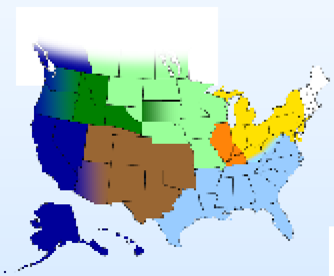
SECARB “Early Test” at Cranfield

DE-FC26-05NT42590

Susan D. Hovorka
Gulf Coast Carbon Center
Bureau of Economic geology
Jackson School of Geoscience
The University of Texas at Austin



Mastering the Subsurface through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, August 1–3, 2017, Pittsburgh, Pennsylvania

Team Structure

SECARB

Southeast Regional Carbon Sequestration Partnership

Bureau of Economic Geology

Gulf Coast Carbon Center

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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

Vendors
e.g. well drilling, landmen

Sandia Technologies
Monitoring Systems Design, Installation, HS&E

50 Vendors
e.g. Schlumberger

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

Recent progress- Knowledge Transfer to Industry

Separately-funded work monitoring large scale commercial projects based on SECARB early test experience

Air Products Port Arthur industrial capture from SMRI at 1 MMT/year transported to Denbury's Hastings Field.

Petra Nova and NRG /Hillcorp/JX capture up to 1.6 MMT/ year and use for EOR at West Ranch field

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								

Synergies

Field data collection

Microseismic --RITE
CO_2 Geothermal-- LBNL
PIDAS – Sun
CCP-BP gravity
Microbes – U KY
NRAP 3-D VSP
Borehole seismic – Groundmetrics
Nobles
U. Edinburgh
Fluid Chem--Ohio State
Well integrity -Schlum/Battelle

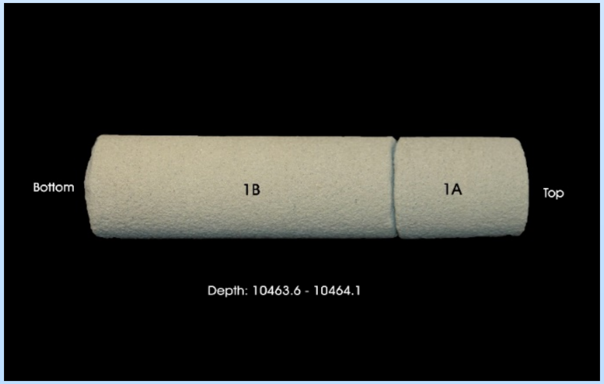
Modeling efforts

SIMSEQ –LBNL 15 teams
CFSES – UT/ SNL
IPARS --Wheeler
NRAP
NCNO
LBNL
CCP3
UT- LBNL Zhang
LLNL (yesterday)

119 history match efforts

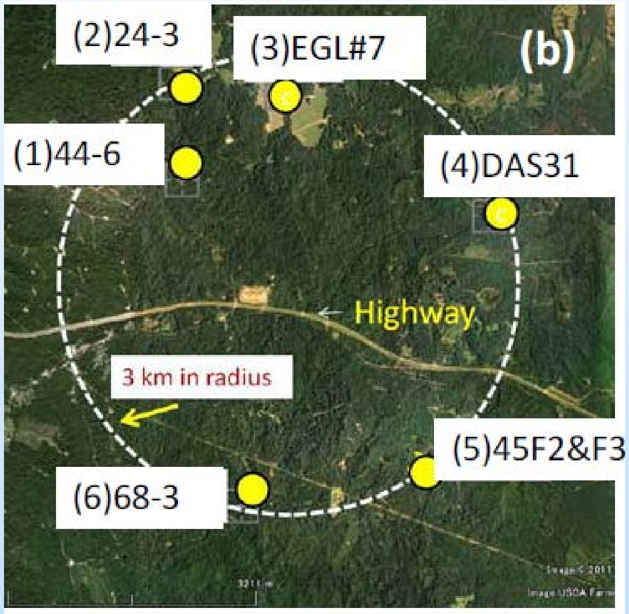
Additional analysis

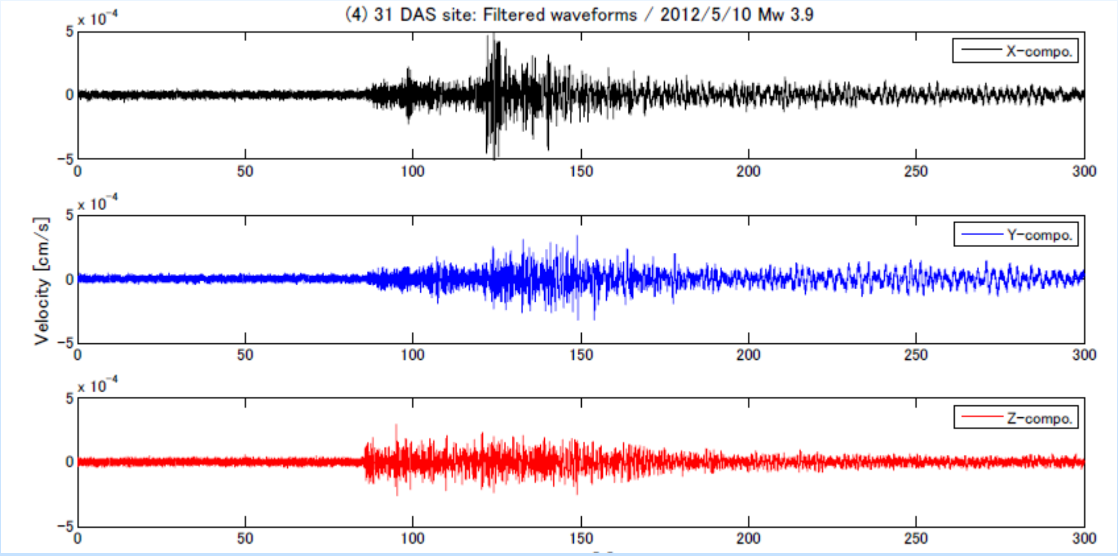
NETL- EOR accounting
Mei/Dilmore
NETL- Rock-water reaction
BES - LLNL



No detectable seismic

Makiko Takagishi, RITE
Magnitude 0.4 horizontal and .07 vertical





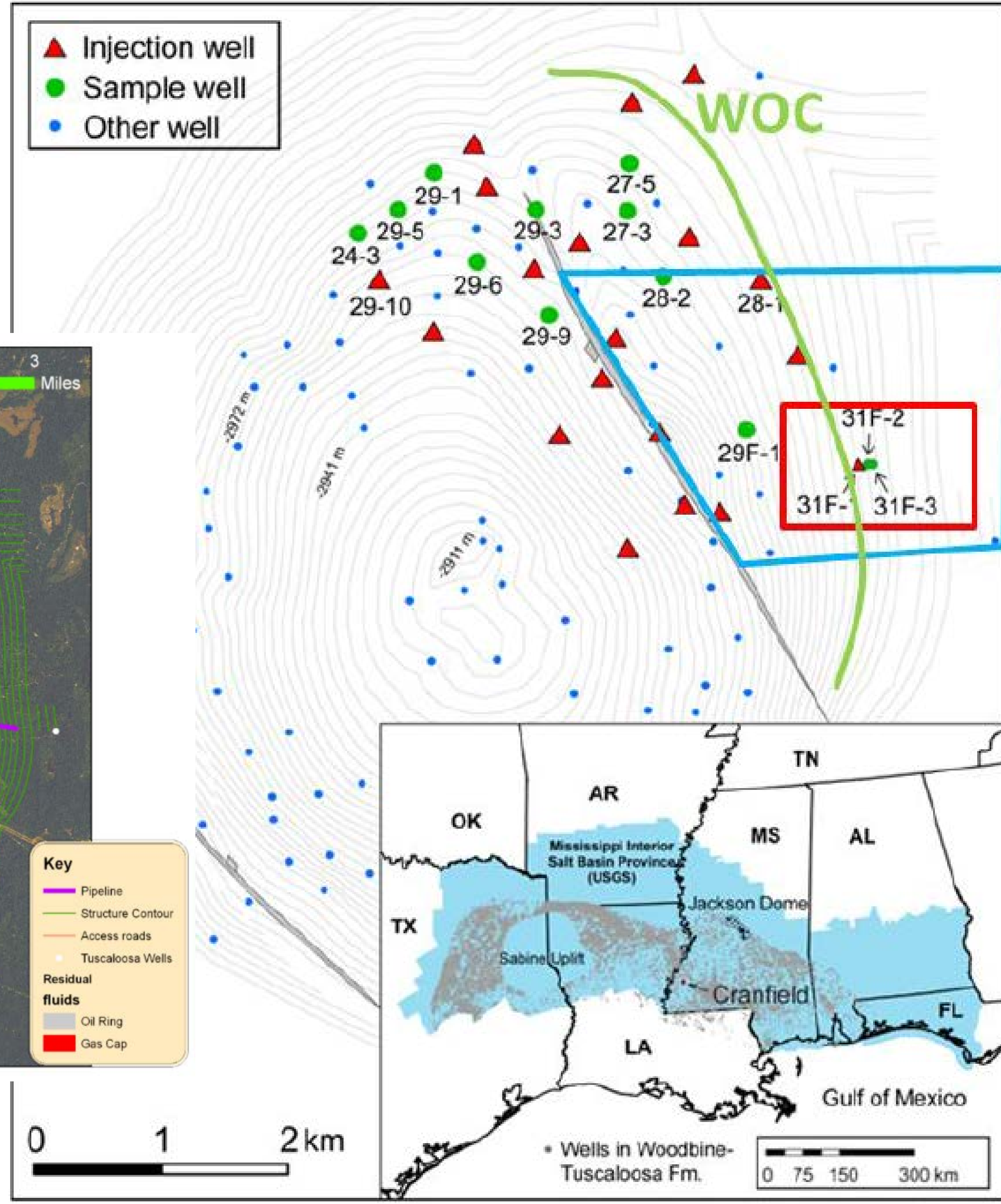
Early Test Motivation

- MIT report "Future of Coal" 2007
  - Set 1 MMT injection goal "proceed .. as soon as possible. Several integrated large-scale demonstrations with appropriate measurement, monitoring and verification are needed. ... establish public confidence for future."
- In 2007 scale and timing of large-scale capture in region still uncertain
  - SECARB anthropogenic test (2011)
  - >1 MMT Commercial Capture in region (2014, 2017)
- Early Test design to progress in the gap
  - Piggy-back on soon-to-start EOR project
  - Permits, source and infrastructure in place
  - Direct injection – relevant to large scale saline CCS

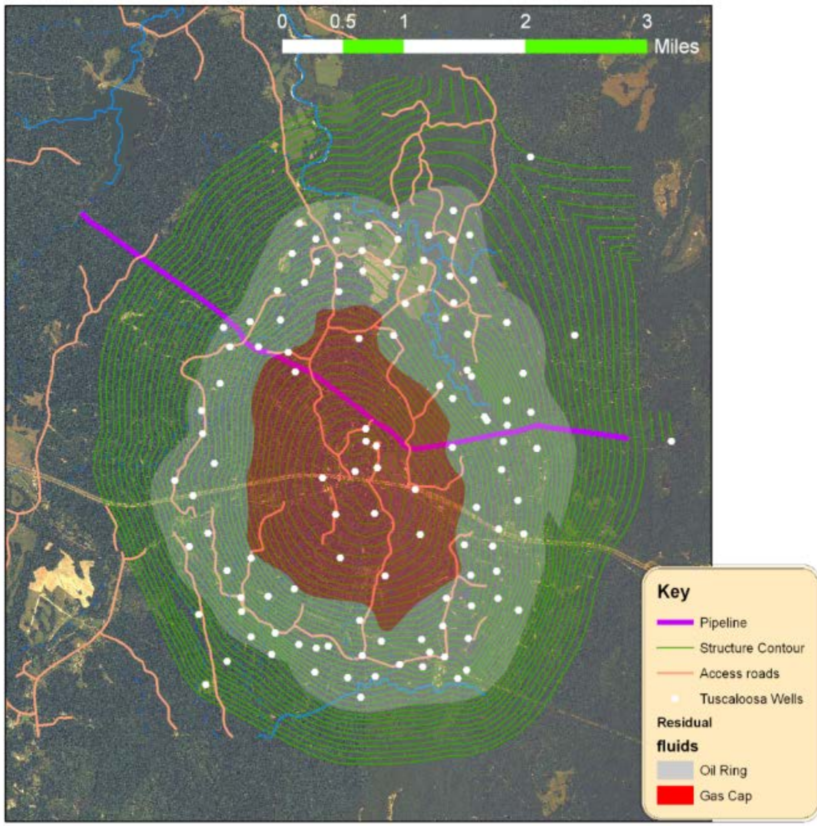
Early Test goals

– Large-scale storage demonstration
  - 1 MMT/year over >1.5 years
    – Periods of high injection rates
    – Result >5 years 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

Location



Injection well
Sample well
Other well
WOC
29-1
29-5
24-3
29-10
29-6
29-3
27-5
27-3
28-2
28-1
29-9
29F-1
31F-2
31F-1
31F-3
-2972 m
-2941 m
-2911 m
0
1
2 km
TN
AR
OK
MS
AL
TX
LA
FL
Mississippi Interior Salt Basin Province (USGS)
Jackson Dome
Sabine Uplift
Cranfield
Gulf of Mexico
Wells in Woodbine-Tuscaloosa Fm.
0 75 150 300 km



0 0.5 1 2 3 Miles
Key
Pipeline
Structure Contour
Access roads
Tuscaloosa Wells
Residual fluids
Oil Ring
Gas Cap

Major Contributions

- Early Test Developed monitoring approaches for later commercial projects
  - Process-based soil gas method
  - Effectiveness of groundwater surveillance
  - Pressure and fluid chemistry monitoring in Above-Zone Monitoring Interval (AZMI)
  - ERT for deep CO_2 plume
  - Limitations of 4-D seismic
- Published and propagated techniques for widespread application

Knowledge Transfer to Industry

93 publications

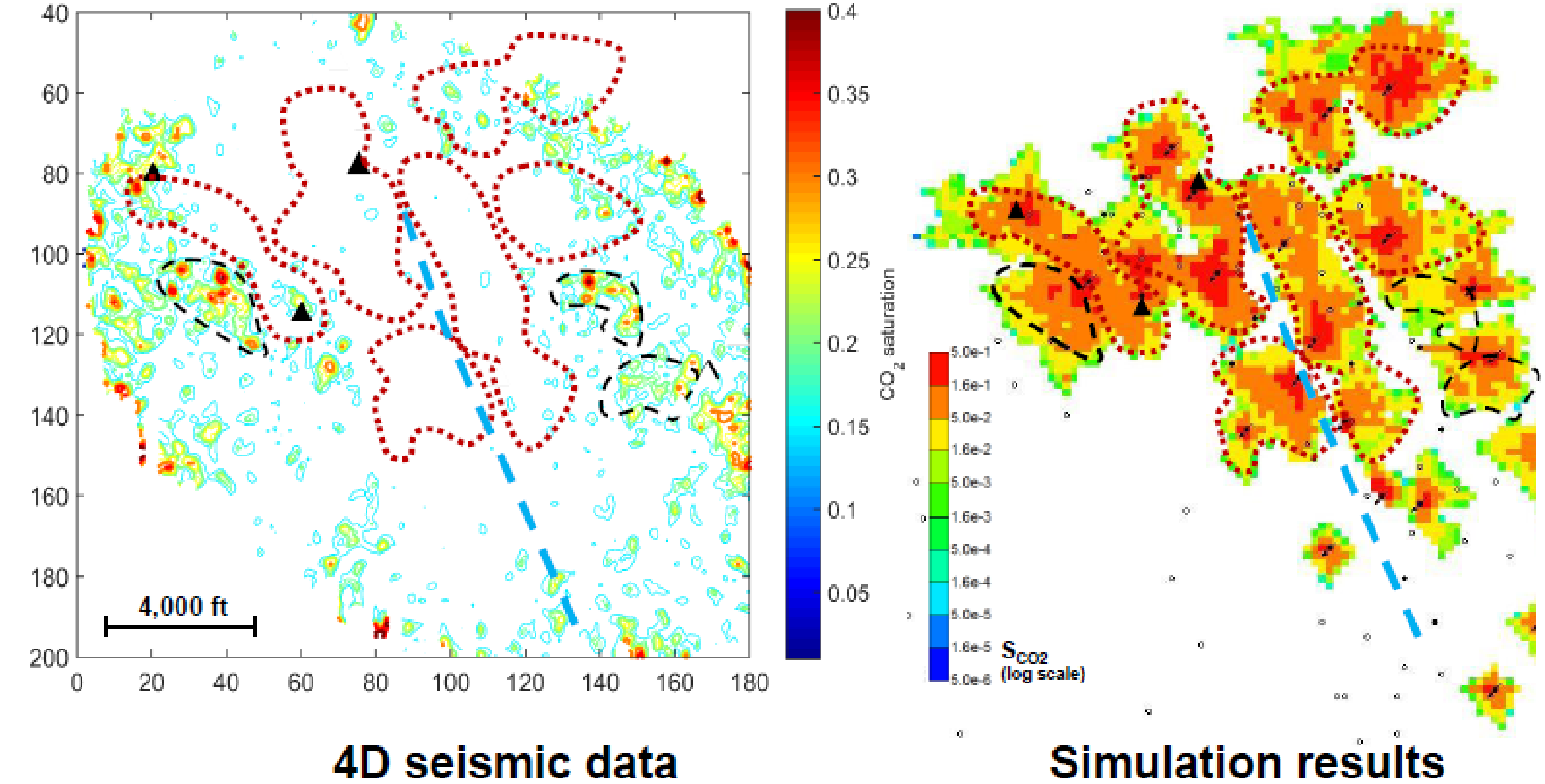
Site visits

Talks, workshops

exchanges

PBS News hour – Miles O’Brien

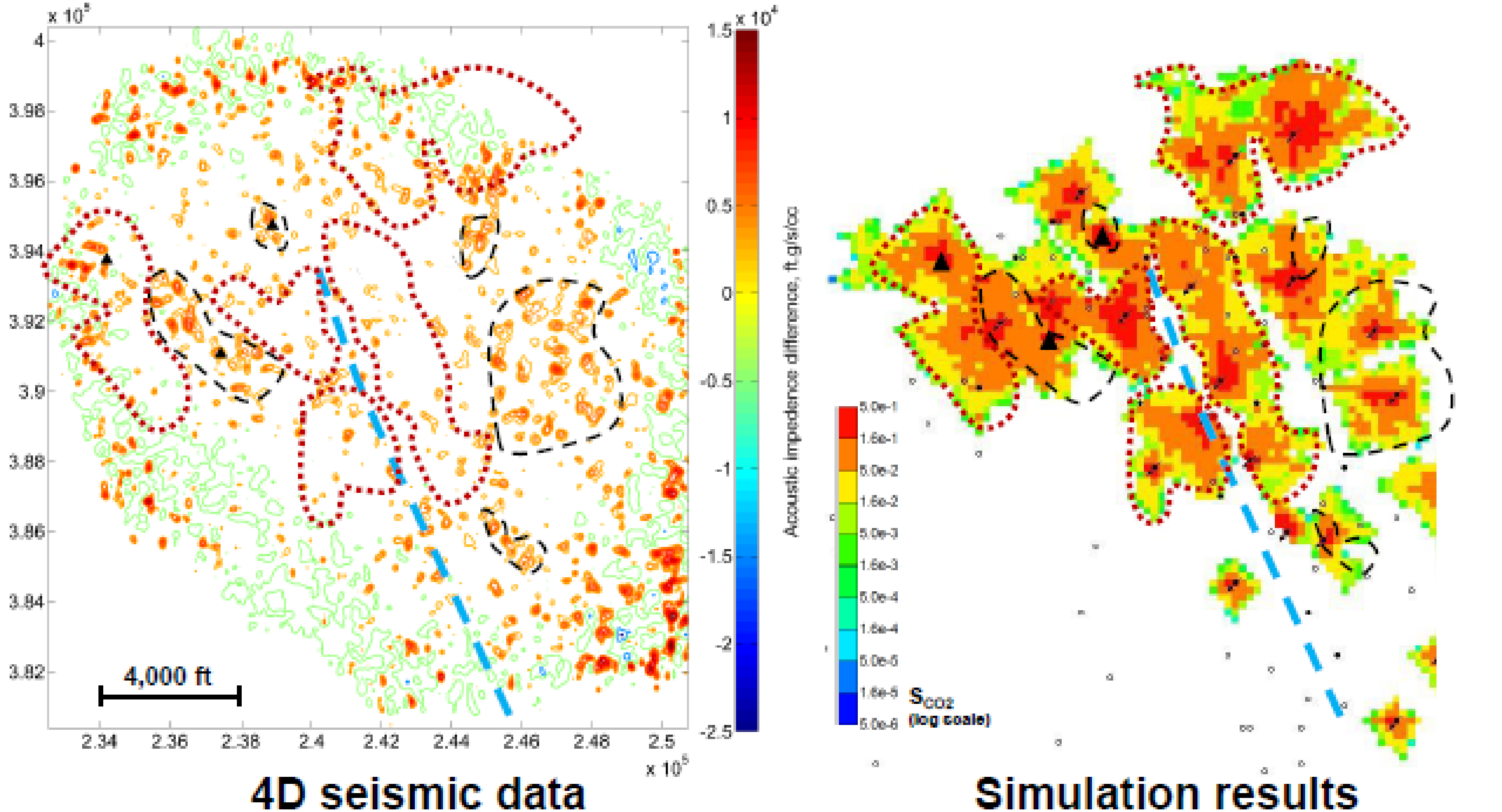
Limitations to 4-D seismic



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

Alfi & Hossieni, BEG

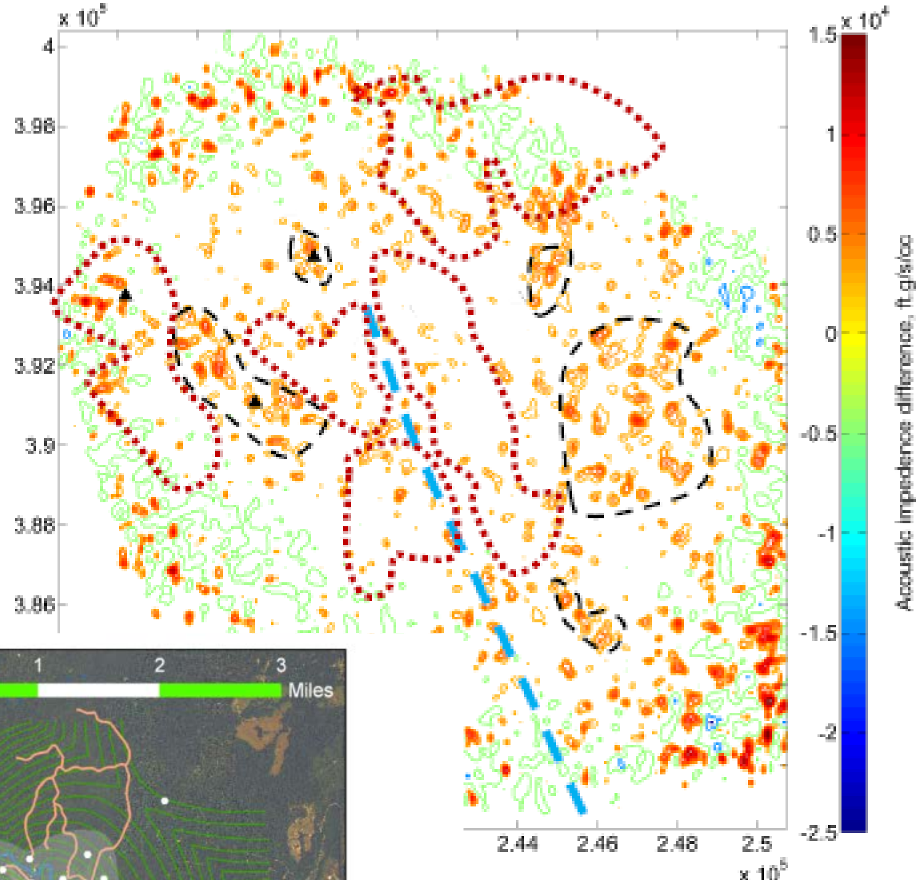
Limitations to 4-D seismic

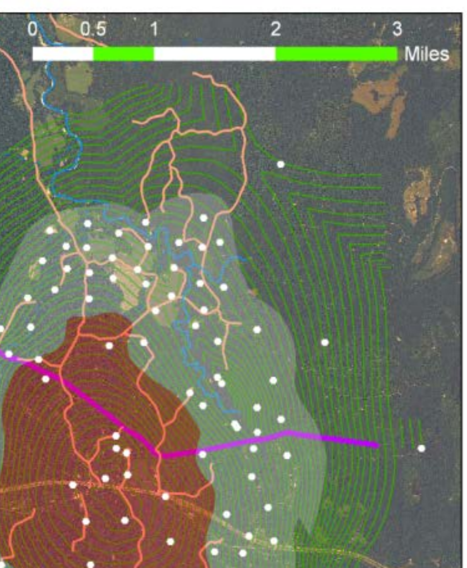


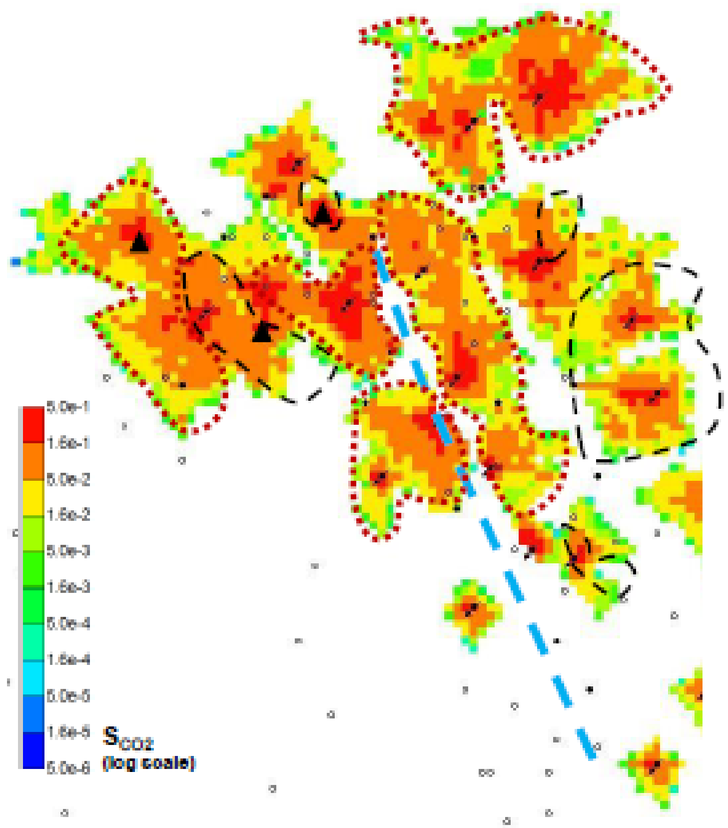
(a) Acoustic impedance difference (Zhang et al. [17]) compared to fluid flow simulation

Alfi & Hossieni, BEG

Limitations to 4-D seismic







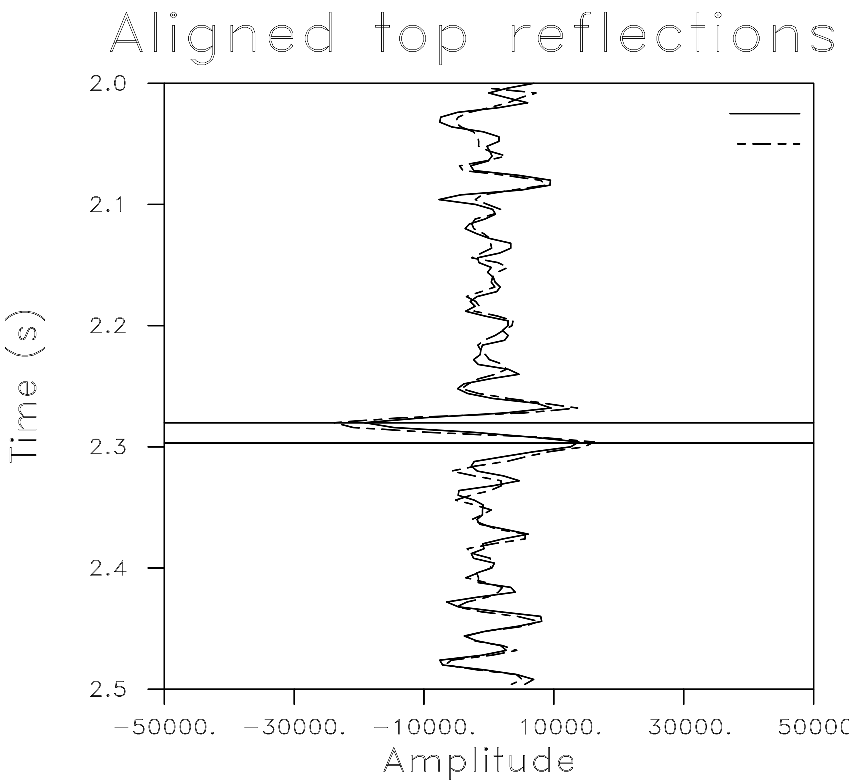
mic data

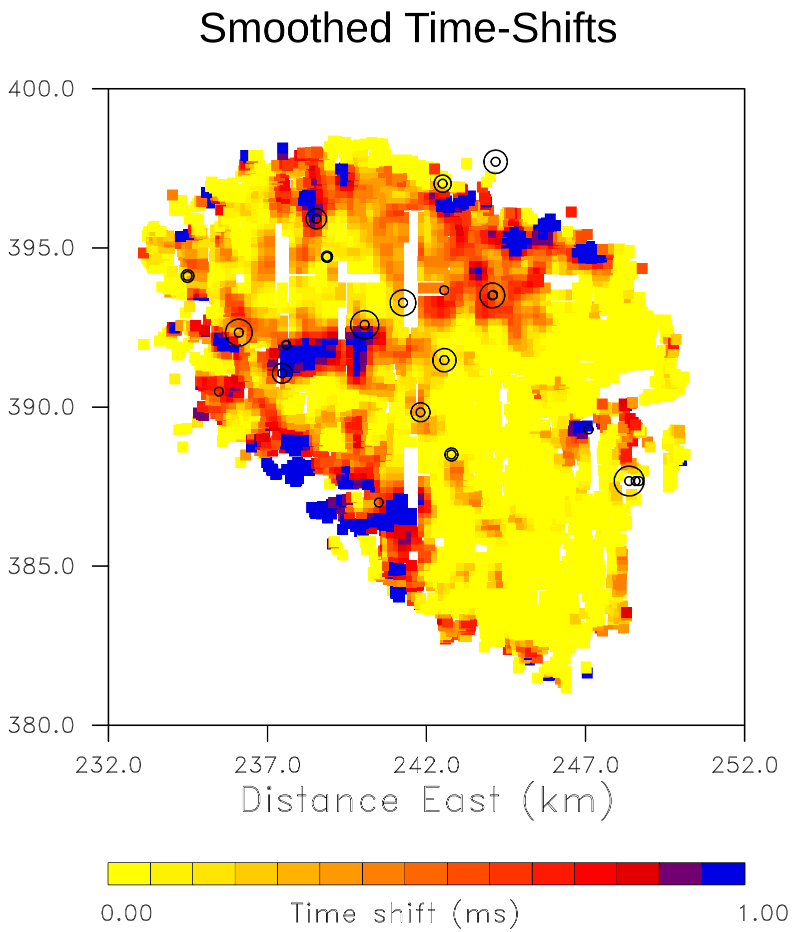
Simulation results

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

Alfi & Hossieni, BEG

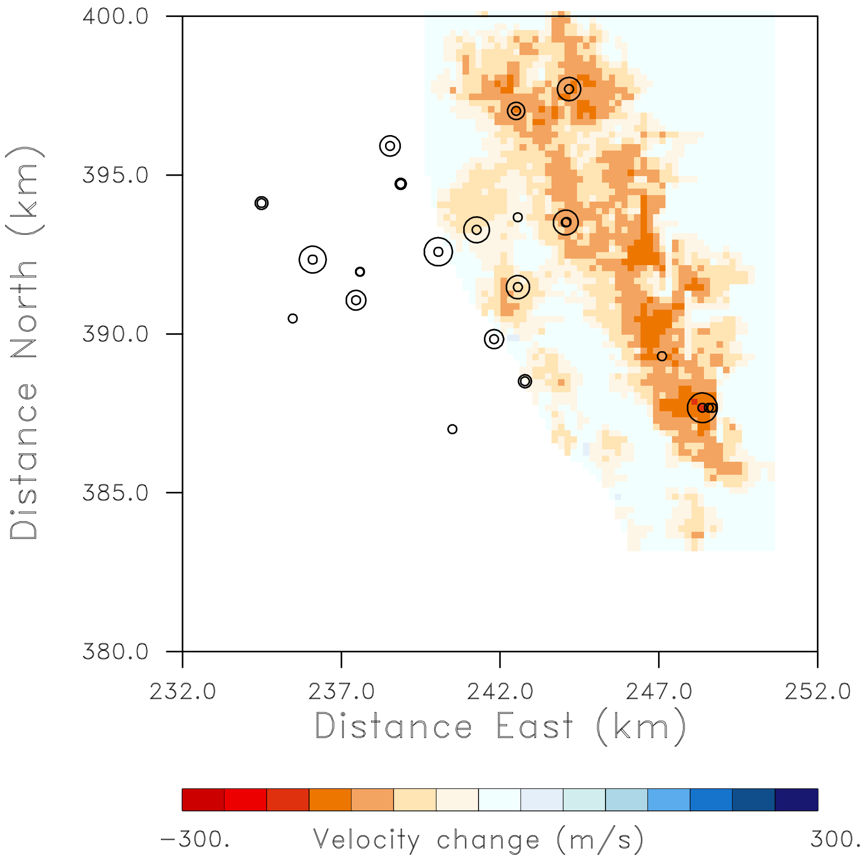
Calculate time shifts resulting from CO_2 emplacement for reflections just below the reservoir.

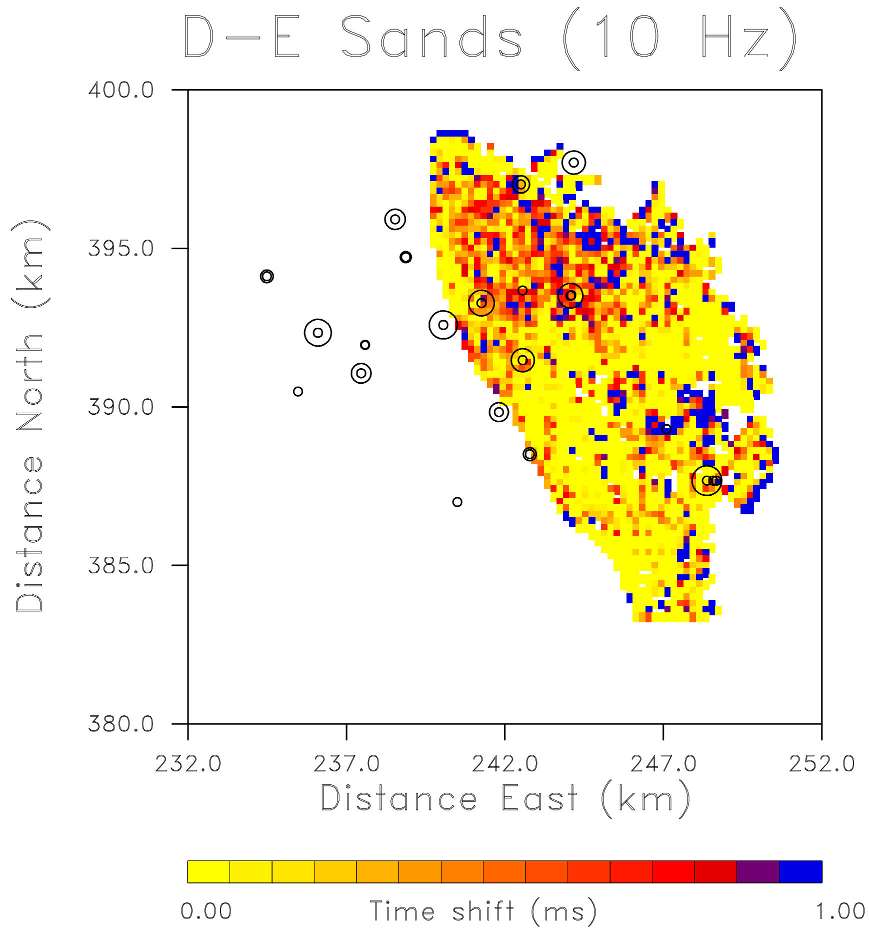




D. W. Vasco, Tom Daley, Jonathan Ajo-Franklin, LBL

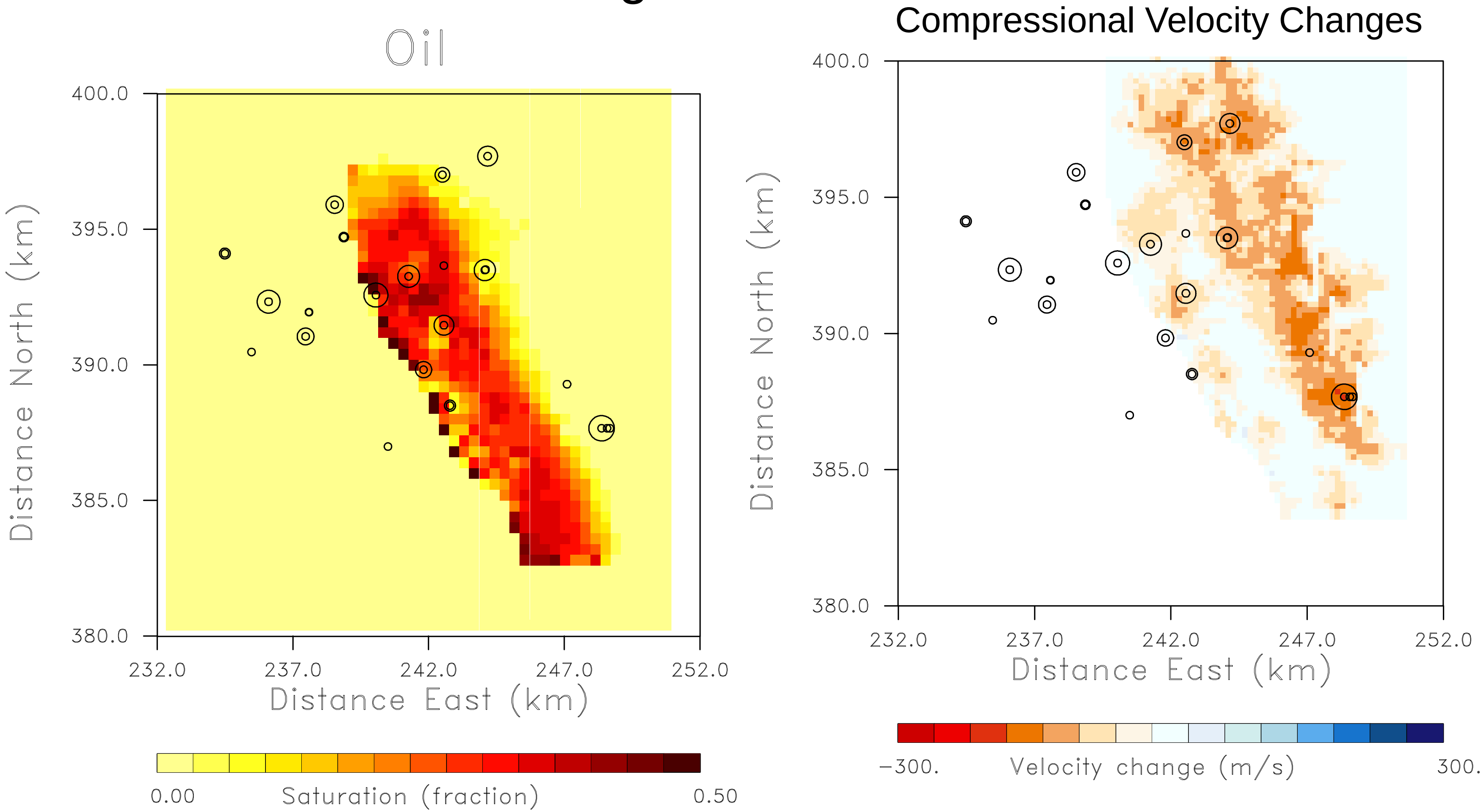
▪Largest seismic time shifts in area with greatest velocity changes





D. W. Vasco, Tom Daley, Jonathan Ajo-Franklin, LBL

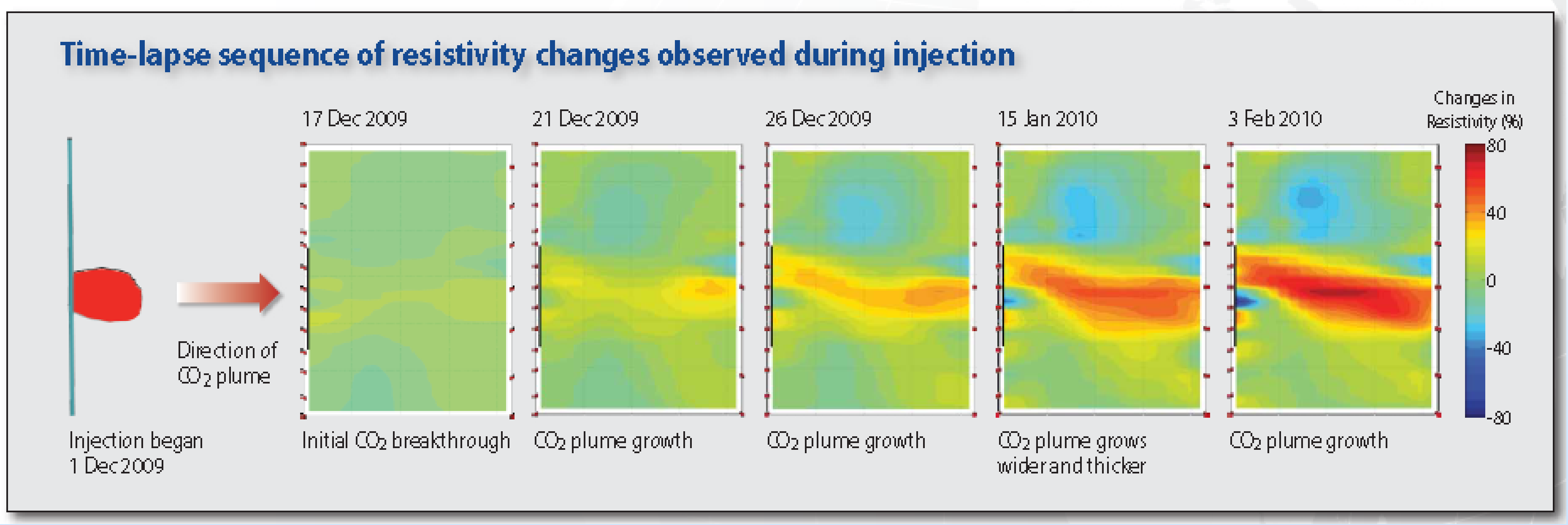
▪Biggest velocity changes due to the injection of carbon dioxide are in the water leg



D. W. Vasco, Tom Daley, Jonathan Ajo-Franklin, LBL

LLNL Electrical Resistance Tomography- changes in response with saturation

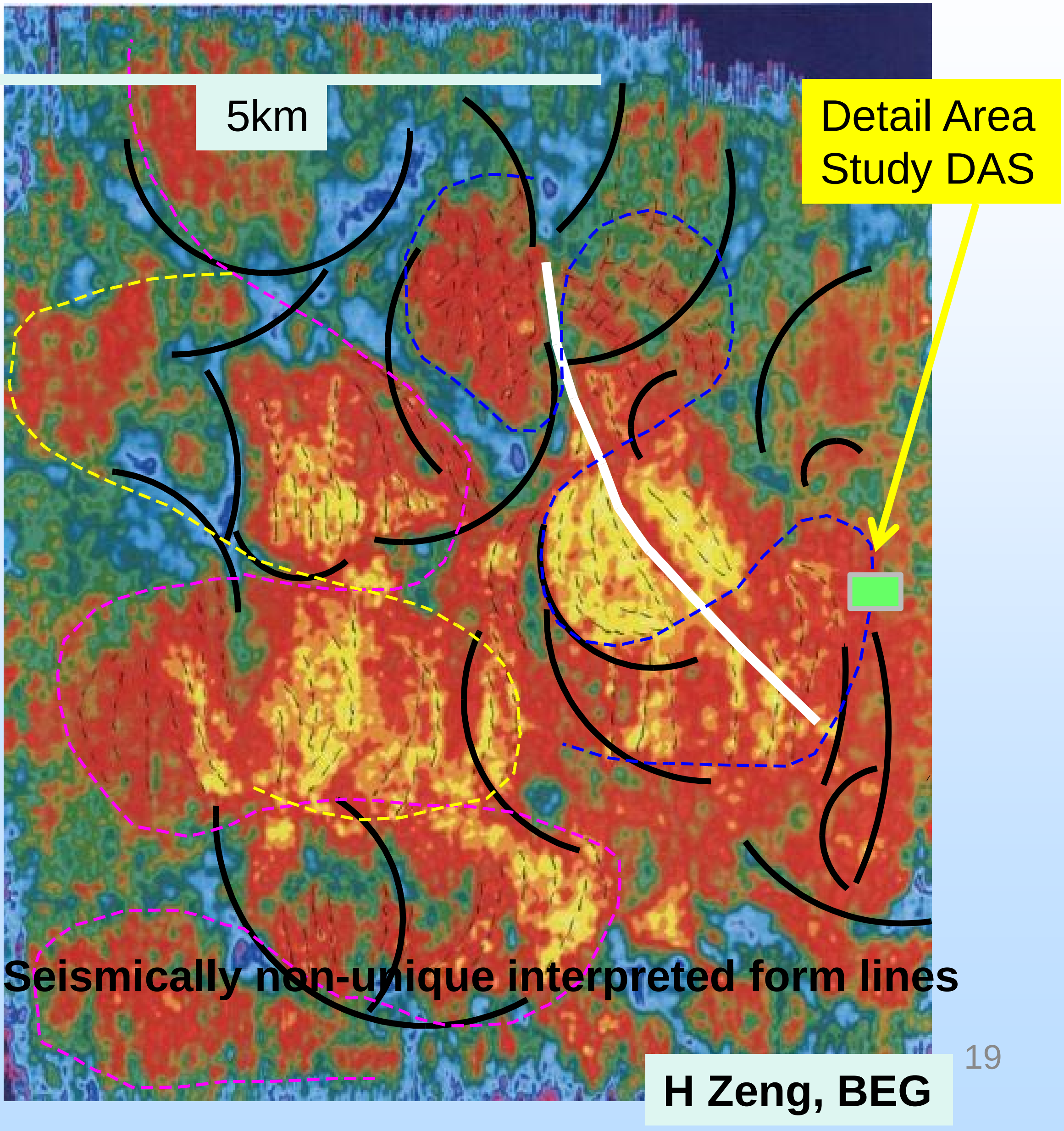
F1 F2 F3



Lawrence Livermore National Laboratory

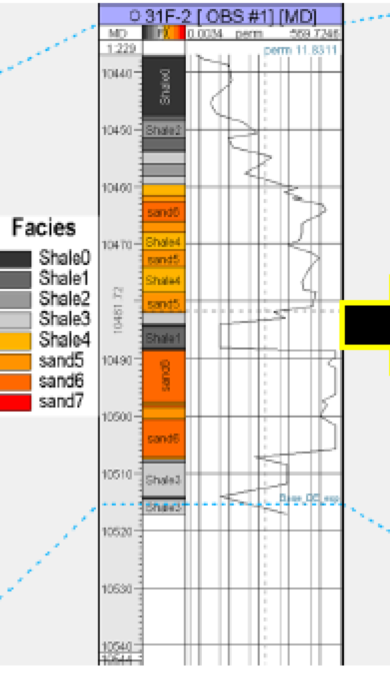
C. Carrigan, X Yang, LLNL
D. LaBrecque Multi-Phase Technologies

Site Characterization Approach

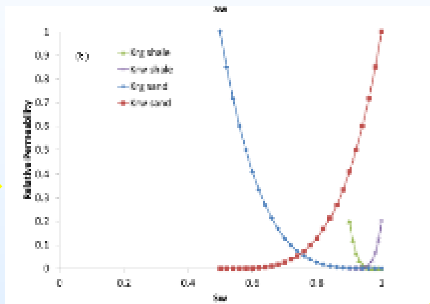


Modeling Approach's

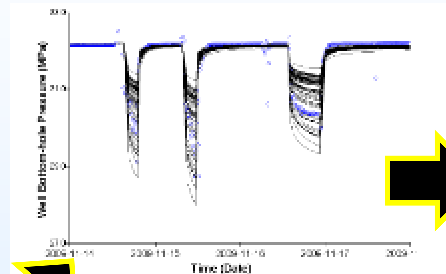
Reservoir characterization



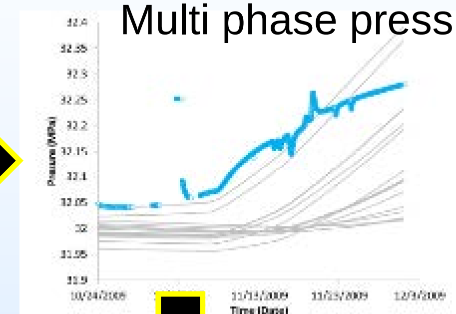
Relative permeablities



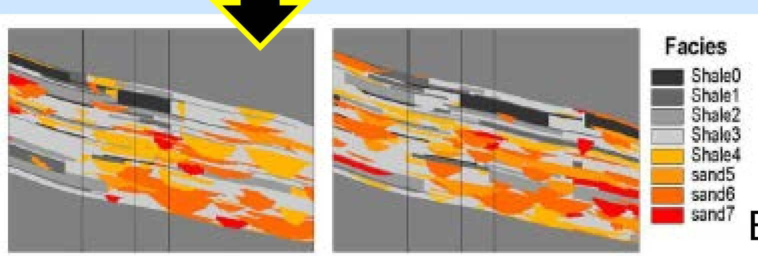
Single phase pressure

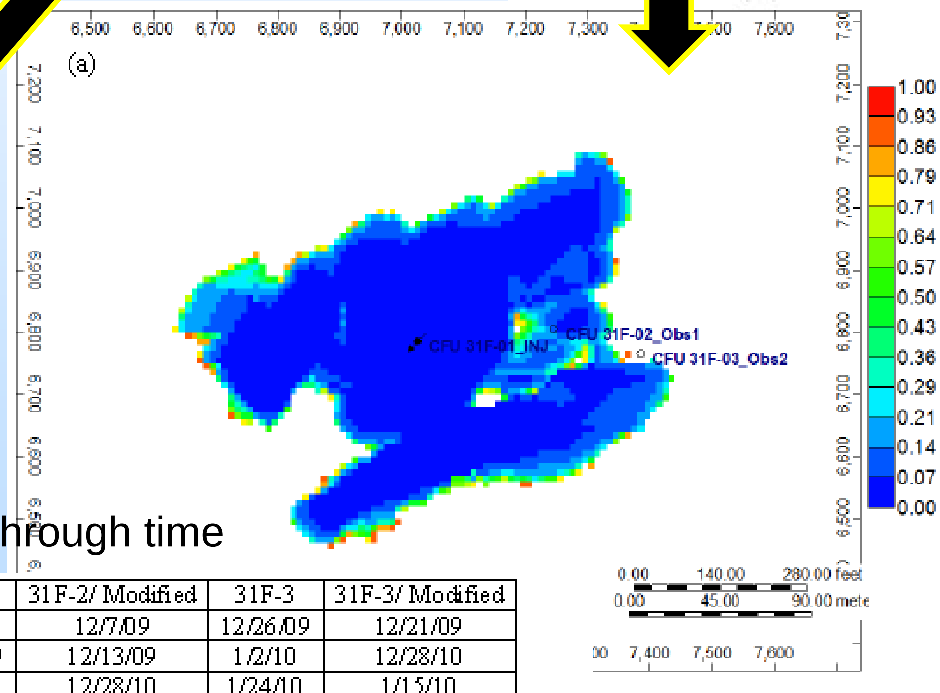


Multi phase pressure



Probabilistic realizations of reservoir architecture





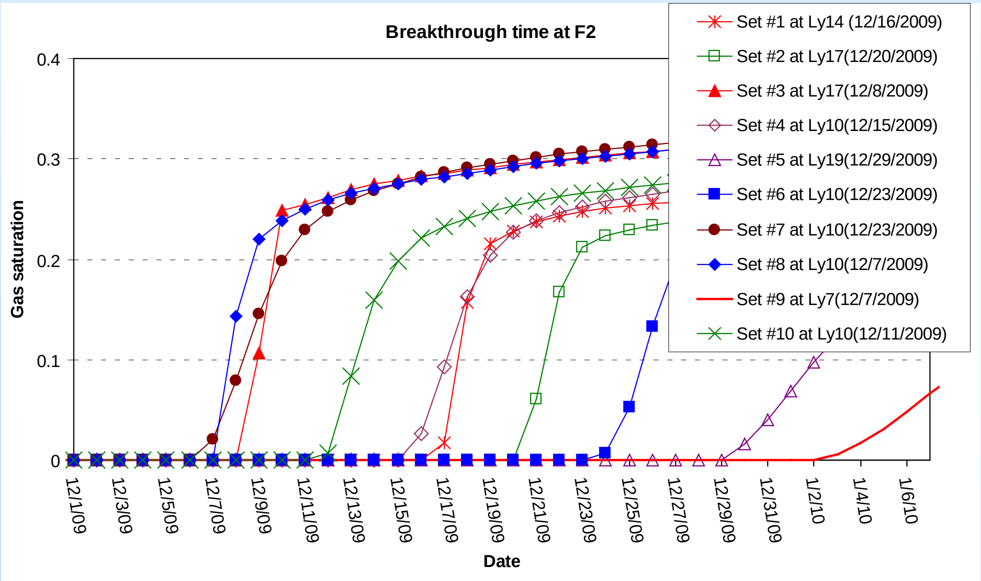
Breakthrough time

Realization Number	31F-2	31F-2/ Modified	31F-3	31F-3/ Modified
35	12/8/09	12/7/09	12/26/09	12/21/09
18	12/15/09	12/13/09	1/2/10	12/28/10
8	1/3/10	12/28/10	1/24/10	1/15/10
15	12/20/09	12/16/09	1/11/10	1/2/10
ACTUAL		12/12/09		12/16/09

Hosseini and others, 2013
Cranfield

Modeling

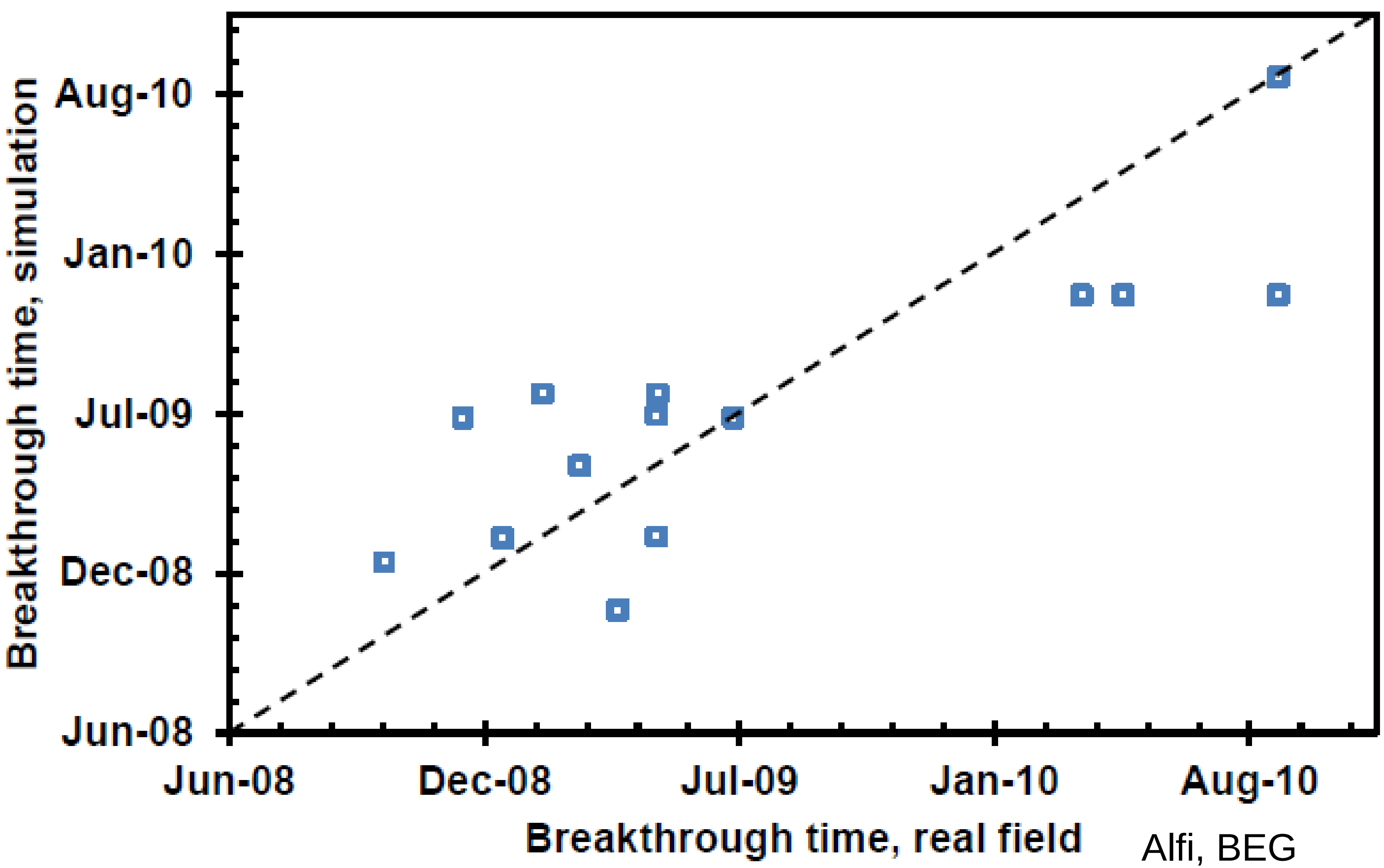
- Multiple models (119)
  - I-PARS
  - SIM-SEQ model approach comparison
- CGM GEM
  - Probabilistic approaches
  - Match 100 realizations to subset of modeled data
  - Forward model scenarios



Pre-injection forward model breakthrough times to design geochemical sampling

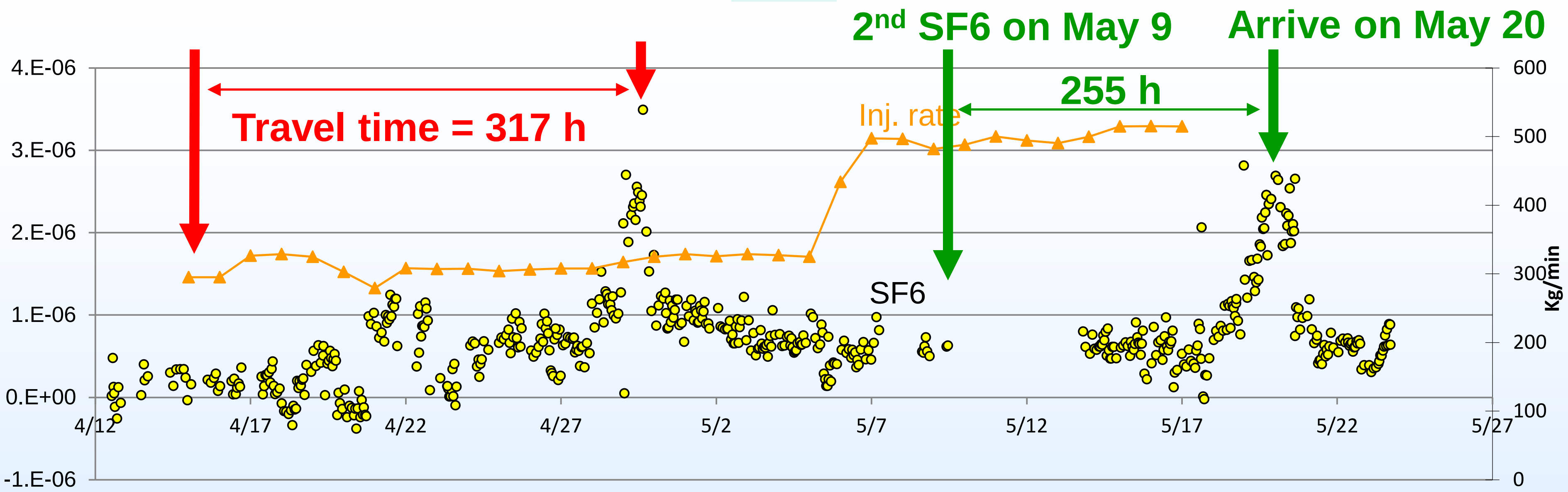
Jong Won Choi BEG

History Match Modeled and measured CO_2 breakthrough

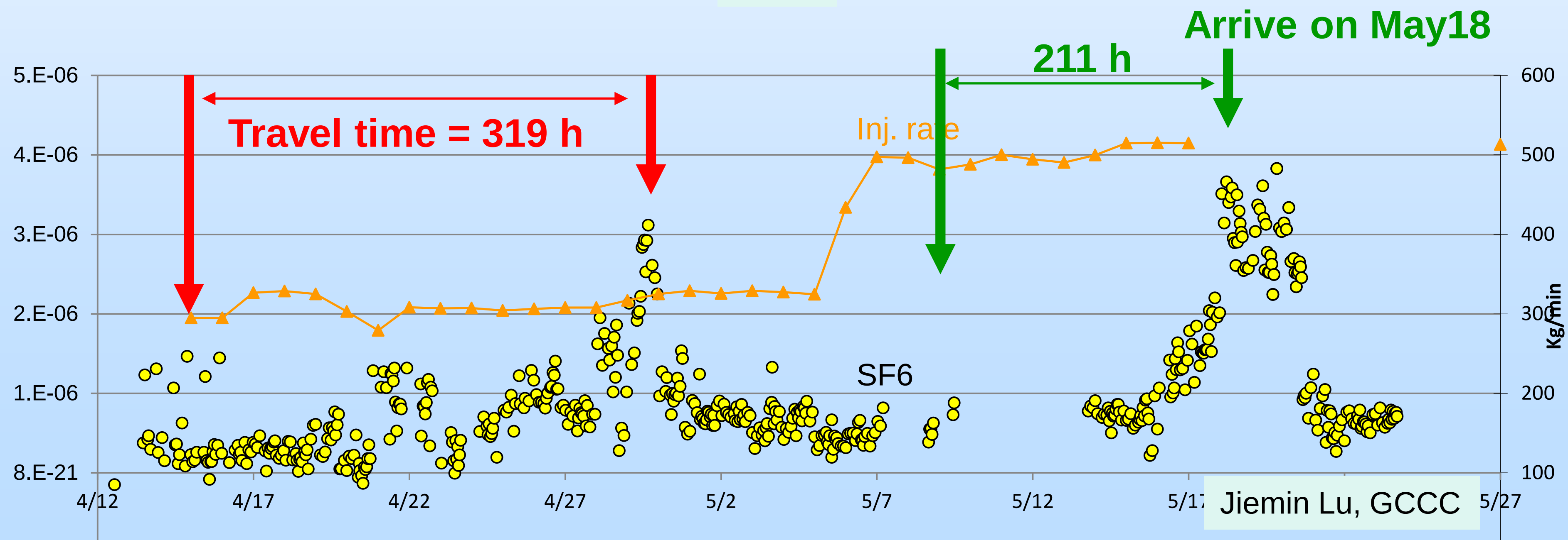


Alfi, BEG

CFU31F-2, 68 m away from injector SF6



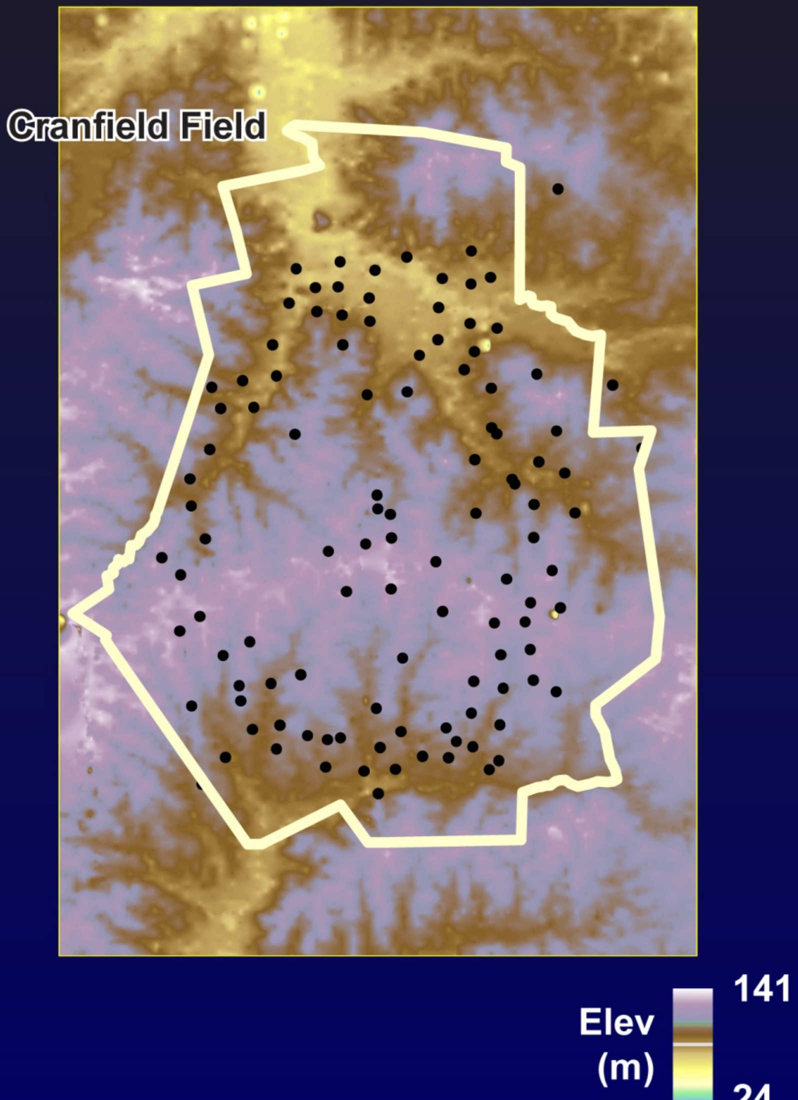
CFU31F-3, 112 m away from injector SF6



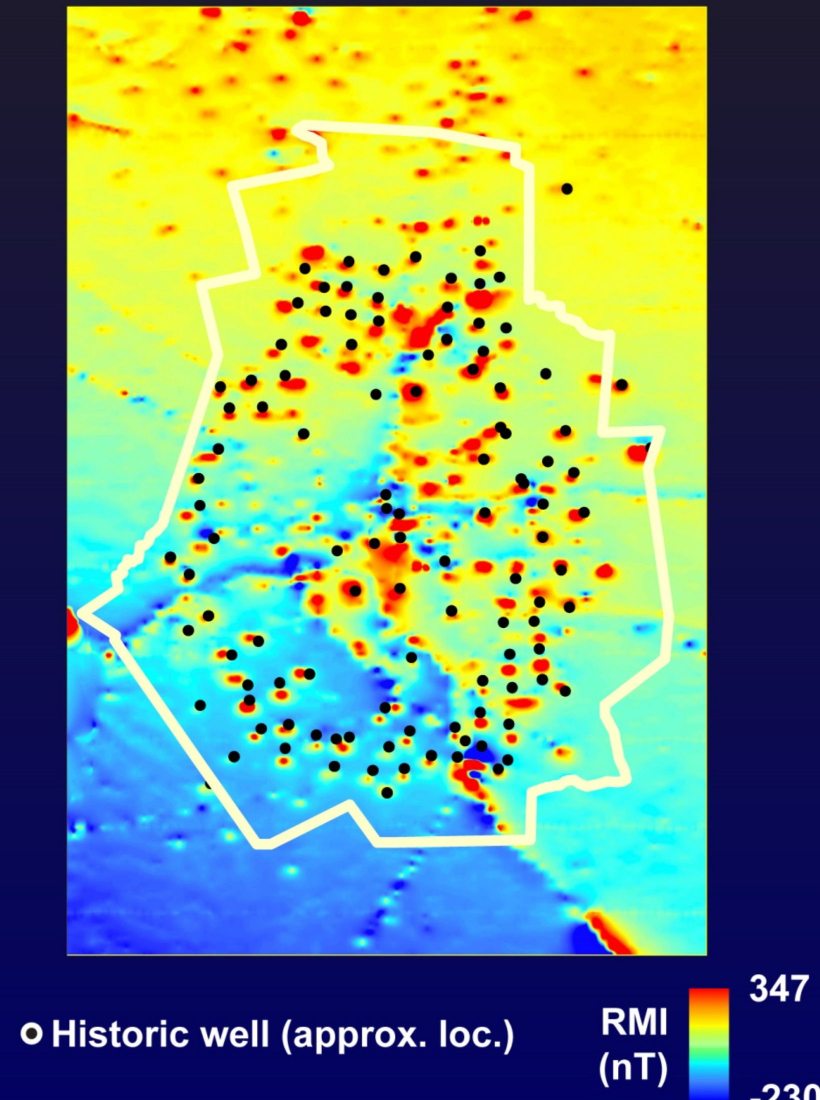
Jiemin Lu, GCCC

Cranfield Airborne Geophysical Survey

Topography

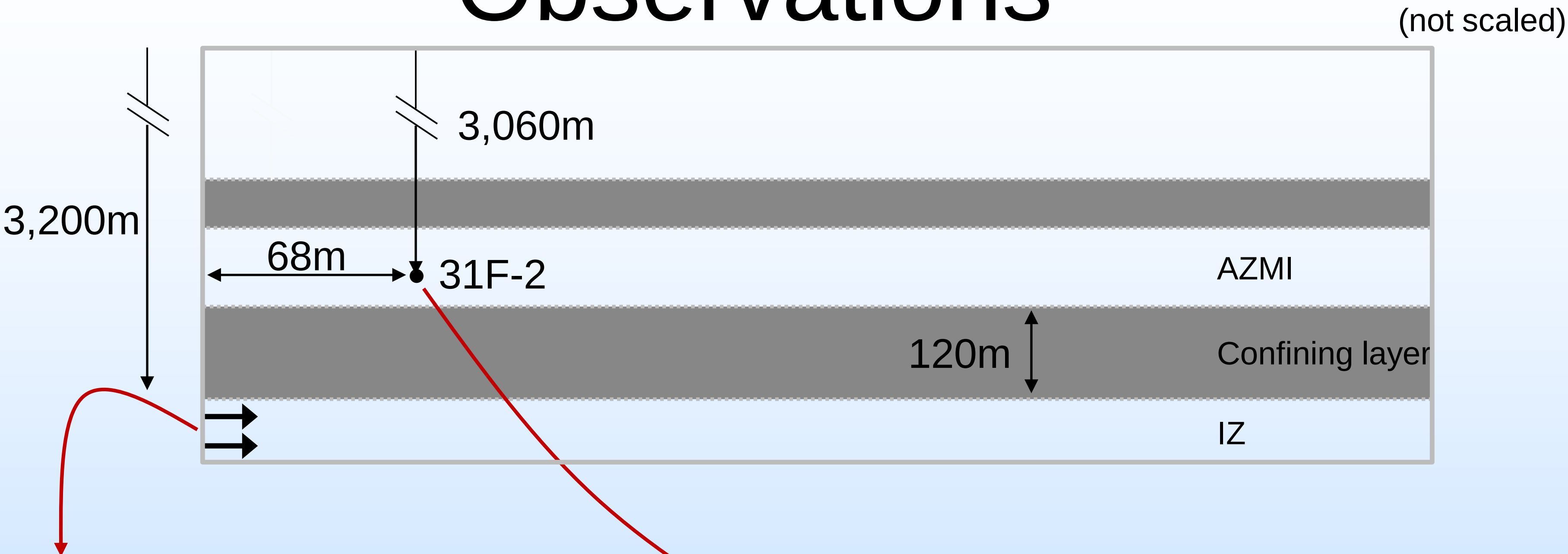


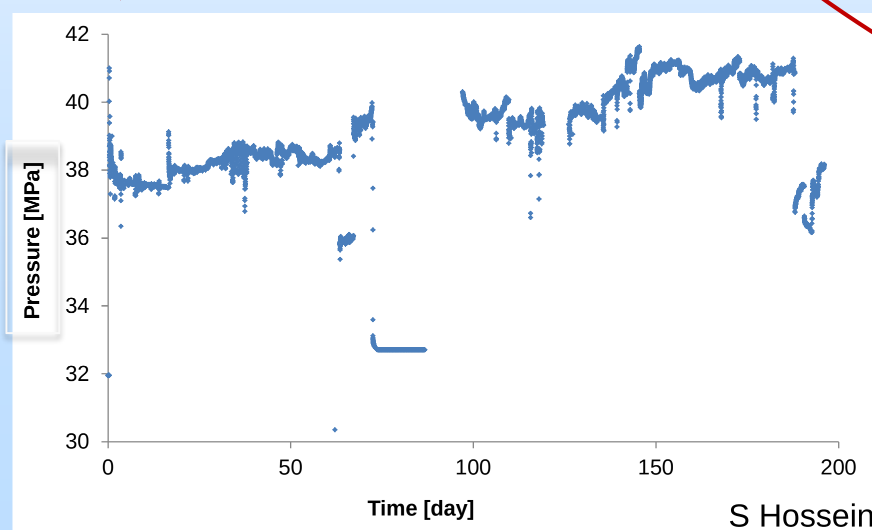
Residual Magnetic Intensity

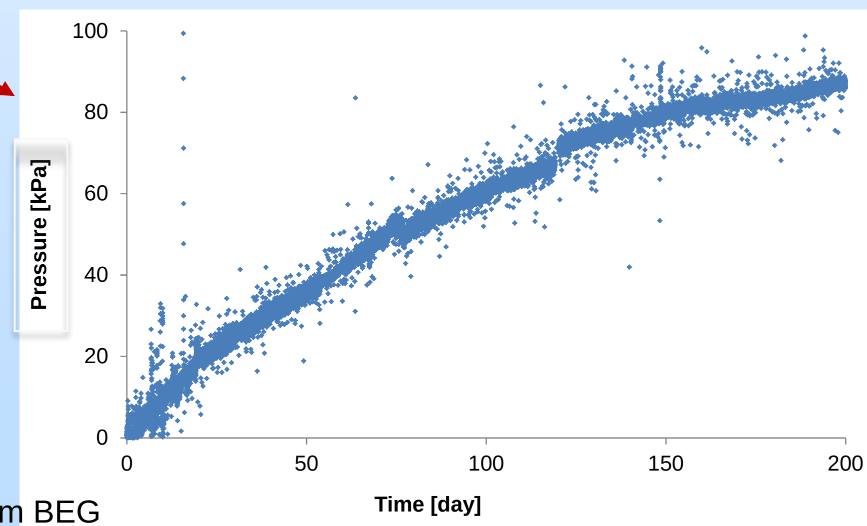


Jeff Paine BEG

Above-Zone Pressure Observations







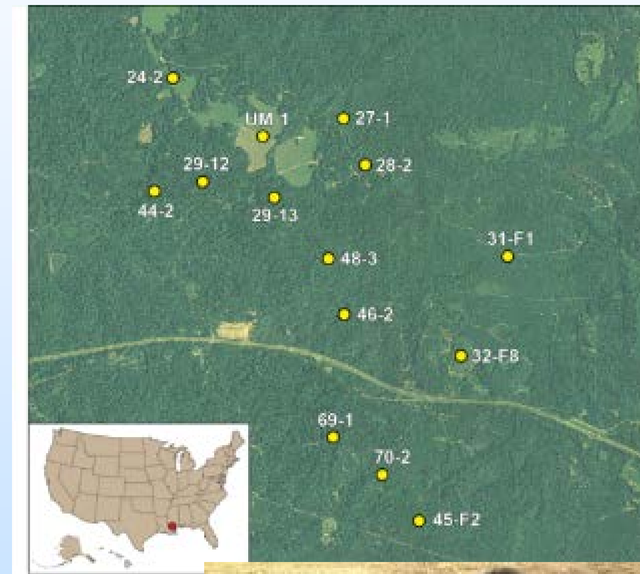
S Hosseini, S. Kim BEG

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

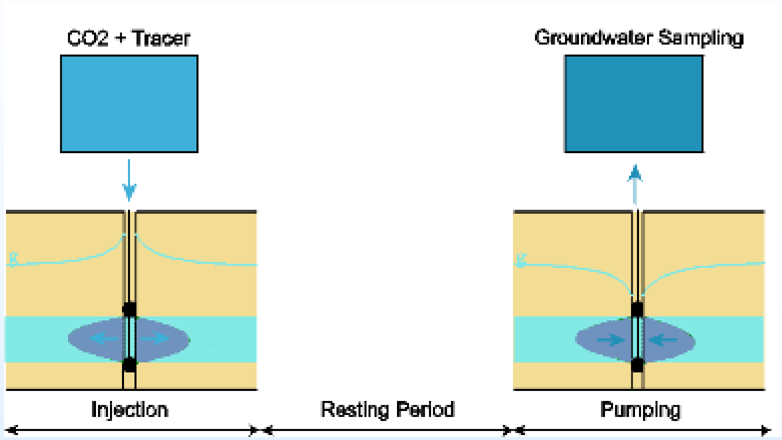


- ~10 samples for noble gases
- ~20 groundwater samples for dissolved CH_4
- 15 Water wells

C. Yang, BEG

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

- 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;



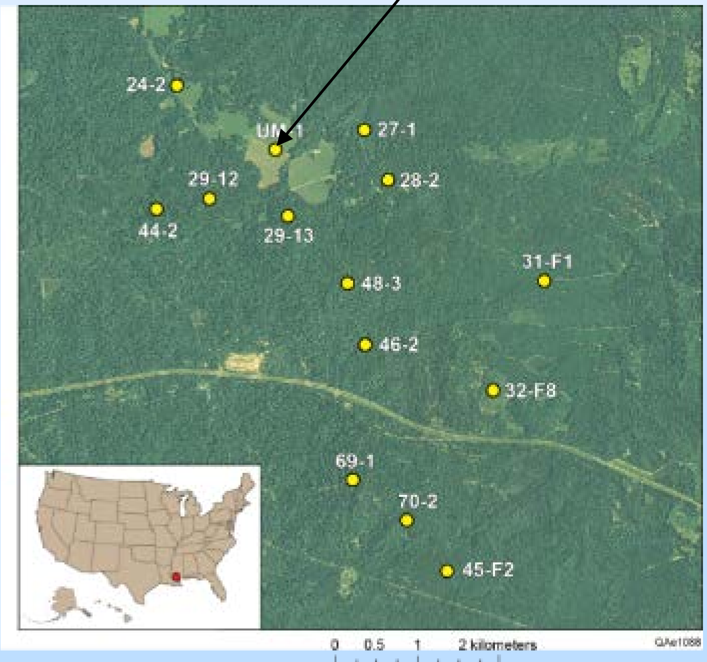
Results were summarized in the following paper

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
ELSEVIER

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

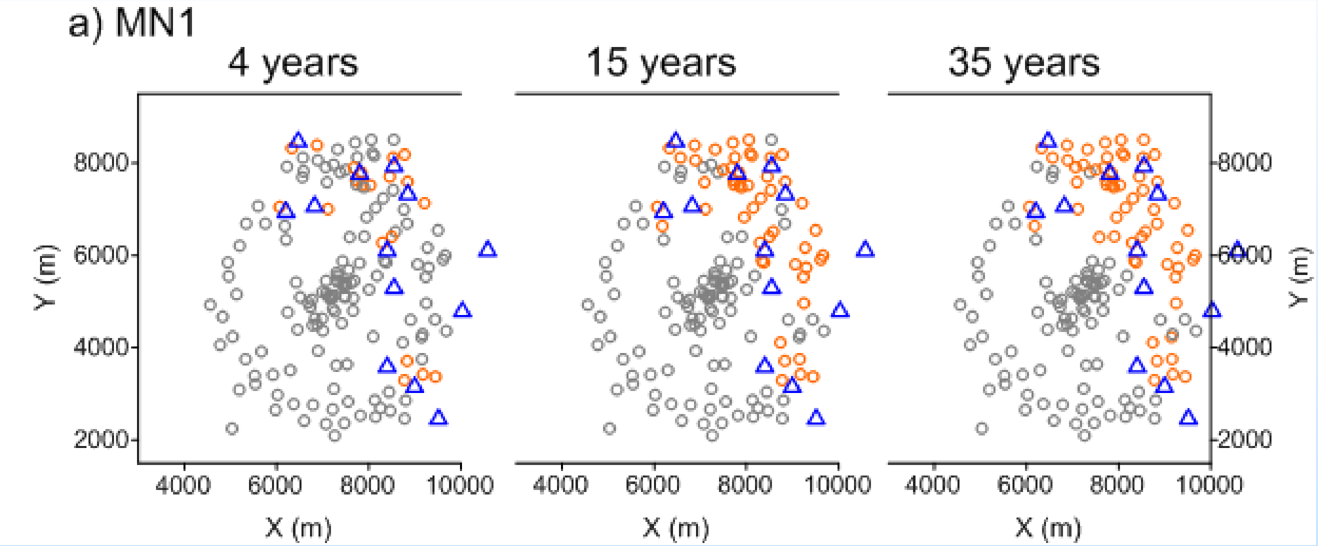


C. Yang, BEG

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

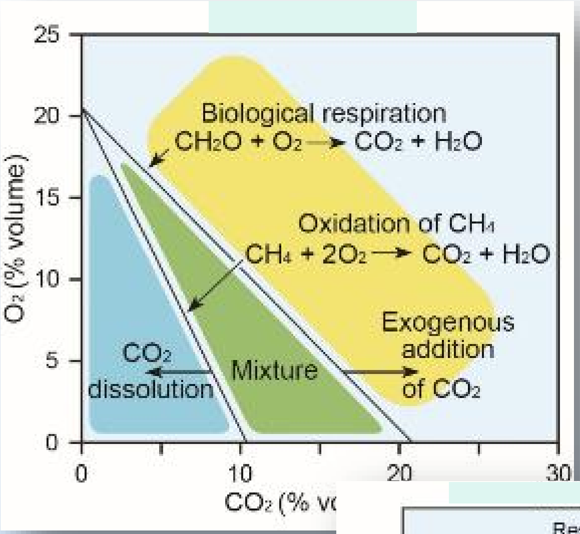


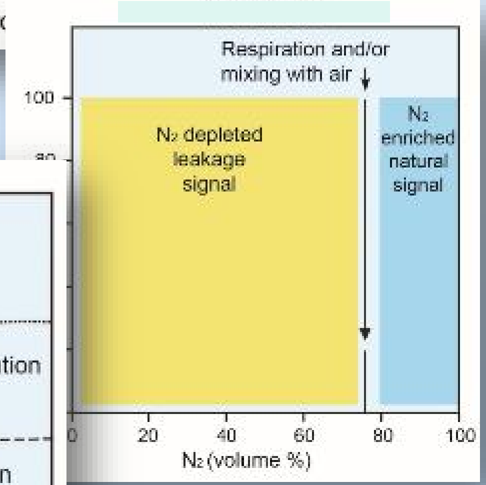
CO_2 leakage from a P&A well is detected by a monitoring net work if change in DIC, dissolved CO_2, or pH in any one of wells of the monitoring network is higher than one standard deviation of the groundwater chemistry data collected in the shallow aquifer over the last 6 years.

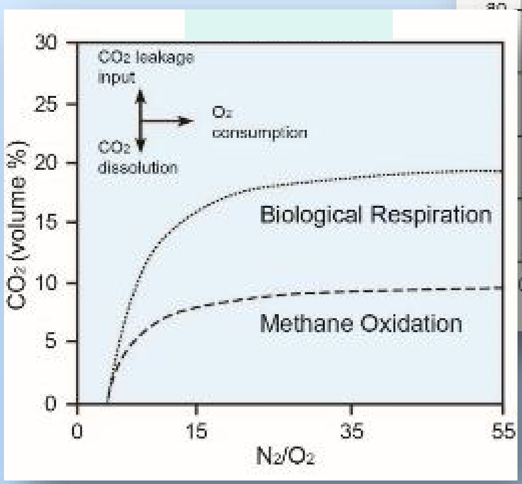
Changbing Yang

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







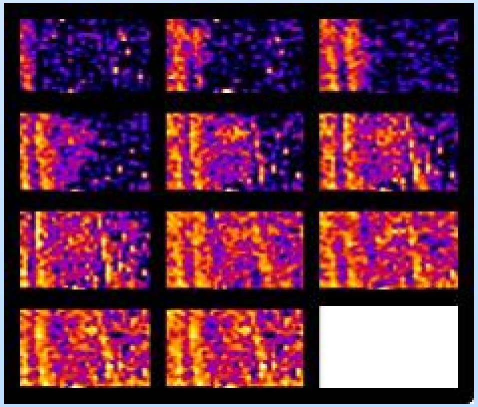
Katherine Romanak BEG

Major Technical Accomplishments

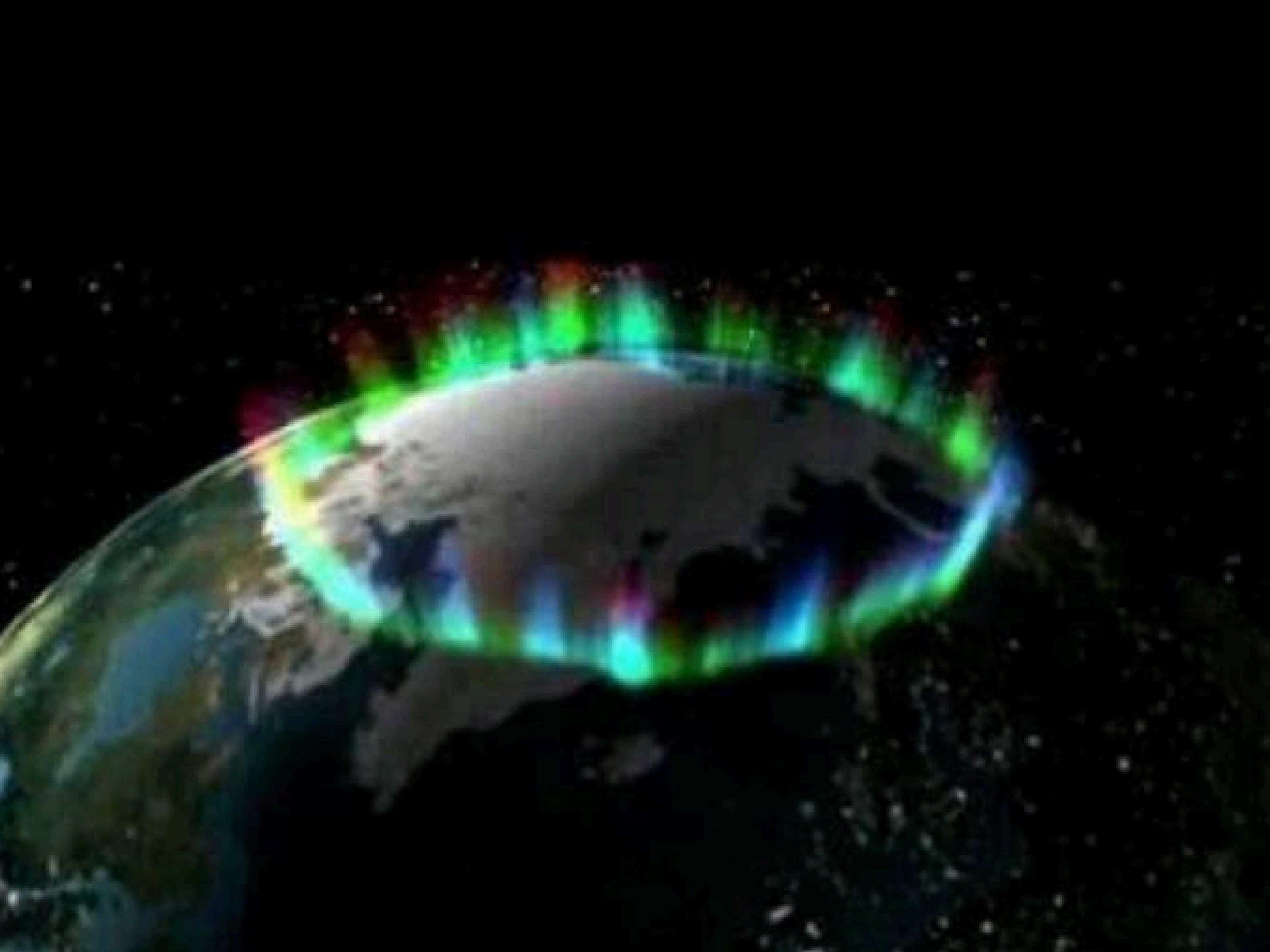
- Multiphysics CO_2 plume detection
  - Surface 4-D; Azimuthal VSP, cross well, ERT, Pulsed neutron, fiber-optic thermal, sonic logs, PNC logs
  - Limits evaluated (depth, gas)
- In-zone and Above-zone pressure method validation
  - Casing deployed BHP with real-time readout
- Minimal geochemical change in-zone, geomechanical softening
- Non-detect of microseismicity by RITE at >1000 psi pressure increase
- Reservoir response to heterogeneity – non-linear breakthrough
- Groundwater sensitivity assessment
  - Value of DIC, sensitivity to carbonate in rock matrix
  - Value for incident or allegation
- Process-based soil gas
  - Reduced sensitivity to environmental fluctuation, not dependent on baseline. Value of attribution

Rate of Progress

- All elements have been completed on plan
  - (three years injection + three “post closure”)
- Under budget
  - Major saving was not needing to purchase CO_2 to meet the project goal; commercial injection was high during early project stages
- Emphasis on publication and technical outreach
  - 93 technical papers published 2009-2017
- Leveraged by data-sharing



Coreflood micro CT J Ajo-Franklin LBNL



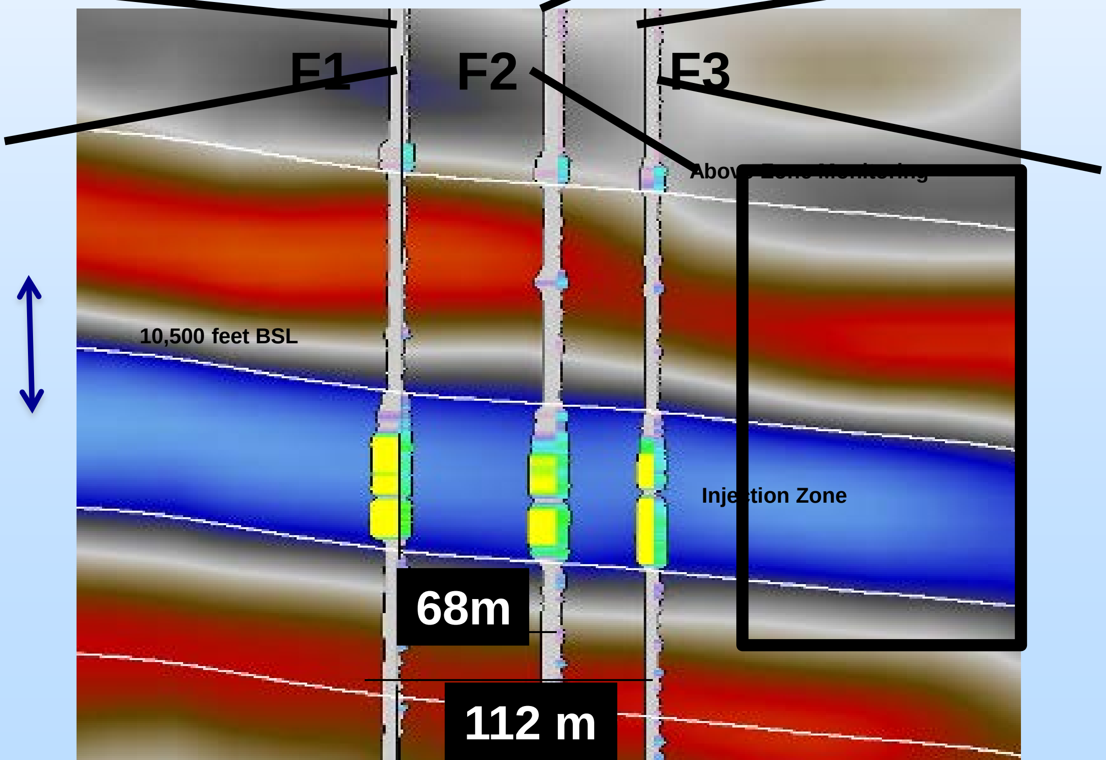
Lessons Learned (where is improvement needed?)

- Simplified AZMI completions
- Improved high temperature and pressure equipment
- Simplified ERT deep installation
- Remote tools for water and soil gas surveillance
- Maturation of monitoring design planning
  - Interaction with international community

Detailed Area Study (DAS)

Closely spaced well array to examine flow in complex reservoir

Tuscaloosa D-E reservoir



Petrel model Tip Meckel
Time-lapse cross well
Schlumberger

Project Status