Monitoring Technology for Deep CO2 Injection

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Geosciences Measurement Facility

Custom Instrumentation for Earth, Energy, and Environmental Science Discovery

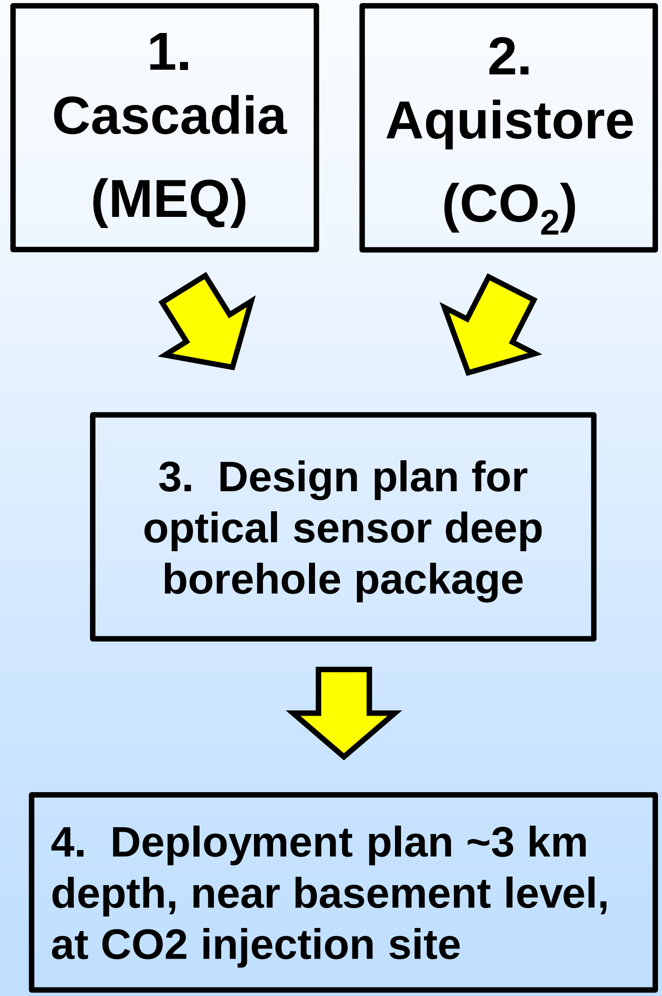
Presentation Outline

- Project Overview
  - Technical Status
  - Accomplishments to Date
  - Lessons Learned
  - Synergy Opportunities
- Project Summary
  - Key Findings
  - Next Steps

Presentation Overview

<u>New task, started June 2018:</u>

- Builds on learnings from two of our existing field sites: Cascadia and Aquistore (FY18)
- Task Plan: Design and deploy discrete wide-band optical 3C sensor on hybrid DAS wireline to ~3 km depth, at or near basement level, monitoring for induced seismicity during CO_2 injection.
- If successful TRL moves from field-laboratory Level 3 to Level 4-5.



Technical Status

Cascadia Field Laboratory

Cascadia Project

Main Task (FY18): Evaluate new optical interferometric sensors (accelerometers) for suitability of monitoring **induced seismicity**.

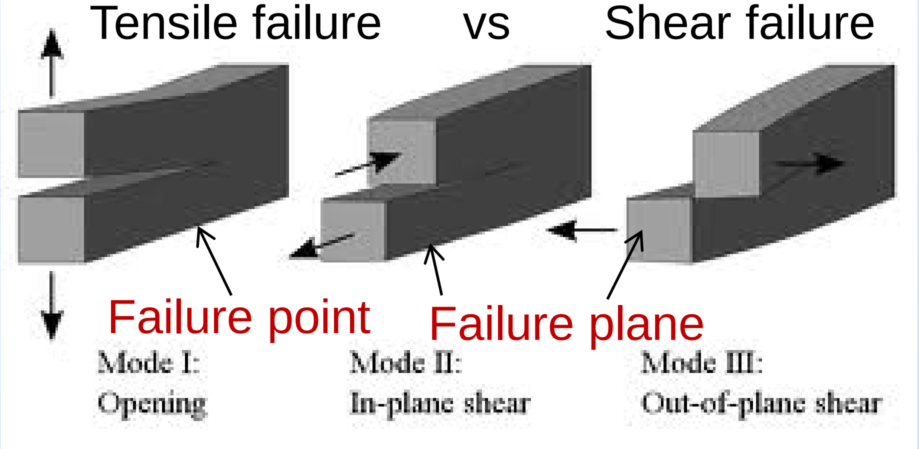
- Relevant to all energy technologies that rely on fluid injections (e.g. carbon sequestration, enhanced geothermal, hydrofracturing for oil and gas).
- Helps to address a critical need for accurate risk assessment of induced seismicity for both hazard mitigation and reservoir management.

Motivation

- We need instrumentation that can capture the total dynamic range and bandwidth of induced seismicity (tensile vs shear failure).
- We need to deploy in boreholes (>300 m) to improve signal-to-noise.

Induced seismicity is a complicated mixture of different fracture mechanisms, each interacting with each other to control permeability creation and fluid flow.

Tensile (volumetric) failure events are either small high frequency (at the tip), or low frequency events resulting from the whole plane slowly opening (usually not detected).



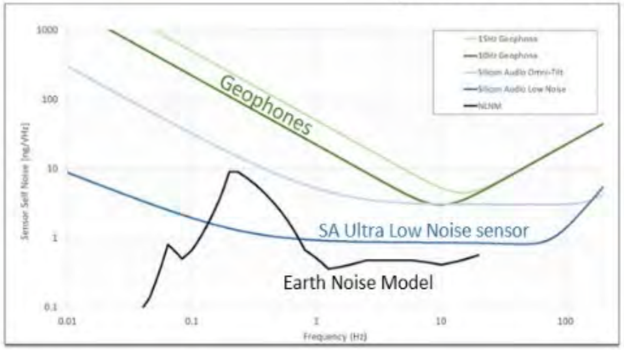
Sensor Candidate: SA-ULN

Silicon Audio Optical Sensors: Acceleration

Silicon Audio Low-Noise Optical Seismometer

SENSOR PERFORMANCE	ULTRA LOW NOISE
Passband	0.005-1kHz (flat to acceleration)
Noise	0.8ng/√Hz [@ 10Hz]
	1ng/√Hz [@ 1Hz]
	3ng/√Hz [@ 0.1Hz]
Clip Level	±2g peak
Dynamic Range	183dB @ 1Hz over 1Hz BW
Sensitivity*	15V/g (High Gain Output) 5V/g (Low Gain Output)
Max Vout	60V pk-pk (High Gain Output) 20V pk-pk (Low Gain Output)
Spurious resonance	>300Hz
Tilt tolerance	±15°
Distortion	<0.03% @ 12Hz and 0.7in/s p-p
POWER	
Power	40mW/axis
Supply Voltage	6-17V DC

Noise Performance



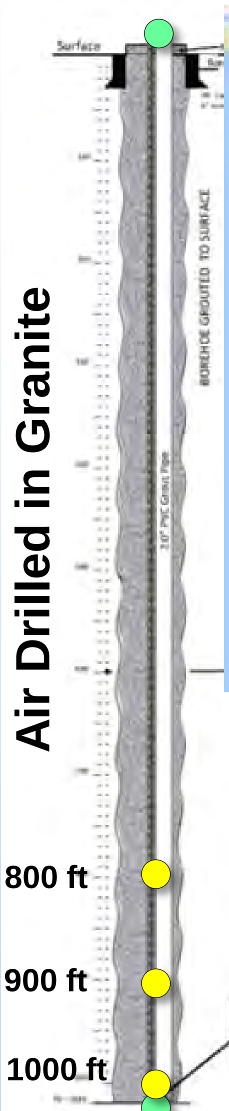
3-component package

Silicon Audio (SA) Ultra Low Noise (ULN) 3-component slim package sensor

Bandwidth: 0.005 – 1 kHz
Sensitivity: 15 V/g (High Gain Output)
Max Vout: 60V pk-pk (High Gain Output)

Discrete fiber optic accelerometer for shallow borehole deployments.
No fiber interrogator box needed

Cascadia Borehole Site

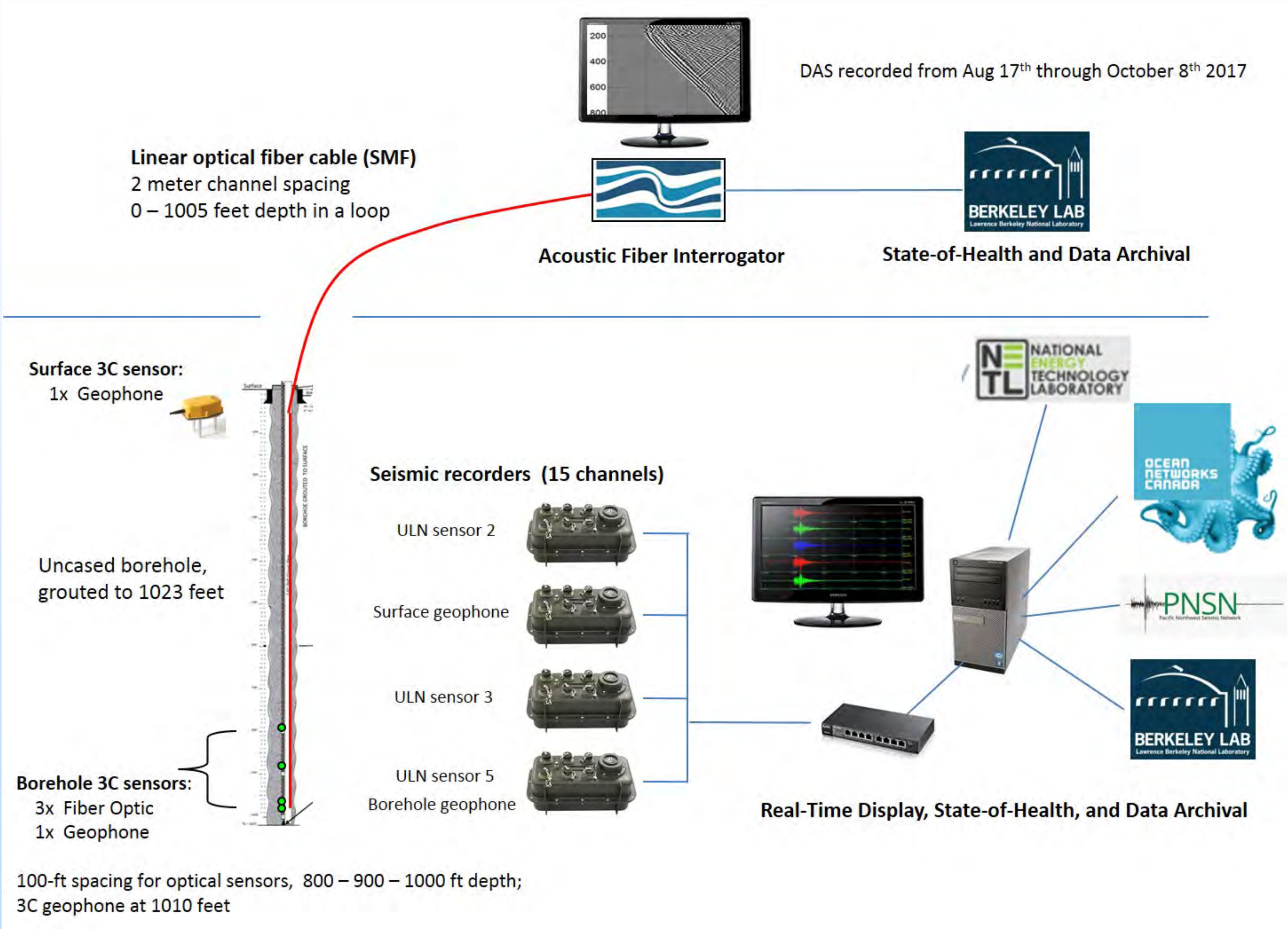


Sensor	Type	TVD (ft)	Notes
Surface 3C	velocity	0	GS HS-1 geophone, 2 Hz
SA ULN 3C	acceleration	800	SA Ultra Low Noise optical accelerometer
SA ULN 3C	acceleration	900	SA Ultra Low Noise optical accelerometer
SA ULN 3C	acceleration	1000	SA Ultra Low Noise optical accelerometer
Bottom 3C	velocity	1010	LBNL sonde with GS-11D geophones, 8 Hz

Station NV_MTC

Neptune Array, Marine Technology Centre, North Saanich, Vancouver Island

Cascadia Acquisition



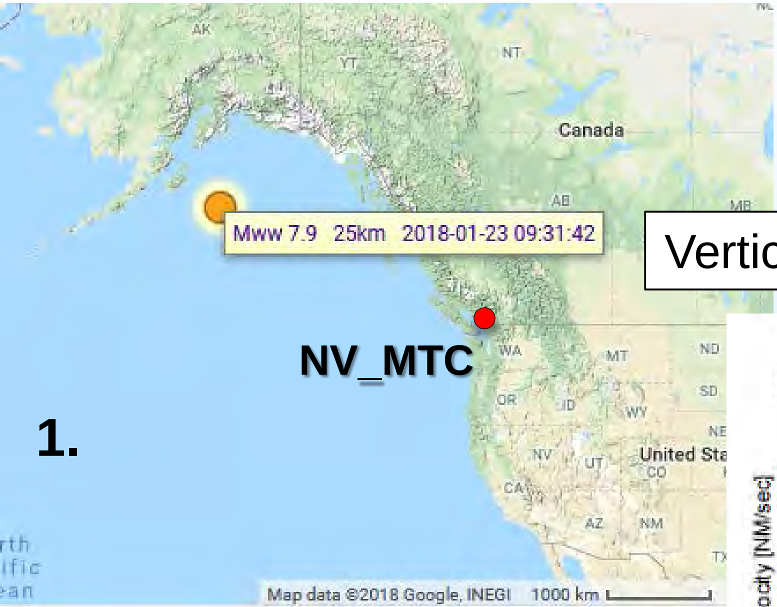
Sensor Comparison

When comparing the Cascadia SA-ULN sensor performance to surface 2 Hz and borehole 8 Hz geophones, and linear fiber:

- Reducing noise is often more important than boosting signal, especially for those small events that may be buried in the noise. Best instrumentation practice is to -
  - Go deep: install in boreholes
  - Go quiet: reduce instrumentation “self-noise”
- The signal to noise ratio (SNR) for seismic events depends on the size of the event (i.e. magnitude), the distance from the event to the sensor, and the characteristics of the subsurface.

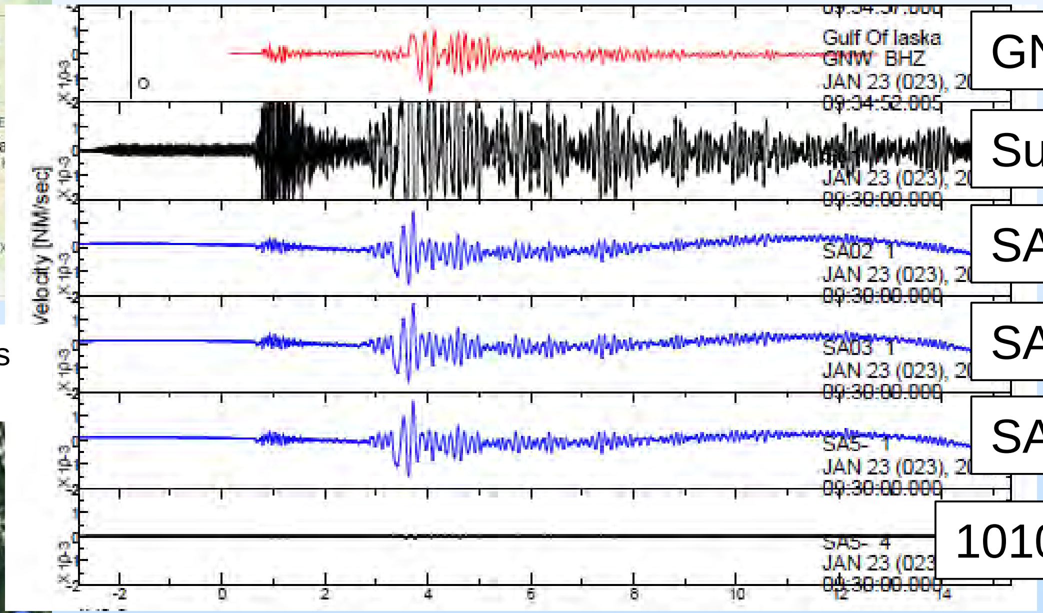
Data Example: M7.9, Alaska, 2018

GNW: local surface broadband station

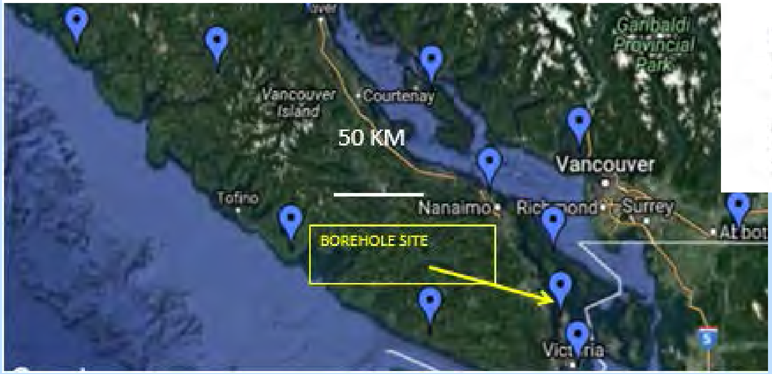


1.

Vertical sensors, (plotted same vert scale, velocity units)



Canadian Short Period Seismic Network locations relative to the Cascadia Site borehole



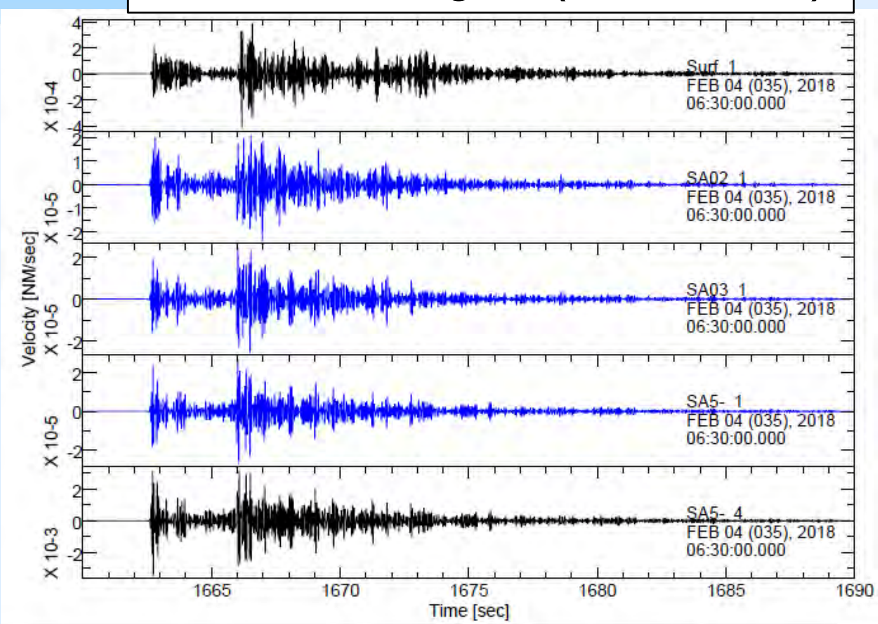
Record length: 30 minutes

M3.1, Vancouver Island, 2018

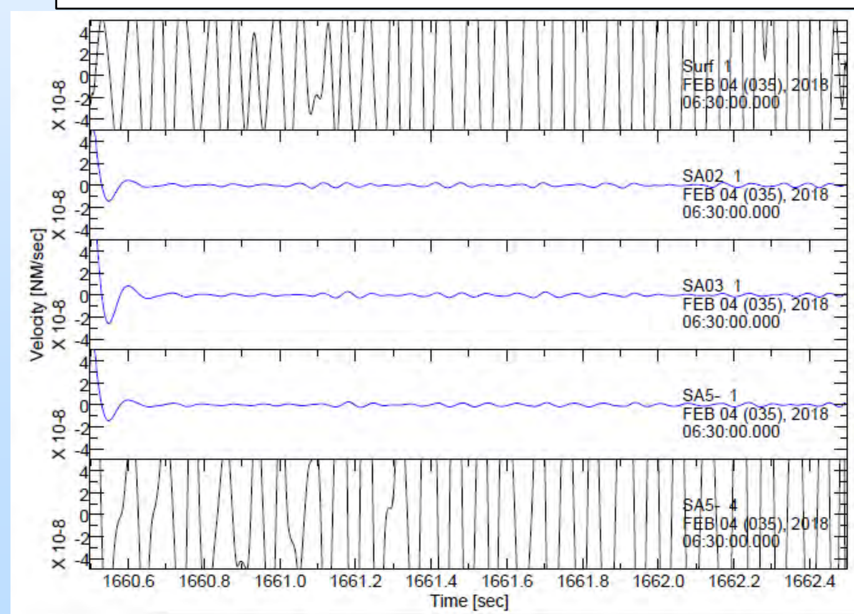
Local event, S-P time ~ 3 seconds
Vertical sensors

Finding: “Self noise” on SA-ULN sensors is 20-100x less than conventional geophones, depending on the event magnitude/distance

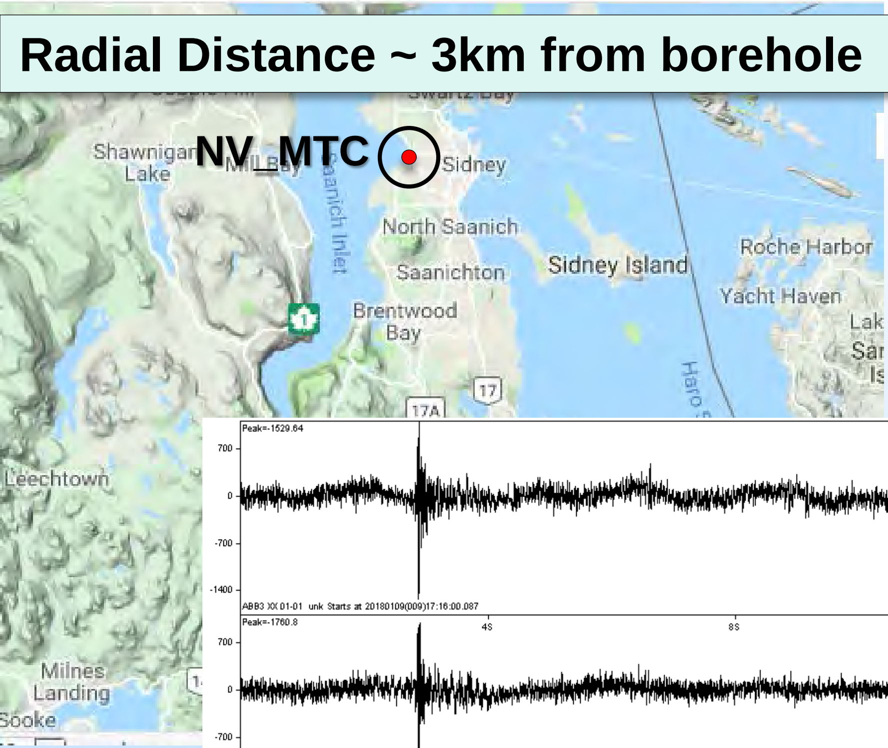
2. Normalized Signal (30 seconds)

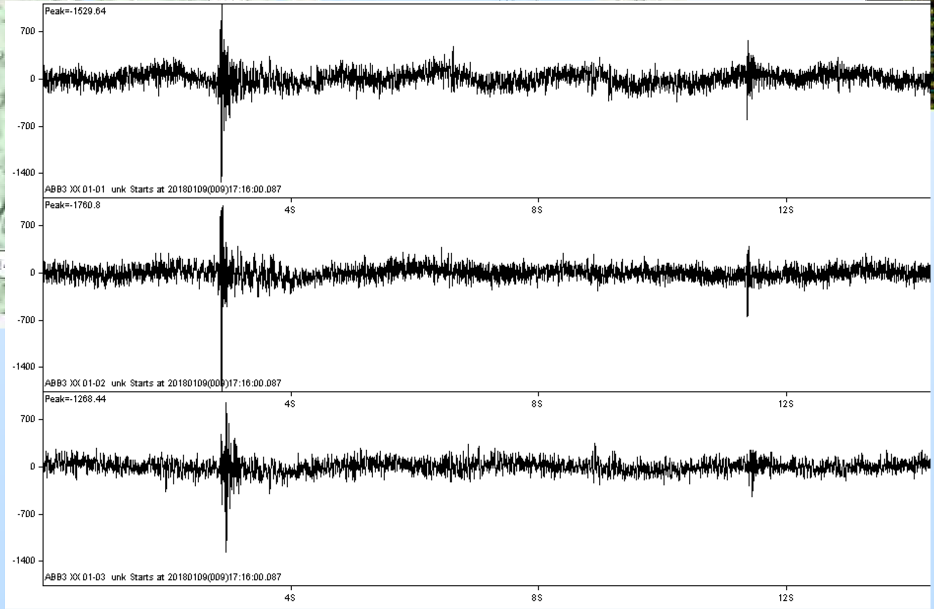


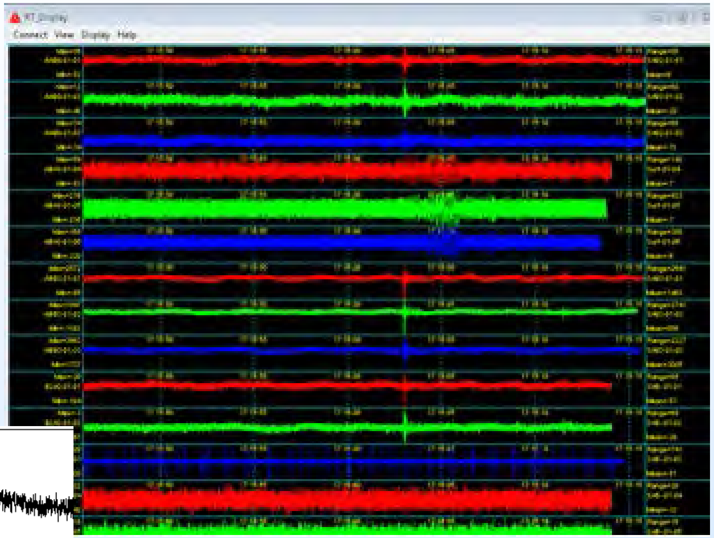
Pre-event noise (plotted same vert scale)



Small Local Events, North Saanich







Small local events are common. S-P times less than 0.5 sec

SA-ULN sensitive to small events, pickable first arrivals

(SNR = 20, vs 5 for geophones)

Raw SA-ULN, 800 ft depth, 15 second record

Technical Status

Aquistore Field Laboratory

Aquistore Project: Williston Basin

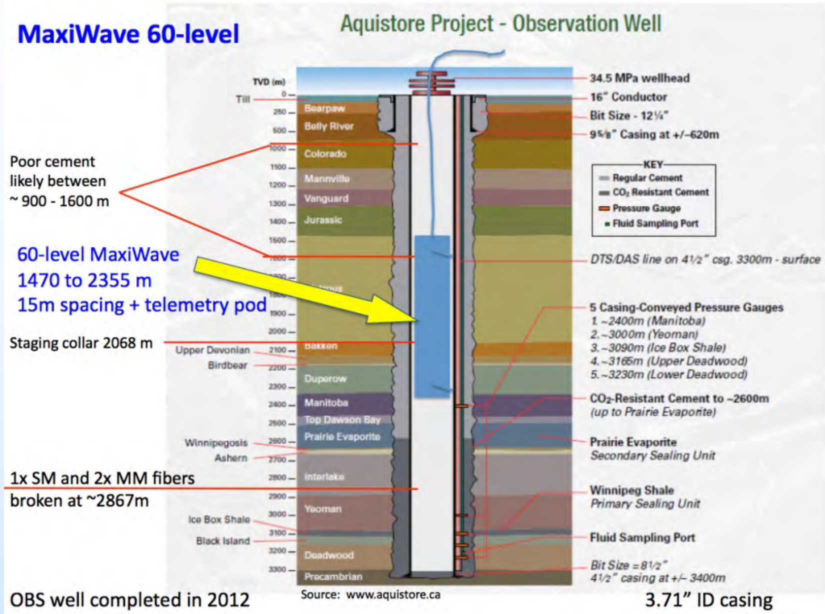
- Integrated CCS:
  - Capture from SaskPower's Boundary Dam Coal-Fired Power Station
  - Transported via pipeline to an injection well at the storage site; over 90% of CO2 for EOR
  - Captured CO_2 stored in a deep (3.2 km) saline aquifer in the Williston Basin
- ~1 Mt/year CO2 capture started in 2014
- Over 120,000 T Injected at Aquistore
- Monitoring Timeline:
  Initial installations 2012
  First Baseline 2013
  Injection 2015
  Surface geophone array monitor Surveys
  Feb. 2016; Nov 2016; Mar 2017, Mar 2018.
- 3.4 km INJ and OBS wells, deepest in Sask.

Aquistore

ptrc
Petroleum Technology
Research Centre

Natural Resources Canada

Aquistore OBS well



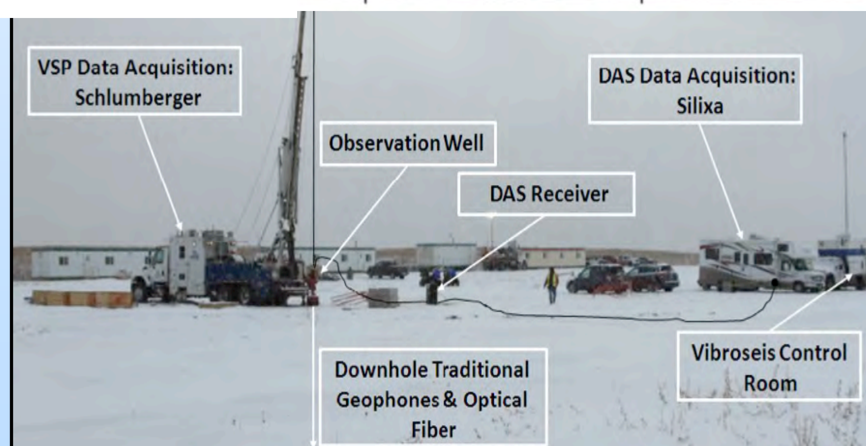
Drilled in 2012

Fiber behind casing

Baseline 3D/VSP surveys in 2013, 2014, 2015 <u>: DAS and Geophone in the OBS well.</u>

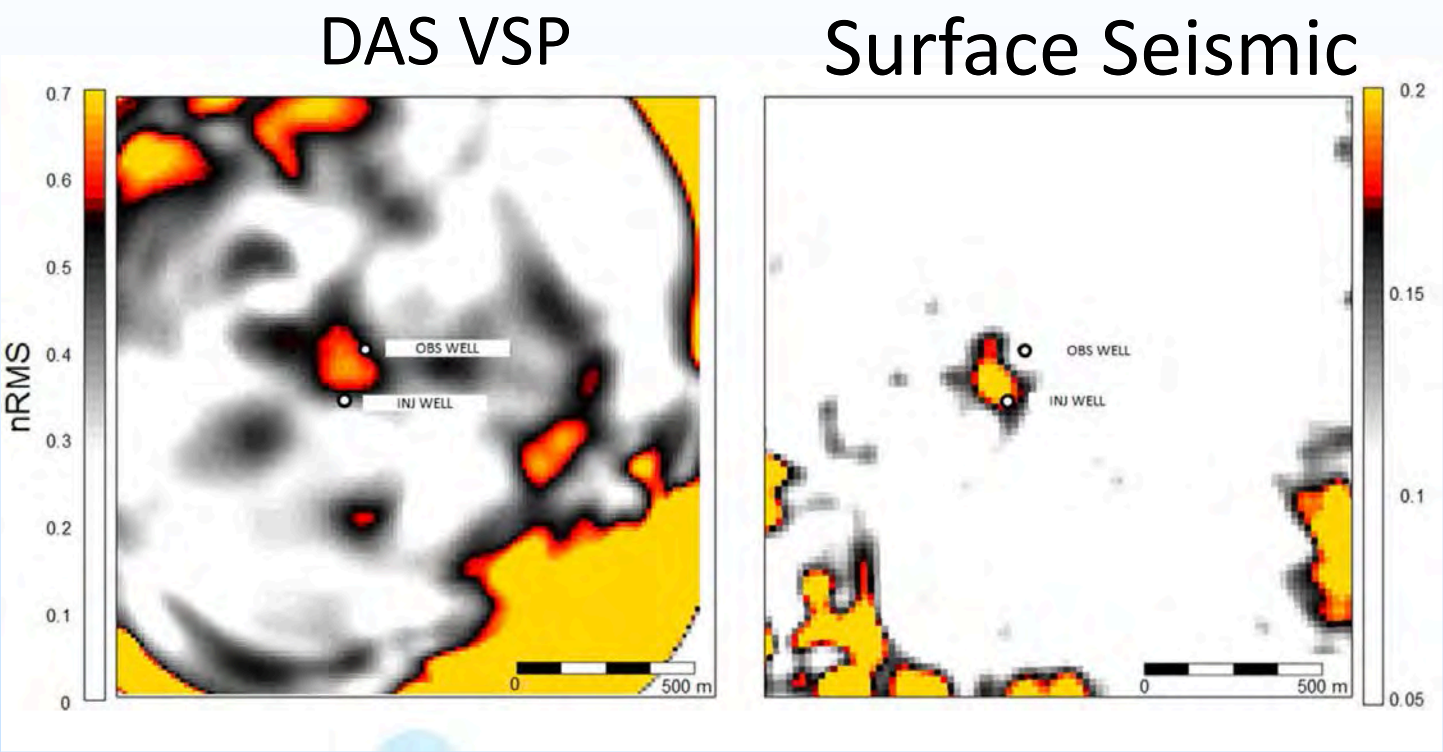
Fiber cable cemented behind casing is a key component of our DAS testing/development program.

2017 and 2018 3D/VSP repeat surveys only used borehole DAS + surface geophones



Aquistore CO_2 Plume Mapping

Harris, et al, 2017
Roach, et al, 2016.



DAS VSP and Surface Seismic for the Upper Deadwood:

Agreement!

Plan view of nRMS difference images in the upper Deadwood showing VSP result (left) and surface-based result (right).

T. Daley (LBNL)

Plume migrating up-dip; INJ and OBS wells 100m apart

Aquistore Project: Main Points

- Plume is being mapped; injection is continuing at 3.4 km depth
- 3D/VSP repeat surveys continuing, using only DAS behind casing for OBS well sensor array (i.e. no borehole geophone array required)

- No MEQs observed yet on NRCan's surface geophone array
- No MEQs observed yet on OBS well fiber data during LBNL's month-long acquisition with fiber interrogator box.

- OBS well casing DAS fiber only extends to 2.7 kms (issues during deployment in 2012)
- OBS extends to 3.4 km (injection depth), but no sensors past 2.7 km

- We need a wide band sensor in the OBS well near 3.4 km for MEQ

Accomplishments to Date

Cascadia site:

- Deployed state-of-the-art sensors in a low noise environment (1000 ft. depth, cemented well in granite) in a seismically active area
- Site has good supporting infrastructure (internet, power, data manipulation and processing, remote control and state of health)
- Data are publicly available in real time from IRIS-PASSCAL
- Addressing relevant science (MEQ and long-period long-duration "tremor" events in the Cascadia Region)

Sensor evaluation:

- Optical accelerometer is a good candidate for modification to test in a deep CO2 injection reservoir environment (Observation well ~ 3 km)
- Aquistore site should be a good candidate for testing SA-ULN at depth

GMF Geosciences Measurement Facility

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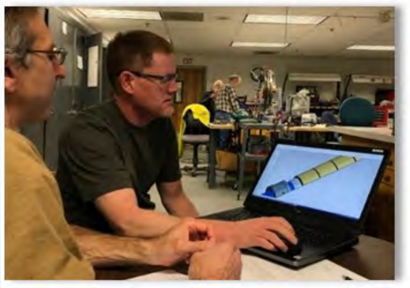
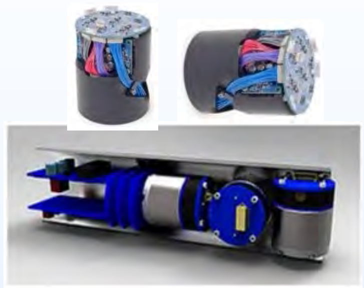
Next Steps





At Berkeley Lab's GMF (gmf.lbl.gov):

- Design sonde for SA-ULN to perform at **~3 km depth**. (**Current sonde** is configured for shallow **300m** well)
- Hybrid wireline cable: 7 conductor for 3C SA-ULN sonde, plus linear fiber for DAS
- Test in LBNL/RFS test wells, analyze
- Finalize deployment plan (Aquistore)
- Deploy sensor package at or near basement ~ 3 km, for 2 to 3 months

Lessons Learned

We've just started this task, but learnings from Cascadia and Aquistore are:

- As always, collaborations with onsite partners are invaluable
- SA-ULN sensors are a good candidate for recording MEQ's during injection, low noise, good performance
- Ready to start sensor design for deep deployment

Synergy Opportunities

- Carbon storage and monitoring projects
    - CaMI, Alberta
    - Otway project in Victoria, Australia
    - ADM, Illinois
- Geothermal fracture monitoring research
    - EGS Collab at the Sanford Underground Research Facility (SURF) mine in South Dakota (4850 level)
- Oil and Gas
    - Lost Hills, CA: CASSM crosswell tomography
- Passive seismic monitoring

Project Summary

- Both carbon sequestration and the oil and gas programs need accurate and comprehensive monitoring for MEQ characterization associated with fluid induced seismicity.

- Borehole sensors need improvement; SA-ULN's are a good candidate:
    - Broader bandwidth (100 sec to 1 KHz)
    - up to 10 times sensitivity of current "conventional" borehole sensors

- Improved sensors would allow data on smaller events, gaining another order of magnitude of range, and higher resolution on fracture creation events (permeability mapping) to contribute toward improved hazard assessment

Geosciences Measurement Facility

Acknowledgements

- Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management, through the National Energy Technology Laboratory (NETL) for the project "Core Carbon Storage and Monitoring Research" (CCSMR) under contract No. DE-AC02-05CH11231.

- Aquistore site: Petroleum Technology Research Council (PTRC); National Resources Canada, Geologic Survey of Canada (GSC); DAS Images Courtesy of Aquistore Project; PTRC/GSC/LBNL/Chevron/ExxonMobil

- Aquistore 4D Seismic Team: Kyle Harris (Carleton University); Lisa Roach (University of Leeds); Claire Samson (Carleton University); Brian Roberts (Geologic Survey of Canada)

Appendix

Benefit to the Program

- Program goals being addressed:
  - Develop and validate technologies to ensure 99 percent storage permanence.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness

- Project benefits:
  - Deployment and testing of new monitoring technologies and methodologies at an operational CCS site.
  - Broader learnings from leveraged international research opportunities
  - Rapid transfer of knowledge to domestic programs

Project Overview

Goals and Objectives

- The Core Carbon Storage and Monitoring Research Program (CCSMR) aims to **advance emergent monitoring and field operations technologies** that can be used in commercial carbon storage projects. This effort aligns with program goals:
  - Improve estimates of storage capacity and efficiency
  - Develop new monitoring tools and technologies to achieve 99% storage confirmation

- Success criteria is if we are able to **advance the technology readiness level (TRL)** of targeted technologies from a level of TRL 2 – 3 up to 3 – 4 through leveraged field testing opportunities.

Organization Chart

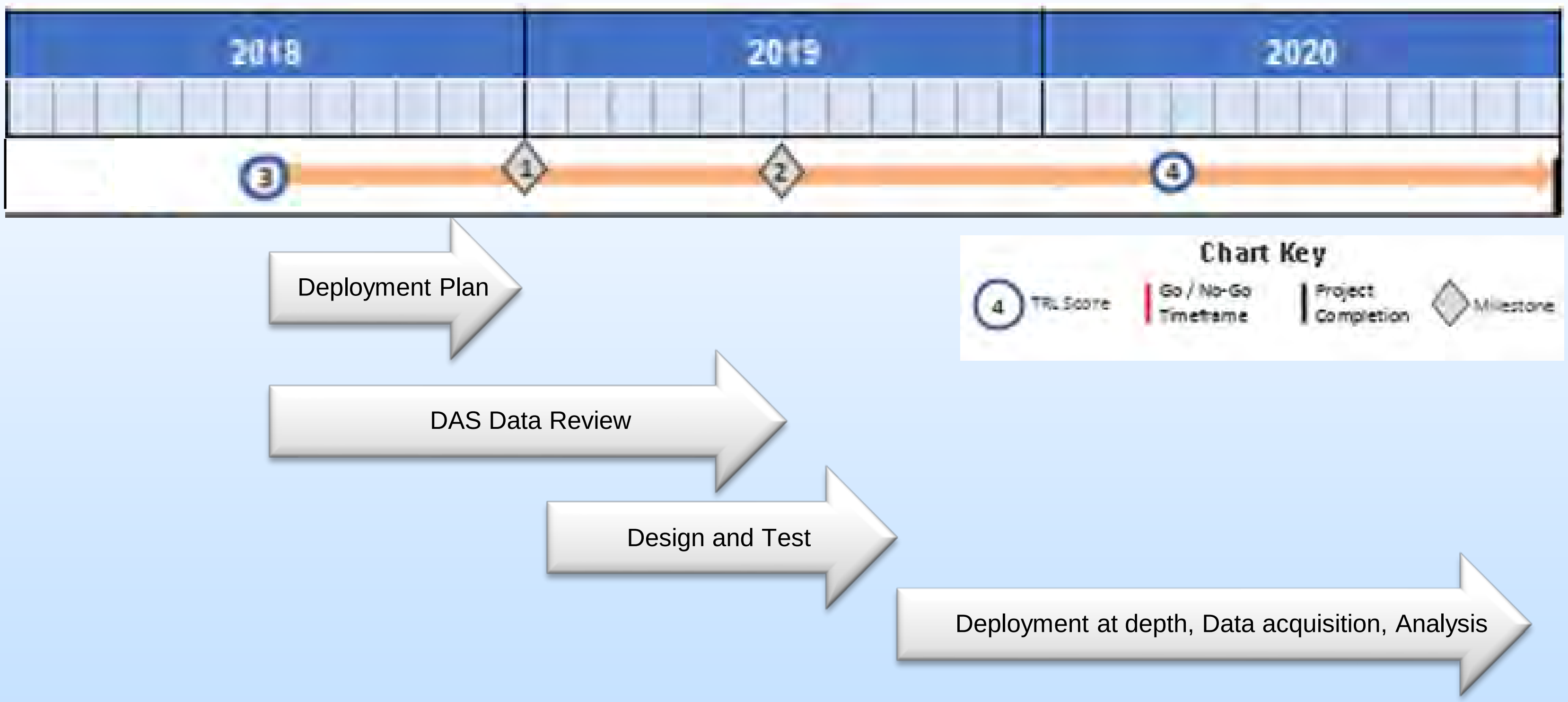
- **LBNL**
  - CCSMR co-PIs: Barry Freifeld and Tom Daley
  - Project Lead: Michelle Robertson
  - Engineering Design: LBNL's Geosciences Measurement Facility (GMF)

- **Petroleum Technology Research Centre (PTRC) ***
  Aquistore Project Management: Afton Leniuk

- **Geological Survey Canada / Natural Resources Canada (NRCan)**
  Seismic monitoring: Don White

* PTRC is operating the Aquistore storage project with seismic monitoring led by Don White. LBNL is providing Task 4 acquisition, processing, analysis.

Gantt Chart (FY)



Milestones

1. Milestone 4-1 Completed deployment plan for a high sensitivity, wide bandwidth, vector fiber-optical or piezoelectric accelerometer sonde for deep borehole operations

2. Milestone 4-2 Review of previously acquired Distributed Acouistic Sensing (DAS) data on cemented linear fiber cable analyzed for passive micro-seismic monitoring at depth.

Bibliography

This Task started in June 2018, no publications yet.