Optimizing monitoring to document storage permanence: lessons learned at SECARB "early" test at Cranfield

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Champaign, IL
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Team Structure

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

Southern States Energy Board

SECARB Anthropogenic Test At Plant Barry/Citronelle

Denbury Resources
Field owner and injection system design, management, 4-D survey, HS&E

Sandia Technologies
Monitoring Systems Design, Installation, HS&E

50 Vendors
e.g. Schlumberger

Vendors
e.g. well drilling, landmen

Core Lab
UT DoG
Anchor QEA

MSU & UMiss
Hydro & hydrochem

Curtin University
3-D Seismic processing

Federal collaborators
Via FWP

LBNL
Well-based geophysics, U-tube and lab design and fabrication

LLNL
ERT

USGS
Geochemistry

Separately funded

NRAP
VSP deployment & analysis

NETL
Rock-water interaction

Model comparisons
LBNL SIM SEQ study

IPARS Modeling
CFSES M. Wheeler

4-D Seismic analysis
K. Spikes UT DoGS

Rock Mechanics
CFSES Sandia NL

Microseismic deployment
RITE, Japan

Groundwater controlled release
AWWA

Early Test Scope

- Monitoring saline and EOR in a commercial EOR project
- “Early” because project was nearly ready to start at time SECARB entered
- 10,000 ft deep Cretaceous Tuscaloosa Formation

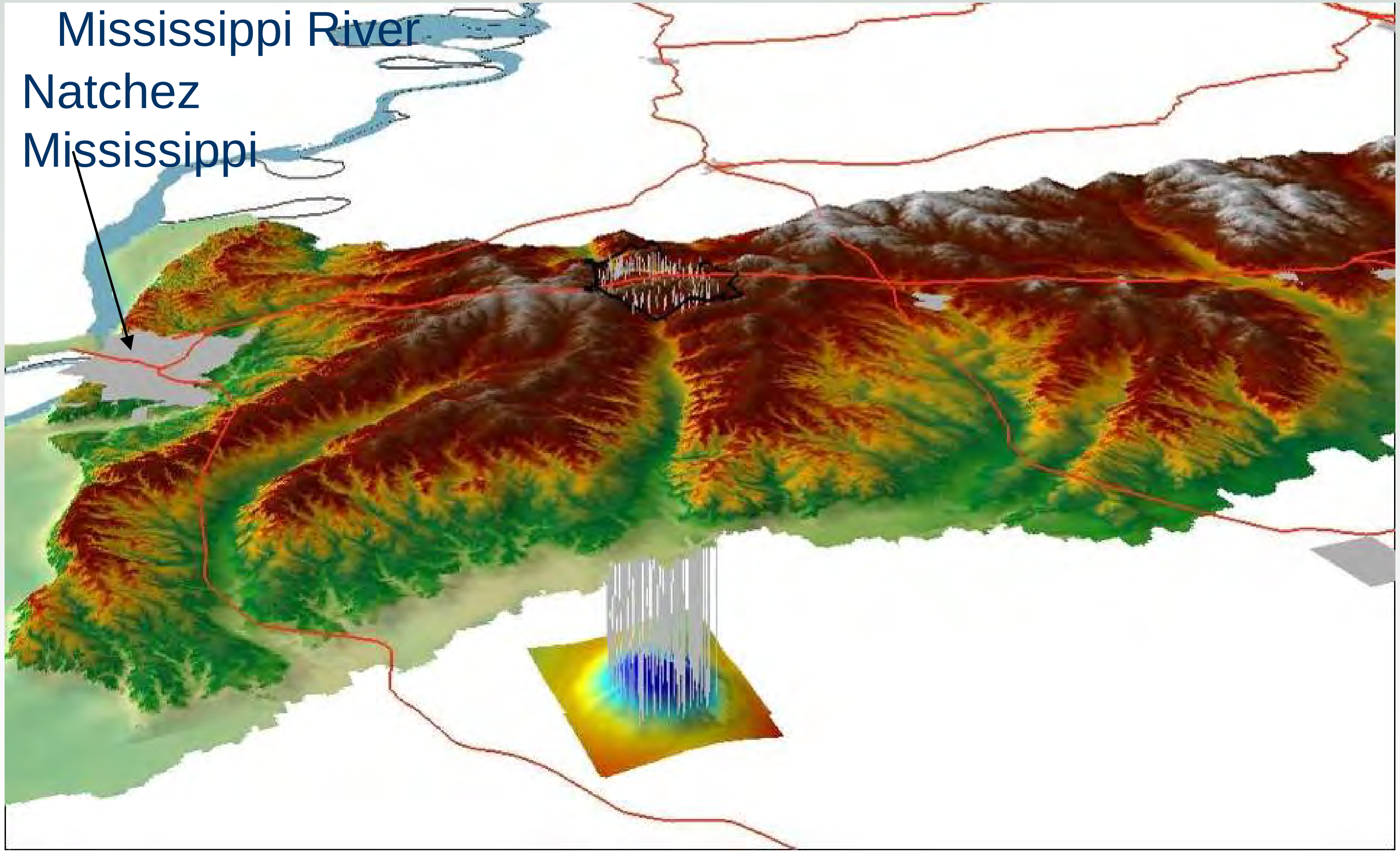

Figure Tip Meckel

Early Test Goals

- Large-scale storage demonstration
  - 1 MMT/year over >1.5 years
  - Periods of high injection rates
    - Result >5 years monitoring with >5 MMT CO_2 stored
- Measurement, monitoring and verification
  - Tool testing and optimization approach
  - Deploy as many tools, analysis methods, and models as possible
- Stacked EOR and saline storage
- Commercial technology transfer
  - Uploaded data to EDX

Current major effort

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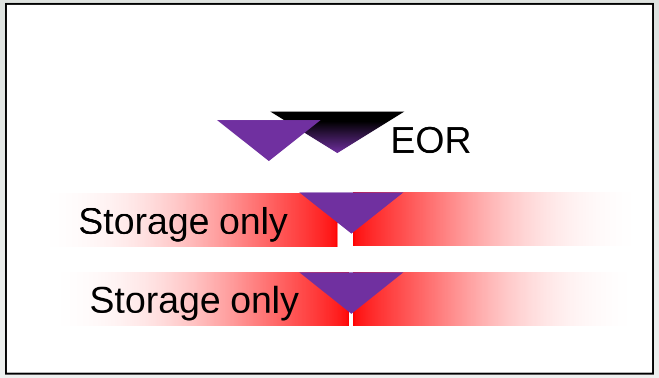
Contributions of Early Test

- Early Test Developed monitoring approaches for later commercial projects
  - Stacked storage concept
  - Fluid flow in heterogeneous media
  - ERT for deep CO_2 plume
  - Limitations of 4-D seismic – hydrocarbon interference, signal/noise
  - No induced seismicity > magnitude 0 (with RITE, Japan)
  - Pressure and fluid chemistry monitoring in Above-Zone Monitoring Interval (AZMI)
  - Process-based soil gas method
  - Limitations to effectiveness of groundwater surveillance for documenting storage



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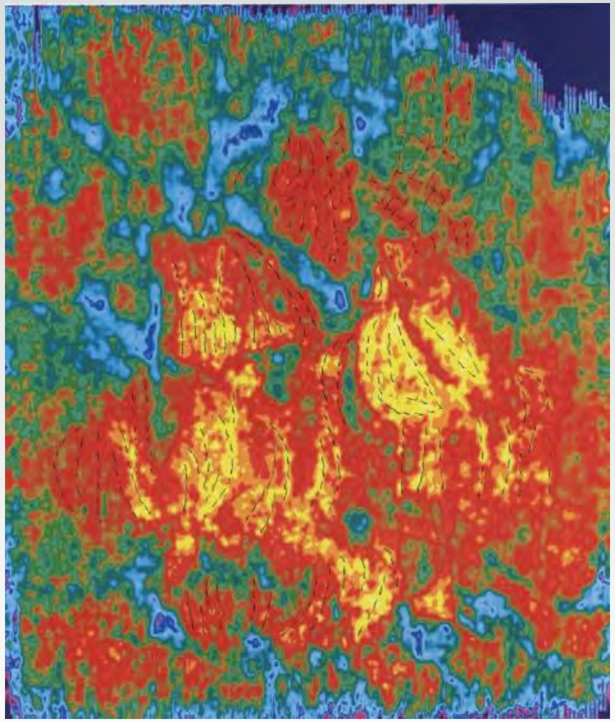
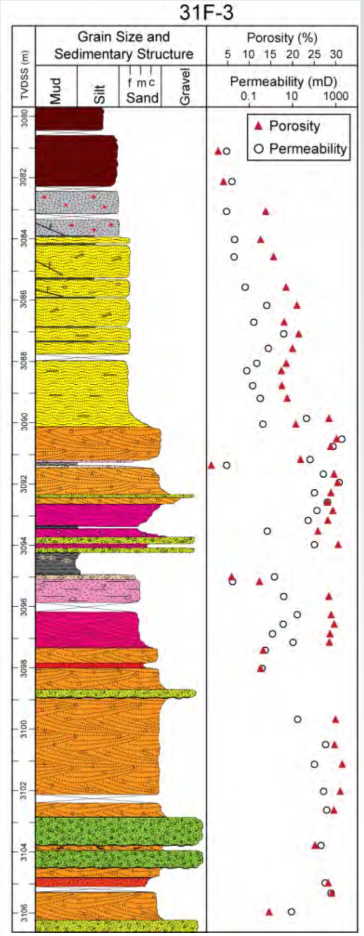
Stacked storage EOR and Saline

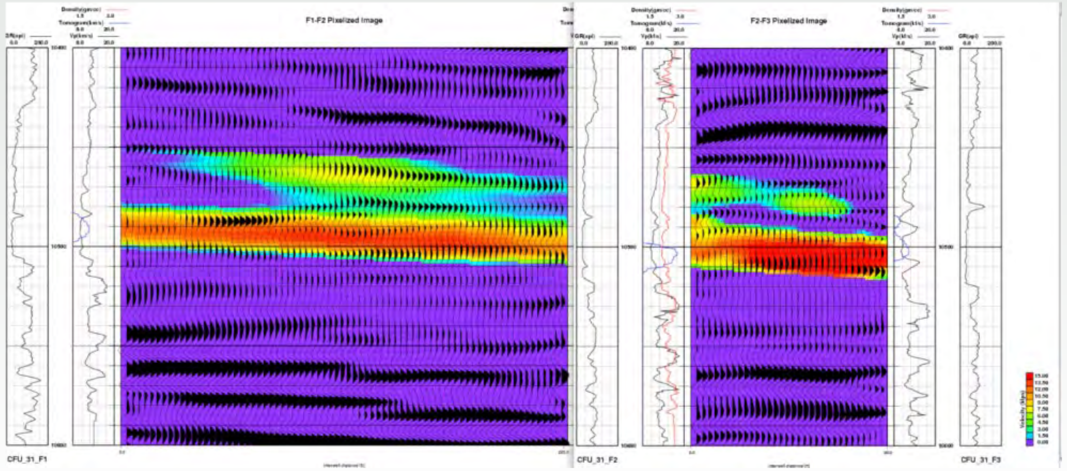
- Characterization based on long production history
- Balanced flood
  - Fluid withdrawal (oil, water, gas CO_2) = Fluid injection (water, CO_2) during most of the operation
  - Area and magnitude of elevated pressure controlled by production
  - Area occupied by CO_2 controlled by production
- Controlled flood
  - Injection and production patterns
- Active surveillance
  - Production, pressure
  - Other techniques as needed
    - Wireline log, seismic, tracers,

Oil and gas trapped over geologic time

Response of highly heterogeneous reservoir to multi-phase flow



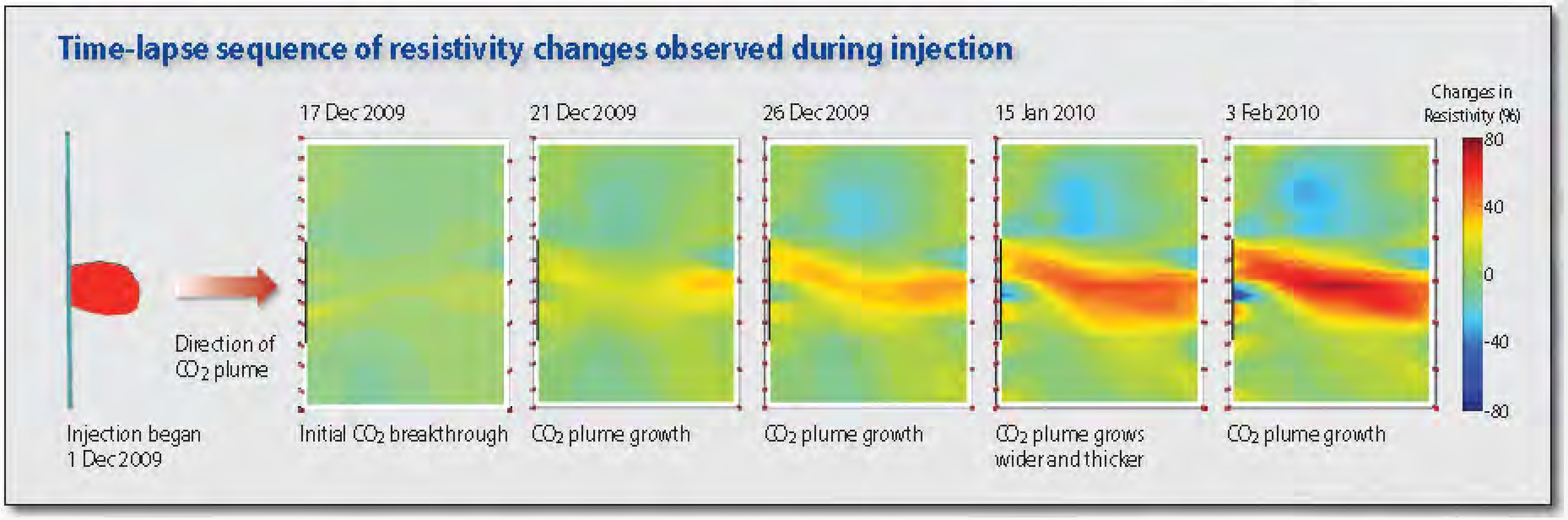




SECARB Time lapse seismic shows fluid change

LLNL Electrical Resistance Tomography- changes in response with saturation

F1 F2 F3



Lawrence Livermore National Laboratory

C. Carrigan, X Yang, LLNL
D. LaBrecque Multi-Phase Technologies

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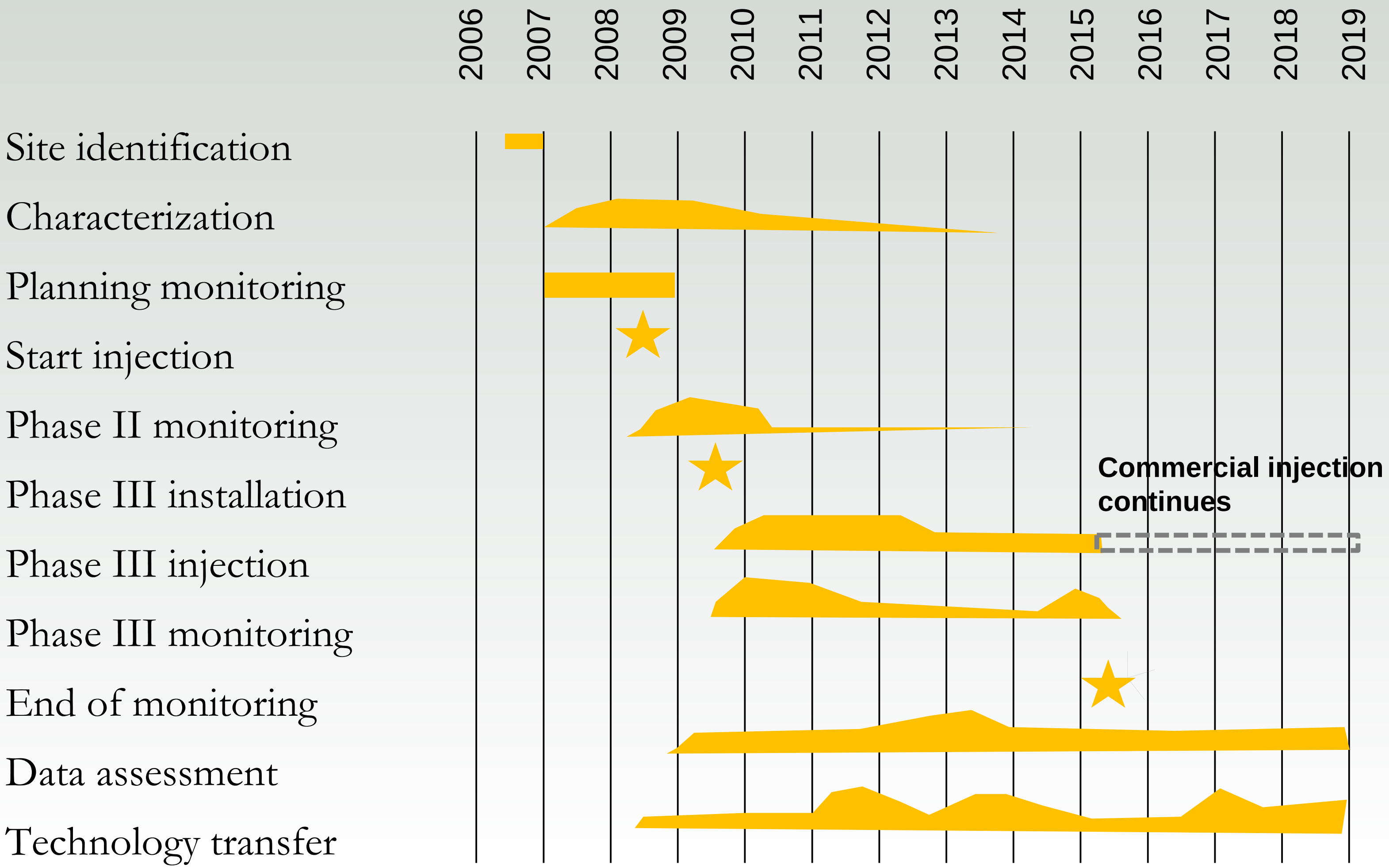
Early Test Evolution



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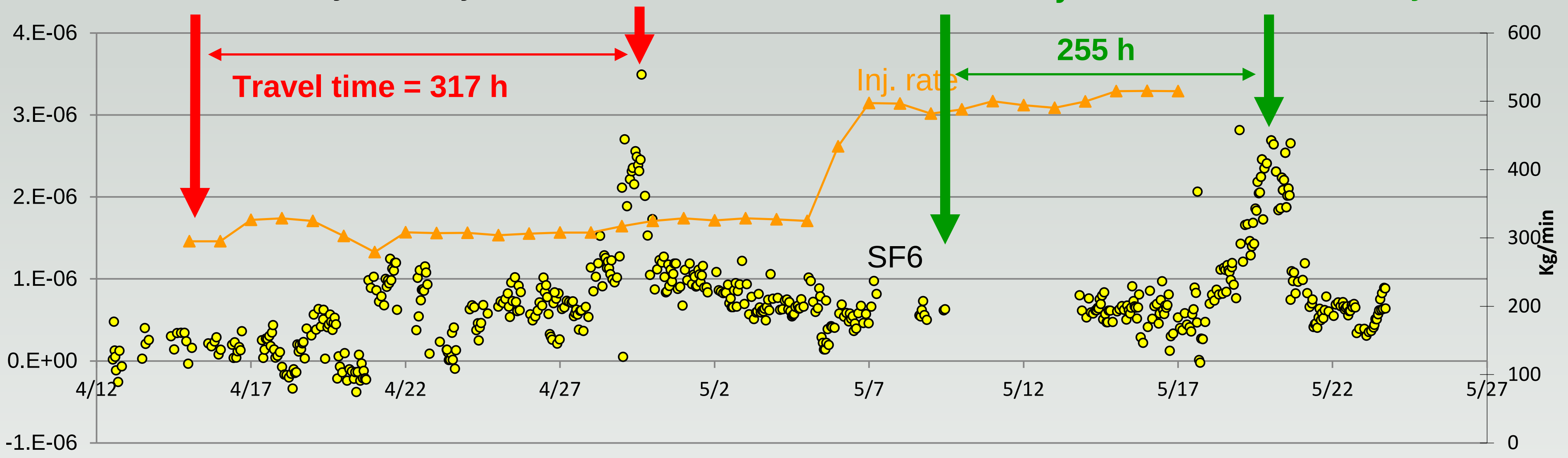
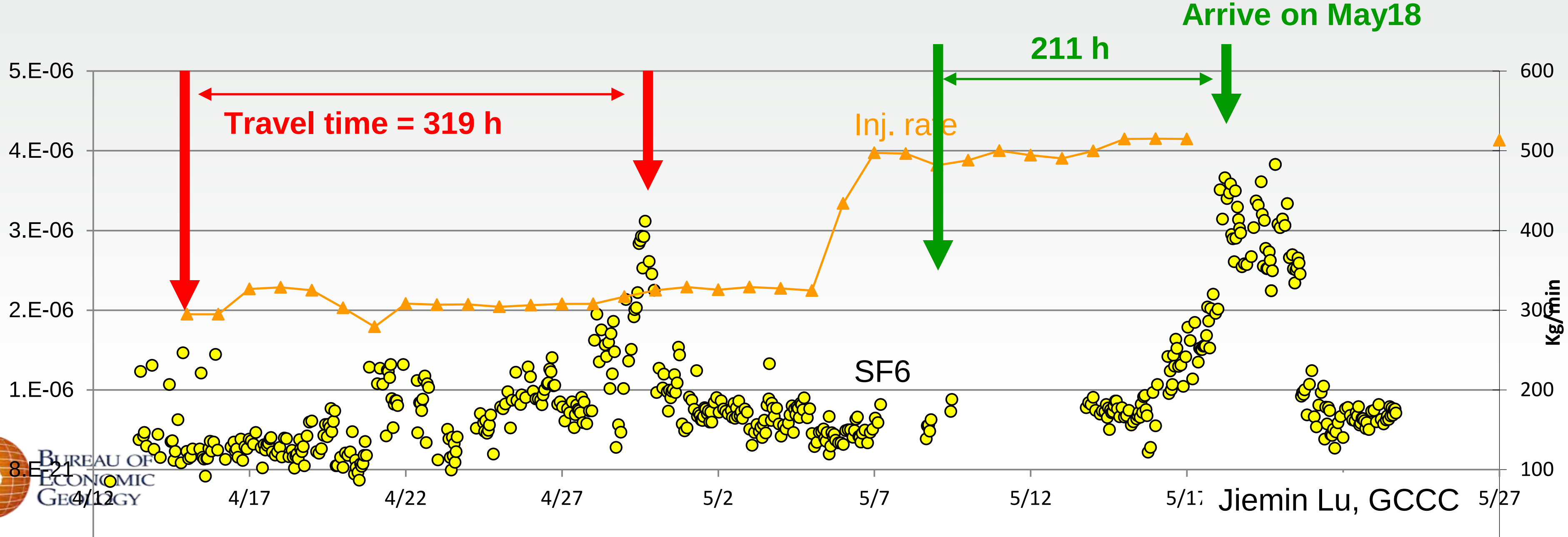
SF6

CFU31F-2, 68 m away from injector

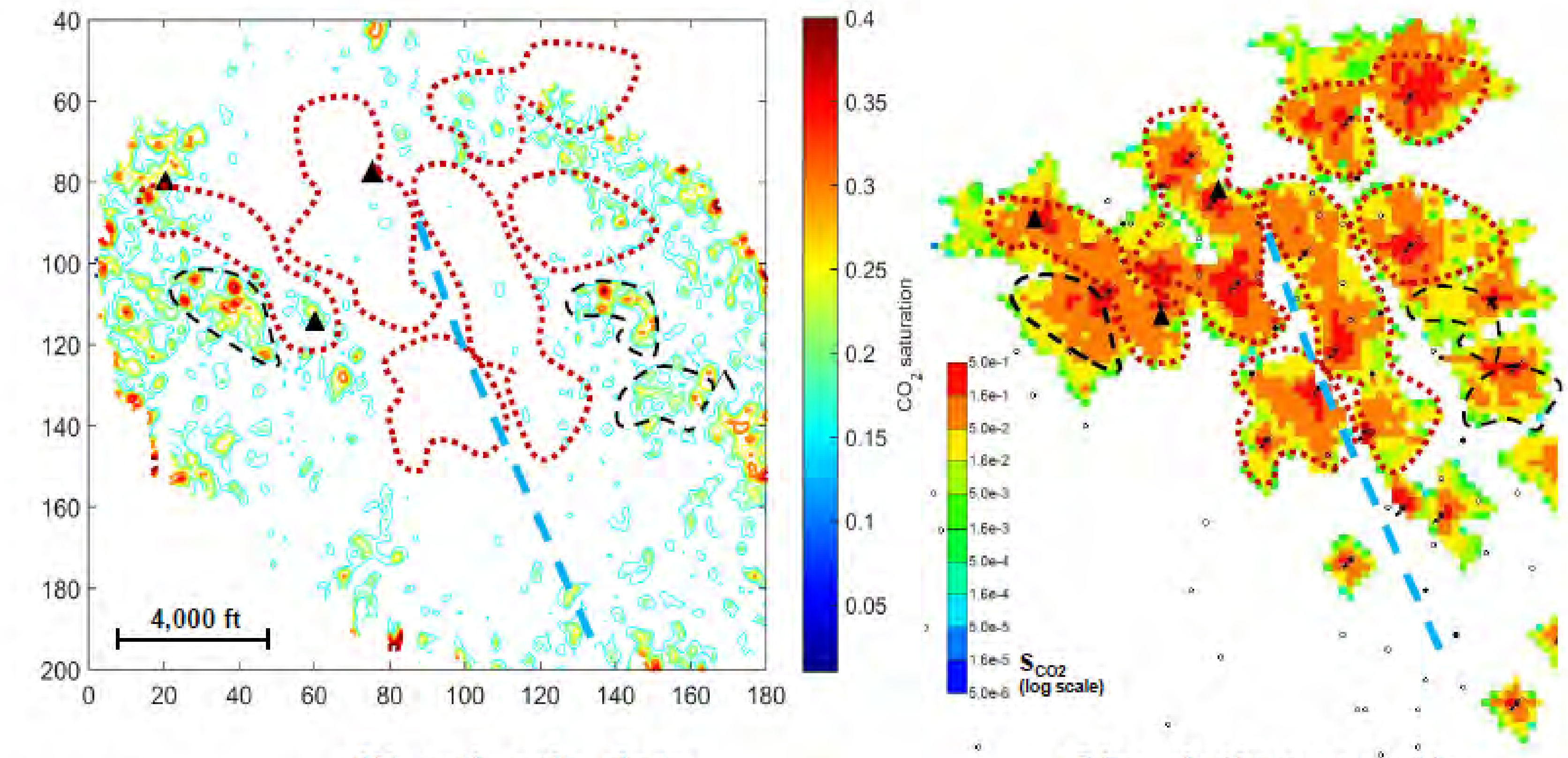


CFU31F-3, 112 m away from injector

SF6



Limitations to 4-D seismic

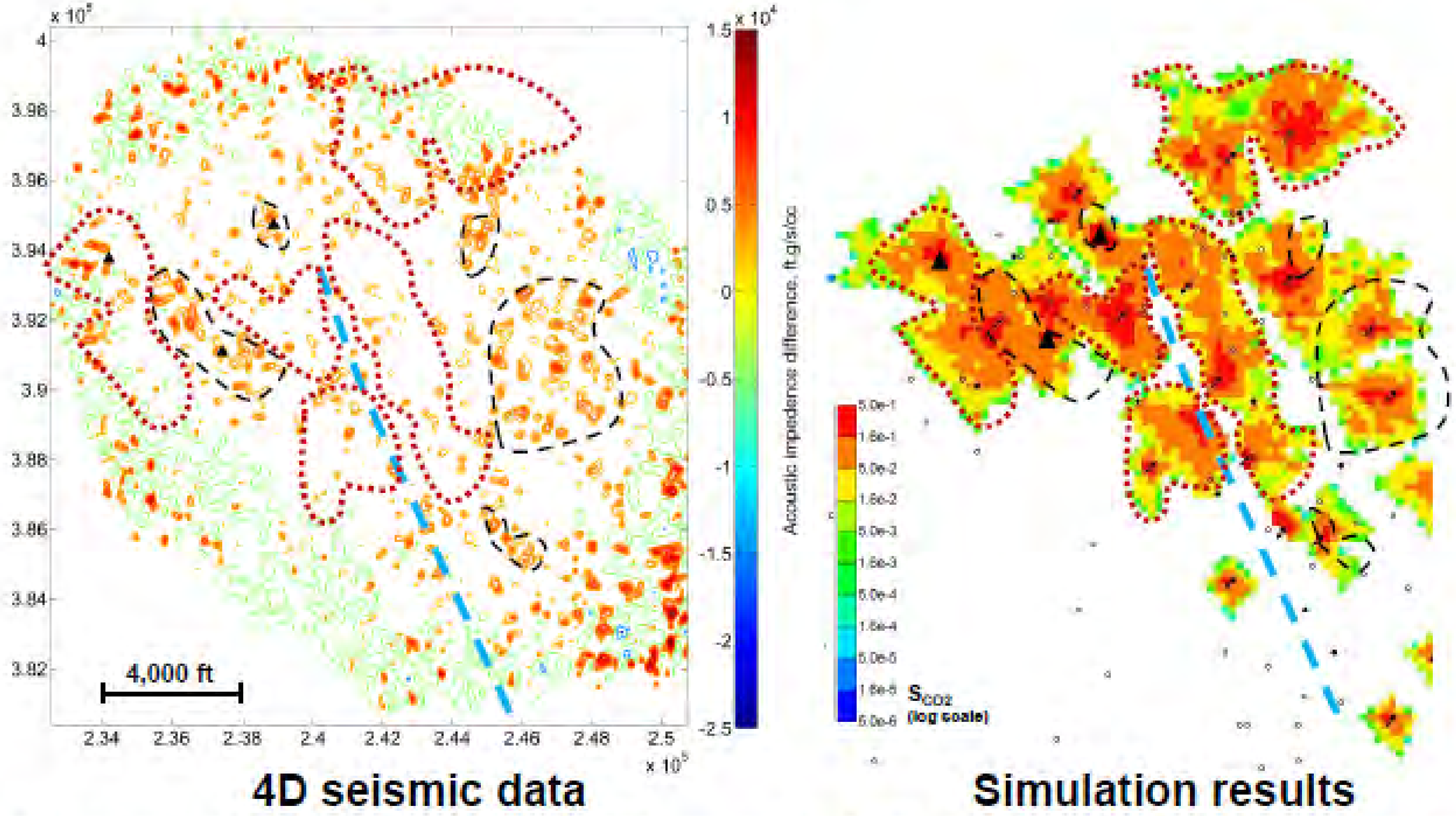


4D seismic data **Simulation results**

(b) CO_2 saturation distribution estimate (Carter [18]) compared to fluid flow simulation

Alfi & Hossieni, BEG

Limitations to 4-D seismic

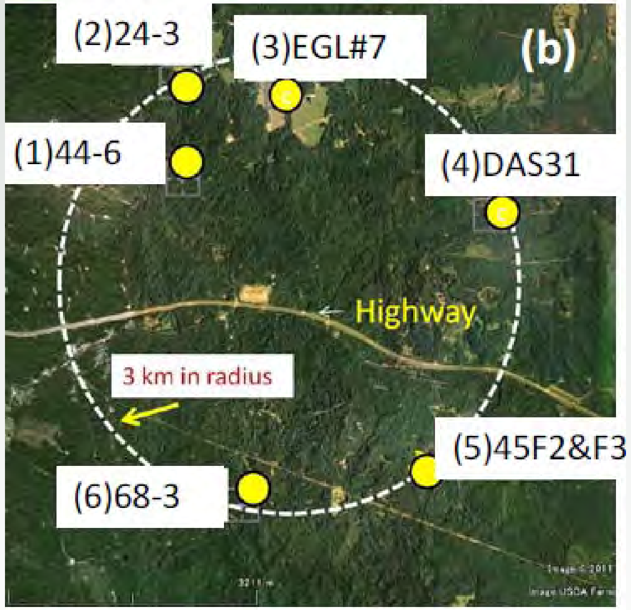


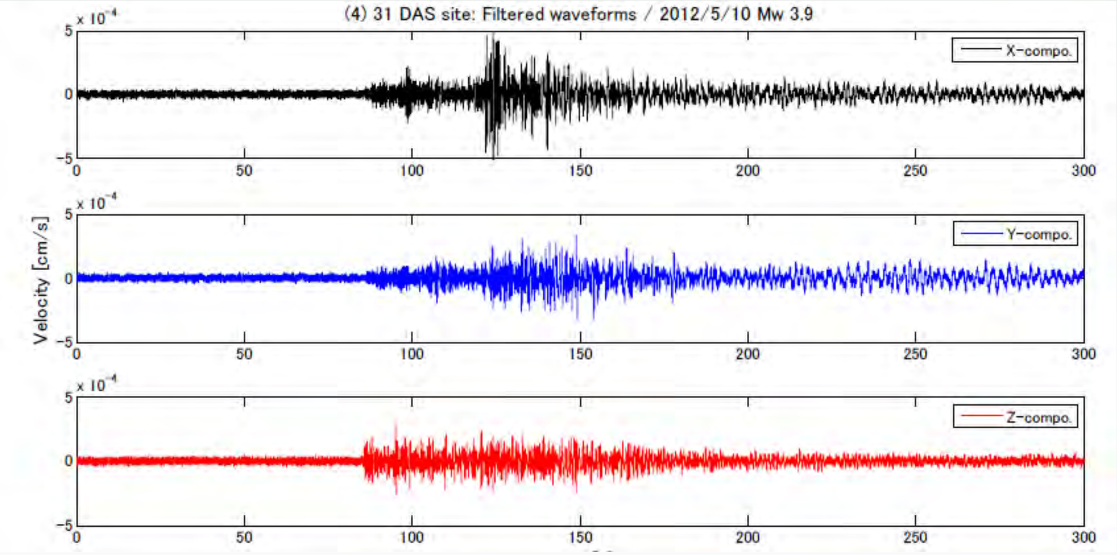
(a) Acoustic impedance difference (Zhang et al. [17]) compared to fluid flow simulation

Alfi & Hossieni, BEG

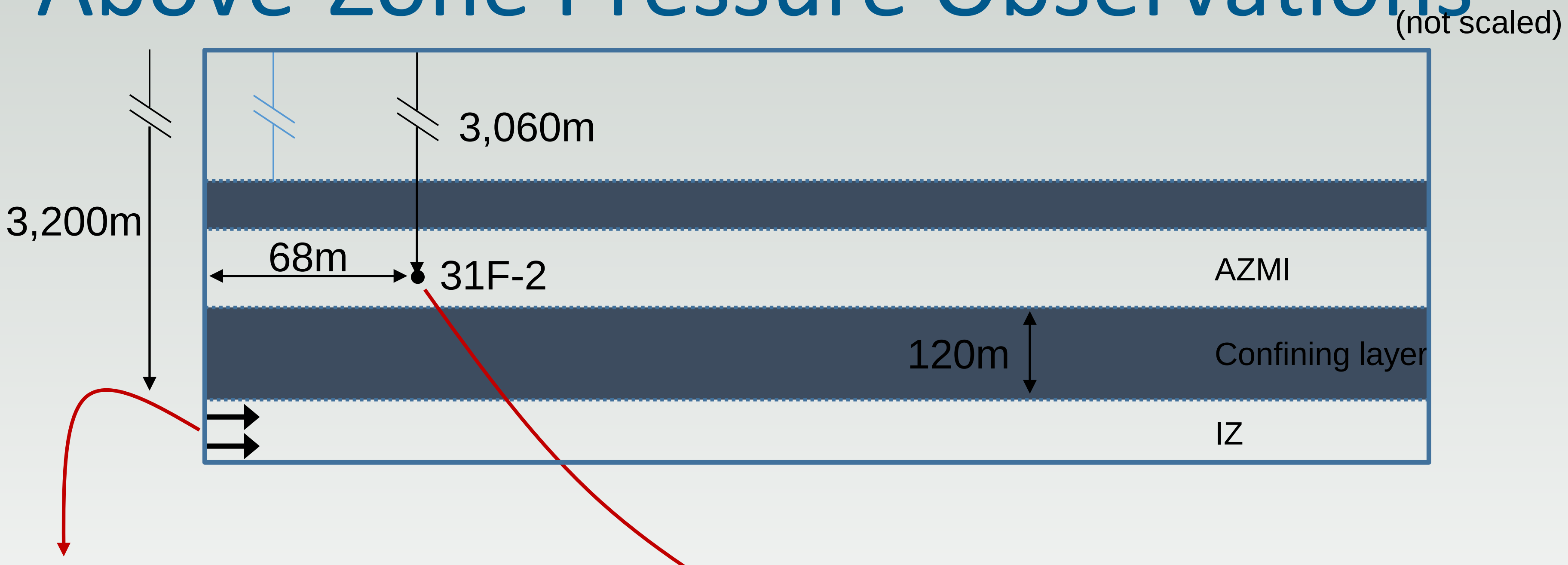
No detectable induced seismic response to 1000 psi overpressure, graben faults

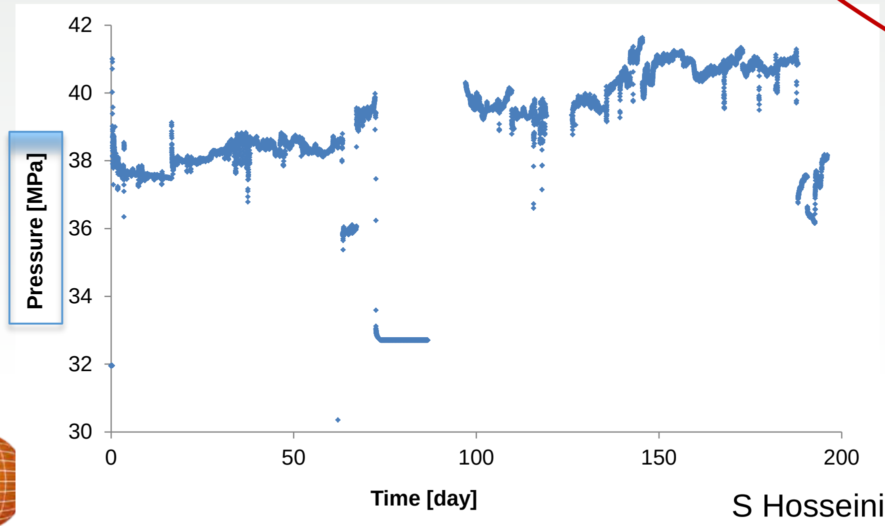
Makiko Takagishi, RITE
Magnitude 0.4 horizontal and .07 vertical

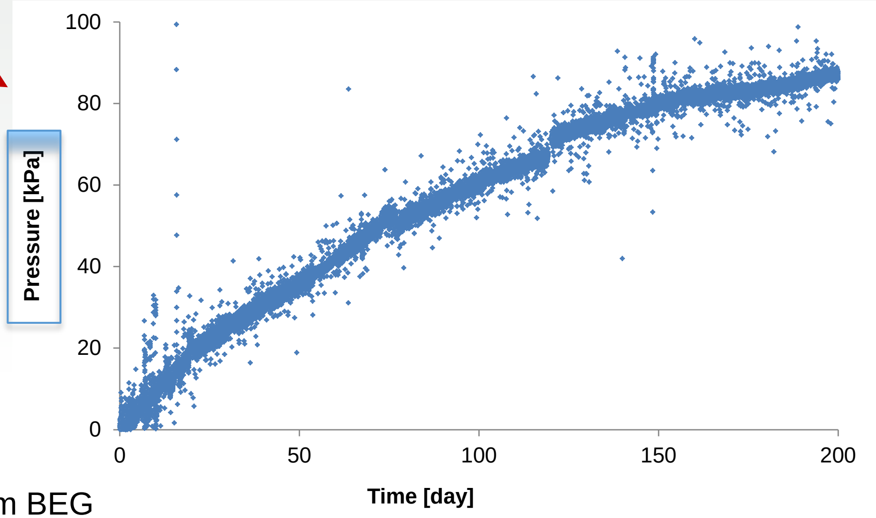




Above-Zone Pressure Observations







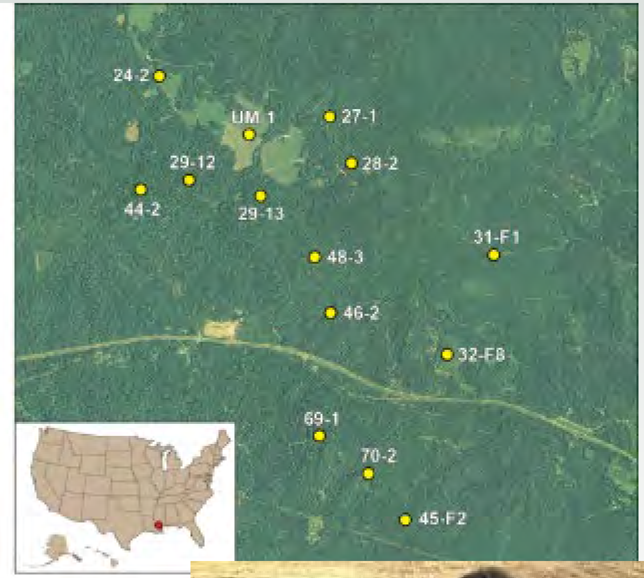
S Hosseini, S. Kim BEG

Groundwater at the Cranfield Site: Sampling

- More than 12 field campaigns since 2008
- ~ 130 groundwater samples collected for chemical analysis of

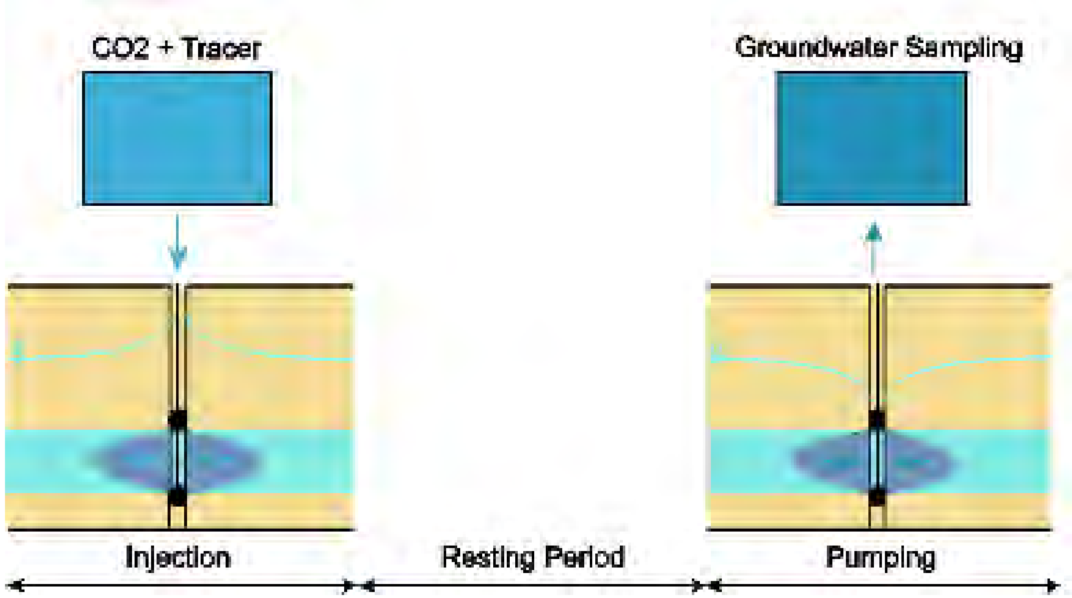
  Cations: Ag, Al, As, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Pb, Se, Zn
  Anions: F^-, Cl^-, SO_4^{2-}, Br^-, NO_3^-, PO_4^{3-}
  TOC, TIC, pH, Alkalinity, VOC, δC13

  On-site: pH, temperature, alkalinity, water level



- ~10 samples for noble gases
- ~20 groundwater samples for dissolved CH_4
- 15 Water wells

Groundwater at the Cranfield Site Single-Well Push-Pull Test



Results were summarized in the following paper


International Journal of Greenhouse Gas Control 18 (2013) 375–387
Contents lists available at ScienceDirect
International Journal of Greenhouse Gas Control
journal homepage: www.elsevier.com/locate/ijggc

Single-well push–pull test for assessing potential impacts of CO_2 leakage on groundwater quality in a shallow Gulf Coast aquifer in Cranfield, Mississippi

Changbing Yang[a,*], Patrick J. Mickler[a], Robert Reedy[a], Bridget R. Scanlon[a], Katherine D. Romanak[a], Jean-Philippe Nicot[a], Susan D. Hovorka[a], Ramon H. Trevino[a], Toti Larson[b]
[a] Bureau of Economic Geology, The University of Texas at Austin, 10100 Burnet Road, Bldg 130, Austin, TX 78758, United States
[b] Department of Geological Sciences, The University of Texas at Austin, 2275 Speedway Stop C9000, Austin, TX 78712-1722, United States

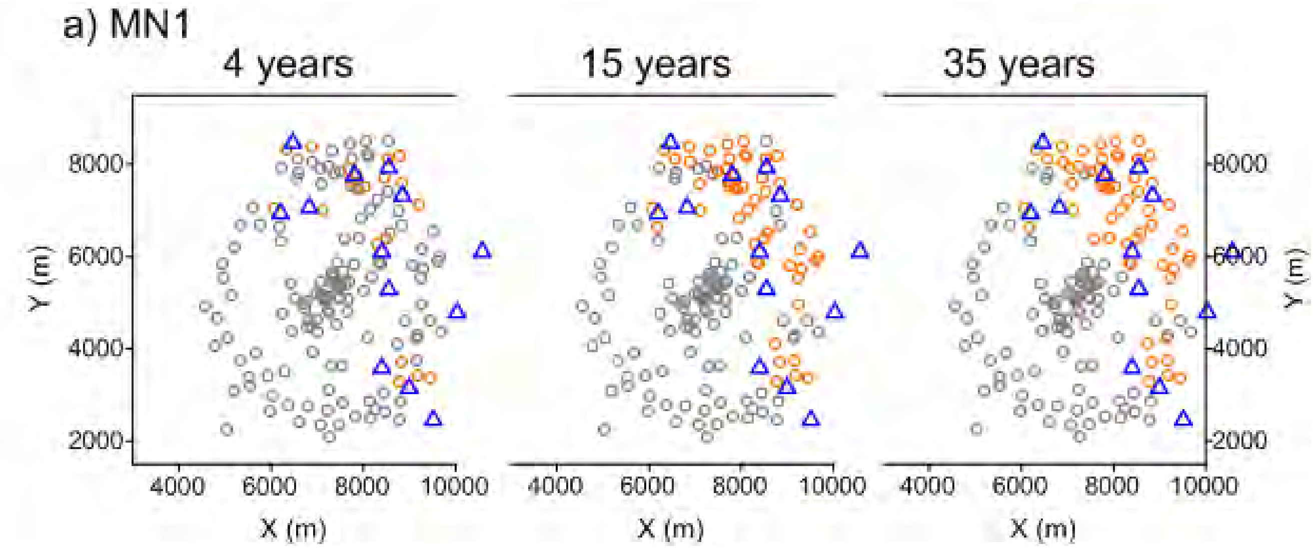
- Maximum concentrations of trace metals observed, such as and Pb, are much less than the EPA contamination levels;
- Single well push-pull test appears to be a convenient field controlled-release test for assessing potential impacts of CO_2 leakage on drinking groundwater resources;

C. Yang, BEG

Groundwater Monitoring Network Efficiency

$$ME = \frac{W^d}{W^T}$$

- 20/151=0.13 by 4 years
- 50/151=0.33 by 15 years
- 58/151=0.38 by 35 years



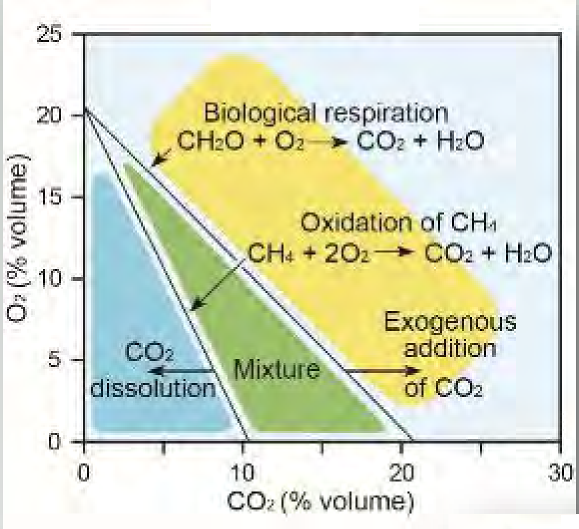
CO_2 leakage from a P&A well is detected by a monitoring net work if change in DIC, dissolved CO_2, or pH in any one of wells of the monitoring network is higher than one standard deviation of the groundwater chemistry data collected in the shallow aquifer over the last 6 years.

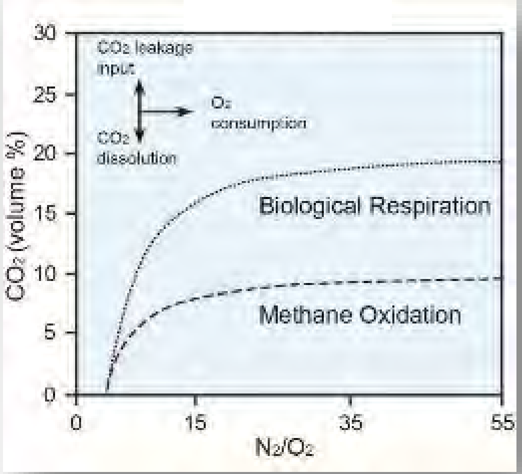
Changbing Yang

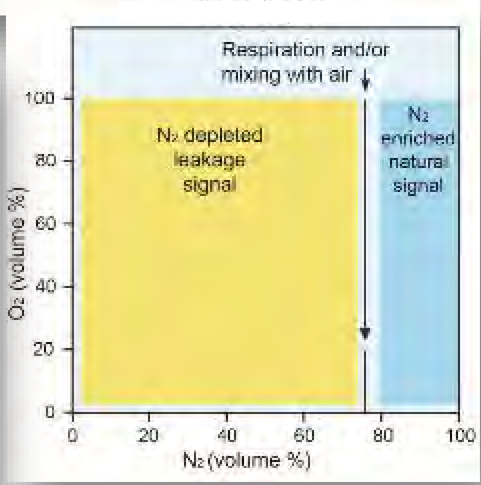
Process-Based Soil Gas Monitoring

- No need for years of background measurements.
- Promptly identifies leakage signal over background noise.
- Uses simple gas ratios

  (CO_2, CH_4, N_2, O_2)
- Can discern many CO_2 sources and sinks
  - Biologic respiration
  - CO_2 dissolution
  - Oxidation of CH_4 into CO_2 (Important at CCUS sites)
  - Influx air into sediments
  - CO_2 leakage







Commercialization of Monitoring

	Mass balance	soil gas	groundwater chem	AZMI chem	AZMI pressure	3D seismic	VSP	ERT	EM	gravity	u-tube	IZ chem	tracers
Frio	x	x	x	x			x		x		x	x	x
SECARB Early test at Cranfield	x	x	x	x	x	x	x	x		x	x	x	x
Industrial capture Air Products -Hastings	x	x	x		x	x	x						
Clean Coal Power initiative Petra Nova/ West Ranch	x	x	x	x	x								

Commercial Down-selection of monitoring tools

You can't have everything! Example limitations:

- Tool interference

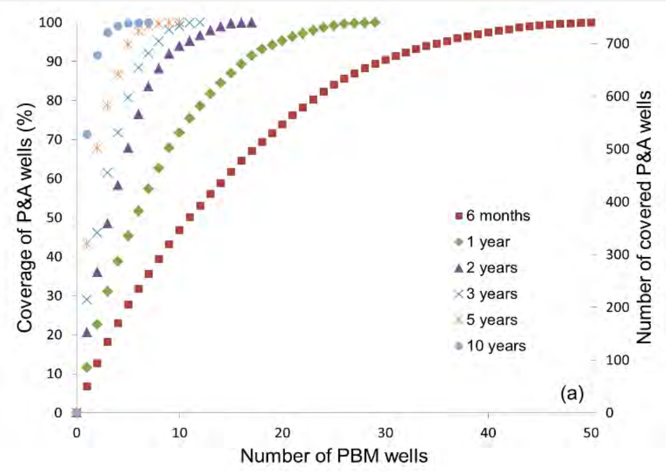
  e.g. "jewelry" on casing interferes with log response

  Perforated well – geochemical and geophysical tool deployment interference

- Tool limitations – cost, cost of analysis

  Papers on cost/value

Sensitivity of time until detection of leakage on number of wells installed, Bolhassani (*2017.)*



Methods for down-selection of monitoring tools

- Optimized tool selection (Assessment of low probability material impact: 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

Method down selects only signals that indicate material impact may occur or may be occurring

Select monitoring tools that can detect these signals at required sensitivity

Approaches like those normally used for 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; collect 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

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

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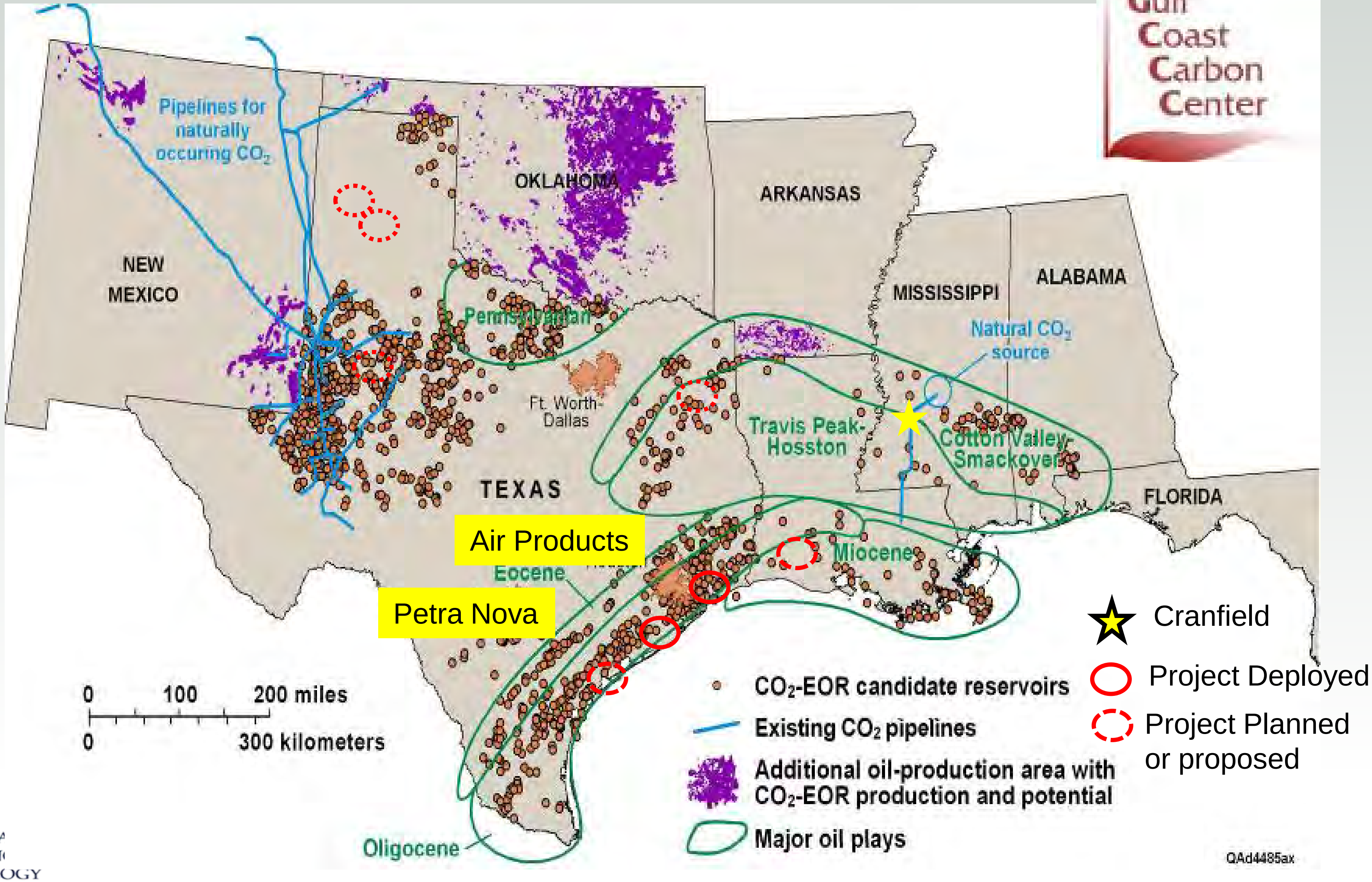
Commercialization of learnings at SECARB Early Test Accomplishments to Date



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