CCSMR Task 2: SOV/DAS (Part 2)

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

Project ESD14095

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management Project Review Meeting

August 15 - 19, 2022

Why monitor microseismicity?

PNAS

Earthquake triggering and large-scale geologic storage of carbon dioxide

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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 <u>at Otway</u>?
Previous twin injection triggered seismicity


Geophysical Research Letters

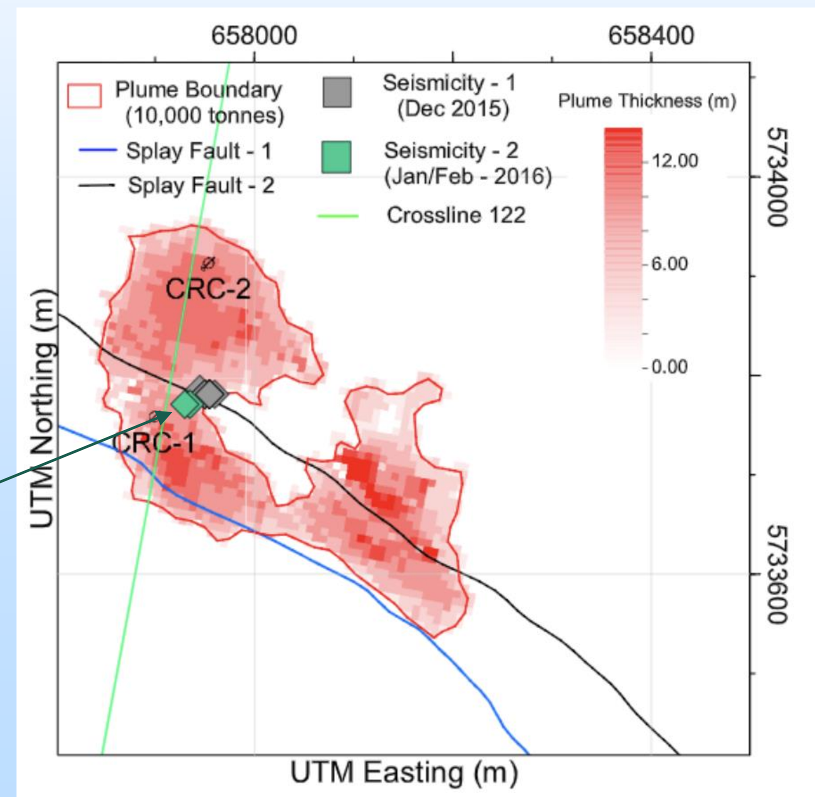
Research Letter

A Small CO_2 Leakage May Induce Seismicity on a Sub-Seismic Fault in a Good-Porosity Clastic Saline Aquifer

Stanislav Glubokovskikh, Erdinc Saygin, Serge Shapiro, Boris Gurevich, Roman Isaenkov, David Lumley, Rie Nakata, Julian Drew, Roman Pevzner

First published: 06 June 2022 | https://doi.org/10.1029/2022GL098062

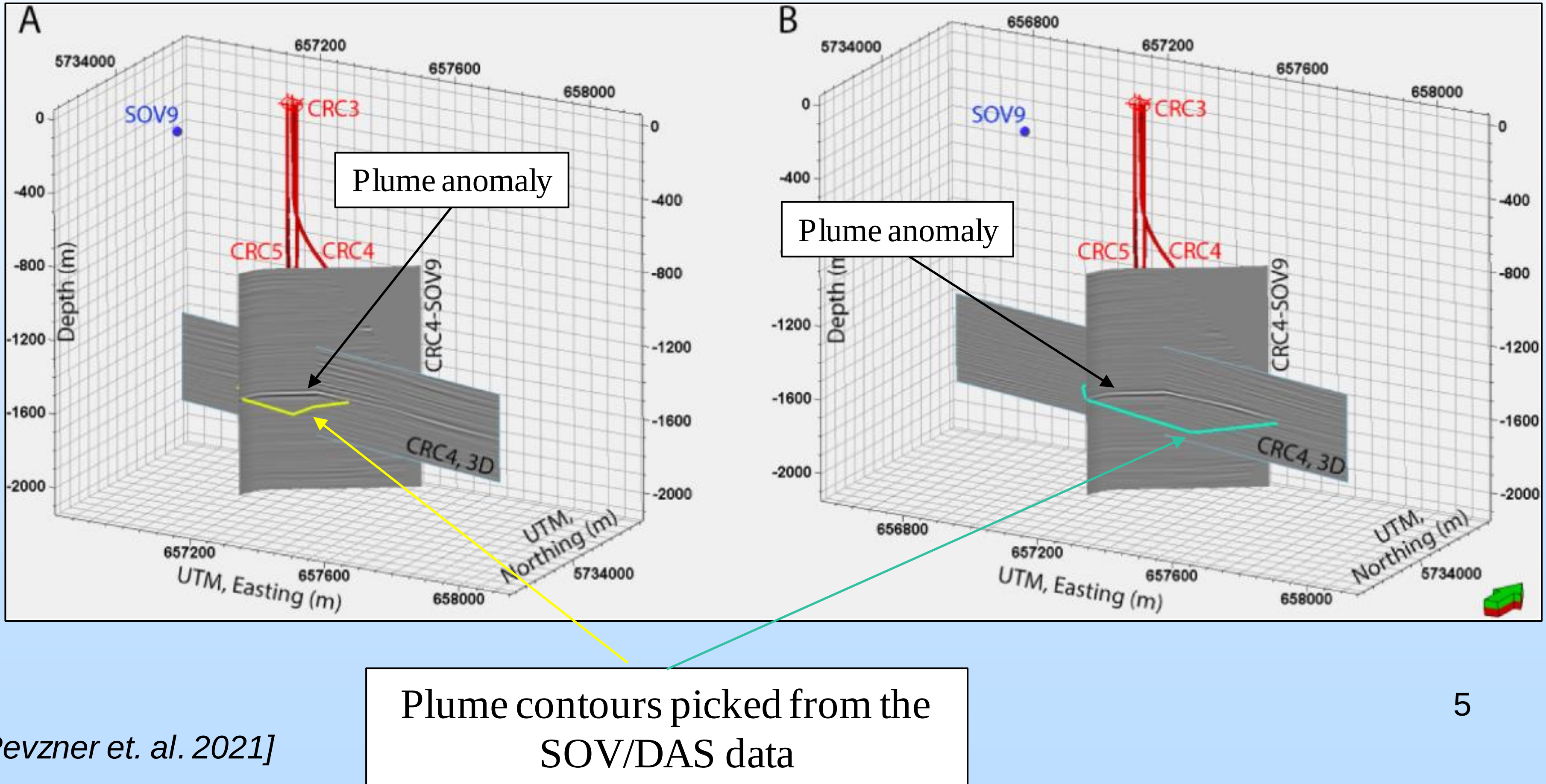
1. **Triggered seismicity augments the active containment monitoring program and**
2. **Informs conformance reservoir simulations**



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

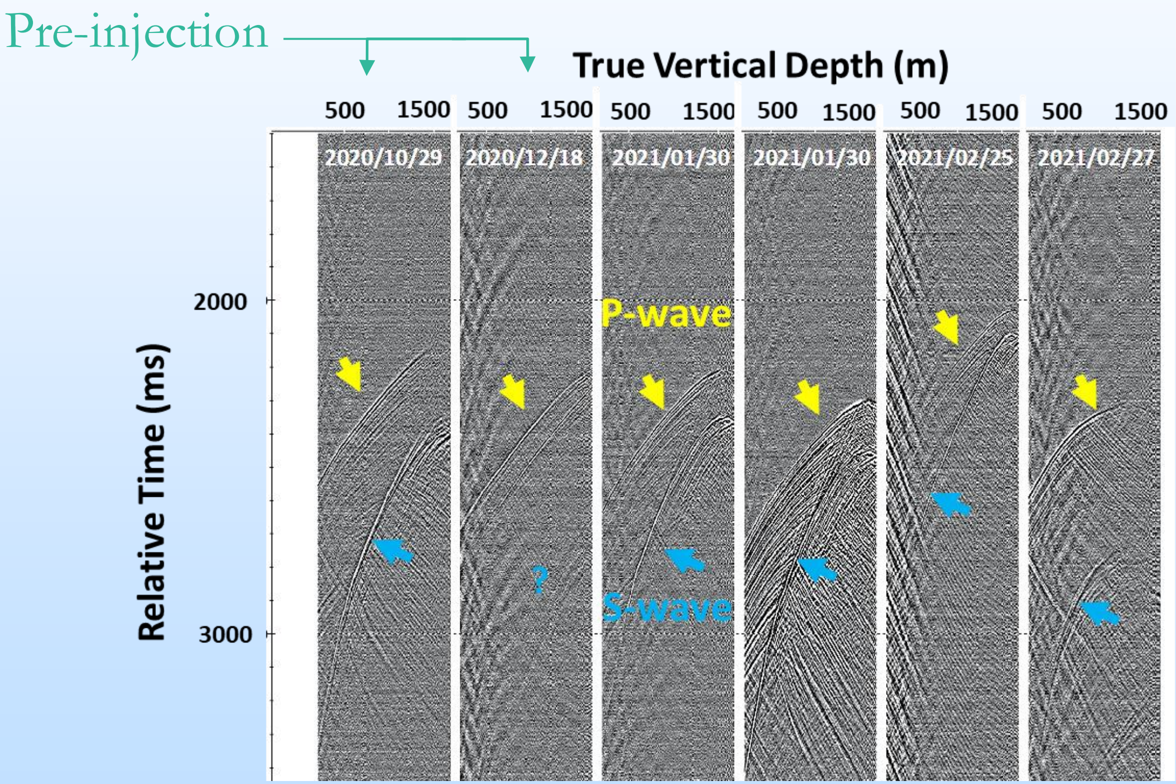
3. **Continuous SOV/DAS snapshots provide insights into the triggering mechanisms**



[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

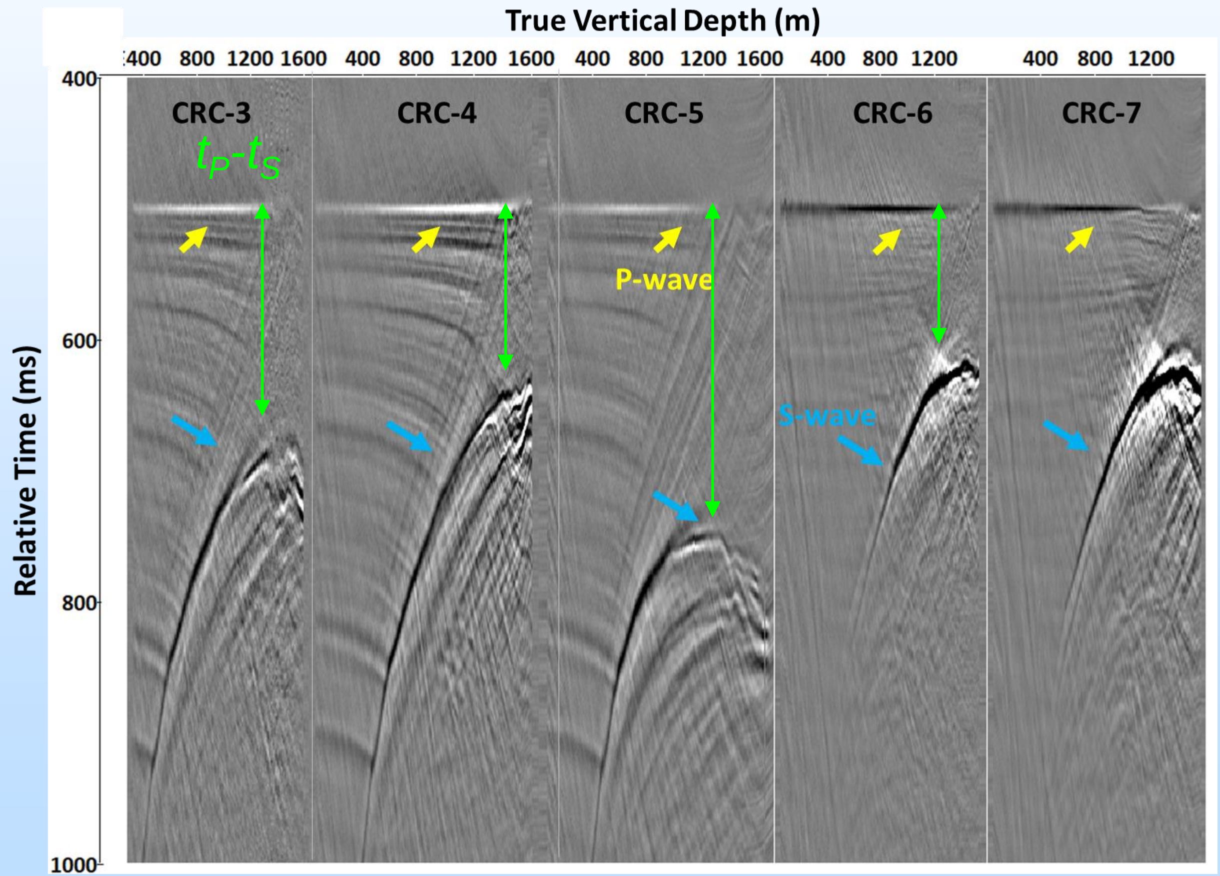


6 events automatically detected in CRC-4

Hypocenters Location:

The travel-time curves locate microearhquakes

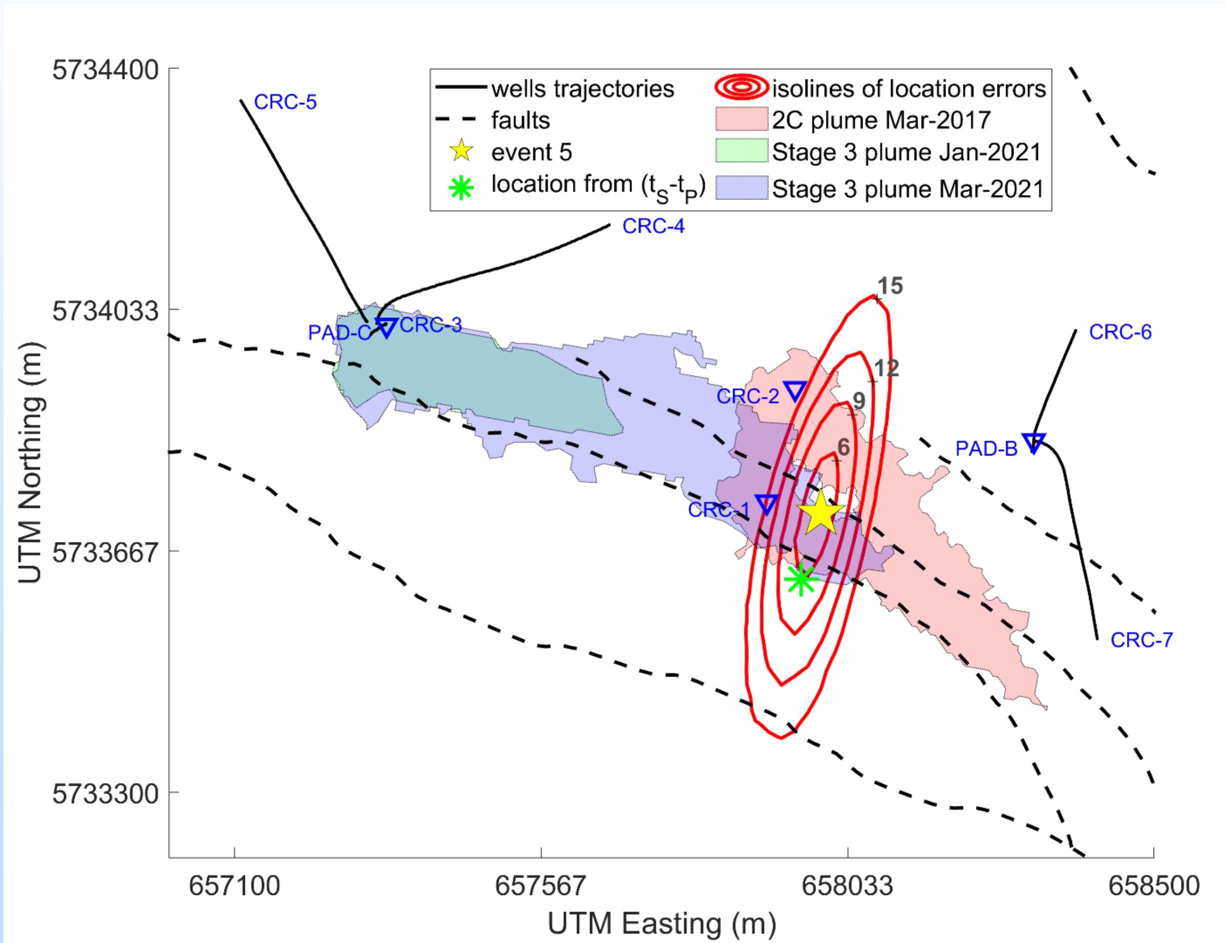
- Travel-time curves in all 5 wells are used to locate the origin of all microseismic events
- Velocity model relies on the analysis for SOV/DAS continuous monitoring system



An event on all DAS wells

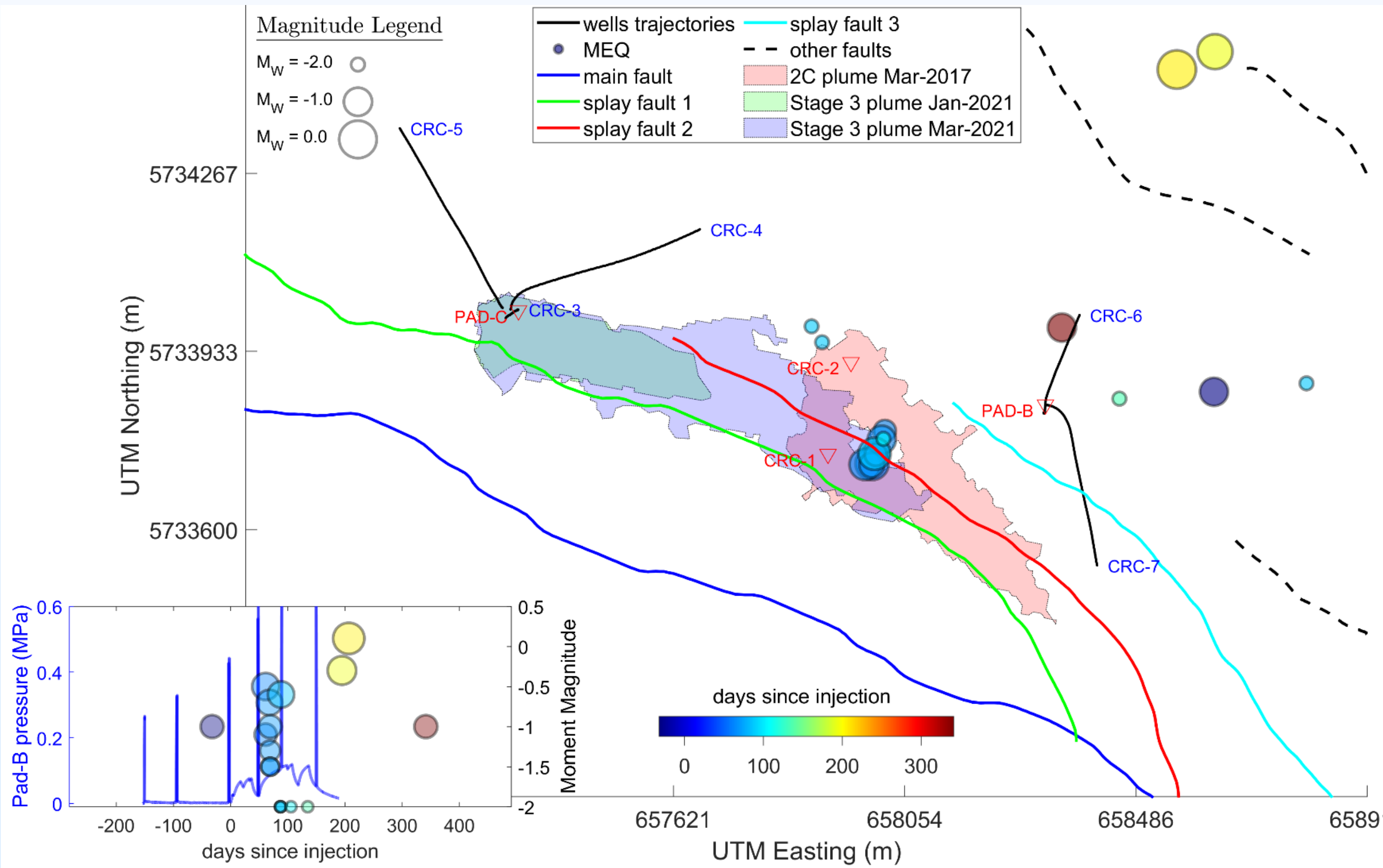
Hypocenters Location:
The uncertainty is relatively small(not vanishing)

- Uncertainty of the hypocenters location ~ 70 m, aligned with SW-NE direction



The Final Catalog:
Three clusters of seismicity in space-time

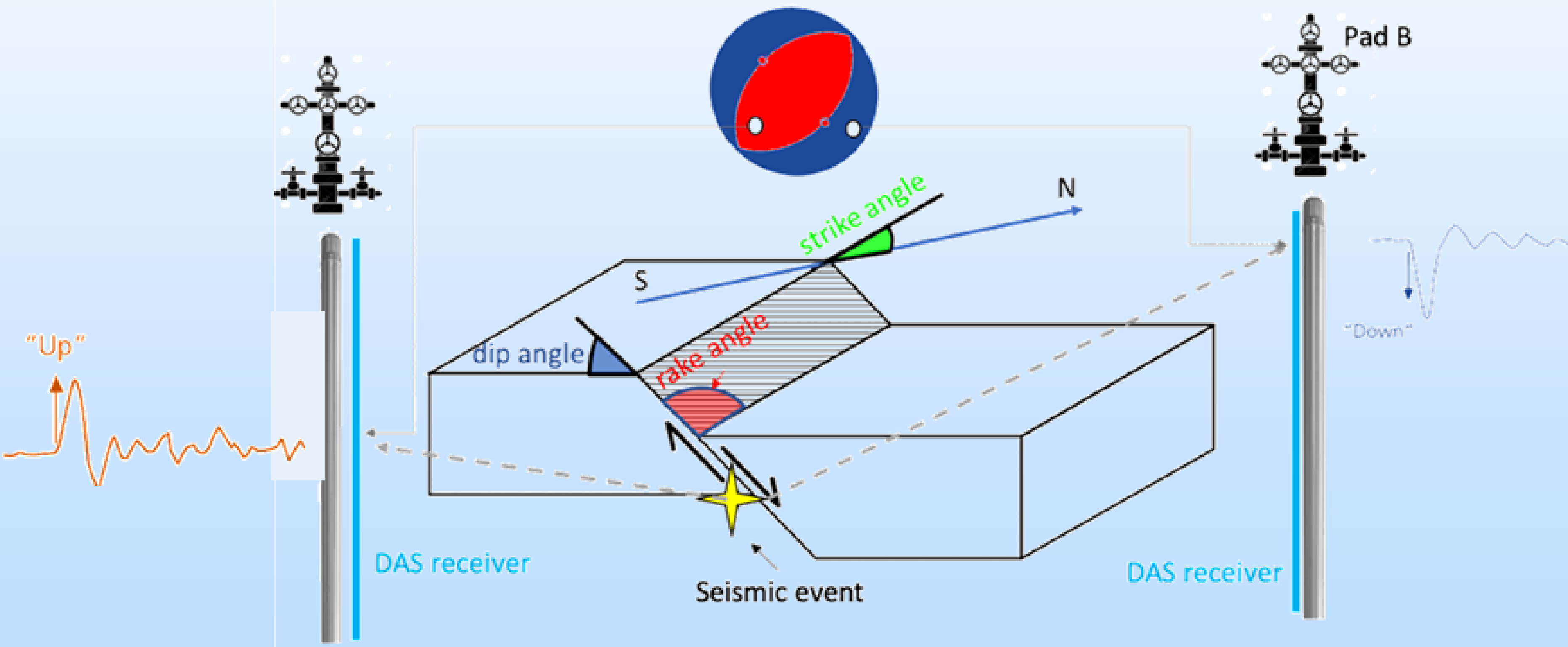
- Uncertainty of the hypocenters location ~ 70 m, aligned with SW-NE direction



Focal Mechanisms:

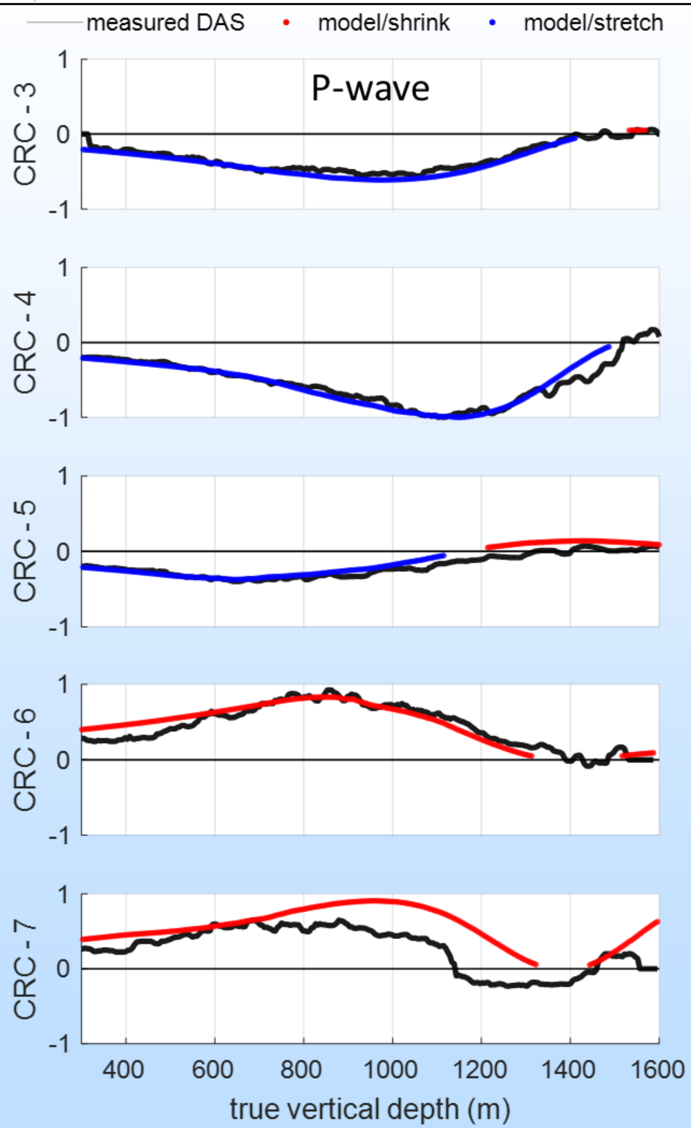
Geometry of the fault and slip from first motions

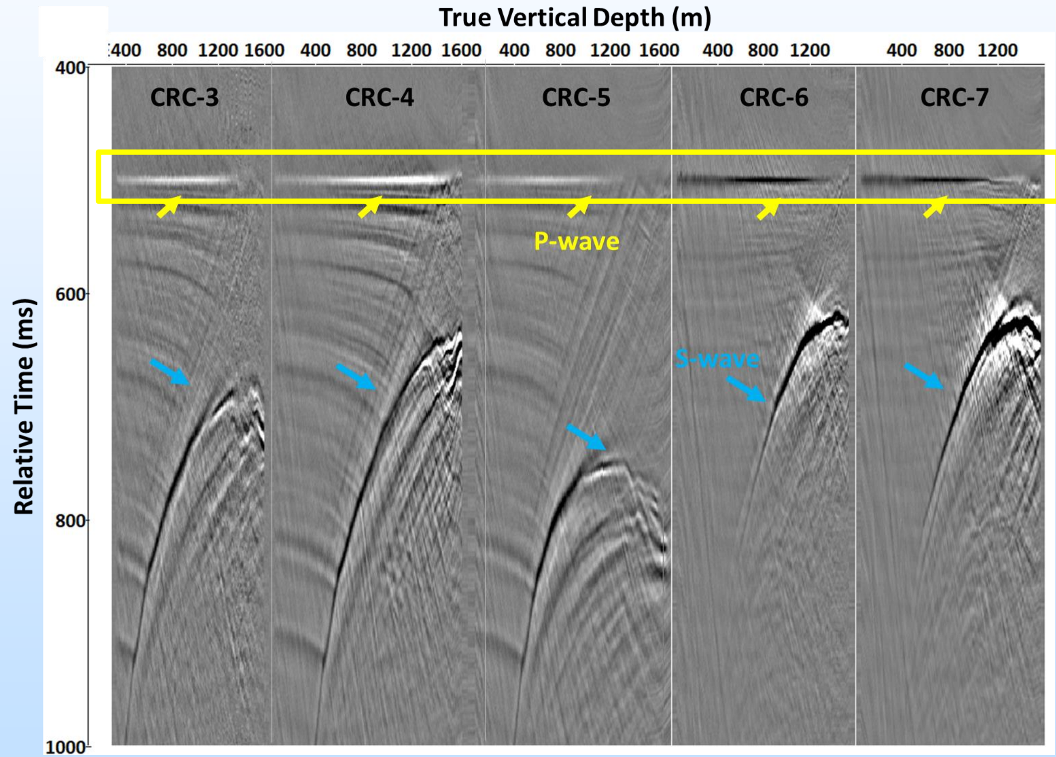
- Radiation pattern (**beachball**) = fault geometry ⊗ slip direction
- Magnitude (M_W) = fault size ⊗ slip displacement



Focal Mechanism:

P-wave for an M_W-0.5 matches the theory

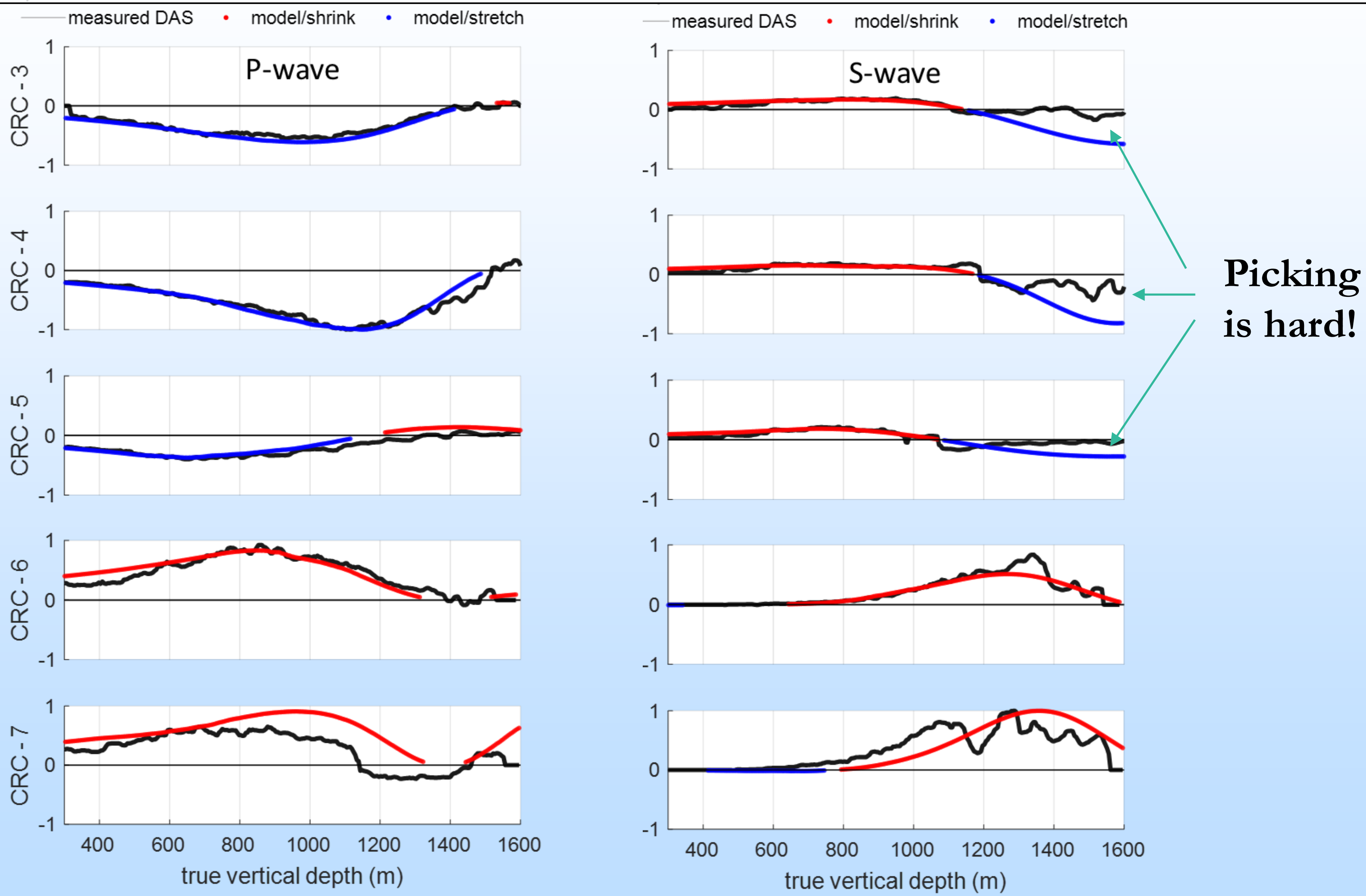




An event on all DAS wells

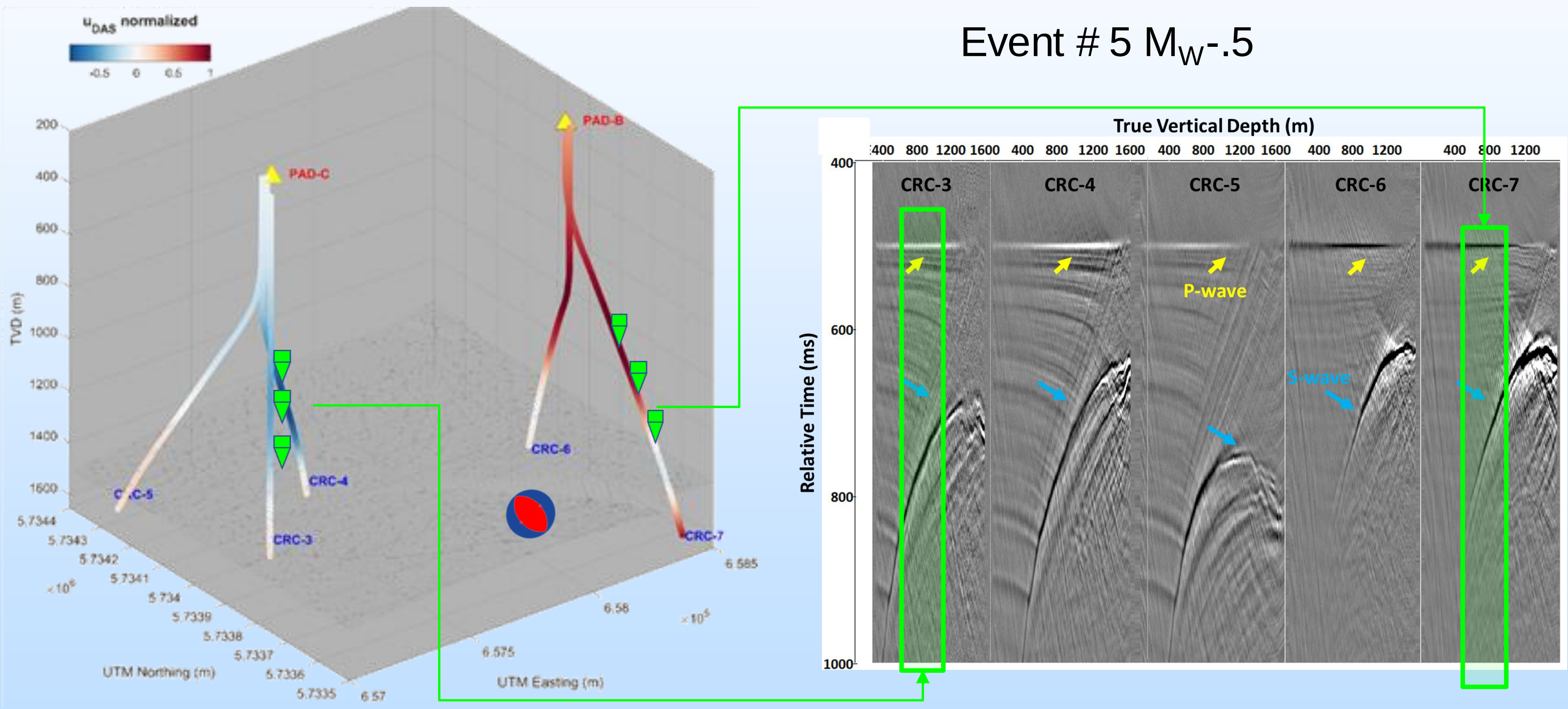
Focal Mechanism:

S-wave for this event validates the inversion



Benefits of the multiwell DAS system:
high SNR + angular coverage + channel number

BETTER detection+hypocenters+focal mechanisms+magnitude



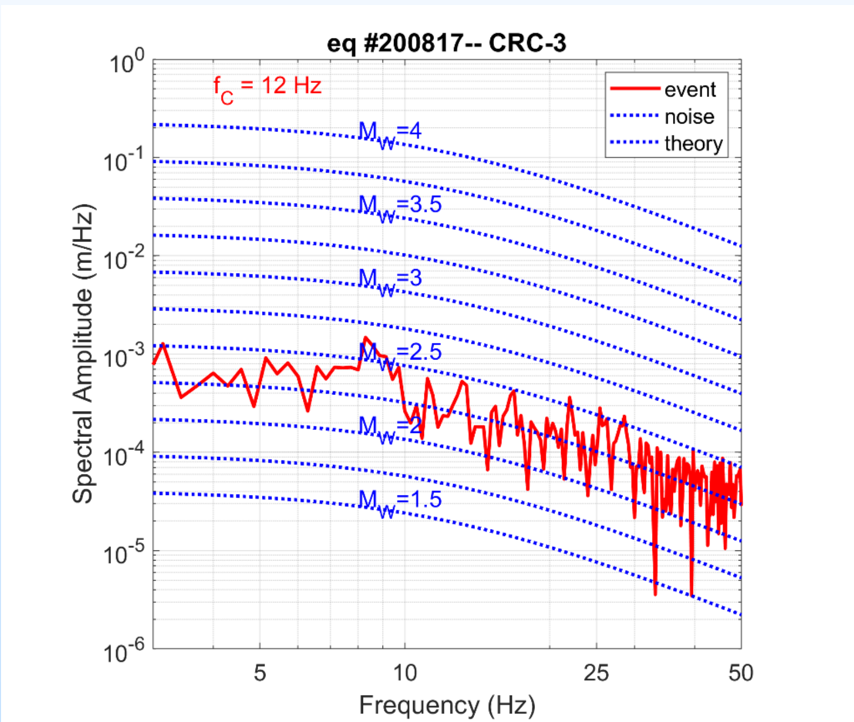
Receivers for a typical situation: 1injector +1M&V

Magnitude estimation:

Calibration of the DAS amplitudes using local EQs

A cluster of M_L~3 earthquakes in Apollo Bay on DAS vs SEISMOMETERS

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



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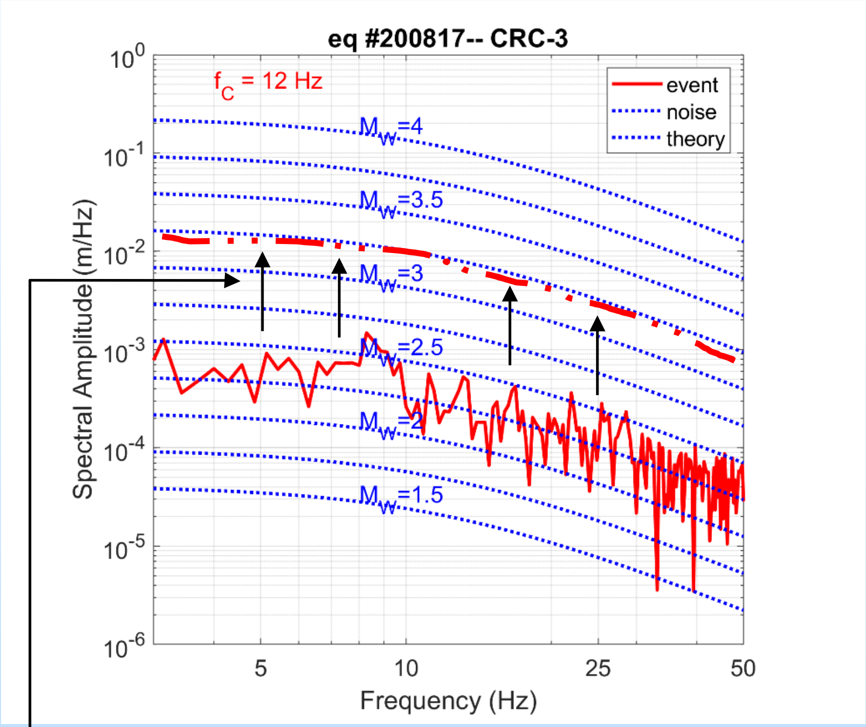
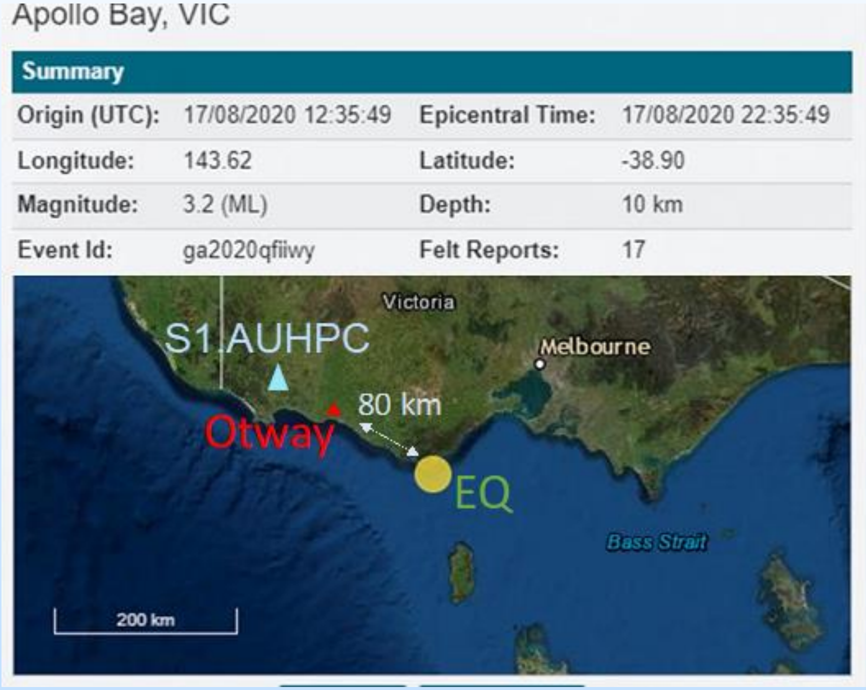
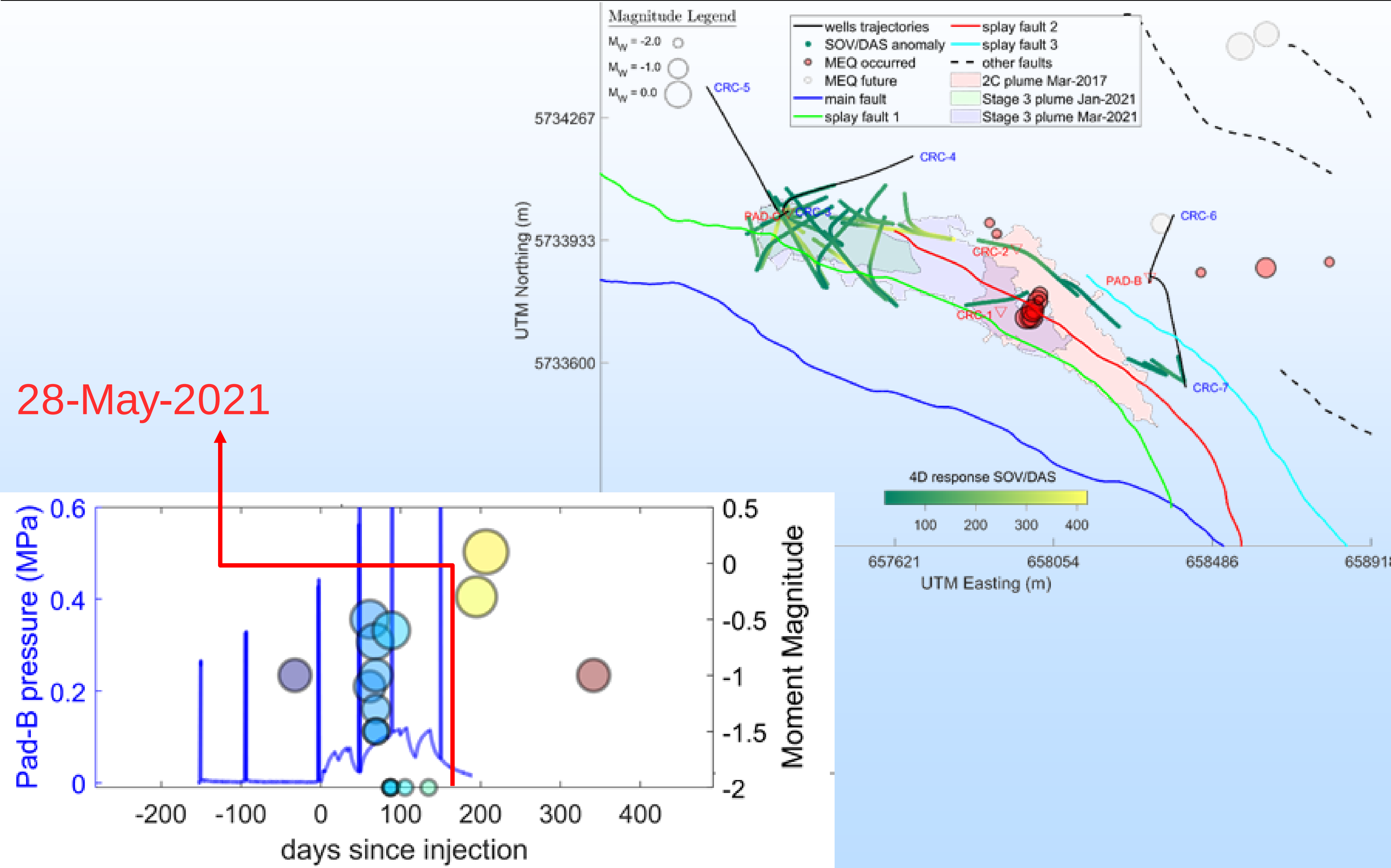




Calibration: **Need to multiply by factor ~8**

Timing of the seismicity:

Most events are triggered by the CO_2 flow



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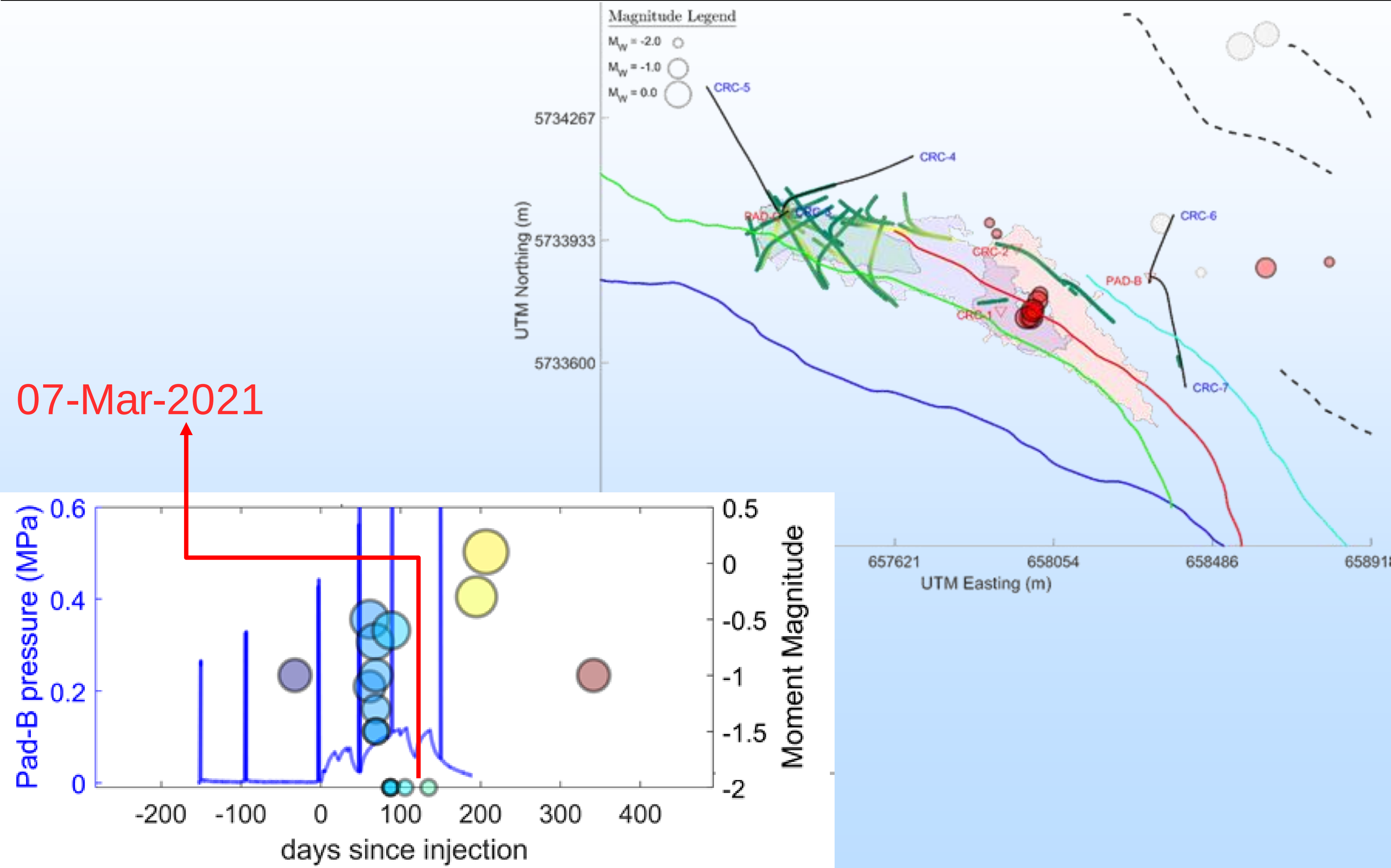

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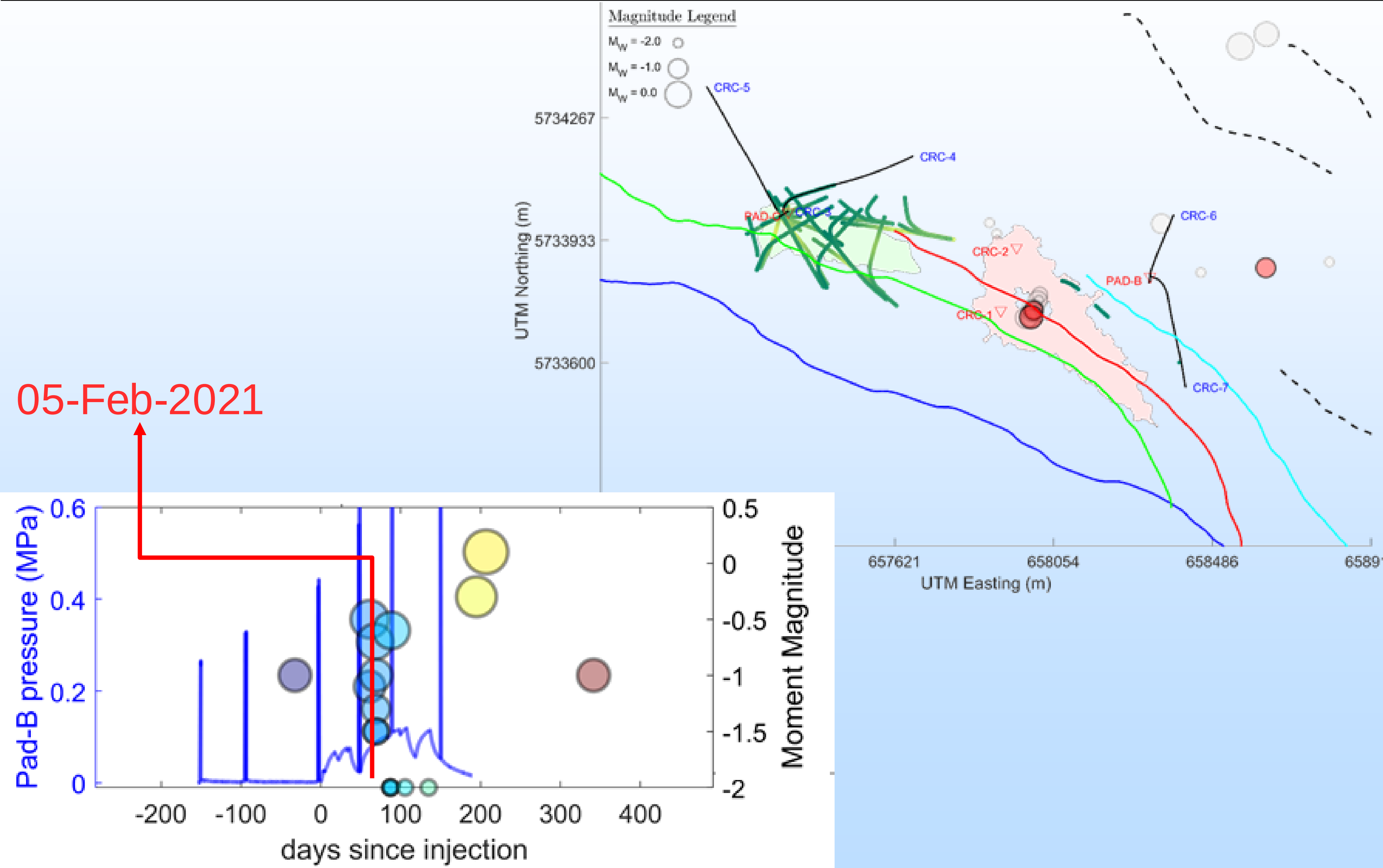

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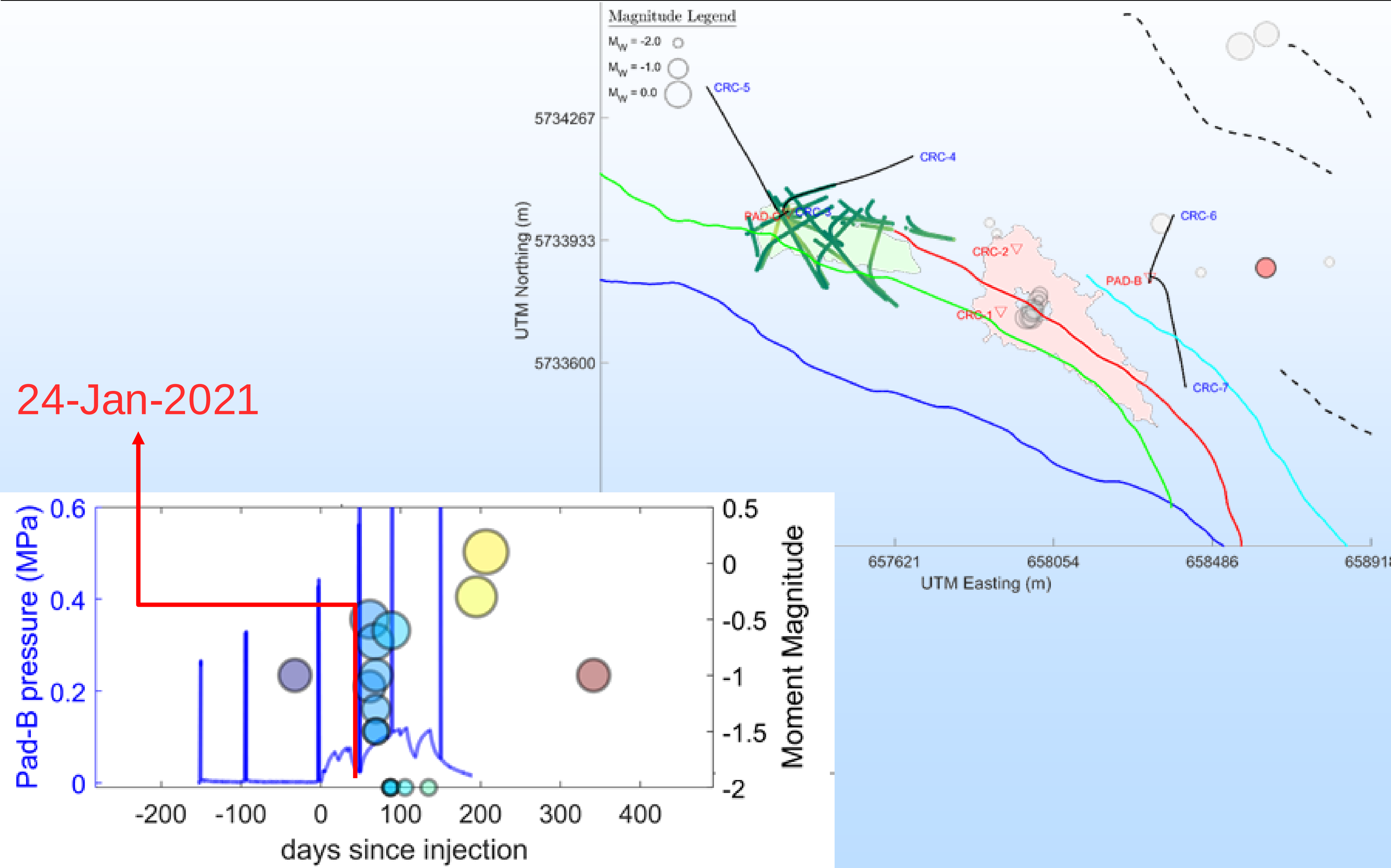
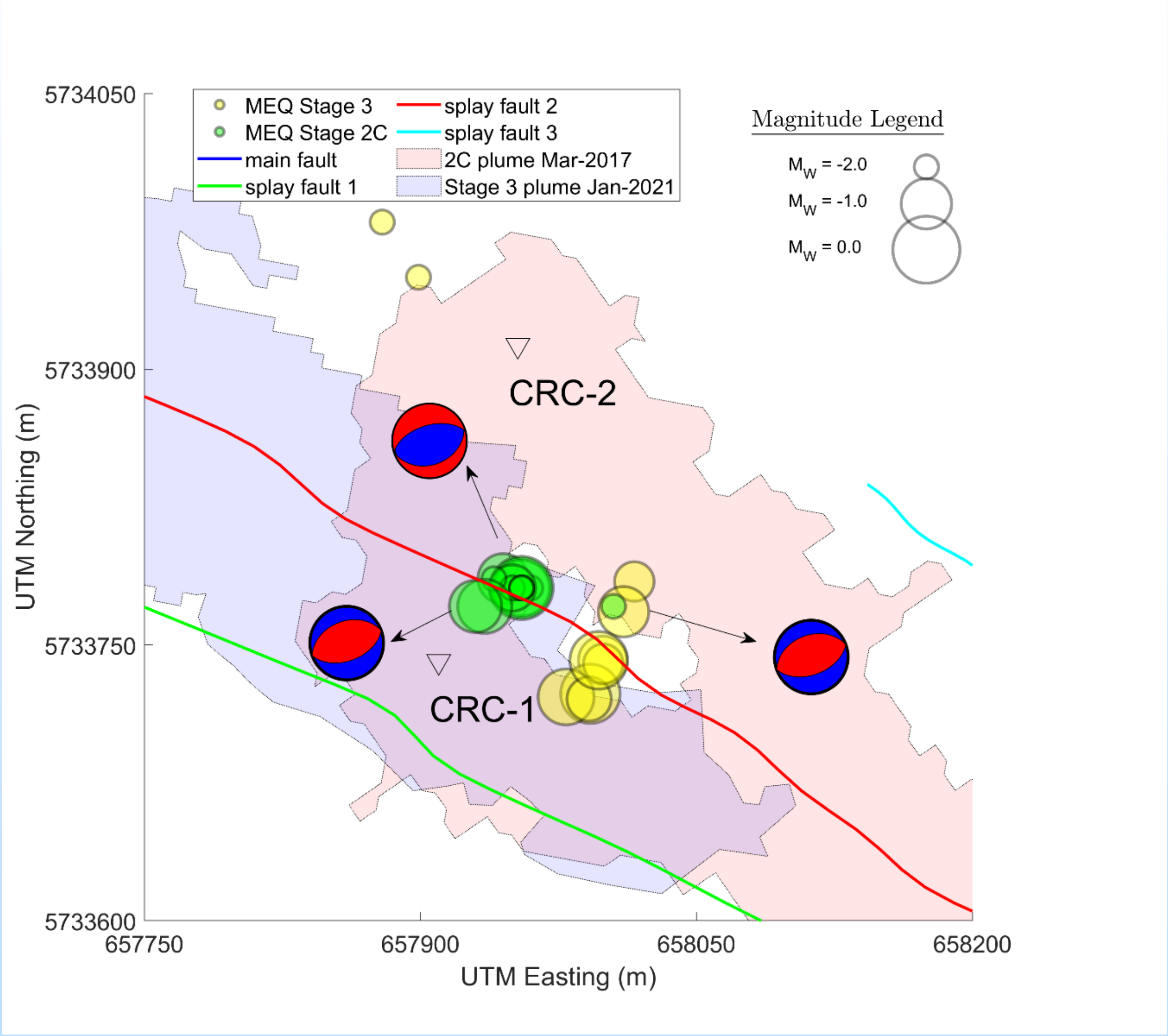


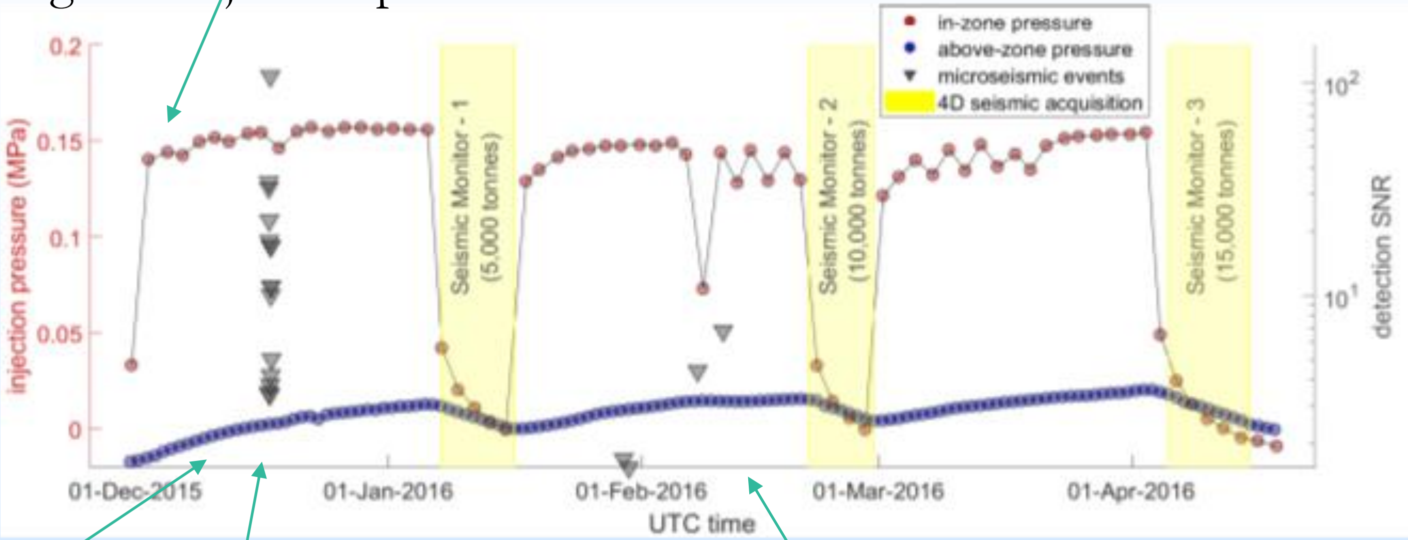
Stage 3 vs Stage 2C events:
Same location + Same moment tensor



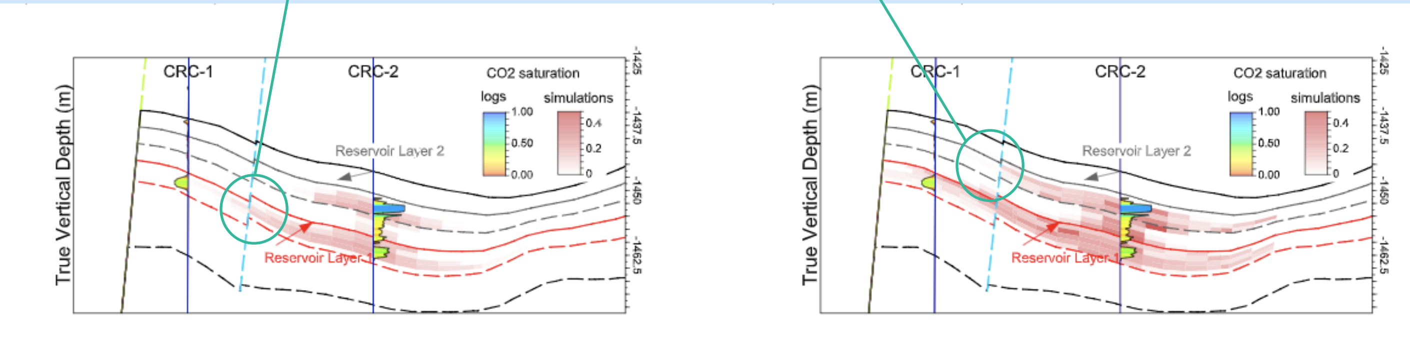
Stage 3 vs Stage 2C events:

Timing is also related to the plume movement

Stage 2C injection pressure



Stage 2C AZMI

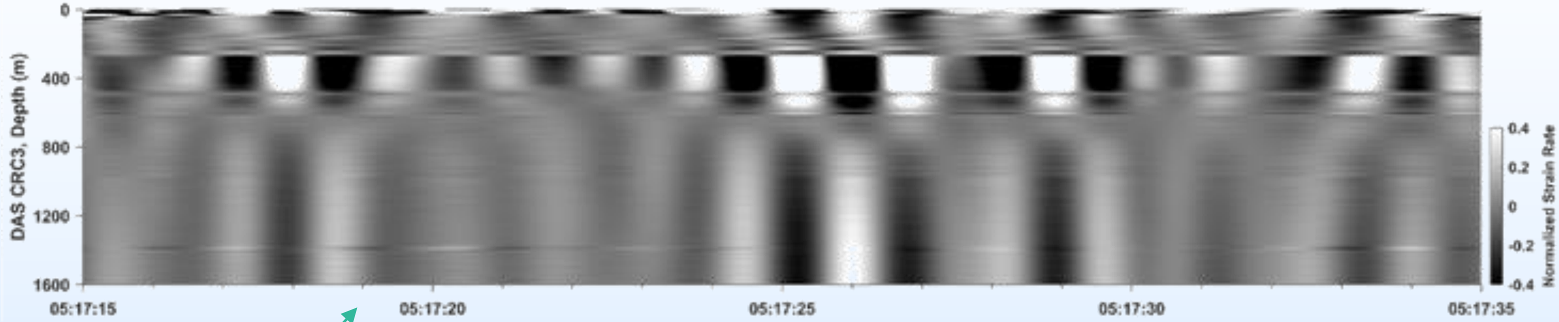


4D seismic and simulations show when the CO_2 plume reached the fault for the first and second time

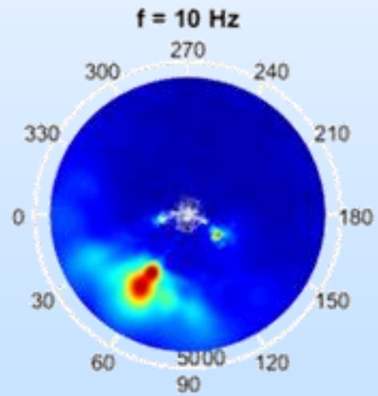
Future Work:

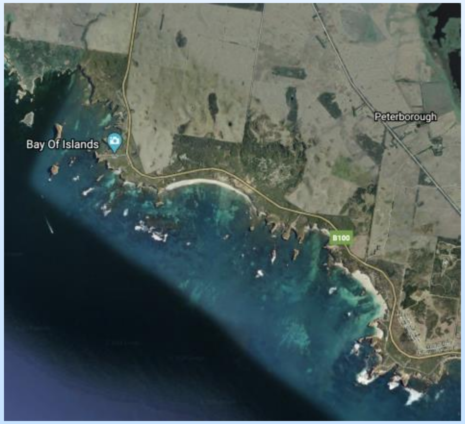
Plume imaging with ocean-generated signals

Repeatable signals during 80 days of monitoring in Otway

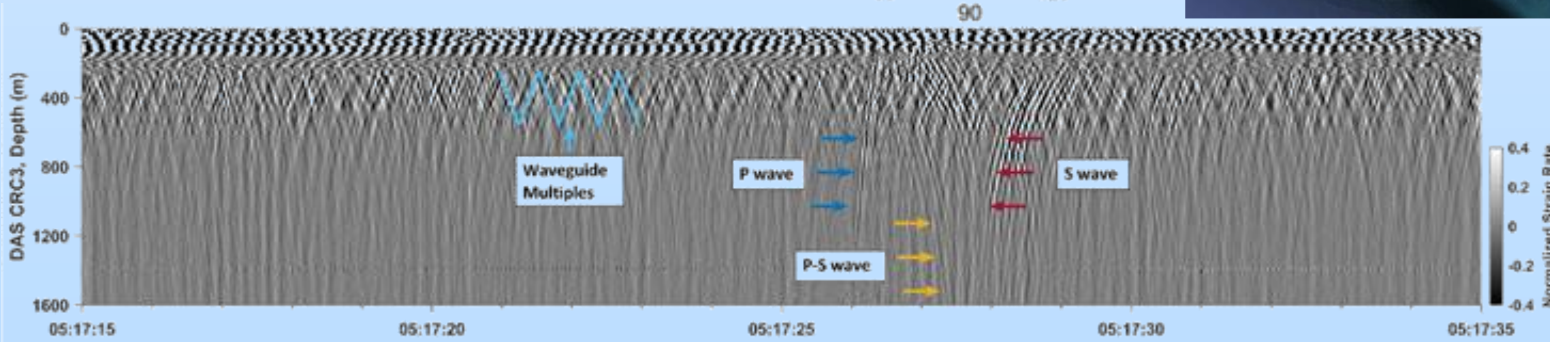


1 Hz local microseisms





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 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

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

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.

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