Pressure-Based Inversion and Data Assimilation System (PIDAS) for CO_2 Monitoring

Project Number DE-FE0012231

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National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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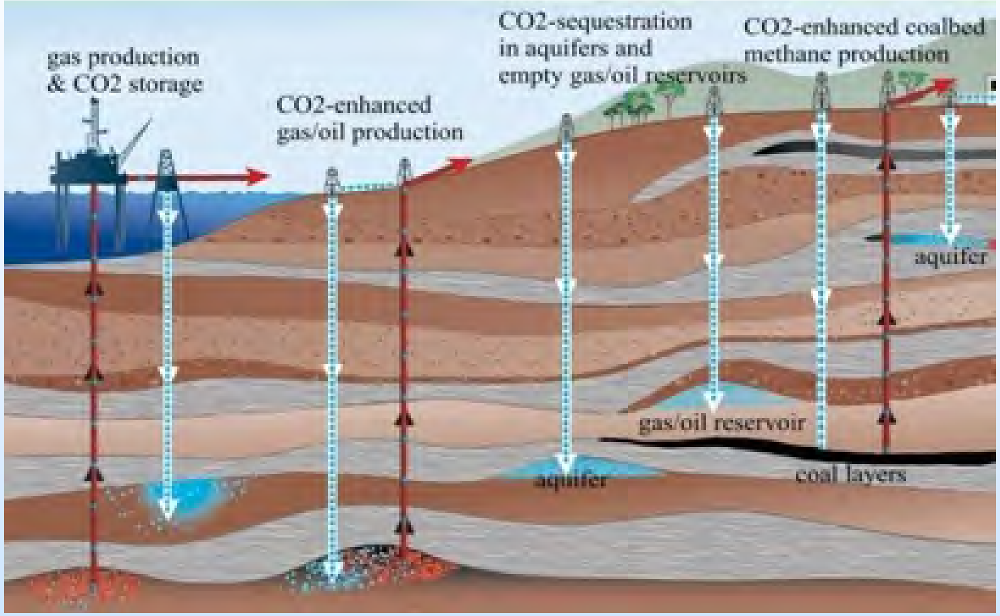
Presentation Outline

- Technical Status
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary

Technical Status

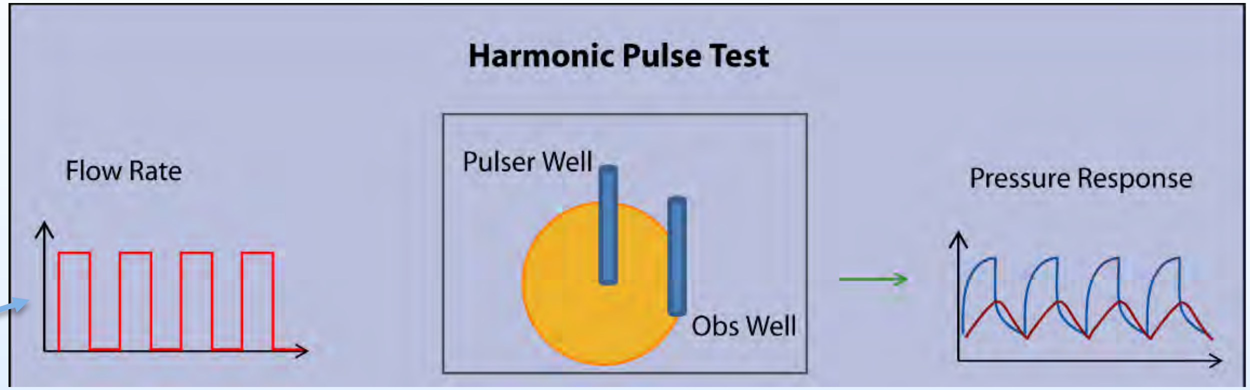
- Background
- Field experiment
- Lab experiment
- Numerical modeling



Global CCS Institute

Background of Harmonic Pulse Testing (HPT)

Coded injection pattern



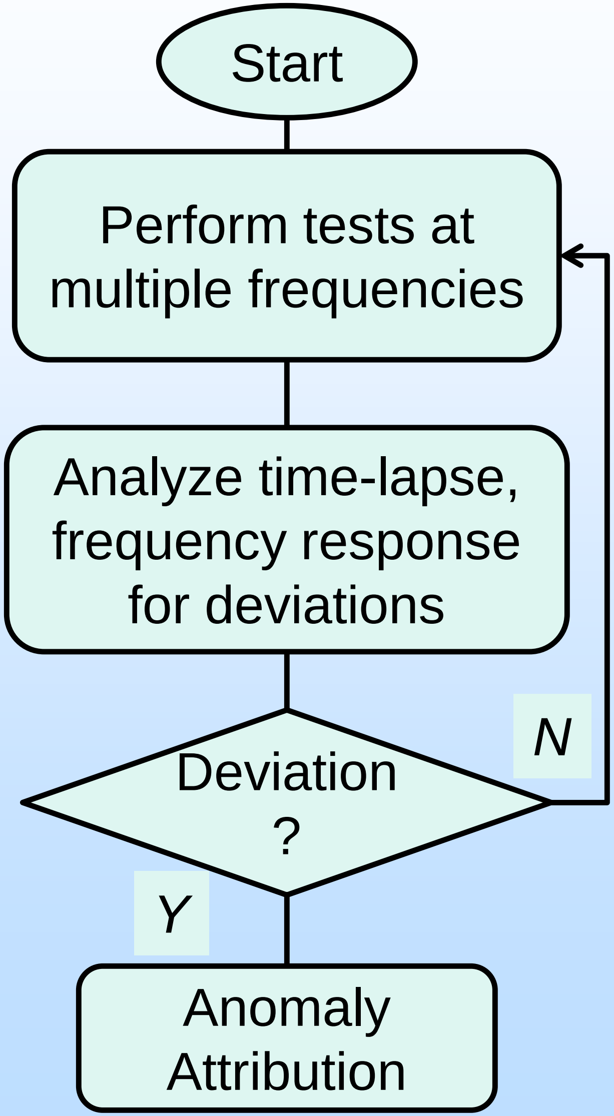
- Has been used for reservoir characterization since 1960s, but got significant attention in the last several years

- Hypotheses:
  - Patterns introduced by modulated injection rate can be uniquely identified
  - Changes in pressure power spectrum are related to anomalies

- Expected advantages over other pressure-based methods
  - Enhanced signal-to-noise ratio
  - Little interruptions to nominal reservoir operations

PIDAS Workflow

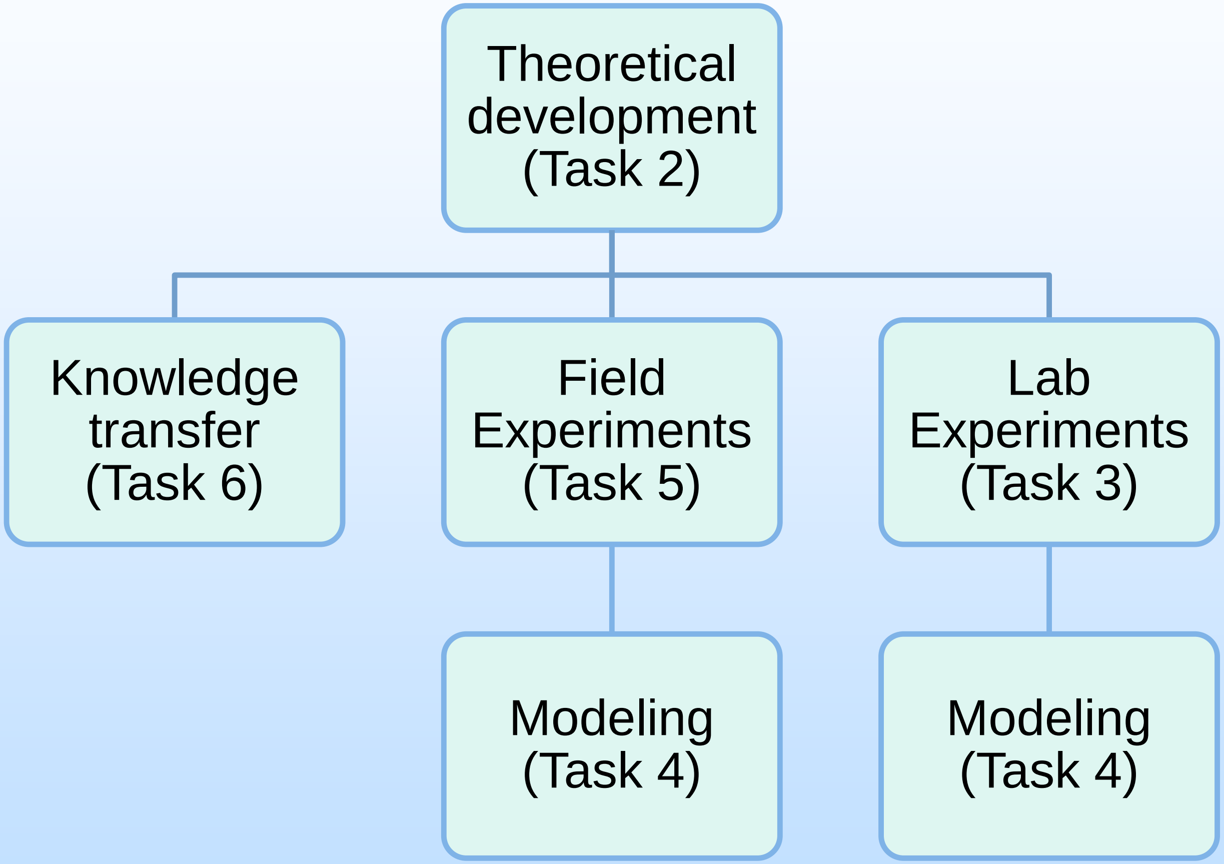
An in-zone monitoring method



Frequency response function

$$\hat{H}(w) = \frac{\hat{P}_{obs}(w)}{\hat{P}_{inj}(w)}$$

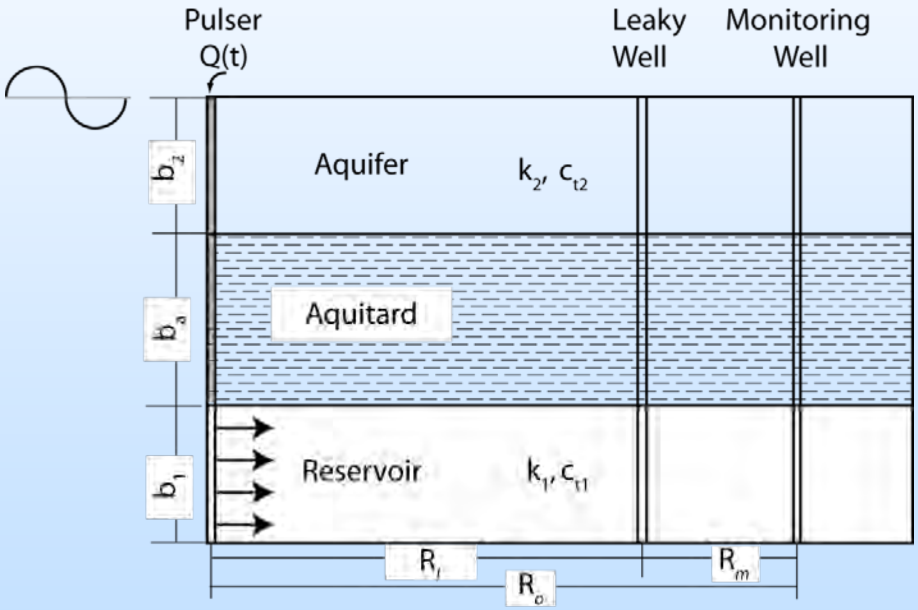
Project Tasks



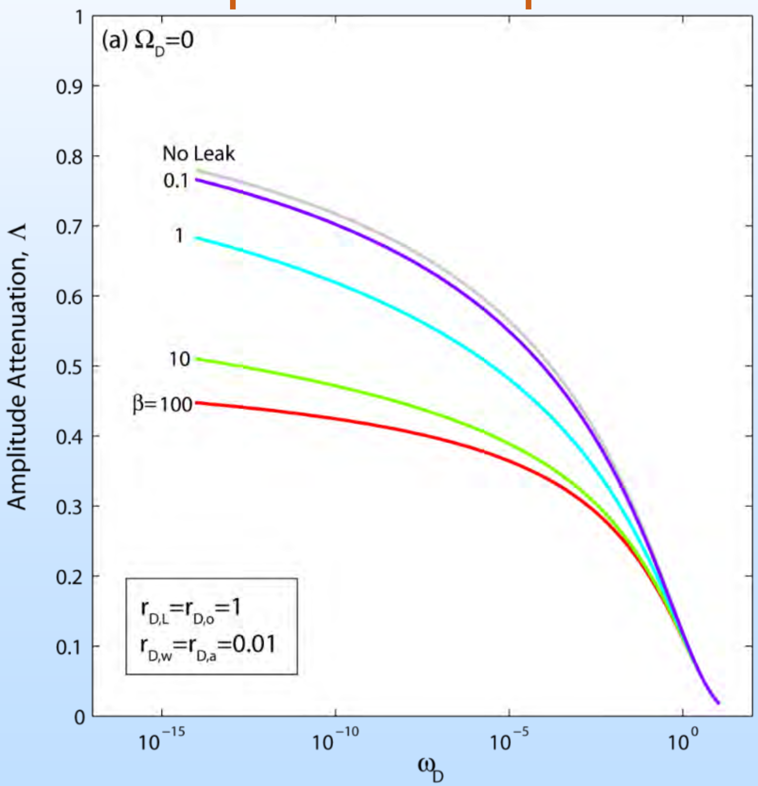
Task 2: Theoretical Development

Established the validity and feasibility of pulse testing

Problem setting



Amplitude response



Ω = Resistance of leaky well to vertical flow

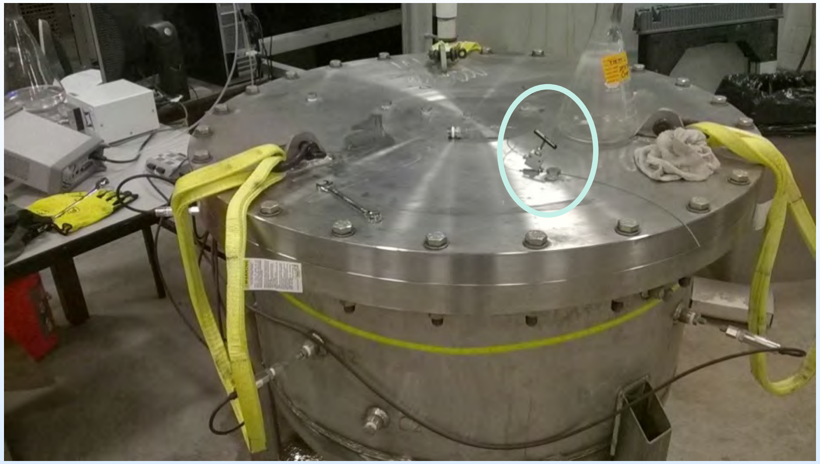
β =Transmissivity ratio between upper and lower aquifers

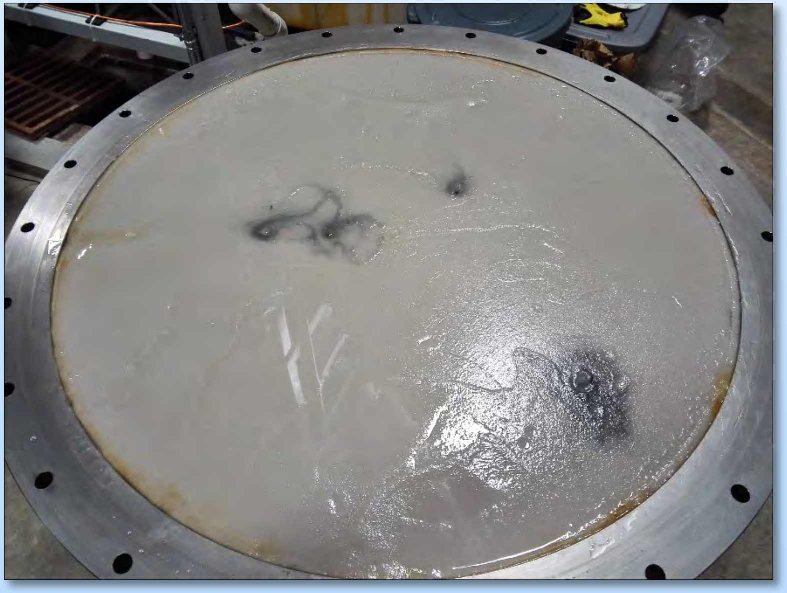
Sun et al., WRR, 2015

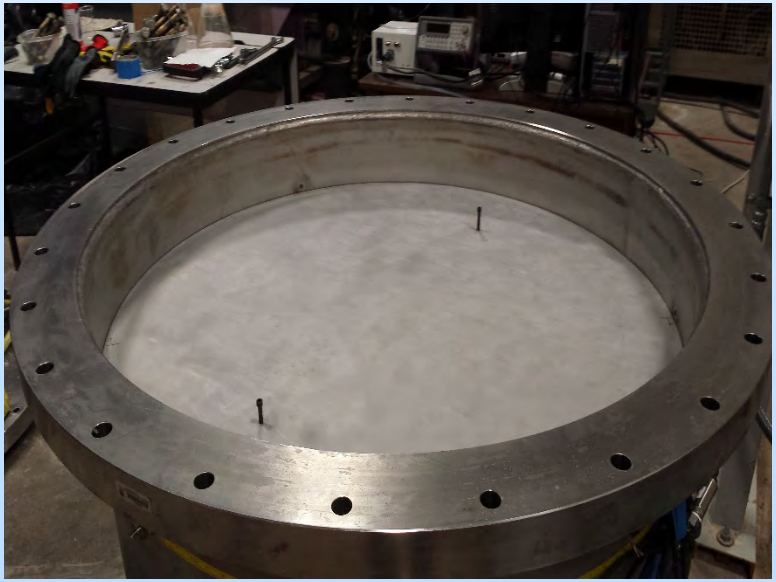
Task 3. Lab Experiments

Experiment Design

1-m diameter, 0.75 m tall

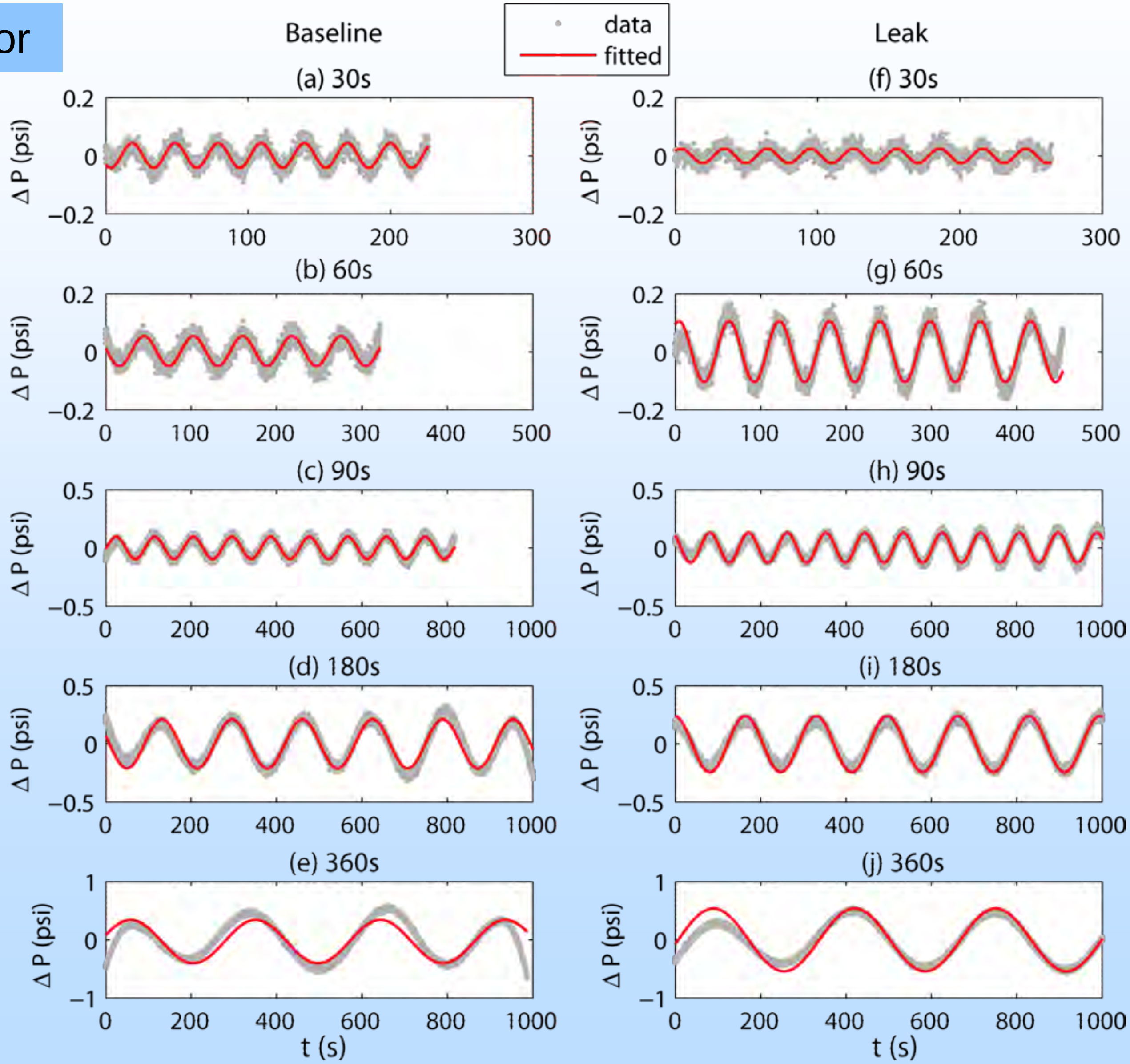






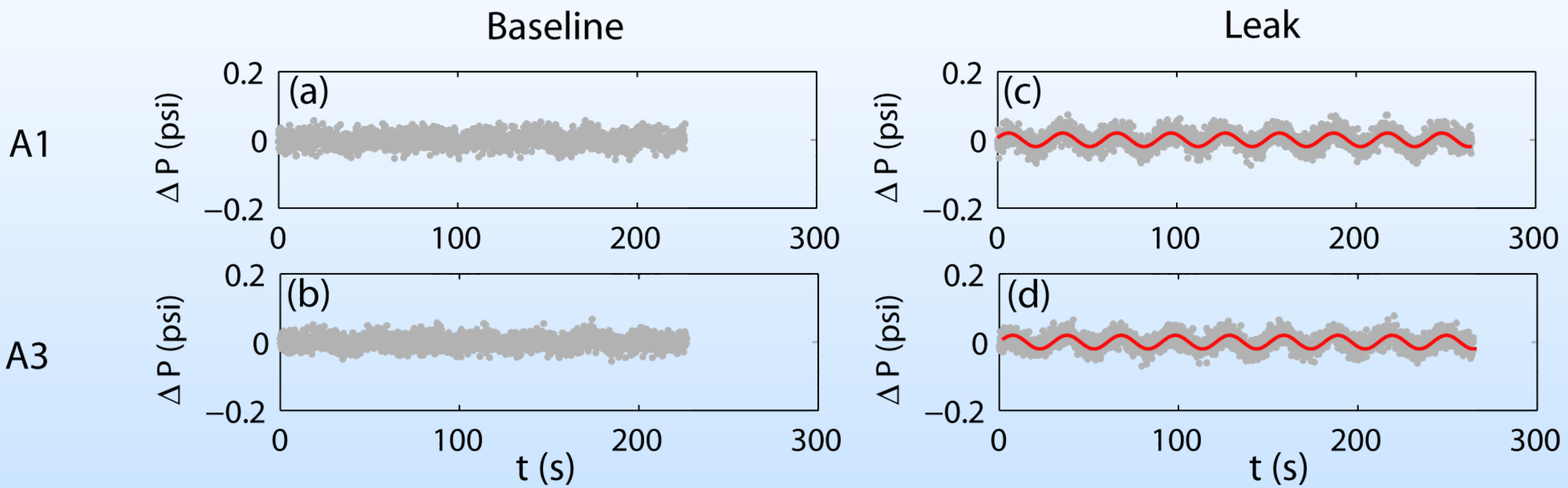
Pressure Results

Inzone sensor

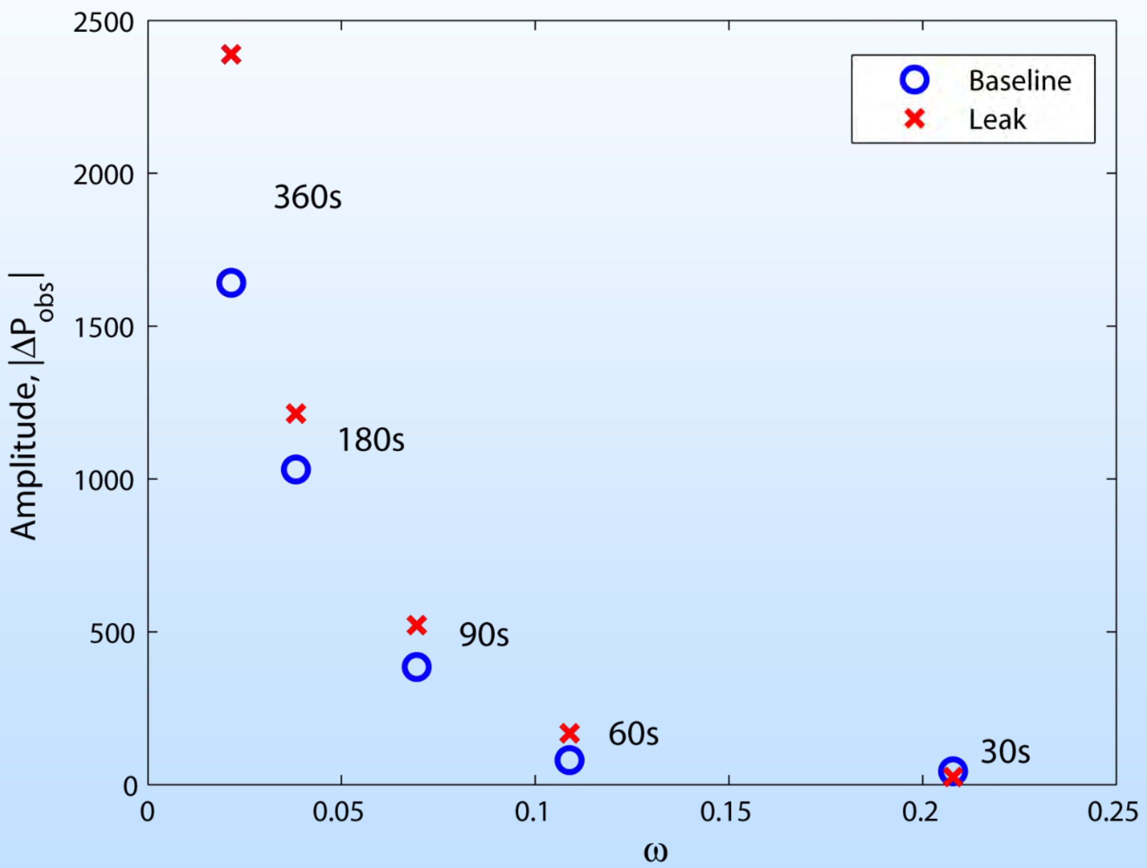


Pressure Results

Above zone sensor



Frequency Domain Detection



Sun et al., 2017, A laboratory validation study of the time-lapse oscillatory pumping test for leakage detection in geological repositories, Journal of Hydrology.

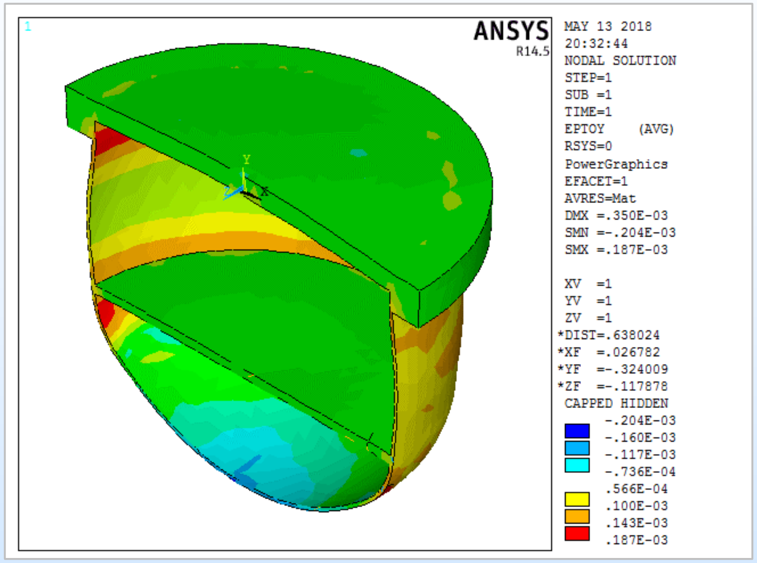
Validation Tests: Distributed Acoustic Sensing

$10^{-4} - 10^{-3}$

- <u>Research Question</u>: How is pressure affected by boundary conditions?

DAS

- Non-invasive techniques
- Deformations cause fiber to elongate or compress
- By monitoring the variation in the phase difference of the backscattered light from two ends of each section, <u>strain rate</u> on that section of the fiber can be quantified

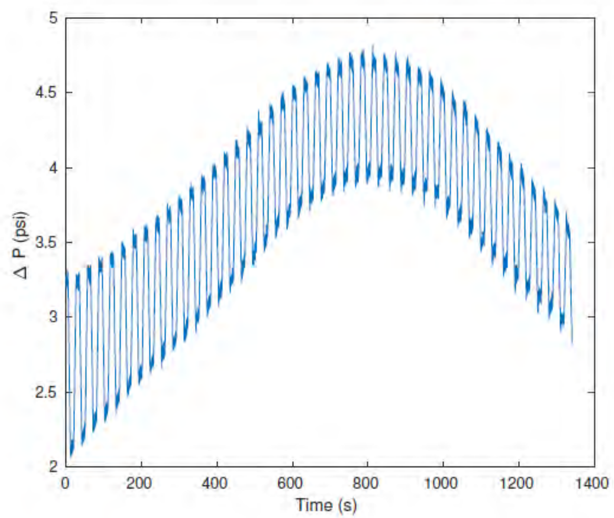


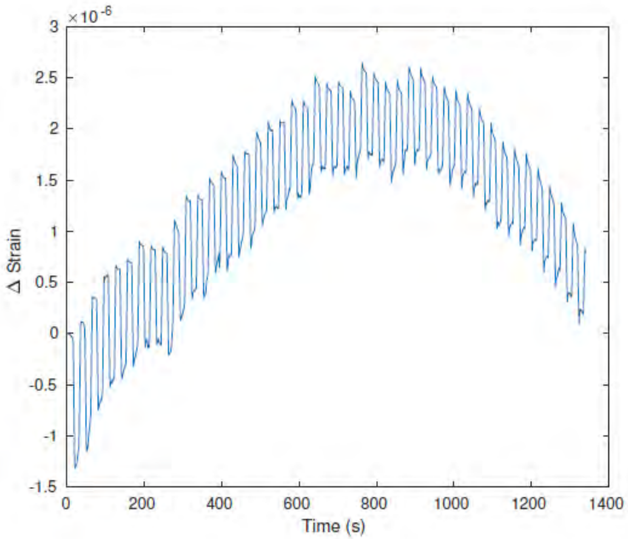
A Breathing Tank!

Pressure vs. DAS

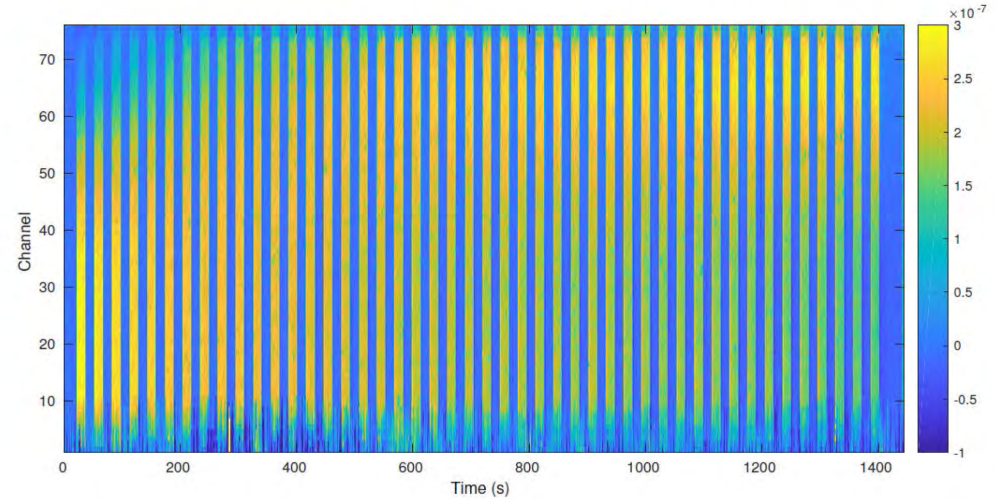
10^{-6}

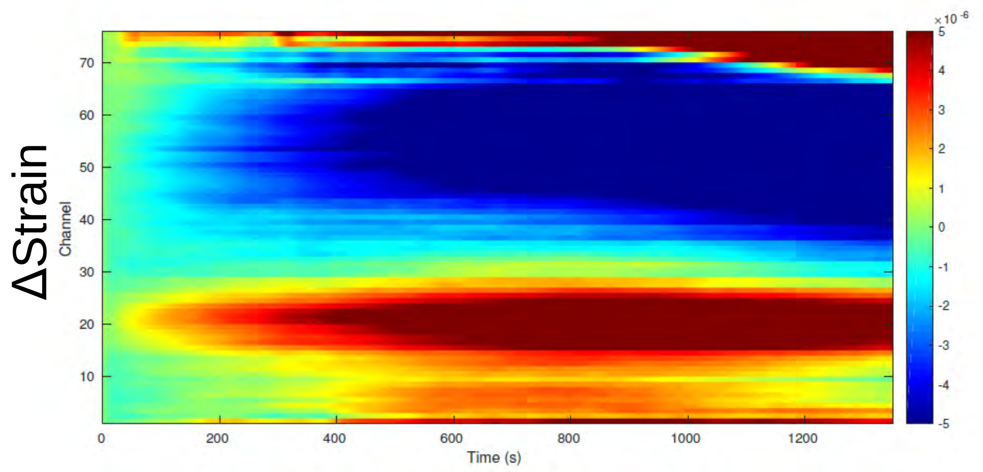
Single Fiber Channel





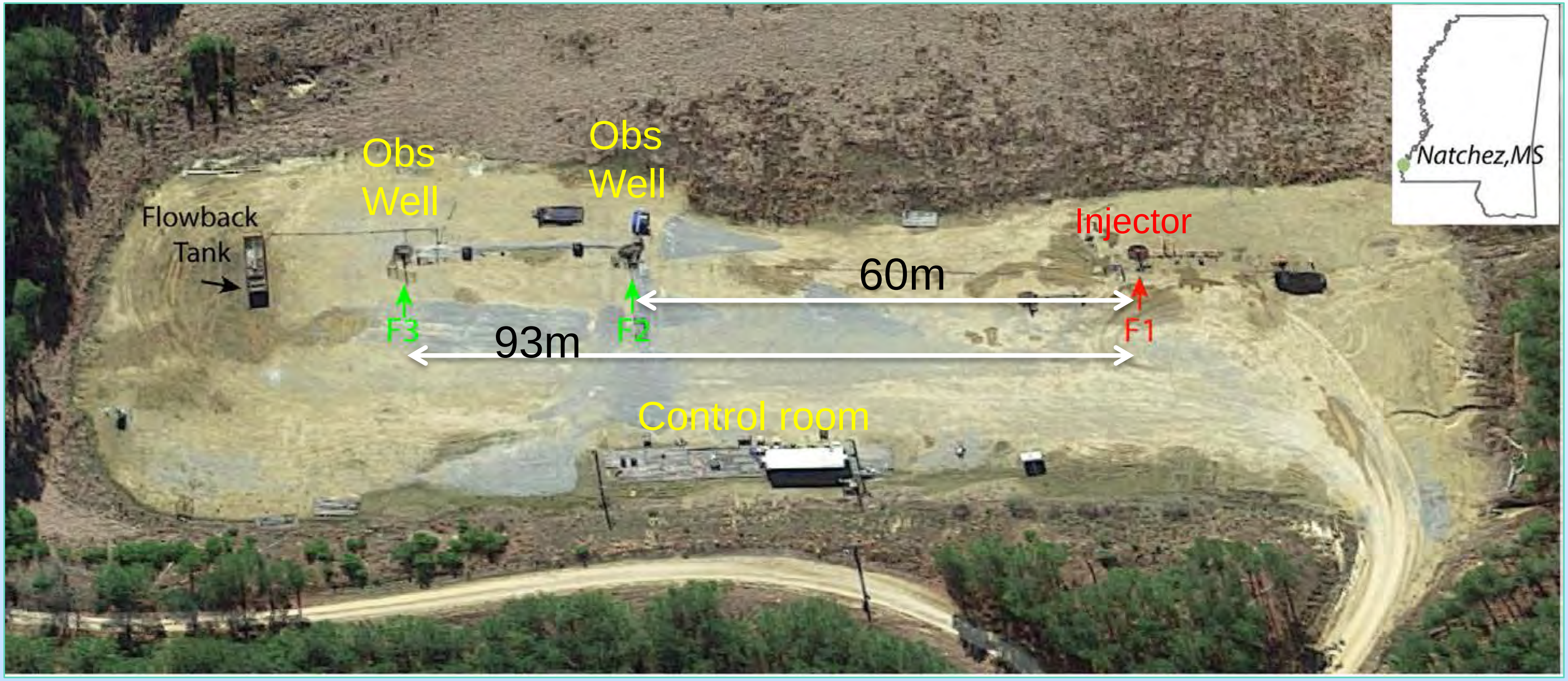
All Fiber Channels





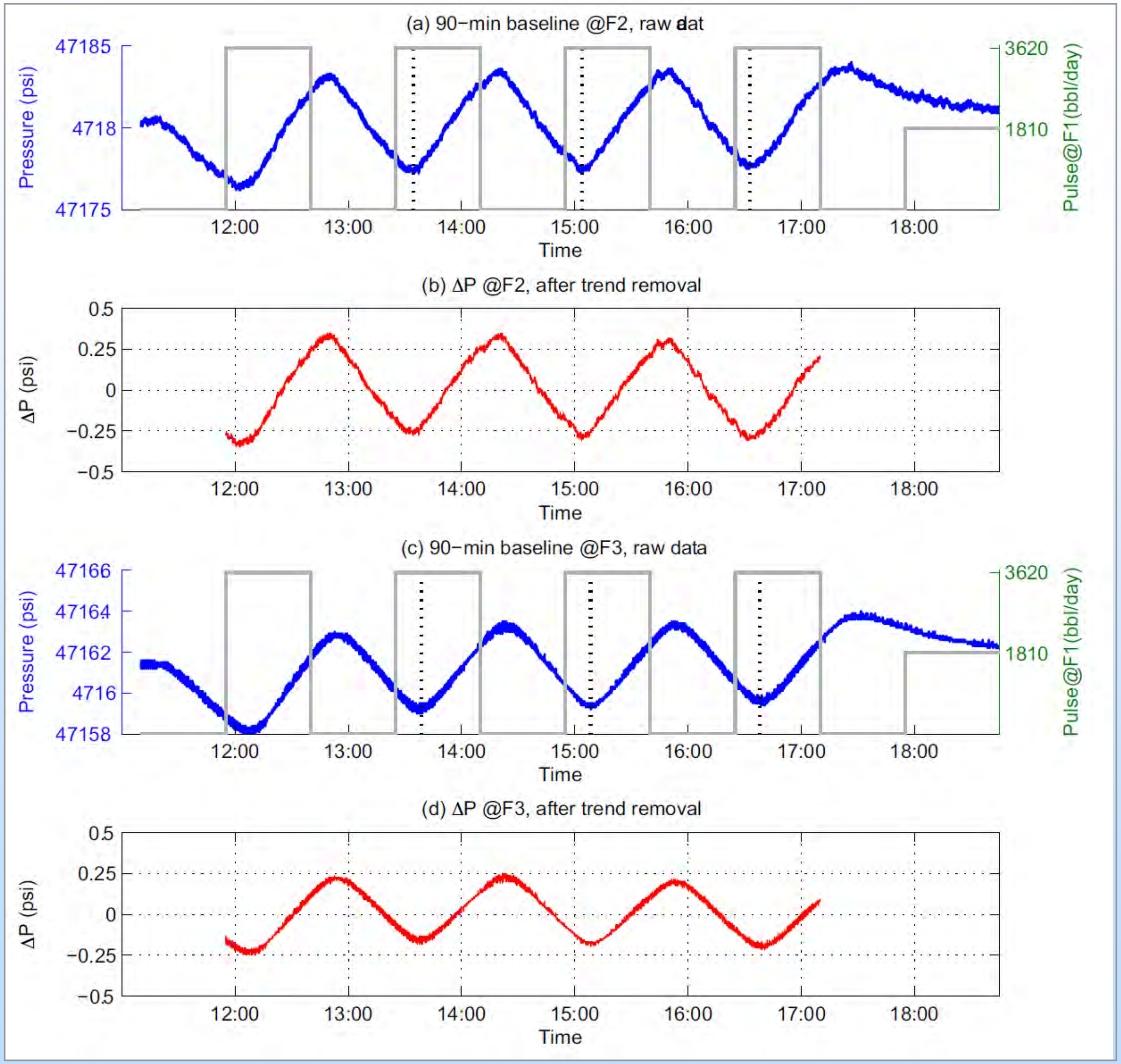
Task 5: Cranfield Experiments

Goal: Validate the concept of pulse testing at field settings



Detailed Area of Study @ Cranfield, MS, January 19-31,2015

Baseline Experiment I



Pulsing Cycle 90min

Filtered Time Series

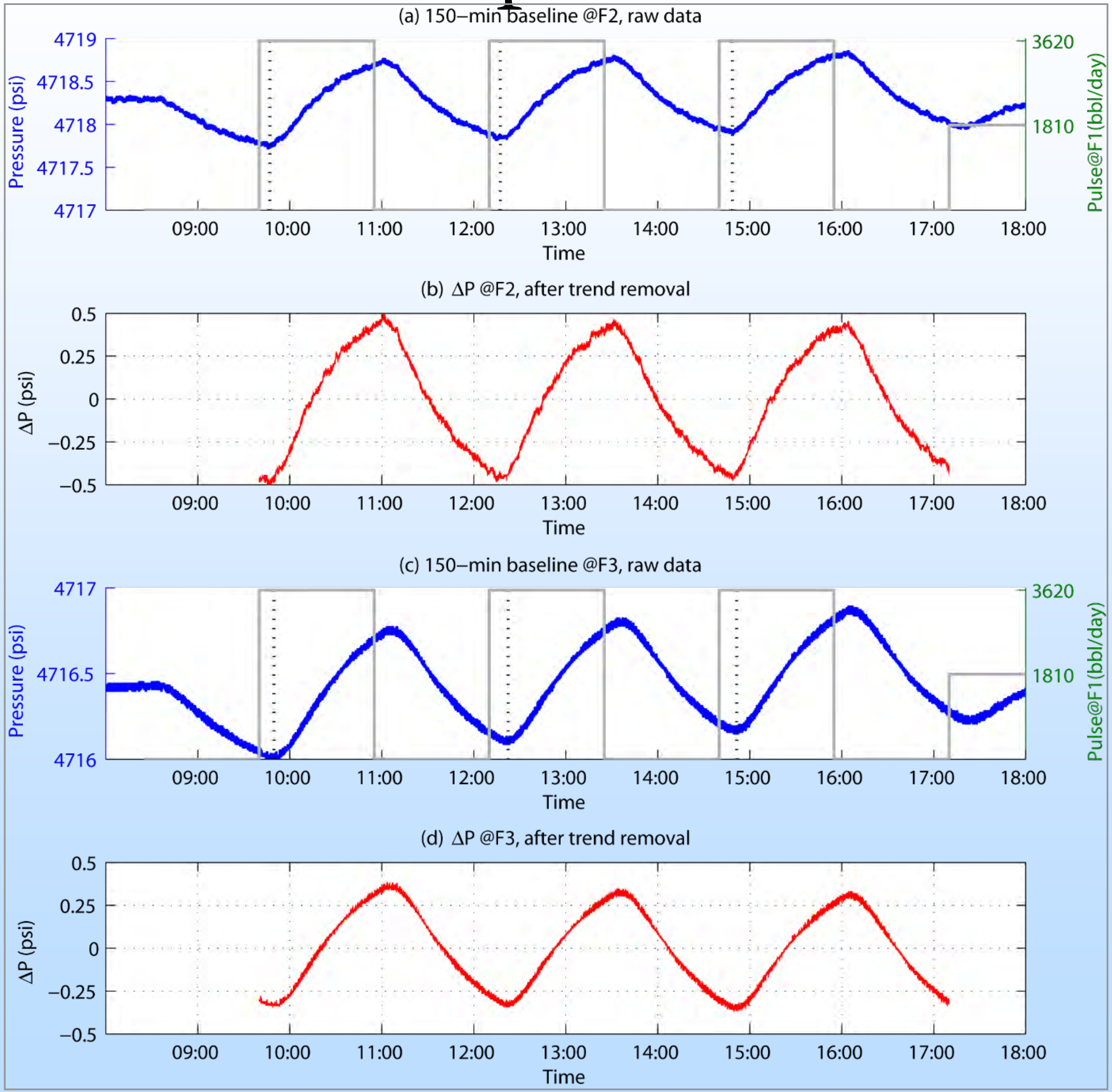
Filtered Time Series

Reservoir temperature ~ 128.8 C
Gauge res: 0.01psi

Base Experiment II

Pulsing Cycle
T = 150min

Filtered
Time
Series

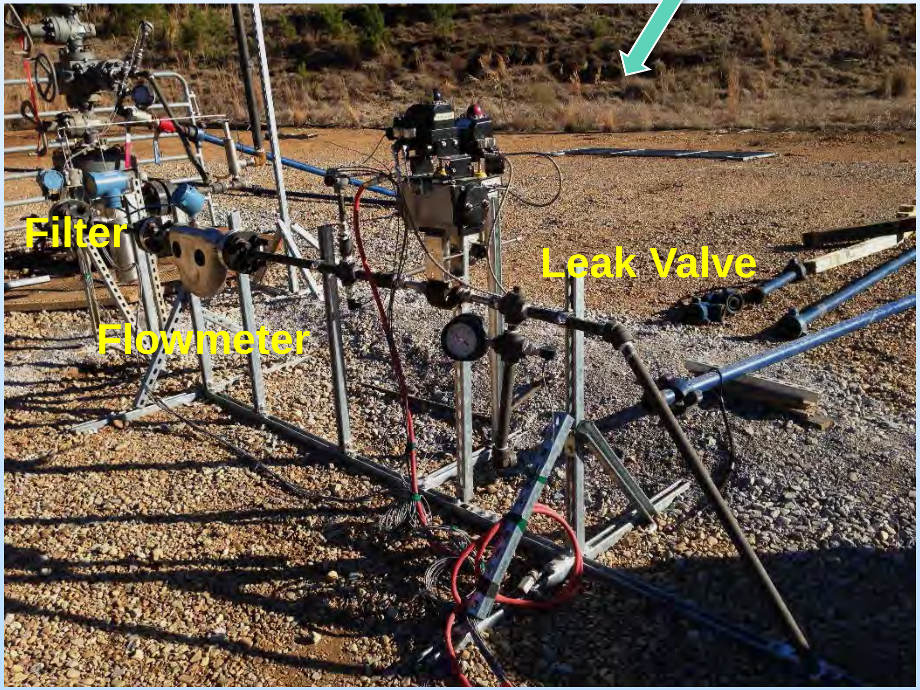


Filtered
Time
Series

Controlled Release Experiments

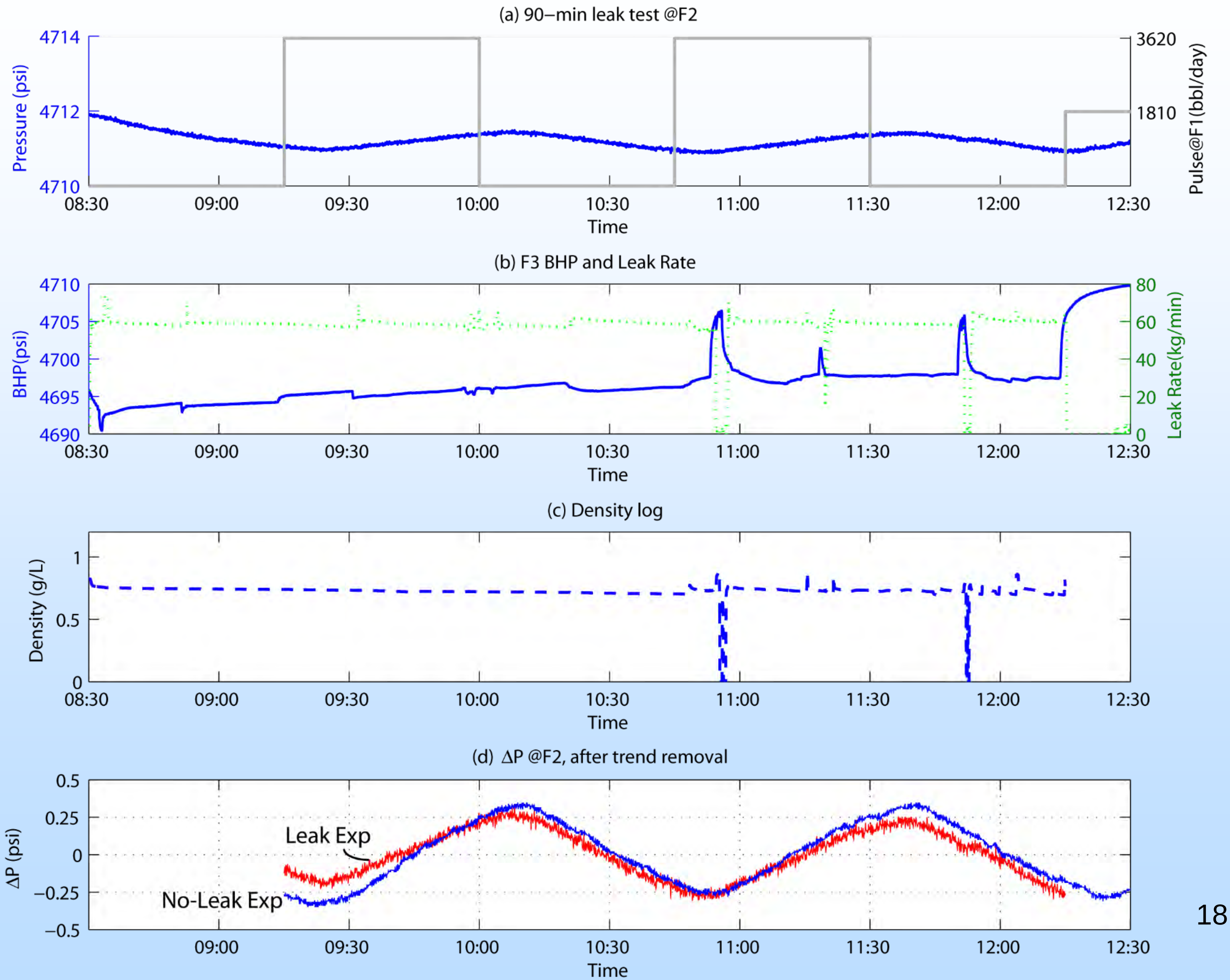
Leak control infrastructure

CFU31-F3

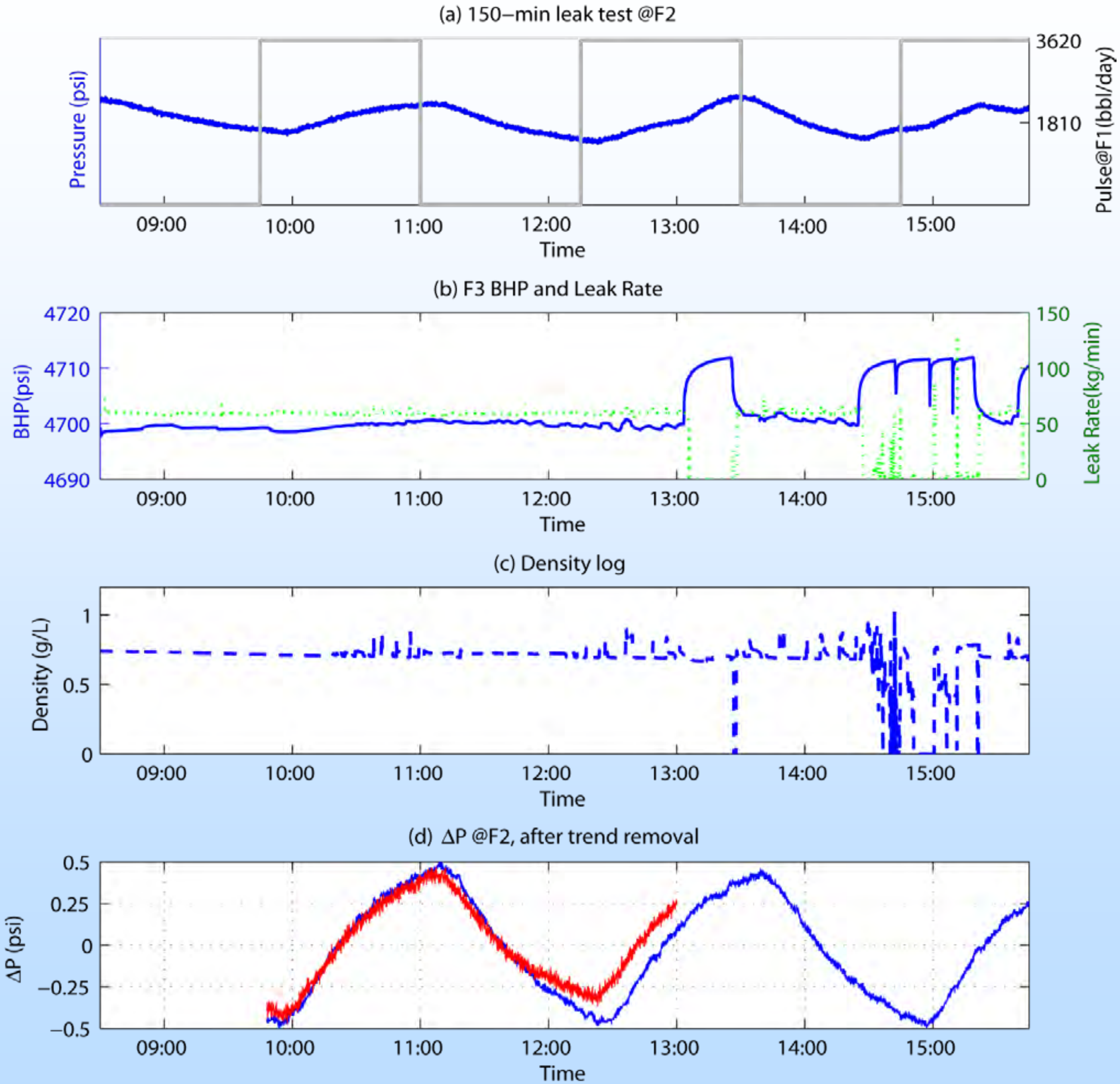


Courtesy: B. Freifeld, LBL

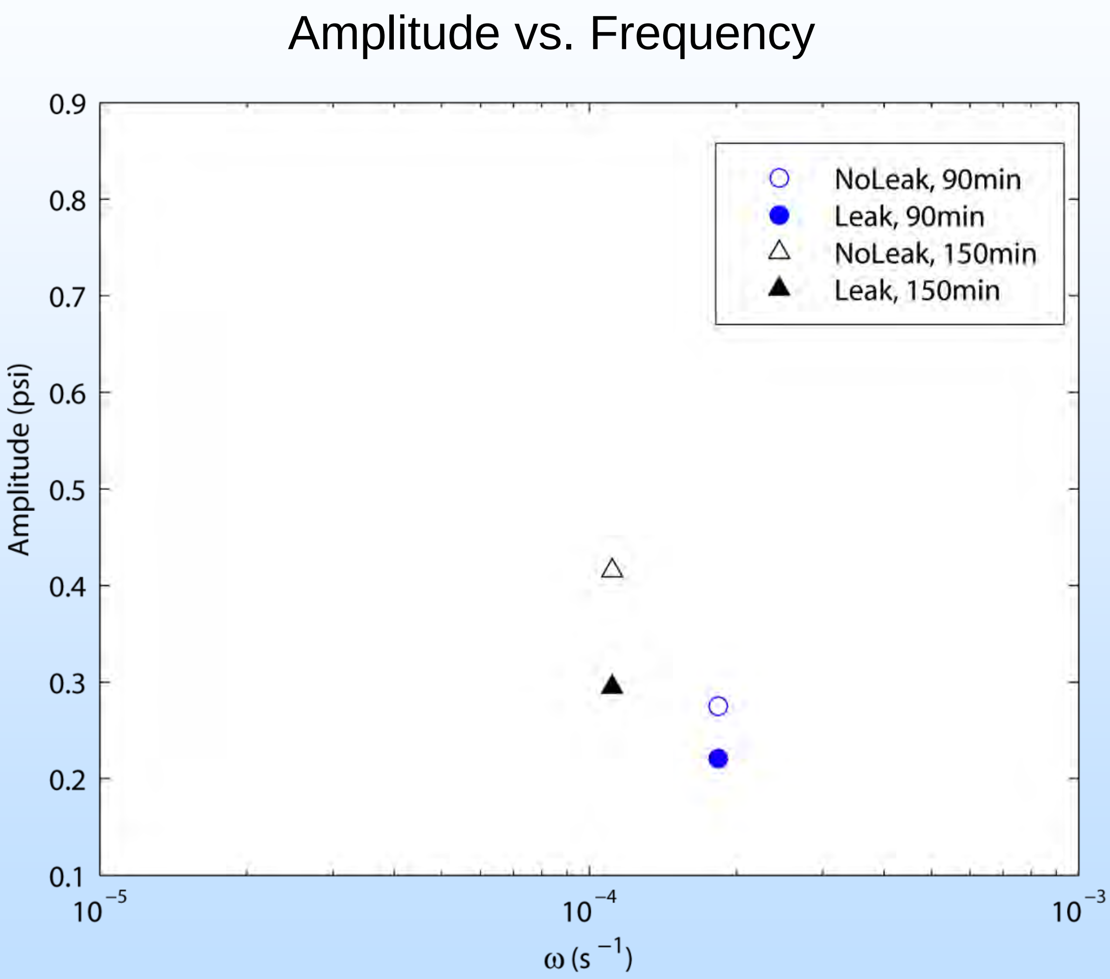
90-min, Controlled Release Experiment



150-min, Controlled Release Experiment

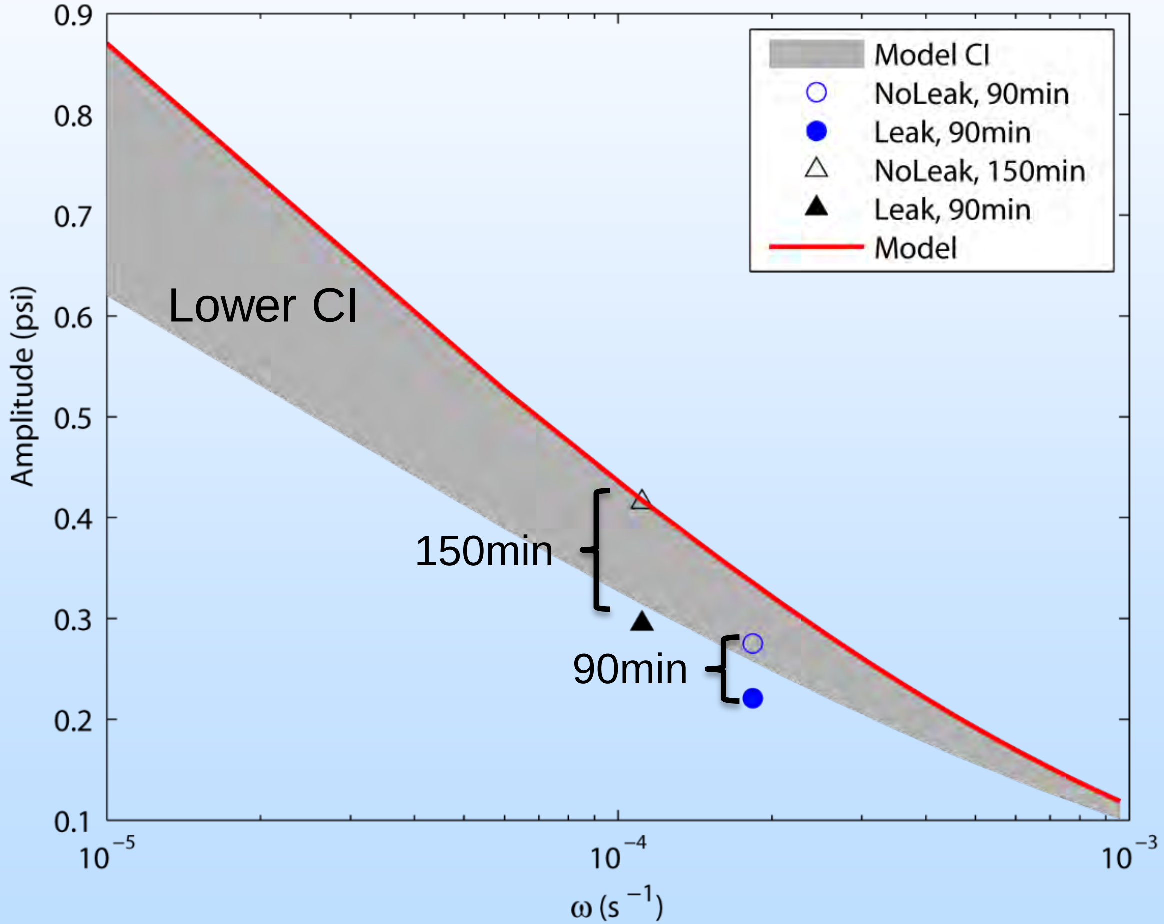


Frequency Domain Anomaly Detection



Each experiment yields one data point on the plot

Frequency Domain Anomaly Detection

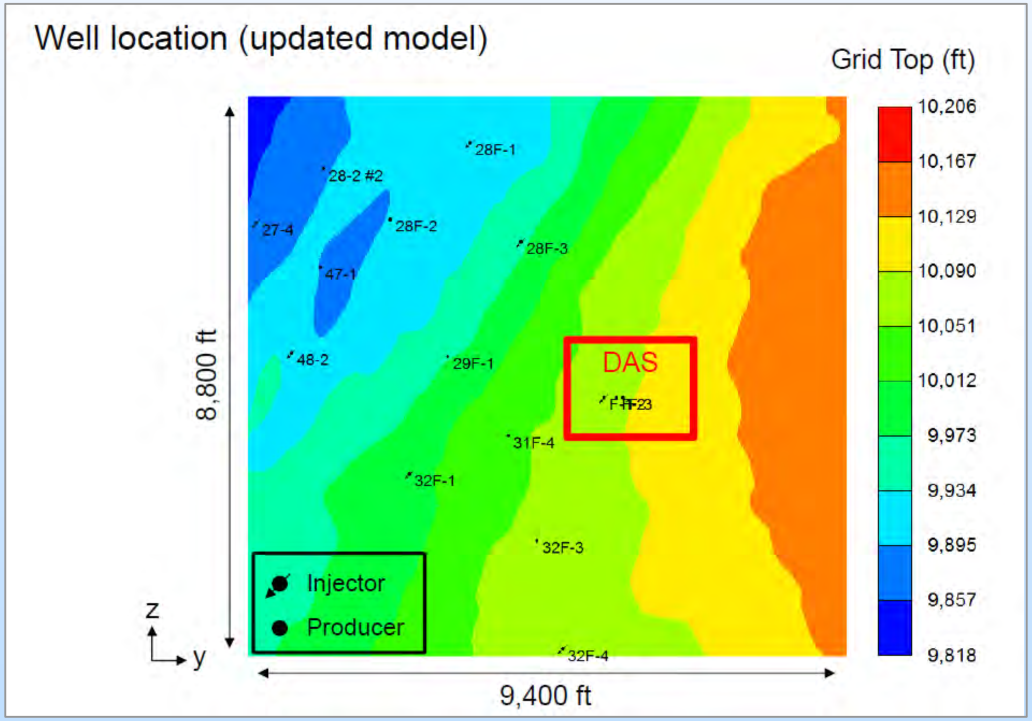


Sun et al., IJGGC, 2016

Task 4. 3D Modeling

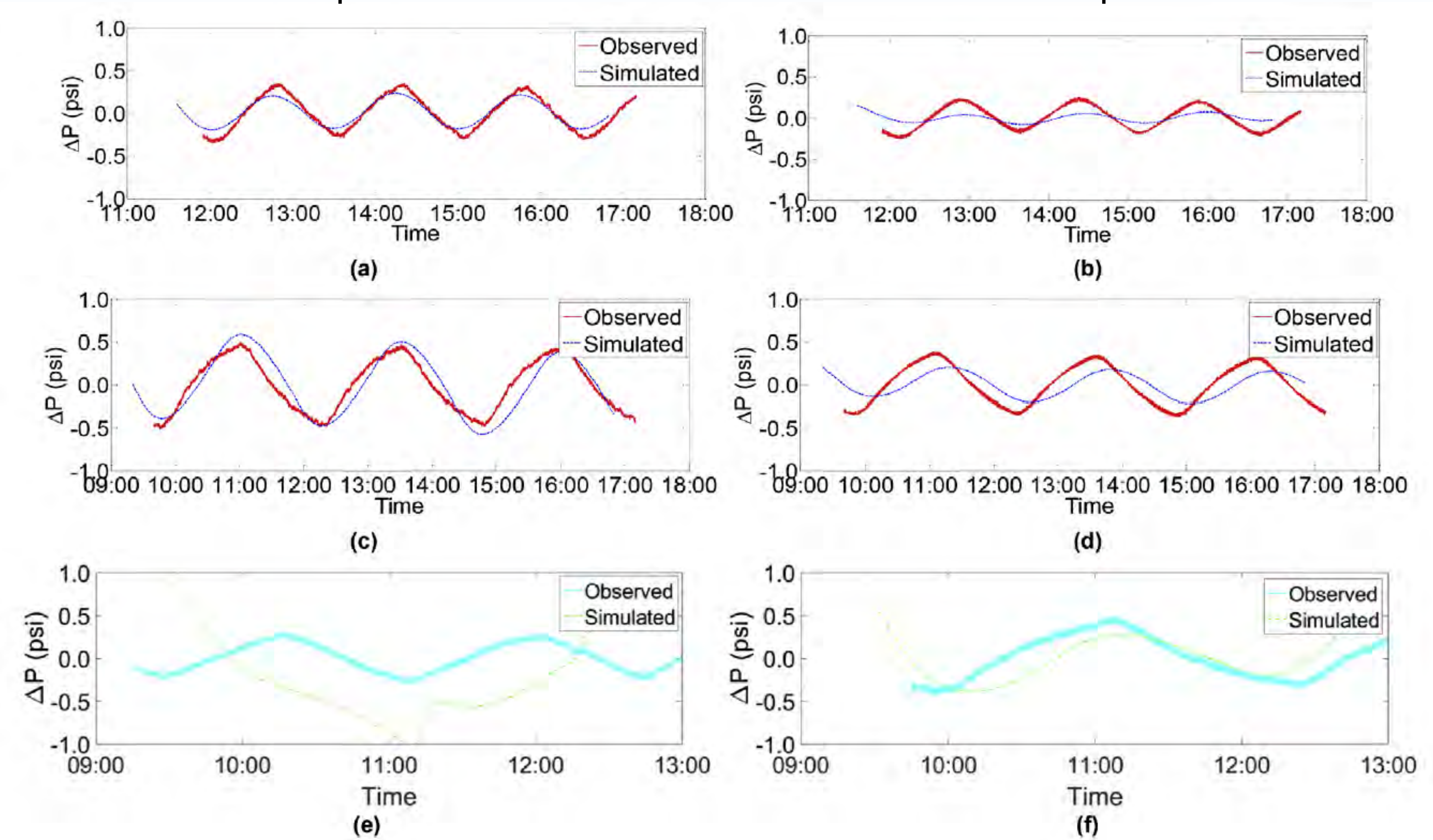
- Research question: Can site-scale model reproduce the DAS pulse testing experiments?
  - Assimilated observation data
  - Refined mesh around DAS

UT IPARS (Integrated Parallel Accurate Reservoir Simulator) Simulation



Min et al., 2018

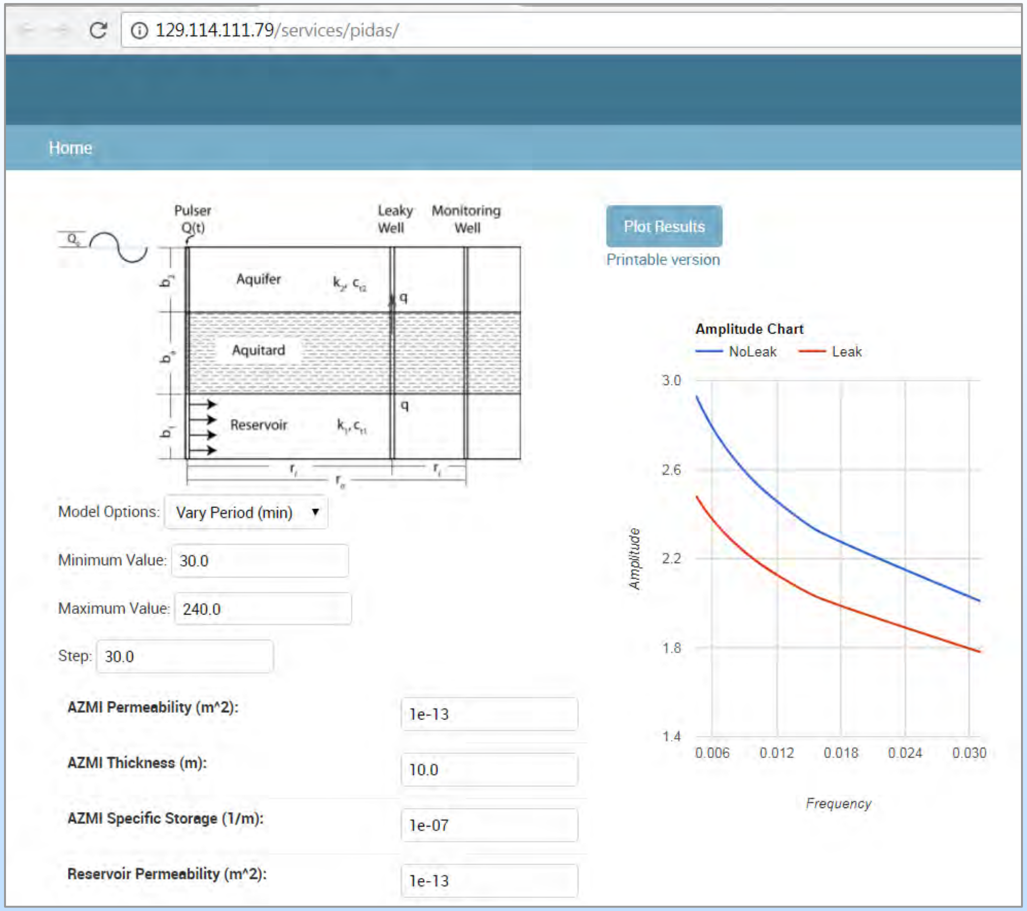
90-min Experiment 150-min Experiment



Min et al., 2018

Task 6 Result Dissemination

- Developed web-based tool
- Documented results from each task in peer-reviewed journal papers



Lessons Learned

- Pulse testing can be deployed as a simple time lapse monitoring method
- Leaks will modify the system frequency response function and can be detected if an appropriate pulsing period is used
- Longer HPT pulsing periods increase coverage area
- Lower reservoir permeability or, equivalently, higher upper aquifer permeability, favors detection of leakage, if all other parameters are fixed
- The amplitude and phase of frequency response function provide independent information regarding the current system status and can be combined to locate leaky well locations
- HPT detects deviations between measurements, but attribution of source may require additional tests

Accomplishments to Date

- Task 2: Theoretical and numerical analyses
  - Year 1: Established theoretical basis and validated the concept of pulse-testing-based leakage detection numerically
- Task 5: Field experiments
  - Year 2: Demonstrated viability of the pulse testing leakage detection technique in the field
- Task 3: Laboratory experiments
  - Year 1: Device manufacturing, experimental design
  - Year 2-5: Performed laboratory validation tests
- Task 4: Data assimilation algorithms
  - Year 2-5: Developing and testing algorithms
- Task 6: Result dissemination

Synergy Opportunities

- Other uses of pulse testing
  - Reservoir characterization
  - Fracture/fault characterization
  - Aquifer characterization
  - Well performance monitoring

Project Summary

- We demonstrated the feasibility of pulse testing using numerical and experimental tests
- Pulse testing may be deployed as a time lapse monitoring tool or site characterization tool
- Pulse testing is complementary (not replacement) to other geophysical based method for CO2 plume monitoring

Acknowledgements

- DOE/NETL PM: Bruce Brown, Brian Dressel
- University of Texas
  - Bureau of Economic Geology: Sue Hovorka, Jiemin Lu (now at SLB), Akand Islam (now at Ford), Ana Gonzalez (now at Universität Stuttgart)
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- LBNL: Barry Freifeld, Paul Cook
- Sandia Technologies LLC: Kirk Delaune
- Silixa Inc.: Thomas Coleman

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- Carbon program goal being addressed

Develop and validate technologies to ensure 99 percent storage permanence

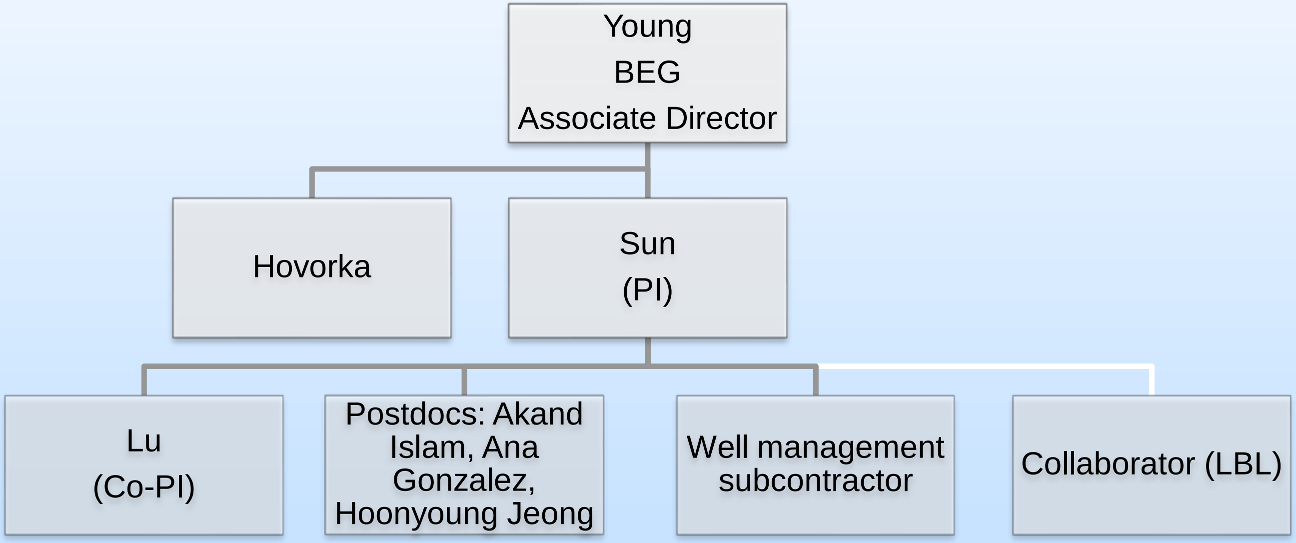
- Project benefits
  - The PIDAS project develops and demonstrates a pressure-based, pulse testing technology for leakage detection in carbon storage reservoirs.
  - Active monitoring strategy for improving signal-to-noise ratio for injection zone monitoring

Project Overview
Goals and Objectives

- Demonstrate the utility of pulse testing for leakage detection
- Develop relevant data analyses and inversion methodologies
- Provide an experimental design tool for CCS operators to apply the technology

Organization Chart

Bureau of Economic Geology, UT Austin
Gulf Coast Carbon Center



Gantt Chart

Table 2. Project Gantt chart
(Numbers in table rows indicate milestones).
(Phase I ; Phase II)

Task	Description	Year 1				Year 2				Year 3			
		1	2	3	4	1	2	3	4	1	2	3	4
1	Update project management plan												
2	Modeling of harmonic pulse tests		1										
3	Lab experiment												
3.1	Experiment design and assembling				2								
3.2	Single-phase experiment												
3.3	Multiphase experiment								5				
4	Algorithm development												
4.1	Inversion technique												
4.2	Data assimilation										6		
5	Field demonstration												
5.1	Field site selection												
5.2	Site access & NEPA determination												
5.3	Field experiments						3	4					
6	Synthesis of results												
6.1	Tool user interface development												
6.2	Technology transfer												

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4. Sun, A. Y., M. F. Wheeler, and A. W. Islam, 2017, Identifying attributes of CO2 leakage zones in shallow aquifers using a parametric level set method. Greenhouse Gases: Science and Technology.

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6. Islam, A.W., Sun, A. Y., and Yang, C., 2016, Reactive transport modeling of the enhancement of density-driven CO2 convective mixing in carbonate aquifers and its potential implication on geological carbon sequestration, Scientific Reports, v. 6, no. 24768, 9 p.

7. Min, B., A. Y. Sun, M.F. Wheeler, H. Jeong, 2018, Parallel multiobjective optimization for the coupled compositional/geomechanical modeling of pulse testing, Journal of Petroleum Science and Engineering.