CCSMR Task 2: SOV/DAS (Part 1)

Monitoring a CO_2 injection in real-time using permanent seismic sources and fiber-optics sensing

(FWP-ESD14095)

Julia Correa[1], Roman Pevzner[2], Roman Isaenkov[2], Stas Glubokovskikh[1], Todd Wood[1], Barry M. Freifeld[3]

[1]Lawrence Berkeley National Laboratory

[2]Curtin University and CO2CRC

[3]Class VI Solutions, Inc.

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management Project Review Meeting

August 15 - 19, 2022

Conventional Time-lapse Seismic vs SOV-DAS

Conventional campaign-based systems

Temporally sparse / **Spatially** dense

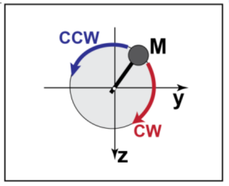
Vibroseis trucks

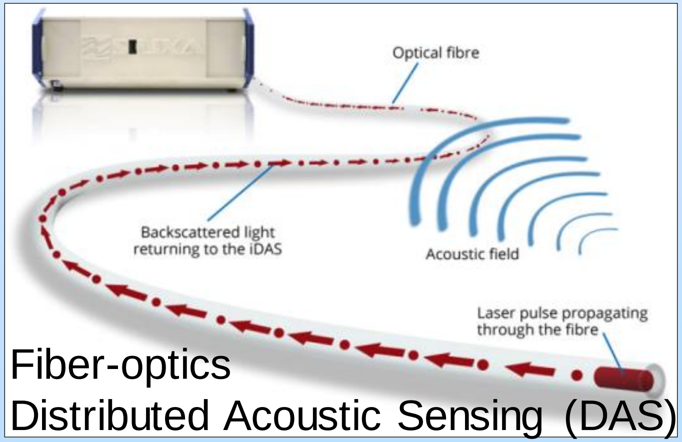
Geophone receivers

SOV-DAS permanent monitoring system

Temporally dense / **Spatially** sparse

Surface Orbital Vibrator (SOV)





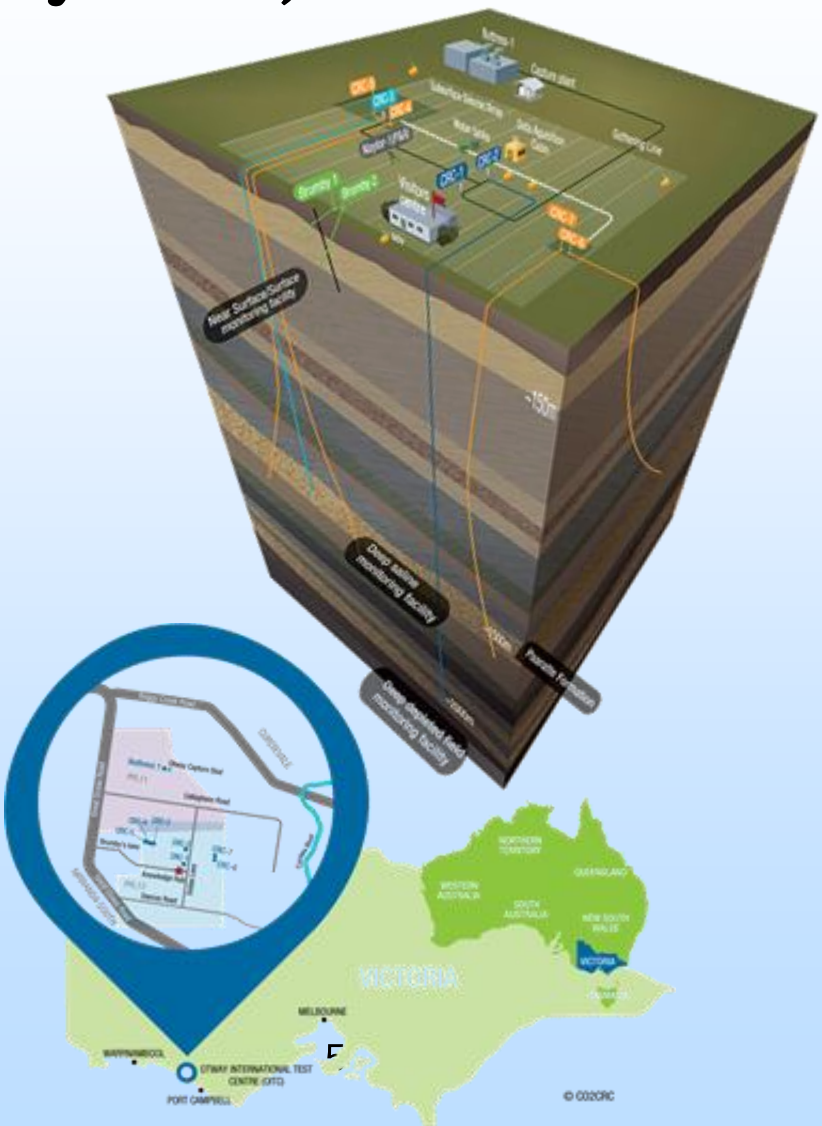
Fiber-optics
Distributed Acoustic Sensing (DAS)

Why SOV-DAS?

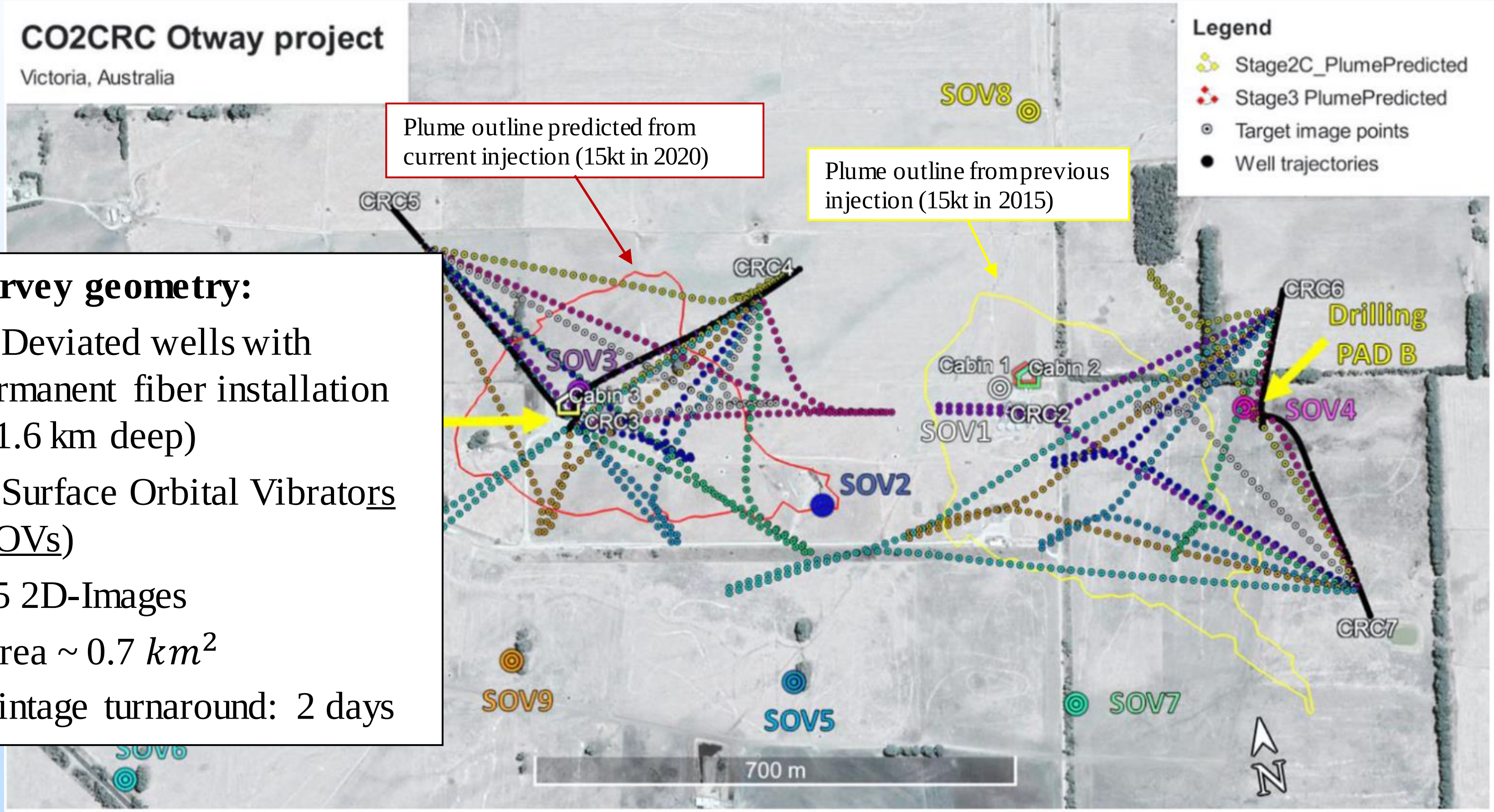
- **Continuous tracking of the CO_2 plume** through 2D seismic images
- **Cost-effective** for long-term seismic monitoring when compared to conventional 4D seismic acquisition
- **High temporal sampling** enables detection of small changes
- Enables **real-time data processing** optimization and analysis, leading to fast decision making
- Simultaneous active and passive seismic monitoring with potential for **monitoring induced seismicity**

SOV/DAS demonstration: CO2CRC Otway Project

- Stage 3: **15 kt of CO_2/CH_4 gas** injected into Paaratte formation ~ 1.5 km depth
  - Injector well CRC-3
  - Monitor wells CRC-4,5,6,7
- **Continuous and automated monitoring** using DAS/SOV system
- Edge computing and automated seismic processing for **rapid plume evaluation**
- **Decrease acquisition footprint** and societal impact from seismic acquisition



Permanent seismic monitoring array at Otway Stage 3



Survey geometry:

-5 Deviated wells with permanent fiber installation (~1.6 km deep)

-9 Surface Orbital Vibrators (SOVs)

-45 2D-Images

-Area ~ 0.7 km^2

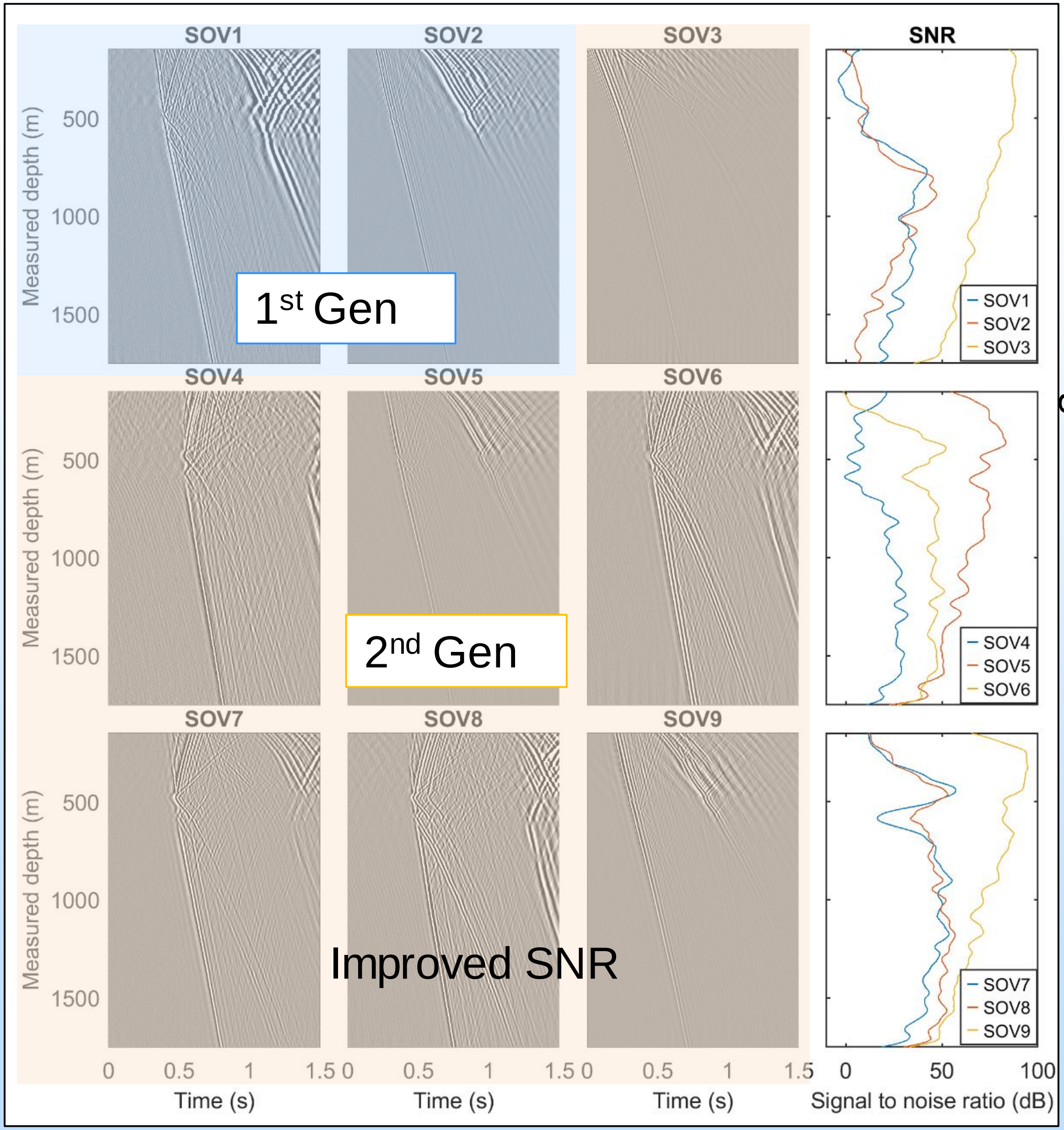
-Vintage turnaround: 2 days

[Isaenkov et. al. 2022]

SOV/DAS VSP data quality

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

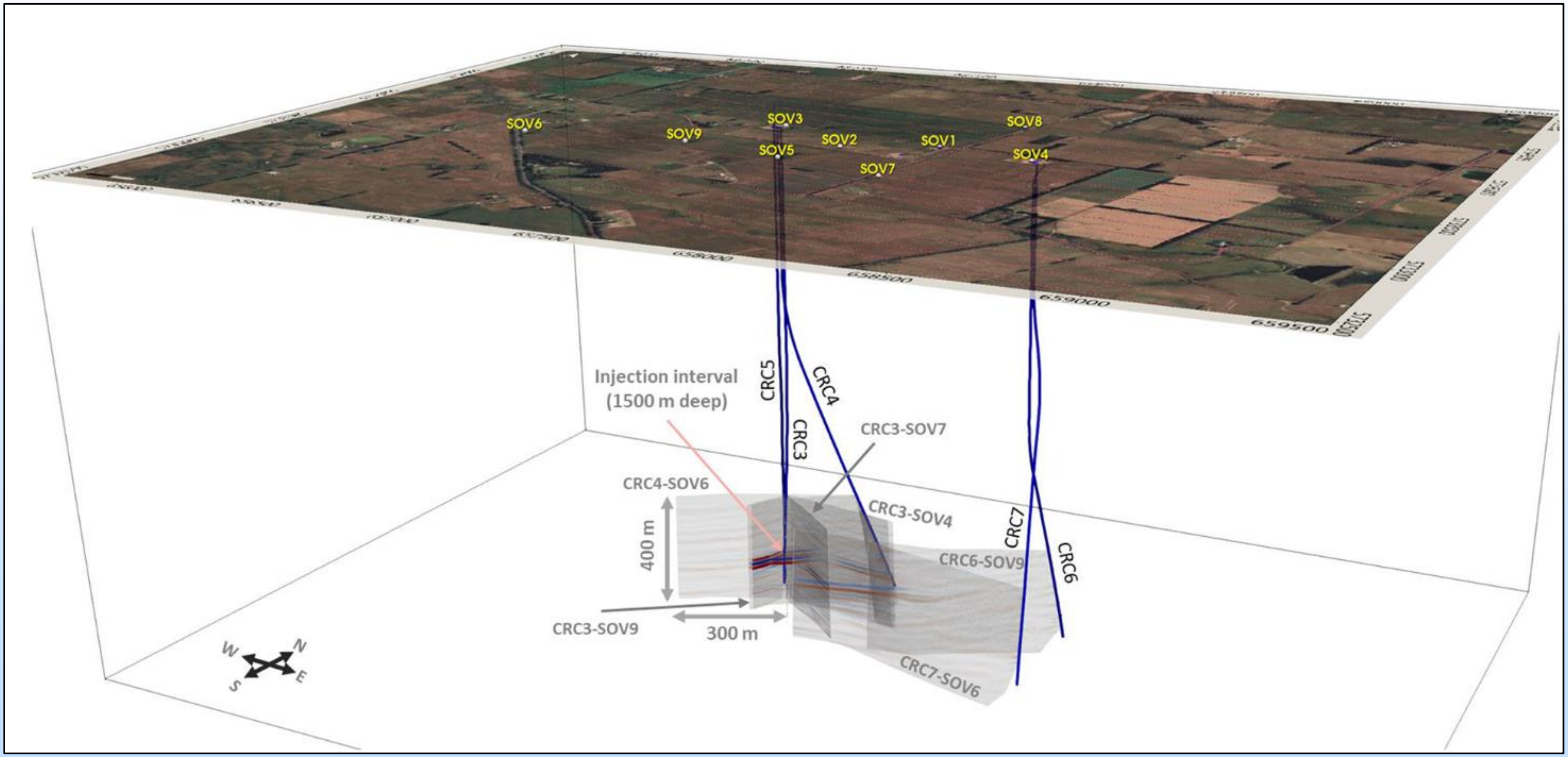
SOV 2nd Generation– SOV3 – SOV9
(deployed early 2020)



[Correa et al., 2021]

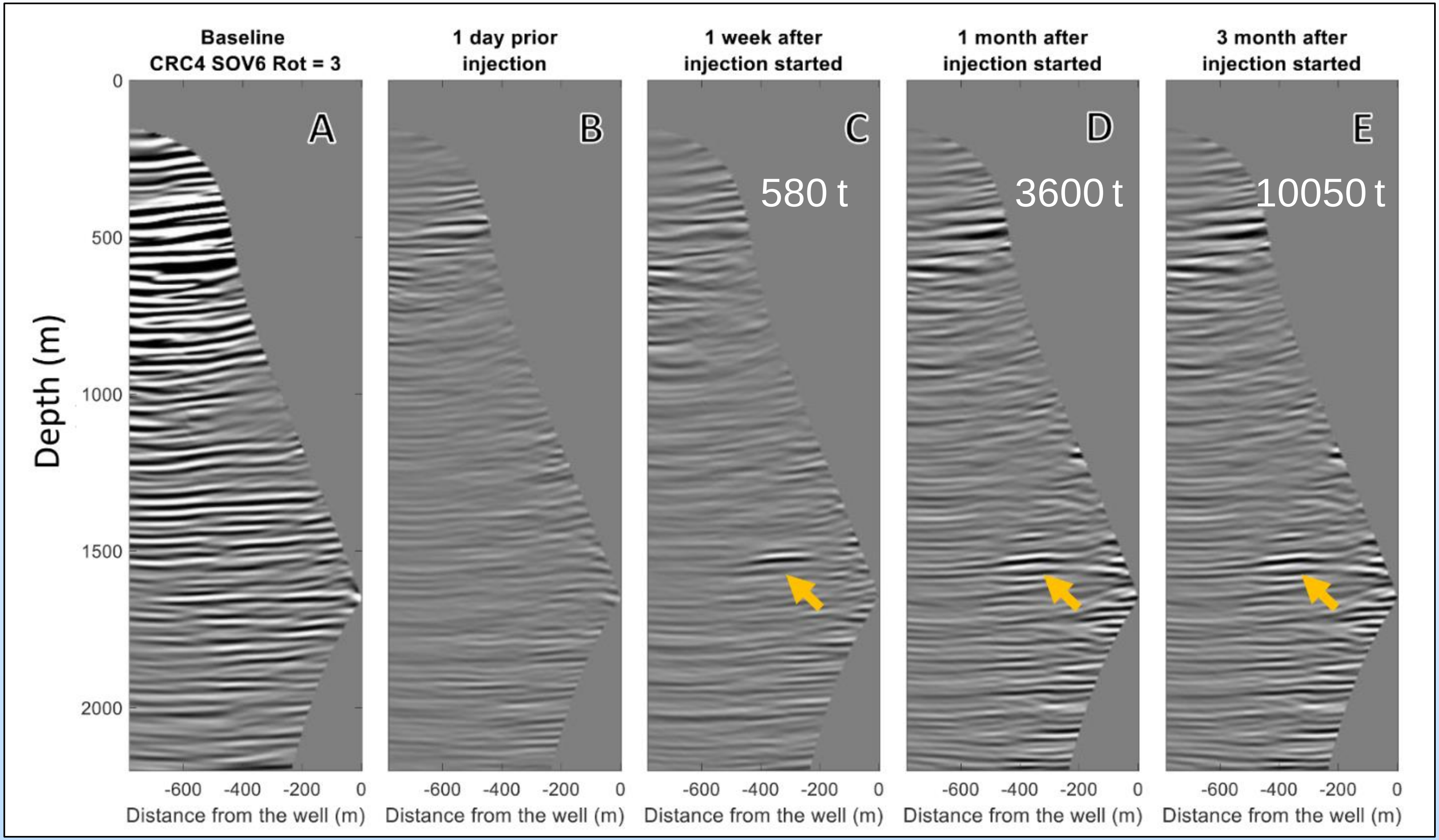
Edge Computing and Automated Processing

Multi-offset time-lapse anomalies show CO_2 plume migrating from injection interval



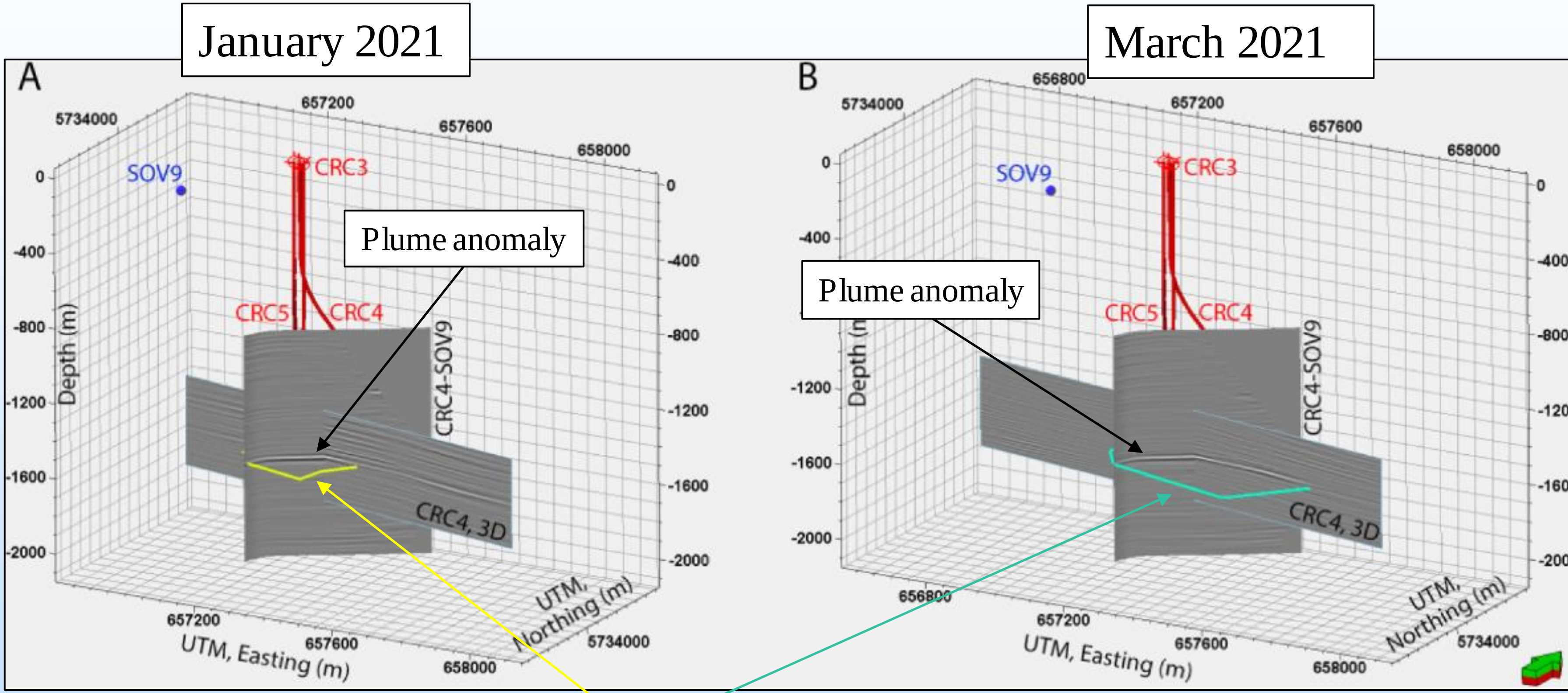
[Isaenkov et. al. 2022]

Baseline and difference seismograms after migration (SOV6/CRC4)



[Pevzner et. al. 2021]

Comparison of SOV/DAS with convention 4D VSP seismic

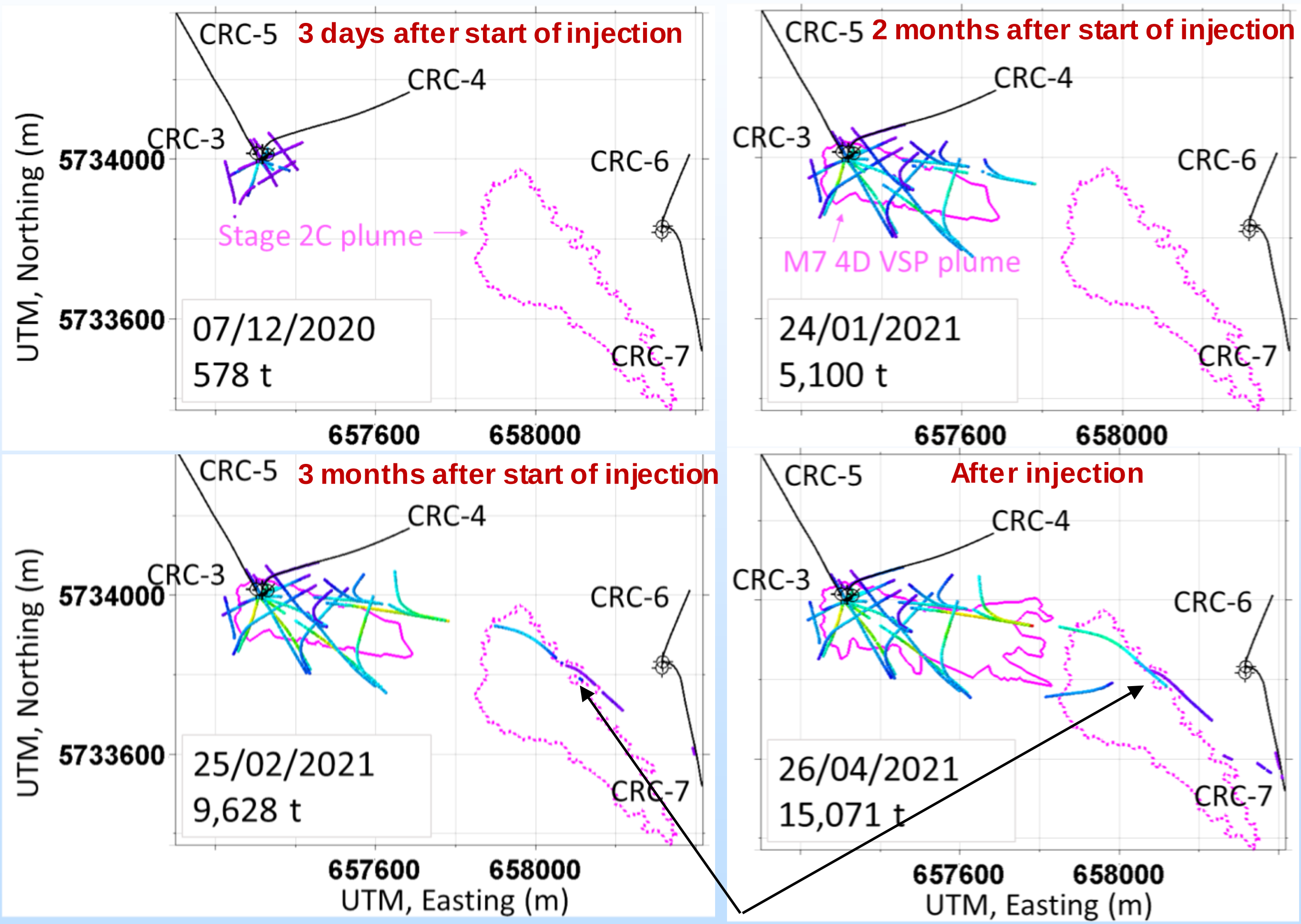


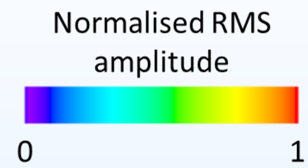
Plume contours were picked from the SOV/DAS data, before the 4D VSP seismic was acquired

[Pevzner et. al. 2021]

Evolution of the CO_2 plume captured by the SOV/DAS

Plan view



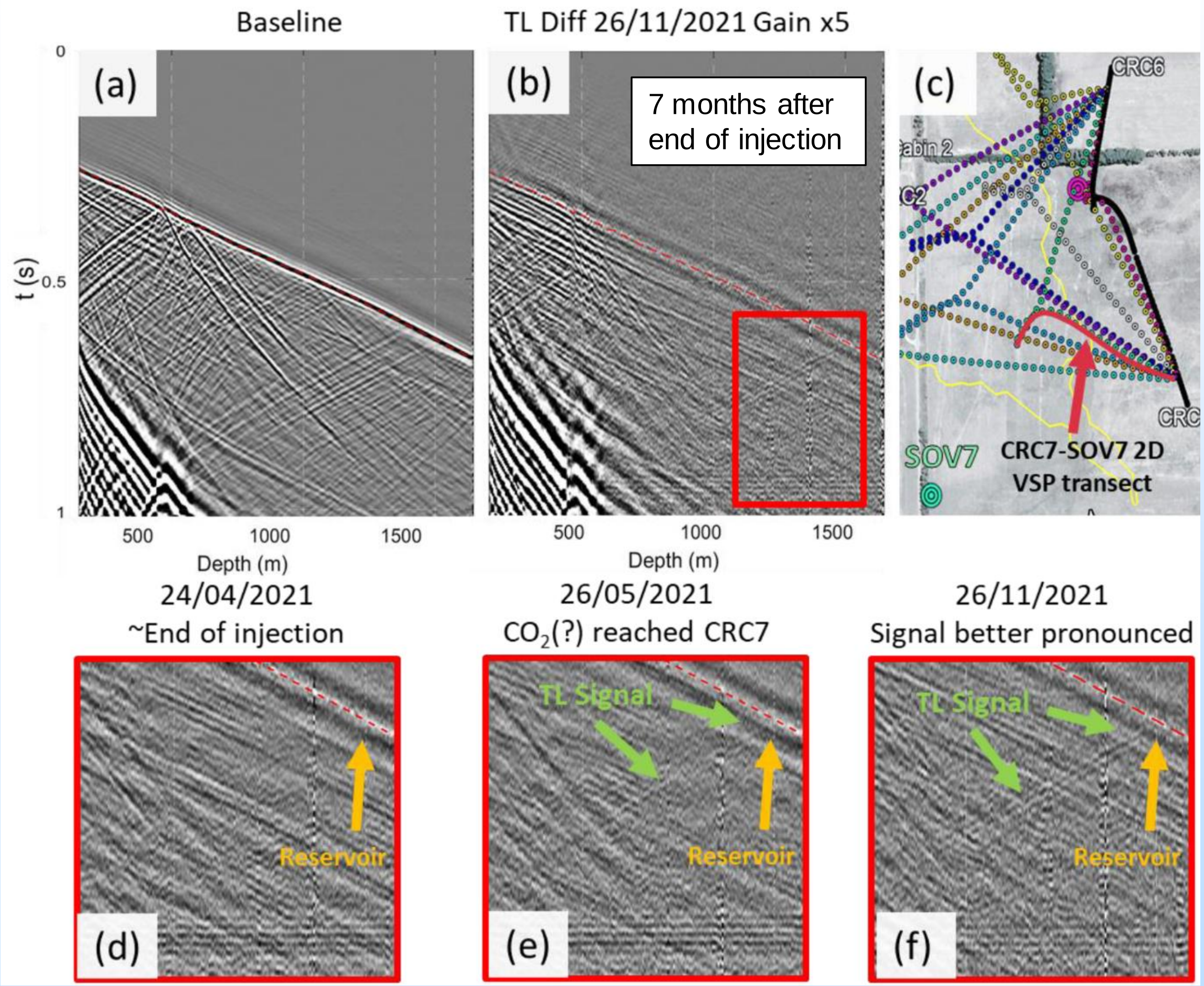


Colours along 2D offset VSP transects show amplitude changes

Stage 2C plume reactivation

[Isaenkov et. al. 2022]

Detection of remobilization of previous CO_2 injection plume

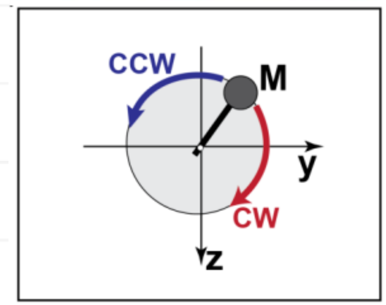


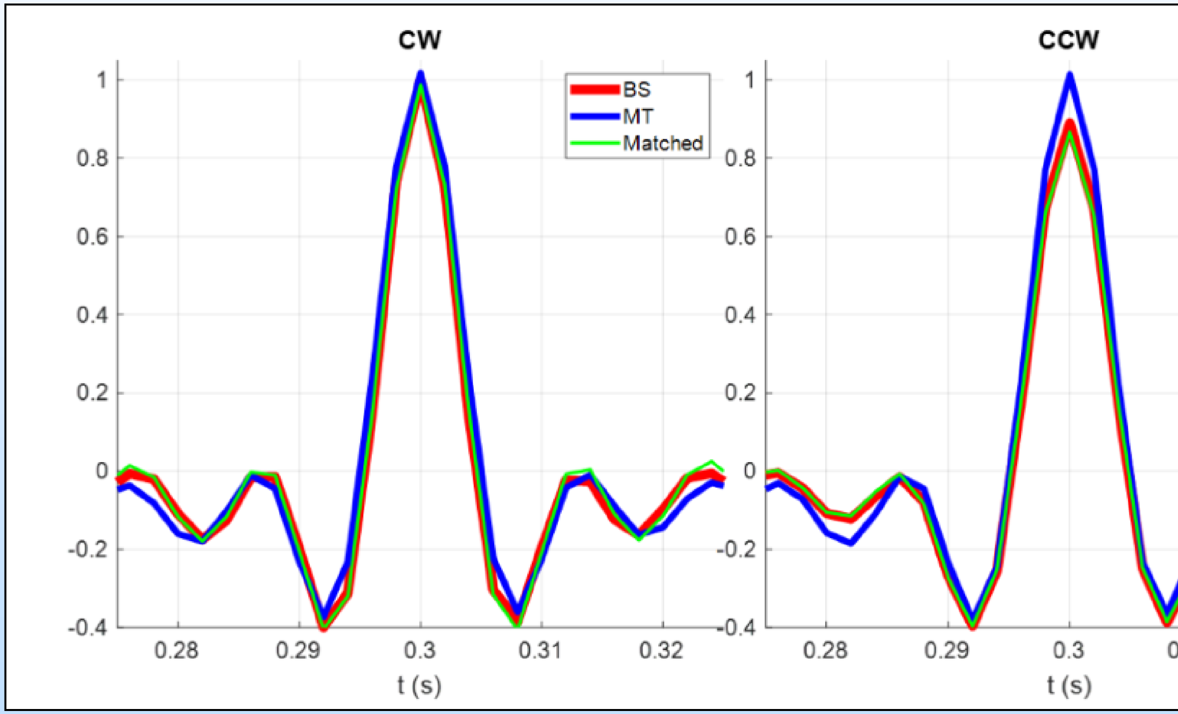
[Isaenkov et. al. 2022]

Repeatability of the SOV source

Clock-wise (CW)

Counter clock-wise (CCW)



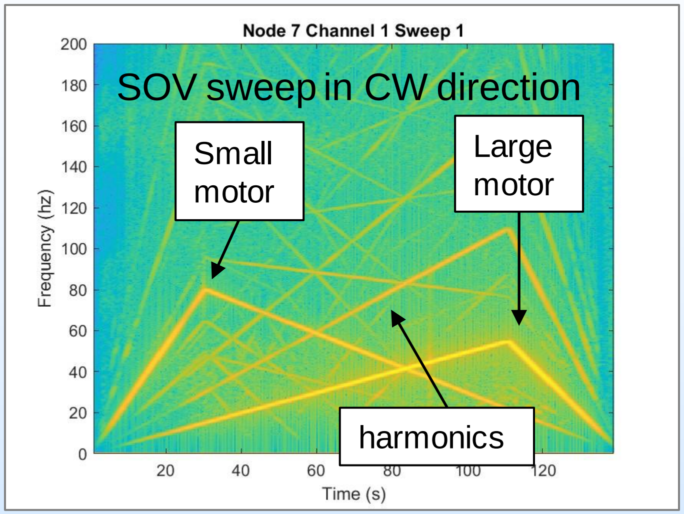


Non-repeatability of source rotation: about 10% difference in amplitude between rotations

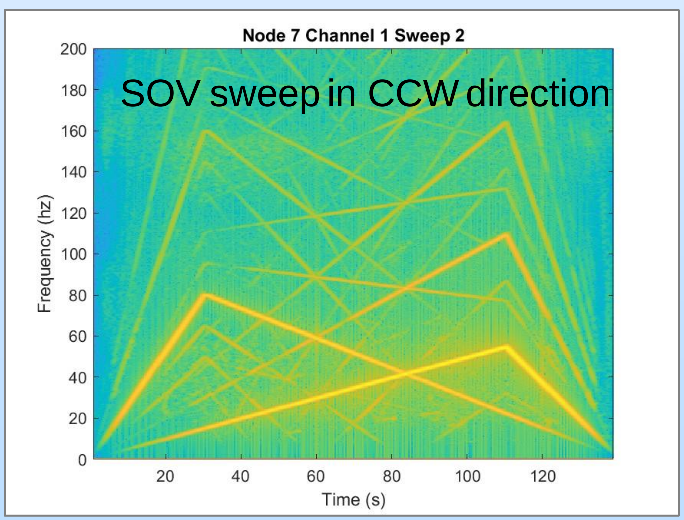
[Isaenkov et. al. 2022]

Signature tests: Preliminary data analysis of differences in sweep direction

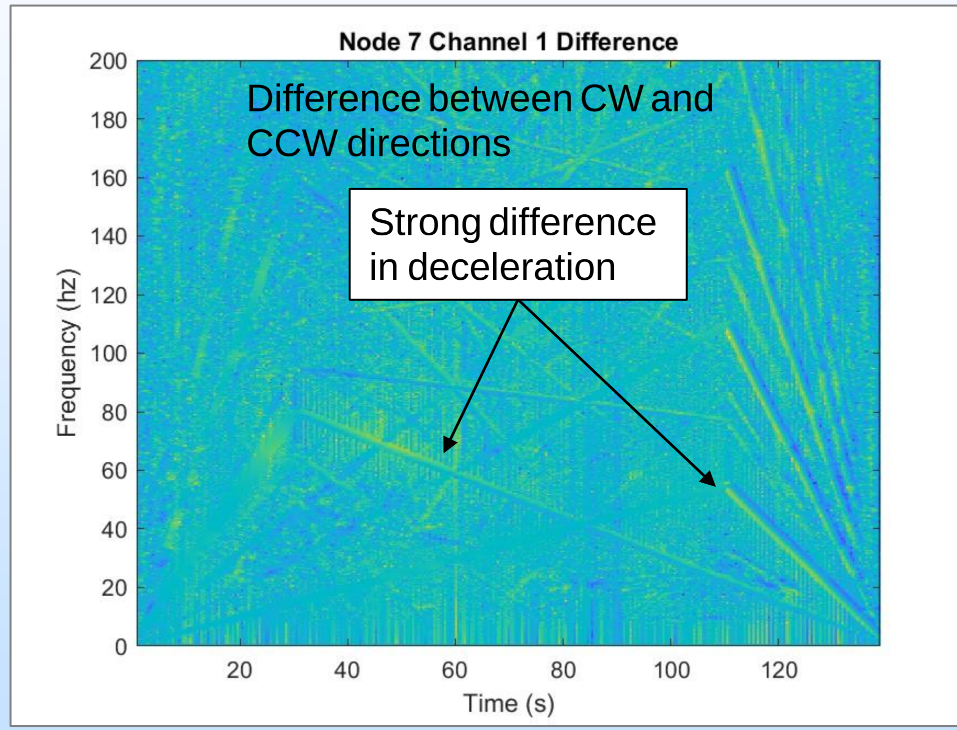
Frequency



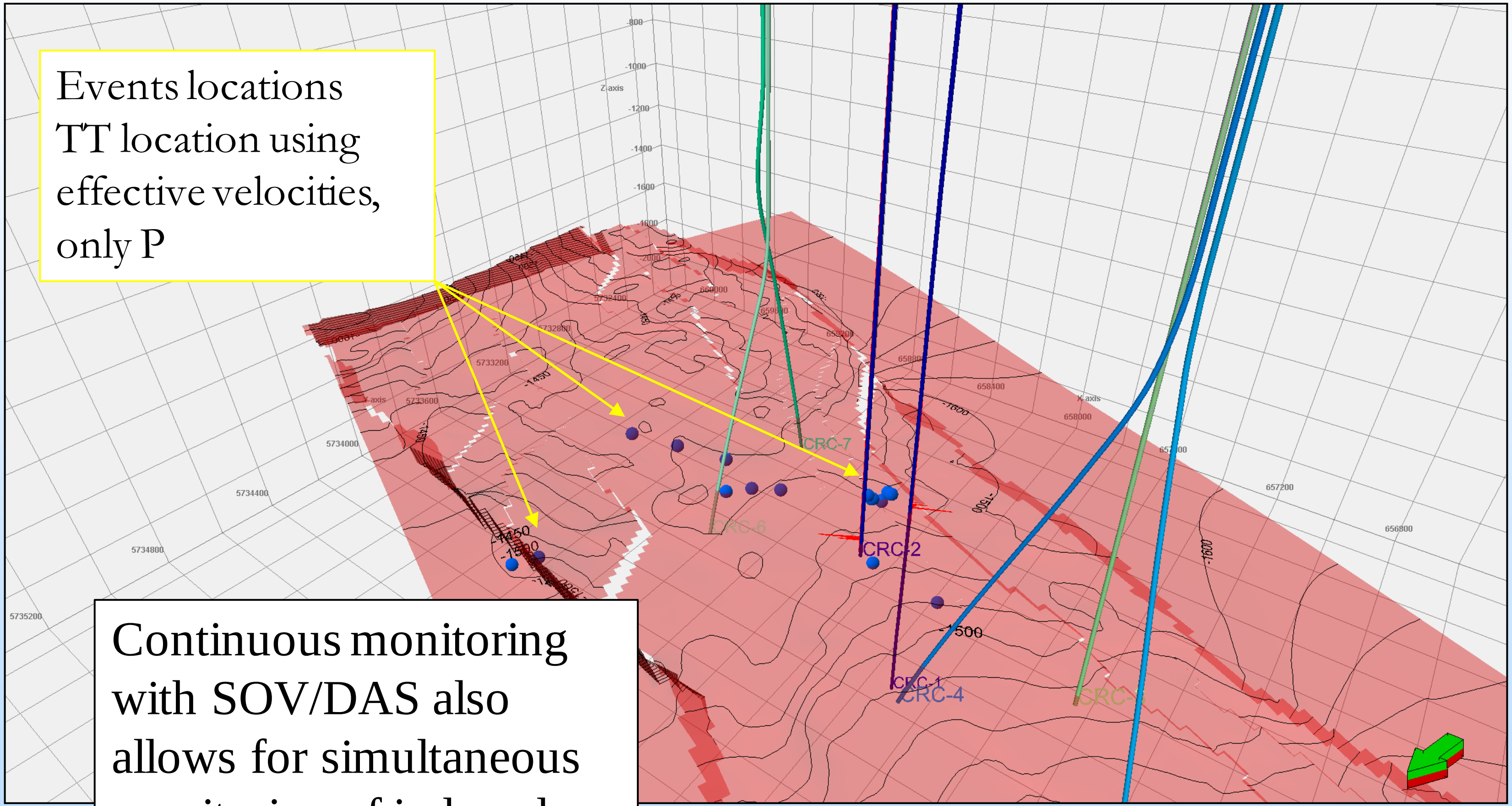
Frequency



Time



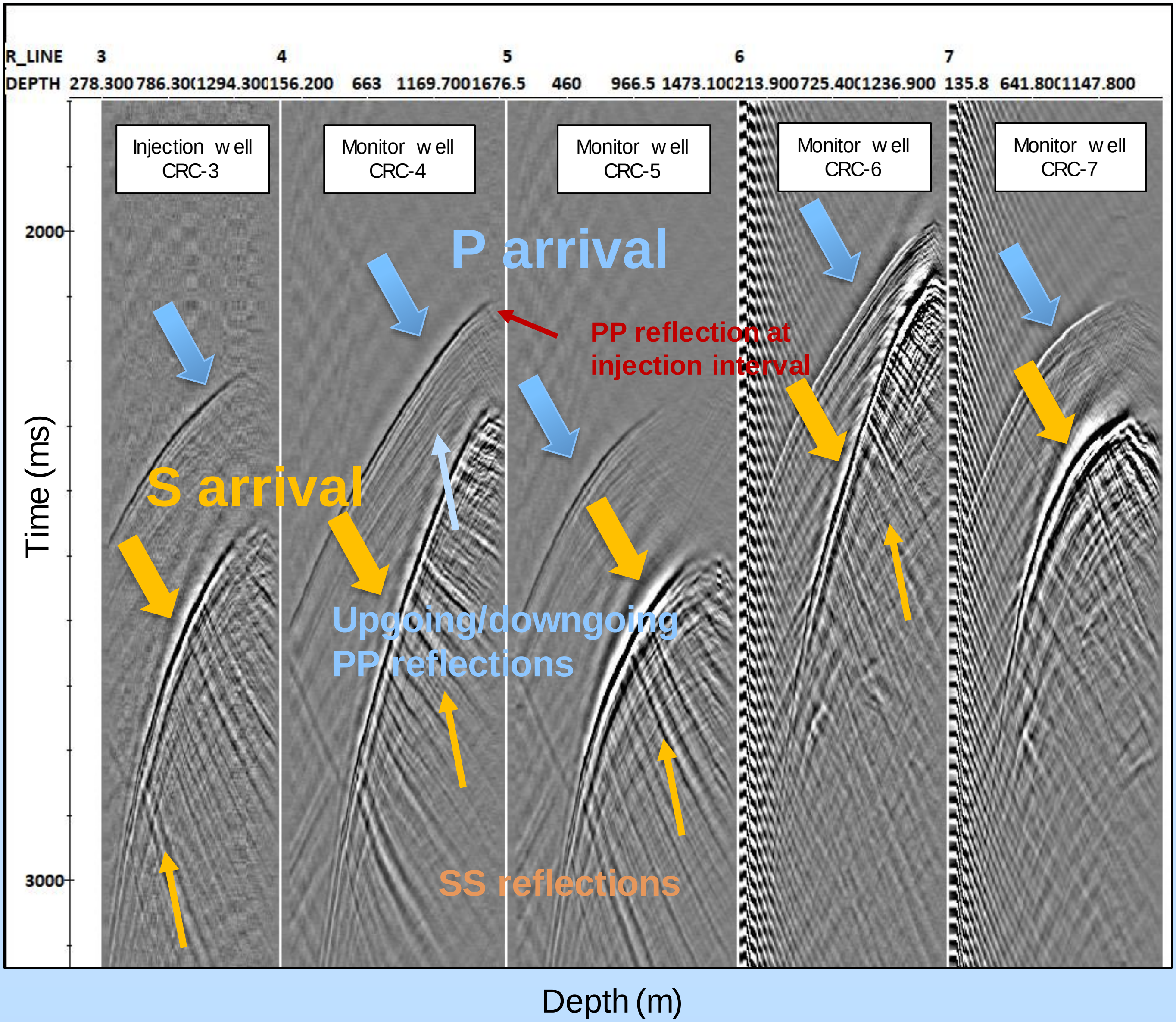
Simultaneous passive monitoring: microseismic detection



Events locations
TT location using effective velocities, only P

Continuous monitoring with SOV/DAS also allows for simultaneous monitoring of induced seismicity

Microseismic event example



Lessons Learned

- Asymmetry between direction of rotation of the SOV source compromise repeatability
- Repeatability of the SOV source signal is currently being explored
- Near field geophone highly affected by near-surface conditions

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 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, SOV/DAS data processing and analysis
- Stanislav Glubokovskikh, LBNL, microseismic 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*	FY22	Fiscal Year 2021 Q1	Q2	Q3	Q4	Planned Start Date	Planned Completion Date (Reporting Date)**	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
Milestone 2-1 (A)	Acquisition of SOV/DAS signature tests	Q3FY22			x		Started	6/30/2022 (7/31/2022)			Completed as reported in Q3FY22 report.
Milestone 2-2 (B)	Analysis of SOV/DAS signature tests	Q4FY22					Started	9/30/2022 (10/31/2022)			Underway.
Milestone 2-3 (C)	Joint analysis of passive DAS and active DAS-SOV data	Q4FY22					Started	9/30/2022 (10/31/2022)			Partially completed.

Bibliography

- Isaenkov, R., Pevzner, R., Glubokovskikh, S., Yavuz, S., Shashkin, P., Yurikov, A., Tertyshnikov, K., Gurevich, B., Correa, J., Wood, T., Freifeld, B., Barraclough, P. (2022). Advanced time-lapse processing of continuous DAS VSP data for plume evolution monitoring: Stage 3 of the CO2CRC Otway project case study. *International Journal of Greenhouse Gas Control,* 119, 103716. https://doi.org/10.1016/J.IJGGC.2022.103716
- Pevzner, R., S. Glubokovskikh, R. Isaenkov, P. Shashkin, K. Tertyshnikov, S. Yavuz, B. Gurevich, J. Correa, T. Wood, and B. Freifeld, (2022), Monitoring subsurface changes by tracking direct-wave amplitudes and traveltimes in continuous distributed acoustic sensor VSP data, *Geophysics*, 87: A1-A6. https://doi.org/10.1190/geo2021-0404.1
- Glubokovskikh, S., Saygin, E., Shapiro, S., Gurevich, B., Isaenkov, R., Lumley, D., et al. (2022). A small CO_2 leakage may induce seismicity on a sub-seismic fault in a good-porosity clastic saline aquifer. *Geophysical Research Letters*, 49, e2022GL098062. https://doi.org/10.1029/2022GL098062
- Correa, J., Pevzner, R., Freifeld, B.M., Robertson, M., Daley, T.M., Wood, T., Tertyshnikov, K., Yavuz, S. and Glubokovskikh, S. (2021). Continuous Downhole Seismic Monitoring Using Surface Orbital Vibrators and Distributed Acoustic Sensing at the CO2CRC Otway Project. In *Distributed Acoustic Sensing in Geophysics* (eds Y. Li, M. Karrenbach and J.B. Ajo Franklin). https://doi.org/10.1002/9781119521808.ch13
- Yavuz, S., Pevzner, R., Popik, S., Tertyshnikov, K., Wood, T., Robertson, M. C., Correa, J., & Freifeld, B. (2022). The appraisal of surface orbital vibrators with buried geophone array for permanent reservoir monitoring. *Geophysical Prospecting, 70*(1), 108–120.

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. *Geophysics, 86 (6), P61-P68*
- Pevzner, R., Isaenkov, R., Yavuz, S., Yurikov, A., Tertyshnikov, K., Shashkin, P., Gurevich, B., Correa, J., Glubokovskikh, S., Wood, T., Freifeld, B., & Barraclough, P. (2021). Seismic monitoring of a small CO2 injection using a multi-well DAS array: Operations and initial results of Stage 3 of the CO2CRC Otway project. *International Journal of Greenhouse Gas Control*, *110*, 103437. https://doi.org/10.1016/J.IJGGC.2021.103437
- 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.

Backup slides