Core Carbon Storage and Monitoring Research (CCSMR)

Field Testing of Emerging Technologies: Task 3: Aquistore Project

Project Number ESD14-095

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U.S. Department of Energy

National Energy Technology Laboratory

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

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Coauthors/Collaborators

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Presentation Outline

- Program Benefits, Project Overview
- Aquistore Introduction
- DAS Technology, Baseline Data
- 2016 Monitoring Data
- 4D DAS Repeatability
- Other DAS R&D tests at Aquistore
- Summary

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.
  - Broader learnings from leveraged international research opportunities
  - Rapid transfer of knowledge to domestic programs

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Monitoring Technology: Supporting the SubTER Program

Wellbore Integrity and Drilling Technologies	Subsurface Stress & Induced Seismicity	Permeability Manipulation & Fluid Control	New Subsurface Signals
Improved well construction materials and techniques	State of Stress (measurement and manipulation)	Manipulating Physicochemical Fluid-Rock Interactions	New Sensing Approaches
Autonomous completions for well integrity modeling	Induced seismicity (measurement and manipulation)	Manipulating Flow Paths to Enhance/Restrict Fluid Flow	Integration of Multi-Scale, Multi-Type Data
New diagnostics for wellbore integrity	Relate Stress and IS to Permeability	Characterizing Fracture Dynamics and Fluid Flow	Adaptive Control Processes
Remediation tools and technologies	Applied Risk Analysis to Assess Impact of Subsurface Manipulation	Novel Stimulation Technologies	Diagnostic Signatures and Critical Thresholds
Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)			
HT/HP well constr. & completion technologies			

Energy Field Observatories

Fit For Purpose Simulation Capabilities

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 sweep 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 3 – 5 up to 6 – 7 through leveraged field testing opportunities.

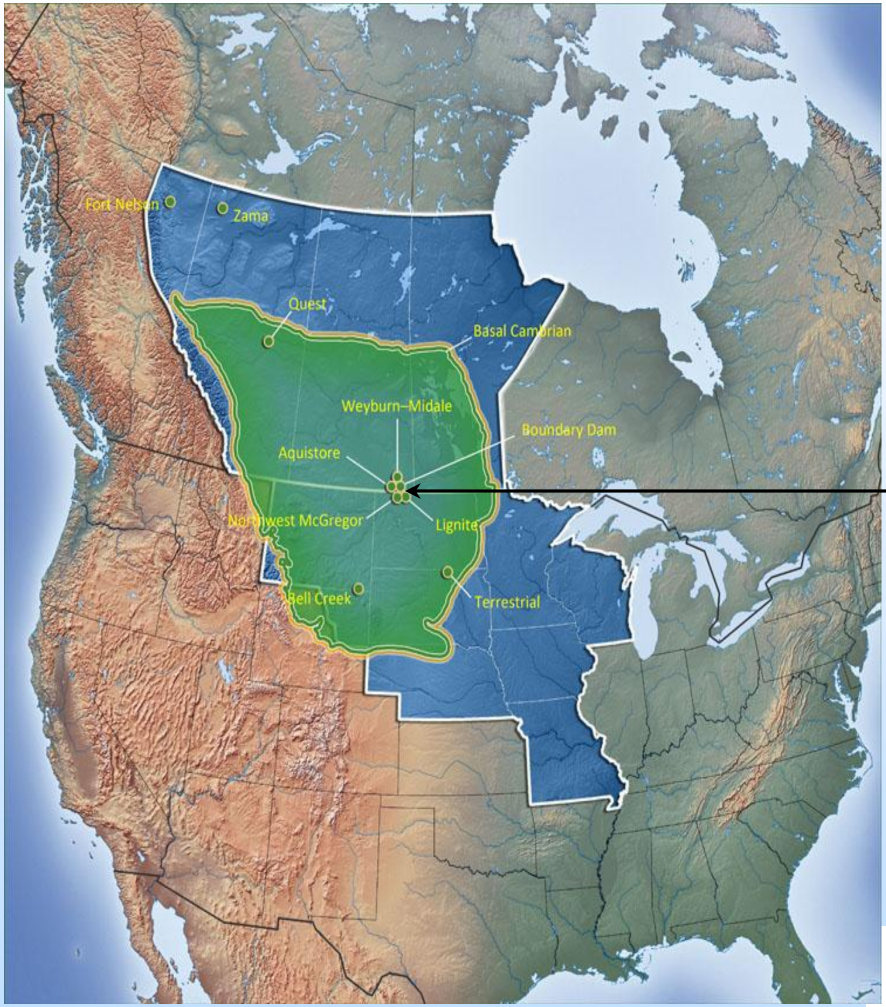
Advanced Monitoring Technology: Seismic / DAS

- Issue: CO_2 storage requires long term repeated monitoring
  - Active source seismic is an important monitoring tool, and we would like to have data collected repeatedly for monitoring (i.e. semi-permanent), but…
  - Marine seismic is expensive, with high fixed cost (few 'small' tests)
  - Land seismic has unique difficulties (surface variability and access)
  - Permanent seismic sensors are expensive for the large numbers (spatial sampling) needed
  - Permanent seismic sources are not standard or generally available

- R&D Approach
  - DAS (distributed acoustic sensing) on Fiber optic cables: a promising technology to improve long term repeatable monitoring with permanent sensor installation and large spatial sampling
  - Permanent, remote-controlled source: provide continuous monitoring and 'trigger' for full 3D seismic acquisition (shown in Task 2 presentation on Otway project)

Aquistore Project

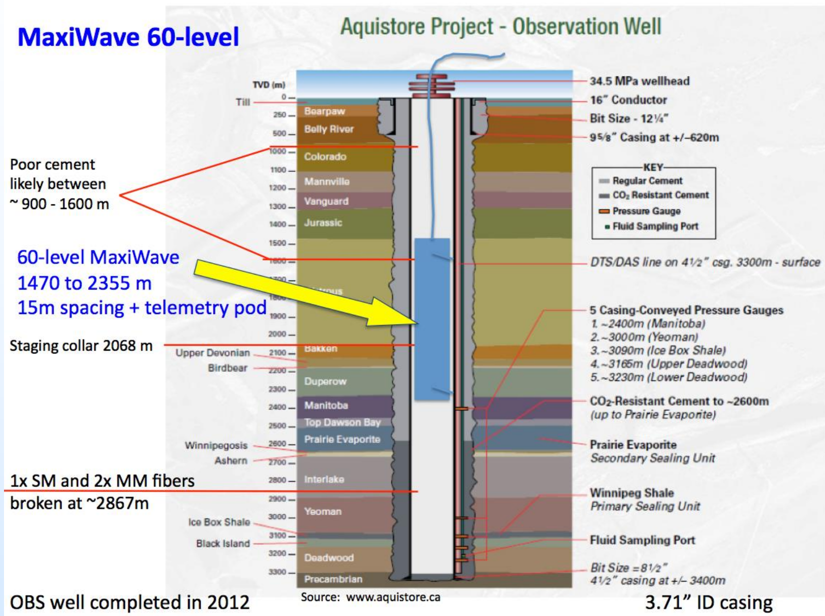
- Integrated CCS:
  - Capture from SaskPower's Boundary Dam Coal-Fired Power Station
  - Transported via pipeline to an injection well at the storage site; ~90% of CO2 for EOR
  - Captured CO_2 stored in a deep (3.2 km) saline aquifer in the Williston Basin
- ~1 Mt/year CO2 capture started in 2014
- Over 70,000 T Injected
- Monitoring Timeline:
  Initial installations 2012
  First Baseline 2013
  Injection 2015
  First Monitor Survey Feb. 2016

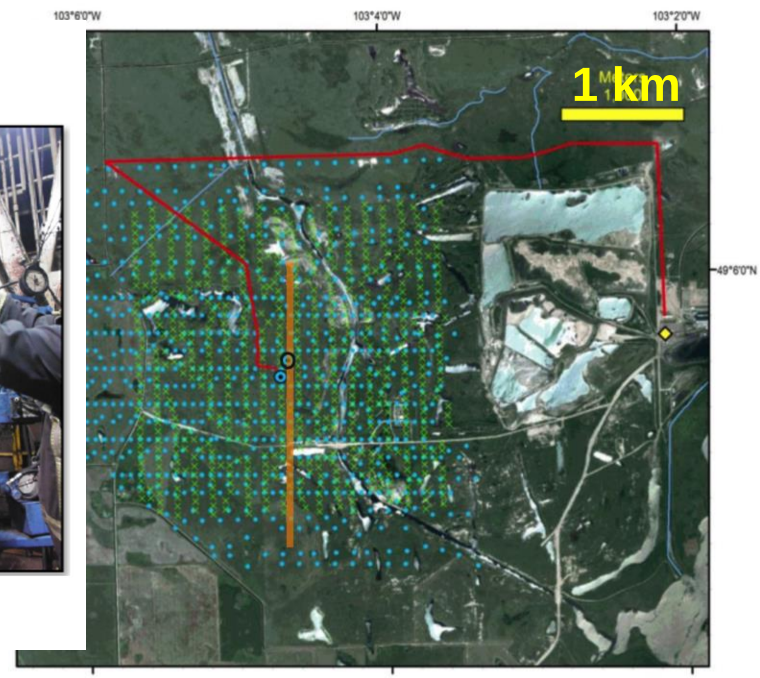


Seismic Monitoring: 3D surface and VSP

Dedicated Monitoring Well with Fiber Cable on *Well Casing (Cemented)*

Instrumented Observation Well

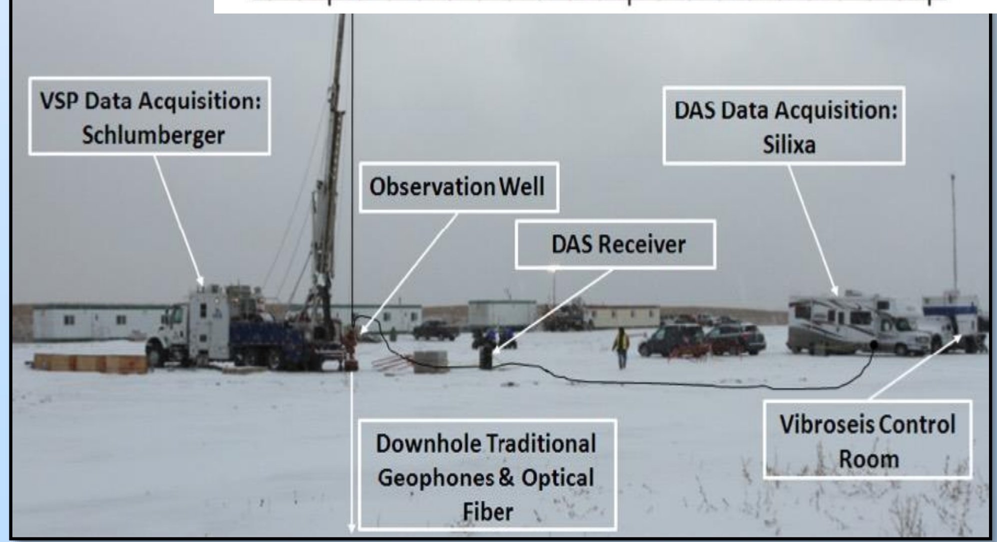




Baseline 3D/VSP surveys in 2013, 2014 and 2015: <u>DAS and Geophone</u>

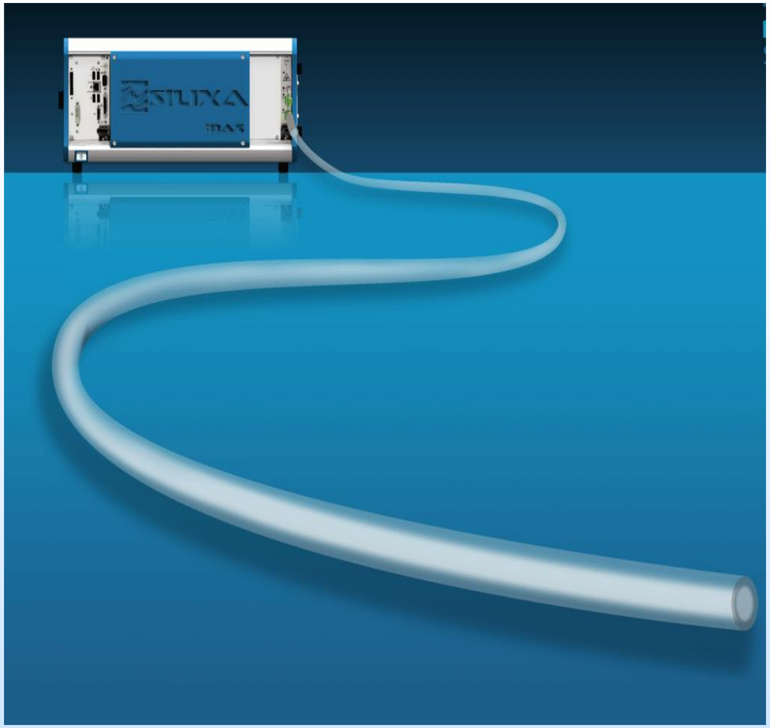
Fiber cable cemented behind casing is a key component of our DAS testing/development program.

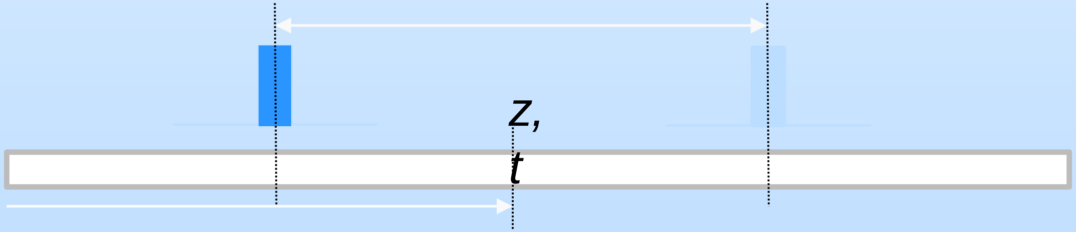
Note: Many other non-seismic monitoring activities, not discussed here.



Distributed Acoustic Sensing (DAS) as implemented by Silixa

- Standard optical fibre acts as a sensor array
  - Typical sampling at 10kHz on 10,000+m fibre
  - Standard gauge length of 10m
  - Spatial sampling of 25cm
  - DAS measures change in average elongation per 10m gauge length per 0.1ms acoustic time sample, sampled every 0.25 m in distance





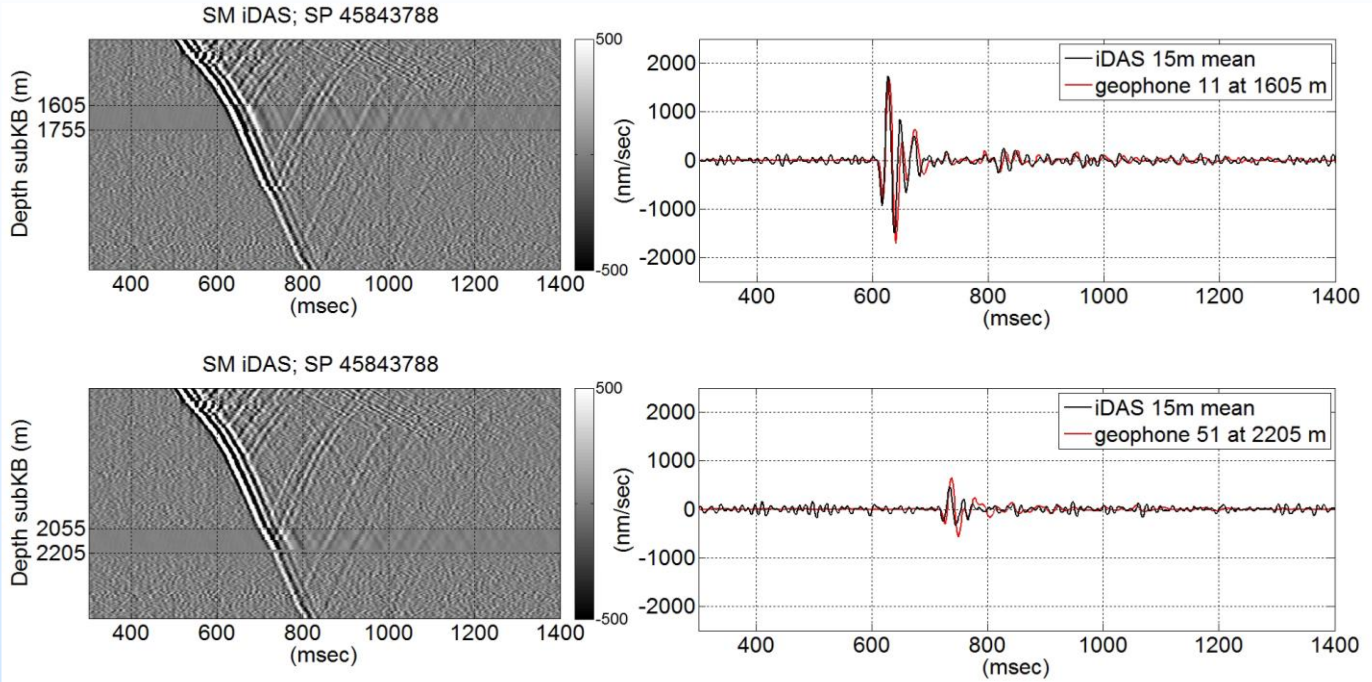
$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

Property measured by Silixa system is strain-rate

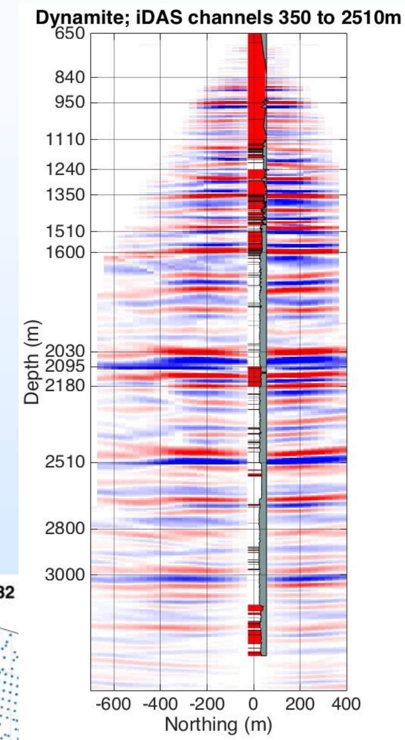
Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, *first break* (32), February 2014

2013 Baseline DAS VSP

DAS - Geophone Comparison (nm/s)

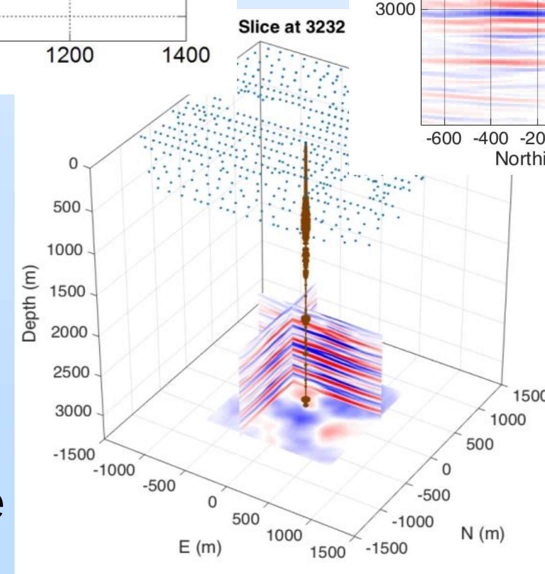


2D Migrated Image



Conclusion: DAS signal can be converted to geophone equivalent and match conventional geophone data.

Strain-rate -> strain -> particle velocity (Daley et al, 2016).

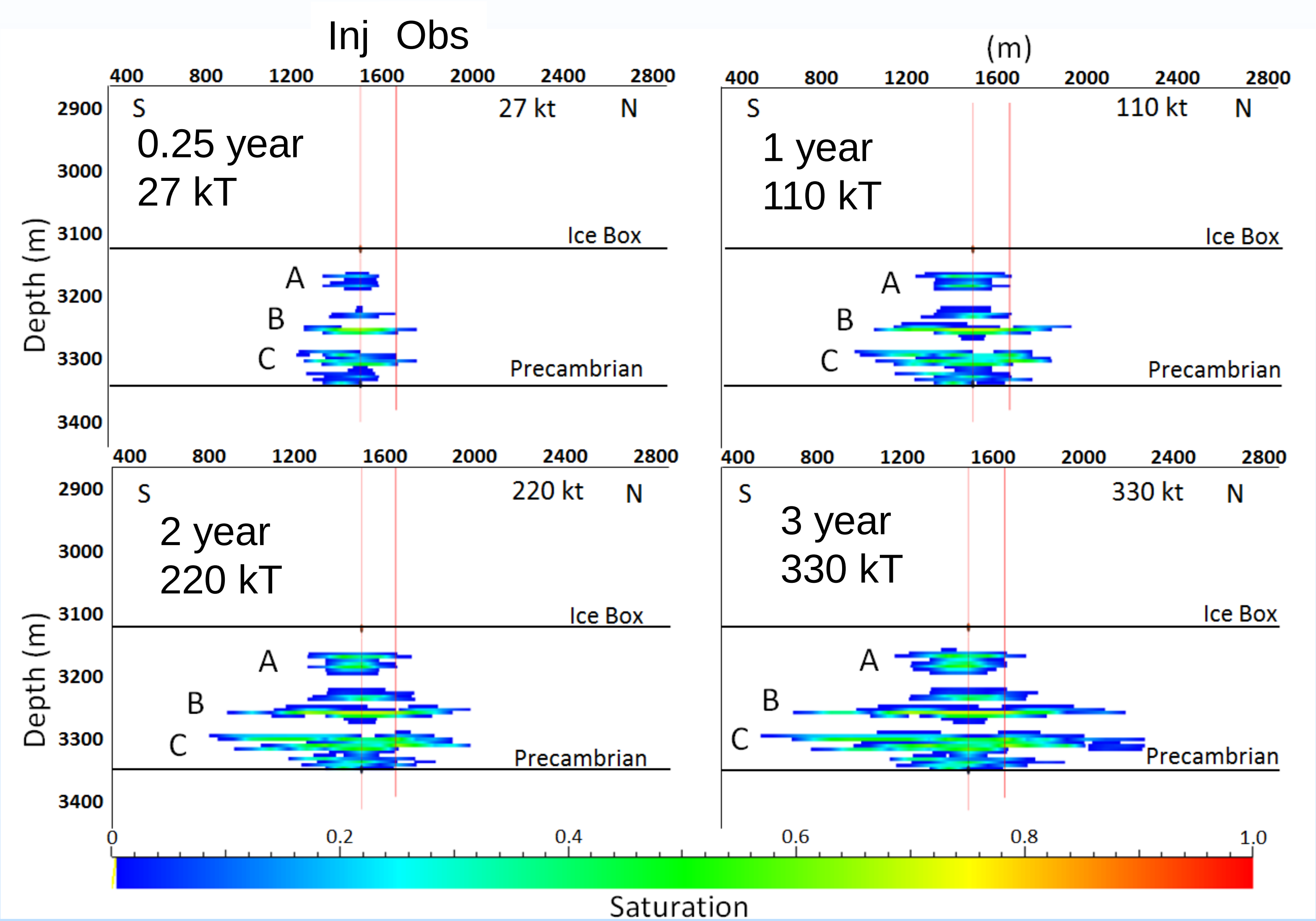


3D Migrated Image

Miller, et al, 2016; CSEG, in press.

Aquistore CO_2 Flow Simulations: Use to Estimate Seismic Detectability

(and decide on monitoring interval)l

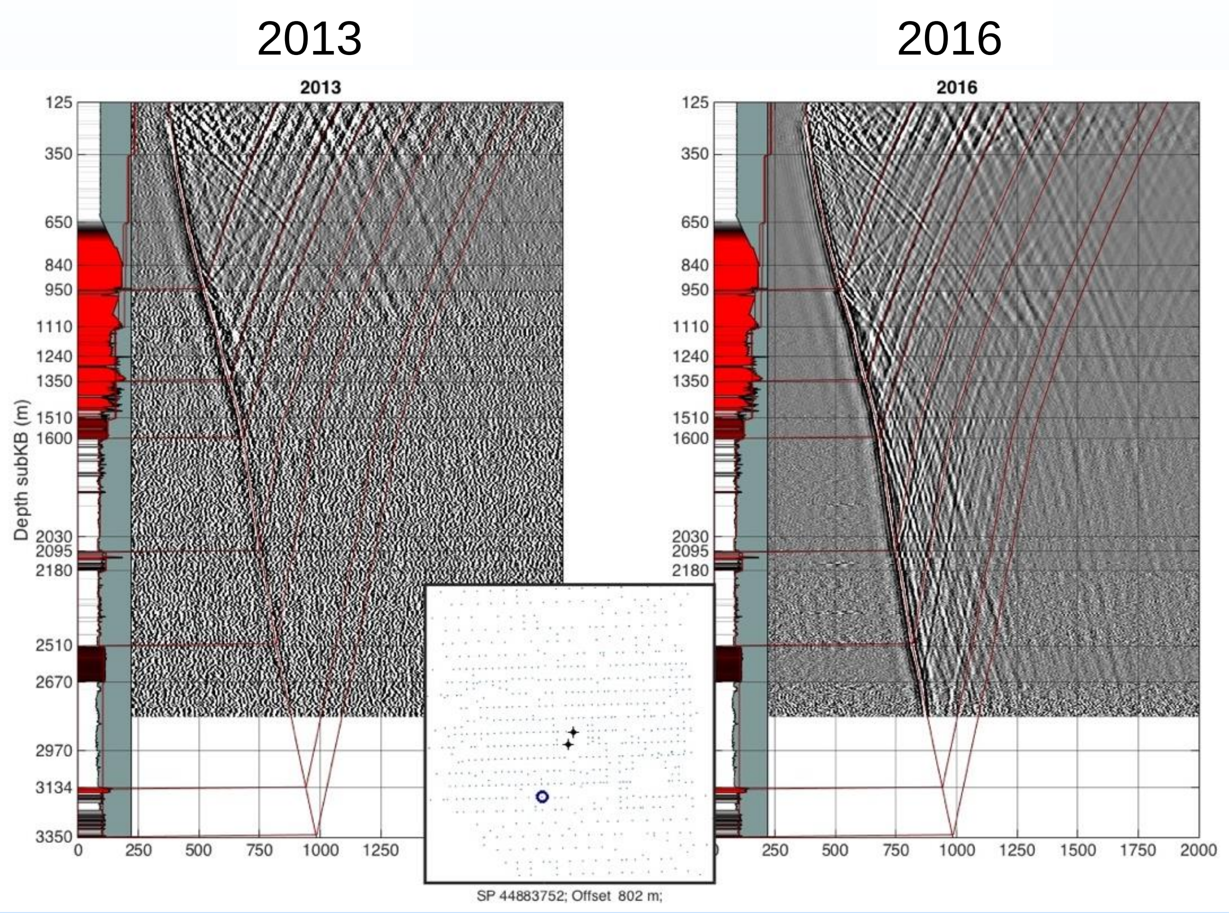


Harris, et al, 2016

February 2016: 1st Monitor DAS VSP

- Repeat 3D surface and VSP surveys
- 80-level 3C Geophone and DAS VSP
- Other R&D Tests:
  - Passive Monitoring
  - Multi-vendor DAS test with Vibroseis Source*
  - Trenched surface DAS cable test*

*results not available yet

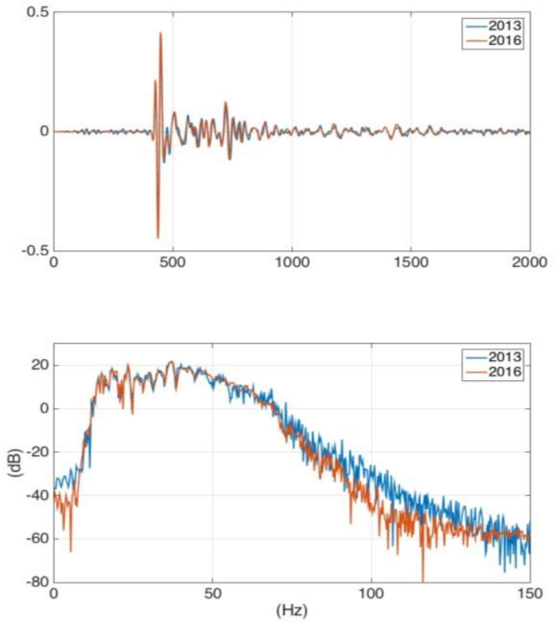


Single Explosive Shot
Downgoing and Upgoing Energy

Note decreased noise in 2016.

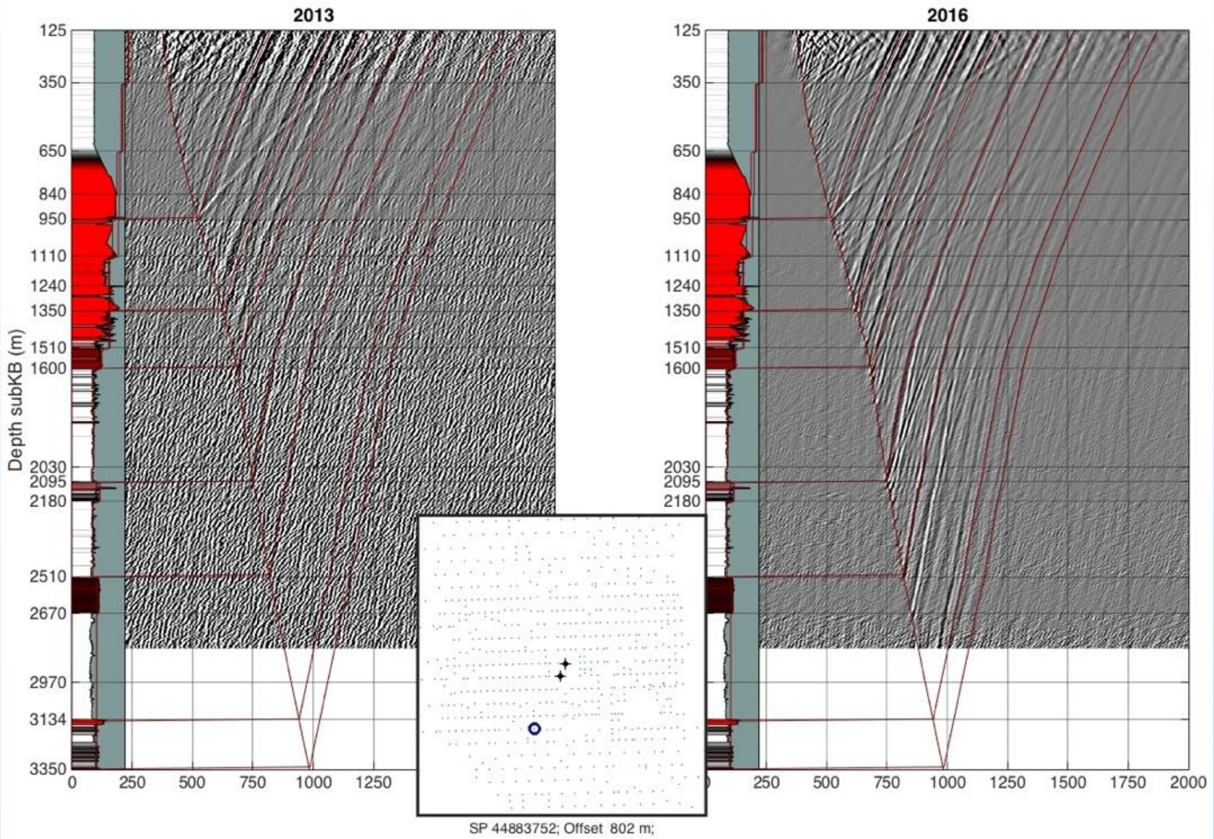
4D DAS VSP: Assessing Repeatability

Initial results indicate that DAS is quite repeatable with the caveat that advancing technology has improved the signal-to-noise ratio



Single DAS Channel
2m sampling
2013 & 2016

Single Shot Reflections (Upgoing Energy)



Processing by Doug Miller

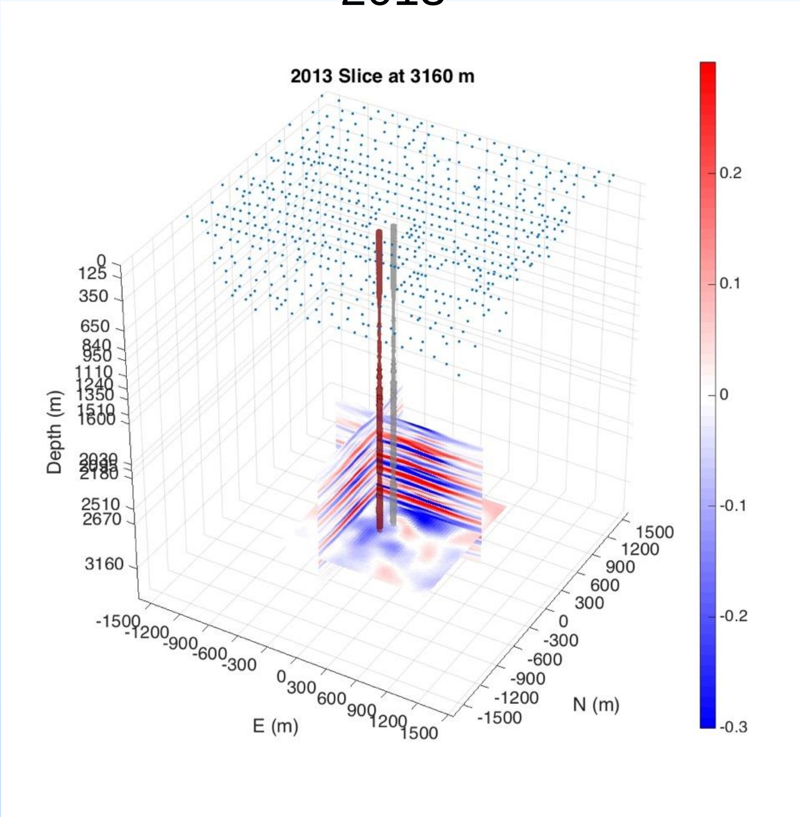
~600 total shots input for 3D DAS migration

Time-Lapse 3D DASVSP

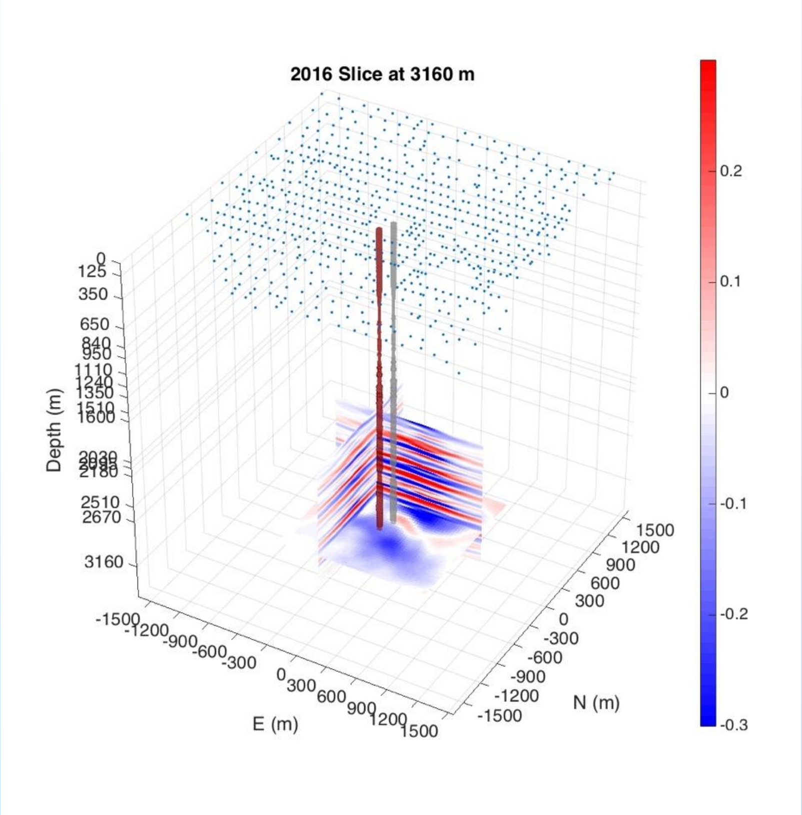
Preliminary results – not ready for interpretation

Current status: Developing processing flow – need to reduce 4D noise

2013

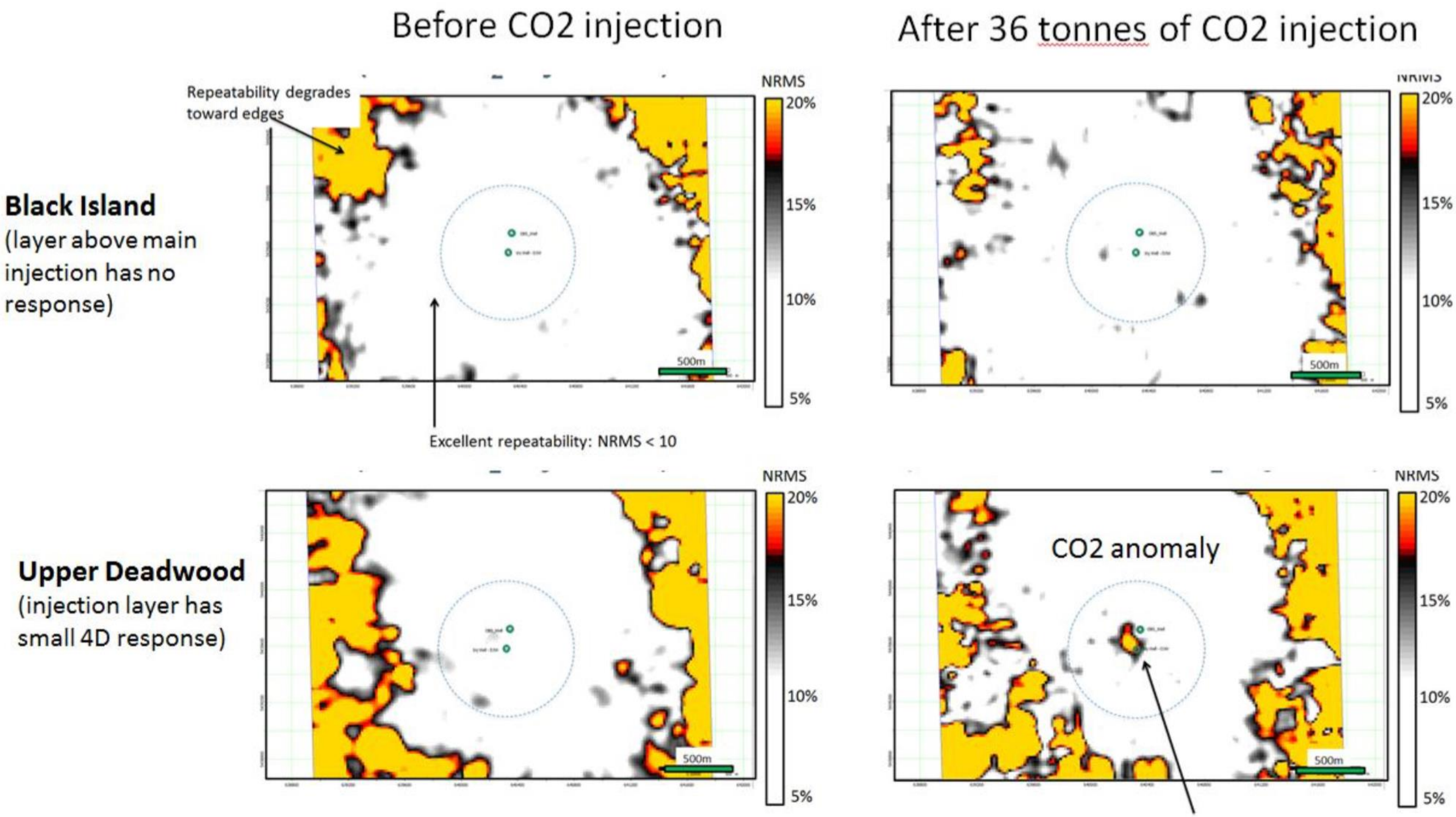


2016



Processing by Doug Miller

4D Surface Seismic



Courtesy: Don White, Lisa Roach

Note: 3D surface seismic used permanent buried receivers.

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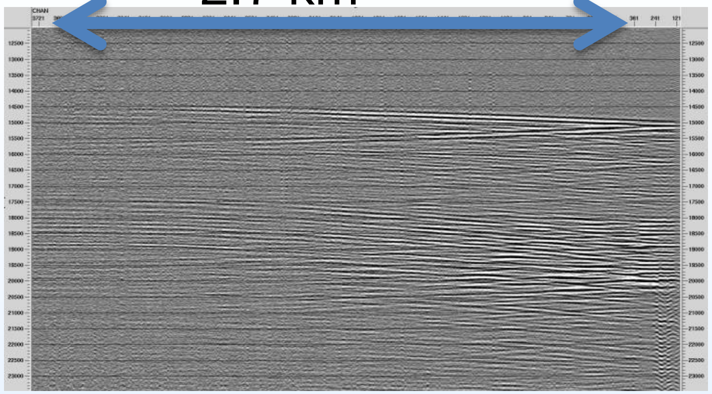
Other Tests with DAS



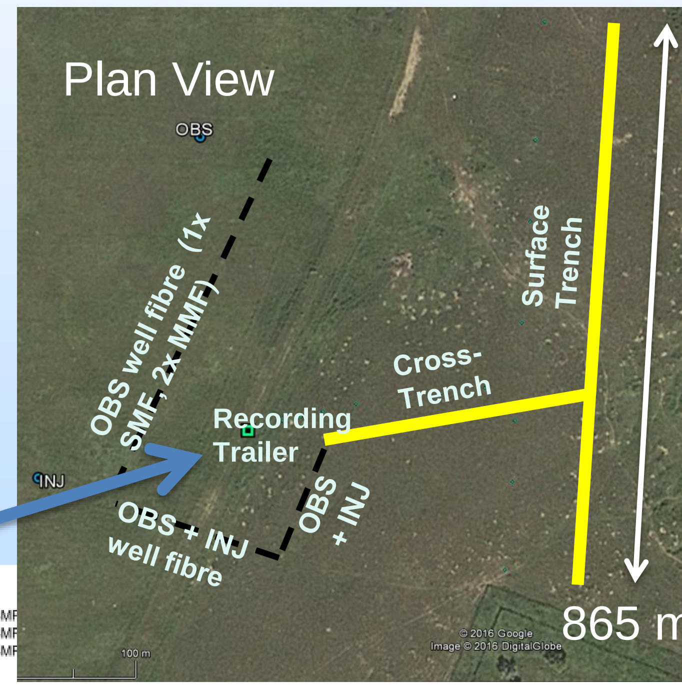
Trenched Surface Cable HWC:

Helical Wound Cable – for angular sensitivity

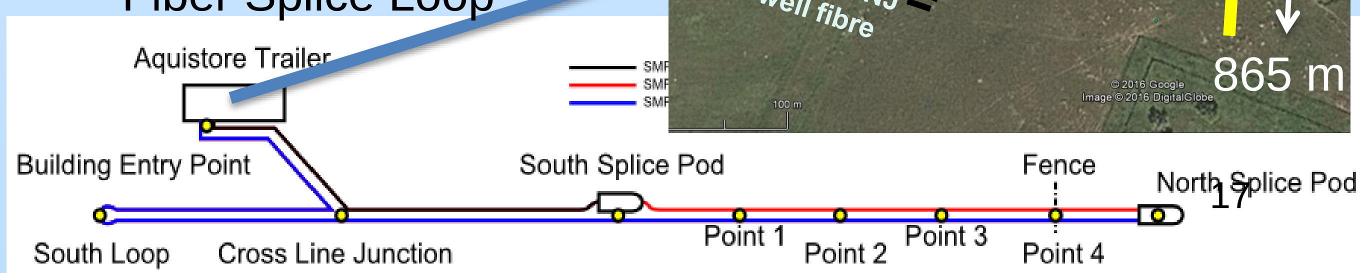
HWC cable: 30-deg winding, single SMF fibre

Passive Monitoring:

- In one month of continuous passive monitoring, no natural events were detected, but local quarry blasts were observed.
- Passive noise monitoring of injection well for ~3 days at start of injection.
- Recording of permanent source operated by JOGMEC (Japan)



Fiber Splice Loop



Aquistore Summary

- Aquistore is storage component of integrated CCS project
- Dedicated observation well and permanent surface instrumentation installed
- DAS testing is part of a multi-component geophysical monitoring program (InSAR/Tilt, seismic, EM, repeat logs)

Accomplishments to Date: Testing of DAS technology

- Baseline DAS VSP (2013)
  - Comparison of dynamite and vibroseis: both work with DAS, some noise reduction possible with vibroseis
  - Comparison of single mode and multimode fiber recording: equal quality

- Injection began 2015; Modeling indicated >30K tonne should be detectable
- First post-injection DAS surveys acquired (Feb 2016) after ~35 K tonne
  - 20+ days continuous passive recording using DAS array following injection in 2015
  - Recording of permanent JOGMEC ACROSS source into fiber-optic array (2015)
  - DAS and Geophone VSP: Data acquired for 4D sensitivity comparison
  - Multivendor DAS test
  - Trenched surface cable test including helical wound cable

LBNL Task Summary

– Key Findings
  - DAS cemented behind casing provides high quality data: this has been an important site for DAS testing
  - Single mode and multi-mode fiber cable can both be used for DAS recording – allows use of more existing cables
  - DAS can operate for long term passive recording
  - DAS can provide VSP data quality comparable to conventional geophones

– Lessons Learned
  - Cables can be damaged when deploying in wells
  - Fiber cable can still be used for DAS above damage point

– Future Plans
  - Analysis of 2016 DAS data including 4D and R&D tests
  - Planning for next monitoring repeat

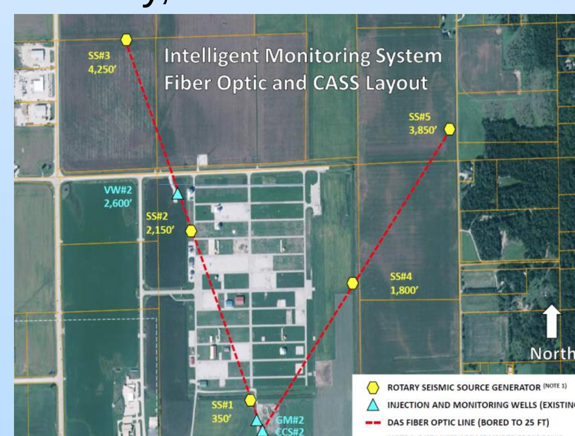
Synergy Opportunities

- Deployment of fiber optic cables in the subsurface allows multiple measurements (Temperature, Acoustics, Chemistry)
- Permanent sensor deployments with semi-permanent sources allows 'continuous' monitoring

CMC CaMI Field Research talk
Thursday 1:50 PM: T. Daley

Development of Intelligent Monitoring System (IMS) Modules for the Aquistore CO_2 Storage Project - University of North Dakota - John Hamling

Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation - Archer Daniels Midland Corporation - Scott McDonald
Thursday, 4:35 PM : B. Freifeld



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- Aquistore
  - Funding from the Petroleum Technology Research Council (PTRC). Additional funding provided by Chevron and Natural Resources Canada (NRC). Special thanks to Don White and Kyle Worth; Also thanks to Anna Stork; Douglas Schmitt; Kyle Harris; Brian Roberts; Claire Samson. Thanks to Doug Miller for DAS processing. DAS acquisition using Silixa iDAS.

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- PTRC: Aquistore Project Management: Kyle Worth
- NR Can., Geol. Survey of Can.: Seismic monitoring: Don White
- LBNL
  - co-PIs: Tom Daley and Barry Freifeld
  - Data Acquisition: Michelle Robertson

- PTRC is operating the Aquistore storage project with seismic monitoring led by Don White. LBNL is providing DAS acquisition, processing, analysis. Chevron is providing supplementary funds for DAS testing at Aquistore (Jon Cocker lead). Multivendor DAS test included funding from industry consortia.

Gantt Chart

MILESTONE GANTT CHART

Milestone Reporting accompanies Quarterly report	Q1 FY16			Q2 FY16			Q3 FY16			Q4 FY16		
Subtask Description	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
Task 1 Project Management and Planning												
Task 2 Otway Project			A*									B
Task 3 Aquistore Collaboration			C						D			
Task 4 Carbon Management Canada, FRS						E			F			

TASK 3. Aquistore Collaboration

Milestone 3-1(C)
Title: Field test report from installation of a surface trenched fiber-optic DAS cable
Planned Completion (Reporting) date: Q1 12/31/15 (1/31/16)
Verification Method: Quarterly Progress report and supplement

Milestone 3-3(D)
Title: Sensitivity comparison between geophone and DAS datasets
Planned Completion (Reporting) date: Q3 6/30/16 (7/31/16) Note: delayed due to funding gap
Verification Method: Quarterly Progress report and supplement

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Bibliography

List peer reviewed publications generated from the project per the format of the examples below

- Harris, K**.,** White, D., Melanson, D., Samson, C., and **Daley, T. M.,** 2016, Feasibility of Time-lapse VSP Monitoring at the Aquistore CO2 Storage Site Using a Distributed Acoustic Sensing System, International Journal of Greenhouse Gas Control, 50, p248-260. doi:10.1016/j.ijggc.2016.04.016
- **Daley, Thomas M**., J. Torquil Smith, John Henry Beyer and Douglas LaBrecque, 2015, Borehole EM Monitoring at Aquistore with a Downhole Source, Chapter 39 in Carbon Dioxide Capture for Storage in Deep Geologic Formations – Results from the CO2 Capture Project, Volume Four: CCS Technology Development and Demonstration Results (2009-2014), Karl F. Gerdes, editor, CPL Press, ISBN 978-1-872691-68-8.
- White, D.J., L.A.N Roach, B. Roberts, **T.M. Daley**, 2015, Initial Results from Seismic Monitoring at the Aquistore CO_2 Storage Site, Saskatchewan, Canada, Energy Procedia 63, 4418-4423.