Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation
Project Number DE-FE-00026517

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Collaborators

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- Nick Malkewicz, Schlumberger
- Sallie Greenberg, Illinois State Geological Survey
- Joe Greer, Silixa LLC
- David Larrick, Richland Community College
Presentation Outline

• Project Overview
  – Technical Status
  – Accomplishment to Date
  – Lessons Learned
  – Synergy Opportunities

• Project Summary
  – Key Finding
  – Next Steps
Seismic surveys are considered the backbone technique for CO2 storage monitoring programs.

Stringing thousands of cables and running thumper trucks every few years can test the limits of good neighbors. Costs are high.

Permanent reservoir monitoring offers a way to obtain higher quality information with minimal intrusion into surrounding lands –

- DAS provides high spatial and temporal resolution.
- Installation can be in horizontal directionally drilled boreholes beneath bodies of water, existing infrastructure.
- Excitation of DAS cables can be achieved through permanent fixed rotary sources for continuous monitoring.
Distributed Acoustic Sensing (DAS)

Example from PTRC Aquistore

DAS Baseline 3D-VSP

DAS VSP is becoming accepted technology.
Distributed Acoustic Sensing

- Standard optical fibre acts as the sensor array
  - Typical sampling at 10kHz on 10,000m fibre
  - Standard gauge length of 10m
  - Spatial sampling of 25cm
  - DAS measures change in average elongation per 10m gauge length per 0.1ms acoustic time sample, sampled every 0.25 m in distance

Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, *first break* (32), February 2014
Surface Orbital Vibrator – VFD Controlled AC Induction Motor

Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d

Force is adjustable
F=mω²r
FAT Helical Wound Cable

Anderson and Shapiro – HWC on soft mandrel 1980 US Patent 4375313

Hornman et al. (2013 75th EAGE) introduced a helical wound FO cable

LBNL trialed multiple designs with varying physical properties

At Oway installed one length of HWC for comparison to straight fiber

30° spiral wound on 58 Shore A rubber mandrel.

Lessons learned – acoustic impedance of cable and surrounding soil is important
Shale Oil Pilot Monitoring (AMSO)

26,000 lb Vibe 70% force

SOV – 2 Single sweep

CO2CRC Otway Project Geophone Data
ADM IMS cable contains new Silixa Ltd. Carina technology – significantly lower noise floor

CO2CRC Otway – SP0, 700 m offset, 5 sweeps, data courtesy R. Pevzner
IMS Fiber Optic and CASSM Layout

Fiber Optic Cable
Bored at approximately 20 feet.

NOTE 1: Distances are measured from CCS#2

VW#2 2,600 ft.
SS#2 2,150 ft.
SS#1 350 ft.
SS#3 4,250 ft.
SS#4 2,705 ft.
SS#5 5,475 ft.
GM#2 CCS#2

ROTARY SEISMIC SOURCE GENERATOR (NOTE 1)
INJECTION AND MONITORING WELLS (EXISTING)
DAS FIBER OPTIC LINE (BORED TO 20 FT)

NOTE 1: Distances are measured from CCS#2
Accomplishments to Date

- TASK 2.0 IMS Design
  - Design and specification DAS cable, rotary sources CASSM, instrumentation, data acquisition and associated subsystems
  - Development of an IMS architecture and the demonstration of its operation using synthetic data feeds
  - Function testing of microseismic monitoring system and real-time event detection system
  - Detail real-time DAS cross-correlation and stacking algorithm and provide analysis of synthetic data evaluation with different levels of synthetic noise
  - Final design review, constructability, and HAZOP meeting
Subtask 2.3 Software Design and Development

Workflow of pre-stack cross-equalization based on experience at Otway and SERDP infrastructure project.

Use of Wiener filter to minimize the influences of precipitation on the SOV generated DAS data.
Testing of SOVs and preliminary data acquisition using the 250-meter-long section of surface DAS array (Testing Array).

SOV source sweeps recorded by pilot geophone
Top panel = time series; Bottom panel = time-frequency spectra.
Hydrological-seismic modeling framework

Close-link software merge of both simulation modules allows for full exploitation of efficient parallel computing in both simulators.
Common shot gather acquired on the test DAS array. (a) Raw shot gather without fk dip filtering. (b) Data after fk dip filtering. (c) VP profile extracted from sonic well log of CCS2. Dash lines in (b) denote travel time predictions of key reflectors. Dash lines in (c) denote the depths of the key reflectors. Tertiary, secondary, and primary = tertiary, secondary, and primary seals; pre Mt. Simon = bottom of the Mt. Simon reservoir.
Subtask 2.3 Software Design and Development

SOV sweep recorded by the permanent N/E DAS surface array.

SOV4 sweep recorded by the northeast DAS surface array.

SOV5 sweep recorded by the northeast DAS surface array.
Subtask 2.4
Design Passive Microseismic Monitoring system

Data filter improvements for the deep borehole seismic network array increase the detection of microseismic events by removing frequencies of repetitive noise.

Spectra for filtered data
Spectra for raw data
Subtask 2.4  
Design Passive Microseismic Monitoring system

Expanding the use of repeat signal detector (RSD) algorithm to the deep borehole array will increase the number of detected events.

RSD increased the number of detected event more than threefold versus standard STA/LTA techniques.

Additional events detected using the shallow borehole network from November 2014 through December 2017 and plotted against the normalized cross-correlation coefficient divided by the median absolute deviation.
Accomplishments to Date

• TASK 3.0 IMS Installation
  – Develop final construction plan for IMS equipment
  – Installation of data acquisition and processing equipment
  – Installation of DAS surface cable and rotary sources CASSM
  – Installation of instrumentation, electrical, and communications subsystems
  – Installation of control, monitoring, and data acquisition software
Subtask 3.2 Installation of IMS data acquisition and processing equipment

Setup of the IMS Server & iDAS units in the CCS#2 building and SOV#2 & 3’s Ethernet switch inside the VW#2 building.
Subtask 3.2 Installation of IMS DAS surface cable

- Horizontal Directional Drilling
- Location and Depth Monitoring
- Prep for DAS cable and grouting conduit pull back
- Cable and Conduit pull back
- Cable reels feeding DAS cable and grouting conduit into bore hole
- Grouting DAS Cable
Subtask 3.2 Installation of rotary sources CASSM

Setup of the IMS Server & iDAS units in the CCS#2 building and SOV#2 & 3’s Ethernet switch inside the VW#2 building.
Subtask 3.2 DAS Cable Fusion Splicing & Acquisition of Geospatial Coordinates

Over 60 fusion splices required for installation of DAS array and networking of SOV panels. Over 700 GPS coordinates with DAS cable depth used to develop the geospatial model.

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Accomplishments to Date

• TASK 4.0 IMS Commissioning and Operation
  – Commissioning of IMS equipment and related controls
  – System commissioning began July 1, 2017 and will continue through Q4 FY 2017.
Lessons Learned

– Data Transfer and Network Latency
  • The project faces challenges in transferring terabyte data sets from the ADM network to the LBNL server at speeds that allow the interactive analysis needed to troubleshoot and optimize the system.
  • The project team has developed a plan to take the IMS Server off the ADM network and use a separate ISP connection to transfer data to the LBNL server.

– HDD installation and grouting requires coordination with the drilling contractor. Most contractors were unfamiliar with our requirements and procedures needed to be developed. DAS cable is sufficiently different from installation utility conduit installation that best practices need to be developed for DAS.
Synergy Opportunities

– Initial trialing of DAS helical wound cables supported by Otway Project
– Further testing of novel Constellation optical fiber
– Development of surface cable DAS data processing flows and HDD. Linkages to the CO2CRC Otway Project Stage 3, CMC CaMI, and PTRC Aquistore
Project Summary

– Key Findings.
  - We are making steady progress on the installation and operation of the DAS-SOV network. Our experience and lessons learned are invaluable for developing future HDD DAS projects

– Next Steps
  - Operation of IMS equipment and related controls
  - Optimization of system with respect to data quality and processing speed
  - Comparison of real time IMS data with state of the art detailed models
  - DAS data feed integration into the passive seismic monitoring system and system optimization
Appendix
Benefit to the Program

• Carbon Storage Program Goal Support:
  • Goal (1) Develop and validate technologies to ensure 99 percent storage permanence by reducing leakage risk through early detection mitigation.
  • Goal (2) Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness by advancing monitoring systems to control and optimize CO2 injection operations.
  • Goal (4) Contributing to the Best Practice Manuals for monitoring, verification, and accounting (MVA) with regard to IMS.
Benefit to the Program

• Reduce overall storage cost.
• Increase monitoring sensitivity.
• Increase monitoring reliability by using an integrated system.
• Optimize operation and maintenance activities.
• Reduce project risk during and after the injection of CO2.
Project Overview
Goals and Objectives

- Develop an integrated IMS architecture that utilizes a permanent seismic monitoring network, combines the real-time geophysical and process data with reservoir flow and geomechanical models.
- Create a comprehensive monitoring, visualization, and control system that delivers critical information for process surveillance and optimization specific to the geologic storage site.
- Use real-time model calibration to provide reservoir condition forecasts allowing site optimization.
Project Overview
Specific Project Objectives

1. Design an IMS using a real-time multi-technology architecture that fully integrates and enhances the site’s existing monitoring infrastructure that includes multi-level 3D seismic arrays, distributed acoustic sensing (DAS), multi-level pressure/temperature sensors, distributed temperature sensing (DTS), borehole seismometers, and surface seismic stations.

2. Augment the sites monitoring capabilities by installing several rotary seismic sources and integrating a network of surface DAS with the existing seismic system to create a continuous active source seismic monitoring (CASSM) array covering over two square kilometers and extending to a depth of 6,300 feet.

3. Develop terabyte level data processing solutions for real time monitoring of reservoir conditions and time lapse imaging of the CO2 plume.
Project Overview

Specific Project Objectives

4. Commission and operate the monitoring system in an industrial setting under actual conditions.

5. Validate and document the economic and environmental benefits of the monitoring system.

6. Update the monitoring verification and accounting best practices guide to include IMS and CASSM monitoring systems.

7. Incorporate DAS channels in routine location of microseismicity using the combination of borehole and surface seismic stations.

8. Develop near real-time data processing techniques to overcome passive seismic monitoring limitations of low signal-to-noise ratio on DAS array.
IMS Organization Chart

• ADM has overall project responsibility and is accountable for:
  – Task 1 Project management and planning
  – Task 3 IMS Installation
  – Task 4 IMS Commissioning and Operation

• LBNL’s team will be accountable for:
  – Task 2 IMS Design
  – Subtask 3.3 IMS DAS Surface Cable and Rotary Sources CASSM
  – Subtask 3.4 IMS Control, Monitoring, and Data Acquisition Software
  – Subtask 4.2 Function test of IMS DAS Surface Cable and Rotary Sources CASSM
  – Subtask 4.5 Validate IMS real-time reduced order models

• USGS’s team will be accountable for:
  – Subtask 2.4 Design of Passive Microseismic Monitoring System
  – Subtask 4.6 Operation Passive Microseismic Monitoring System
IMS Organization Chart

• Silixa’s team will be accountable for:
  – Subtask 2.1 IMS Data Acquisition and Processing Equipment,
  – Subtask 3.2 IMS Data Acquisition and Processing Equipment,
  – Subtask 4.1 IMS Instrumentation, Controls, and Data Network,

• RCC’s team will be accountable for:
  – Subtask 1.4 Project Outreach and Education.

• ISGS's team will participate in:
  – Subtask 1.4 Project Outreach and Education,
  – Subtask 2.4 Design of Passive Microseismicity Monitoring System
  – Subtask 4.6 Operating Passive Microseismicity Monitoring System

• SLB’s team will participate in:
  – Subtask 2.1 Data Acquisition and Processing Equipment
  – Subtask 4.5 Validate IMS real-time reduced order models
IMS Organization Chart

General Task Overview

Task 1.0
Project Management
Scott McDonald - ADM

Task 2.0
IMS Design
Barry Freifeld - LBNL

Task 3.0
IMS Installation
Scott McDonald - ADM

Task 4.0
IMS Commissioning & Operation
Scott McDonald - ADM
IMS Organization Chart

Task 1.0 - Project Management

Subtask 1.1
Project Management Plan
Scott McDonald - ADM

Subtask 1.2
Reporting
Salil Arora - ADM

Subtask 1.3
Project Management
Scott McDonald - ADM

Subtask 1.4
Outreach & Education
David Larrick - RCC
IMS Organization Chart

Task 2.0 - IMS Design

Subtask 2.1
Data Acquisition and Processing Equipment
Barry Freifeld - LBNL

Subtask 2.2
DAS Surface Cable and Rotary Sources CASSM
Barry Freifeld - LBNL

Subtask 2.3
Software Design & Development
Michael Commer - LBNL

Subtask 2.4
Passive Microseismicity Monitoring System
Ole Kaven - USGS

Subtask 2.5
Final Design Review
Scott McDonald - ADM

Subtask 2.6
Equipment Procurement
Steve Ryan - ADM

Subtask 2.7
Construction & Environmental Permits
Scott McDonald - ADM
Task 3.0 - IMS Installation

Subtask 3.1
Construction Plan for Equipment
Steve Ryan - ADM

Subtask 3.2
Data Acquisition and Processing Equipment
Chris Matlock – ADM

Subtask 3.3
DAS Surface Cable and Rotary Sources CASSM
Scott McDonald - ADM
Barry Freifeld – LBNL

Subtask 3.4
Control, Monitoring, and Data Acquisition Software
Barry Freifeld – LBNL
IMS Gantt Chart

On schedule to meet project milestones
Bibliography

- No publications yet. AGU abstract submitted for Fall 2017 Conference.