CCSMR Task 2: SOV/DAS (Part 2)

High-precision seismicity tracking for augmenting the active CO2 plume monitoring

Project ESD14095

Stas Glubokovskikh¹, Julia Correa¹ and Roman Pevzner², Pavel Shashkin², Boris Gurevich²

¹Lawrence Berkeley National Laboratory
²Curtin University

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022
Why monitor microseismicity?

1. Contamination of aquifers
2. Ground subsidence
3. Felt seismicity is bad PR

VS.

Only 4 documented cases of seismicity:
- In Salah (Algeria) fractured caprock
- Decatur (USA) - basement faults
- QUEST (Canada) - basement faults
- And…
Why monitor microseismicity at Otway?

Previous twin injection triggered seismicity

1. Triggered seismicity augments the active containment monitoring program and
2. Informs conformance reservoir simulations

Induced events triggered at a subseismic fault by a small Stage 2C plume
Why monitor microseismicity at Otway? We have HQ SOV/DAS to explain the triggering

3. Continuous SOV/DAS snapshots provide insights into the triggering mechanisms

[Plume contours picked from the SOV/DAS data]

[Plume anomaly]

[Pevzner et. al. 2021]
Detected Events:
High signal-to-noise ratio of the DAS data

- Iterative data scanning detected 24 events in ~2yr
- HQ data: sensitive in full frequency range some injection noise

6 events automatically detected in CRC-4
Hypocenters Location:
The travel-time curves locate microearthquakes

- Travel-time curves in all 5 wells are used to locate the origin of all microseismic events
- Velocity model relies on the analysis for SOV/DAS continuous monitoring system
Hypocenters Location:
The uncertainty is relatively small (not vanishing)

- Uncertainty of the hypocenters location ~ 70 m, aligned with SW-NE direction
The Final Catalog:
Three clusters of seismicity in space-time

- Uncertainty of the hypocenters location ~ 70 m, aligned with SW-NE direction
Focal Mechanisms:
Geometry of the fault and slip from first motions

- Radiation pattern (beachball) = fault geometry \( \times \) slip direction
- Magnitude (\( M_W \)) = fault size \( \times \) slip displacement
Focal Mechanism:

P-wave for an $M_W - 0.5$ matches the theory

An event on all DAS wells
Focal Mechanism:

S-wave for this event validates the inversion

Picking is hard!
Benefits of the multiwell DAS system:
high SNR + angular coverage + channel number

**BETTER** detection + hypocenters + focal mechanisms + magnitude

Event # 5 $M_w - 0.5$

 Receivers for a typical situation: 1 injector + 1 M&V
Magnitude estimation:
Calibration of the DAS amplitudes using local EQs

A cluster of $M_L \sim 3$ earthquakes in Apollo Bay on DAS vs SEISMOMETERS

S1.AUHPC has the same radiation pattern overprint and propagation path
Magnitude estimation:
Calibration of the DAS amplitudes using local EQs

A cluster of $M_L \sim 3$ earthquakes in Apollo Bay on DAS vs SEISMOMETERS

S1.AUHPC has the same radiation pattern overprint and propagation path

Calibration: Need to multiply by factor $\sim 8$
Timing of the seismicity:
Most events are triggered by the CO$_2$ flow

28-May-2021
Timing of the seismicity:
Most events are triggered by the CO$_2$ flow
Timing of the seismicity:
Most events are triggered by the CO$_2$ flow
Timing of the seismicity:
Most events are triggered by the CO$_2$ flow
Stage 3 vs Stage 2C events:
Same location + Same moment tensor
Stage 3 vs Stage 2C events:
Timing is also related to the plume movement

Stage 2C injection pressure

Stage 2C AZMI

4D seismic and simulations show when the CO\textsubscript{2} plume reached the fault for the first and second time
Future Work:
Plume imaging with ocean-generated signals

Repeatable signals during 80 days of monitoring in Otway

1 Hz local microseisms

Relatively high-frequency surf breaks
Accomplishments to Date:
Multi-well DAS can accurately track seismicity from a small CO$_2$ injection

– Detected/located 17 induced microseismic events at Stage 3
– Developed an original workflow for the moment tensor inversion
– Established the relationships between the triggered events and anomalies in SOV/DAS and 4D VSP
Lessons Learned

- Cemented engineered fiber is a sensitive tool for high-precision tracking of low-magnitude seismicity.
- Low-magnitude → high-frequency, which means dense sampling.
- Important to have perforation shots or calibrated downhole sensors for amplitude interpretation.
- Seismically invisible faults may pose a risk of felt seismicity.
- CO$_2$/rock interaction in conventional aquifers may be real.
Appendix
Project Summary

- Time-lapse VSP acquired with SOV can be used to conduct continuous reservoir monitoring (with automated acquisition and data processing);
- Acquiring VSP surveys using DAS and SOV sources offers an alternative to surface vibroseis surveys for TL monitoring;
- DAS/SOV provide datasets sufficient to image injection depth;
Benefit to the Program

• 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.
• Successful development of SOV-DAS will enable more cost effective monitoring and can serve to either reduce or replace more expensive traditional 4D seismic methods.
• Simultaneous acquisition of active and passive seismic monitoring is a step towards monitoring the CO2 plume using ambient noise
Synergy Opportunities

– SOVs will be used in the Eagle Ford Shale Laboratory project (Texas A&M, LBNL)
– The ADM CCS project used SOV/DAS based monitoring
– Enhanced geothermal system (EGS) projects, such as at FORGE, could benefit from the oriented $S_H$ SOV to identify anisotropy and evaluate fracture stimulation
– University of North Dakota EERC (Energy and Environmental Research Center) SOVs at Bell Creek Field, Montana
– Red Trail Energy continuous monitoring with DAS/SOV
Project Overview

Goals and Objectives

• Project Goal: To improve the performance of SOV-DAS by trialing new field hardware and data processing methodologies. Develop best practice and guidance for incorporating SOV-DAS into permanent reservoir monitoring programs.

• This project will be considered a success if it is able to improve SOV-DAS performance such that it provides equal or better quality data as compared to current state-of-the-art approaches to seismic acquisition.

• Leverage from active seismic and passive seismic components of the DAS acoustic data
Organization Chart

- Julia Correa, LBNL Task Leader
- Julia Correa, LBNL, SOV/DAS data processing and analysis
- Stanislav G, LBNL, microseismic data analysis
- Todd Wood, LBNL, Electrical engineering and software development
- Michelle Robertson, Project Scientists – field logistics and operations management

Collaborators:
- Curtin University (Roman Pevzner lead scientist for Otway Stage 3 experiment)
- CO2CRC (Paul Barraclough Project Leader for Stage 3)
# Gantt Chart for LBNL Target Research Program

<table>
<thead>
<tr>
<th>Task</th>
<th>Milestone Description*</th>
<th>Fiscal Year 2021</th>
<th>Planned Start Date</th>
<th>Planned Completion Date (Reporting)</th>
<th>Actual Start Date</th>
<th>Actual End Date</th>
<th>Comment (notes, explanation of deviation from plan)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1 Q2 Q3 Q4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Milestone 2-1 (A)</strong></td>
<td>Acquisition of SOV/DAS signature tests</td>
<td>Q3FY22 x</td>
<td>Started</td>
<td>6/30/2022 (7/31/2022)</td>
<td></td>
<td></td>
<td>Completed as reported in Q3FY22 report.</td>
</tr>
<tr>
<td><strong>Milestone 2-2 (B)</strong></td>
<td>Analysis of SOV/DAS signature tests</td>
<td>Q4FY22</td>
<td>Started</td>
<td>9/30/2022 (10/31/2022)</td>
<td></td>
<td></td>
<td>Underway.</td>
</tr>
<tr>
<td><strong>Milestone 2-3 (C)</strong></td>
<td>Joint analysis of passive DAS and active DAS-SOV data</td>
<td>Q4FY22</td>
<td>Started</td>
<td>9/30/2022 (10/31/2022)</td>
<td></td>
<td></td>
<td>Partially completed.</td>
</tr>
</tbody>
</table>


Bibliography


