CCSMR Task 2: SOV/DAS (Part 1)
(FWP-ESD14095)

Permanent monitoring of a CO_2 plume using permanent seismic sources and fiber-optics sensing

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Contributors

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- **CO2CRC**: Paul Barraclough
- **Class VI Solutions, Inc**.: Barry M. Freifeld

Project Overview: Goals and Objectives

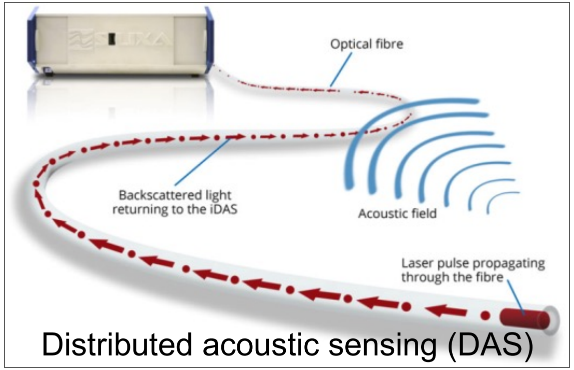
- Project Goal:
  - To build a cost-effective technology for long-term timelapse seismic acquisition using autonomous seismic sources and receivers (SOV-DAS).
  - To improve the performance of SOV-DAS by trialing new field hardware and data processing methodologies. Develop best practice and guidance for incorporating SOV-DAS into permanent reservoir monitoring programs.
  - Leverage from active seismic and passive seismic components of the DAS acoustic data
- 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.

Subsurface Monitoring with SOV-DAS

Conventional campaign-based systems
Temporally sparse / **Spatially** dense

SOV-DAS permanent monitoring system
Temporally dense / **Spatially** sparse

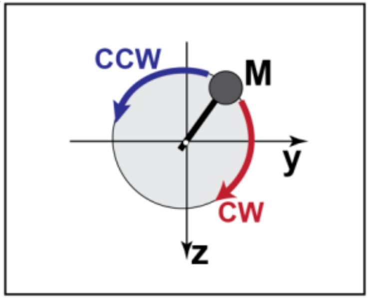
Surface orbital vibrator (SOV)



Distributed acoustic sensing (DAS)

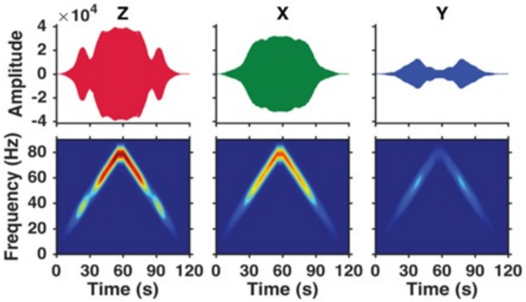
What is a surface orbital vibrator (SOV)?

Rotation of eccentric mass
=> force ~ f^2



An SOV can rotate clockwise (CW)
or counter-clockwise (CCW)

1st generation SOV
8-80 Hz



3C Reference geophone buried 3 m
below records a sweep

2nd generation SOV
8-105 Hz

[Correa et al 2021, Geophysics]

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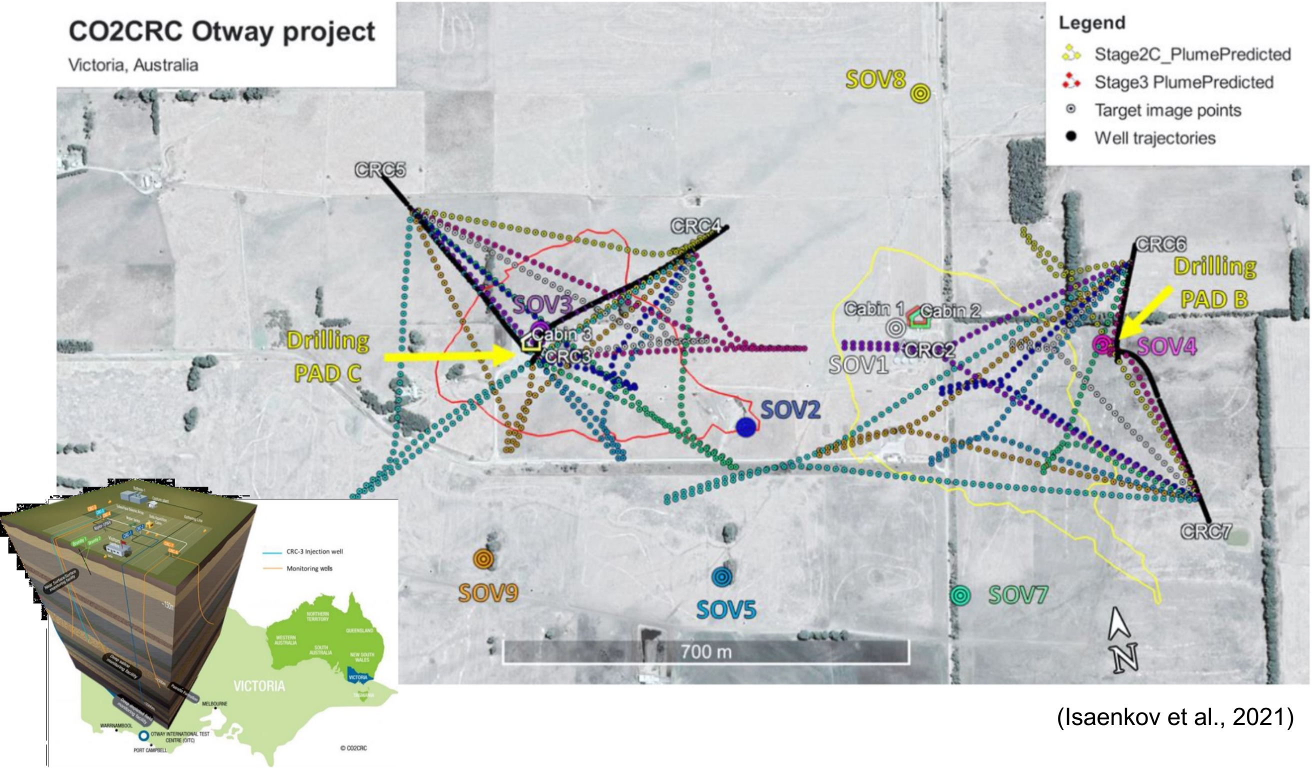
Why SOV-DAS?

- **Cost-effective** solution for long-term seismic monitoring when compared to conventional 4D seismic acquisition
- **Remote**, **on-demand** seismic acquisition
- Enables **real-time data processing** and analysis, leading to fast decision making
- **High temporal sampling** enables the detection of small changes
- Active and passive seismic with **potential for simultaneous monitoring of induced seismicity**

SOV/DAS demonstration: Otway Project Stage 3

Seismic coverage from DAS/SOV permanent system

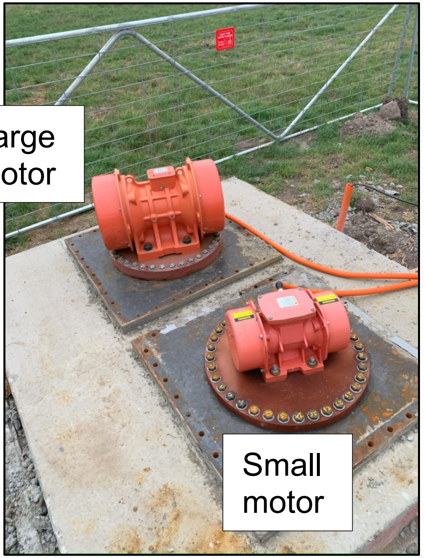


(Isaenkov et al., 2021)

Objectives of experiment:

- Demonstrate **continuous and automated seismic acquisition** using DAS/SOV system
- Demonstrate automated seismic processing for **rapid plume evaluation**
- **Decrease acquisition footprint and societal impact** from seismic acquisition

Installation of additional seven SOV locations – new SOV design



Large motor

Small motor

Control board

Adjustable weight setting

Old motor version

Permanent set-up

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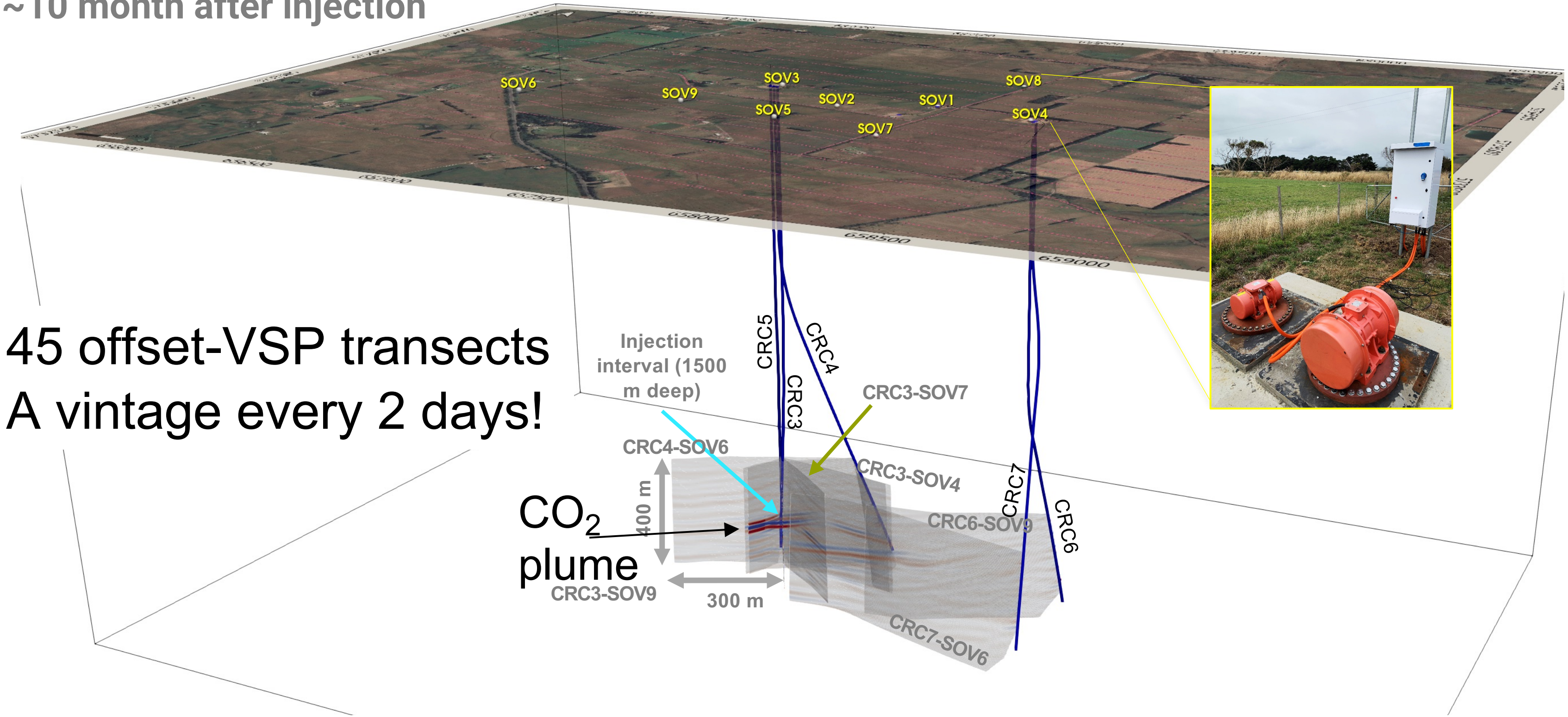
CO_2 monitoring using SOV/DAS: Otway Project Monitoring

24/08/2021
~10 month after injection

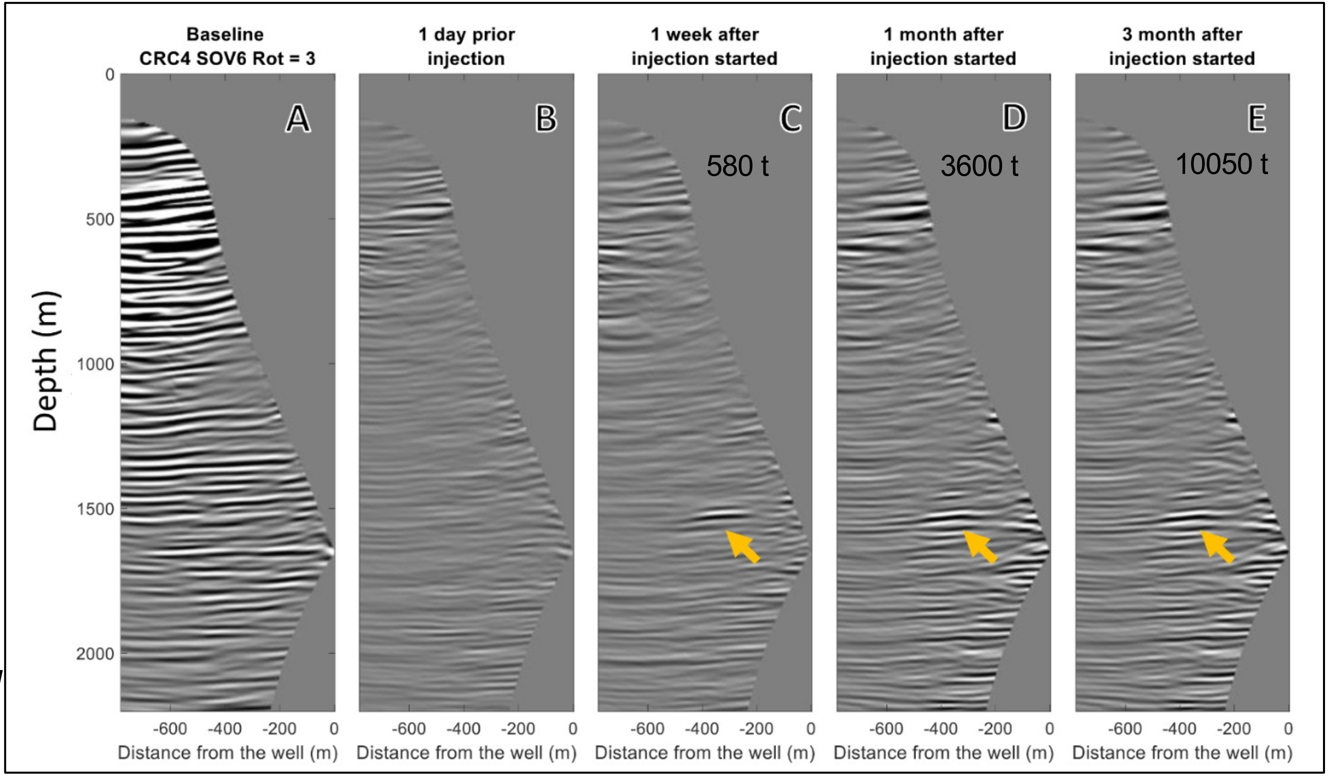
45 offset-VSP transects
A vintage every 2 days!



[Pevzner et. al. 2021]

Baseline and difference seismograms after migration

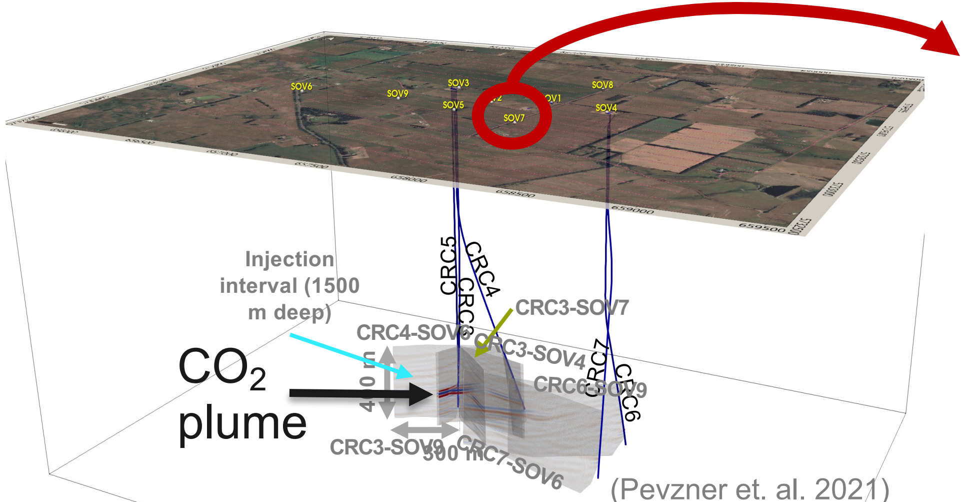
Detection of CO_2 plume after 580 t injection



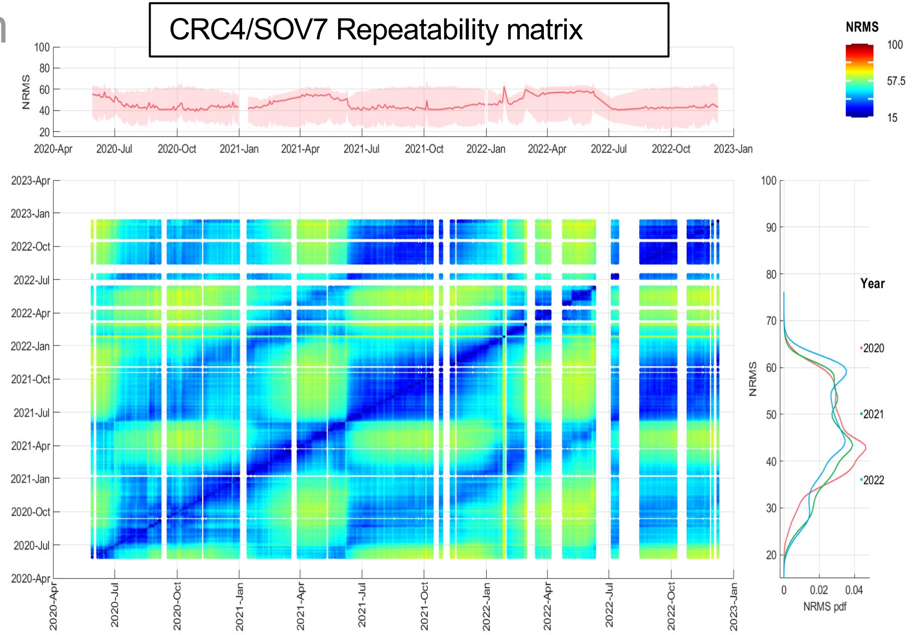
[Pevzner et. al. 2021]

Long-term repeatability analysis

Repeatability over the 3 years of operation



(Pevzner et. al. 2021)



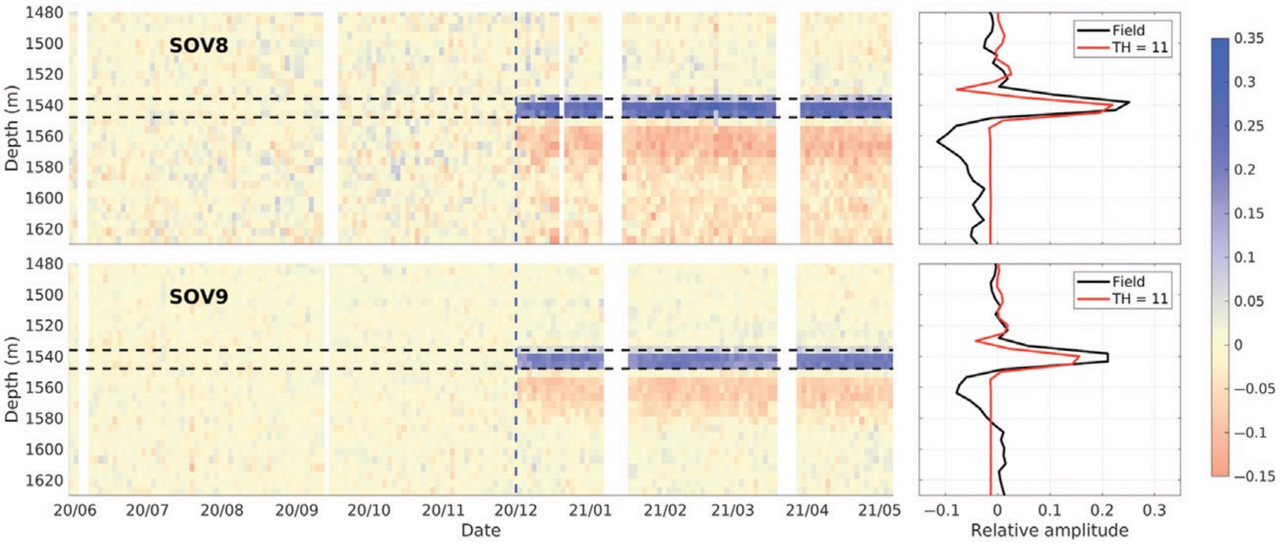
- 15 kt of CO2 injected at 1500 m depth
- 9 SOVs on the surface and 5 fiber wells
- Automated and continuous CO2 plume monitoring
- 45 x 2D seismic images intersecting the plume every 2 days

- Changes between wet and dry seasons affects negatively repeatability values
- A good (long) estimation of background baseline (noise, frequency, velocity) is needed

SOV/DAS amplitude response to the repeated seismic signals *in-situ*

Amplitudes inside the plume provide a free repeat sonic logging tool

The presence of CO2 softens the formation, increases the strain produced by the same seismic signal



Can we also use the amplitudes of the direct P to infer on the geometry of the plume?

[Pevzner et. al. 2021, https://doi.org/10.1190/geo2021-0404.1]

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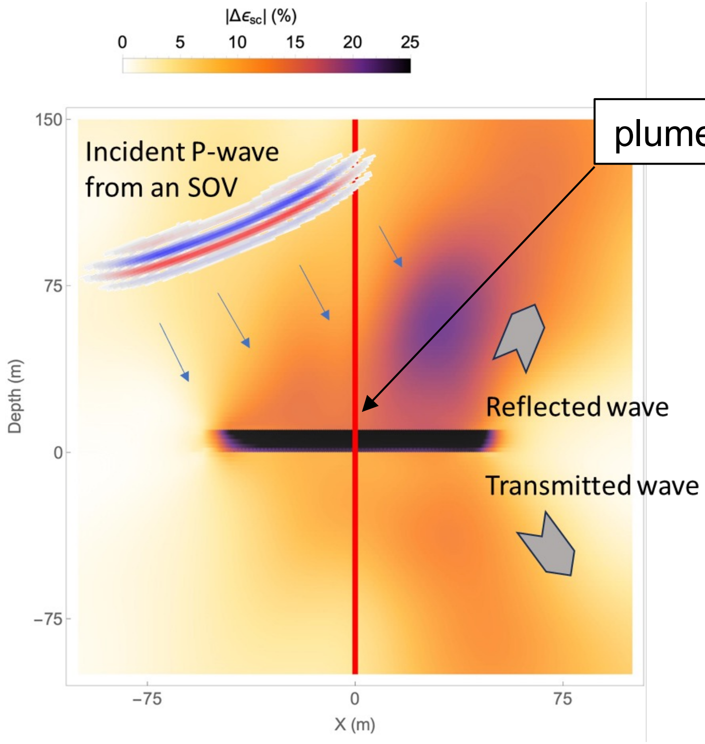
SOV/DAS amplitude response to the repeated seismic signals *in-situ*

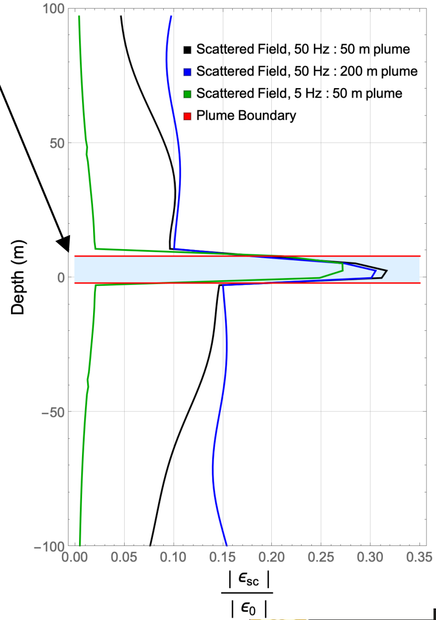
Modelling of the amplitudes relies on the near-field scattering

[Glubokovskikh et. al. 2023, AGU'23]

Vertical slice through the scattered wave filed, incident P-wave at 50 Hz



Monitoring DAS amplitudes through the center of the plume



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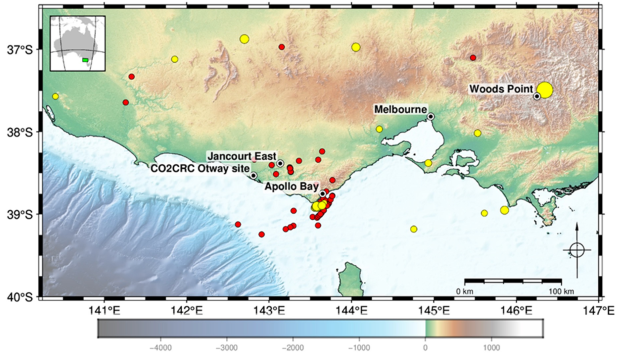
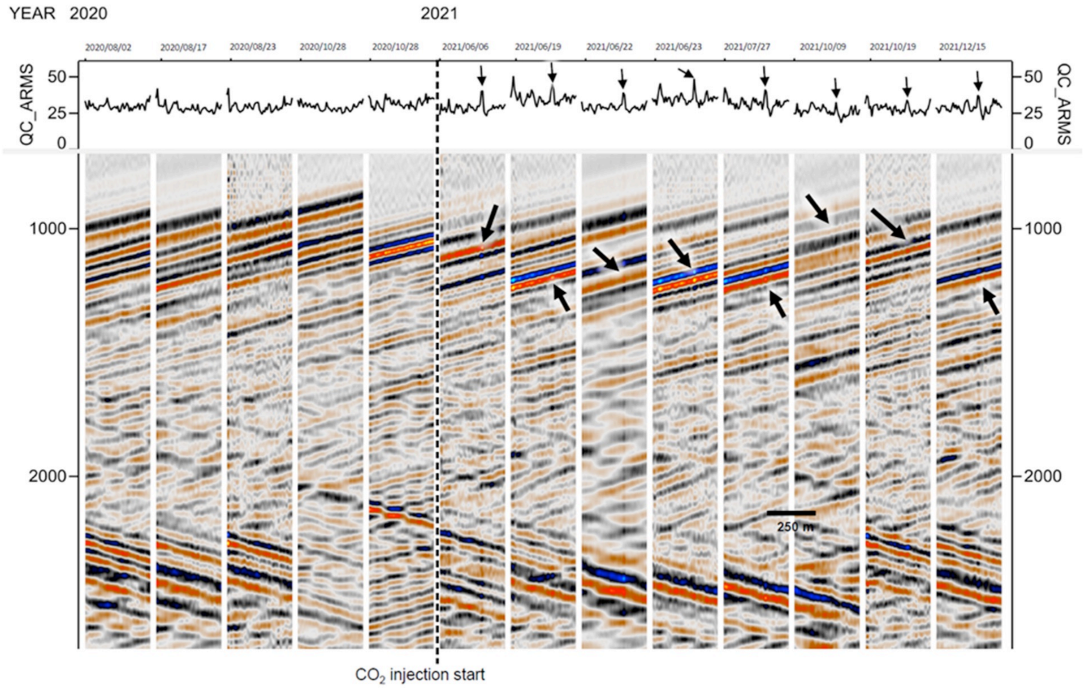
Earthquake DAS amplitude response *in-situ*

Regional earthquakes provide a free repeat sonic logging through the plume





[Shashkin et. al. 2022, https://doi.org/10.3390/s22207863]

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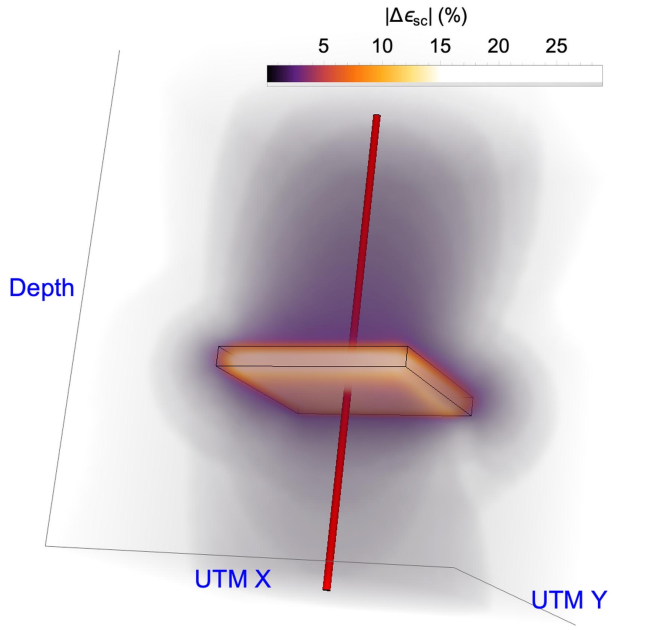
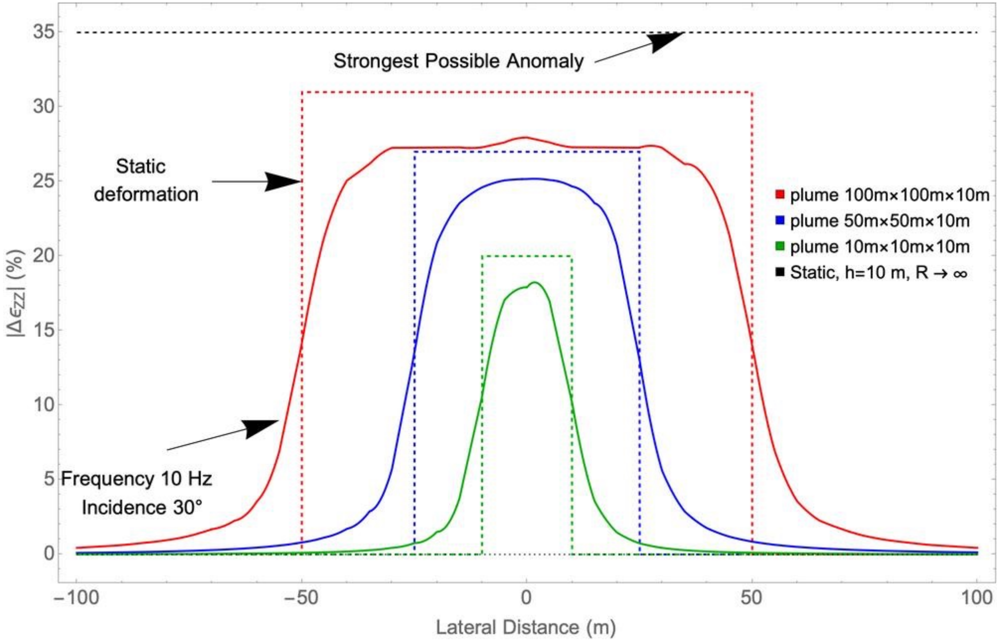
Modelling of the DAS amplitude response *in-situ*

Amplitudes inside the plume may be viewed as near-field scattering

3D scattered amplitude at 10 Hz from a small plume



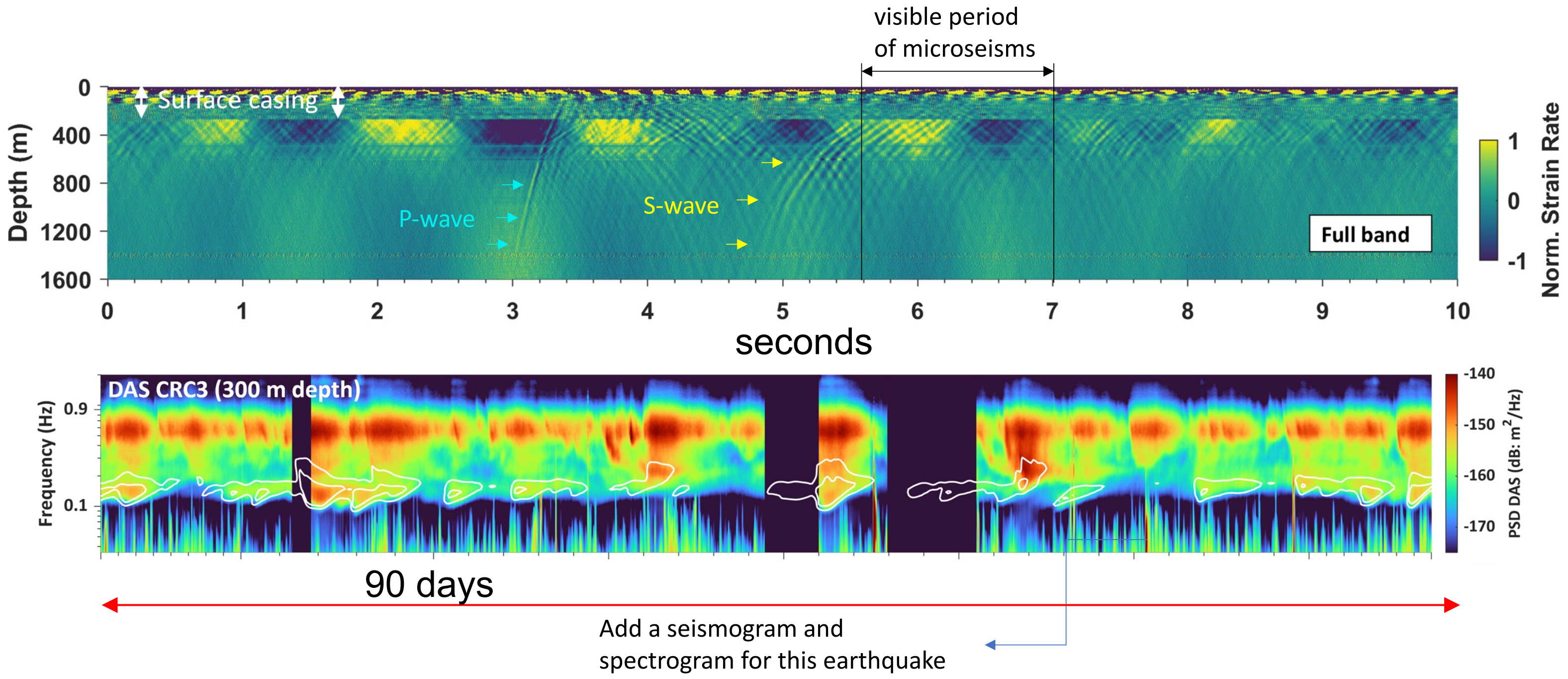
Given that we can see variations on the direct P due to the presence of CO_2, and these amplitude vary depending on the plume size, can we use that to monitor plume evolution?



[Glubokovskikh et. al. 2023]

Ocean-generated DAS amplitude response *in-situ*

Oceanic microseisms and surf breaks log through the plume constantly



[Glubokovskikh et. al. 2021, https://doi.org/10.1029/2020JB021463]

Key findings

- SOV-DAS generated highly repeatable signal, though, near-surface variations with season changes affect the repeatability
- At the Otway Project, we saw a clear change of DAS amplitudes within the CO_2 plume
- We can model it as near-field scattering by the reduced-stiffness reservoir
- DAS amplitude analysis within the plume enable repeat sonic logging for free
- … but calibration of the amplitude is needed to convert to saturation/pressure

Accomplishments to Date

- *Take away message*: Cost-effective, long-term and continuous seismic monitoring of a CO_2 injection can be successfully achieved with SOV/DAS

- Detection of the injected CO_2 plume with volume as low as 580 ton using the SOV/DAS data)

- Continuous operation since March 2020 with minimum down-time

- Remote operation and acquisition of SOV/DAS for quasi-real time monitoring

- Simultaneous passive monitoring for joint active/passive interpretation

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 with sufficient quality 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 CO_2 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 CO_2 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

Organization Chart

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

- Collaborators:
  - Curtin University (Roman Pevzner lead scientist for Otway Stage 3 experiment), SOV/DAS data processing and analysis
  - CO2CRC (Paul Barraclough Project Leader for Stage 3)

Gantt Chart for LBNL Target Research Program

Task	Milestone Description*		Fiscal Year 2021				Planned Start Date	Planned Completion Date (Reporting Date)**	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
		FY22	Q1	Q2	Q3	Q4					
Milestone 2-1 (A)	**Milestone 2-1:** Analysis of long-term SOV/DAS operation and source repeatability since March 2020	Q2FY23		x			Started	3/31/2023 (4/30/2023)			Completed. Reported in FY23Q2.
Milestone 2-2 (B)	**Milestone 2-2:** Analysis of the time-lapse signatures of the CO_2 injection in ocean-generated wavefield	Q3FY23			x		Started	6/30/2023 (7/31/2023)			Completed. Reported in FY23Q3.
Milestone 2-3 (C)	**Milestone 2-3:** Feasibility of subsurface imaging using injection induced microseismic events	Q4FY23					Started	9/30/2023 (10/31/2023)			Delayed.
Milestone 2-4 (C	**Milestone 2-4:** Experiment planning and design of leakage detection and cap integrity monitoring using fiber-optic sensing and SOVs in preparation for experiment	Q4FY23				x	Started	9/30/2023 (10/31/2023)			Partially completed.

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