Cranfield Large Scale CO_2 Injection-- Monitoring 3.5 Million Tons

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Gulf Coast Carbon Center (GCCC)

Gulf Coast Carbon Center

Bureau of Economic Geology

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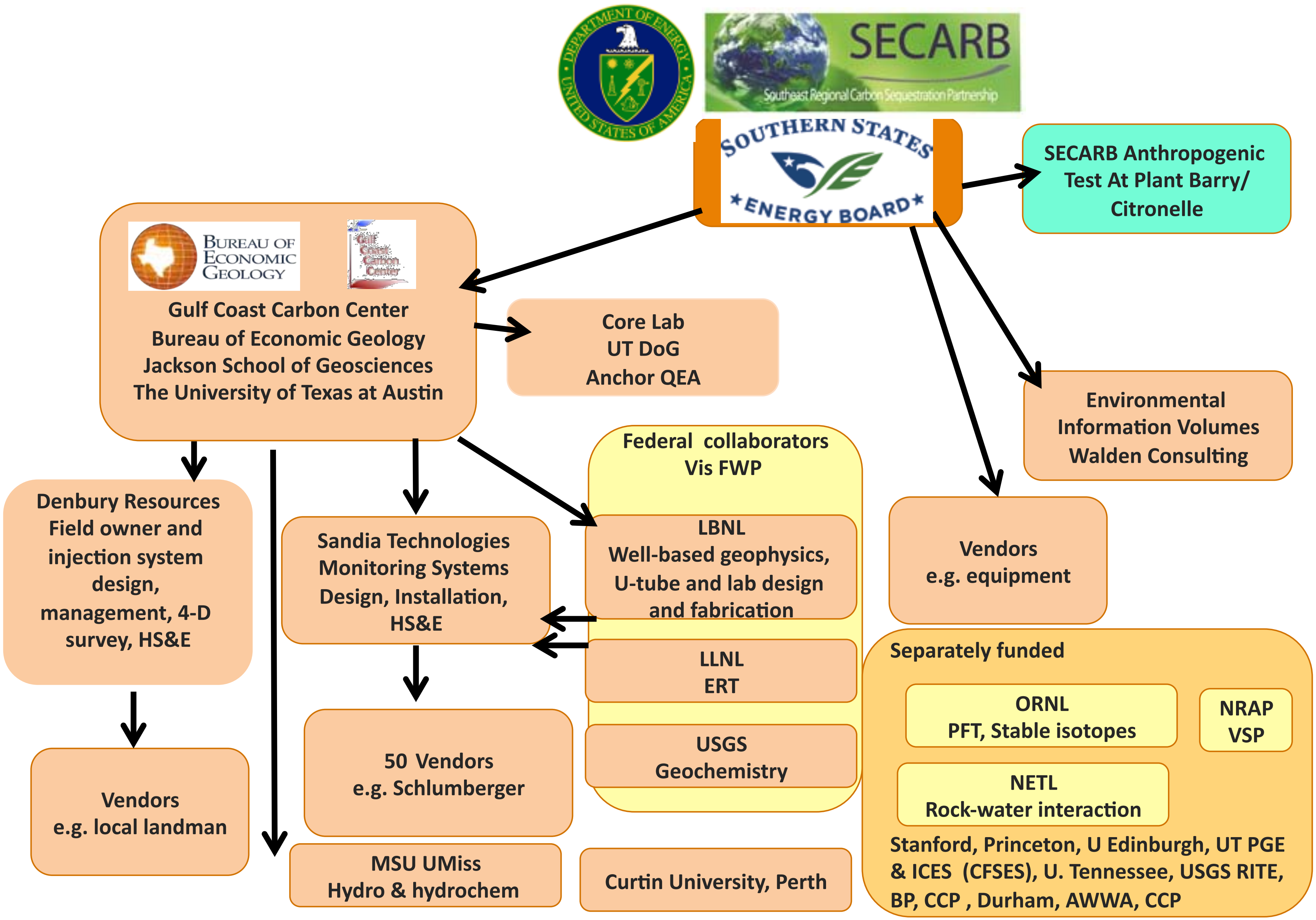
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Southeast Regional Carbon Sequestration Partnership
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Sandia Technologies Monitoring Systems Design, Installation, HS&E
Vendors e.g. equipment
Separately funded
ORNL
PFT, Stable isotopes
NRAP
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Rock-water interaction
Stanford, Princeton, U Edinburgh, UT PGE & ICES (CFSES), U. Tennessee, USGS RITE, BP, CCP , Durham, AWWA, CCP
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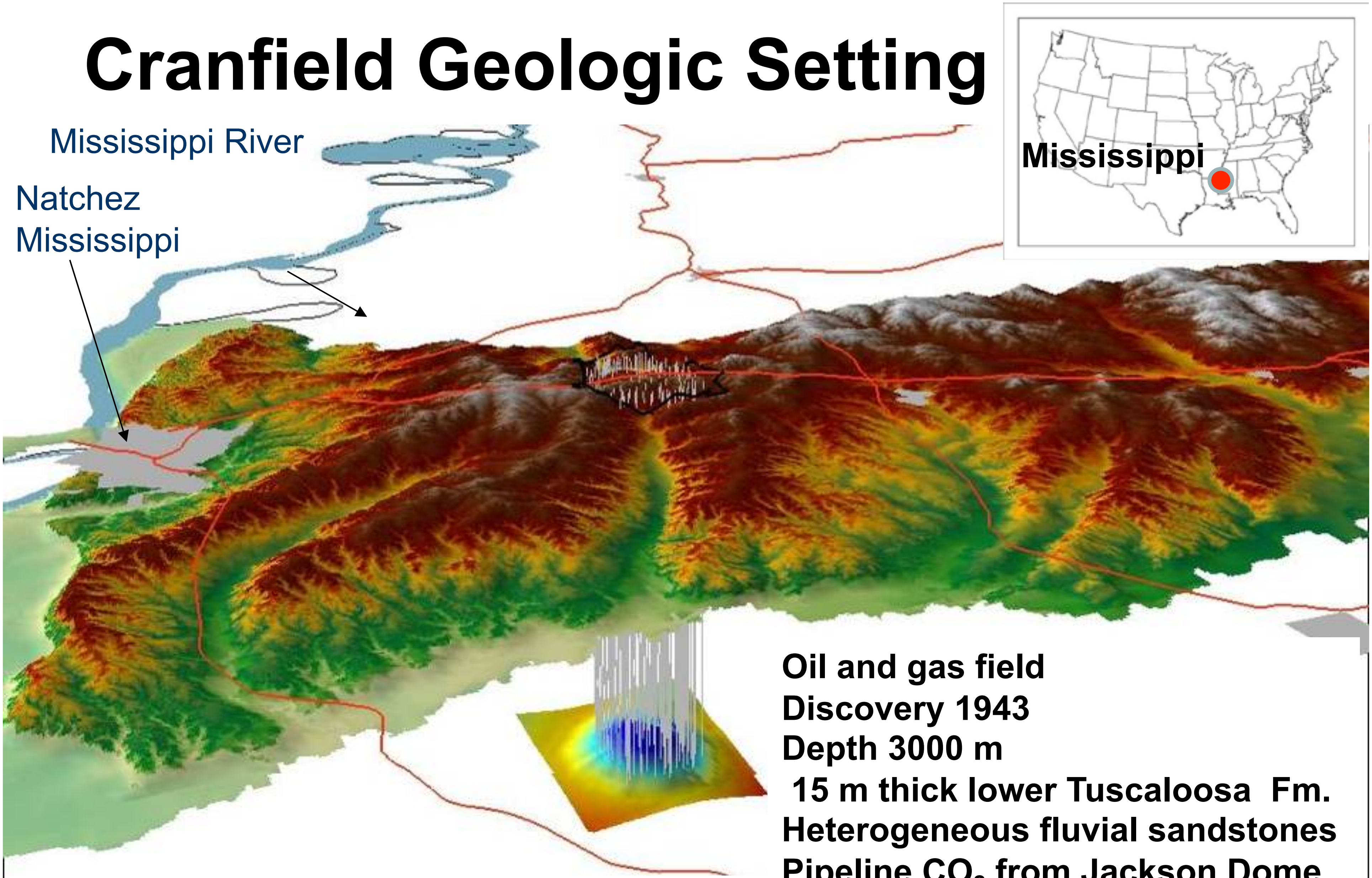
Cranfield Geologic Setting



Oil and gas field
Discovery 1943
Depth 3000 m
15 m thick lower Tuscaloosa Fm.
Heterogeneous fluvial sandstones
Pipeline CO_2 from Jackson Dome
@ 1 Million metric tones/year

Illustration by Tip Meckel

Approach Cranfield Monitoring Plan Development and Constraints

- Research-based: not regulatory- or risk-based
  - Scoped, designed, and budgeted 2006, prior to regulation
  - Operator holds risk
- Designed to respond to DOE programmatic questions
  - Evaluate protocols to demonstrate that it is probable that 99% of CO_2 is retained
  - Predict storage capacities within +/- 30%
- Lessons learned are derived products not duplicated processes

Transition From…To

Research Monitoring

Tests-

- Hypotheses about the nature of the perturbation created
  - compare response modeled to the response observed via monitoring.
- Performance and sensitivity of monitoring tools
  - sensitivity to the perturbation
  - conditions under which tool is useful,
  - reliability under field conditions.

Commercial Monitoring

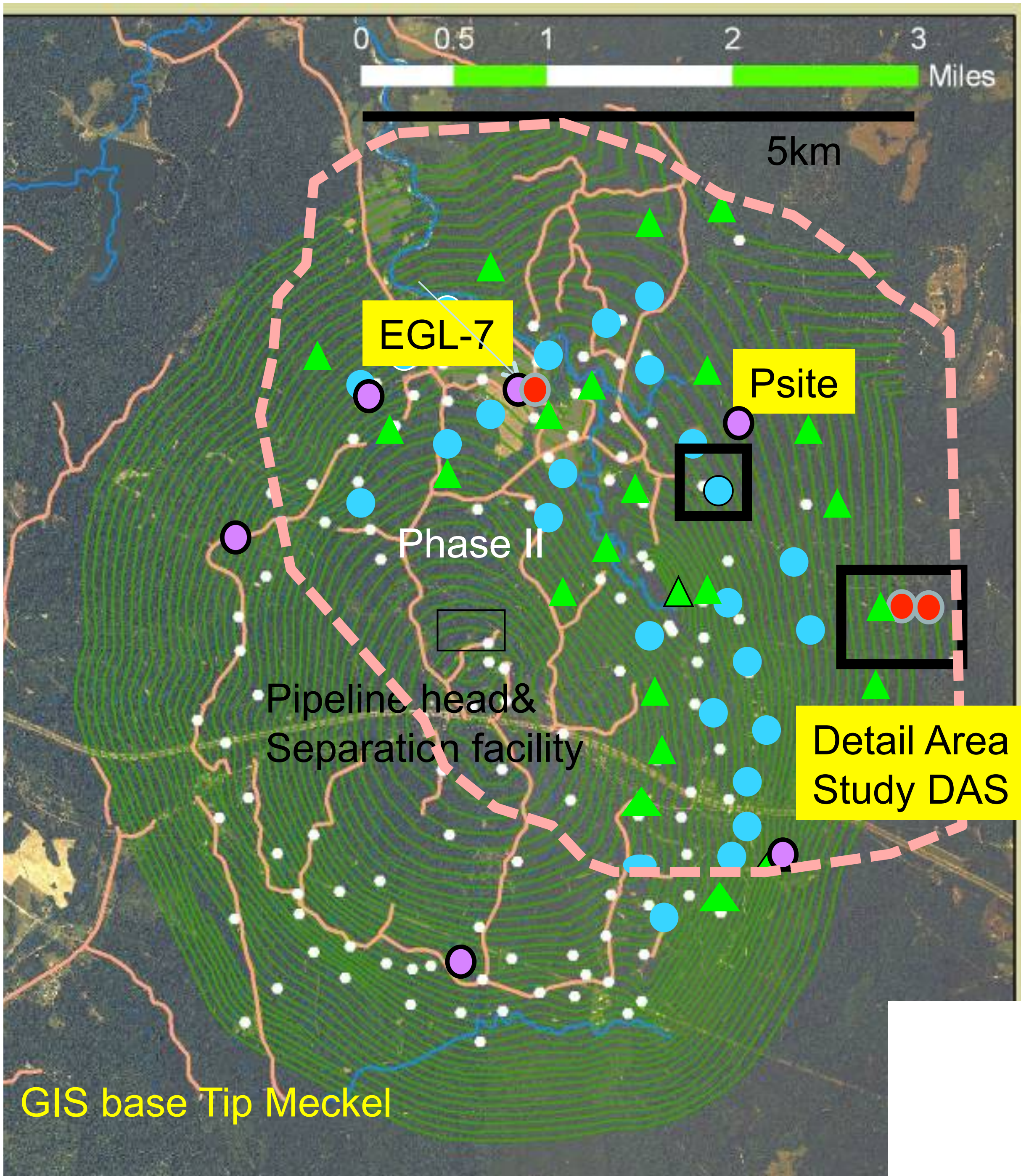
Confirms -

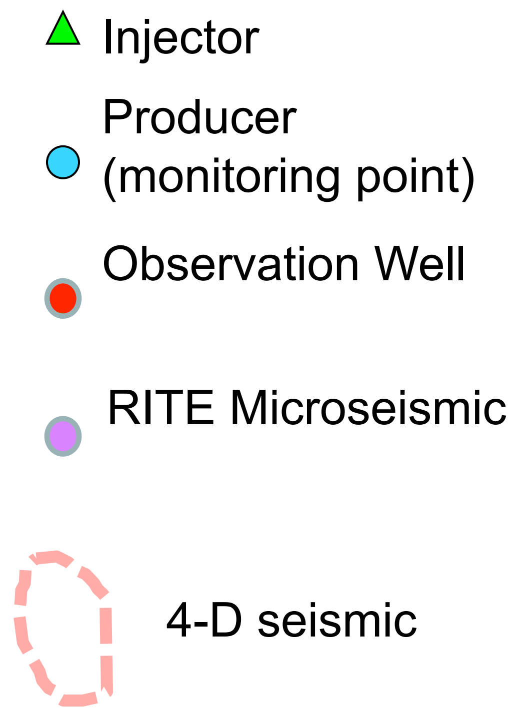
- predictions of containment based on site characterization at the time of permitting are correct
- Confidence to continue injection is gained
  - monitoring observations that are *reasonably close* to model predictions
  - any non-compliance explained.
  - no unacceptable consequences result from injection
- Monitoring frequency could be diminished through the life of the project
  - eventually stopped, allowing the project to be closed.

Cranfield Monitoring Design (Layout)

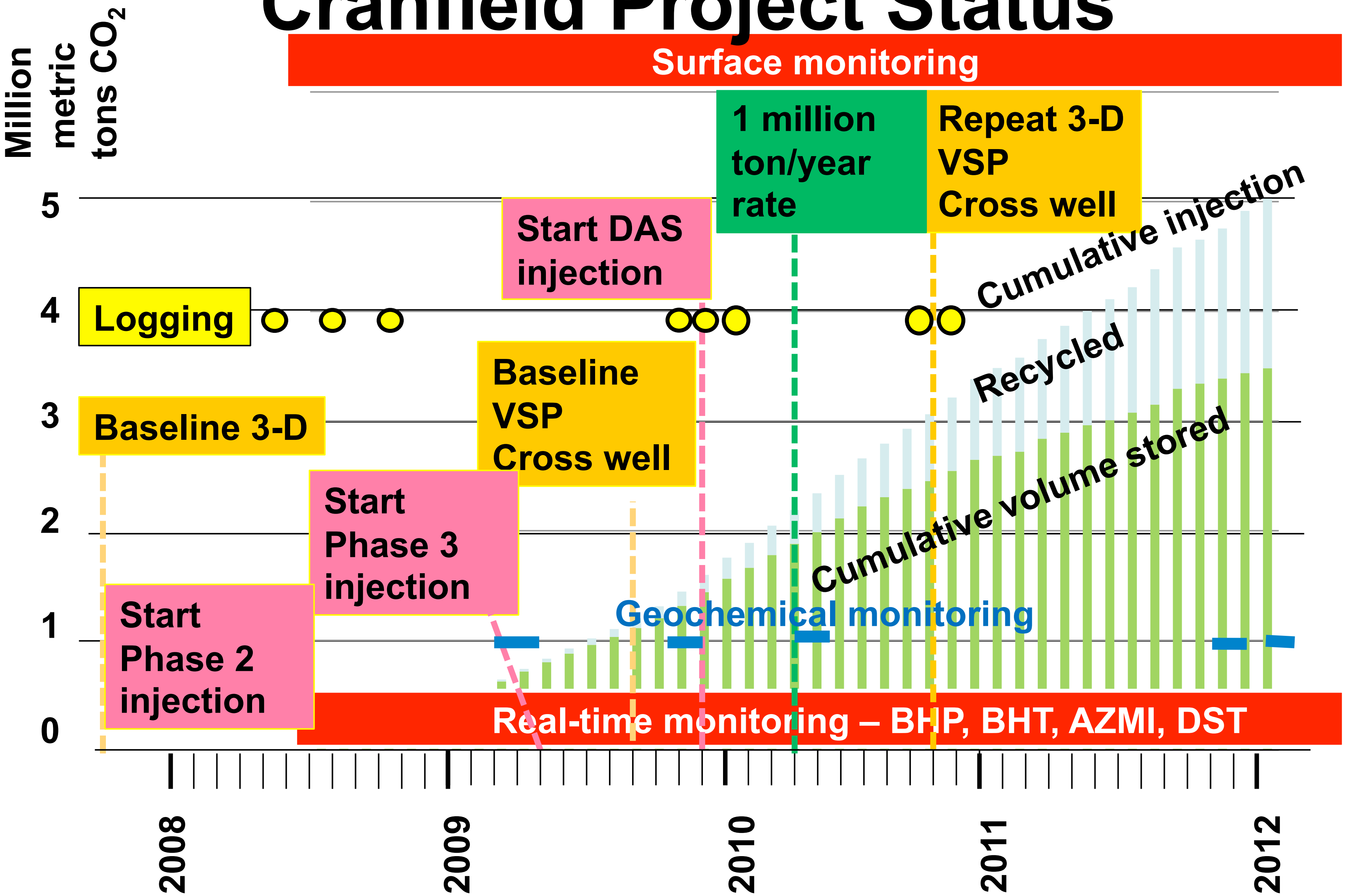
Area tested	Whole plume	Focus study
Atmosphere	Not tested	Not tested
Soil gas	Active and P&A well pads	"P site" methodology assessment
Groundwater	Monitoring well at each injector	EGL-7 UM test well, Push-pull test
Shallow production	Not tested	Not tested
AZMI	Not tested	DAS pressure and EGL 7 pressure + fluids
Geo-mechanics	RITE micro seismic study	GMT(failed)
Injection zone	Geochemistry breakthrough	DAS multi-well multi tool array

Cranfield Monitoring Layout





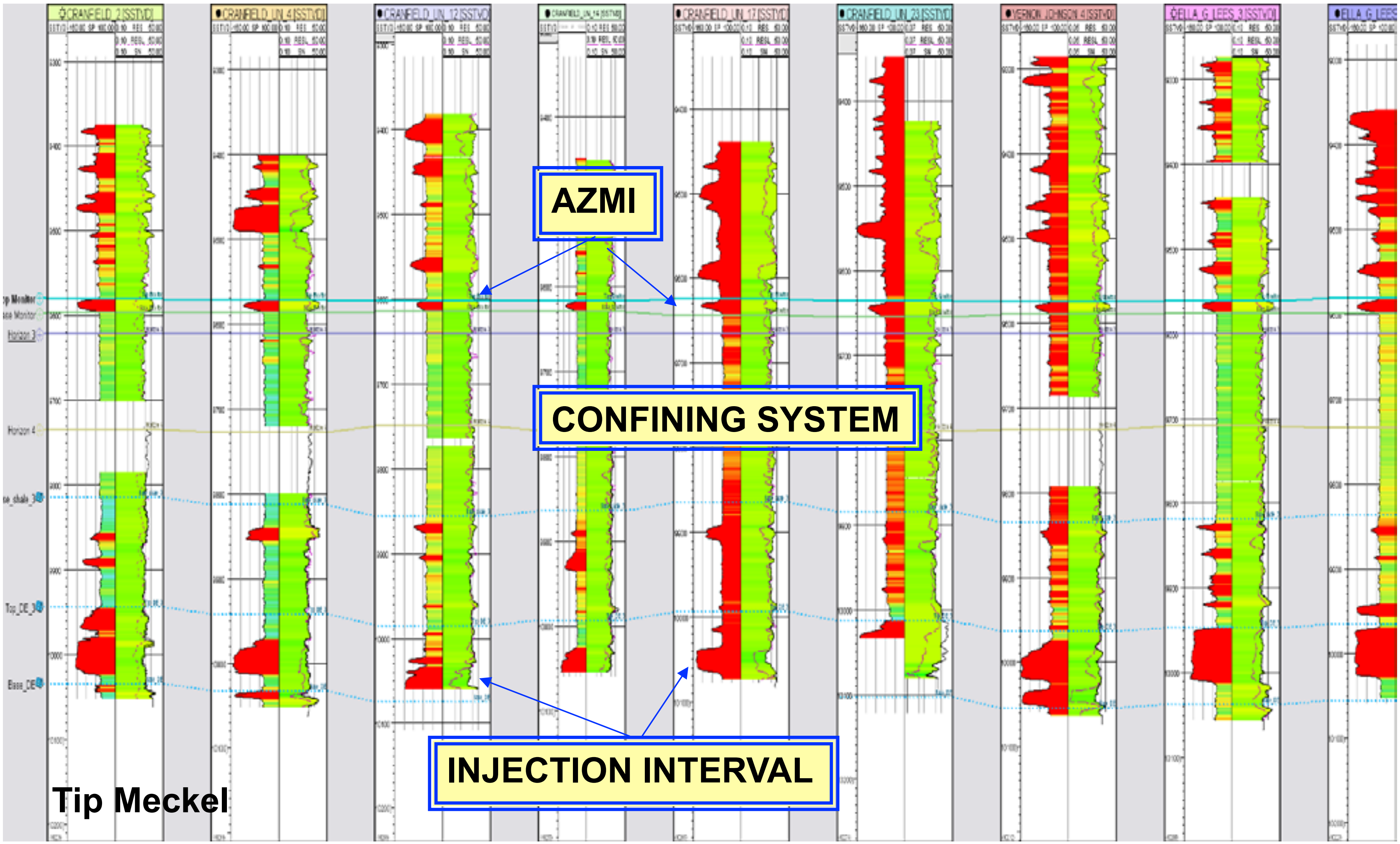
Cranfield Project Status



RCSP program goal: Evaluate protocols to demonstrate that it is probable that 99% of CO_2 is retained

- Permanence of geologic system well understood prior to test.
  - Oil and gas retained
- Assessment of leakage risk.
  - Well performance is highest uncertainty and focus of monitoring research
- Conformance of flood in the injection zone
  - **Pressure**
  - Plume confined by 4-way closure.
    - Uncertainty – amount of radial flow (down dip/out of pattern)
- Measure changes above the injection zone
  - along well
  - **above zone monitoring interval (AZMI)**
  - **Seismic response**
  - **at surface over long times**

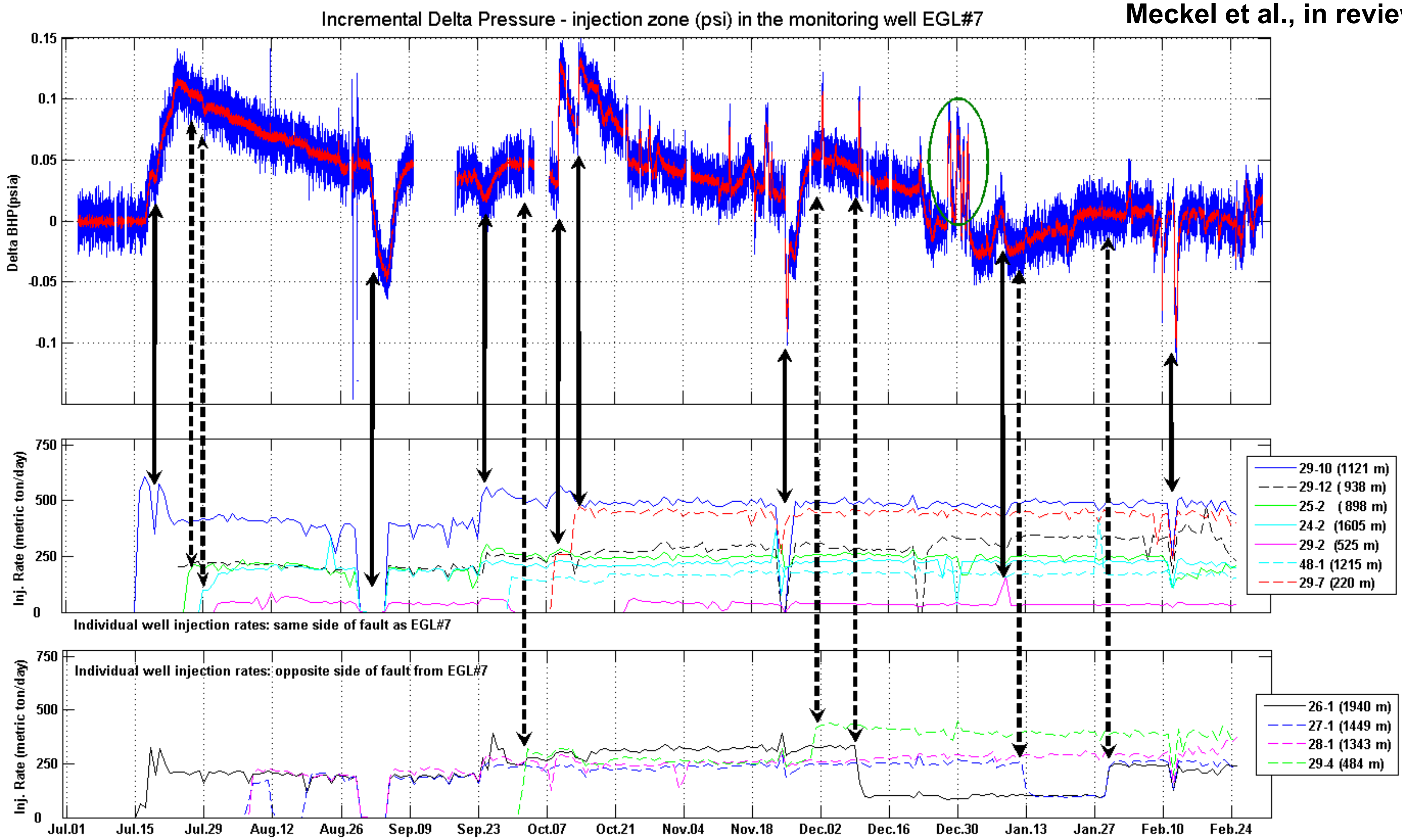
In-zone and AZMI pressure monitoring



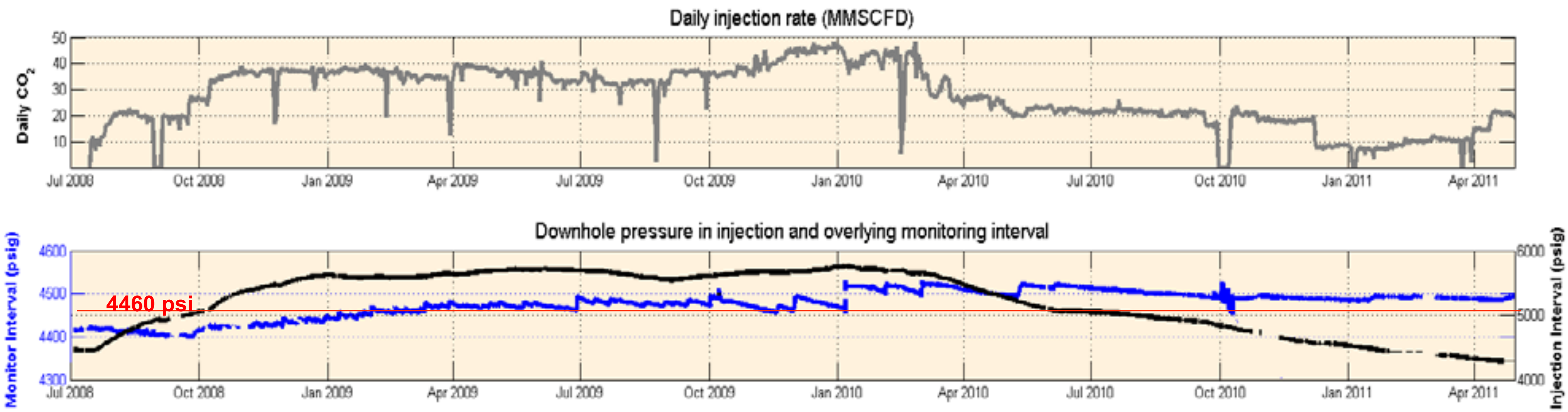
Continuous field data from dedicated monitoring well

- Large perturbations obvious
- Even small perturbations observable (100's tons/day flux from 1 km)
- Fault observed to be sealing

Meckel et al., in review



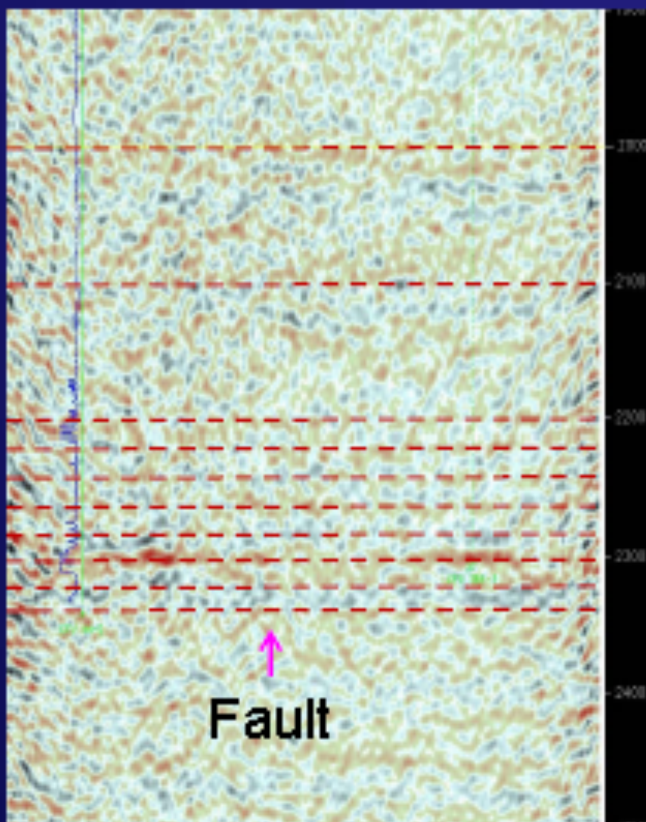
Continuous In-zone and AZMI data series 3.7 years



AZMI gauge depth ambient pressure is 4460 psi / 307 bar / 30.7 MPa.

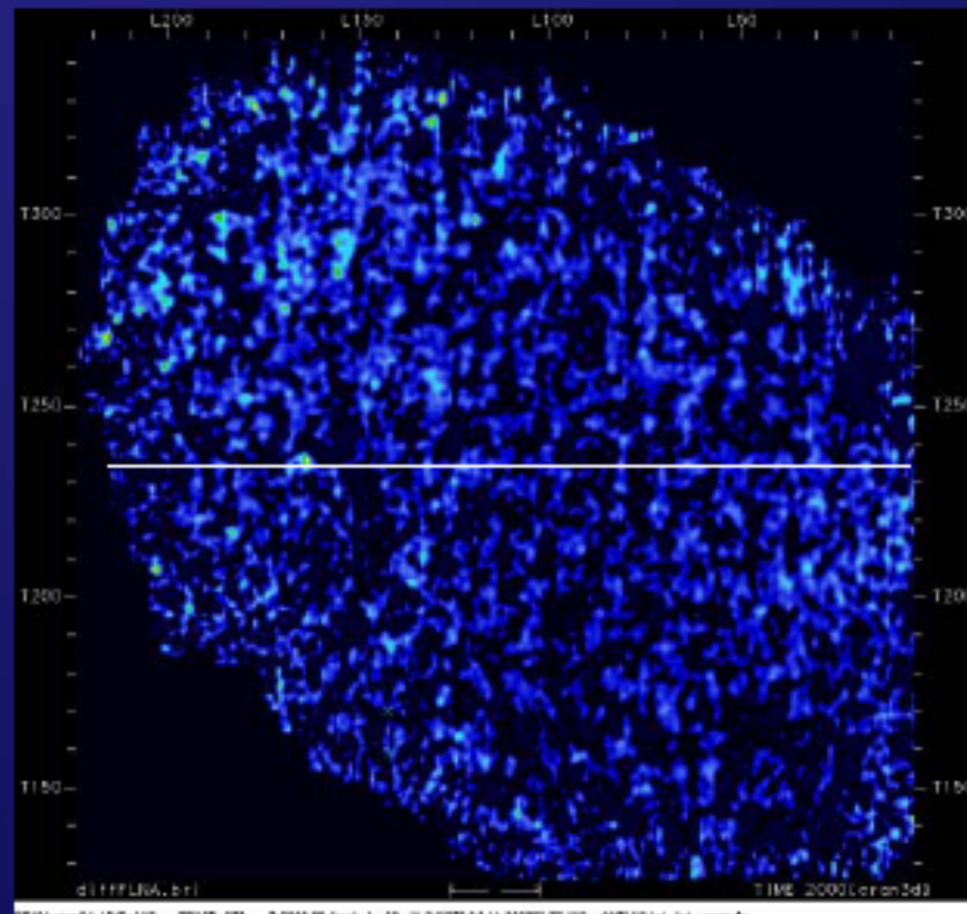
Maximum sustained pressure differential ~1,200 psi / 80 bar / 8 MPa

Stratal slices: there is no sign of leaking!



Cross-section flattened
Velocity difference

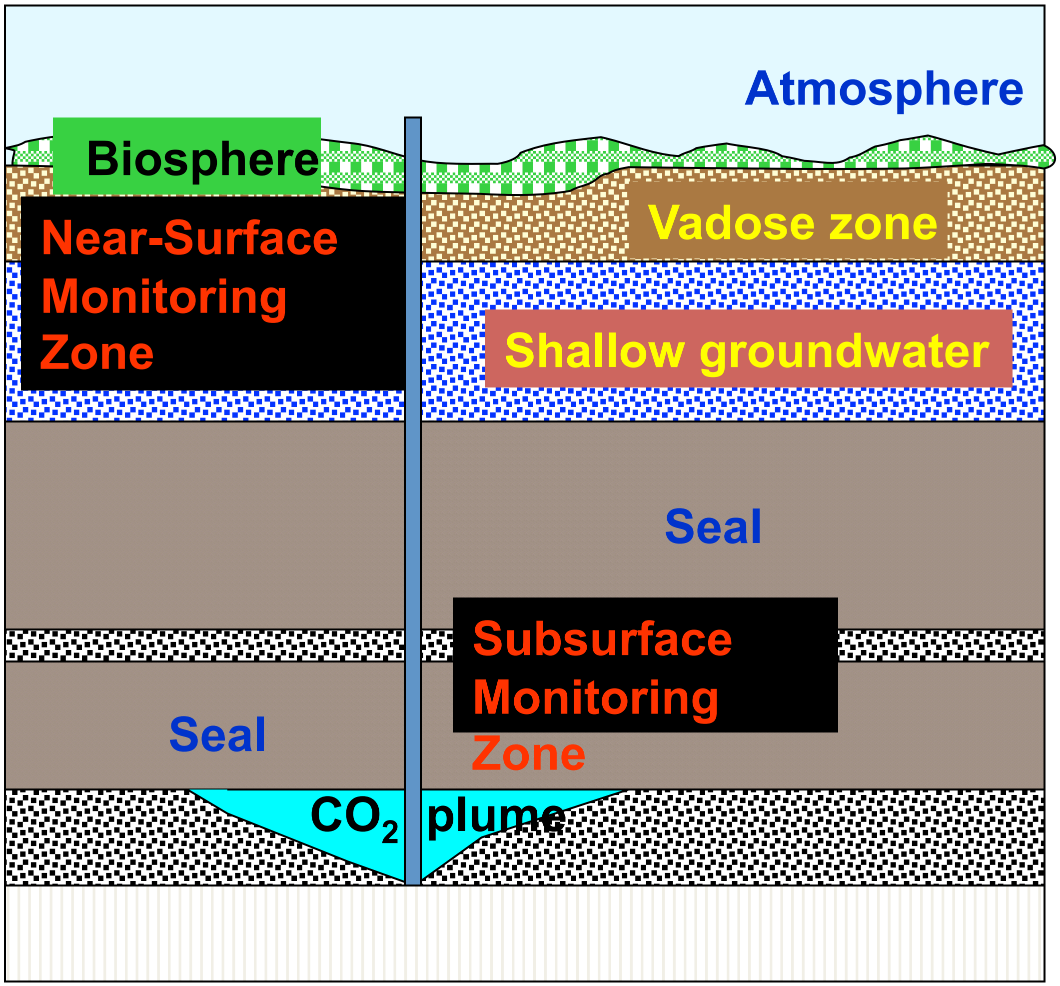
Velocity difference above zone



Initial result: Hongliu Zeng

Near-surface monitoring

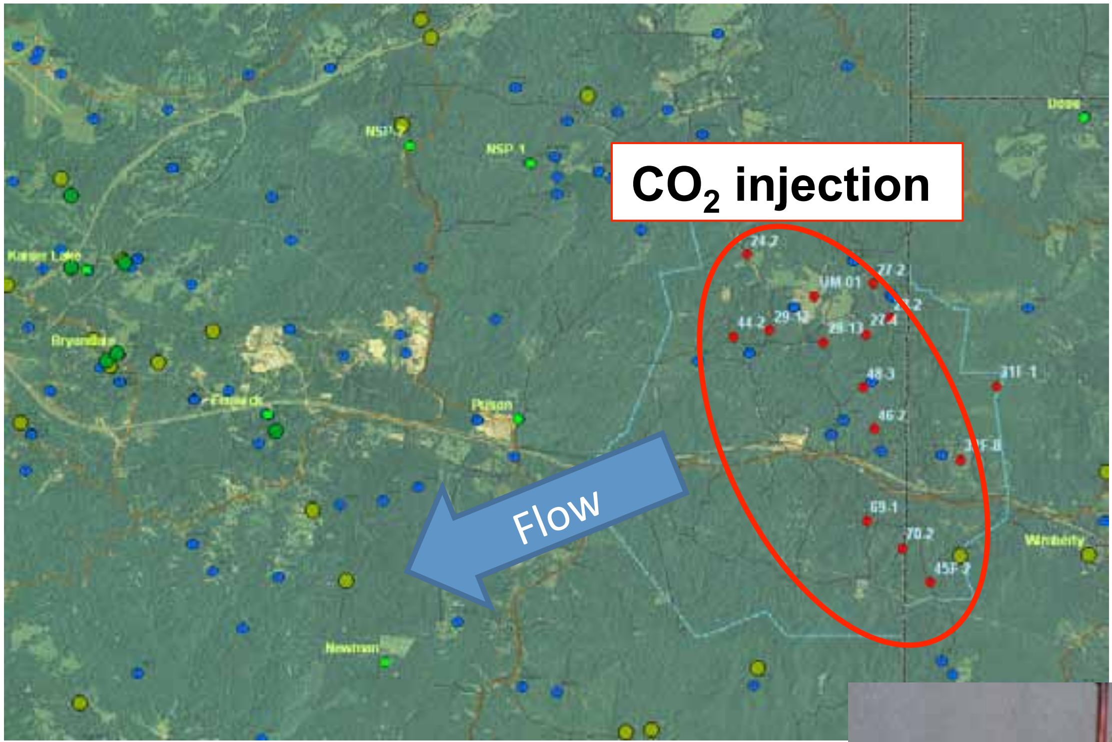
- **Shallow groundwater monitoring**
- **Soil gas monitoring (P-site)**



Objective

To assess near-surface monitoring technologies for leakage detection at a CO_2 sequestration site

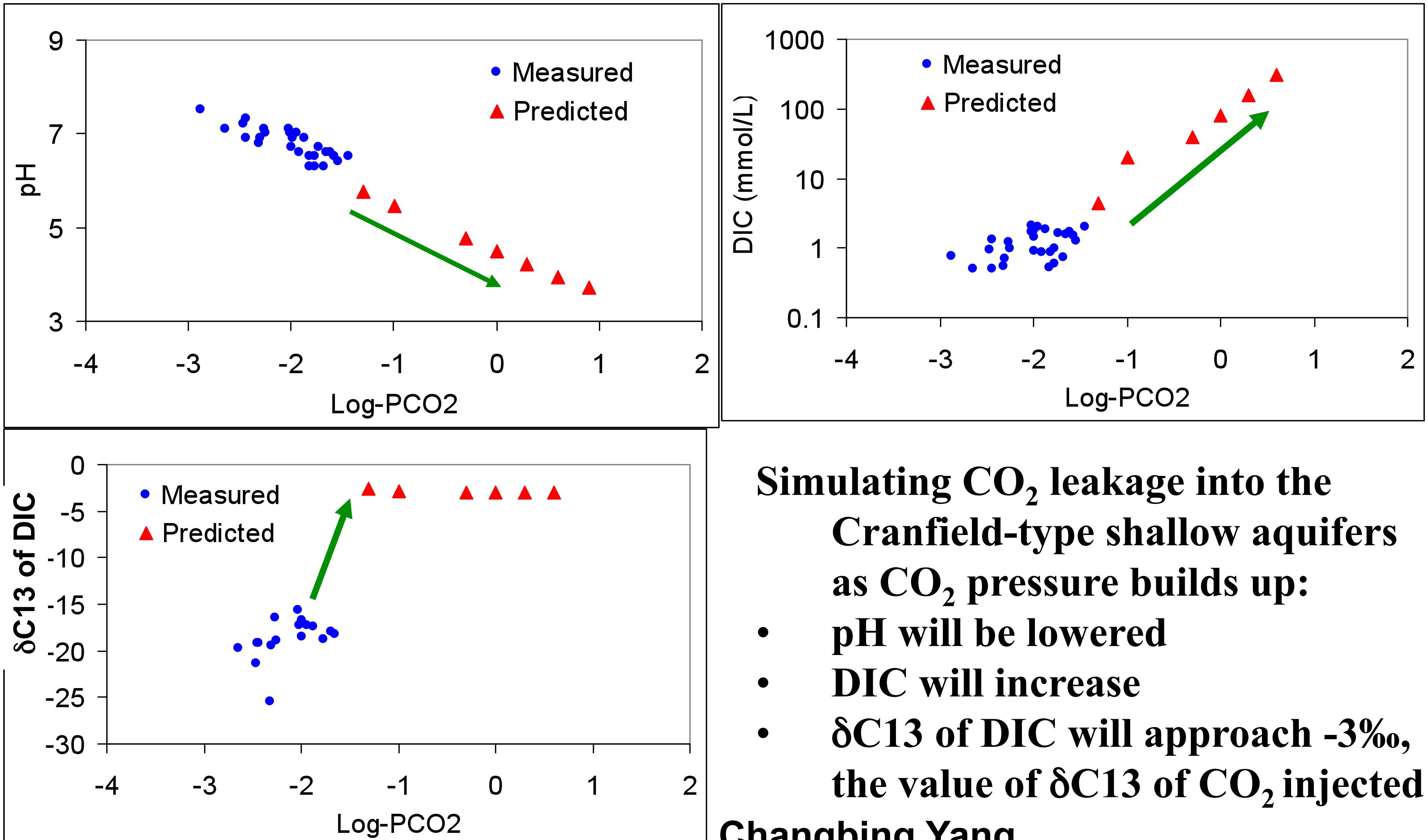
Groundwater Monitoring



- Each injection well has a 200-300 ft deep groundwater well
- Quarterly geochemical monitoring by University of Mississippi,& Mississippi State
- Sensitivity studies at BEG

Changbing Yang

Geochemical modeling to determine sensitivity of groundwater chemistry to CO2 leakage

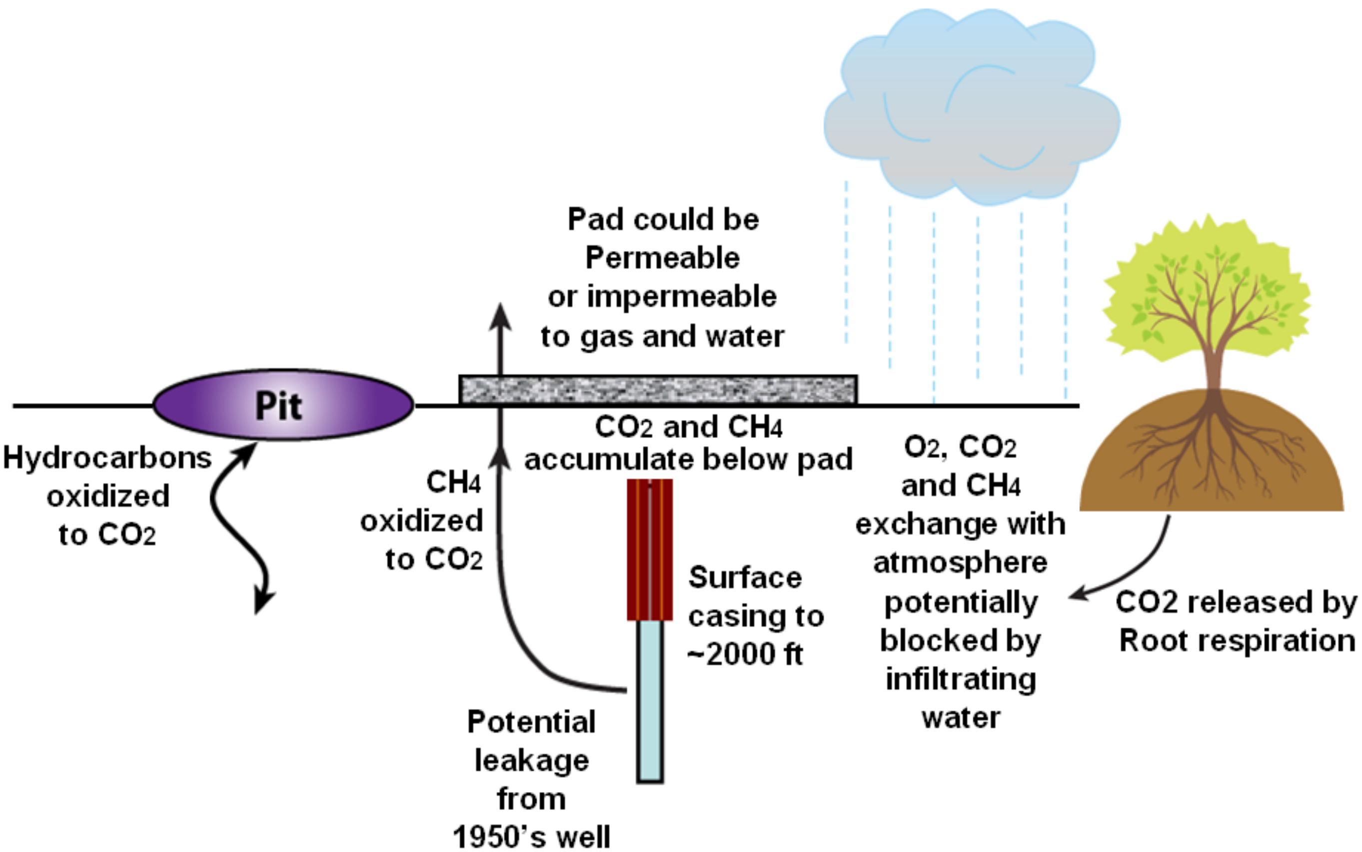


Simulating CO_2 leakage into the Cranfield-type shallow aquifers as CO_2 pressure builds up:

- **pH will be lowered**
- **DIC will increase**
- **δC13 of DIC will approach -3‰, the value of δC13 of CO_2 injected**

Changbing Yang

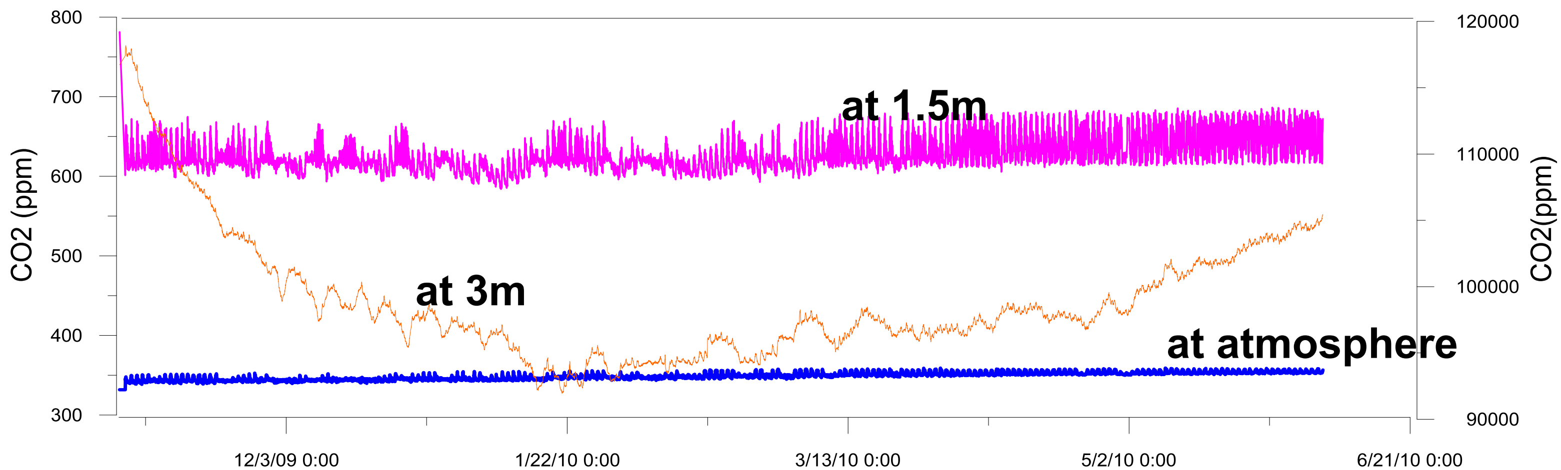
Soil Gas Monitoring via process accounting



Katherine Romanak

CO_2 concentrations at different depths

CO_2 concentration alone may not reliable indicator for leakage detection



- **CO_2 concentrations show variations in depth, average CO_2 conc. ~350 ppm in the atmosphere, ~630 ppm at depth of 1.5 m below surface show, and ~99000 ppm at depth of 3 m over the observation time period**

Changbing Yang and Katherine Romanak

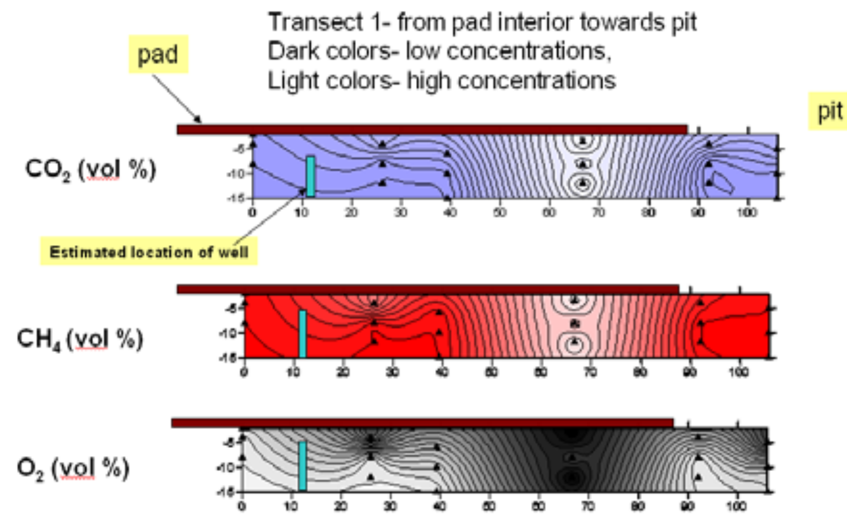
Soil gas composition - Unique leakage signal

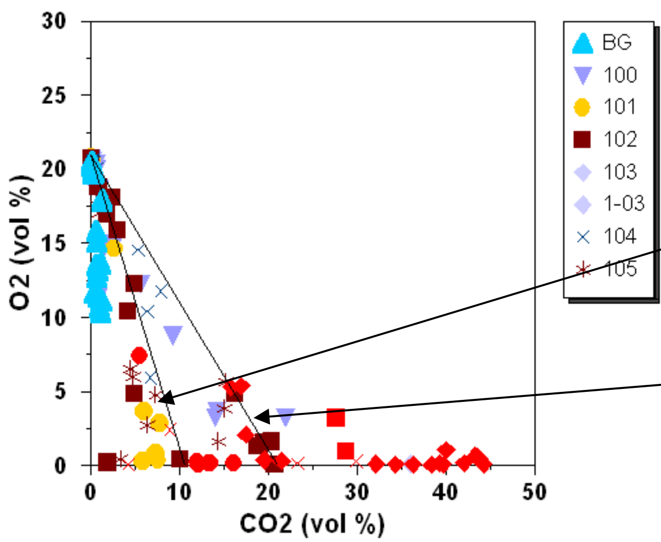
$CH_4 \leq 34$ vol. %

N_2 42-85%

O_2 2- 21%

$CO_2 \leq 45$ vol. %





Methane oxidation

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Org. oxidation

$CH_2O + 2O_2 \rightarrow CO_2 + H_2O$

Katherine Romanak

RCSP program goal:
Predict storage capacities within +/- 30%

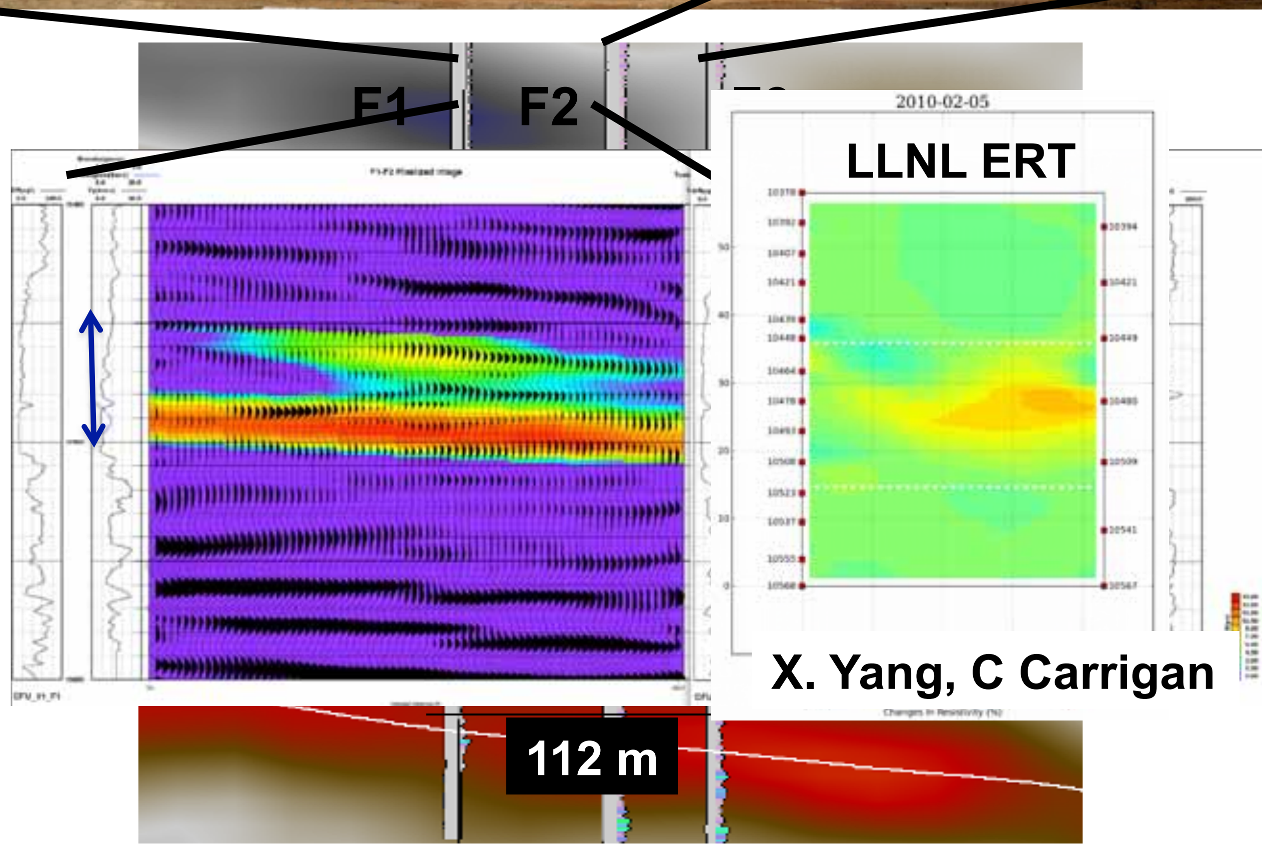
- Capacity and injectivity well known at project start.
  - Open boundary conditions predicted during characterization are demonstrated by good model match.
  - CO_2 moved radially from injectors at the scale of the test (density contrast did not dominate)
- Advance understanding of efficiency of pore-volume occupancy (E factor)
  - Measure saturation during multiphase plume evolution Increase predictive capabilities (underway through modeling)
  - The plume continued to thicken over time, increasing capacity

DAS Monitoring

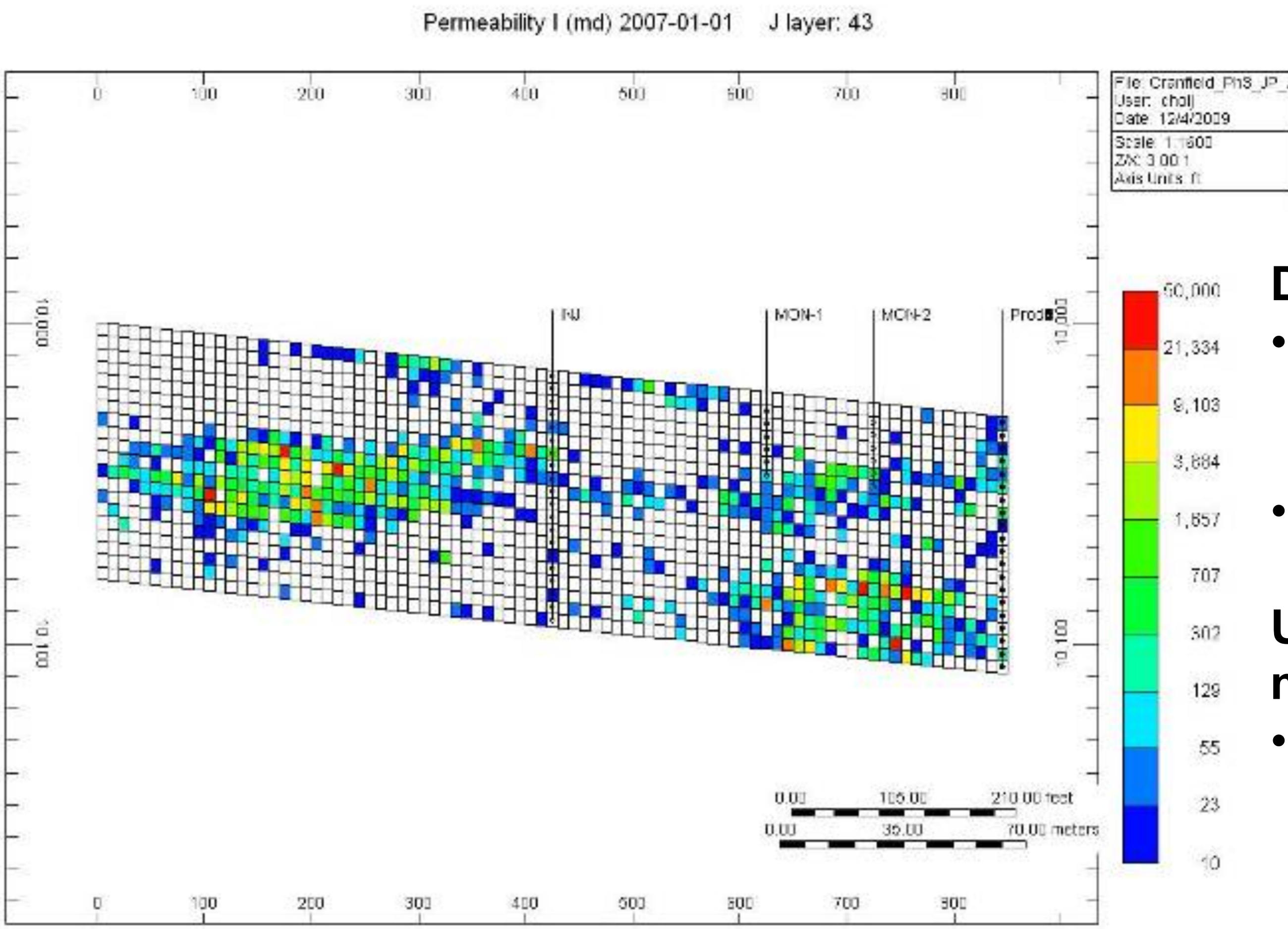
Closely spaced well array to examine flow in complex reservoir

Tuscaloosa D-E reservoir

Petrel model Tip Meckel



A Role of Geological Characterization: Probabilistic realization of permeability



Data collected:

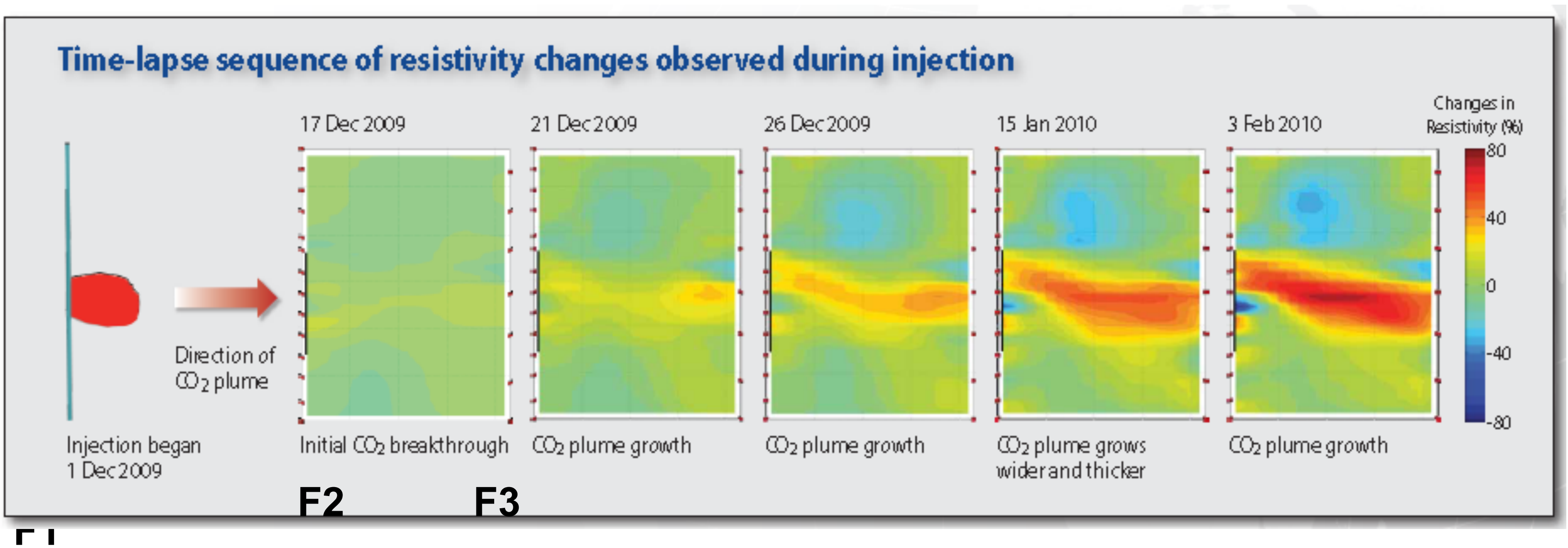
- **Tracer breakthrough times**
- **1-D and 2-Saturation**

Update model – match

- **Multiple modeling teams**

Seyyed Hosseini, Jong-Won Choi and J.-P Nicot BEG

LLNL Test of Electrical Resistance Tomography



Lawrence Livermore National Laboratory

C. Carrigan, X Yang, D. LaBreque

Research fluid sampling via U-tube yields data on flow processes

Adding tracer

- Small diameter sampler with N_2 drive brings fluids quickly and high frequency to surface with tracers intact
- High labor effort
- Unique data on fluid flow

BUREAU OF ECONOMIC GEOLOGY

USGS science for a changing world

BERKELEY LAB

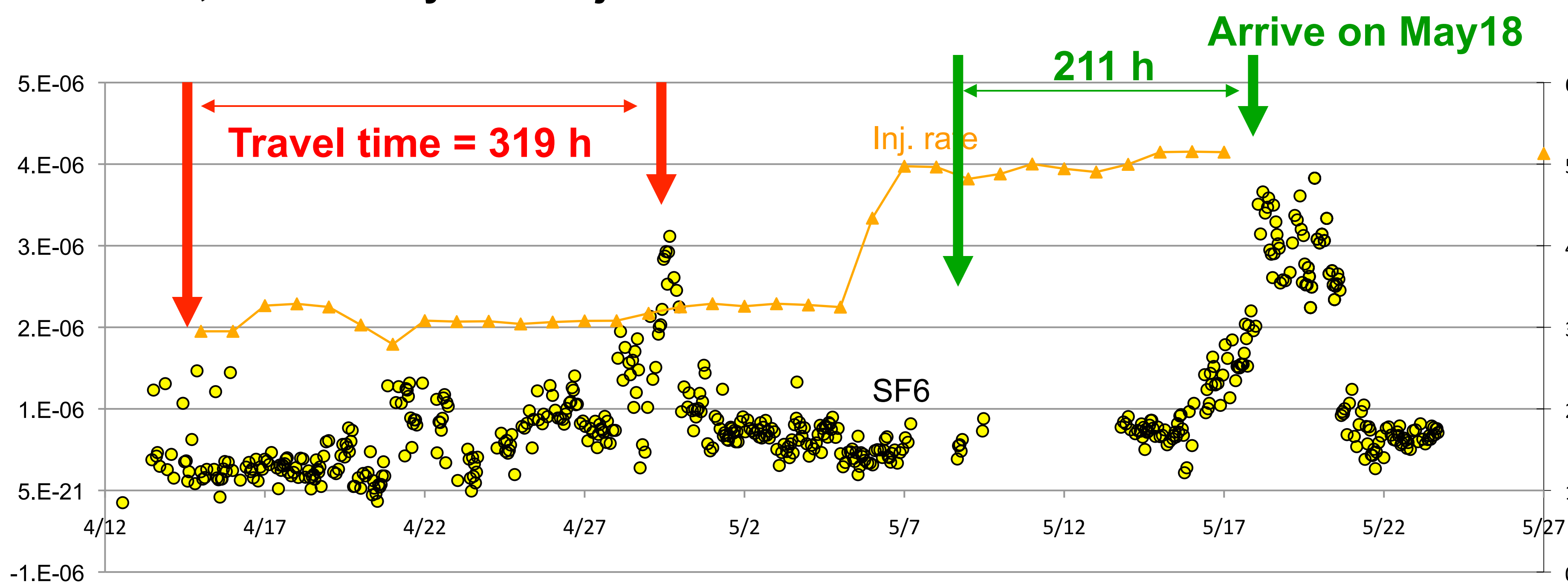
OAK RIDGE NATIONAL LABORATORY
Managed by UT-Battelle for the Department of Energy

UTDoG,

Gulf Coast Carbon Center

Tracers show that capacity is rate dependent

CFU31F-3, 112 m away from injector SF6



Jiemin Lu

Document storage permanence

Storage only saline green field

- Prove-up capacity
- Prove-up confinement
- Simple fluid – low solubility
- Few wells
- Historical uses?
- Evolving regulatory and legal framework
- Unknown public acceptance

CCUS – EOR in brownfield

- Well-known capacity
- Well-demonstrated confinement
- Complex fluids, high solubility
- Many wells
- Complex history
  - Perturbation from past practices
- Mature regulatory and legal framework
- Good public acceptance

Lessons learned

- In-zone monitoring does not yield unique non-leakage determination
- Continuous AZMI pressure monitoring for permanence
  - Viable method
  - Invest characterization and well completion
  - Geomechanical study needed
- Near surface leakage monitoring strategy based on modeling
  - Process-based soil gas methods
  - Geochemical – groundwater methods