Field Testing of Emerging Technologies: Otway Project

Project Number ESD14-095 (Task 2)

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Lawrence Berkeley National Laboratory

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

August 1-3, 2017

Coauthors/Collaborators

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**LBNL Co-PI*

Presentation Outline

- Otway Stage 2c overview
- Conventional seismic results
- Fiber-optic DAS data and SOVs
- Accomplishments and Conclusions

ACKNOWLEDGEMENTS

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We would like to acknowledge the funding provided by the Australian government to support CO2CRC research.

We also acknowledge funding from ANLEC R&D and the Victorian Government for the Stage 2C project.

We thank the National Geosequestration Laboratory (NGL) for providing the seismic sources (INOVA Vibrators) for this project. Funding for NGL was provided by the Australian Federal Government.

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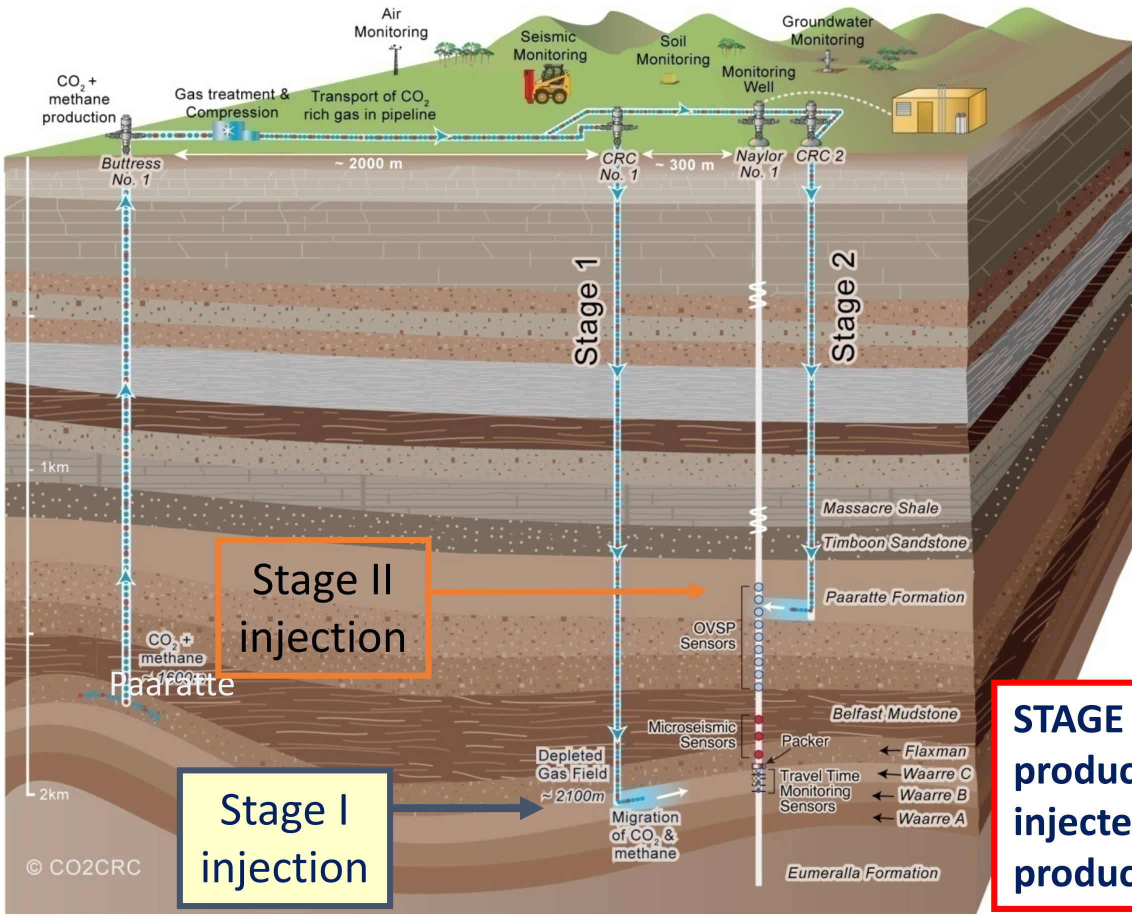
CO2CRC
BUILDING A LOW EMISSIONS FUTURE

Otway Basin Pilot Project (Victoria, Australia)



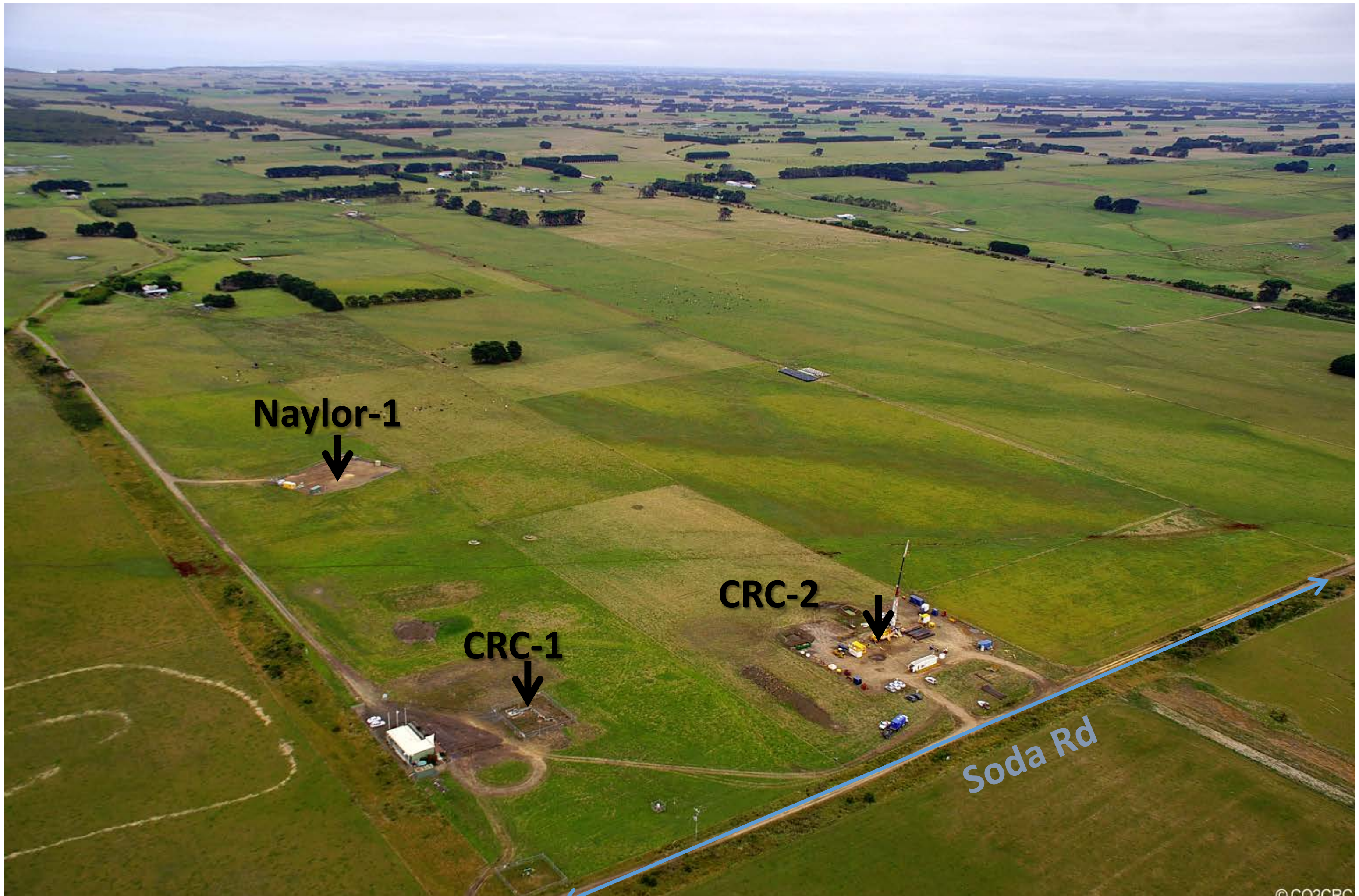
STAGE I: An 80/20 % of CO_2/CH_4 stream produced from Buttress, transported and injected into CRC-1 well (previous CH_4 production well) -65 Kt.

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

Stage 2C Project goals

- Detect injected Buttress gas in the subsurface: ascertain minimum seismic detection limit
- Observe the gas plume development using time-lapse seismic
- Verify stabilisation of the plume in the saline formation using time lapse seismic
- Trial new monitoring technology including surface DAS and permanent surface orbital vibrators

Otway site aerial photo



Stage 2C monitoring strategy

Full 4D finite-difference time domain (FDTD) synthetic dataset was generated prior commencement of the first monitor survey and used to pre-define and validate processing flows (Glubokovskikh et al., IJGGC 49, 2016)

4D seismic with buried receiver array acquired concurrently with 4D VSP

- Baseline: March 2015
- Monitor surveys: 5 kt, 10kt, 15 kt of injection (January-April 2016), 1&2 years post injection (January 2017&2018)

Offset VSPs

Passive seismic using buried receiver array

LBNL responsibility: Trialing 4D seismic with buried DAS array, 4D VSP in CRC-2 (optical fiber on the tubing) and surface orbital vibrators (SOVs)

Timeline

February 2015 – Receiver array (Conventional & DAS) installed

March 2015 – Baseline data acquired

September 2015

- LBNL installs permanent vibroseis sources on site, baseline acquired;
- passive seismic acquisition tested

November 2015

- Passive seismic data acquisition commences, including iDAS (8000 s / day)

January 2016 – Monitor 1 (5122 t CO_2) acquired, new foundations for permanent vibes built

February 2016

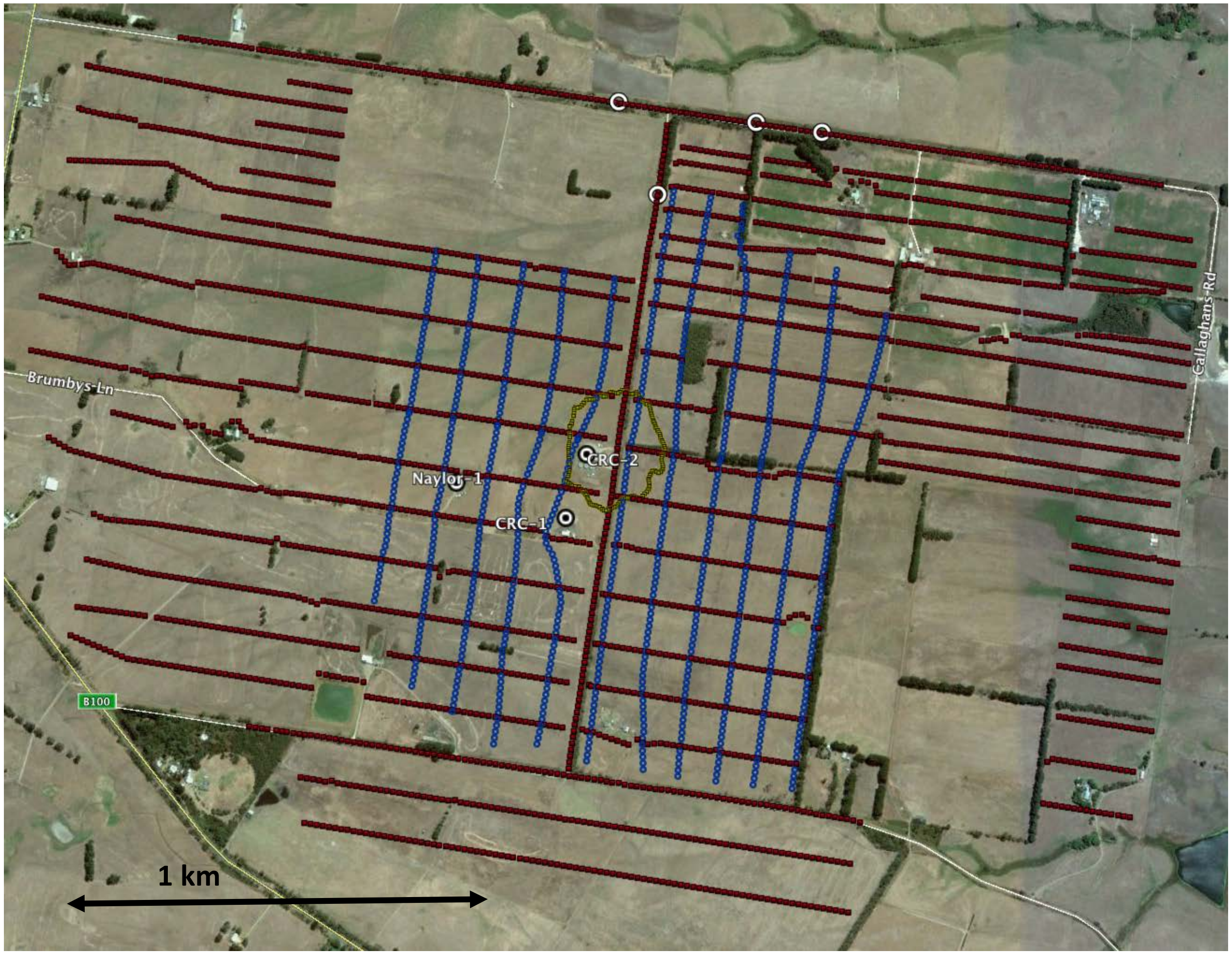
- Both permanent vibes became operational
- Monitor 2 (10000 t) acquired

April 2016 – Monitor 3 (15000 t) acquired

January 2017 – Monitor 4 (1 year post-injection) acquired

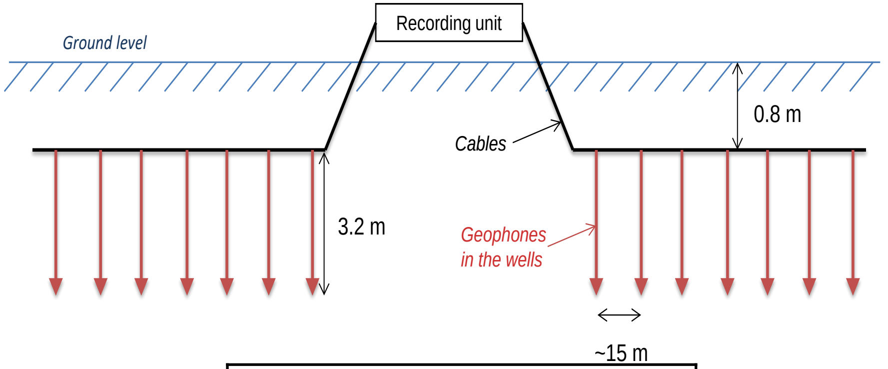
May 2018 – Drill and complete CRC-3. Record cementing using DTS & DAS

Acquisition geometry



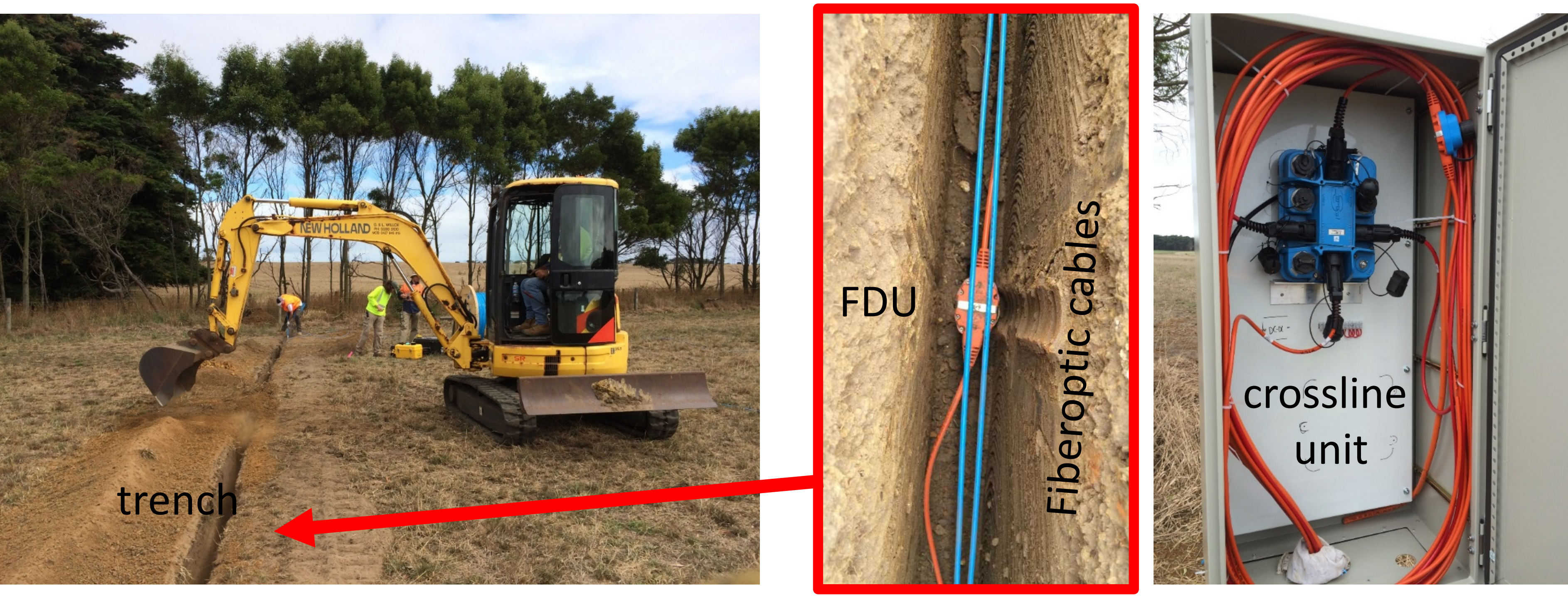
General Survey Parameters	
Total Number of Source Lines	26+1 Lines
Total Number of Sources	3003 Points
Source Line Spacing	from 50 m to 100 m
Source Point Spacing	15 m
Total Number of Receiver Lines	11 Lines
Total Number of Receivers	909 Points
Receiver Line Spacing	100 m
Receiver Point Spacing	15 m
Max Offset	2480 m
Sample Interval	1 ms

Receivers



RECEIVER PARAMETERS	
Receiver Type	Sercel SG-5
Recording Pattern	Orthogonal cross-spread pattern
Receiver Line Spacing	100 m
Receiver Point Spacing	15 m
Receiver Depth	4 m
Cables Depth	0.8 m

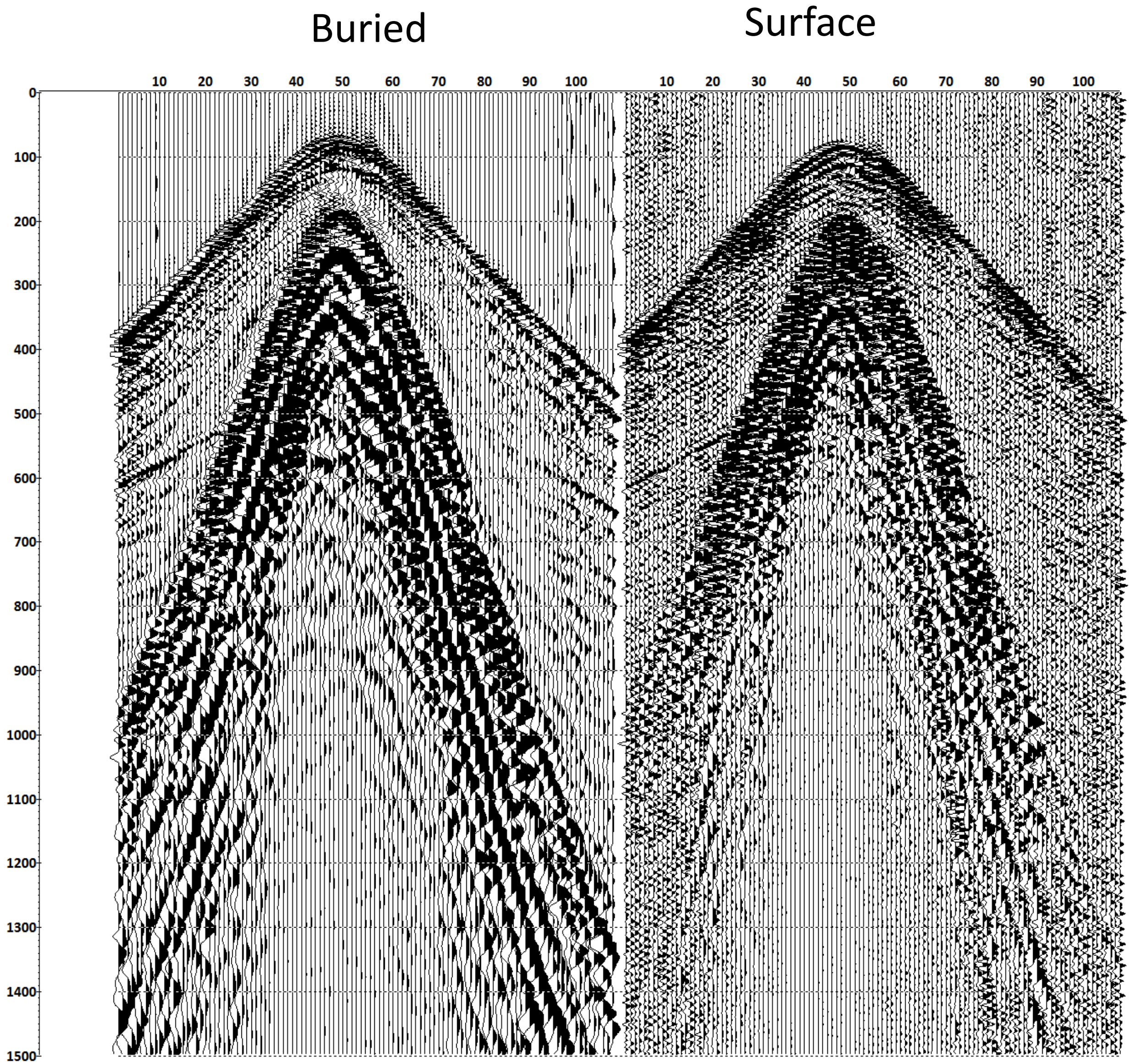
Receivers



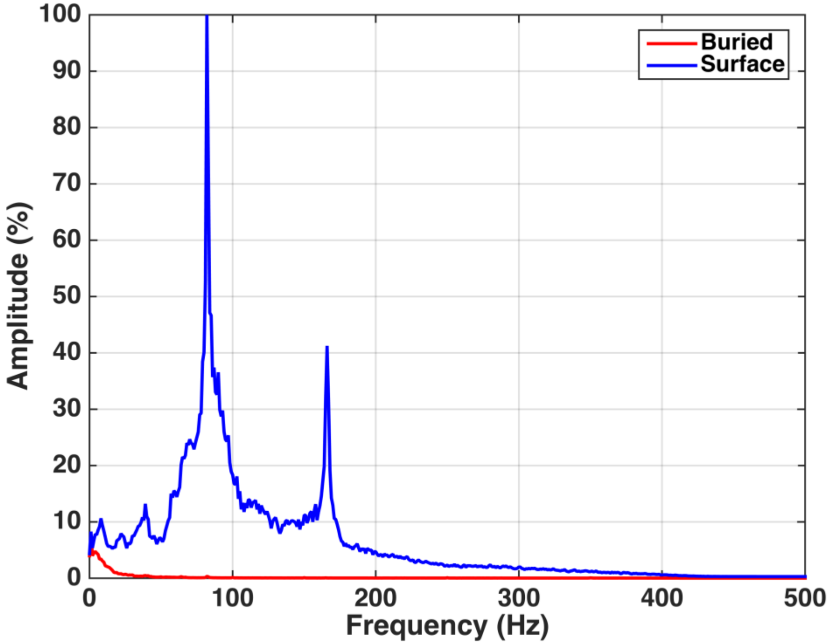
Source

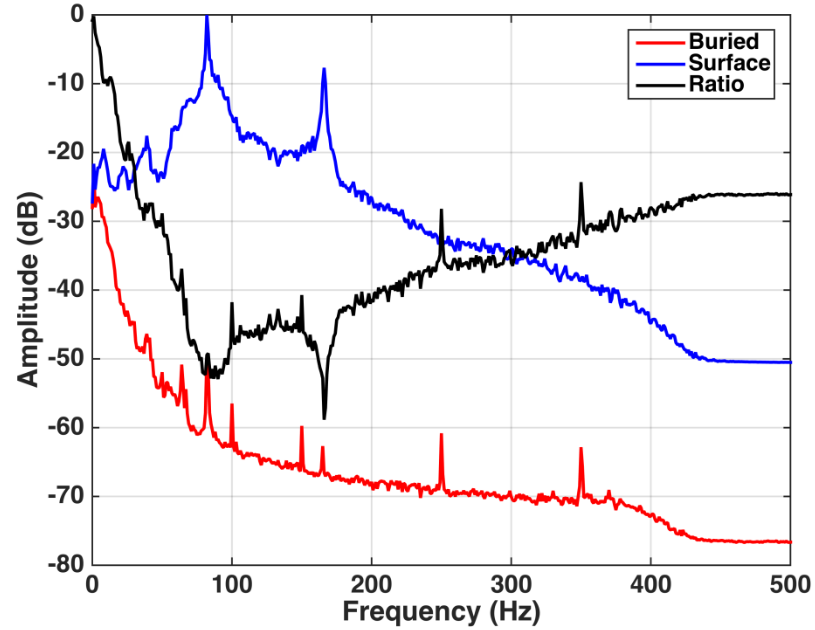
SOURCE PARAMETERS	
Source Type	INOVA UniVibe 26000 lbs
Sweep frequency	6-150 Hz
Tapers	0.5 s
Sweep Length	24 s
Listening Time	5 s

Line 5, receiver 46, common receiver gather



Noise floor reduction ~ 25 dB

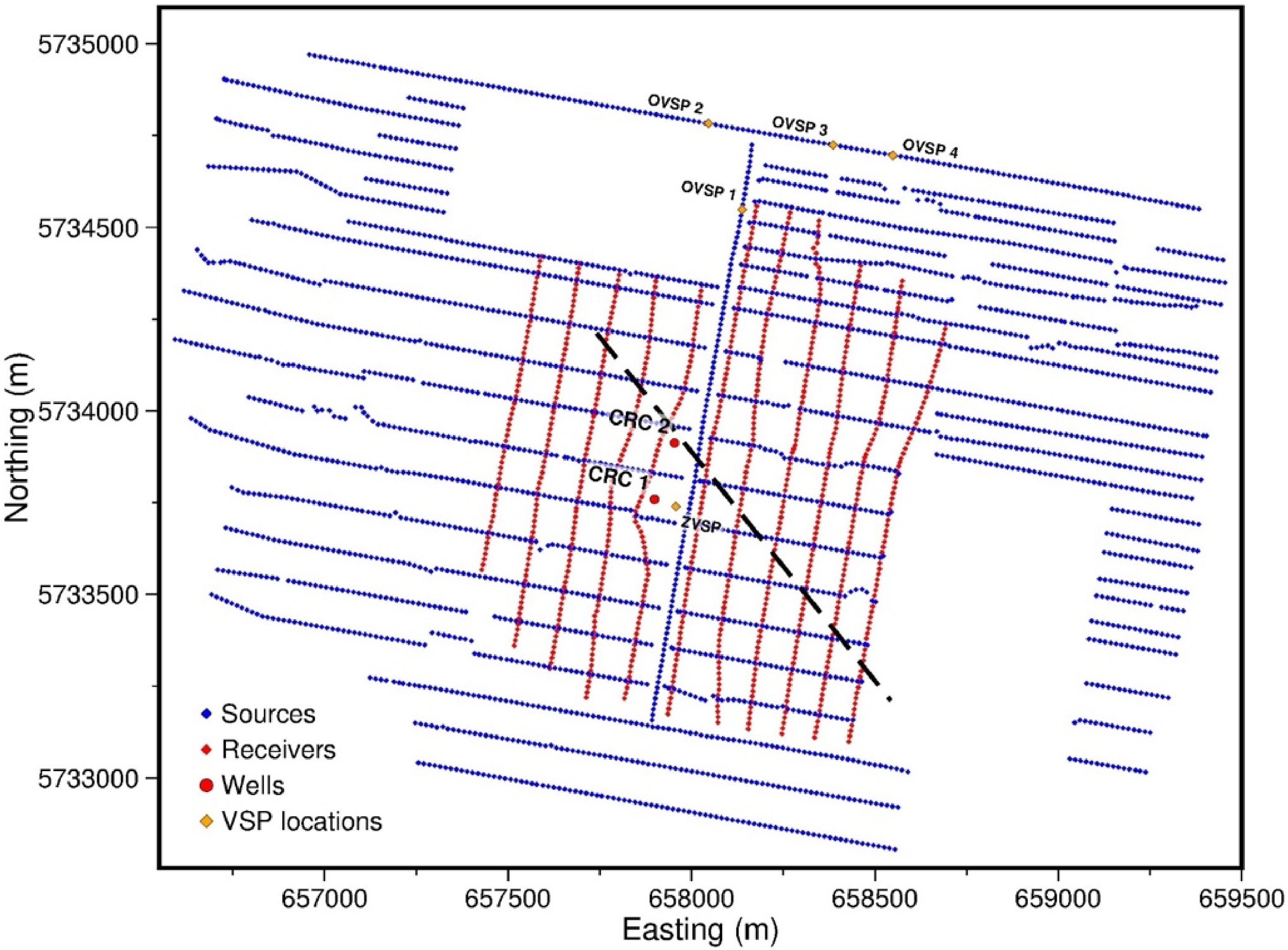




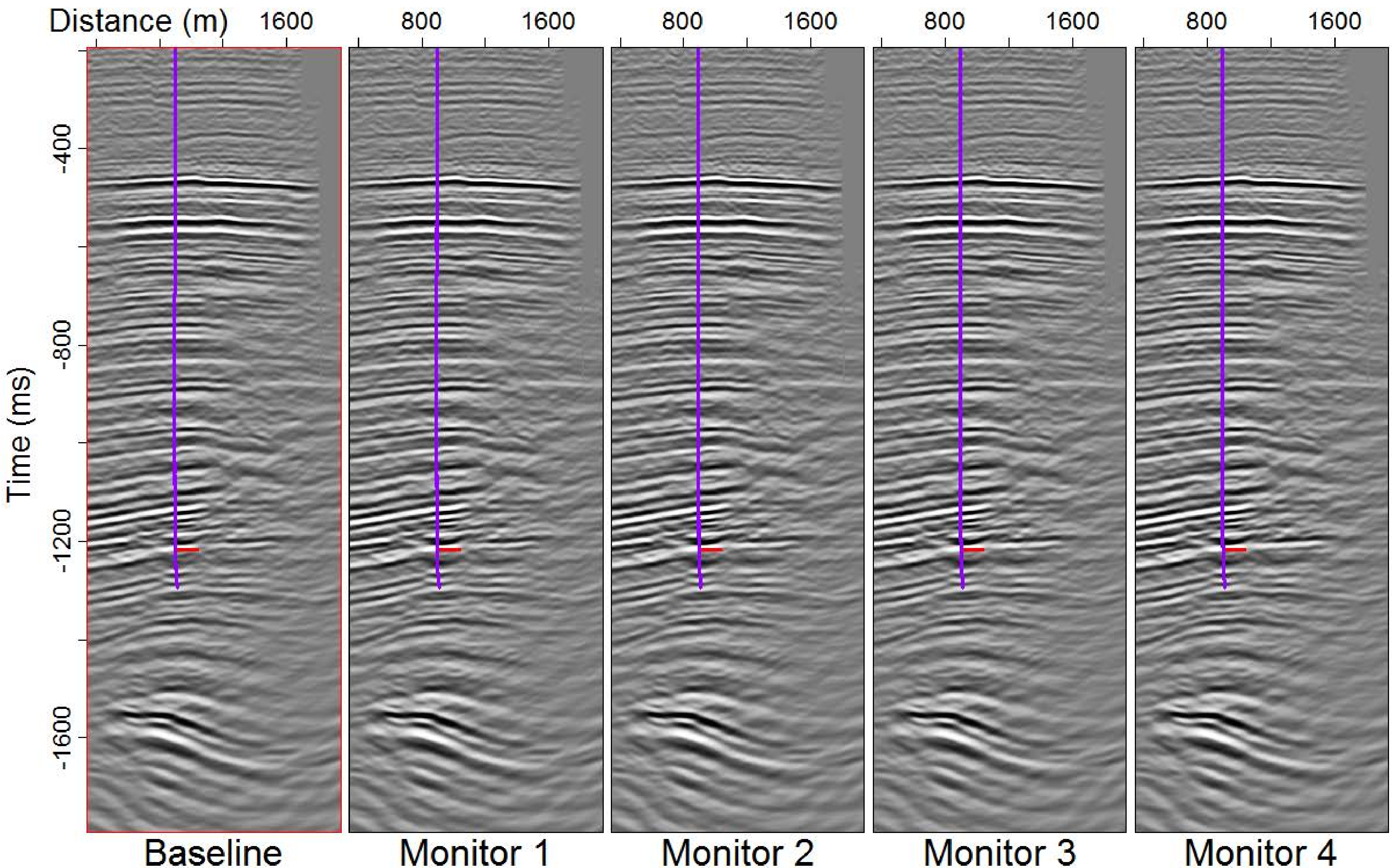
Buried receiver array – preliminary results

- Buried array higher resolution
  - ~25 dB ambient noise floor reduction
  - Virtually all-weather acquisition
  - Lower impact on the land occupiers with no cables on the ground
- Overall higher quality of the data
  - higher resolution – better source + sensitivity of the geophones

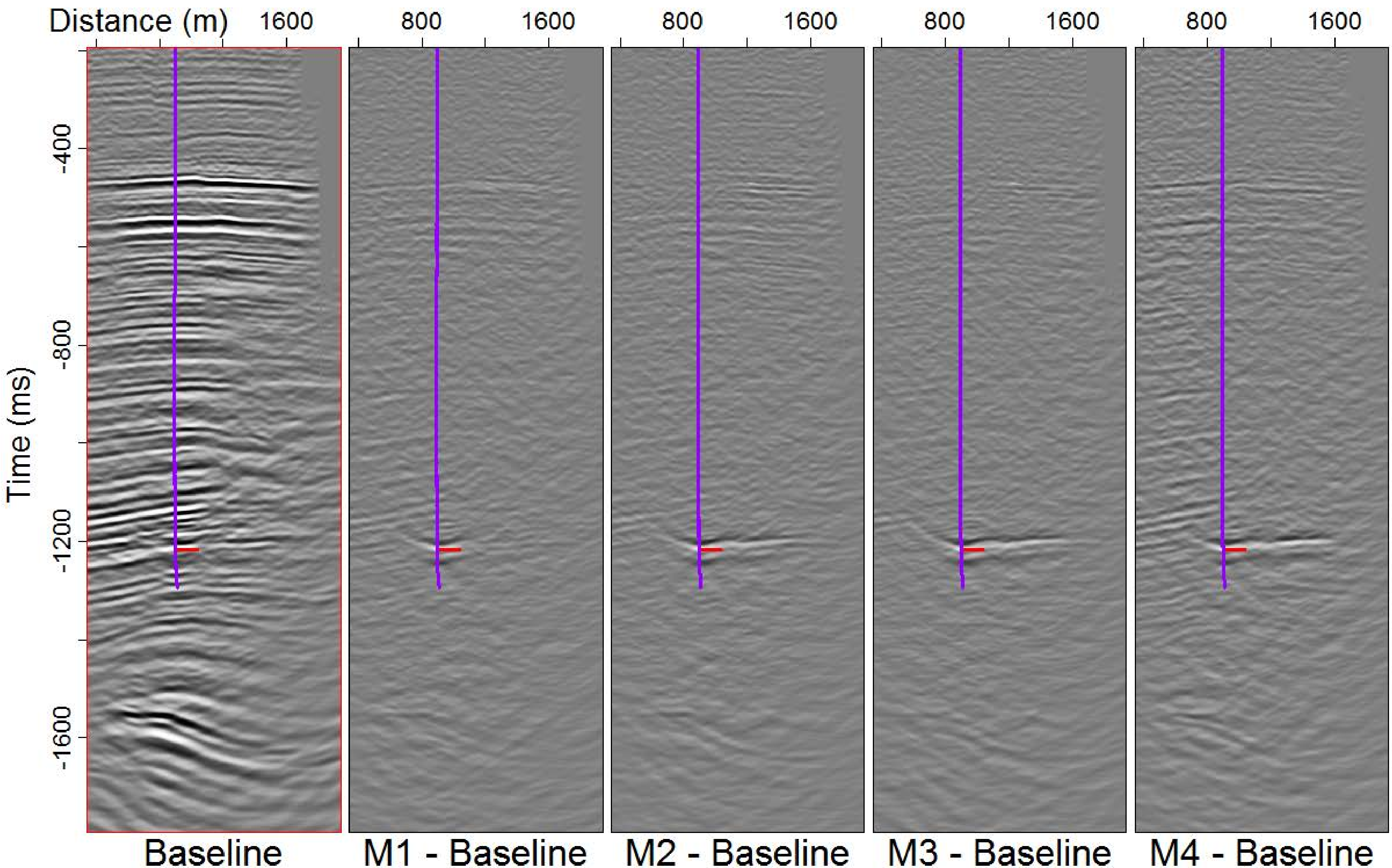
Survey area map



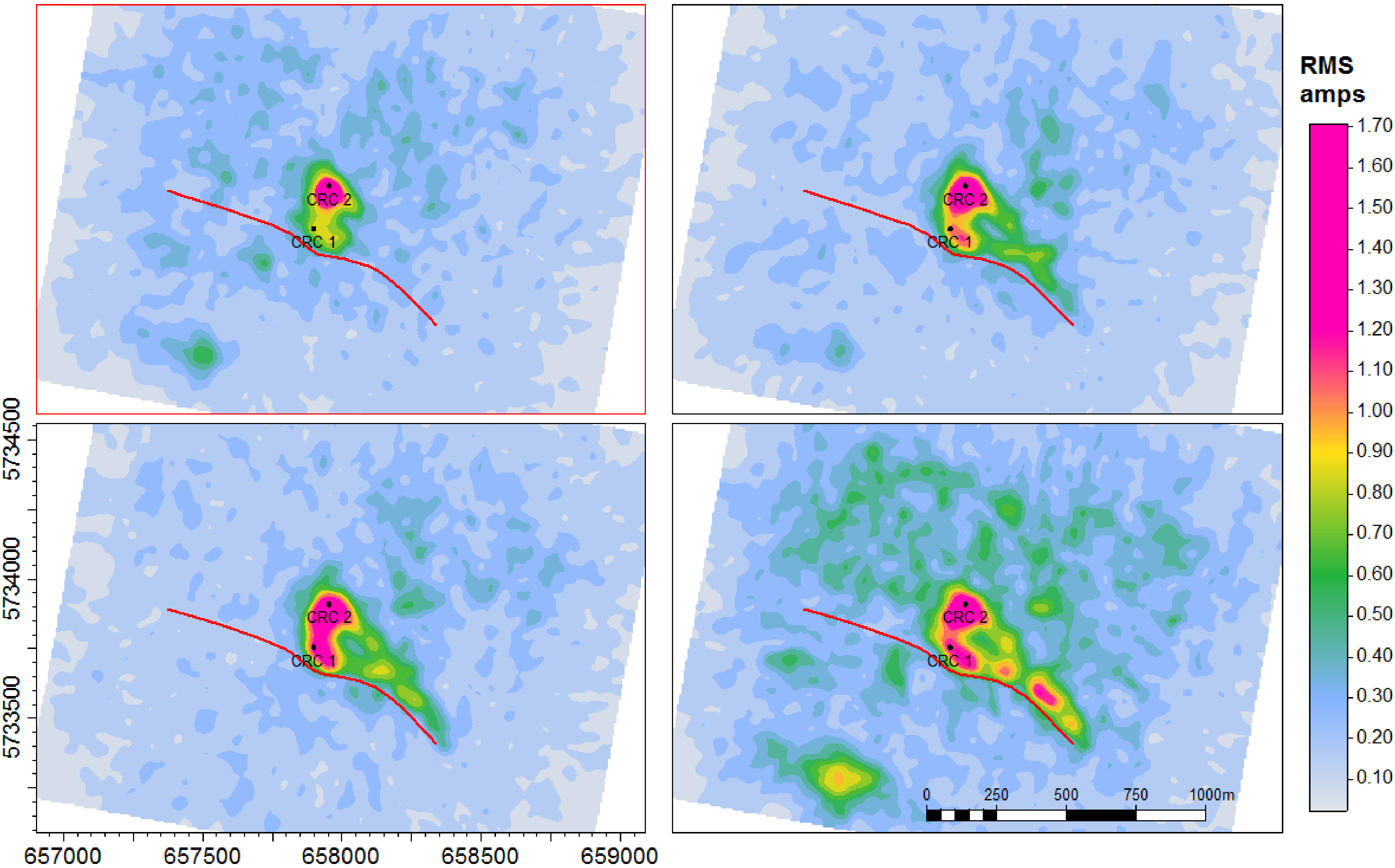
Intersection along the arbitrary line



Intersection along the arbitrary line



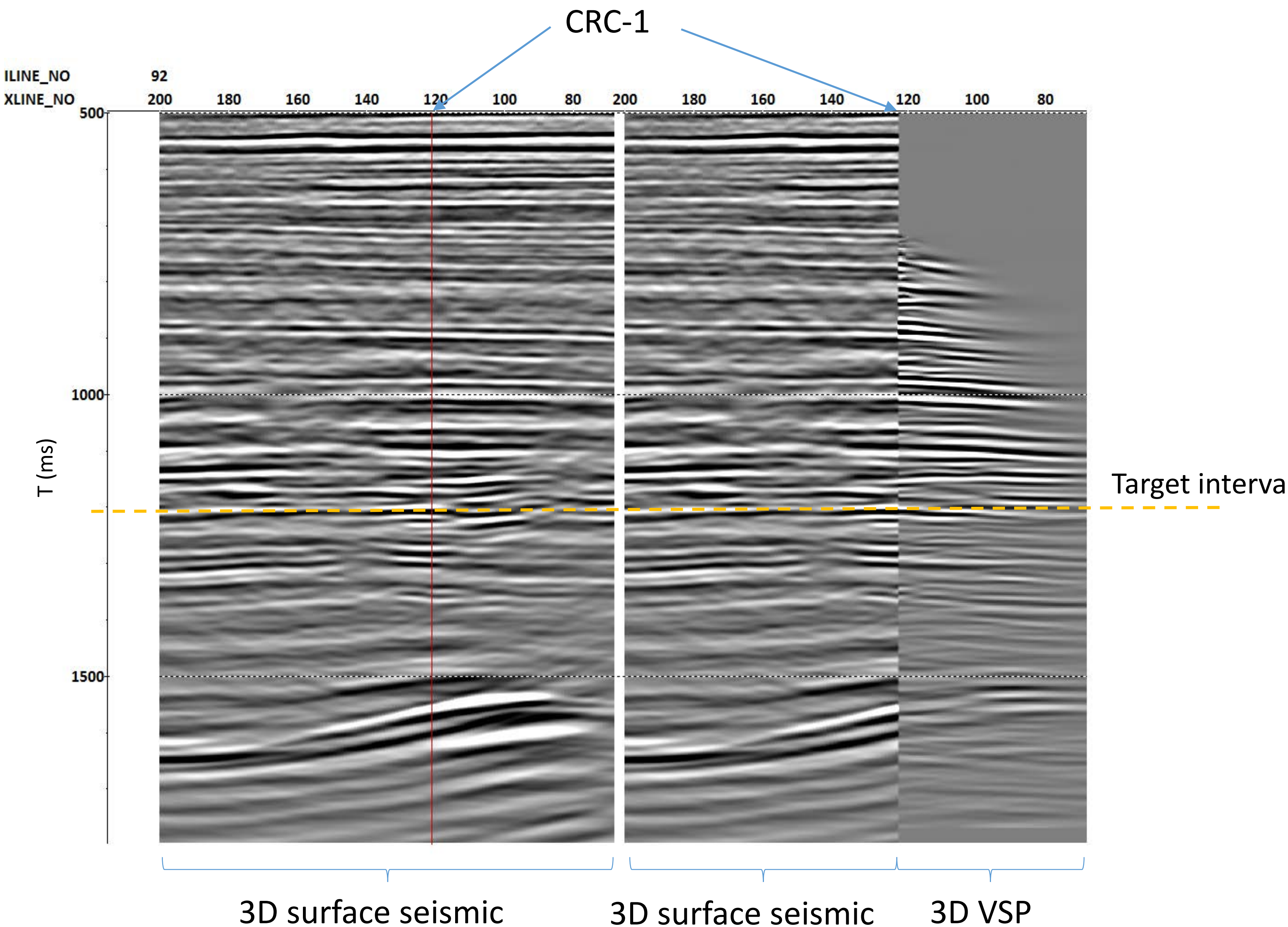
RMS amplitudes of the differences computed in 24 ms window centred at the plume level (1210 ms). The differences are computed between B and (top-left to bottom-right): M1, M2, M3, M4



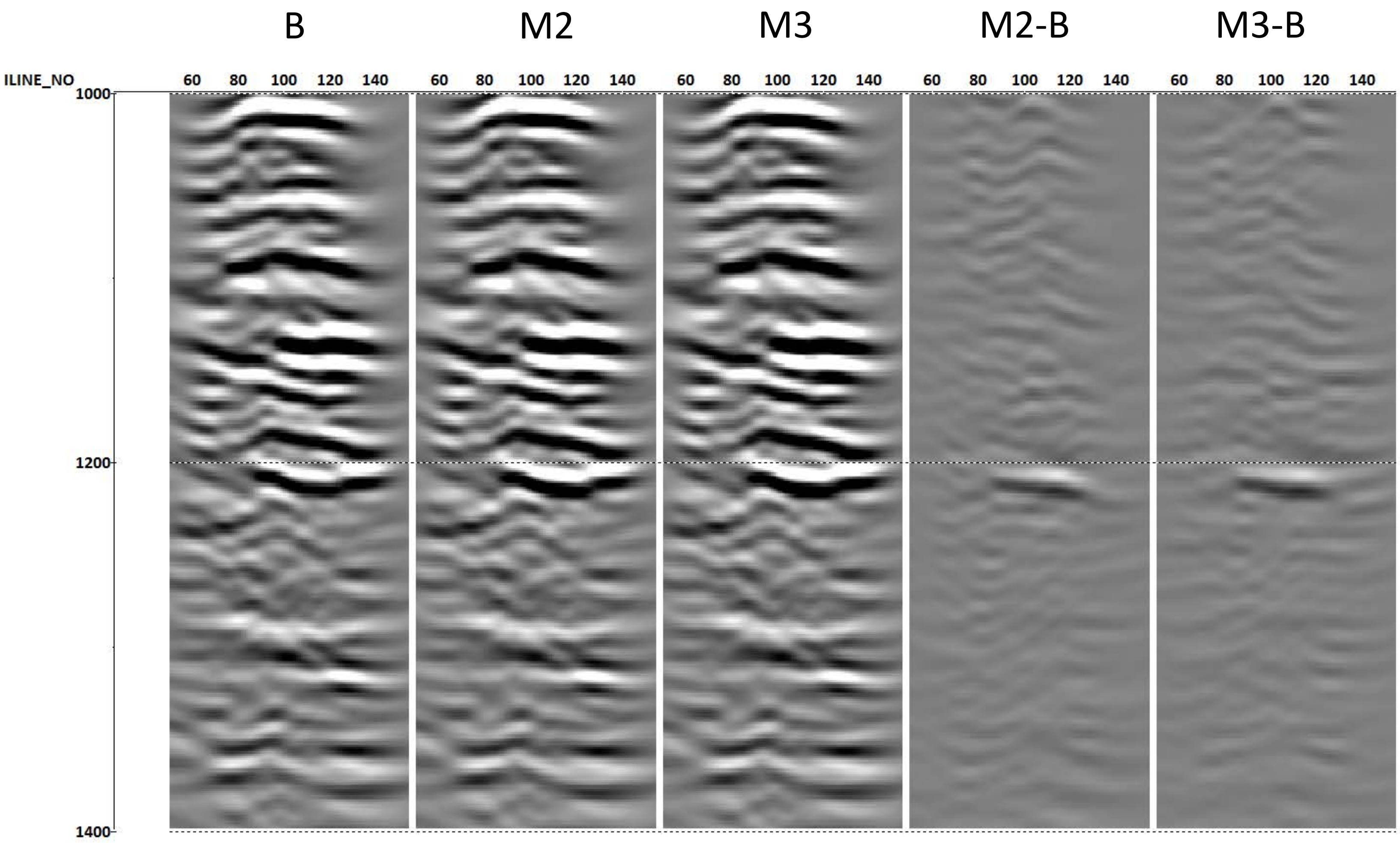
VSP in CRC-1

- Sercel SlimWave 3C VSP tool (10 levels, 15 m spacing)
- 3D VSP with tool @ 760-880 m MD
- 4 offset VSPs

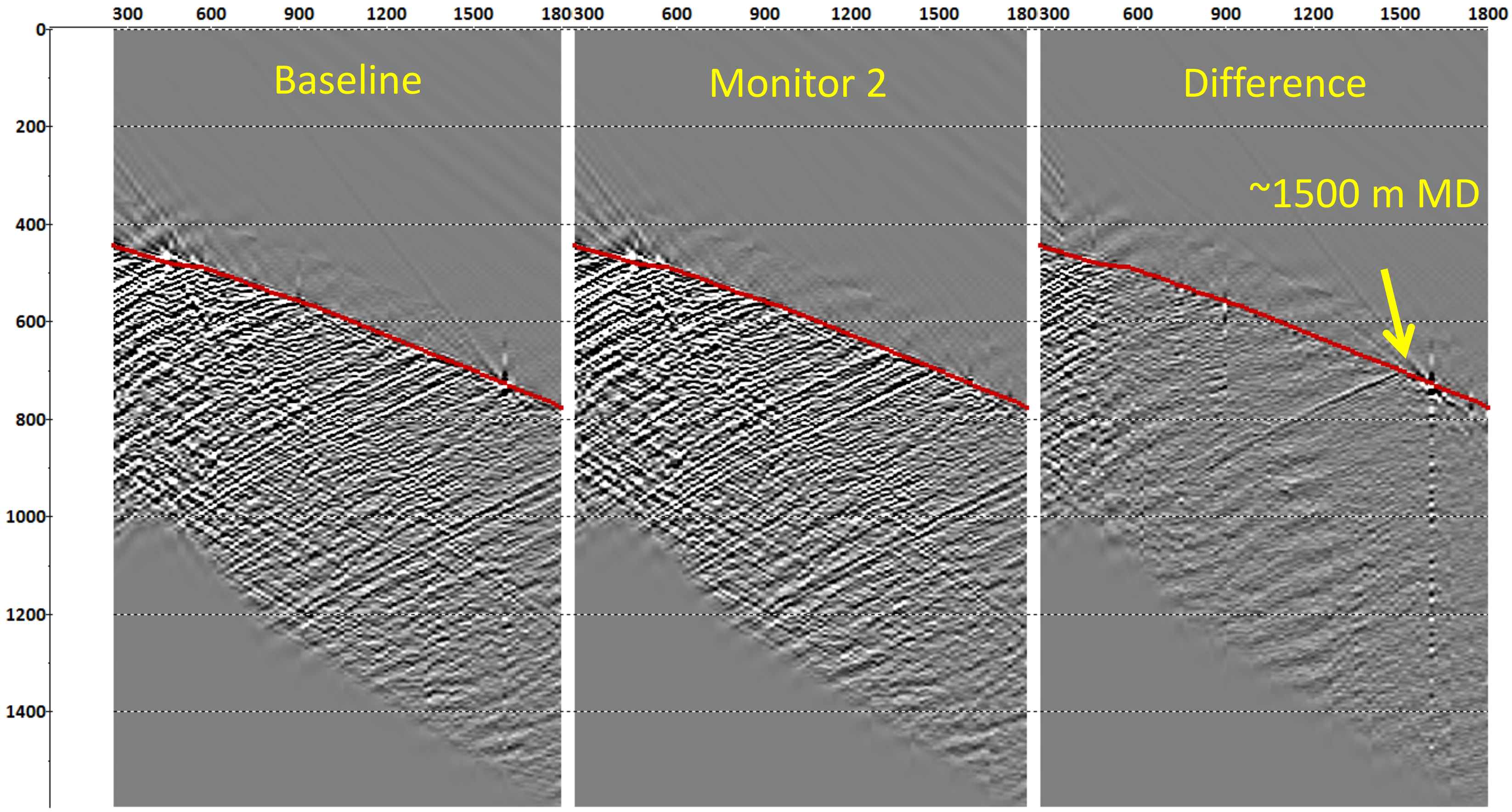
Comparison of baseline 4D VSP and surface seismic data



Stage 2C 4D VSP results, xline 122

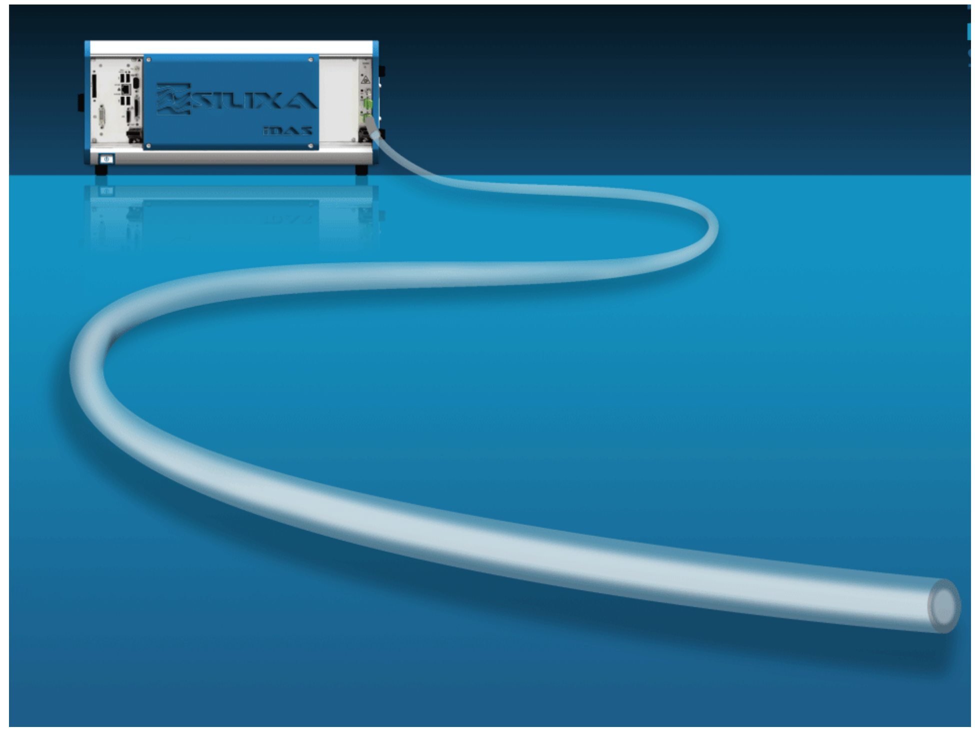


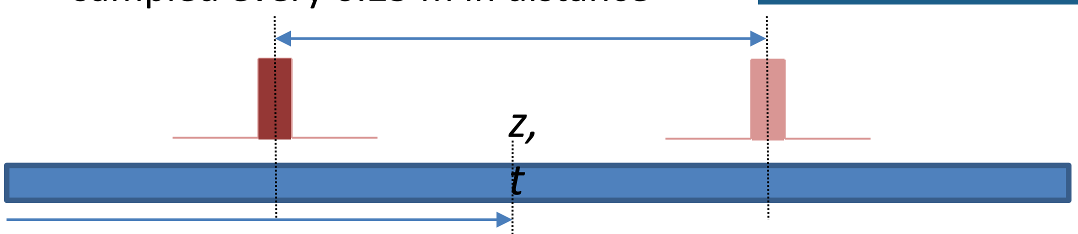
Offset VSP, SP1, M2-B



Distributed Acoustic Sensing

- 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

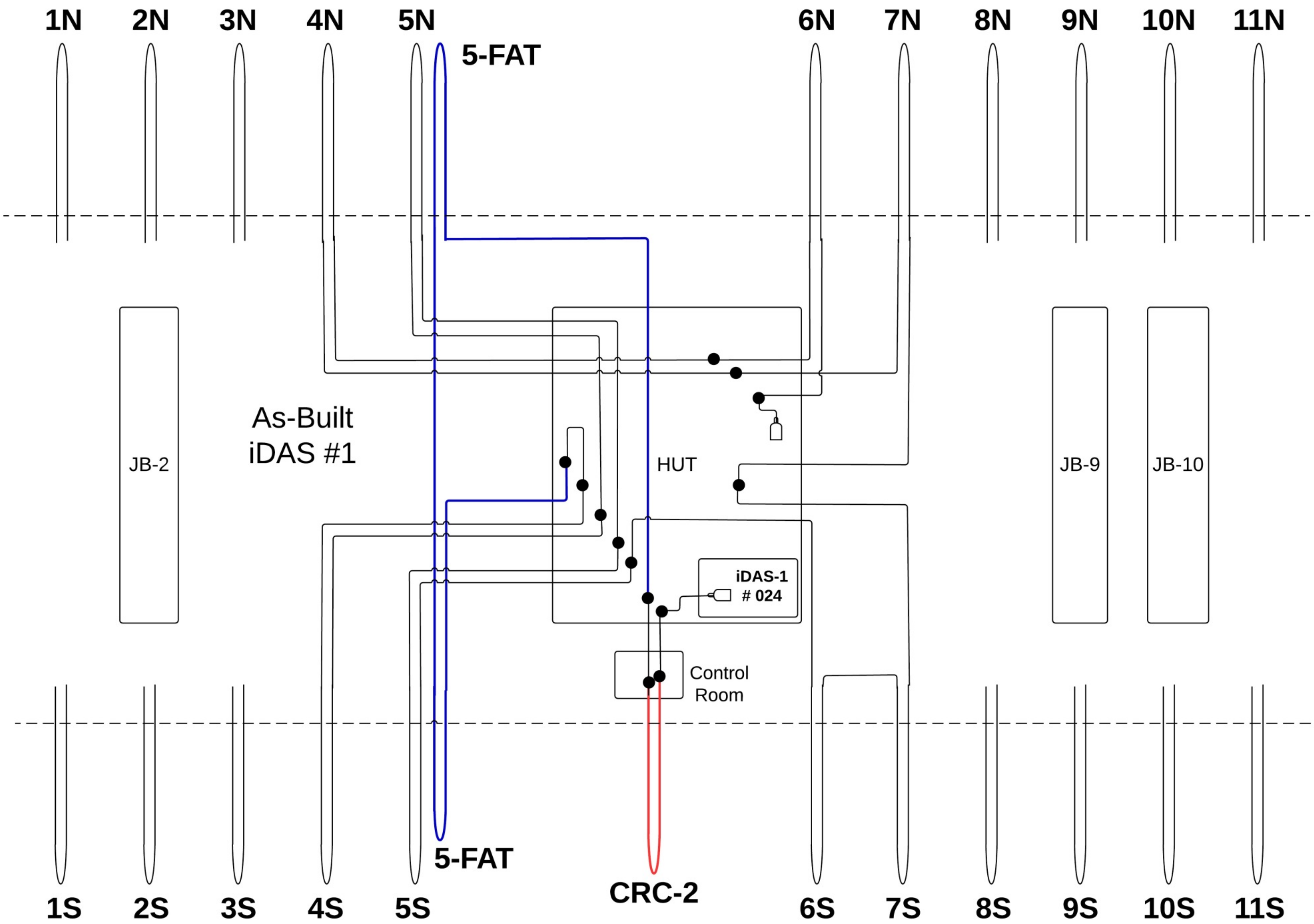




$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

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

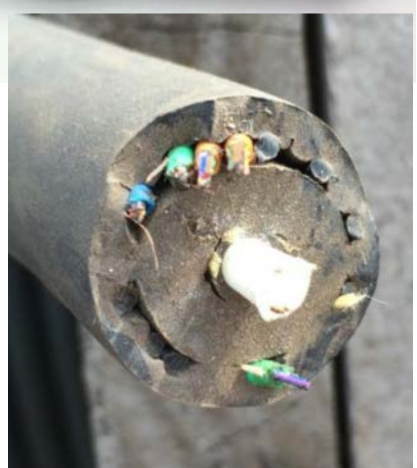
Fiber-optic Cable Layout – iDAS #1



FAT Helical Wound Cable

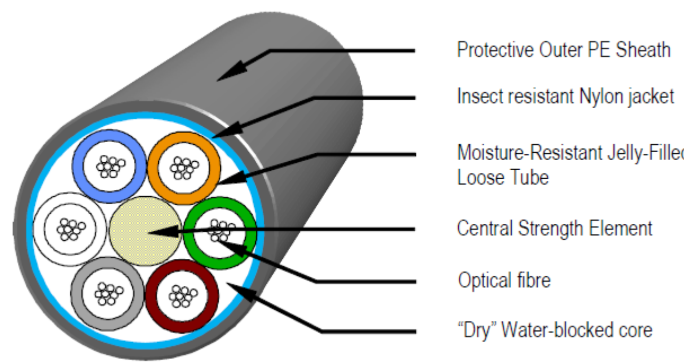
- Anderson and Shapiro – HWC on soft mandrel 1980 US Patent 4375313
- Hornman et al. (2013 75th EAGE) introduced a helical wound FO cable
- LBNL trialed multiple designs with varying physical properties
- Line 5 installed one length of HWC for comparison to straight fiber

30° spiral wound on 58 Shore A rubber mandrel.

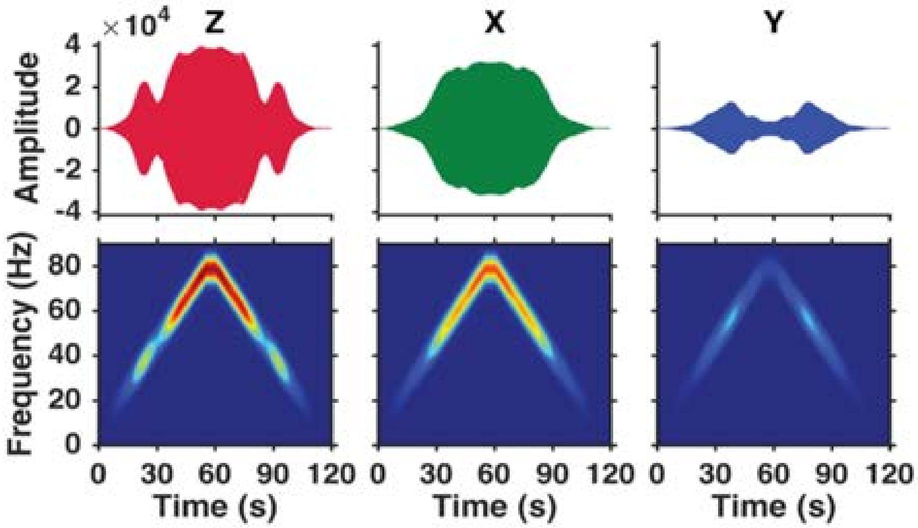


Lessons learned – acoustic impedance of cable and surrounding soil is important

Normal Telecom Cable used in all trenches



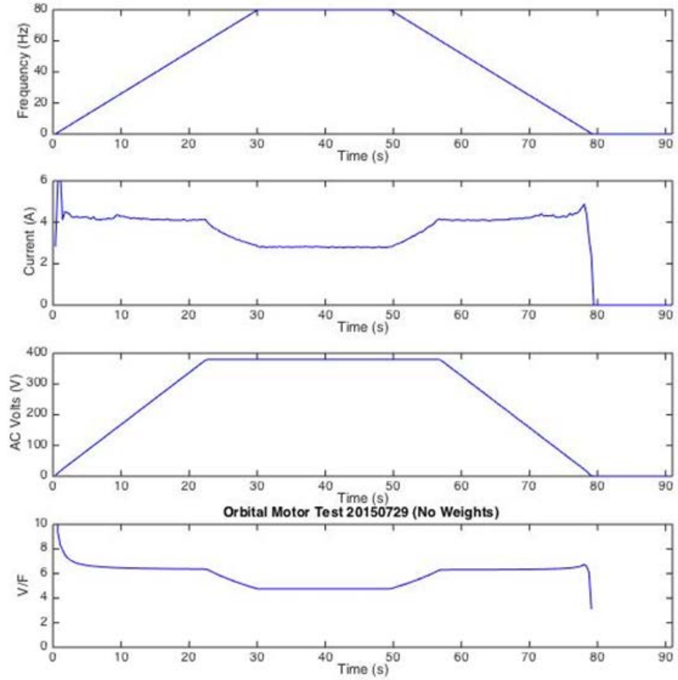
Surface Orbital Vibrator – VFD Controlled AC Induction Motor



Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d

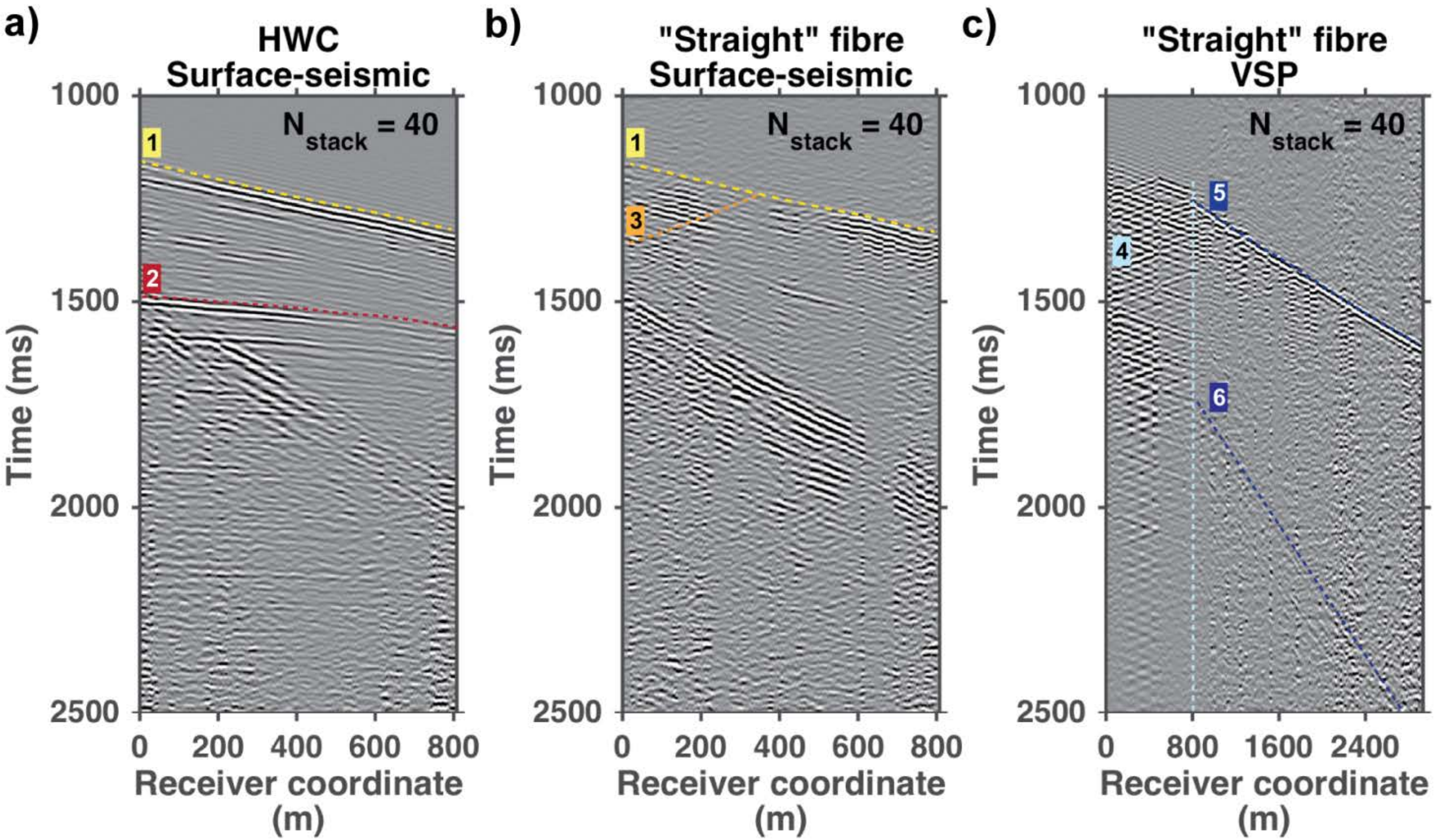
Force is adjustable

$F=m\omega^2 r$



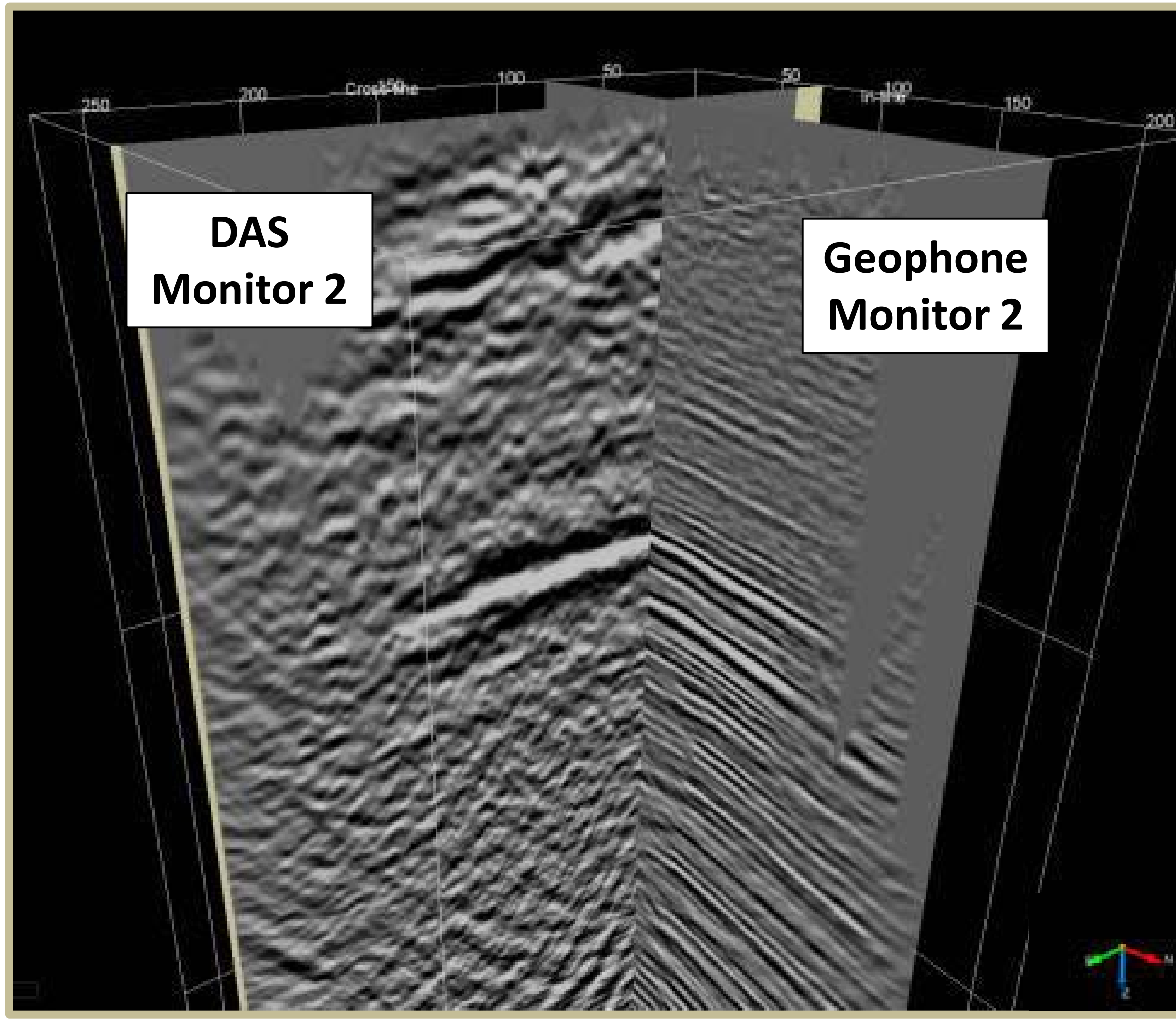
Deconvolved SOV Data

- Helical Cable shows good sensitivity to reflected P.
- Straight telecom less sensitivity

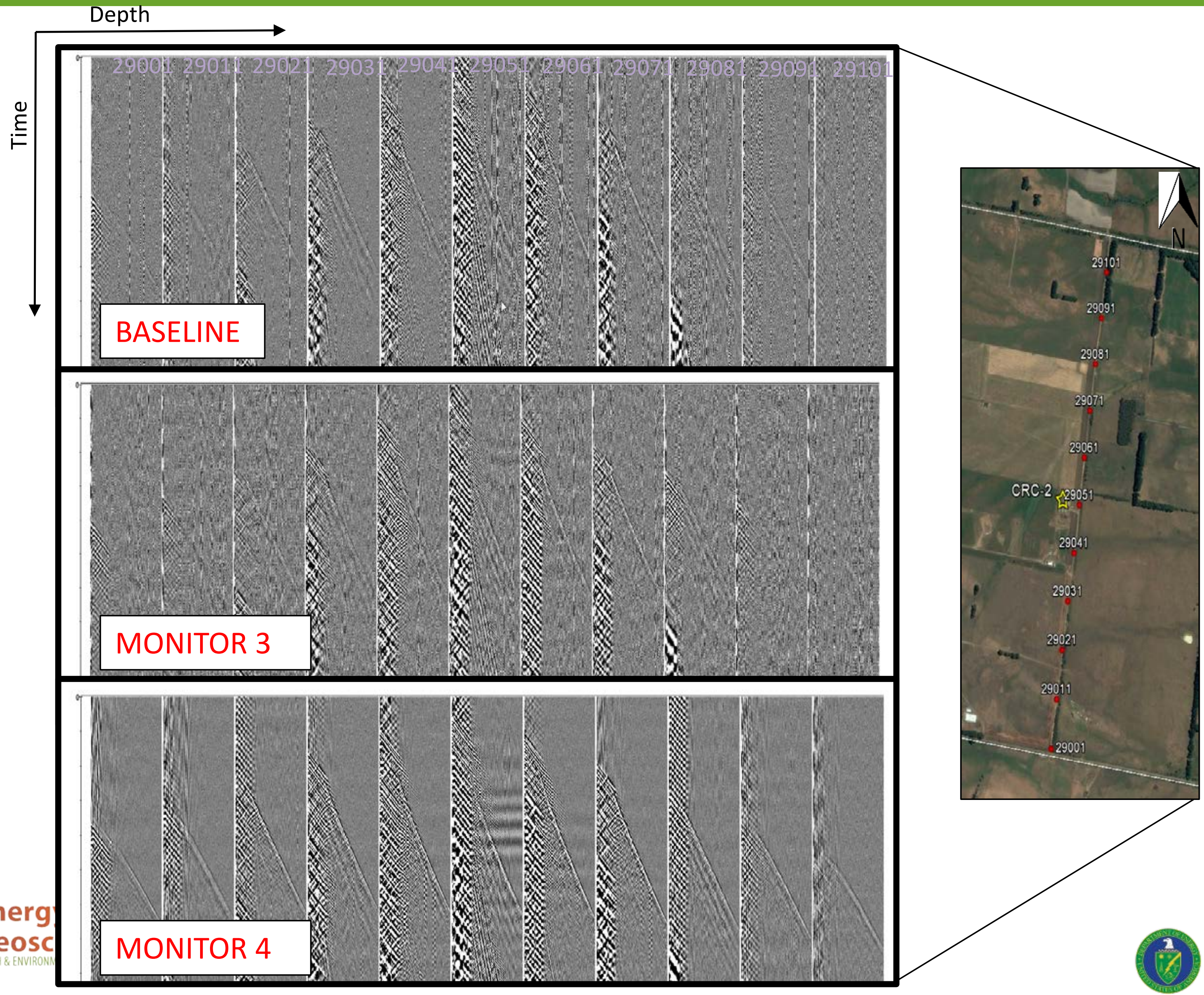


DAS 3D cube

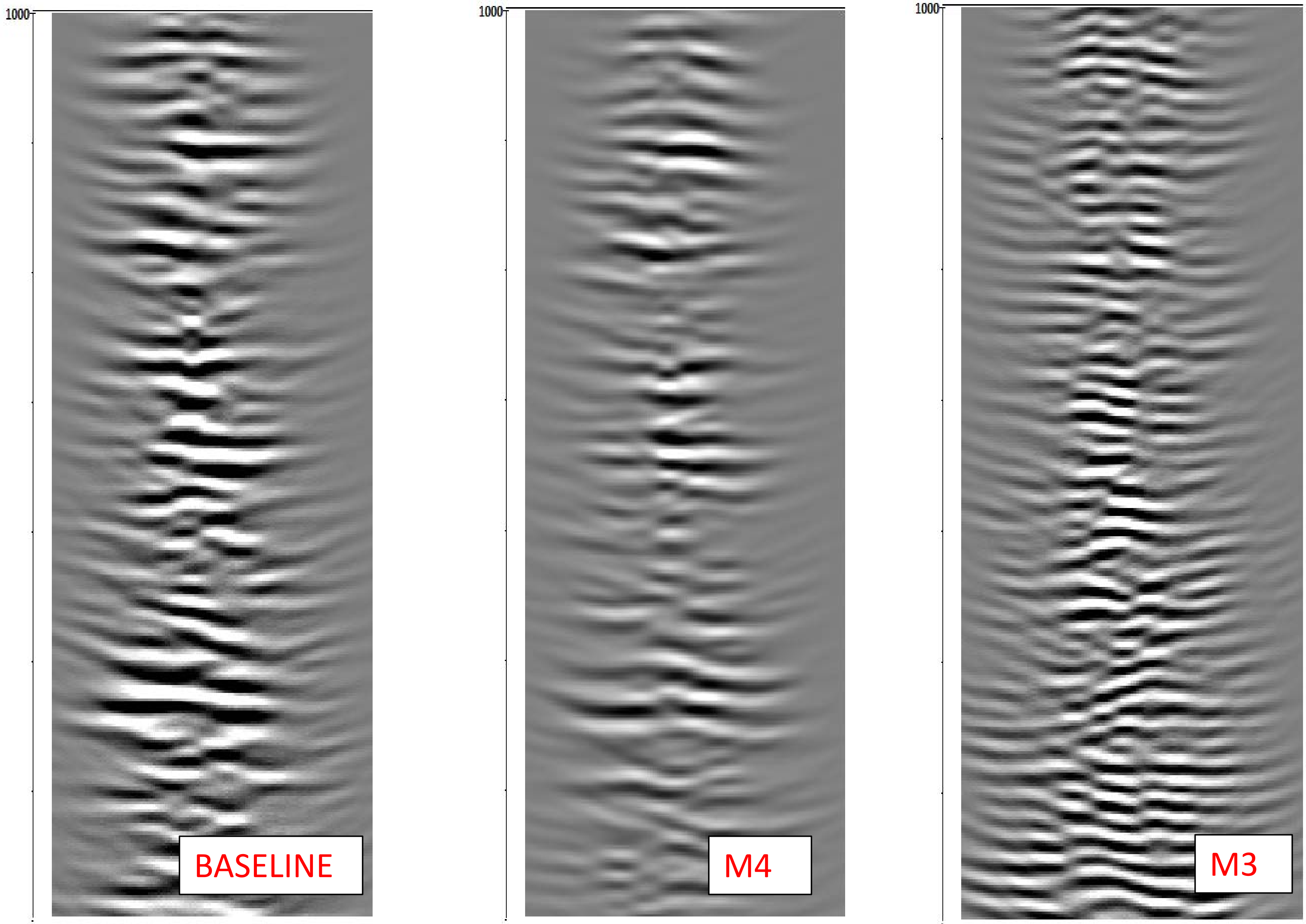
- DAS after Post Stack Time Migration
- Strong reflection at 500 ms (related to a carbonate layer)
- Far offsets were included in the stack (due to directionality)



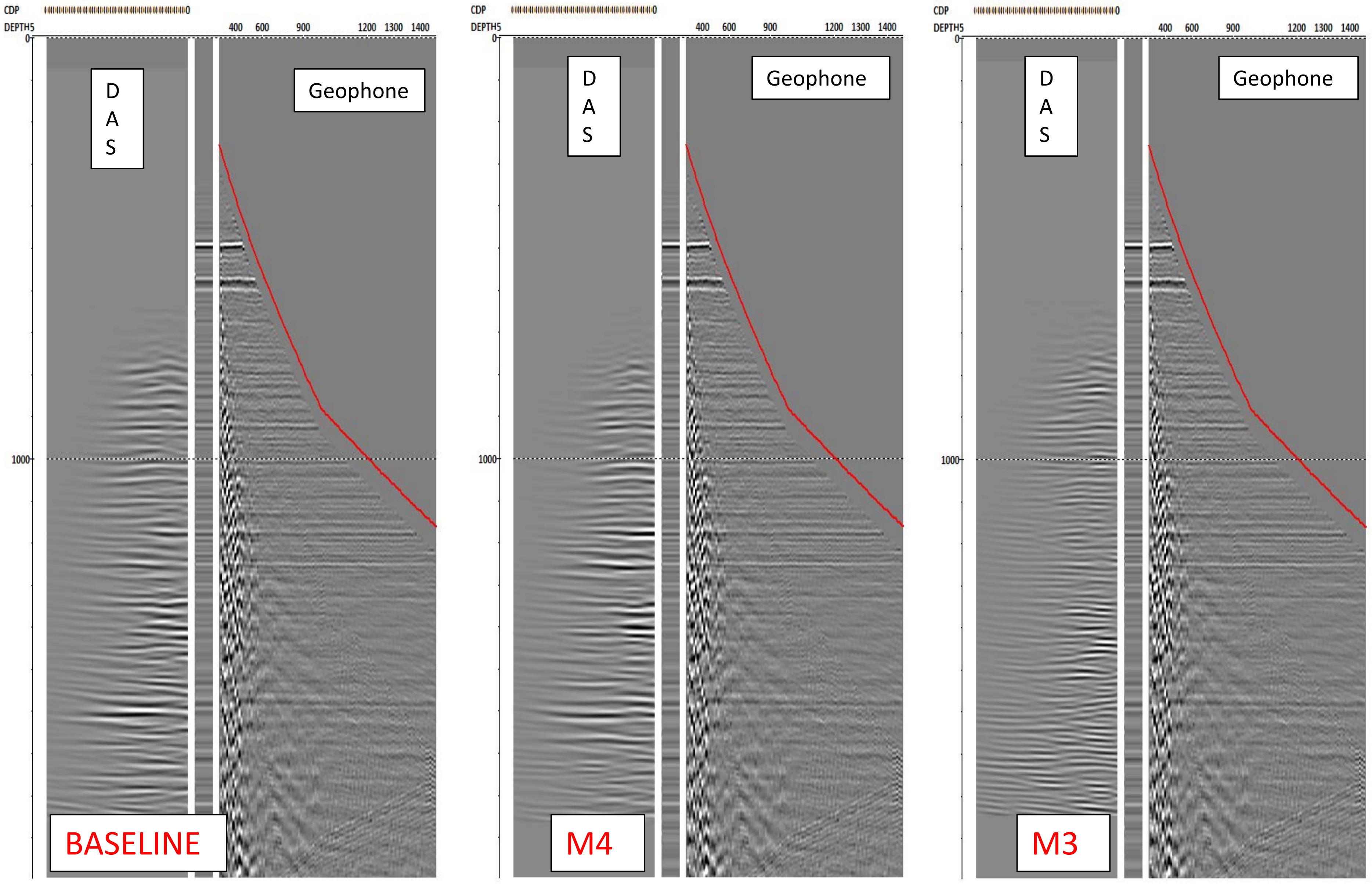
DAS VSP – visual comparison between surveys



Migrated walk-away VSP DAS (result in time)

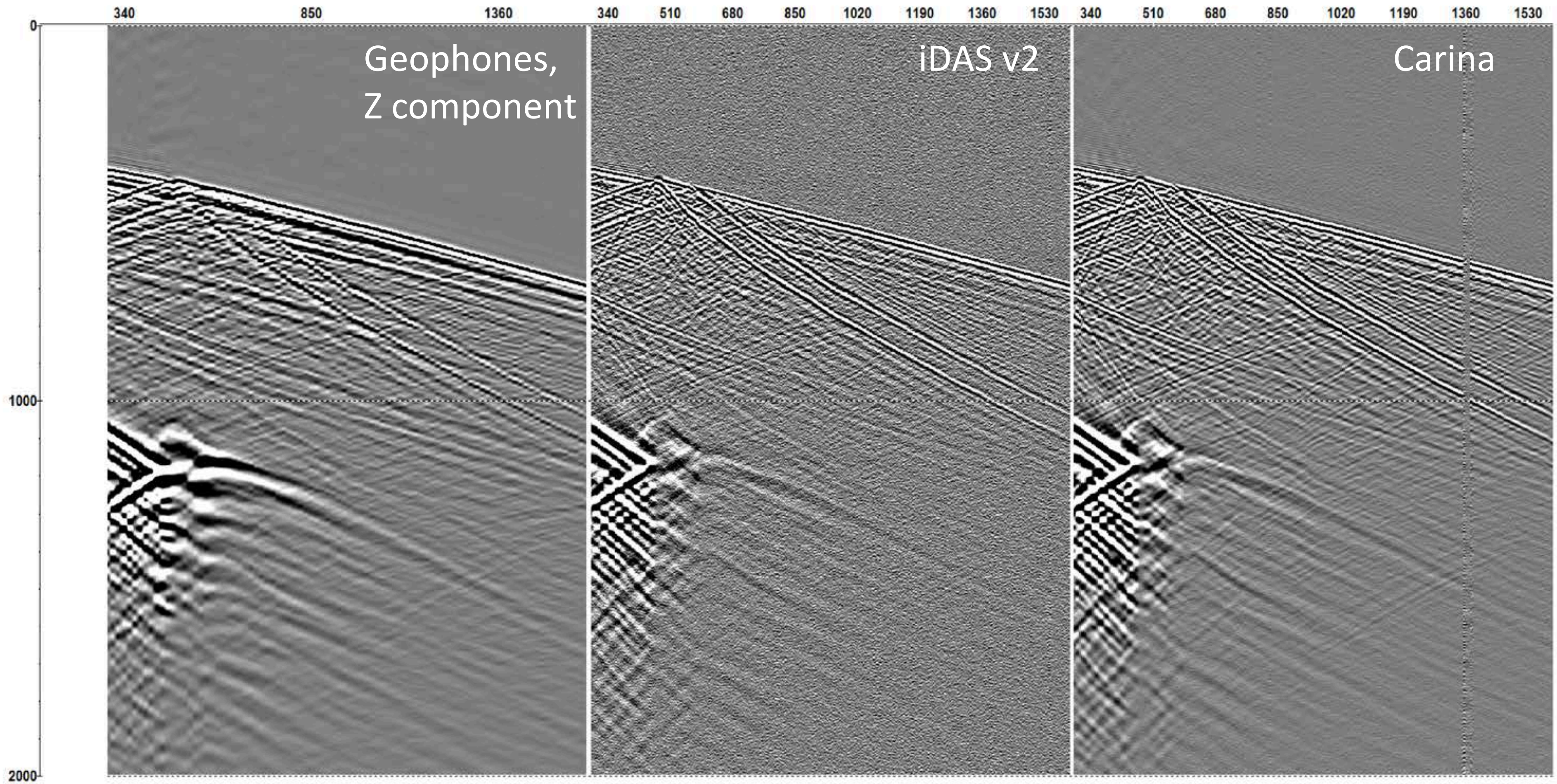


DAS migrated walk-away VSP x Geophone corridor stack x Geophone zero-offset NMO



Next steps for DAS – Improving sensitivity through new cable designs and HDD installation

Stage 3: Comparison Carina DAS cable vs standard telcom in CRC-3, SP0, 700 m offset, 5 sweeps



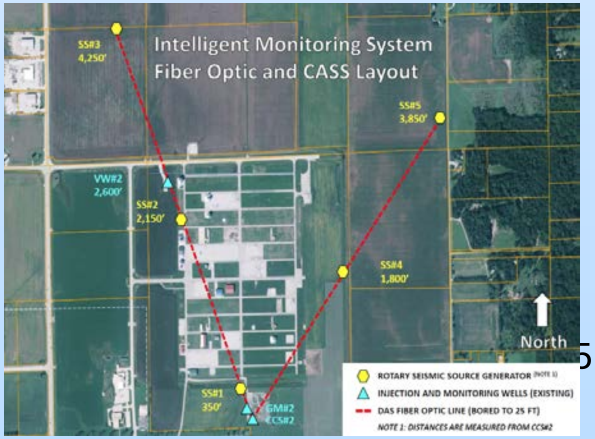
Synergy Opportunities

- 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 12:05 PM: T. Daley
Aquistore Project 1:25 PM T. Daley

Development of Intelligent Monitoring System (IMS) Modules for the Aquistore CO_2 Storage Project - University of North Dakota – Jose Torrez
Thursday 12:10 PM

Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation - Archer Daniels Midland Corporation – Barry Freifeld & Scott McDonald Wednesday 1:30 PM



Otway project Stage 2c – Accomplishments and Conclusions

- 15,000 t were injected into the subsurface and an extensive seismic monitoring program was carried out
- The data is likely to be sufficient to claim detection & observation of the plume evolution
- Buried receiver array
  - Better S/N, higher repeatability
  - Lower impact on landowners
  - Passive recording capability + ability to pair it with permanent sources
- VSP data agrees with the surface seismic data
- DAS (in trenches) can be used to image subhorizontal reflectors
- Permanent vibes – operational and provide strong signal

Lessons Learned – fiber-optic array has operated trouble free since installation. Buried geophones have had numerous electrical and reliability issues. Additional work needed to increase sensitivity of DAS.

LBNL continues work on DAS cable designs and installation methods

Appendix

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

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

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 2 – 3 up to 4 – 5 through leveraged field testing opportunities, with field sites being used as in-situ laboratories.

Organization Chart

- CO2CRC Project Management: Tania Constable CEO, Dr. Matthias Raab, COO
- Roman Pevzner, Curtin University, Geophysics Lead
- LBNL
  - PI: Barry Freifeld and coPI Tom Daley
  - Field Support, Installation and Instrumentation: Michelle Robertson and Todd Wood
  - Data analysis: Shan Dou

Gantt Chart

MILESTONE GANTT CHART

Milestone Reporting accompanies Quarterly report	Q1 FY17			Q2 FY17			Q3 FY17			Q4 FY17		
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 5 US-Japan CCS Collaboration on Fiber-Optic Technology			G									H
Task 6 Mont Terri Project						I						J

* A & D are AOP Tracked milestone

TASK 2. Otway Project Collaboration
Milestone 4-1 (A)
Time-lapse rotary orbital source data interpretation report
Milestone 4-2 (B)
Otway Stage 3 DAS Monitoring areal network design

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

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Bibliography

- Roman Pevzner, Milovan Urosevic, Dmitry Popik, Valeriya Shulakova, Konstantin Tertyshnikov, Eva Caspari, Julia Correa, Tess Dance, Anton Kepic, Stanislav Glubokovskikh, Sasha Ziramov, Boris Gurevich, Rajindar Singh, Matthias Raab, Max Watson, Tom Daley, Michelle Robertson, Barry Freifeld, 2017, 4D surface seismic tracks small supercritical CO 2 injection into the subsurface: CO2CRC Otway Project,, International Journal of Greenhouse Gas Control 63, 150-157

- JC Correa, 2017, BM Freifeld, M Robertson, R Pevzner, A Bona, D Popik, S Yavuz, KV Tertyshnikov, S Ziramov, V Shulakova, TM Daley, Distributed Acoustic Sensing Applied to 4D Seismic-Preliminary Results from the CO2CRC Otway Site Field Trials, 79th EAGE Conference and Exhibition 2017

- Shan Dou, Jonathan Ajo-Franklin, Thomas Daley, Michelle Robertson, Todd Wood, Barry Freifeld, Roman Pevzner, Julia Correa, Konstantin Tertyshnikov, Milovan Urosevic, Boris Gurevich, Surface orbital vibrator (SOV) and fiber-optic DAS: Field demonstration of economical, continuous-land seismic time-lapse monitoring from the Australian CO2CRC Otway site, SEG Technical Program Expanded Abstracts 2016

- S Yavuz, BM Freifeld, R Pevzner, K Tertyshnikov, A Dzunic, S Ziramov, V Shulakova, M Robertson, TM Daley, A Kepic, M Urosevic, B Gurevich, Subsurface Imaging Using Buried DAS and Geophone Arrays-Preliminary Results from CO2CRC Otway Project, 78th EAGE Conference and Exhibition 2016

- BM Freifeld, R Pevzner, S Dou, J Correa, TM Daley, M Robertson, K Tertyshnikov, T Wood, J Ajo-Franklin, M Urosevic, B Gurevich, The CO2CRC Otway Project deployment of a Distributed Acoustic Sensing Network Coupled with Permanent Rotary Sources, 78th EAGE Conference and Exhibition 2016