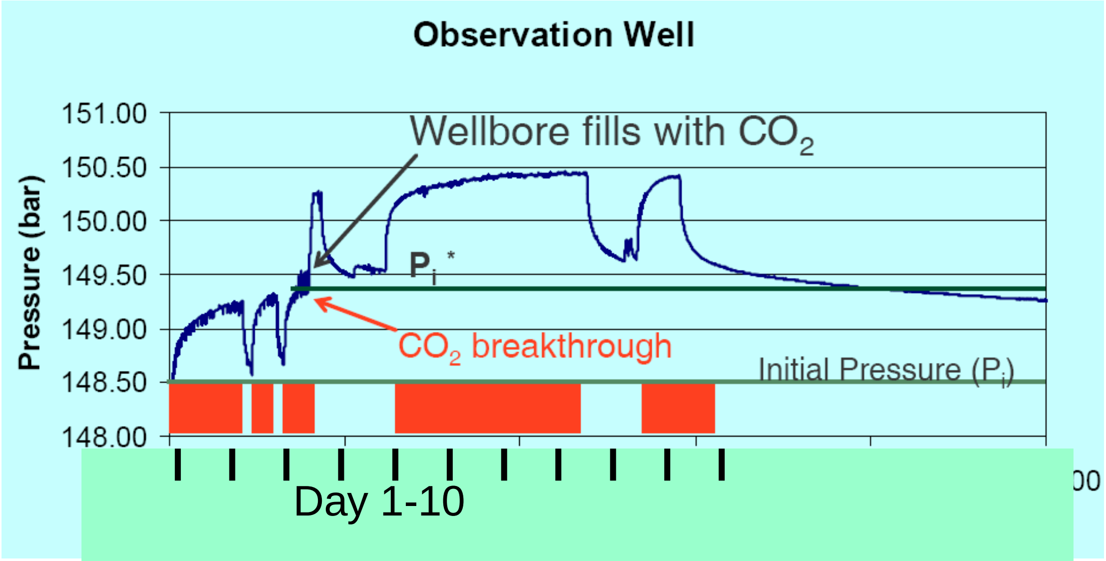
- Introduced materials that travel with $CO_2$ can uniquely fingerprint migration
  - Nobel gasses
  - PFT's and other chemically unique materials
  - Detection at very low concentrations
- $CO_2$ can be geochemically unique –
  - C isotopes
  - Impurities
- Hydrologic analysis to determine fractional 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

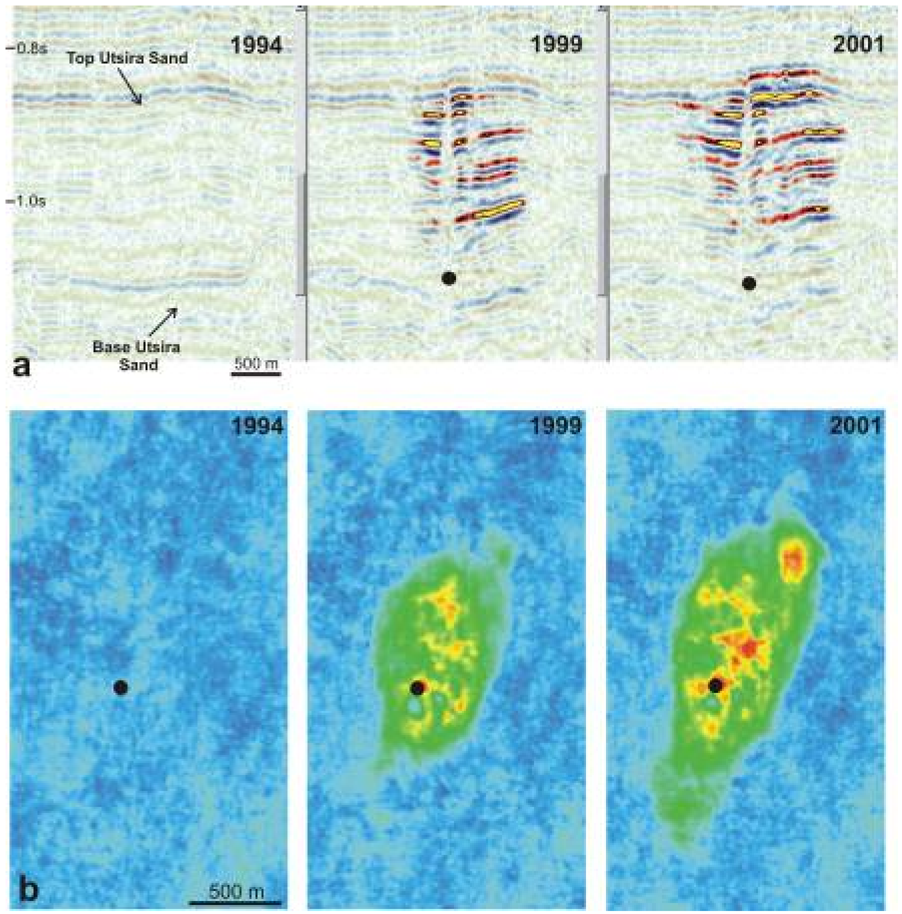



Sally Benson, LBNL

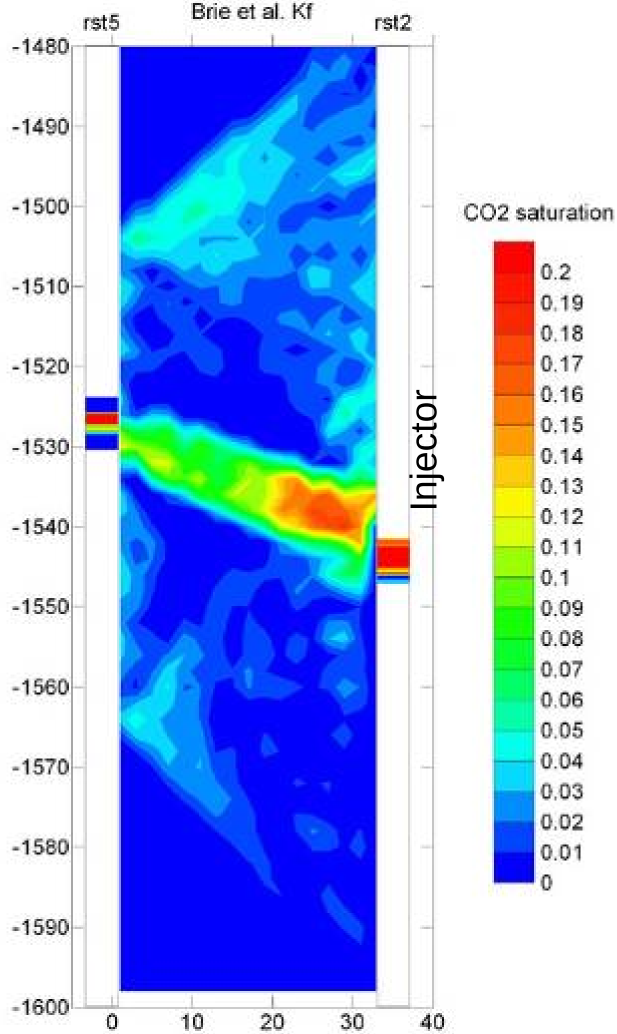
# Surface Geophysics

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




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

# Time-laps Crosswell Seismic and Vertical Seismic Profiling




- Image host setting and $CO_2$
- Sensitivity to concentration is model dependent
- Resolution limits detection of small volumes
- May not detect slow leakage

**Frio X-well Tom Daley, Mike Hoversten, L. Myer, LBNL**

# 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, Thambimathu, 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/