The value of microseismic in practical applications of CCS monitoring

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GeoREST - induced seismicity workshop
Palma, 13. March 2024

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Exploring the Earth

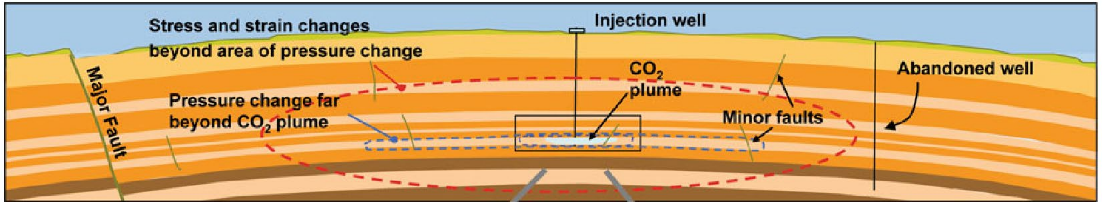
Microseismic monitoring of CO_2 storages

- Established early-stage diagnostic of reservoir response to injection
- Seismicity shows injection-induced fluid pathways and stress transfer
  - ➢ Indication of reservoir behavior ahead of the CO_2 front
  - ➢ Detection of potential seal integrity, or well problems, before leakage occurs
- Important risk mitigation tool
  - ➢ Correct association of events to injection operation → **requires accurate event depth**
  - ➢ Feedback protocol to operation (traffic light system) → **requires real-time monitoring**

Successful monitoring depends:

- ➢ Network geometry
- ➢ Sensor type (DAS, geophones..)
- ➢ Processing workflow

(Rutqvist, Geotech Geol Eng, 2013)



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CCS case studies

In Salah

- Insufficient monitoring network
- High level of seismicity
- Events cannot be located sufficiently

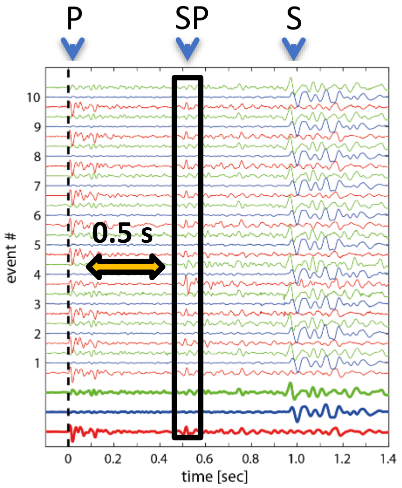
Decatur

- Excellent instrumentation and geophysical monitoring
- High level of seismicity
- Good control on focal depth due to deep geophones

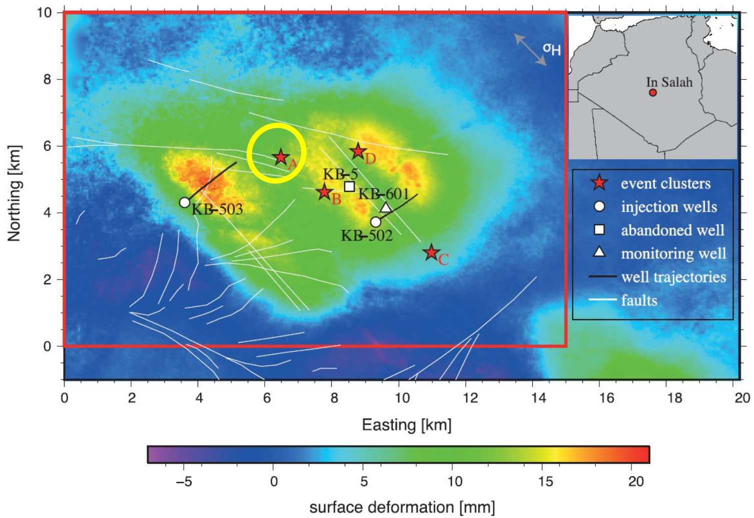
Quest

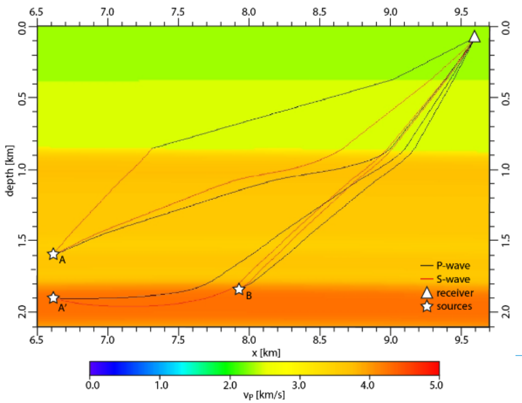
- Various monitoring setups → ideal for comparison
- Low seismicity, but far-reaching
- Poor depth control, despite high quality network(s)

In Salah, Algeria



Cluster A





- 4 MT CO_2 injection at about 1.9 km depth started in 2004
- Downhole monitoring well but only one geophone at 30 m provided reliable data.
- More than 5000 events grouped in 4 clusters separated by S-P traveltime and azimuth.
- Event location cannot be estimated sufficiently accurate with only one geophone!
- Additional phase arrival (e.g., SP-converted phase) can help to constrain focal depth.

Goertz-Allmann et al. (2014), GJI

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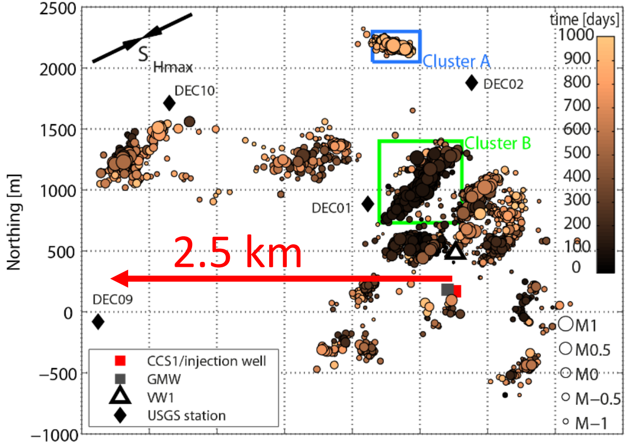
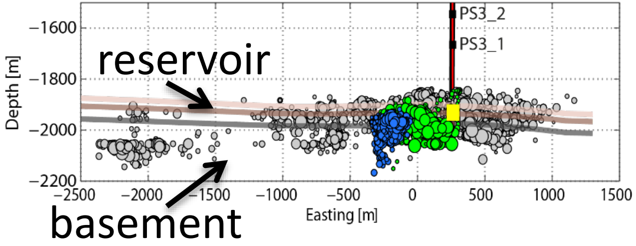
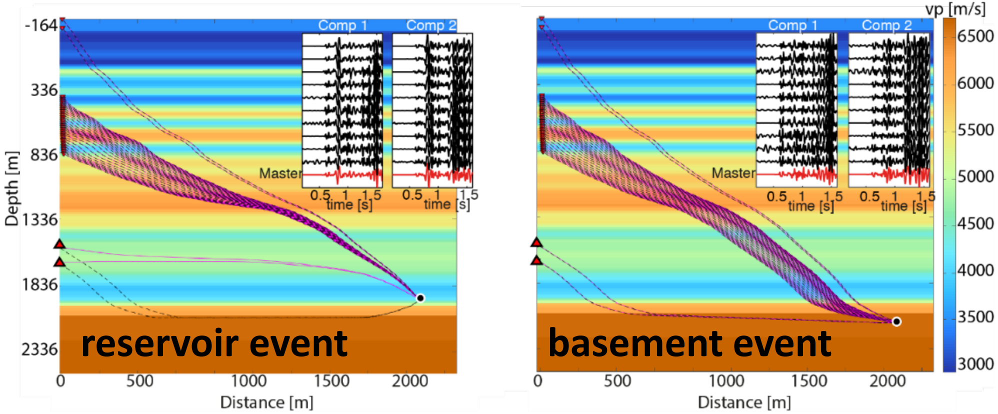
The Decatur CCS site, Illinois

- 1 M tons CO_2 injected at 1.9 km depth (2011-2014).
- Borehole & surface sensors.
- Over 4,800 microseismic events located.
- Different waveform signature for reservoir & basement events.
- Deep borehole geophones are ideal for detectability and are crucial for good focal depth estimation.







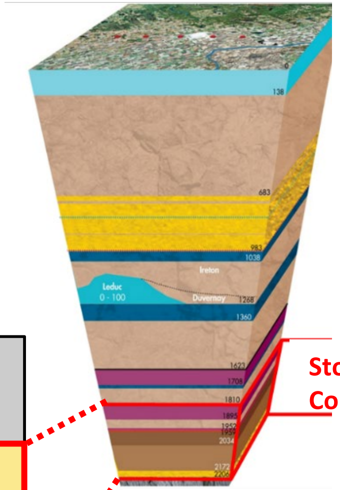
travel path differs for different event depth

Goertz-Allmann et al. (2017), JGR

The Quest CCS Facility

- 1 M tonnes CO_2 per year into deep saline aquifer at 2 km depth
- Goal of 25 million tonnes of CO_2 over a 25-year period
- 9 Mt since August 2015
- High quality sandstone (~17% porosity) reservoir
- Excellent permeability (~1000mD)

Inject → Storage

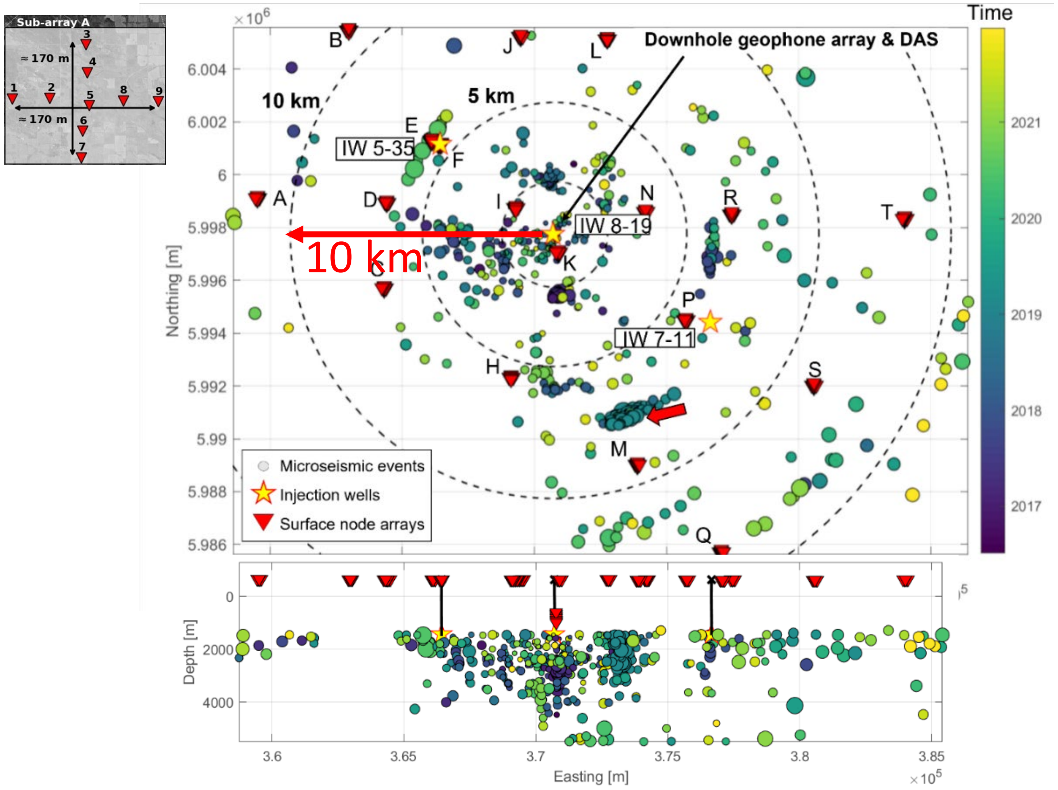


Ensure

85m	Prairie Evaporite – Additional Seal	
85m	Upper Lotsberg Salt – Ultimate Seal	Storage Complex
35m	Lower Lotsberg Salt – Secondary Seal	
45m	Middle Cambrian Shale – Primary Seal	
40m	**Basal Cambrian Sandstone – Storage Reservoir**	
	PreCambrian Basement	

Shell operated joint venture between Canadian Natural Resources, Chevron and Shell

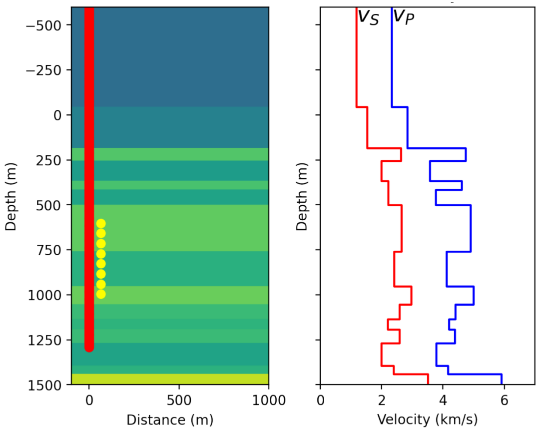
Microseismic monitoring at Quest



events until December 2021

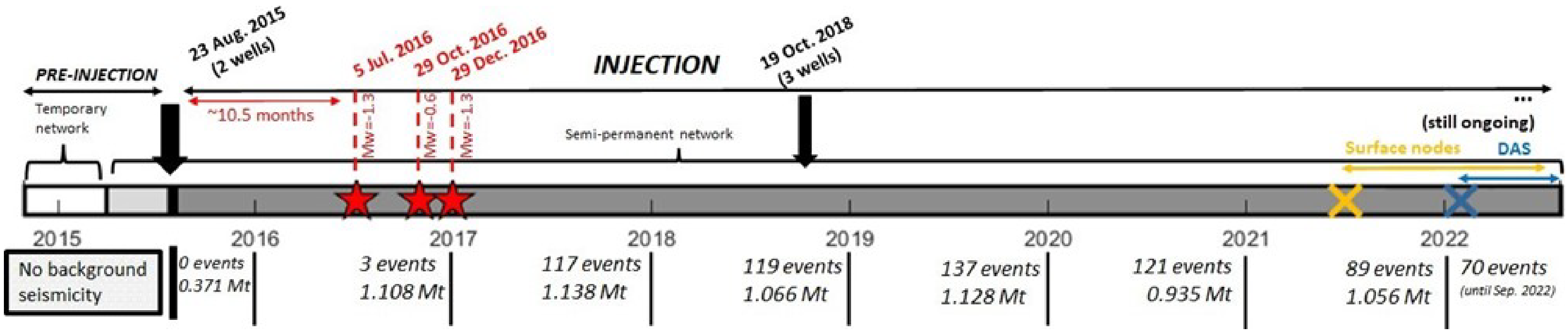
Almost ideal monitoring setup!

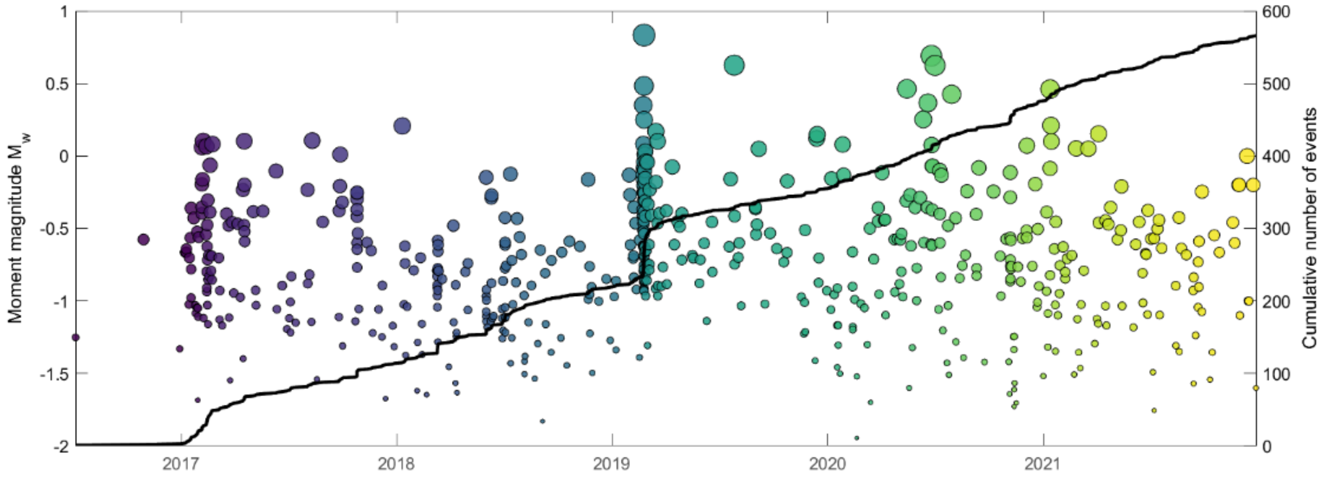
- Three injection wells
- Downhole array with 8 3C geophones
- DAS cable within central injector
- Surface arrays with 153 nodes arranged in 17 sub-arrays
- All events in the Precambrian basement



Goertz-Allmann et al. (2022), GHGT

Microseismic monitoring at Quest





- No background seismicity
- First locatable event after 10.5 months
- Magnitudes between -2 and 0.8

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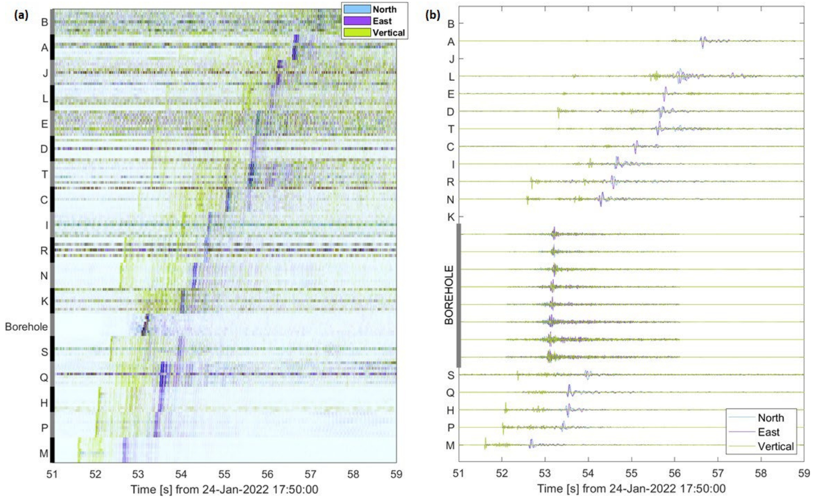
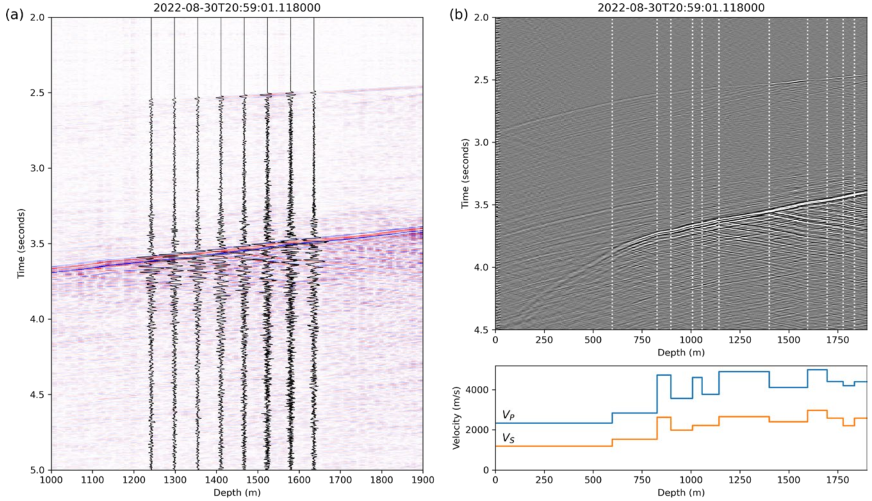
Microseismic monitoring at Quest

Comparison of various microseismic monitoring solutions highlight benefits and challenges of individual technologies for **detectability** and **locatability**.

Surface versus borehole



DAS versus borehole



Goertz-Allmann et al. (2024), IJGGC

Event locatability:

downhole geophones versus surface beams

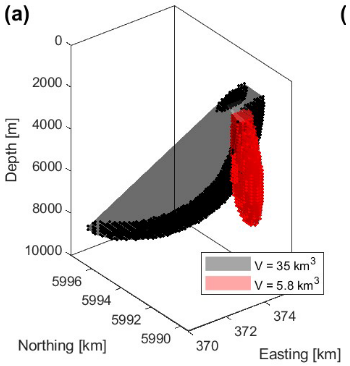
Borehole:

- Poor azimuthal coverage
- Trade-off between horizontal position and focal depth

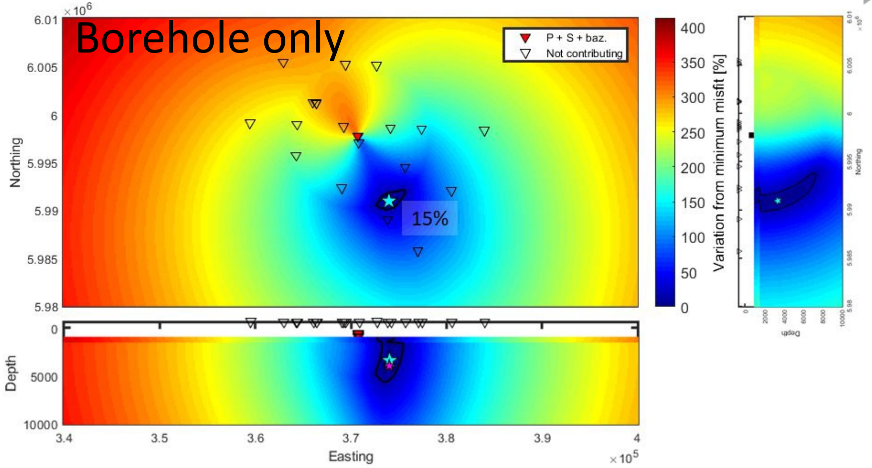
Surface nodes:

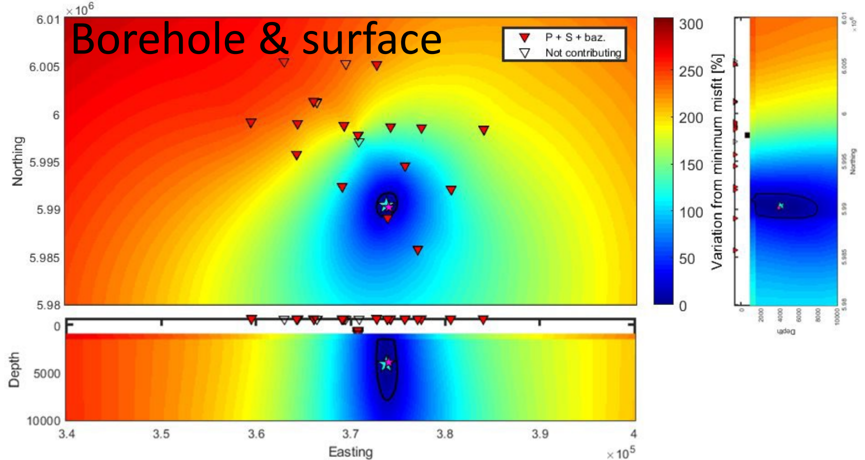
- Improved azimuthal coverage

By combining downhole and surface we obtain a reduced uncertainty, no trade-off, ellipsoidal misfit volume

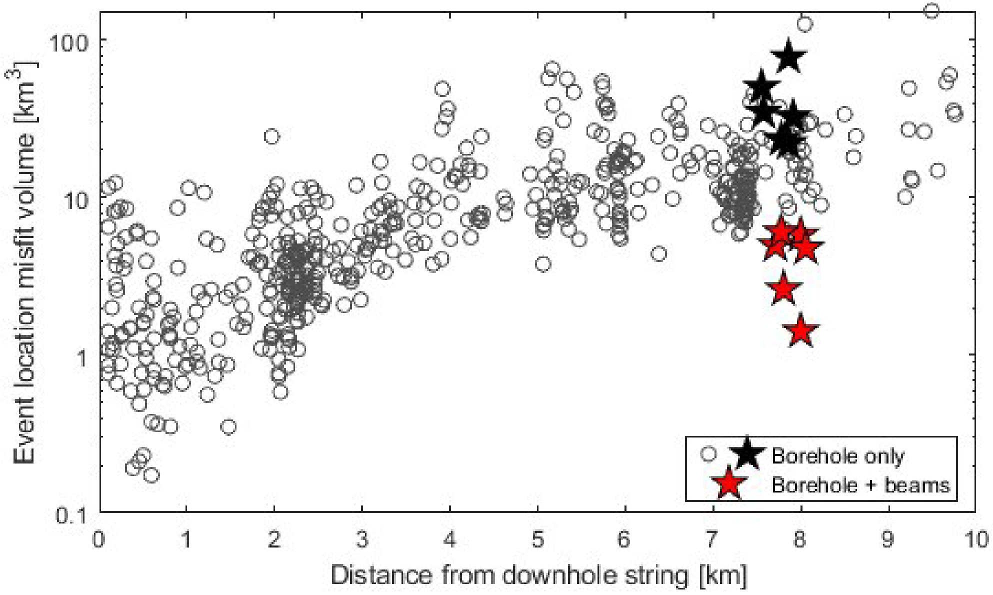


Goertz-Allmann et al. (2024), IJGGC,





Event locatability:
downhole geophones versus surface beams



- Location uncertainties are much reduced (especially for events within the network)
- Still too large depth uncertainty (± 3 km) for unambiguous event association.
- Uncertainties increase with distance from the monitoring well.

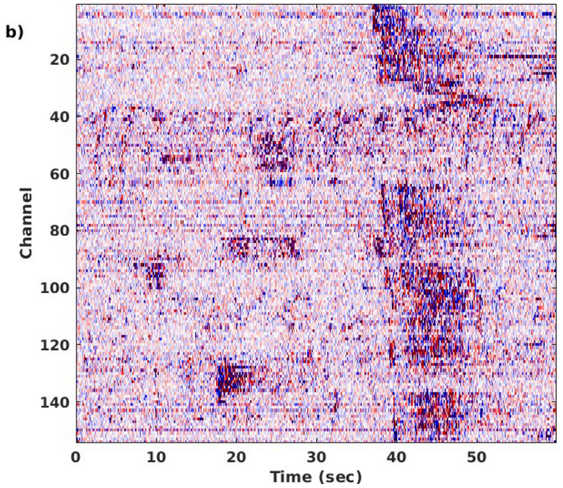
Event detectability

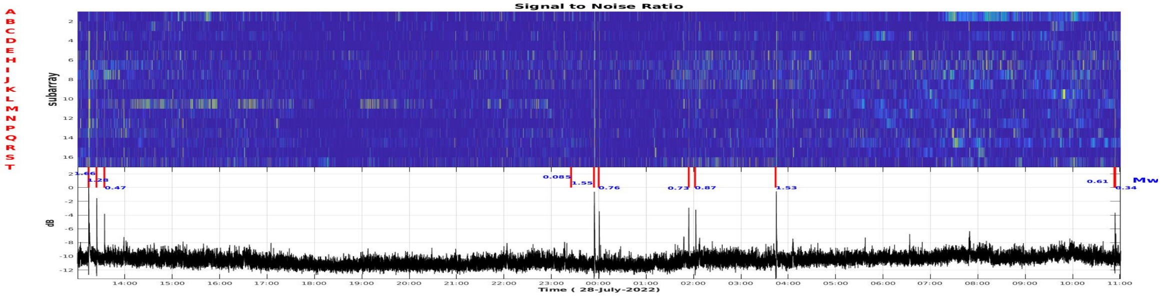
Borehole: ➡ ground truth event catalog

- High SNR

Surface nodes:

- Lower SNR
- Array beamforming to enhance SNR
- Noisy traces can distort beamforming result
- Requires advanced pre-processing/ filtering: 2-60 Hz + spectral subtraction + spatial interpolator





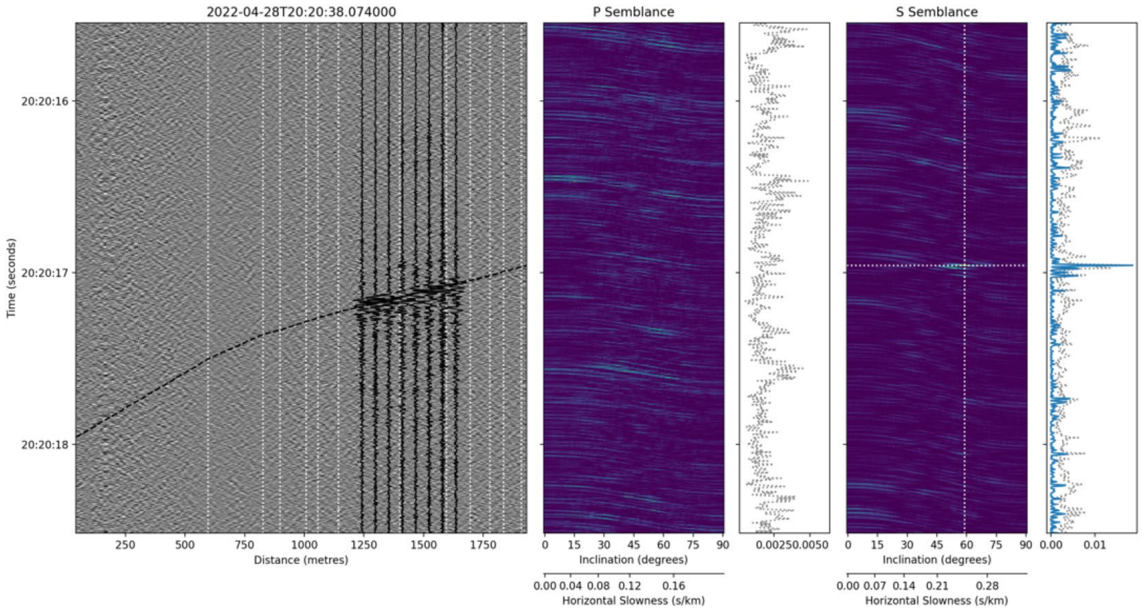
- About 80 % detections with at least one beam
- But: high false detection rate

Event detectability

DAS:

- Higher instrument noise
- Weak P-wave
- Semblance stacking to detect events

→ about 50 % of events detected with DAS after advanced processing



Baird et al. (2024), EAGE, submitted

Lessons learned - Quest

- A combination of microseismic monitoring solutions is very useful to reduce event location uncertainties and make use of the different technology advantages.
- Focal depth uncertainty will remain large if no deep sensors (around reservoir depth) are available.
- Location uncertainty increases with distance from monitoring well
    - ➢ As plume grows with time, event association will be increasingly difficult
- Using detailed information on additional phase arrivals from DAS could provide further improvement.

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Conclusions

- During CCS operations: most important is event depth resolution to verify seal integrity, correct event association, and support reservoir characterization.
- Reservoirs are generally thinner than depth uncertainty from standard seismological methods. Therefore, additional constraints need to be exploited to improve depth resolution (e.g., later arrivals / multipathing).
- Good network planning:
  - Vertical aperture with borehole array(s) for depth resolution
  - Azimuthal coverage for location accuracy and source parameter inversion
  - Monitoring adjustment with time may be necessary
- Real-time data stream and automatic processing can provide "traffic light" feedback to operations.
- Source parameters (b, $\Delta\sigma$) can provide hints of reservoir hydraulics, but require good calibration, large catalogs, and excellent network coverage.

Thank you for your attention!

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