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Advanced Monitoring Technology: DAS (Distributed Acoustic Sensing) at Otway and Aquistore

Thomas M (Tom) Daley

Barry Freifeld (LBNL), multiple coauthors (next slide)

Coauthors

- Otway Project: (Material from Freifeld, et al, 2016 EAGE)

R. Pevzner[2,3], S. Dou[1], J. Correa[2,3], M. Robertson[1], K. Tertyshnikov[2,3], T. Wood[1], J. Ajo-Franklin[1], Milovan Urosevic[2,3], Dmitry Popik[2,3] and B. Gurevich[2,3,4]

1. Lawrence Berkeley National Lab, 2. Curtin University, 3. CO2CRC, 4. CSIRO Energy

- Aquistore Project:

D. E. Miller[1], D. White[3], M. Robertson[2], J. Cocker[4], A. Strudley[4],M. Craven[4], K. Worth[5], K. Harris[6]

[1] Silixa, LLC, [2] Lawrence Berkeley National Laboratory, [3]Geological Survey of Canada-NRCan, [4]Chevron, [5]PTRC, [6]Carleton Univ.

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- Otway
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- Aquistore
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Advanced Monitoring Technology

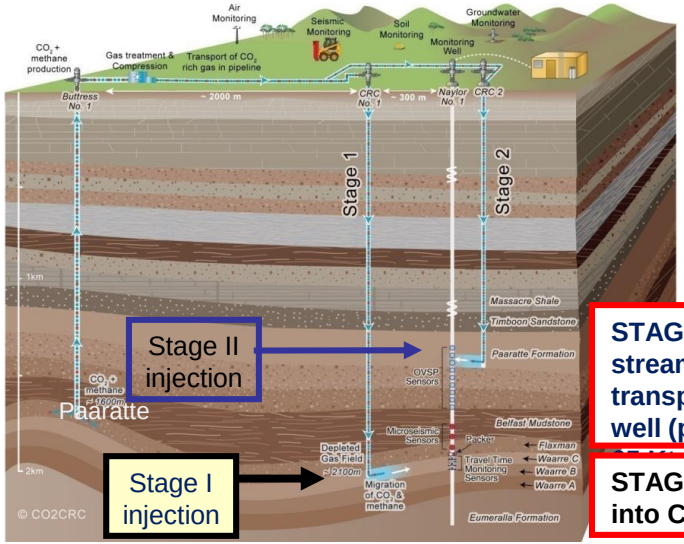
- Issue: CO_2 storage requires long term repeated monitoring
  - Active source seismic is an important monitoring tool, but…
  - Marine seismic is expensive, with high fixed cost (few ‘small’ tests)
  - Land seismic has unique difficulties (surface variability and access)
  - Permanent seismic sources are not standard or generally available

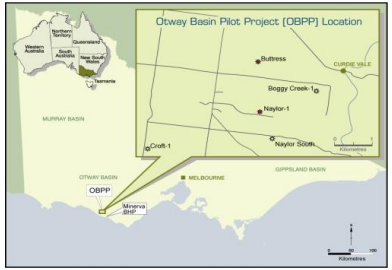
- R&D Approach
  - DAS on Fiber optic cables: a promising technology to improve long term repeatable monitoring with permanent sensor installation
  - Permanent, remote-controlled source: provide continuous monitoring and ‘trigger’ for full 3D seismic acquisition

Otway Project - Background

- Stage 1: ~65,000 tonnes stored at ~2 km in depleted gas reservoir

- Stage 2c: Injection of 15,000 T
- 1.5 km depth (saline aquifer)
- 3D seismic data: buried geophones, vibrator truck
- Installed buried surface fiber-optic DAS network
  - > 30 km of standard fiber cable
  - ~1 km of novel helical wound fiber cable
- First ever 3D reflection seismic survey using DAS! (to our knowledge)
- Installed and operated permanent seismic sources





STAGE I: An 80/20 % of CO_2/CH_4 stream produced from Buttress, transported and injected into CRC-1 well (previous CH_4 production well) -

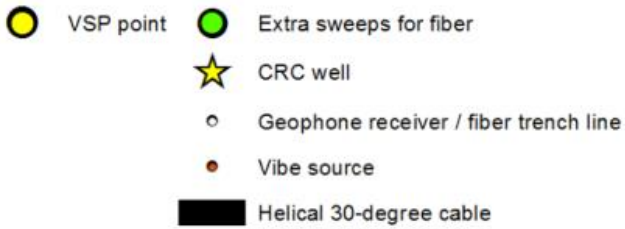
STAGE II: CO_2/CH_4 stream injected into CRC-2 well – up to 15 Kt.

Otway Stage 2C Experiment (CO2CRC)

Permanent 3D Surface Seismic Sensor Array

LBNL: 2 Permanent Sources and surface DAS fiber cables in trenches

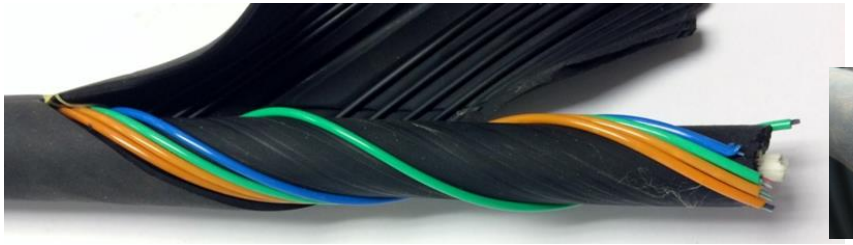
- 3 x 5k Tonne Injections with full monitoring of each
- 1500 m depth
- Saline aquifer

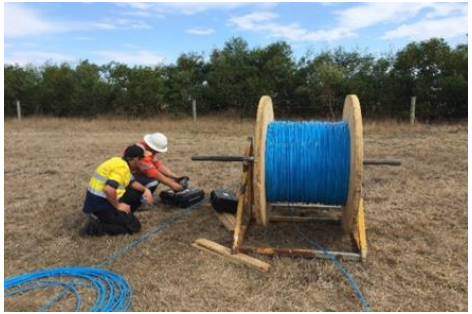


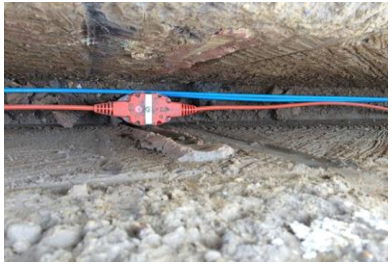
Courtesy R. Pevezner, Curtin Univ, CO2CRC

Problem: Standard DAS Cable is not good for surface seismic geometry
Development: Helical Wound Cable (HWC)

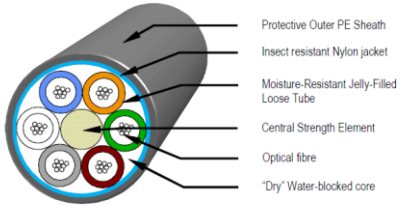
- Latest Helical Cable: ‘FAT’ cable. Used in one trench.
- Based on results of Hornman et al. (2013 EAGE) for deployment of a broadside sensitive cable we deployed our own design
- Initial testing of spiral wound cable with hard plastic showed strong attenuation of seismic signal and a new design was developed. 30° spiral wound on 58 Shore A rubber mandrel.







Normal Telcom Cable used in all 11 trenches



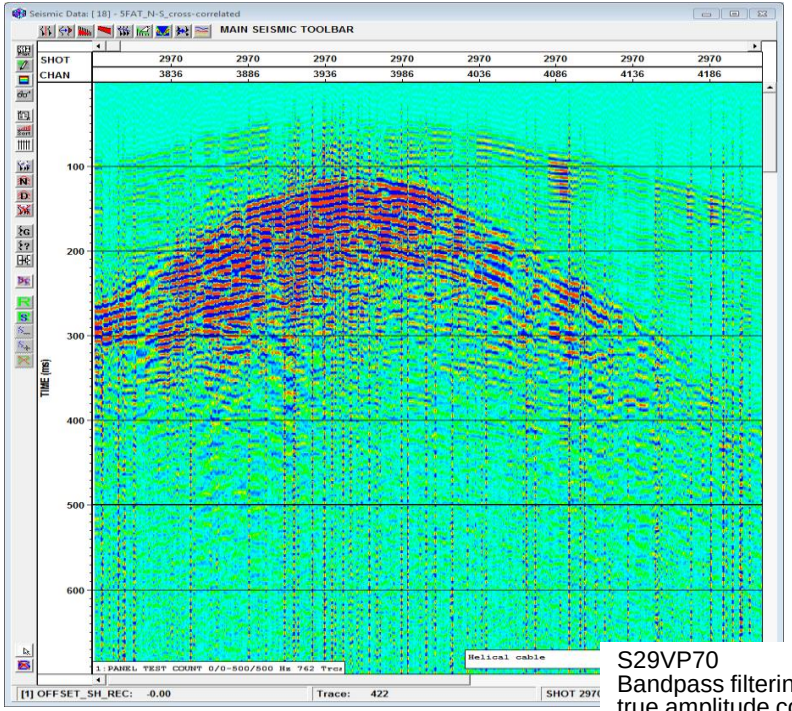
March 2015 Otway Deployment

Freifeld, et al, 2016, EAGE

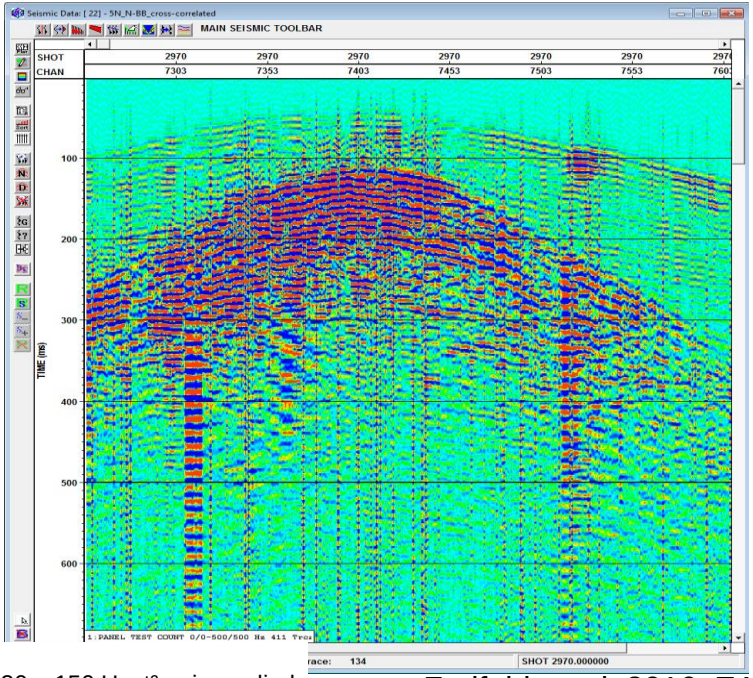
Comparison shot gathers – Vibroseis Source

First Result: Comparable Data

Line 5 - FAT Helical Cable



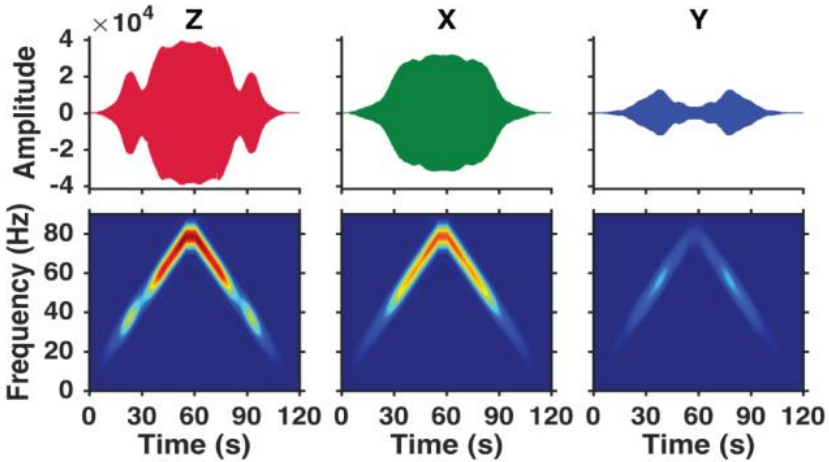
Line 5 - N (Conventional Cable)



S29VP70
Bandpass filtering: 30 – 150 Hz, t^2 gain applied, true amplitude comparison.

Freifeld, et al, 2016, EAGE

Permanent Seismic Source for 4D Monitoring source runs once a day – remote control



An example of the source function as recorded using a 3-C geophone buried at a depth of 4 m.

Freifeld, et al, 2016, EAGE

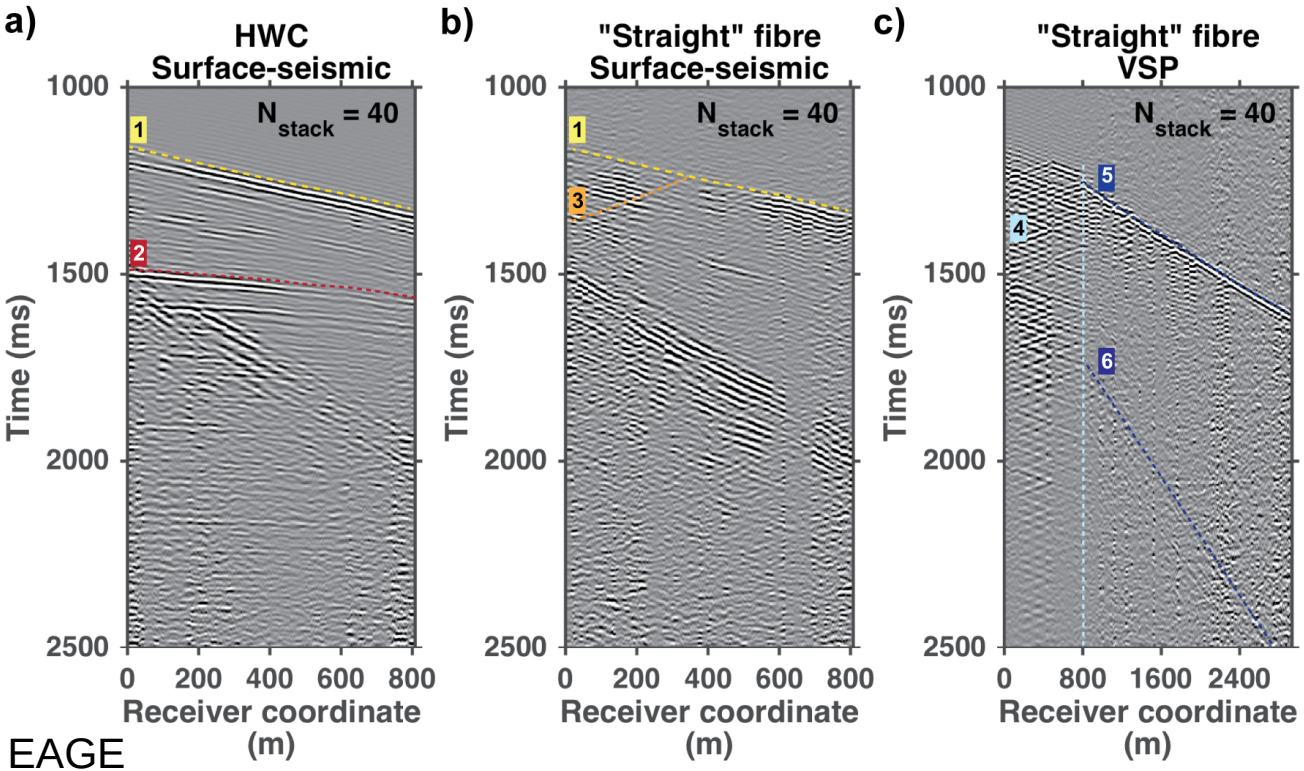
Swept frequency fixed rotary source –

- Design for extended periodic seismic excitation (e.g. 1 hr/day)
- 20 to 80 Hz sweep
- Reverse motor direction each sweep
- F_{peak} = 10 T

Helical and Straight Fiber Surface and VSP with Permanent Source

Helical cable design clearly better for surface seismic – when ground is saturated

Permanent seismic monitoring data consisting of a) surface seismic data (common shot gather) recorded with helically wound cable (HWC) (wrapping angle = 30°) and (b)"straight" fibre (wrapping angle = 11°), and c) VSP data recorded with "straight" fibre. The origin of the time axes is relative to the beginning of the listen time (which starts earlier than the actual sweep onsets).



Freifeld, et al, 2016, EAGE

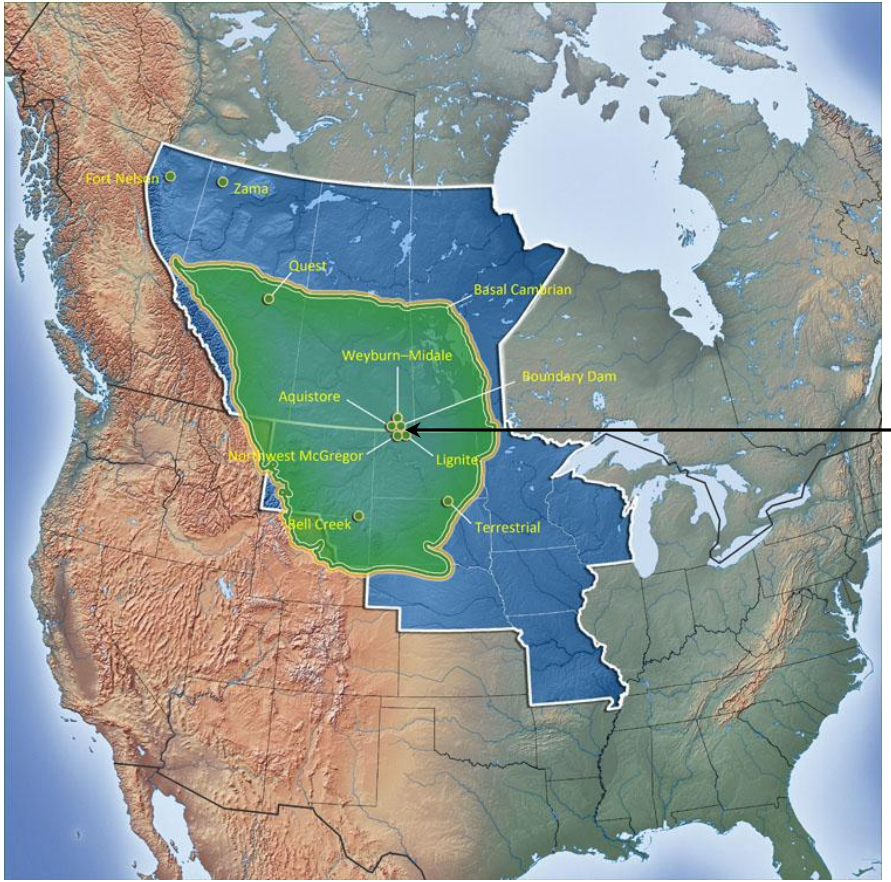
Otway Accomplishments to Date

(In collaboration with our international partners)

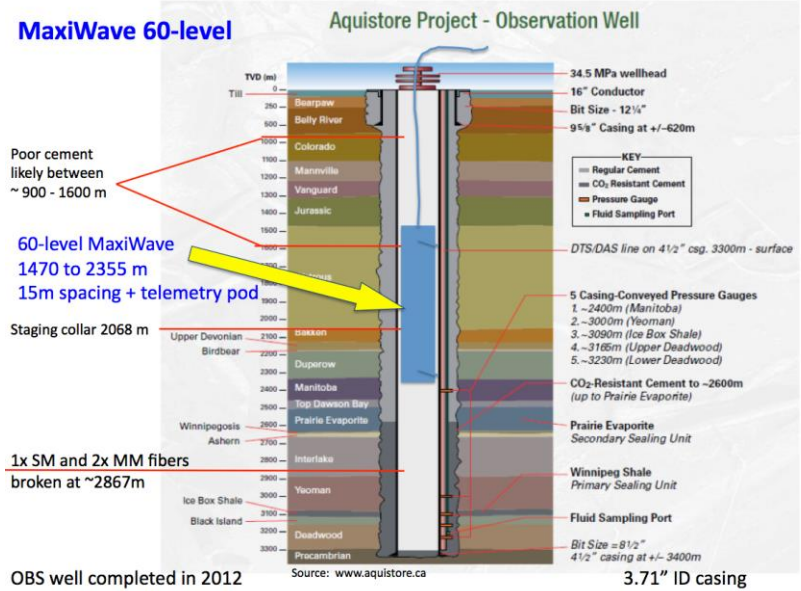
- Installed surface trenched fiber-optic seismic network at Otway Project Site, in conjunction with permanent buried geophone array.
- Installed two permanent surface seismic sources. Daily monitoring.
- 15,000 tonnes injected in saline aquifer at ~1500 m depth.
- Full 3D baseline and two monitor data sets: collection complete.
- Processing and analysis is in progress.

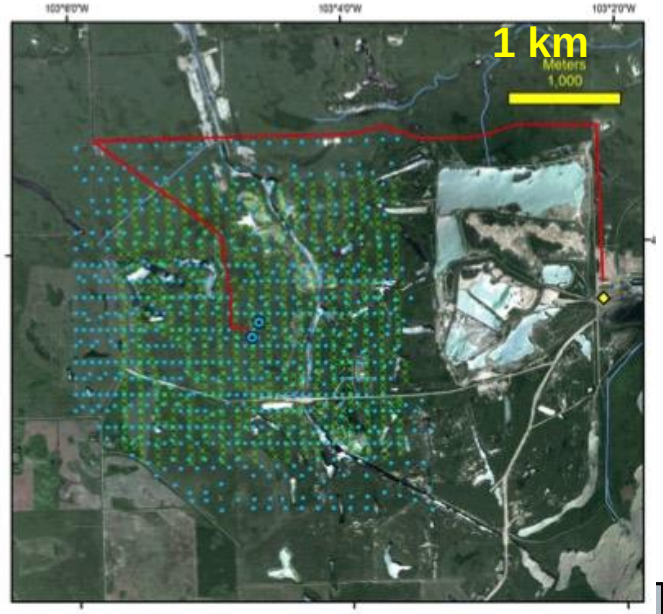
Aquistore

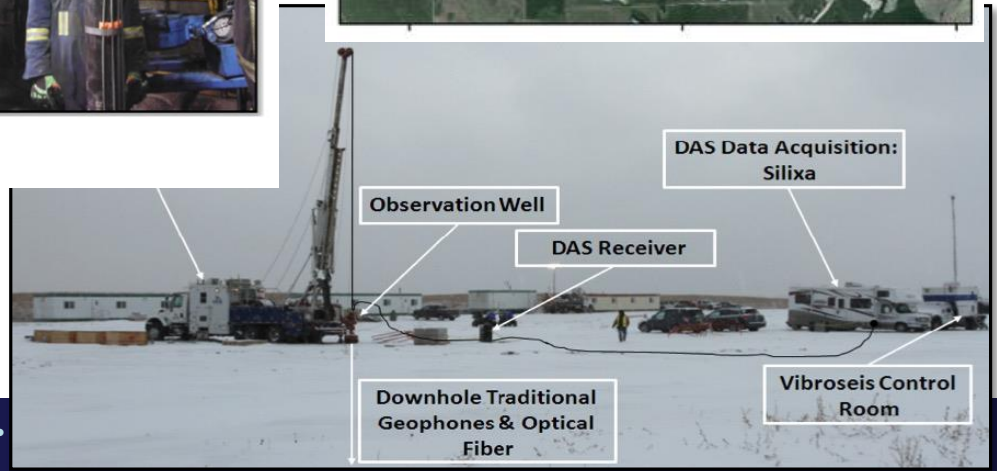
- Integrated CCS:
  - Capture from SaskPower's Boundary Dam Coal-Fired Power Station
  - Transported via pipeline to an injection well at the storage site; 90% of CO2 for EOR
  - Captured CO_2 stored in a deep (3.2 km) saline aquifer in the Williston Basin
- ~1 Mt/year CO2 capture started in 2014
- Over 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)

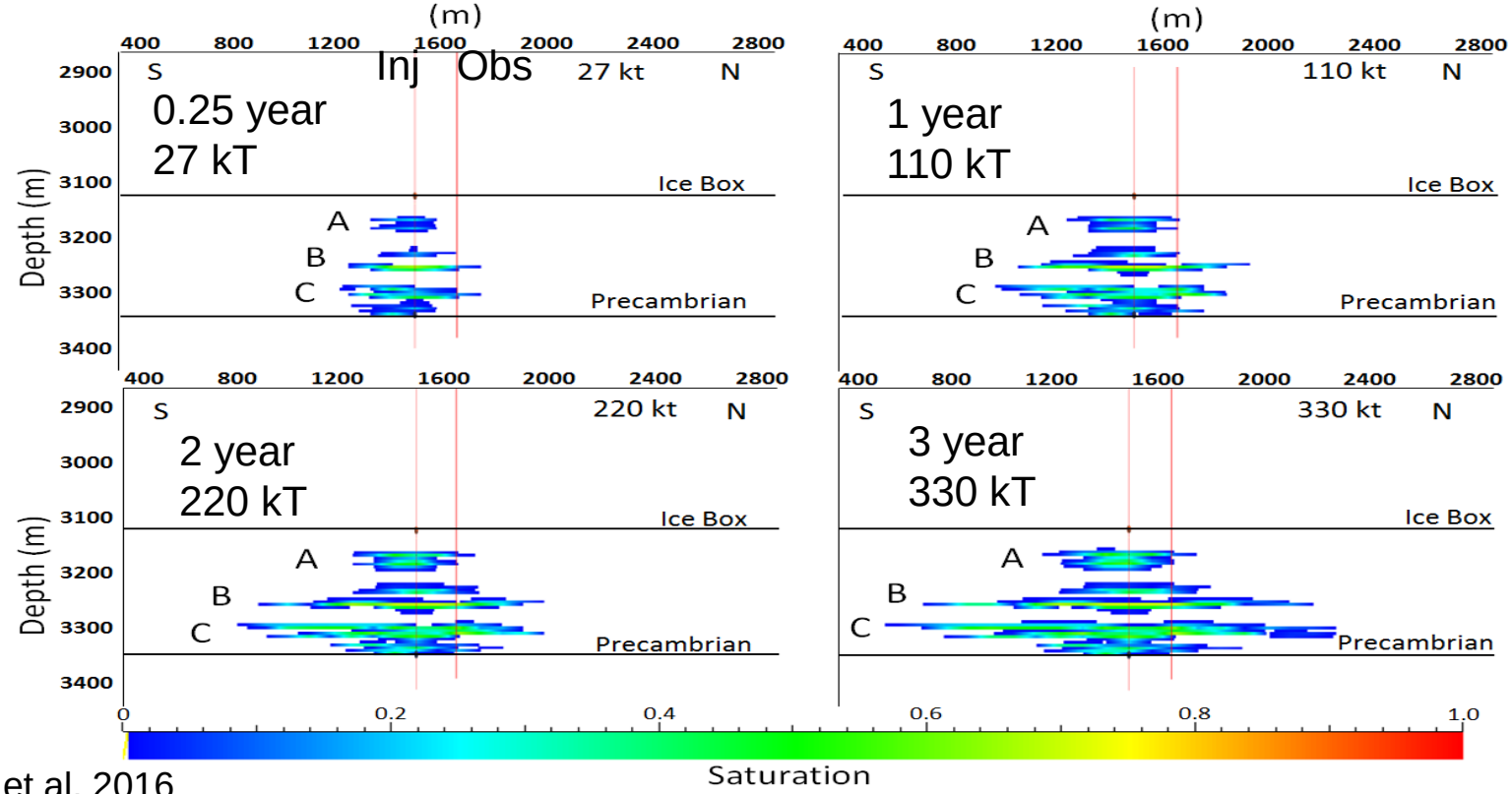






Baseline 3D/VSP surveys in 2013, 2014 and 2015

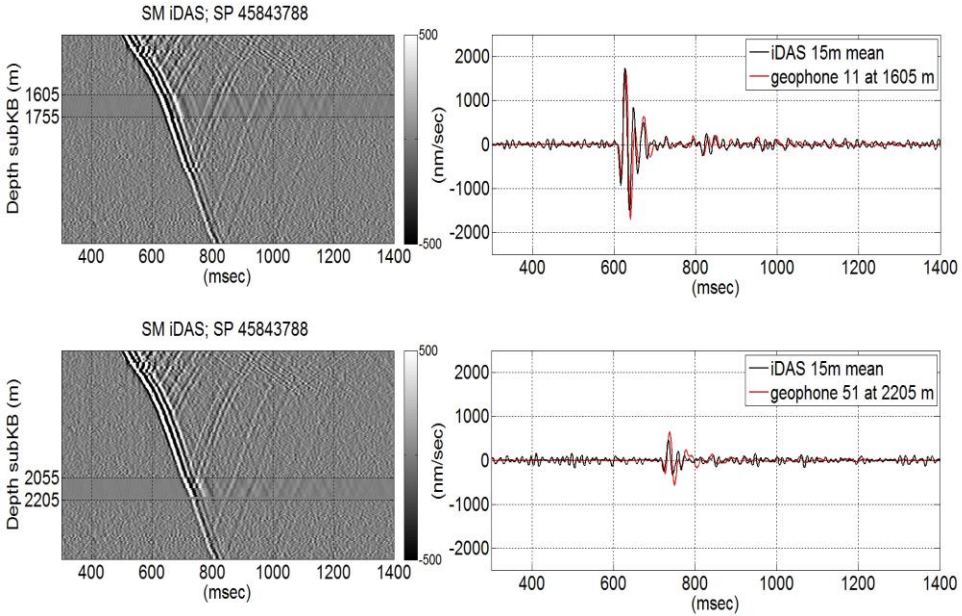
CO_2 Flow Simulations: Use to Estimate Seismic Detectability



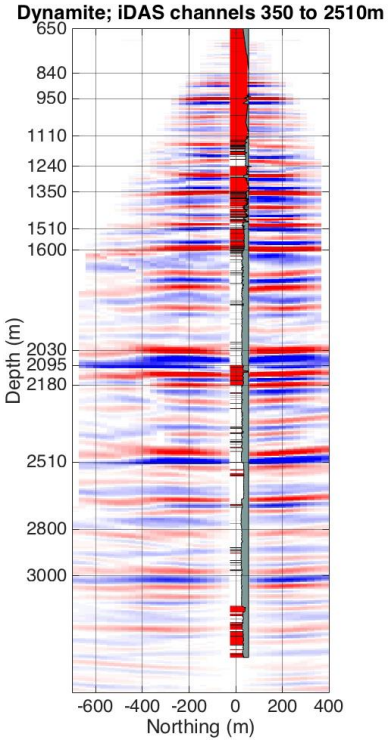
Harris, et al, 2016

2013 Baseline DAS VSP

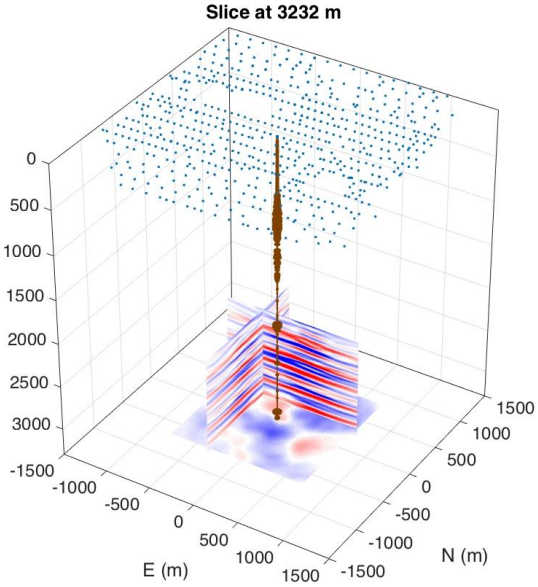
DAS Geophone Comparison



2D Migrated Image



3D Migrated Image

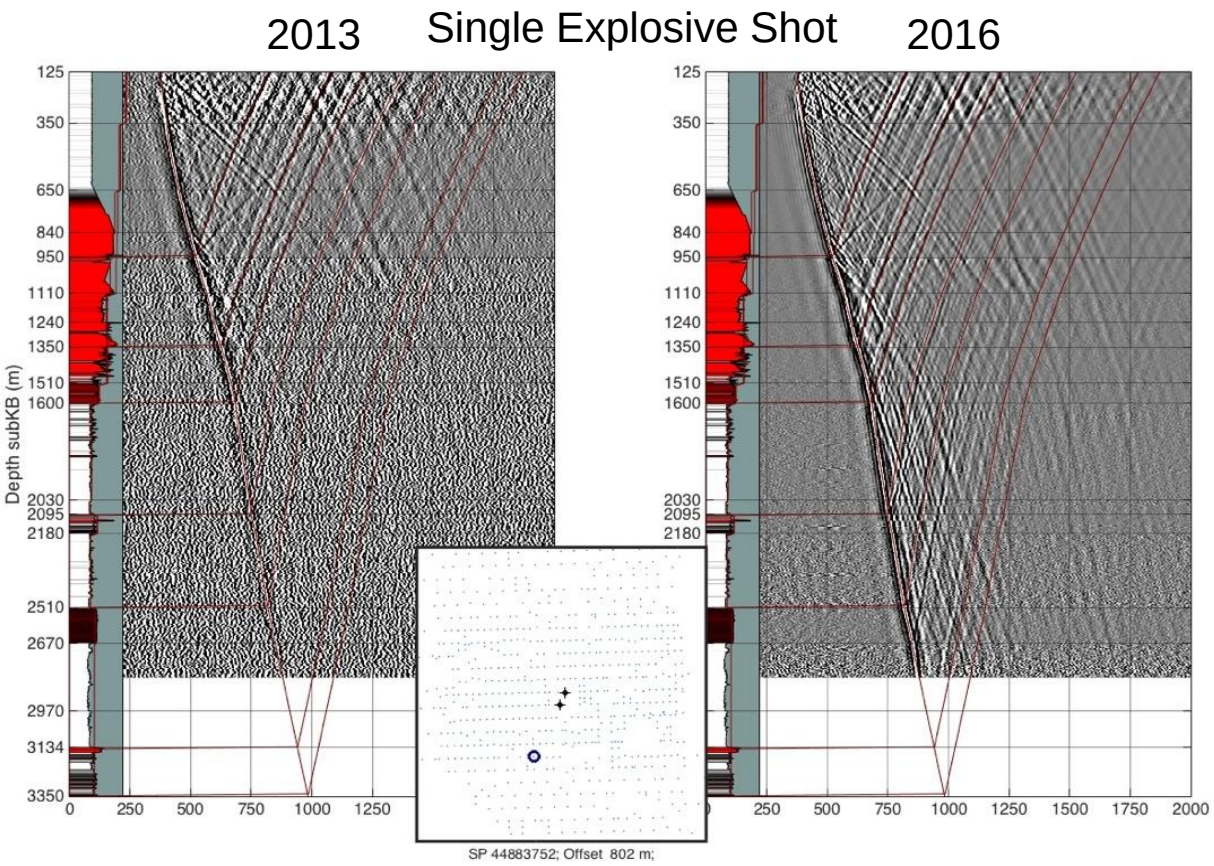


Miller, et al, 2016; in press.

February 2016: 1st Monitor DAS VSP

- Repeat 3D surface and VSP surveys
- 80-level 3C Geophone and DAS VSP
- Multi-vendor DAS test with Vibroseis Source*
- Trenched surface DAS cable test*

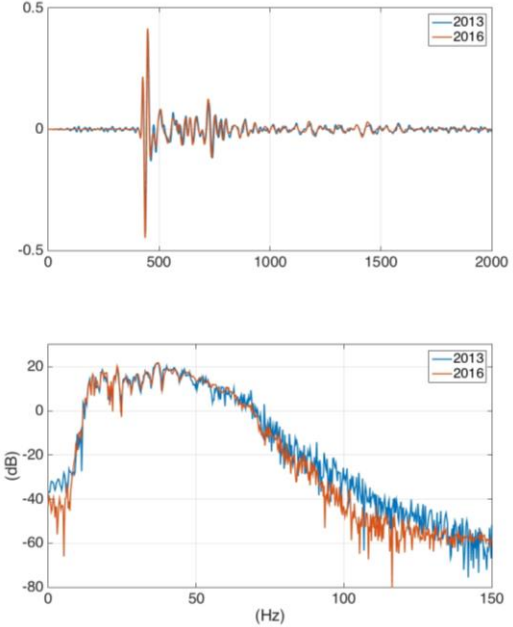
*results not available yet



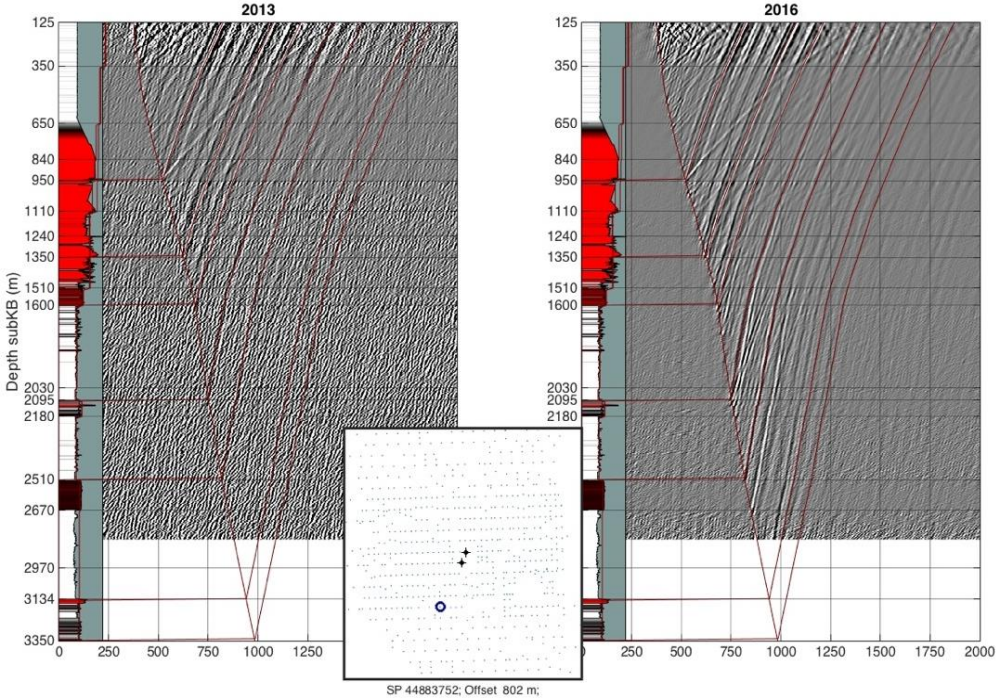
4D DAS Assessing Repeatability

Initial indications are that DAS is quite repeatable with the caveat that advancing technology has <u>improved</u> the signal-to-noise ratio

Single DAS Channel
2m sampling



Single Shot Reflections (Upgoing)



~600 Shots input to 4D migration

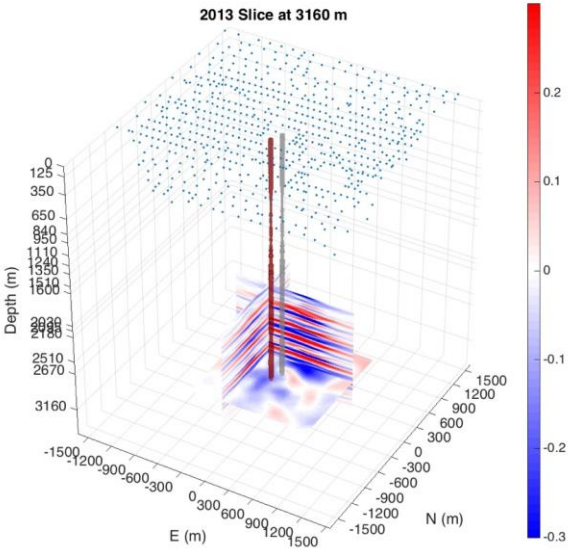
Processing by Doug Miller

Raw 4D DAS

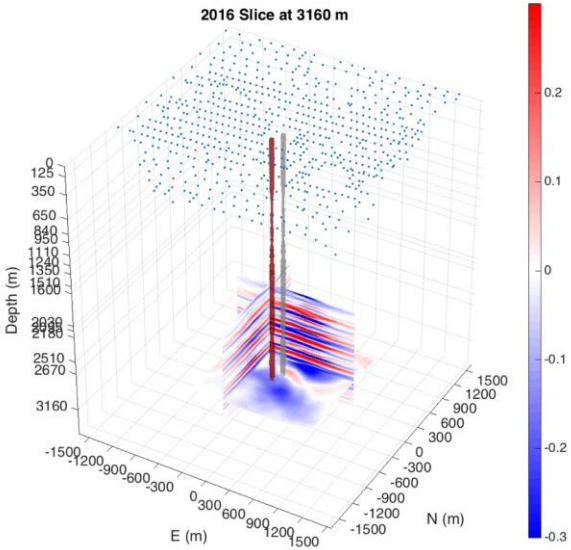
Preliminary results – not ready for interpretation

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

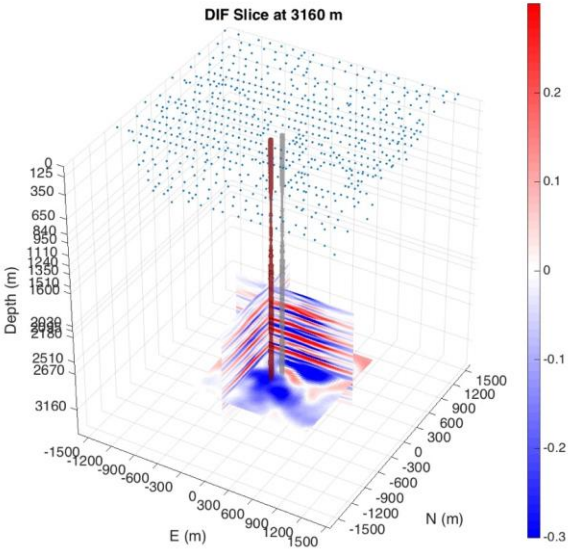
2013



2016



Difference



Processing by Doug Miller

Aquistore Summary

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

- **Testing of DAS technology,**
- Baseline DAS VSP (2013)
  - Comparison of dynamite and vibroseis
  - Comparison of single mode and multimode fiber recording

- 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 recording using DAS array following injection in 2015
  - Recording of permanent JOGMEC ACROSS source into fiber-optic array (2015)
  - DAS and Geophone VSP: 4D comparison
  - Multivendor DAS test
  - Trenched surface cable test

Summary

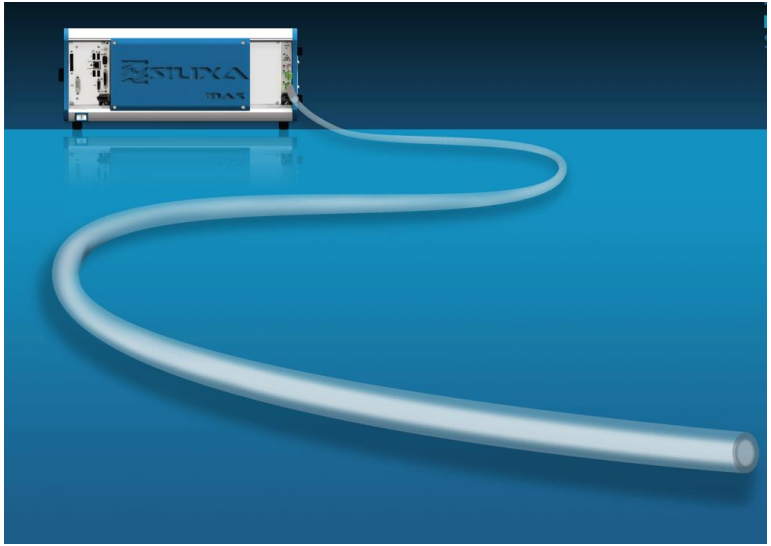
- We are working towards permanent, continuous seismic monitoring.

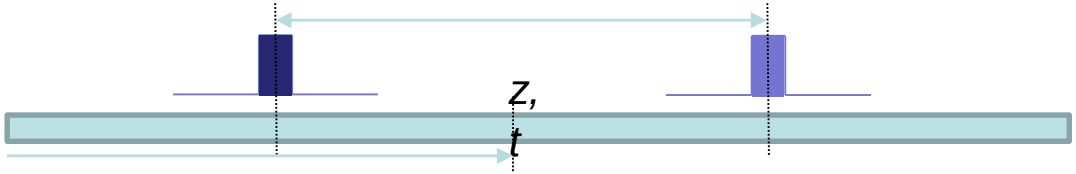
- Potential for New Paradigm:
  - Permanent fiber optic cables in trenches and available wells.
    - Helical cables better than straight in trenches
    - Cementing behind casing better than tubing deployment in well.
  - Select permanent sources, operating remotely, can provide ‘triggers’ for full surveys
  - Full 3D surface seismic and VSP as needed with temporary sources (explosive, vibroseis, air gun (marine)

- International CCS projects have provided a great collaborative test bed for new technology at the forefront of the geophysical industry

Distributed Acoustic Sensing (DAS) as implemented by Silixa

- Standard optical fibre acts as the sensor array
  - Typical sampling at 10kHz on 10,000m 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





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

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