# 2nd Generation SOV-DAS

## Task 2: Core Carbon Storage and Monitoring Research (CCSMR), Project ESD14095

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U.S. Department of Energy

National Energy Technology Laboratory

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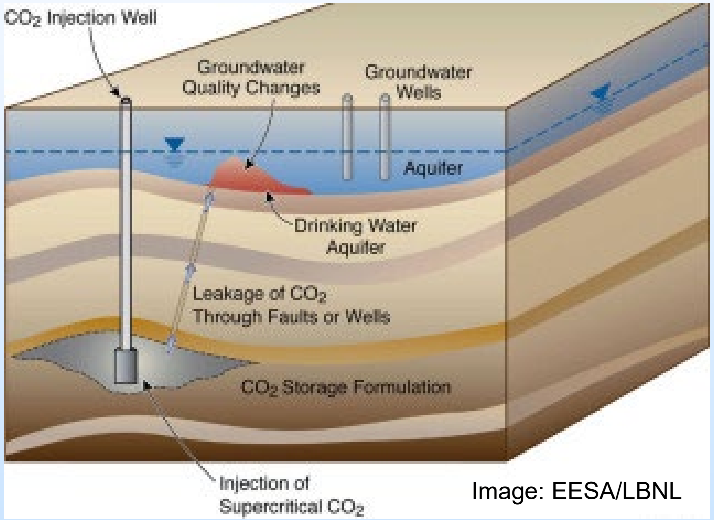
# Presentation Outline

- Motivation for SOV-DAS Technology
- Permanent monitoring at the Otway Project using SOV-DAS array
- 2nd Generation SOV-DAS
  - Signal-to-noise ratio
  - Automated processing
  - Repeatability
  - Frequency improvement
- Accomplishments and Lessons learned
- Project summary

# Motivation

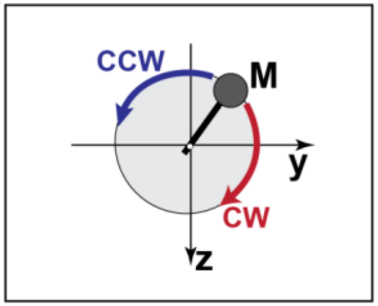
- Carbon Capture an Storage (CCS) requirements:
  - Ensure **safe containment** of the injected $CO_2$
  - Ensure there is **no $CO_2$ leakage** with time
- Continuous seismic monitoring
  - Improves understanding of **reservoir fluid flow**
  - Improves **temporal resolution**
  - Improves **safety** in operations
- We need to:
  - Find a **cost-effective solution** for real-time monitoring
  - Provide **minimally invasive** and **autonomously operated** technologies

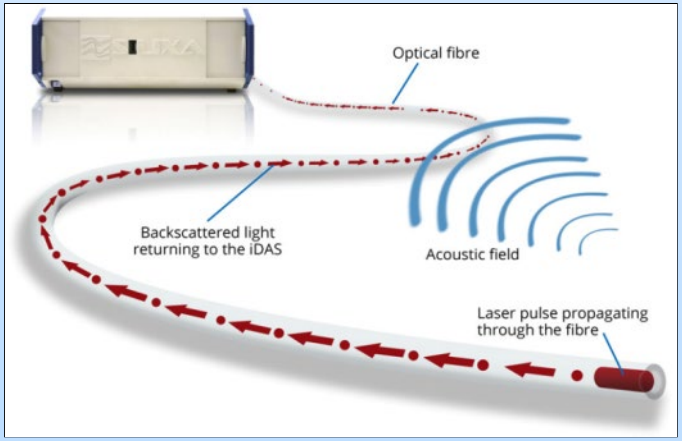


# Conventional Time-lapse Seismic vs SOV-DAS

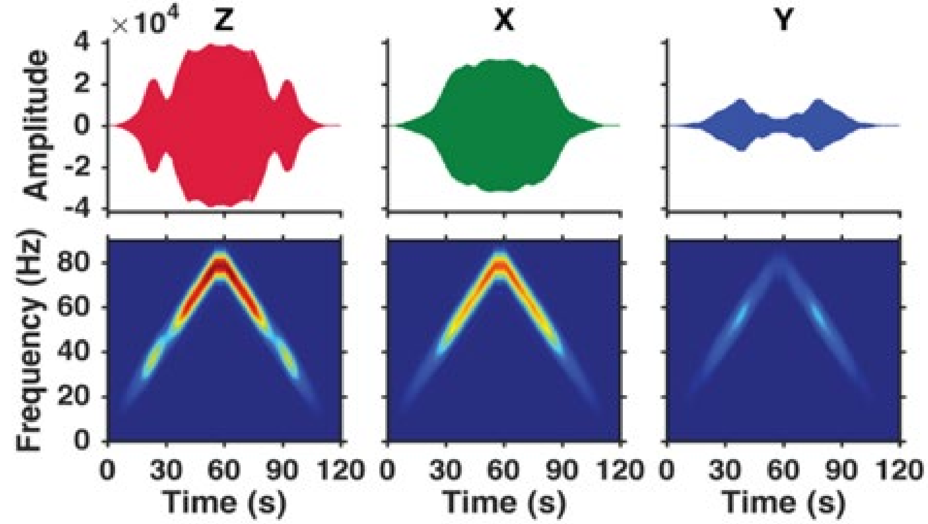
Conventional
campaign-based systems
**Temporally** sparse / **Spatially** dense

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

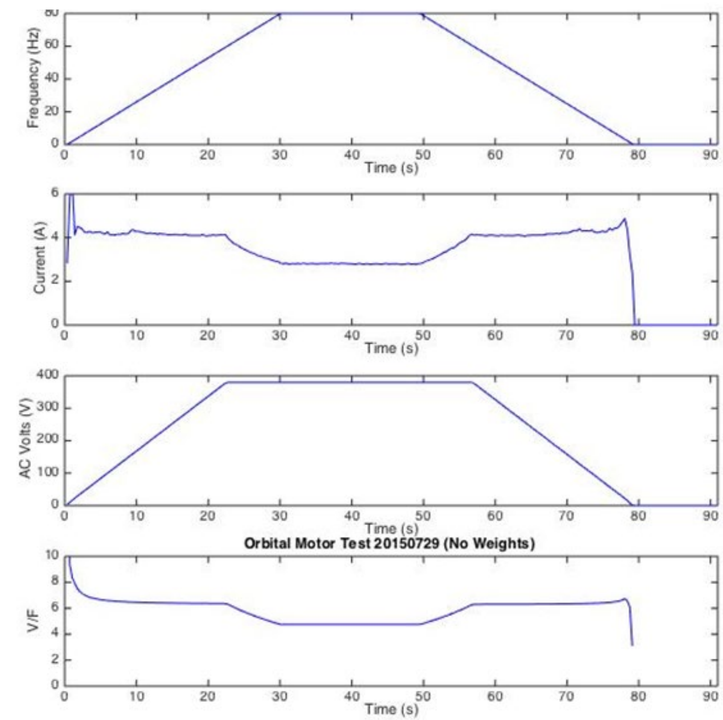
# **Surface Orbital Vibrator (SOV)** – Controlled AC Motor




Max Frequency  80 Hz, Force (@80Hz) 10 T-f
Operate 2.5 hr/d

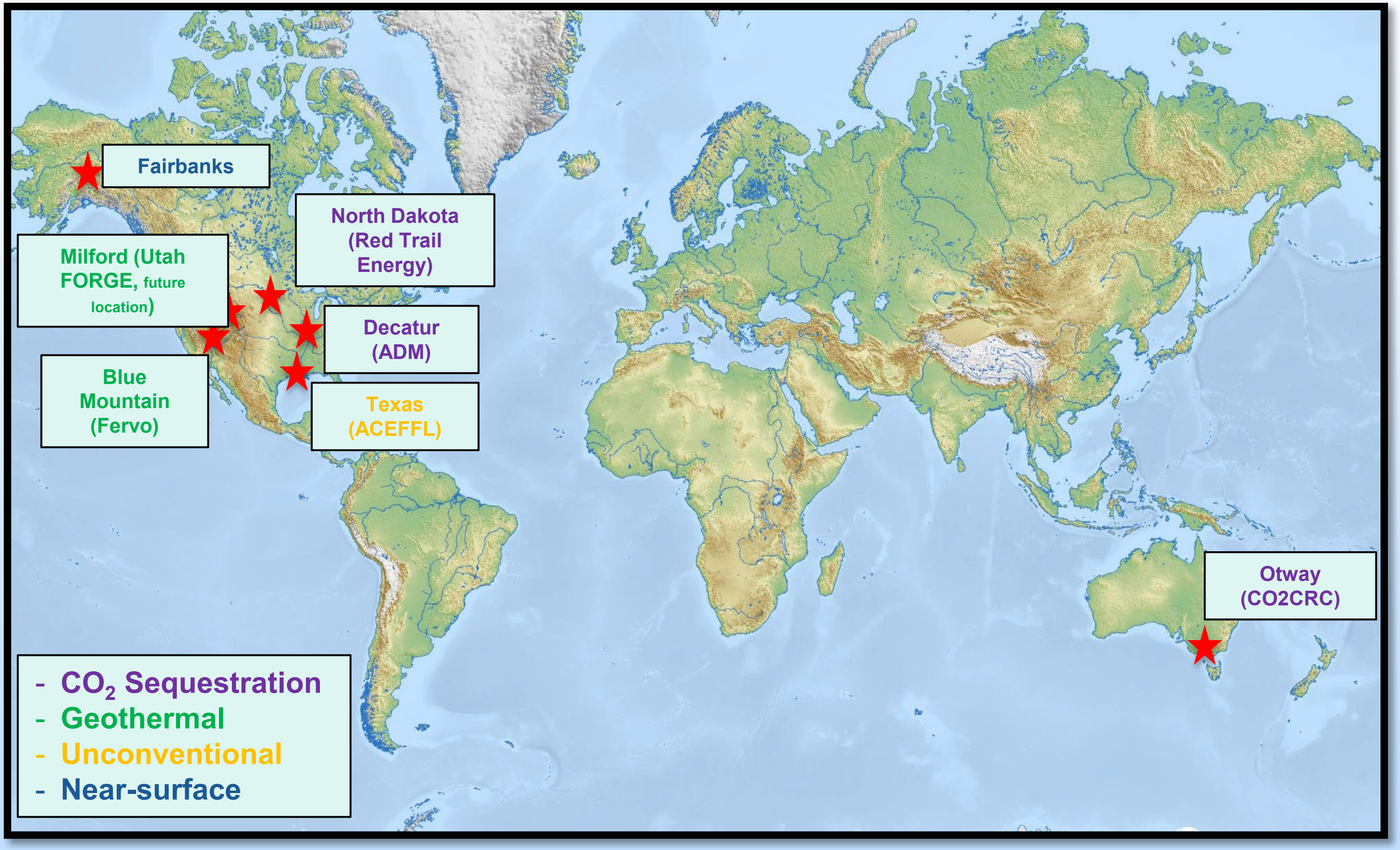
Force is adjustable

$F=m\omega^2r$

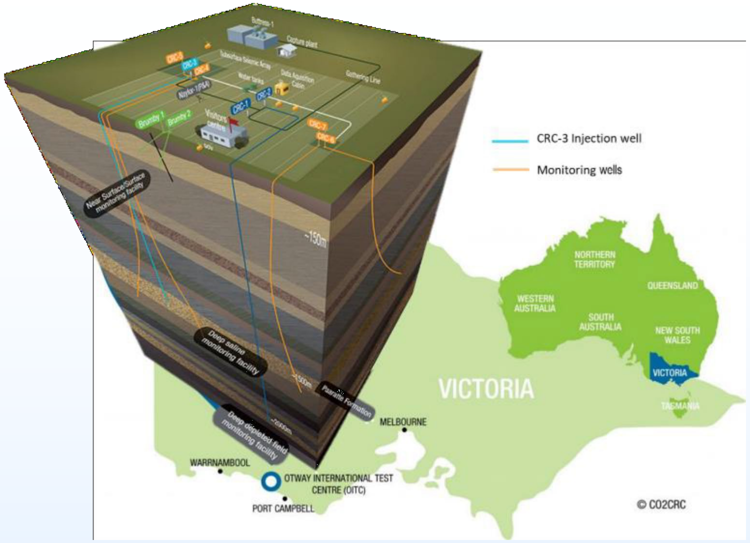


# SOV/DAS

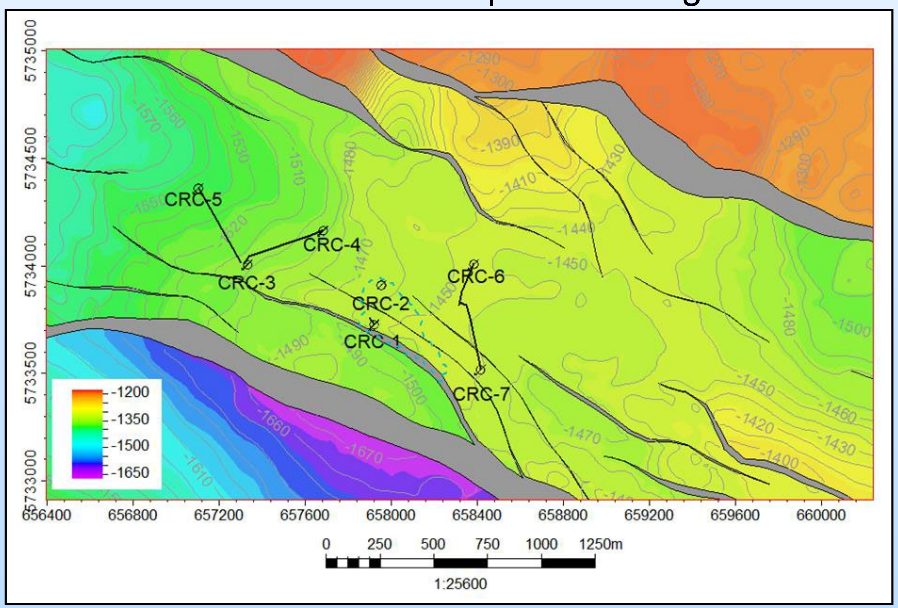
# locations and applications



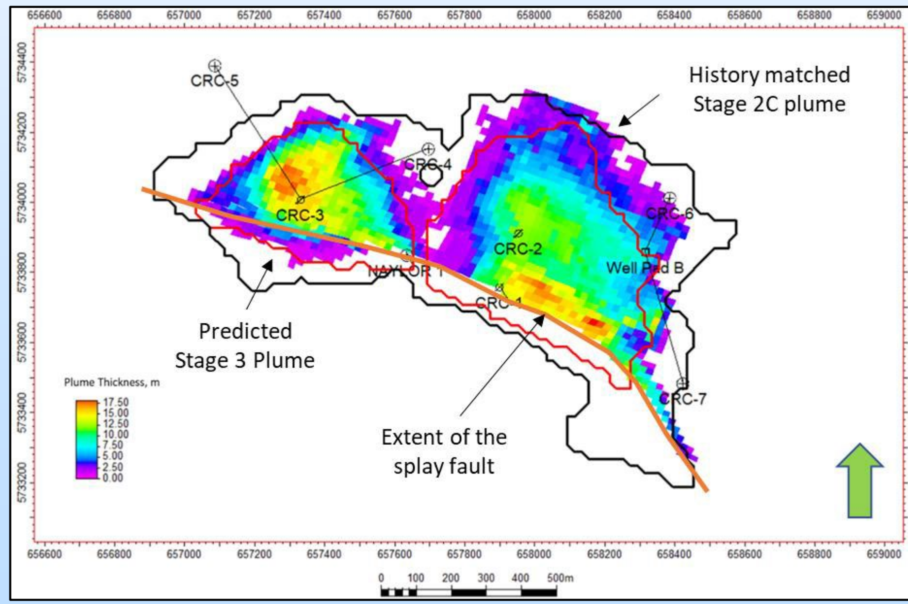
# CO2CRC Otway Project Stage 3




Well locations and trajectories over structure surface of Parasequence 1 target.



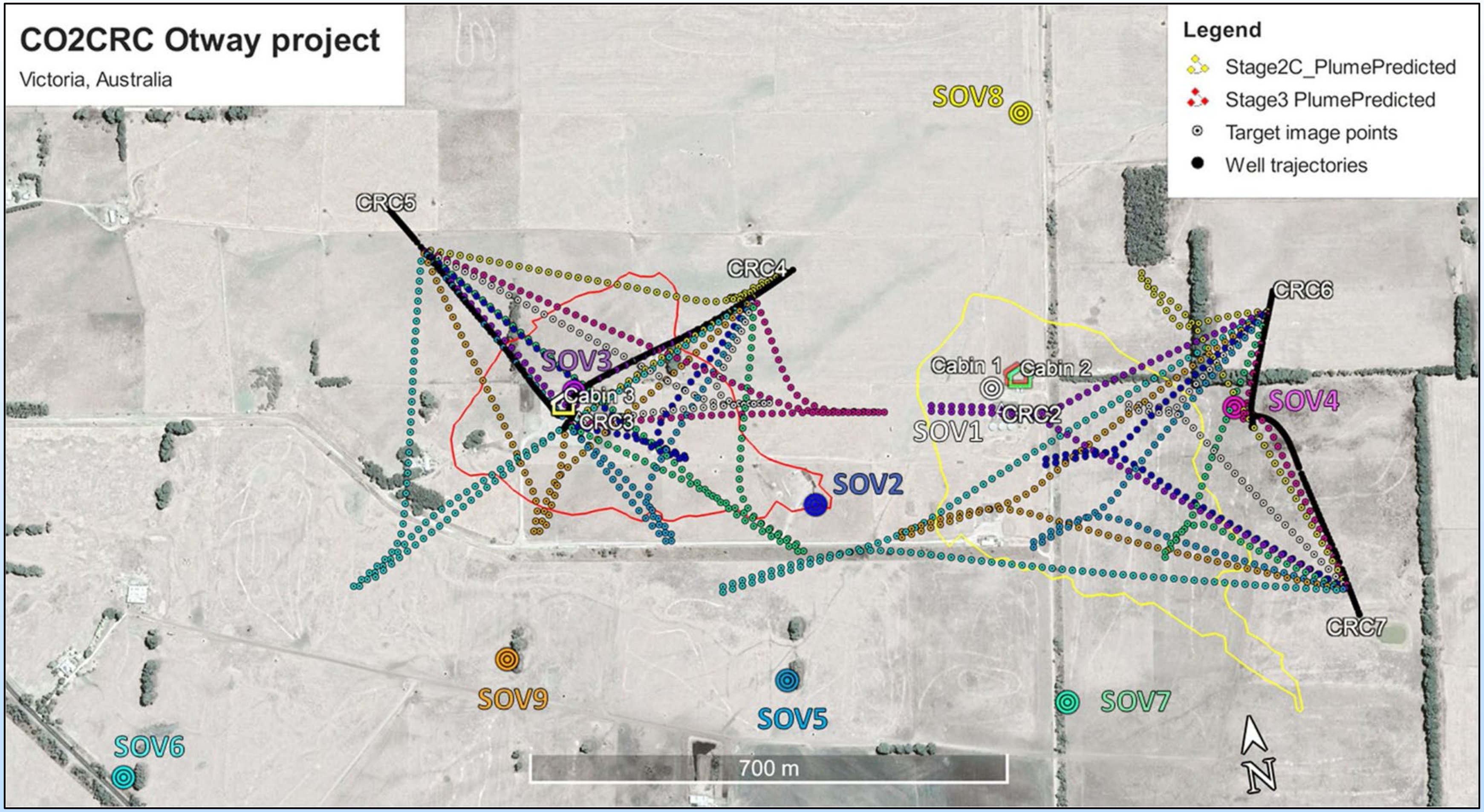

Plume modelling combining both Stage 2C and Stage 3 plumes. Black and red outlines are the P90 and P50 plume extents, respectively.




(Jenkins et al., 2021, *GHGT-15*)

# SOV-DAS

## Seismic array for every-day plume tracking

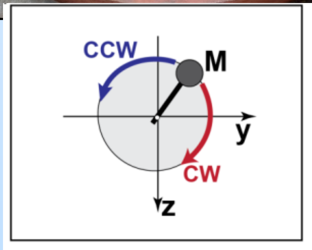



(Isaenkov et al., 2021)

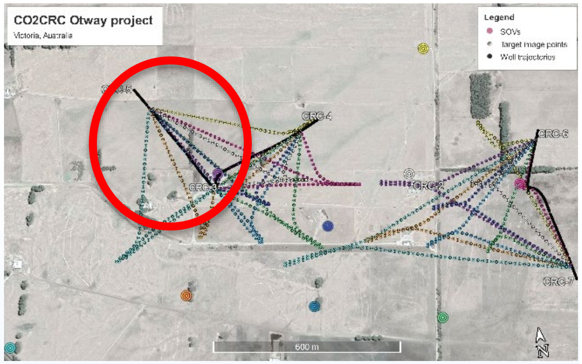
# Surface Orbital Vibrators advancements

**SOV 1st Generation** – SOV1 & SOV2 (deployed 2016)

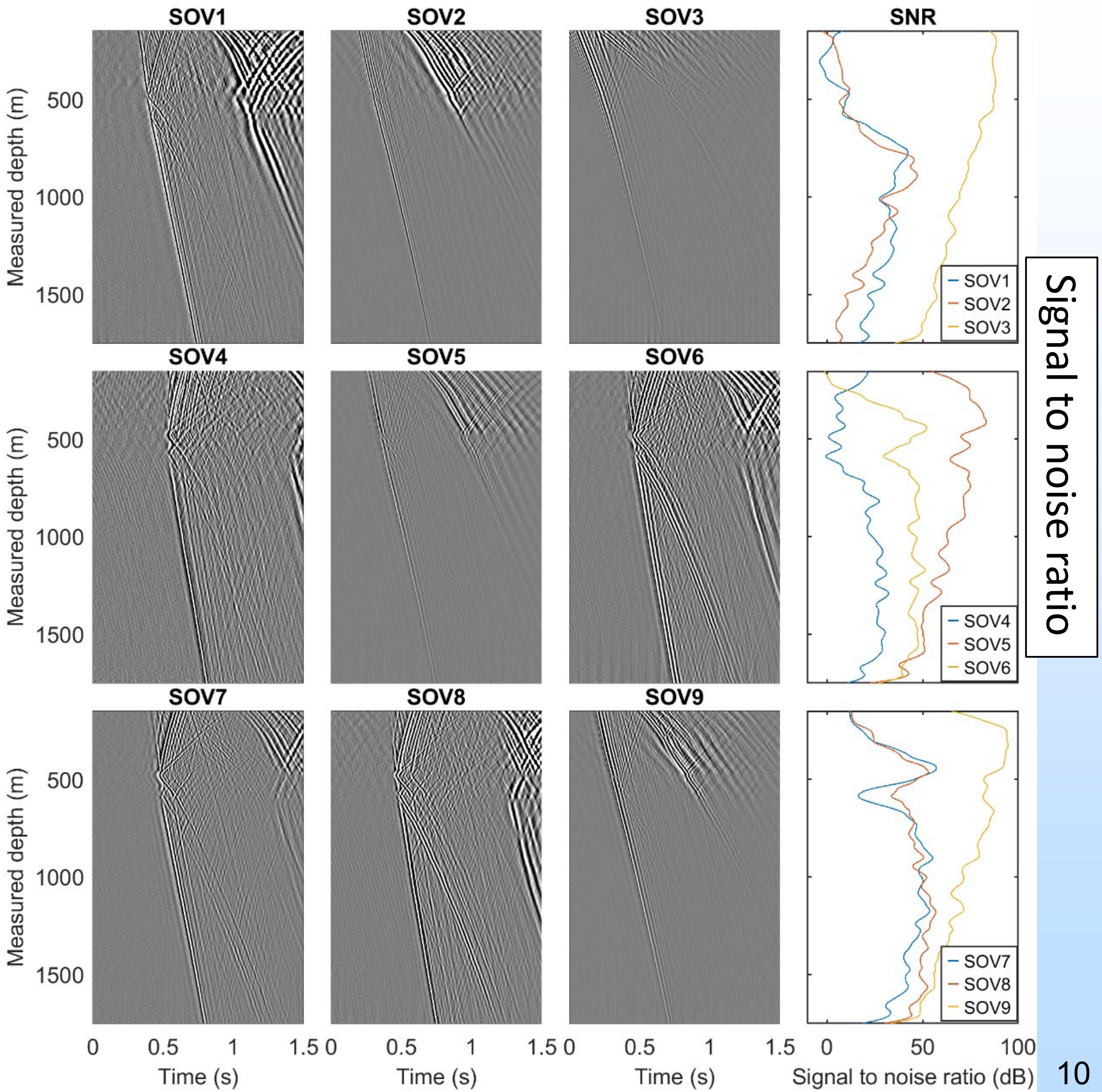
**SOV 2nd Generation**– SOV3 – SOV9 (deployed early 2020)



# SOV/DAS VSP data



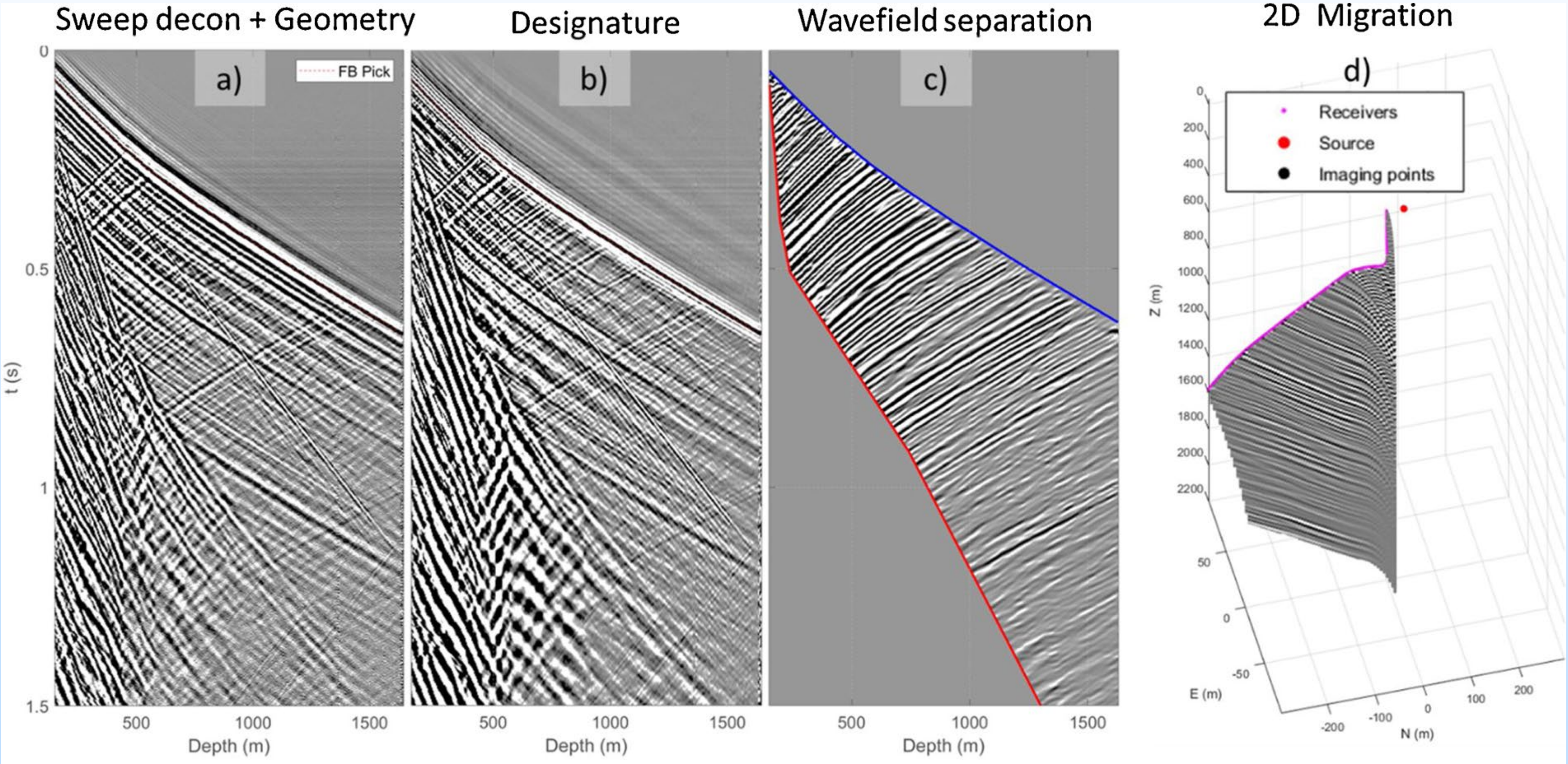

- SOV1 and SOV2 are single-motor (1st generation installation)
- SOV 3 to SOV9 are double-motor
- Signal-to-noise ratio is 50 db to 100 db at mid- to near-offset locations




(Correa et al., 2021)

# Automated processing

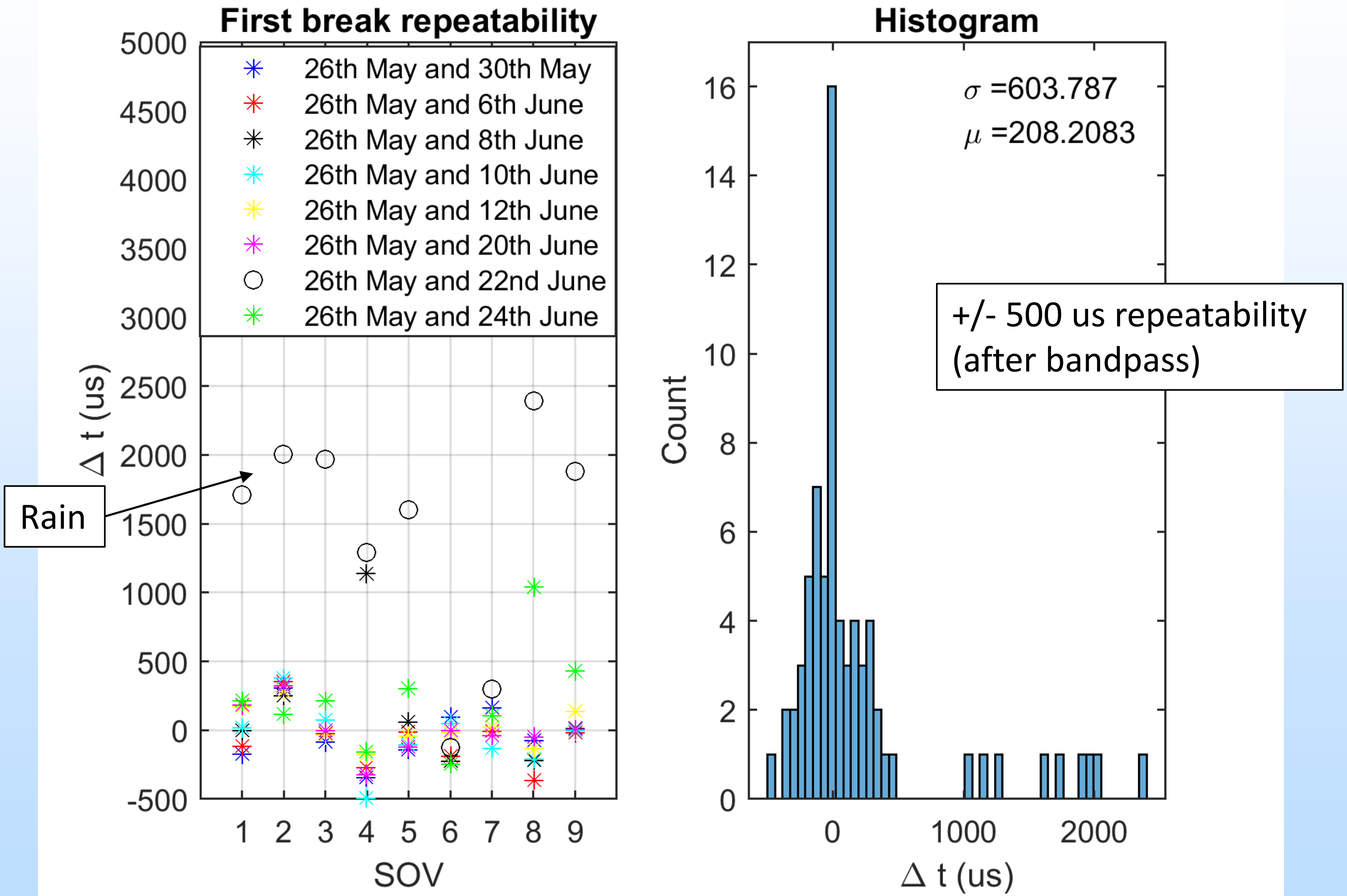
**Geometry** | **Signature deconvolution** | **Wavefield separation** | **2D Depth imaging**




(Isaenkov et al., 2021, *IJGG*)

$10^6$ data reduction

# DAS/SOV repeatability

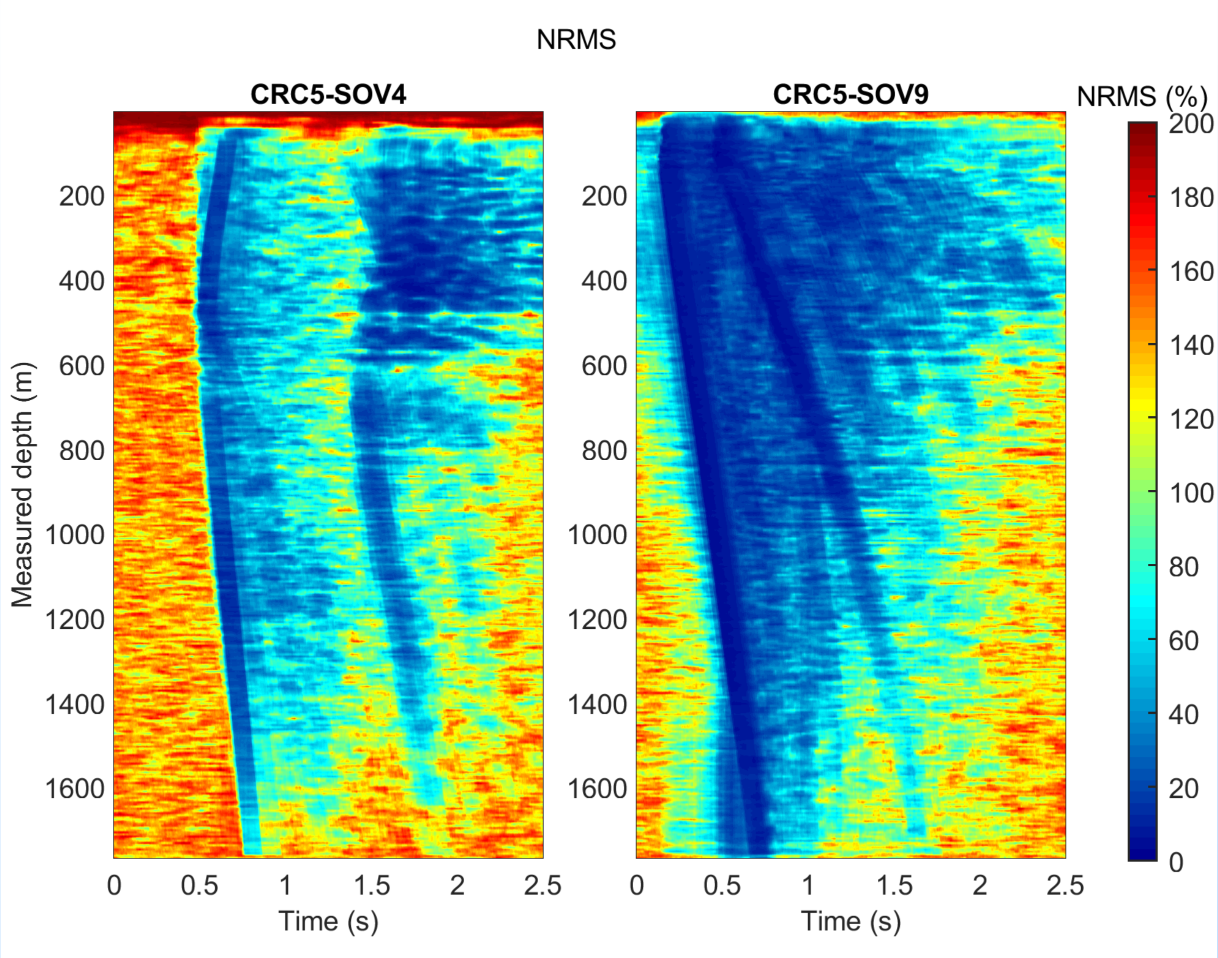



(Correa et al., 2021, *Geophysics*)

# DAS/SOV repeatability

- Far-offset example: CRC5-SOV4
- Near-offset example: CRC5-SOV9

$$NRMS = 200\frac{RMS(b-m)}{RMS(b)+RMS(m)}$$

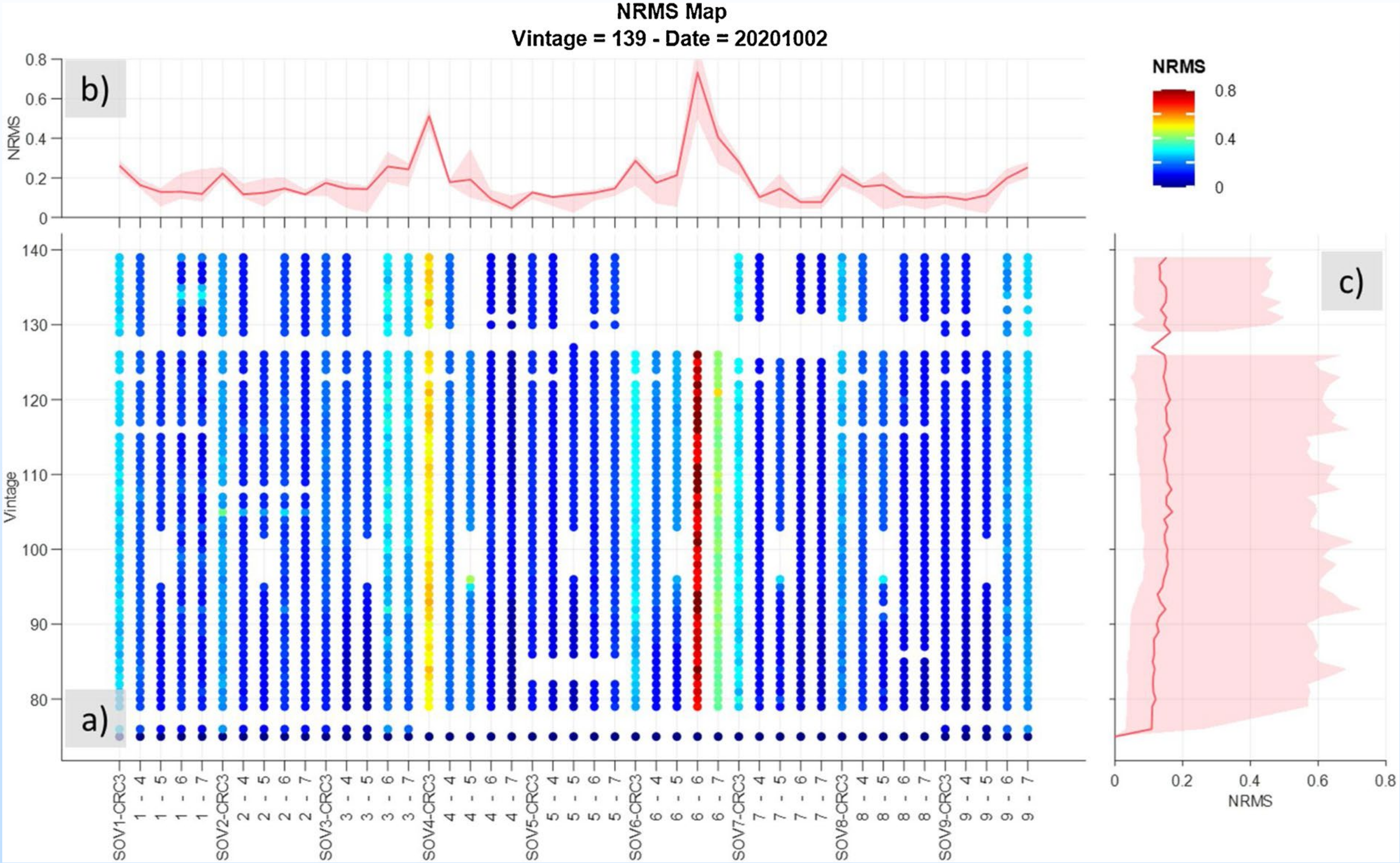



(Correa et al., 2021, *Geophysics*)

# DAS/SOV repeatability

## After processing (designature)

Days



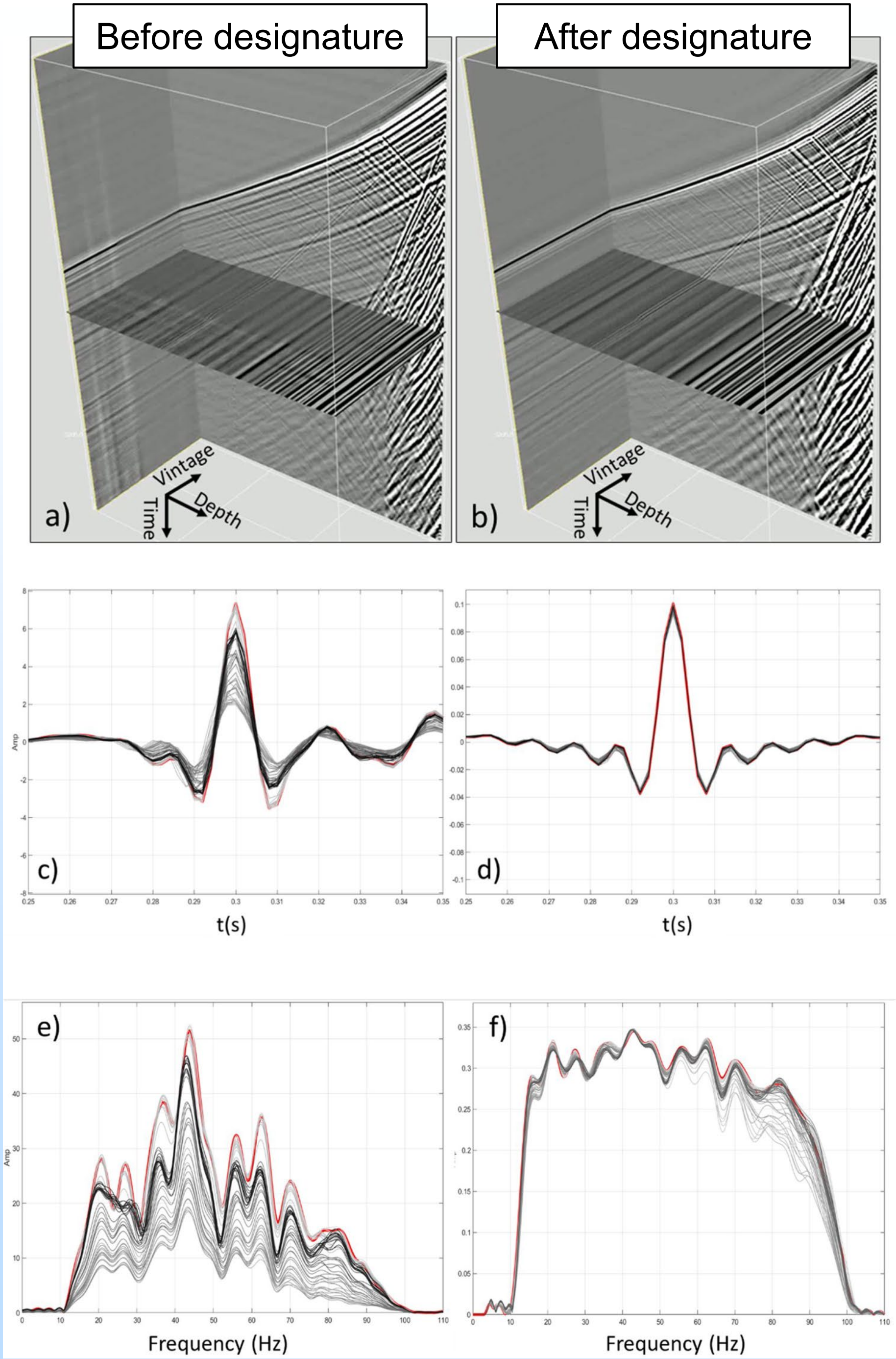

SOV – well pair



(Isaenkov et al., 2021)

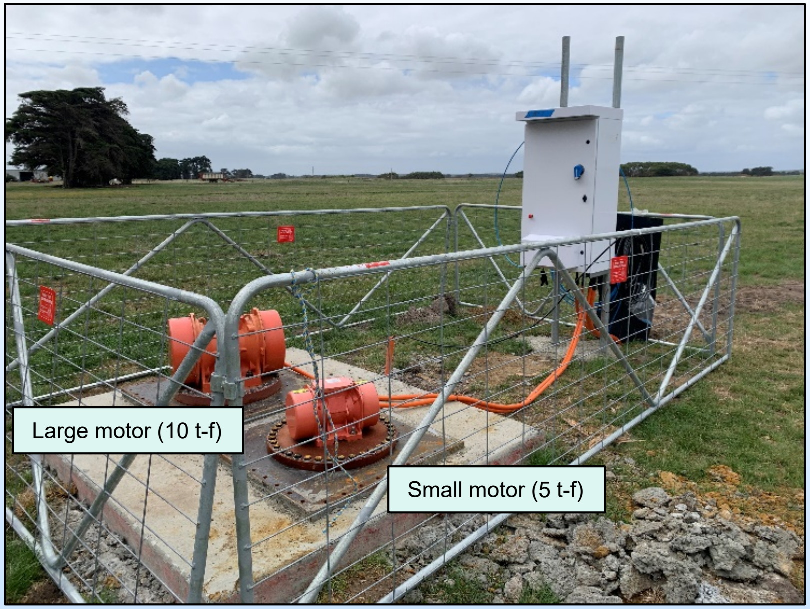
# DAS/SOV repeatability

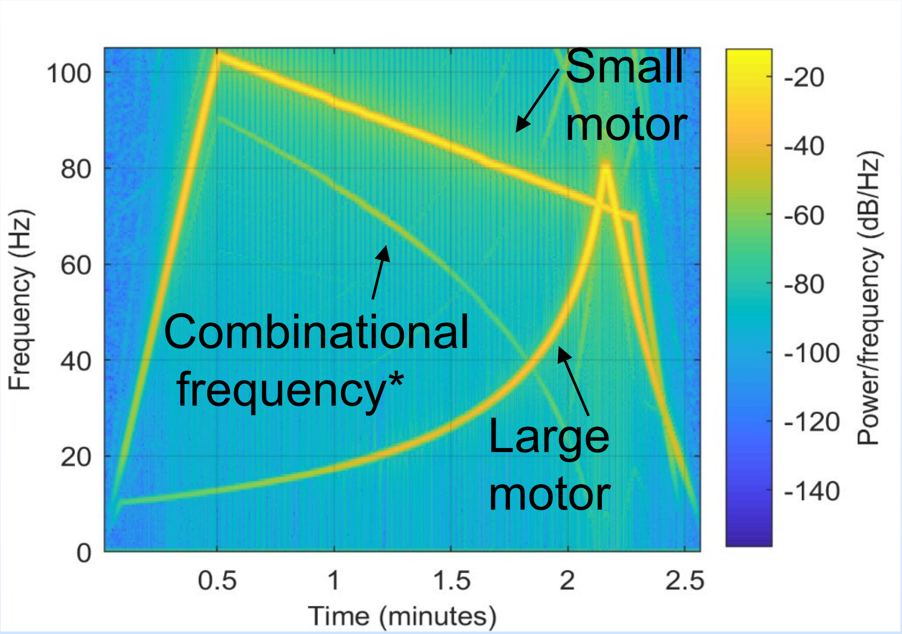
- “Vintage” axis shows seismic data in every two days
- Amplitude of the signal varies over time due to changes in the near surface
- Designature process is essential to improve repeatability
- “Slow-time axis” visualization offers easy way for detecting changes in the seismic signal over time




(Isaenkov et al., 2021)

# Dual-motor: Improving the frequency range



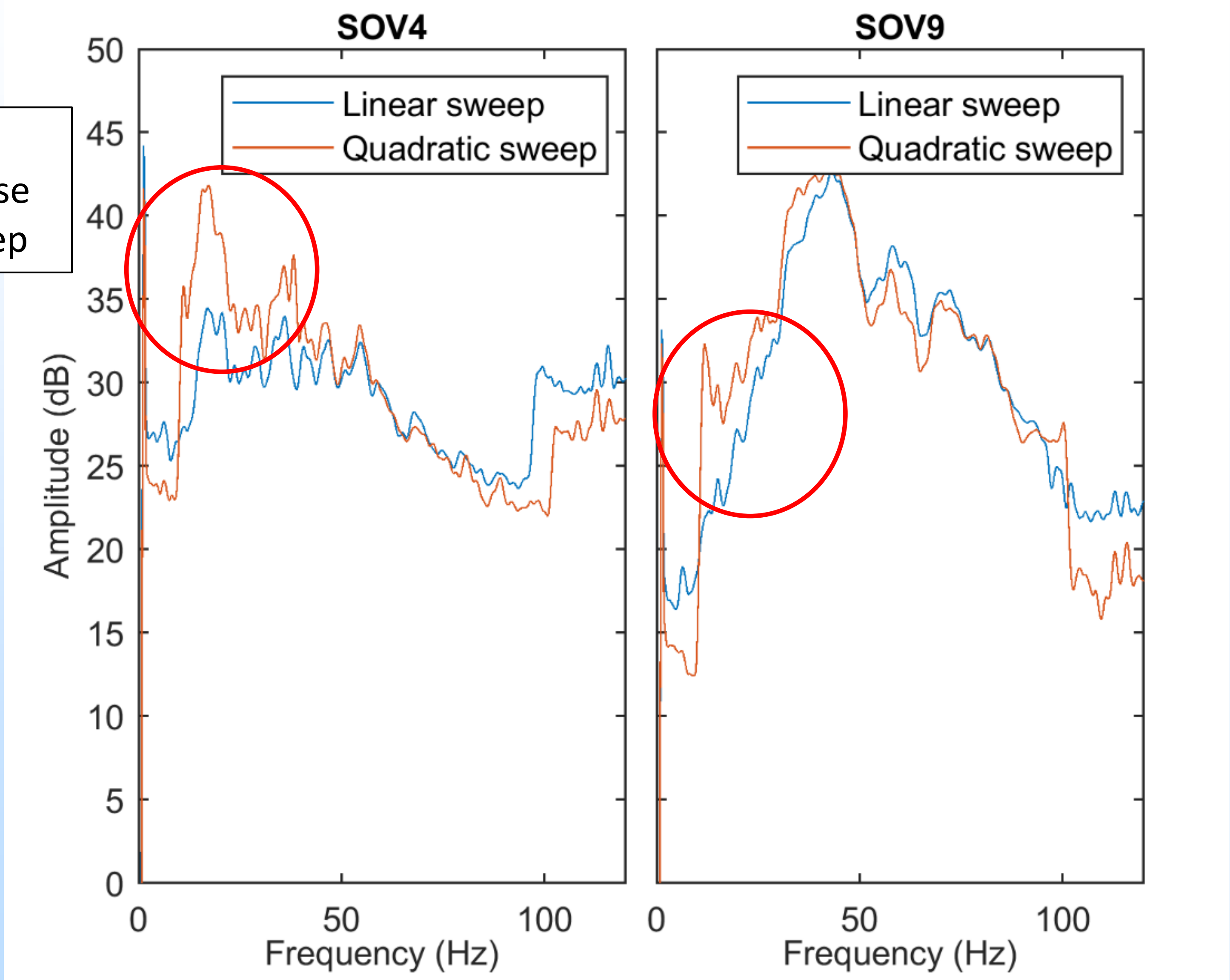




Can we use combinational frequency to augment source frequency range?

(Correa et al., 2021)

# Linear vs Quadratic sweep

Stronger low frequency response on quadratic sweep




(Correa et al., 2021)

# Accomplishments to Date

- Detection of the injected CO2 plume with volume as low as 580 ton using the SOV/DAS data (as reported in the FY21Q3 quarterly report)
- Quadratic sweep design allows for flatter frequency response at low frequencies
- Improved VSP repeatability with optimized seismic processing
- Remote operation and acquisition of SOV/DAS for quasi-real time monitoring
- Over a year of successful continuous operation

# Lessons Learned

– Near field geophone highly affected by near-surface conditions

– Repeatability of the SOV source signal should be further explored and understood

– Quadratic sweep design can improve frequency spectrum in the lower frequencies

– Interaction between the two motors could be further explored to improve the frequency range

# 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

# 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;

# Appendix

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

# 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.

# 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.

# Organization Chart

- Julia Correa, LBNL Task Leader
- Julia Correa, LBNL, Data processing and analysis
- Todd Wood, LBNL, Electrical engineering and software development
- Paul Cook, LBNL, Mechanical engineering
- 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

| Task | Milestone Description* | FY20 | Fiscal Year 2021 | | | | Planned Start Date | Planned Completion Date (Reporting Date)** | Actual Start Date | Actual End Date | Comment (notes, explanation of deviation from plan) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Q1 | Q2 | Q3 | Q4 | | | | | |
| **Milestone 2-1 (A)** | SOV/DAS optimized data processing and workflows | Q3FY20 | | | | | Started | 6/30/2020 (7/31/2020) | | | Completed as reported in Q3FY20 report. |
| **Milestone 2-2 (B)** | Data report on SOV/DAS baseline surveys and initial testing of 2nd Gen SOV | Q3FY20 | | | | | Started | 6/30/2020 (7/31/2020) | | | Completed as reported in Q3FY20 report. |
| **Milestone 2-3 (C)** | Data acquisition and analysis covering monitoring period | | | | x | | Started | 3/31/2021 (4/30/2021) | | | Completed as reported in Q3FY21 report. |
| **Milestone 2-4 (D)** | $CO_2$ plume detection - difference of DAS/SOV surveys | | | | | X | Started | 9/30/2021 (10/31/2021) | | | Partially met. |

# Bibliography


- Correa, J., Isaenkov, R., Yavuz, S, Yurikov, A., Tertyshnikov, K., Wood, T., Freifeld, B. M., Pevzner, R., 2021, DAS/SOV: Rotary seismic sources with fiber-optic sensing facilitates autonomous permanent reservoir monitoring. **Accepted to Geophysics.**
- Isaenkov, R., R. Pevzner, S. Glubokovskikh, S. Yavuz, A. Yurikov, K. Tertyshnikov, B. Gurevich, J. Correa, T. Wood, B. Freifeld, M. Mondanos, S. Nikolov, and P. Barraclough, 2021, An automated system for continuous monitoring of CO2 geosequestration using multi-well offset VSP with permanent seismic sources and receivers: Stage 3 of the CO2CRC Otway Project: **International Journal of Greenhouse Gas Control**, 108, 103317.
- Jenkins, C., P. Barraclough, M. Bagheri, J. Correa, T. Dance, J. Ennis-King, B. Freifeld, S. Glubokovskikh, C. Green, J. Gunning, B. Gurevich, R. Isaenkov, S. Jackson, R. Pevzner, L. Ricard, K. Tertyshnikov, A. Wilkins, T. Wood, S. Yavuz, and A. Yurikov, 2021, Drilling an Array of Monitoring Wells for a CCS Experiment: Lessons From Otway Stage 3: **Proceedings of the 15th Greenhouse Gas Control Technologies Conference** 15-18 March 2021.
- Correa, J., Pevzner, R., Freifeld, B., Robertson, M., Daley, T., Wood, T., Tertyshnikov, K., Yavuz, S., Glubokovskikh, S., Bona, A. & Gurevich, B., 2021, Continuous Downhole Seismic Monitoring Using Surface Orbital Vibrators and Distributed Acoustic Sensing at the Otway Project – Field Trial for Optimum Configuration. **Accepted chapter for AGU Books Series.**
- Pevzner, R., Urosevic, M., Tertyshnikov, K., AlNasser, H., Caspari, E., Correa, J., Daley, T., Dance, T., Freifeld, B., Glubokovskikh, S., Greenwood, A., Kepic, A., Popik, D, Popik, S., Raab, M., Robertson, M., Shulakova, V., Singh, R., Watson, M., Yavuz, S., Ziramov, S. & Gurevich, B. 2020. Active surface and borehole seismic monitoring of a small supercritical CO2 injection into the subsurface: experience from the CO2CRC Otway Project. **In: Active Geophysical Monitoring**, Elsevier, 497-522.

# Bibliography


- Yavuz, S., Isaenkov, R., Pevzner, R., Tertyshnikov, K., Correa, J., Wood, T., Freifeld, B., Processing of continuous vertical seismic profile data acquired with distributed acoustic sensors and surface orbital vibrators. Submitted to EAGE Workshop on Fiber Optic Sensing for Energy Applications in Asia Pacific 2–4 November 2020, Kuala Lumpur, Malaysia
- Yavuz, S., Freifeld, B., Pevzner, R., Dzunic, A., Ziramov, S, Bóna, A., Correa, J., Tertyshnikov, K., Urosevic, M., Robertson, M., Daley, T. 2019. The initial appraisal of buried DAS system in CO2CRC Otway Project: the comparison of buried standard fibre-optic and helically wound cables using 2D imaging, **Exploration Geophysics** (50) 1, https://doi.org/10.1080/08123985.2018.1561147
- Correa, J., Tertyshnikov, K., Wood, T., Yavuz, S., Freifeld, B., Pevzner, R., (2018) Time-Lapse Vsp with Permanent Seismic Sources and Distributed Acoustic Sensors: Co2crc Stage 3 Equipment Trials, **14th Greenhouse Gas Control Technologies Conference Melbourne (GHGT-14)**
- Correa, J., Freifeld, B., Pevzner, R., Wood, T., Tertyshnikov, K., Bona, A., (2018) Continuous DAS VSP monitoring using surface orbital vibrators: field trials for optimal configuration at the CO2CRC Otway Project, **80th EAGE Conference & Exhibition 2018 Workshop Programme**, DOI: 10.3997/2214-4609.201801917