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Microseismic Monitoring Using SADAR Arrays at the Newell County Carbon Storage Facility: Four Years and Continuing

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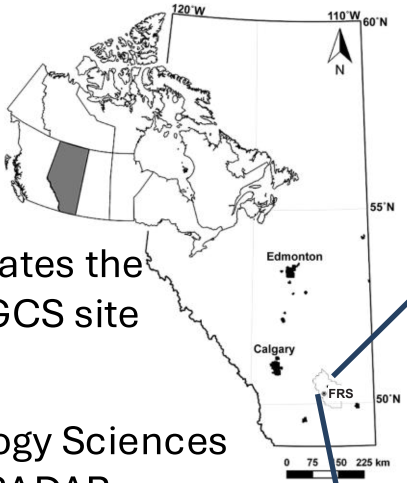
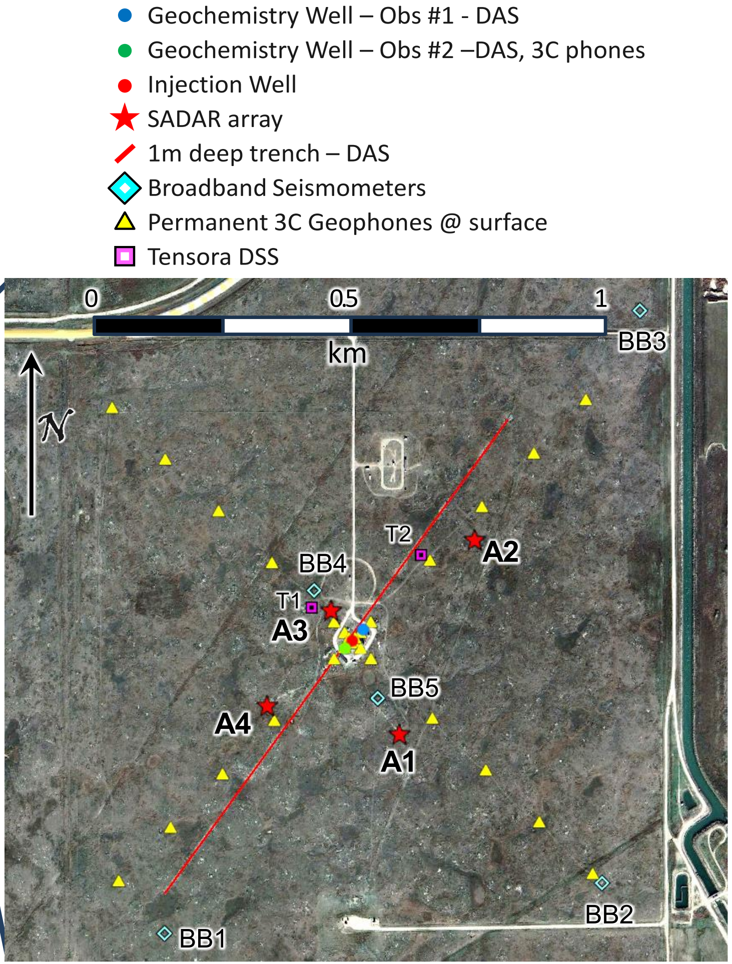
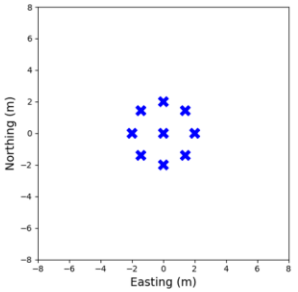
Introduction

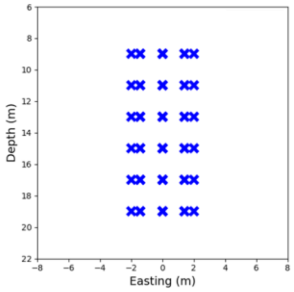


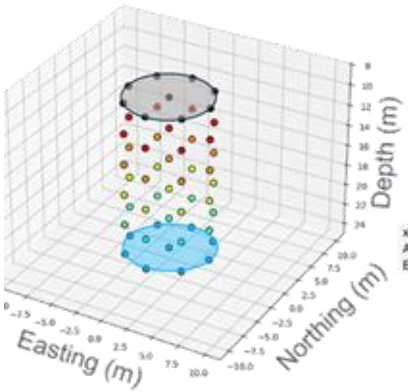
- Carbon Management Canada operates the Field Research Station (FRS) as a GCS site for evaluating MMV technologies
- November 2021 Quantum Technology Sciences installed a sparse network of four-SADAR-arrays
- The sparse SADAR network and processing system performs passive microseismic event monitoring for the FRS
- Four years of continuous monitoring
  - Bulletin containing ~14,000 events with a magnitude of completeness of -2.5 Mw.
  - Bulletin includes the uncertainty ellipse for each location and the depth uncertainty.

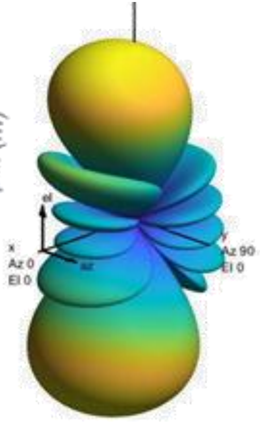


SADAR Arrays









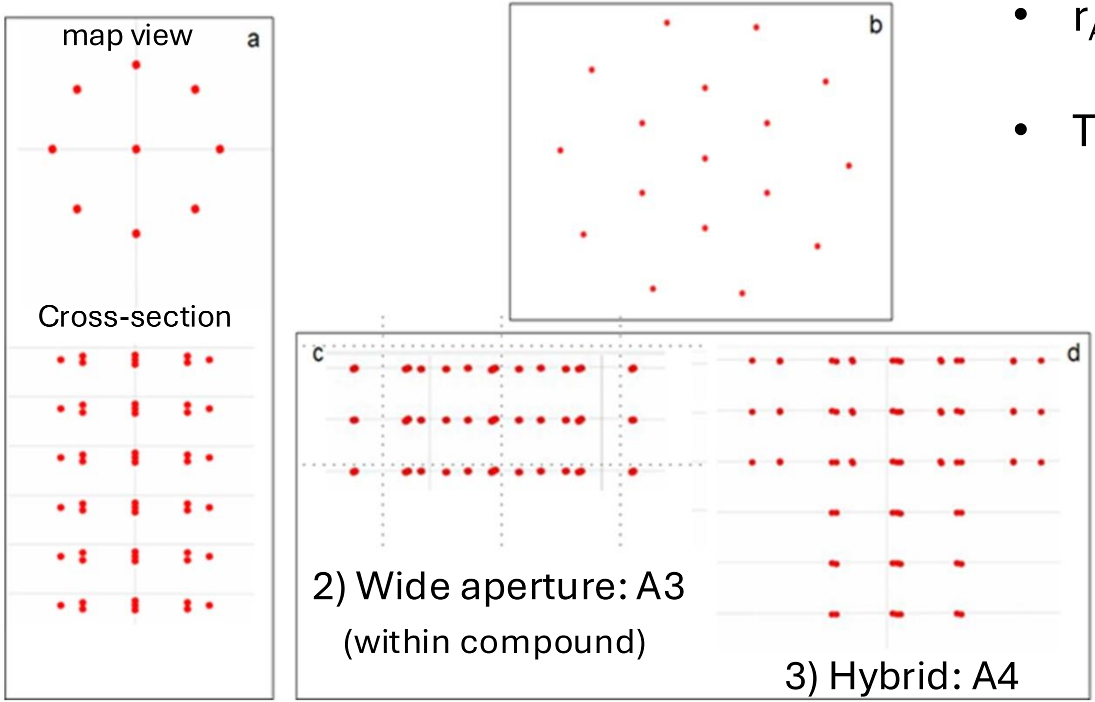
- <u>SADAR arrays:</u> *Compact Volumetric Phased Arrays*
  - *Designed to meet microseismic monitoring requirements*
  - *Permanently emplaced below weathering layer*
  - *Enable coherent phased array signal processing*
  - *Maximizes SNR and useable bandwidth*
  - *Provides enhanced receiver gather optimum-offset imaging*
  - *Available 24-7, durable, and robust*

- <u>SADAR sparse passive monitoring network:</u>
  - *Designed to meet microseismic monitoring requirements*
  - *Improved microseismic locations with lower uncertainties*
  - *Scalable / extensible architecture separates single-array processing functionality from network processing functionality*

SADAR Designs at CMC-FRS

1) Standard:
A1 and A2

A3 and A4 map view



- Depth 9-19 m
- r_{A1}=2m, r_{A3}=3.75m
- Three array designs evaluated

Example Gains

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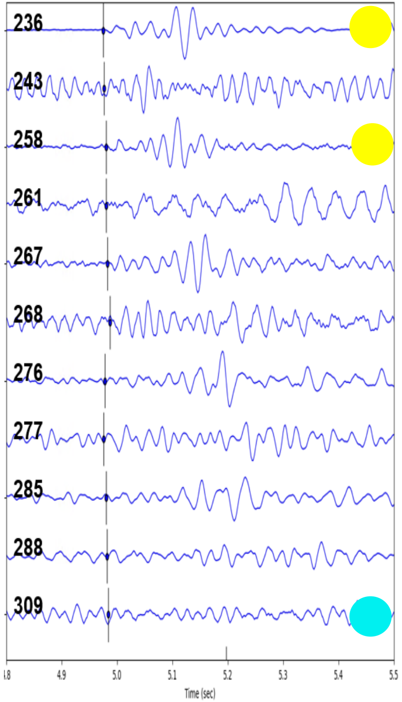
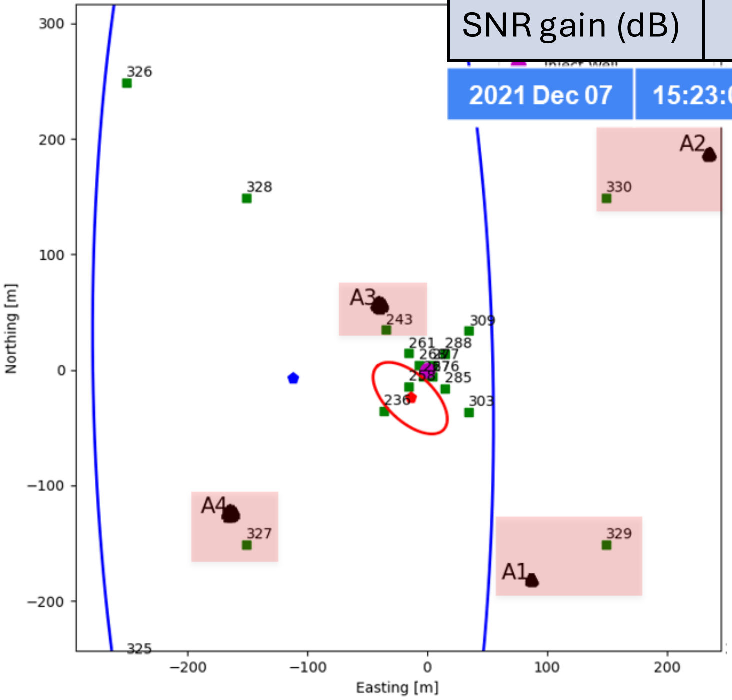
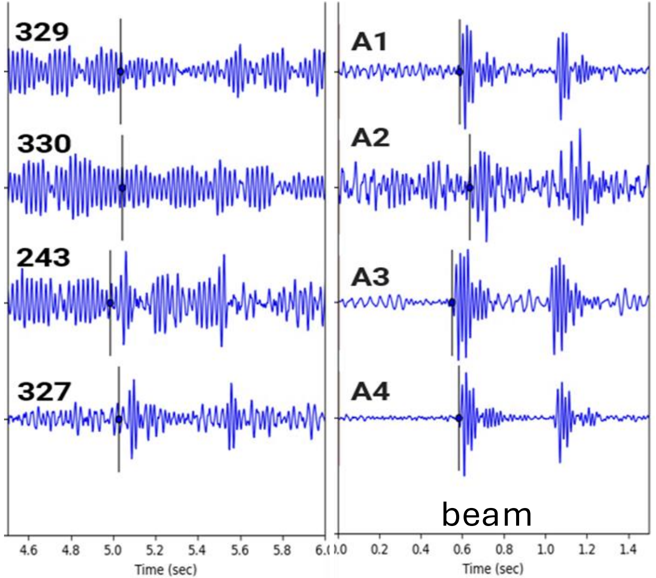
Array	A1	A2	A3	A4
SNR gain (dB)	18	8	20	20

2021 Dec 07	15:23:06.285	50.45020N	112.12087W	107m	Mw=-1.9

Surface (near range)





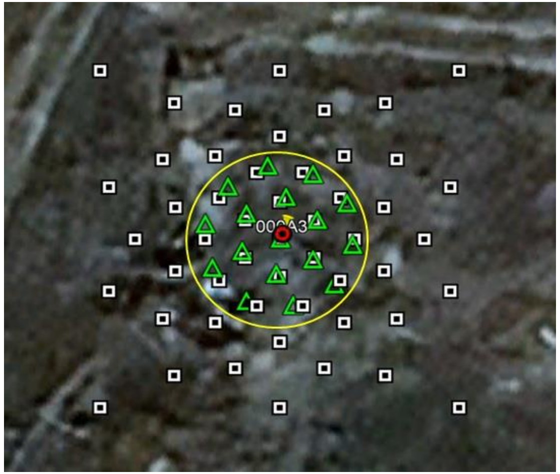


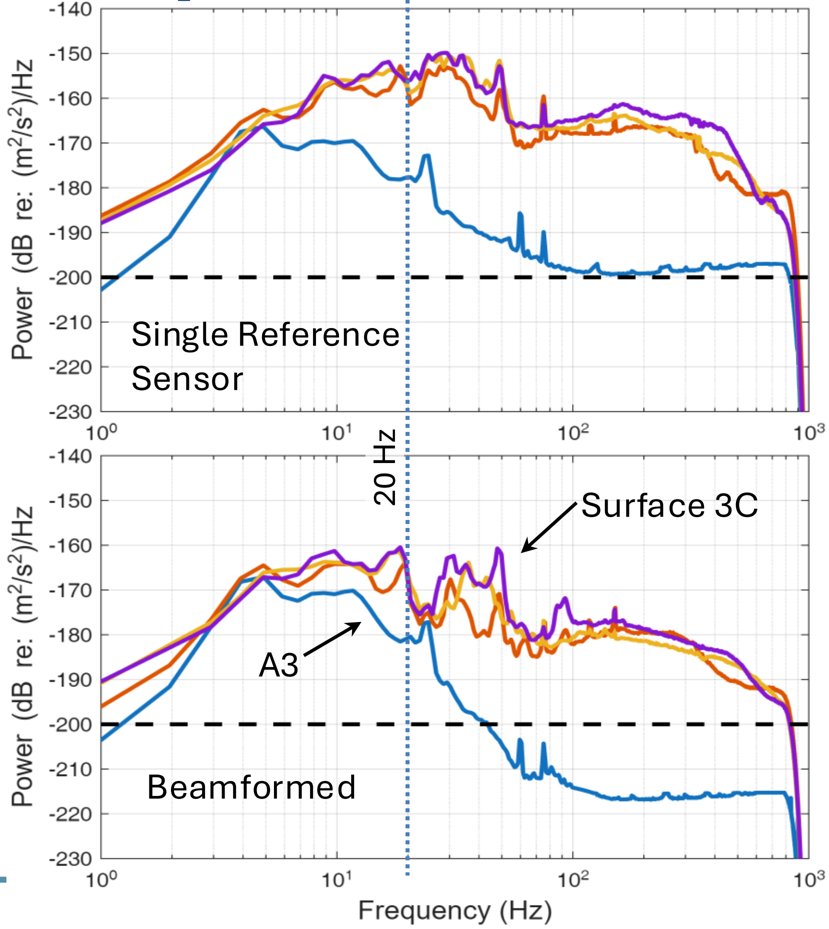
Arrays provide better SNR and resolution than even the closest surface stations

Zhang, J., Hutchenson, K.D., Nyffenegger, P.A., Grant, E.B., Jennings, J., Tinker, M., Macquet, M., Lawton, D.C. [2023] Performance comparison of compact phased arrays and traditional seismic networks for microseismic monitoring at a CO2 sequestration test site. *The Leading Edge*, 42(5), 332-342 https://doi.org/10.1190/tle42050332.1

Noise Levels: Surface vs. Depth

Comparison during GHGT-17 October 2024





- Noise is suppressed by shallow borehole emplacement
- Conventional beamforming provides notable gains against noise as a function of frequency
  - ~20 dB gain maximum vs. single sensor
  - ~30 dB gain vs. surface array

Automated Processing Pipeline

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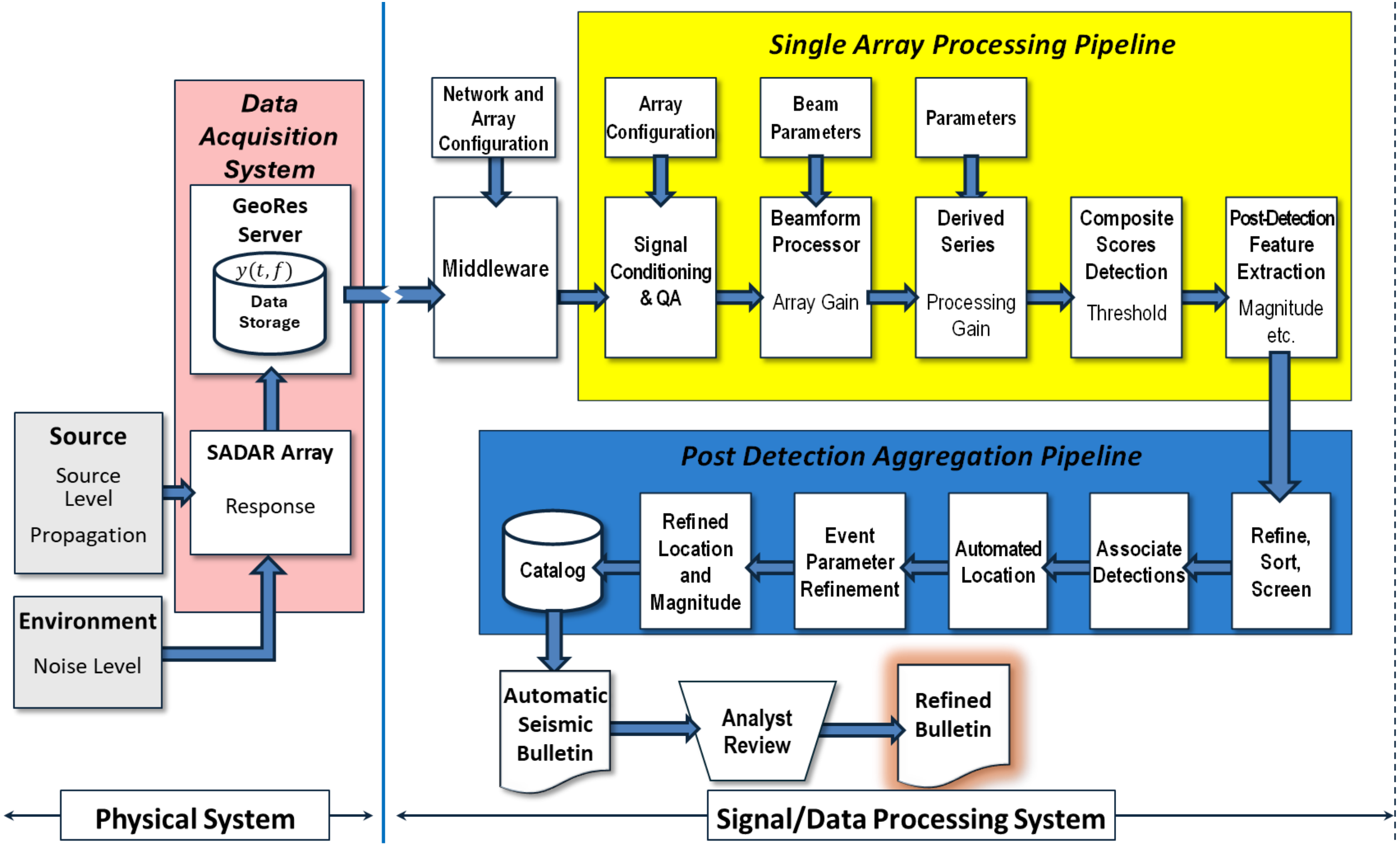
Conceptual Model

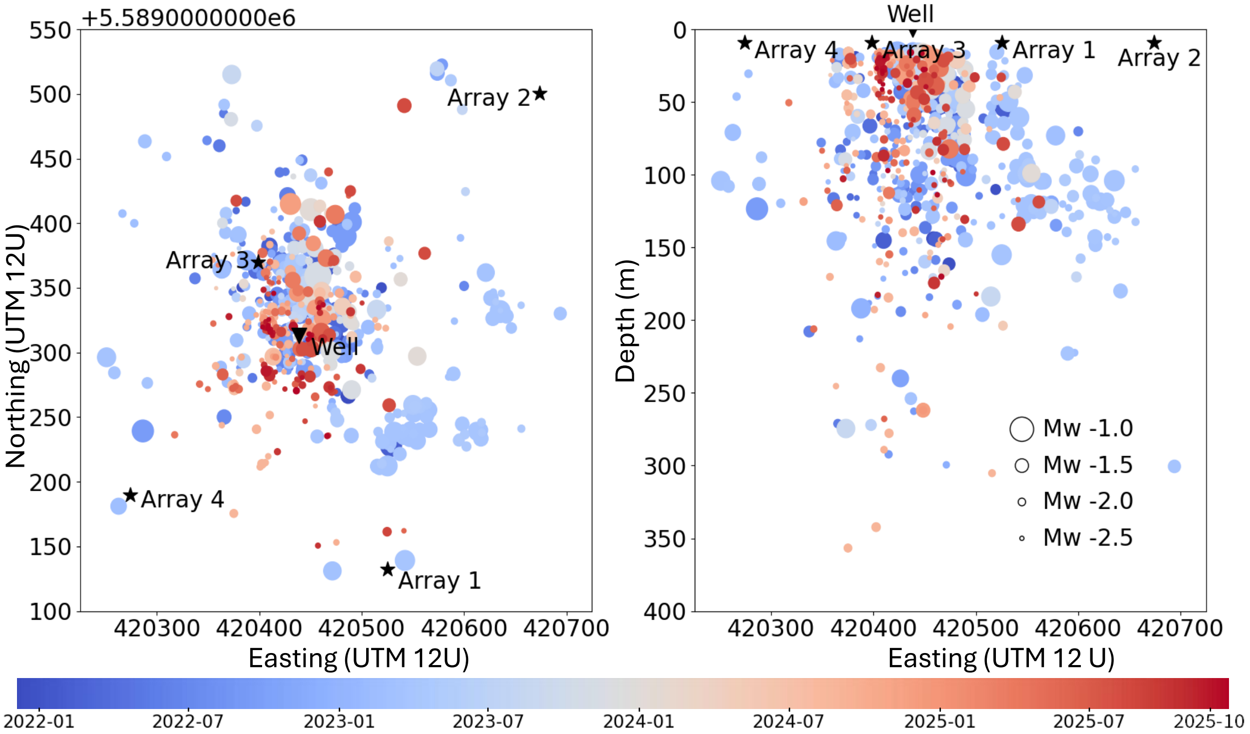
- Engineered data reduction system
- Automated seismic bulletin result
- Reviewed, refined seismic bulletin is the product
- Variants used for monitoring longwall mining and reservoir engineering



Resulting Bulletin

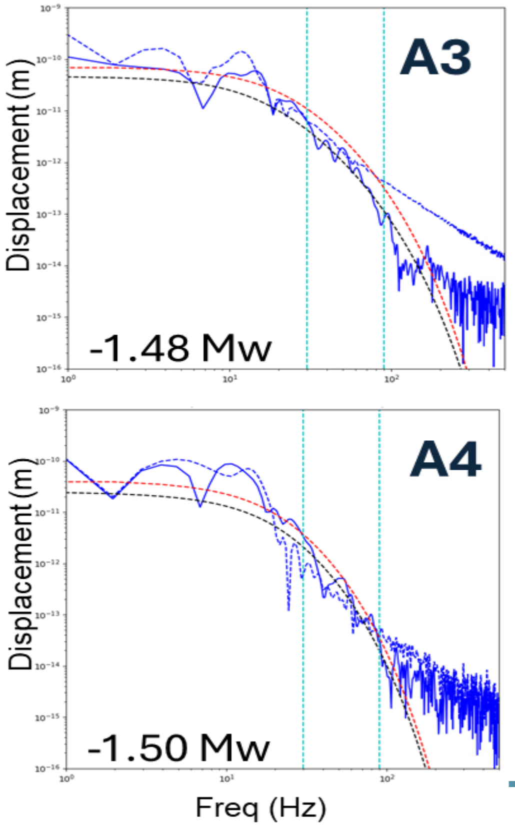
- Four years of monitoring
- 99% system availability
- Total population 14,073
- z>15 m
  1,583 events
- Best events, ndef = 4 arrays
  741 events

Sparse network of four arrays effective at locating events down to -3 Mw, depth approaching 400 m

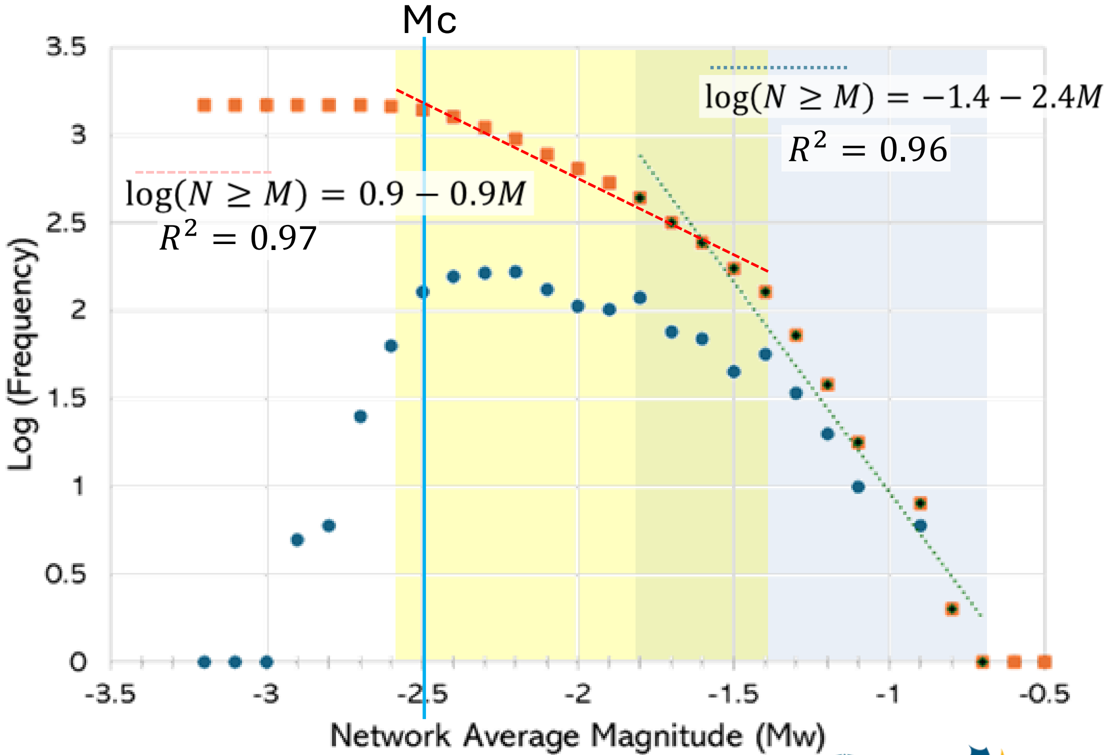


Moment Magnitude

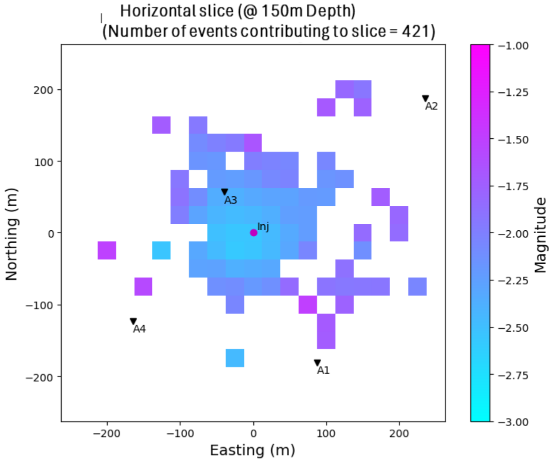
Brune(1970) method

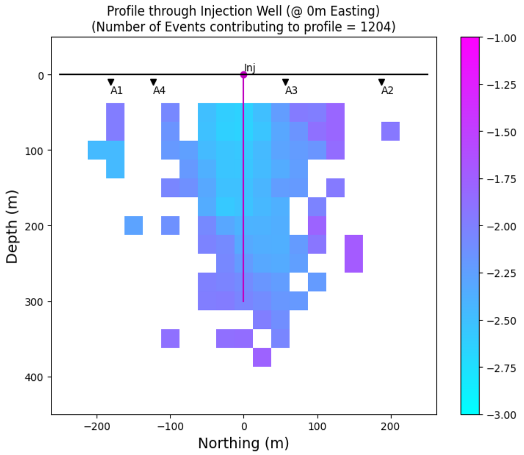


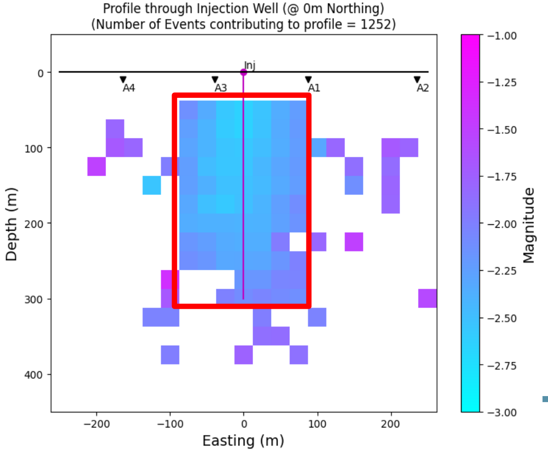
Magnitude frequency distribution for 1583 events



Performance Result: Minimum Magnitudes







Passive Monitoring System Conformance

- On going continuous evaluation through October 2025
- Assessing performance vs. system prediction
- 25m voxel sort
- 25m < depth z ≤ 425m
- $\Delta x < 275$m from well
- 3486 events of all quality grades
- White zones show zones of no support

Supports Core AOR Mc ~ -2.5 Mw (Red Box)

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Signal Power vs Range

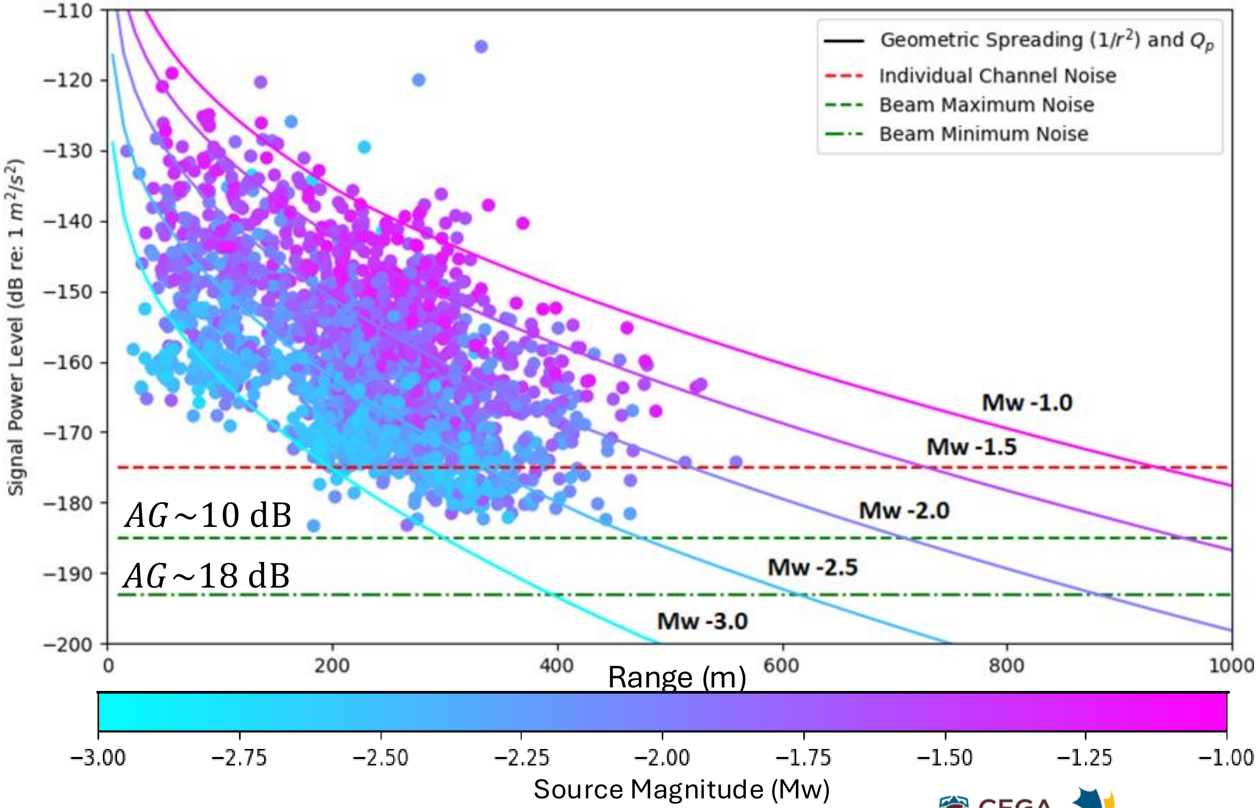
- Using 545 well-located events with z > 25m,
- One point per array, 2,180 points
- Solid lines are predicted signal level with propagation loss.

Brune model source :

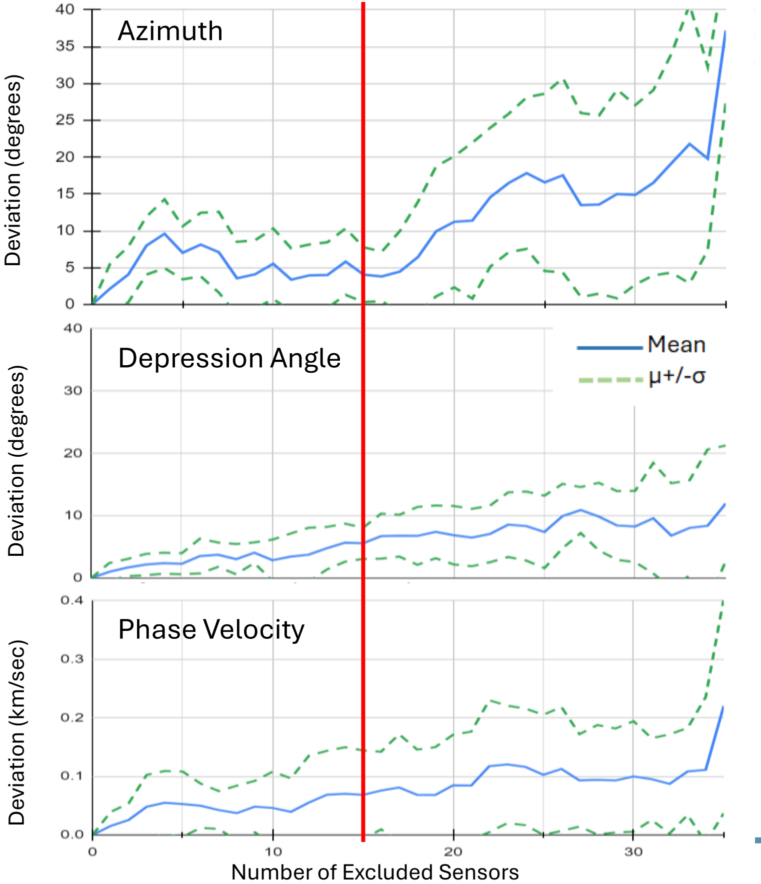
Stress drop = 1kPa
Pvelo = 2500 m/s
Svelo = 1100 m/s
Density = 2400 kg/m³
Q_p = 10

- Dashed lines are time domain noise measurements and gain

Supports AOR Mc ~ -2.5 Mw



Reliability (demonstration)



Robust to sensor attrition (demonstration)

- Given -1.52 Mw event with ~6 dB SNR, array A1 (standard design, 54 elements)
- Randomly exclude n elements from array a_l with element index $l = [1, 2, \dots 54]$.
- 10 trials for each value of n
- Measure the vector wavenumber and phase velocity using FK technique in three dimensions
- SNR loss expectation is ~1.5 dB
- (red line) up to ~15 sensors (27%) may be inoperative without degrading measurements
- Same exercise performed for active imaging, similar result.

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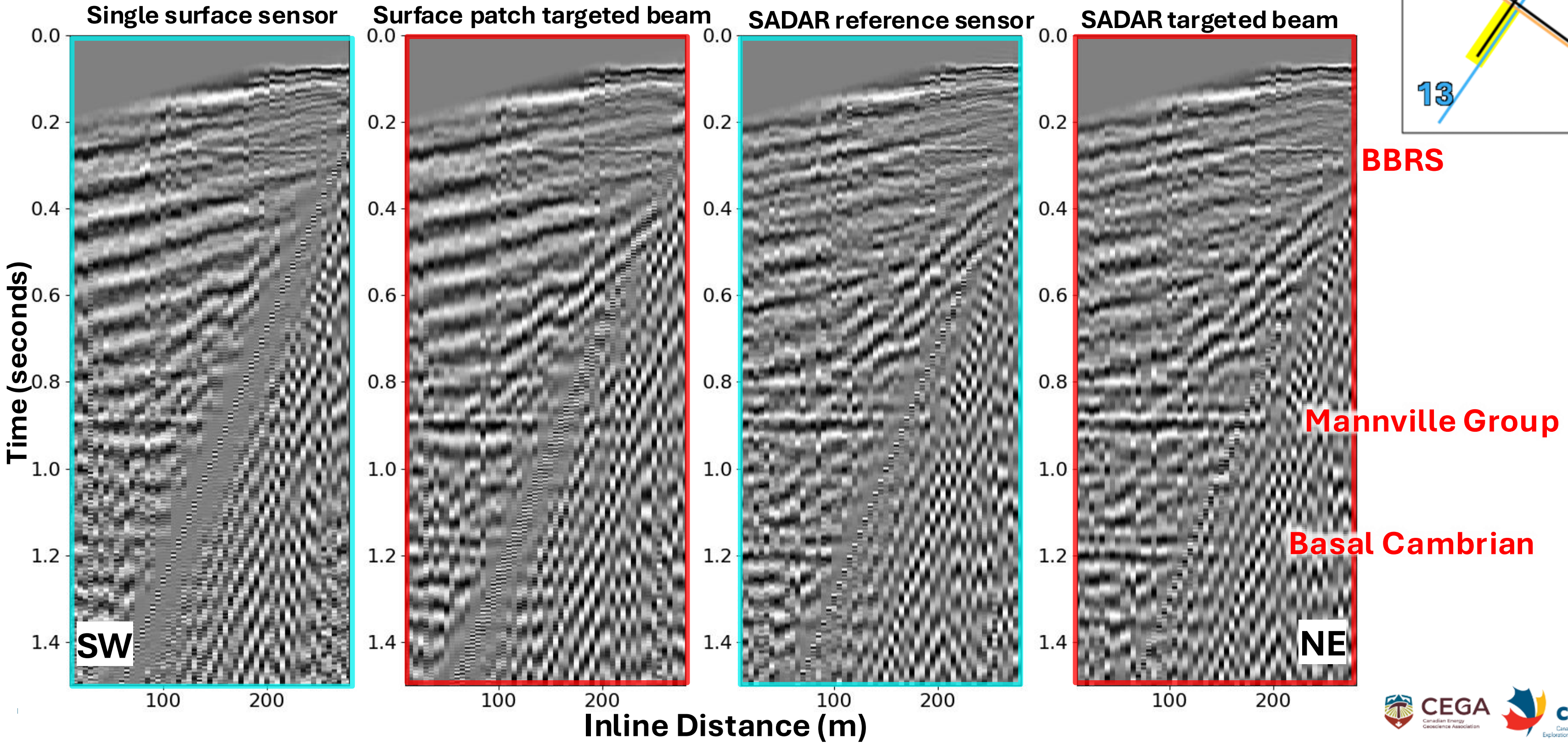
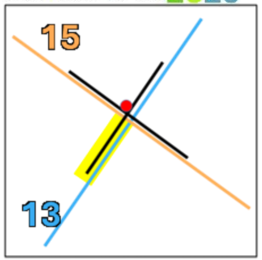
SADAR Multi-use Arrays

Shot Line13–Array3





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Discussion

48 Months of Passive Monitoring Using The SADAR Sparse Network

- Event location down to -3 Mw
- Magnitude of completeness down to -2.5 Mw
- Single array signal measurements tolerant to ~30% sensor attrition

- Transportable processing chain for analysis center or near-real-time
- Also suitable for active-source surveys
- Reduced footprint (~150 m^2) to monitor wide area (~156,000 m^2)
- Both array design and network are adaptable and scalable

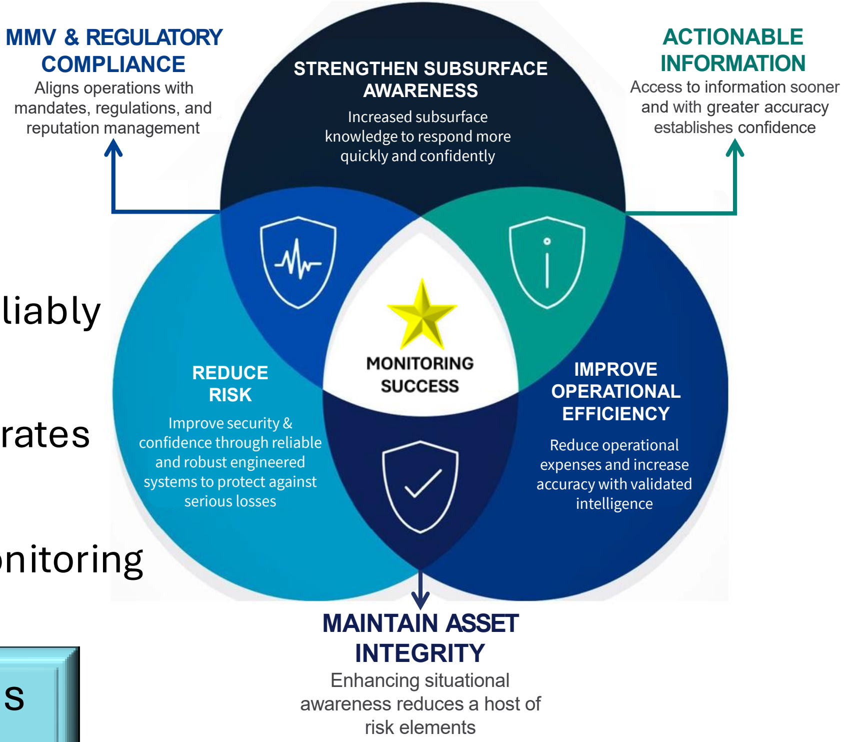
Capabilities Transportable to Related Monitoring Applications

Conclusions

48 months of persistent SADAR sparse network passive monitoring demonstrates:

- Continuously performing to requirements
- 48 month microseismic bulletin with locations, uncertainties, attributes
- Substantial array gain from beamforming enables reliably located events below Mw<-2.5 at 200 m (+)
- Engineered-in robustness of SADAR arrays demonstrates field-proven reliability
- A single sensor system for passive microseismic monitoring and active source imaging

Altogether, SADAR systems for MMV decreases operator financial and performance risks



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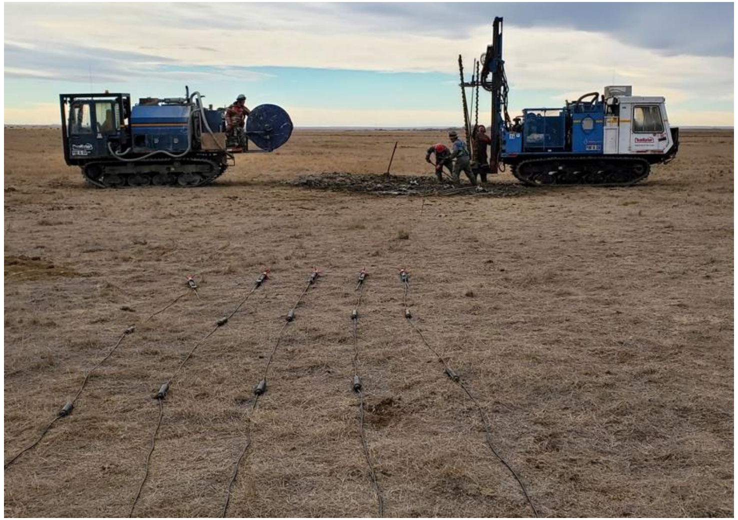

Acknowledgements

Geospace Technologies thanks to Carbon Management Canada for access to the Newell County Field Research Station, operational data, and support for SADAR system installation. The facility is funded by the Joint Industry Project.

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