CCSMR Task 2: 2nd Generation SOV-DAS

Project ESD14095

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U.S. Department of Energy

National Energy Technology Laboratory

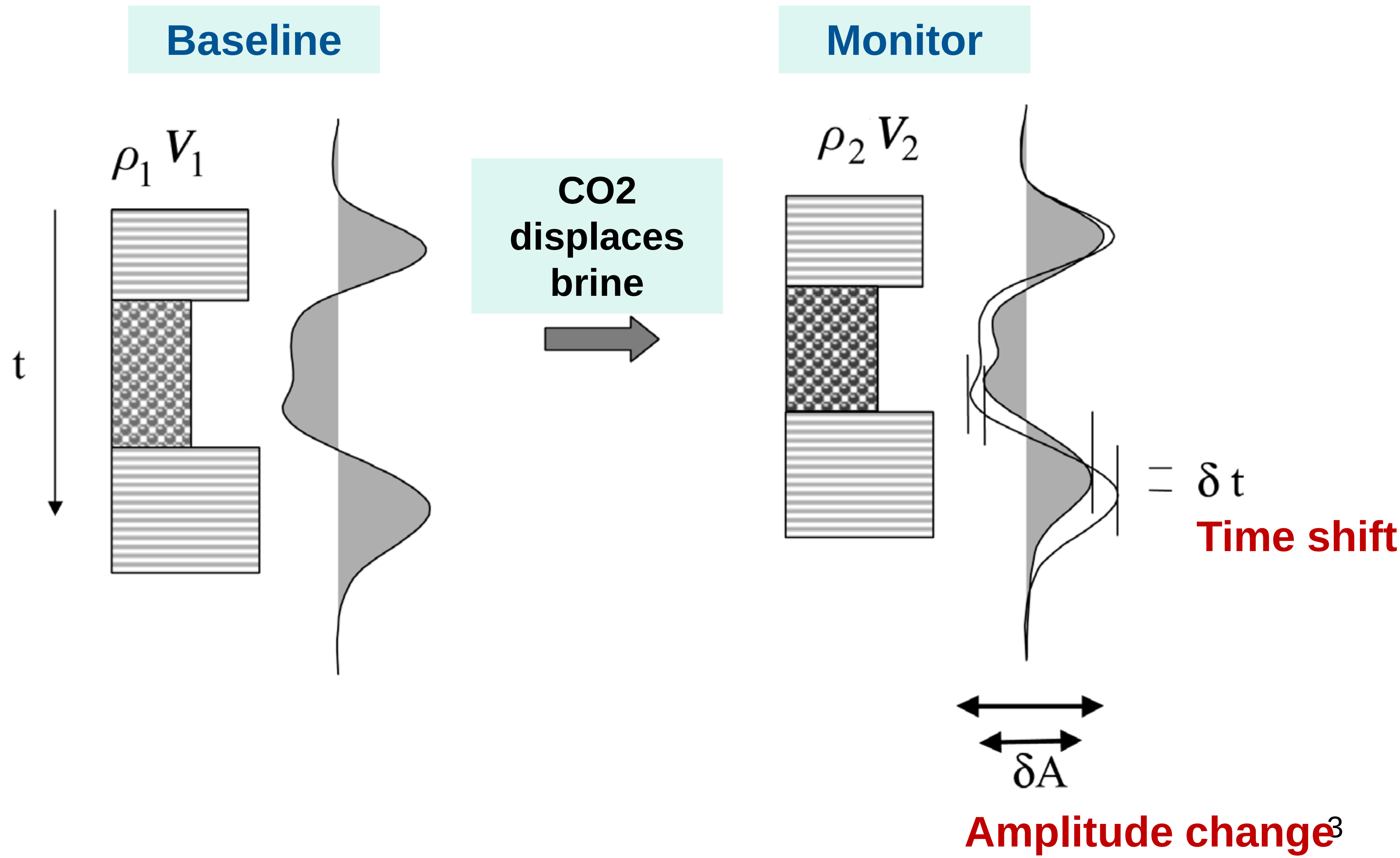
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

Presentation Outline

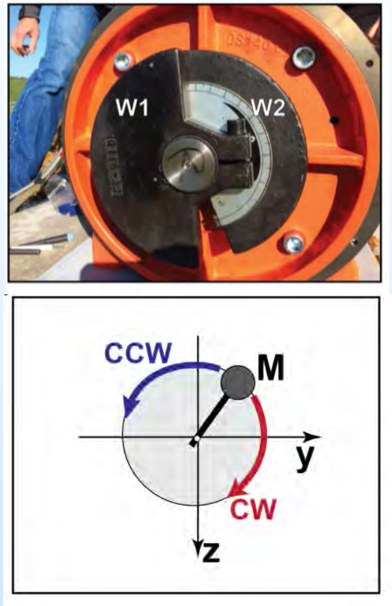
- Motivation for SOV-DAS Technology
- 1st Generation SOV-DAS
  - Otway Project Deployment
  - ADM Lessons learned
- 2^{nd} Generation SOV-DAS (THIS PROJECT)
  - Redesign of SOV (swept S_H source)
  - Improvements to DAS Sensing
  - Planned Otway Stage 3 Deployment

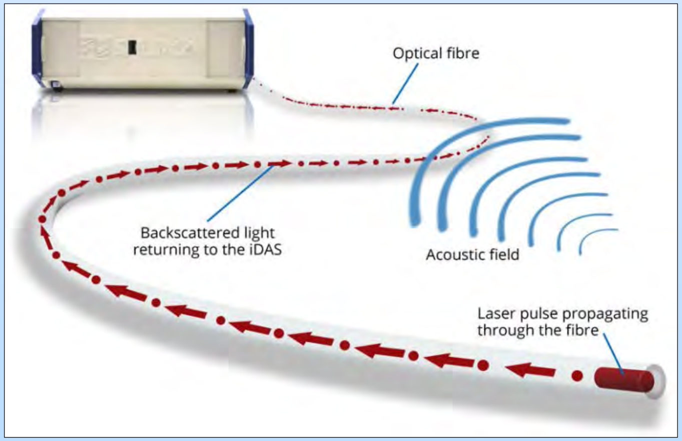
Why Seismic for Imaging CO_2



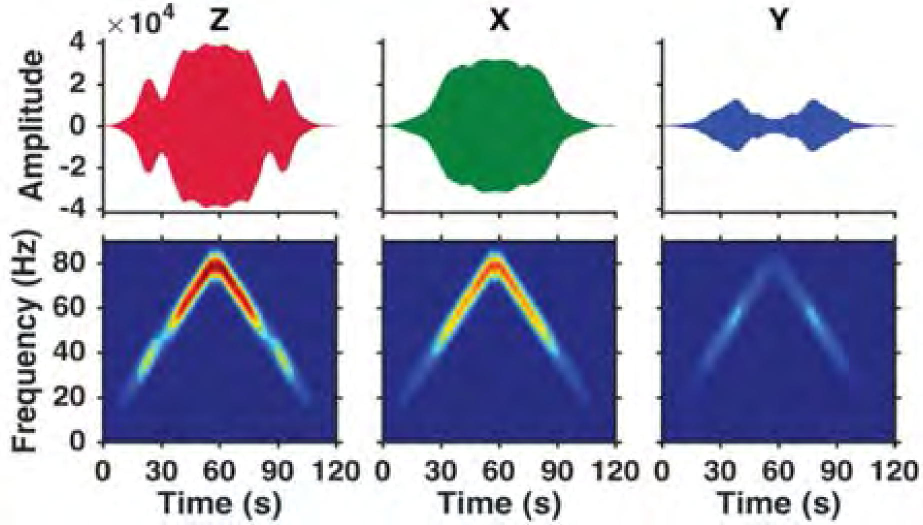
Conventional
campaign-based systems
small T, large N

SOV-DAS permanent monitoring system
large T, moderate N





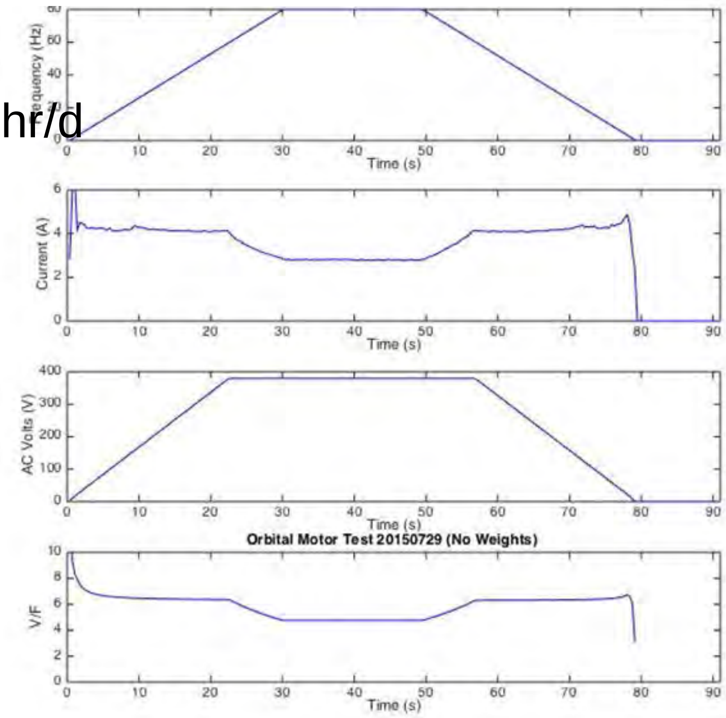
Surface Orbital Vibrator – VFD Controlled AC Induction Motor



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

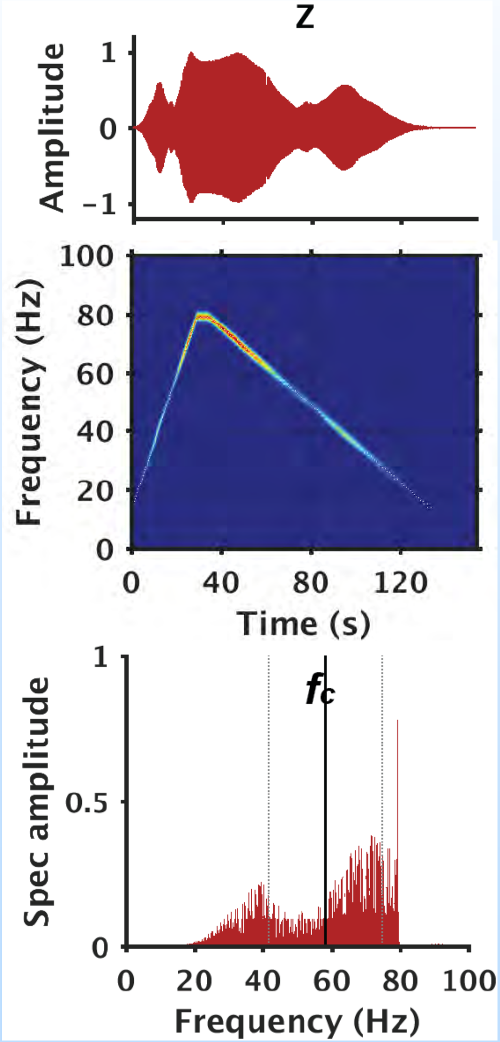
Force is adjustable

$F=m\omega^2 r$



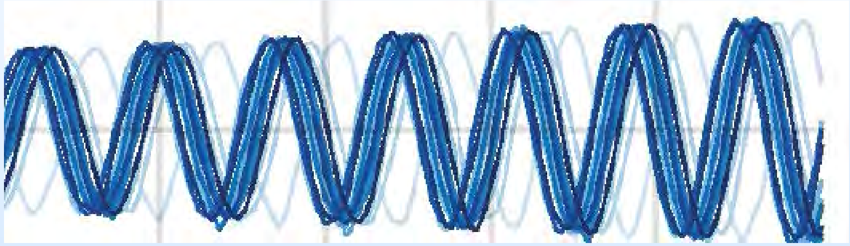
SOV for permanent reservoir monitoring

Sweep-based:
controlled release of seismic energy

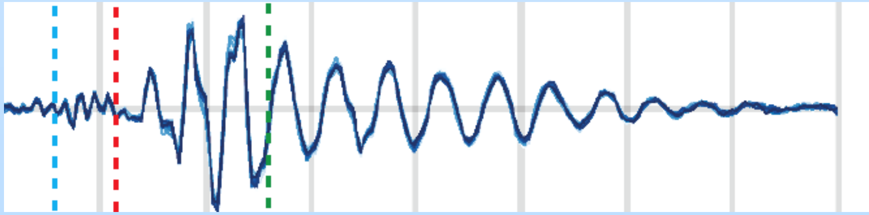


Not phase-controlled:
simpler system

DAS records before deconvolving source sweeps (t_{shift} up to 20 ms)

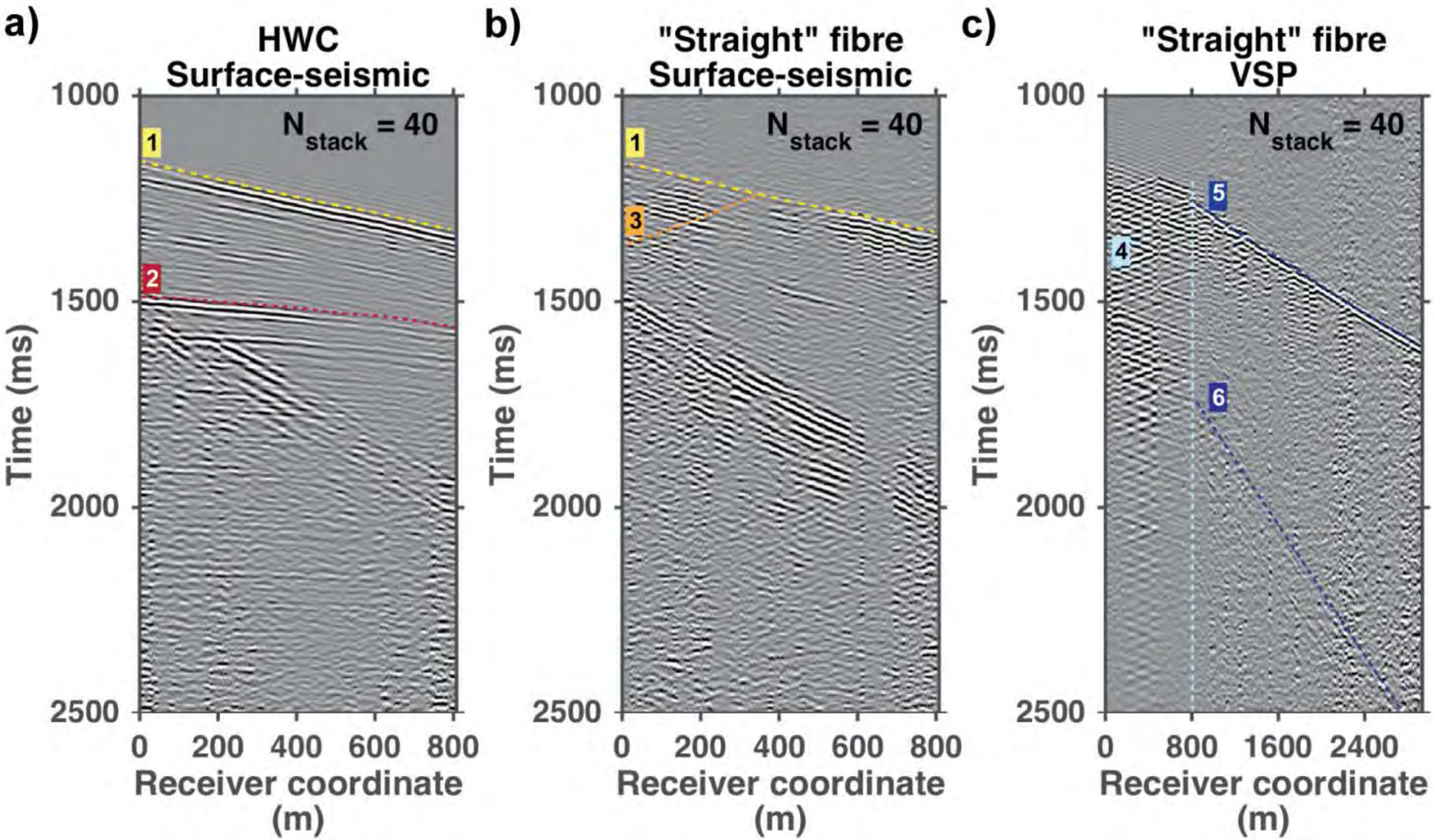


Same records after deconvolving source sweeps (t_{shift} < 1 ms)



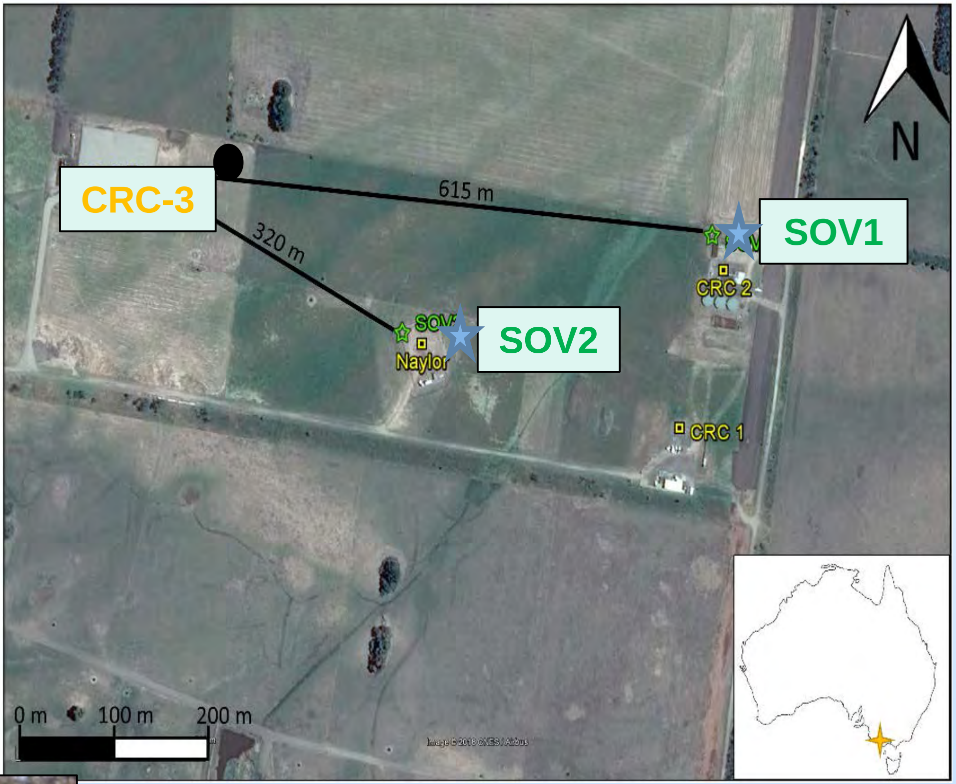
Deconvolved SOV Data

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



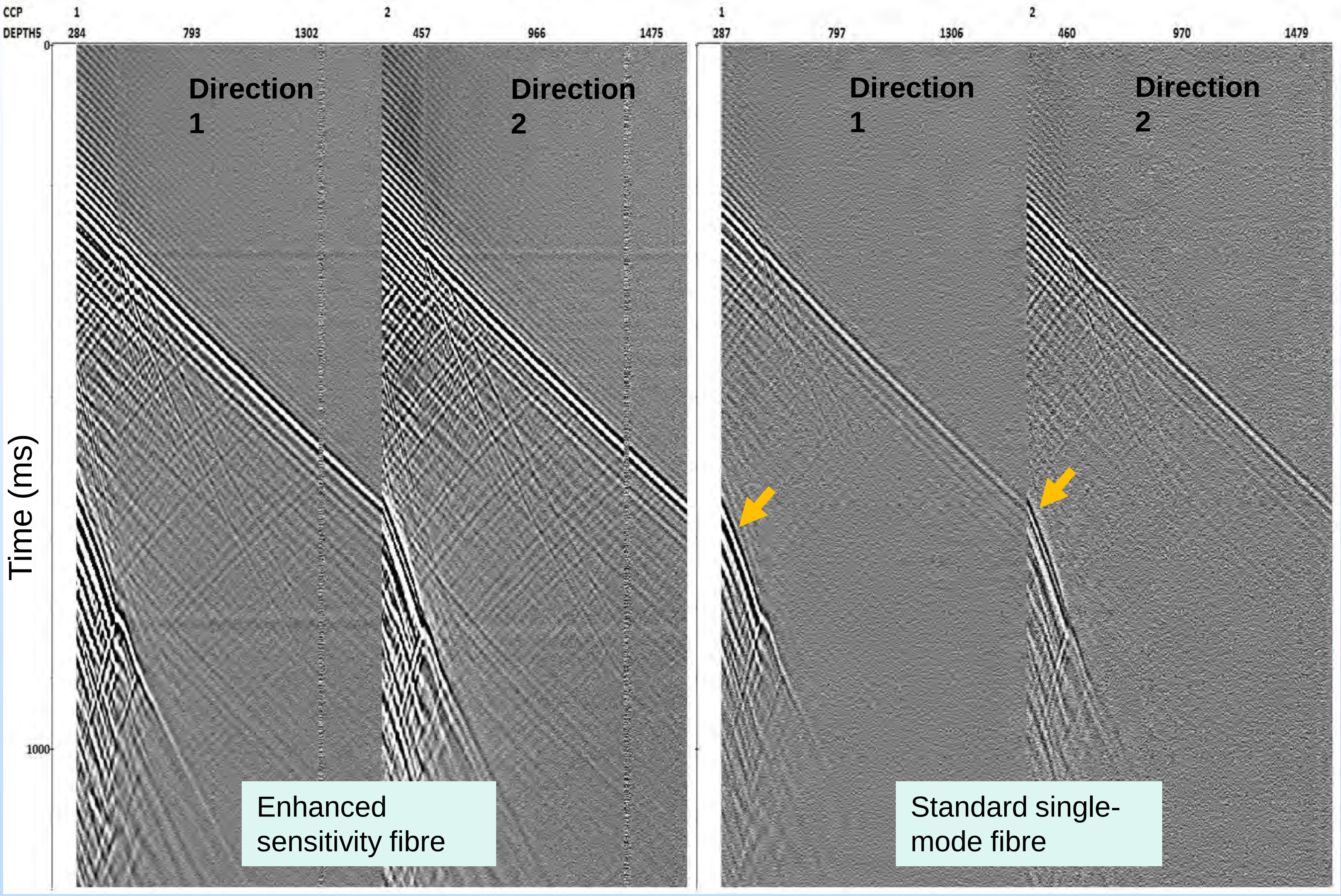
Test SOV-DAS with Silixa Carina System (May 2017)

- Sweep design:
  - Up to 80 Hz
  - ~10 t force at 80 Hz
  - 155 s sweep (30 s upsweep, 5 s hold, 120 s downsweep)
- 14 sweeps stacked each direction



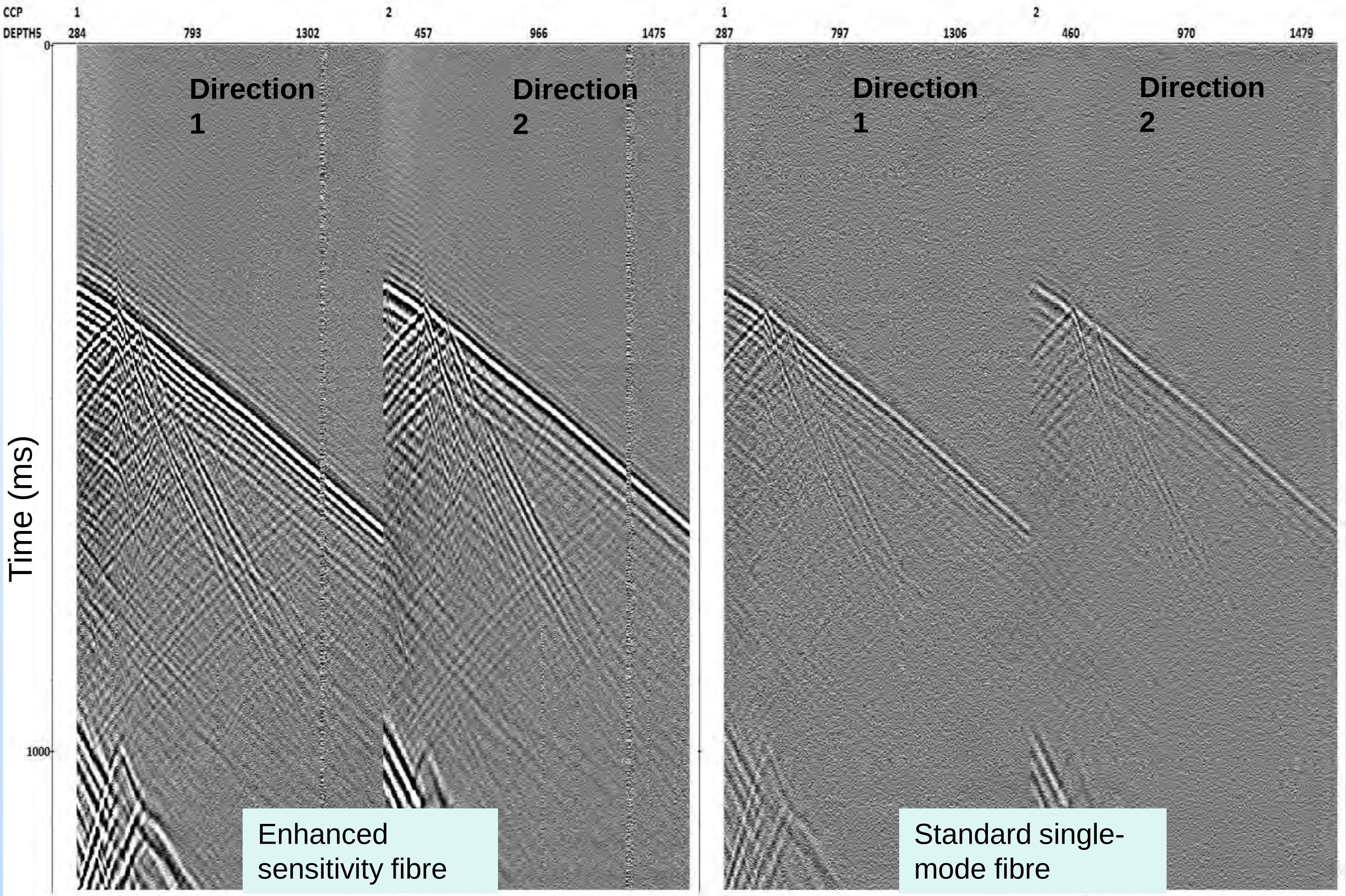
Conventional SMF vs Constellation (May 2017)

SOV 2 (165 s to 80 Hz sweeps), stack 14 sweeps



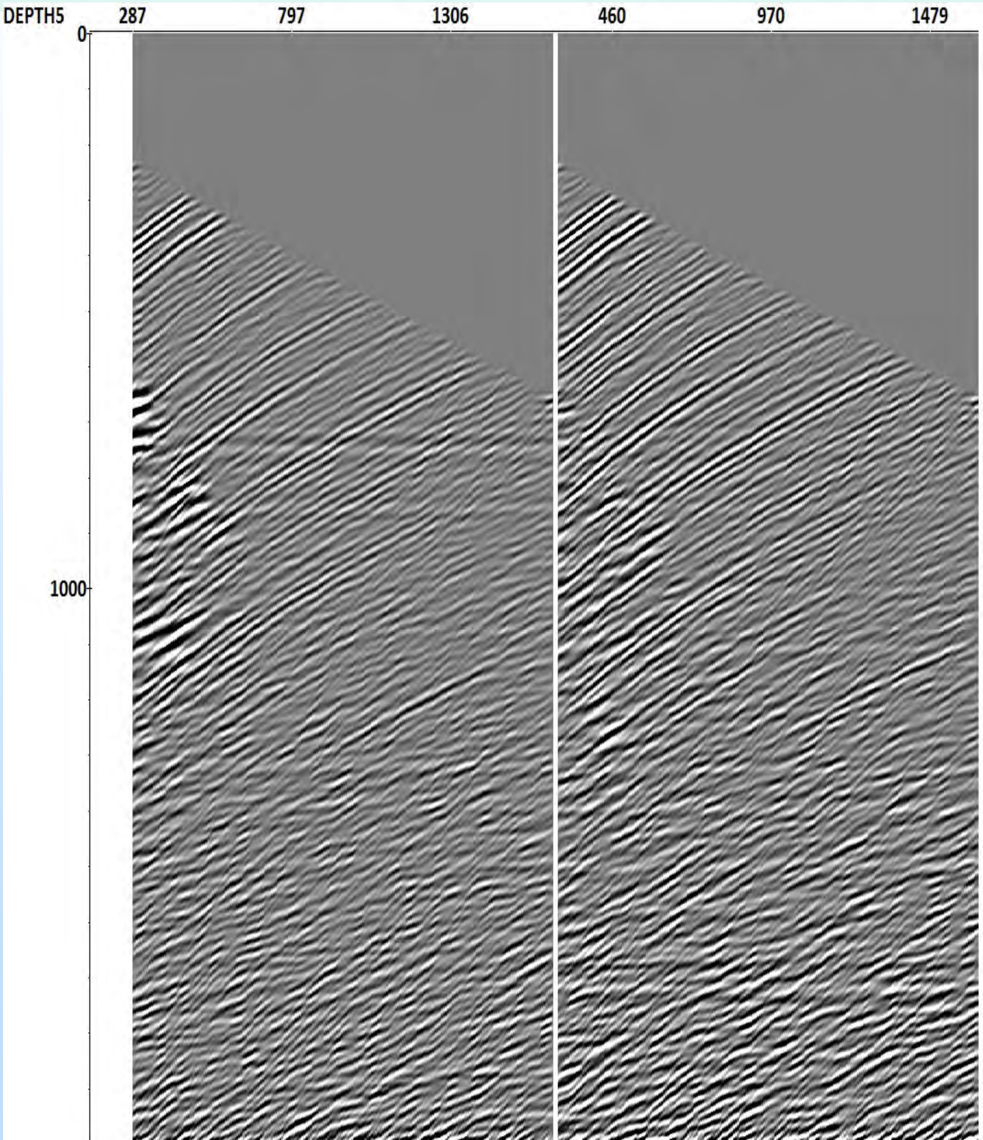
Conventional SMF vs Constellation (May 2017)

SOV 1 (165 s to 80 Hz sweeps), stack 14 sweeps



VSP processing flow

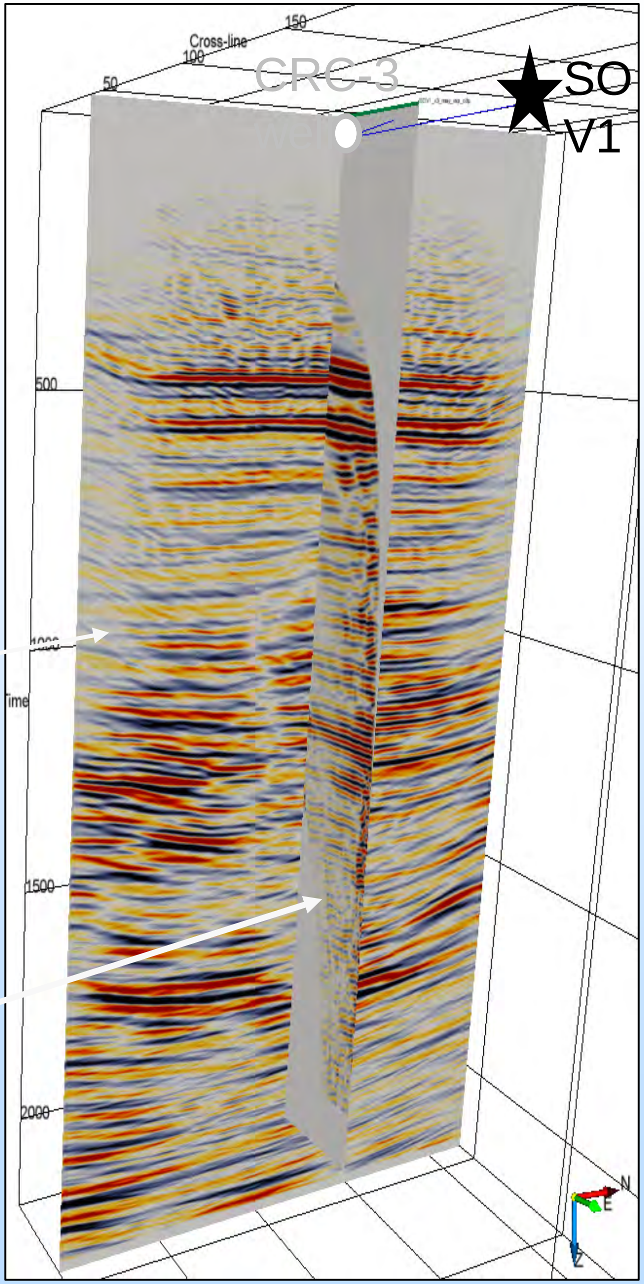
Upgoing waves SOV2 (clockwise + counter-clockwise directions)



Deconvolution with sweeps
Band pass filter
Statics to adjust sweeps
Stack of multiple sweeps
Geometry assignment
Band pass filter
Wavefield separation (FK filter)
S- and PS-waves attenuation
Amplitude correction
VSP to CDP transform
Kirchhoff VSP migration

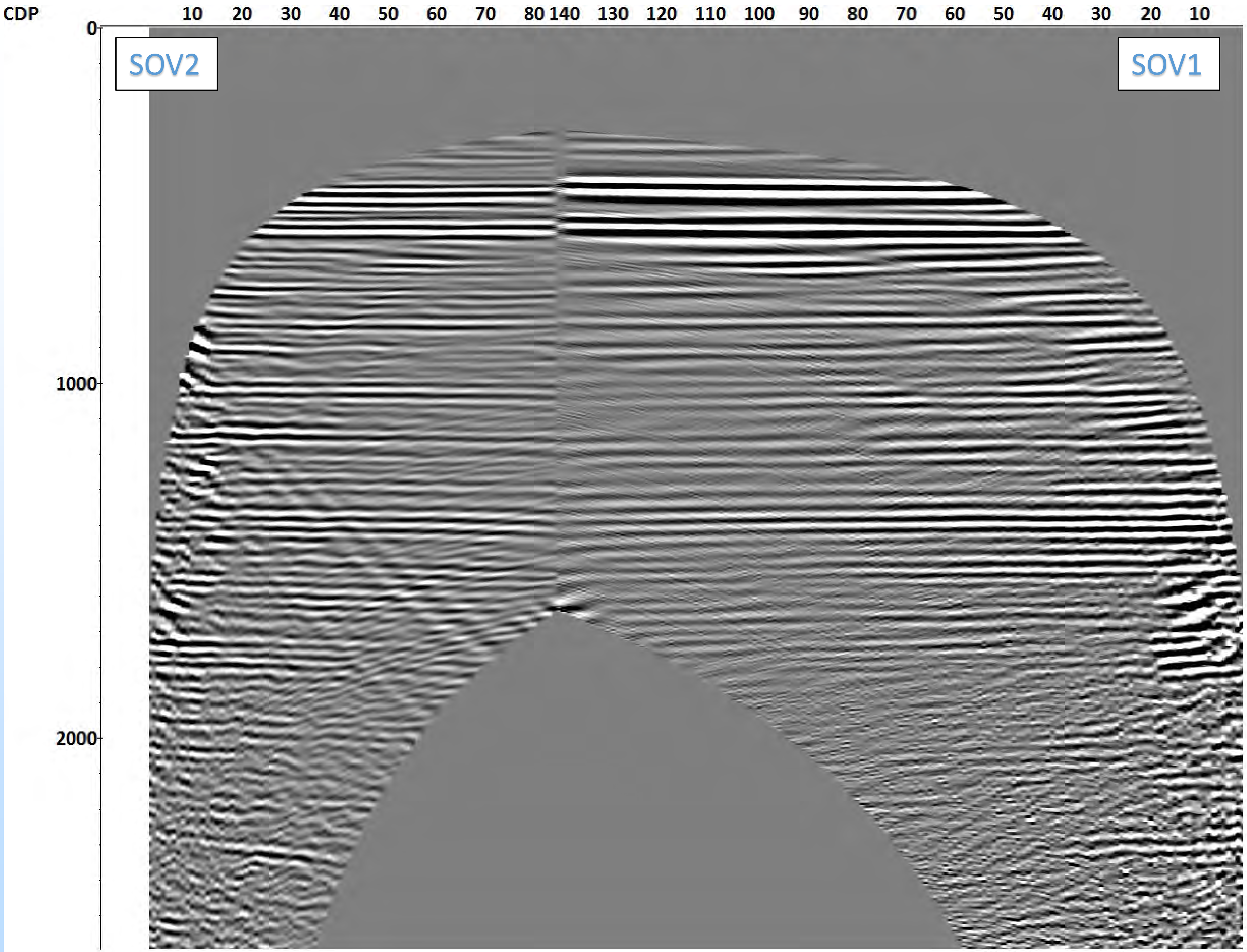
DAS/SOV1 in comparison with Geophone surface seismic

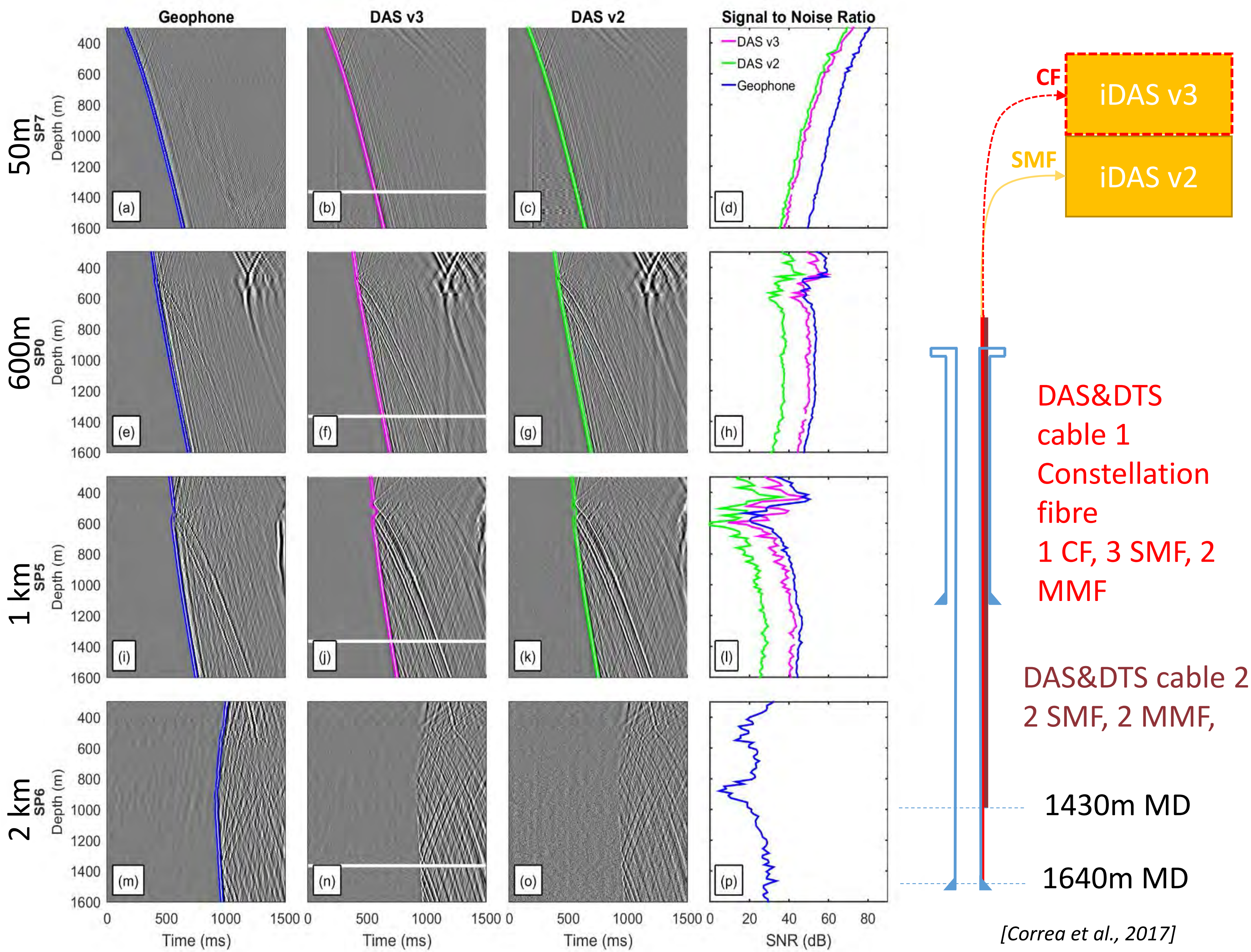
- DAS/SOV 2D line shows good match with crossline acquired with conventional geophone surface seismic (Monitor 5 survey)



Crossline from **conventional** geophone surface seismic acquired using vibroseis source

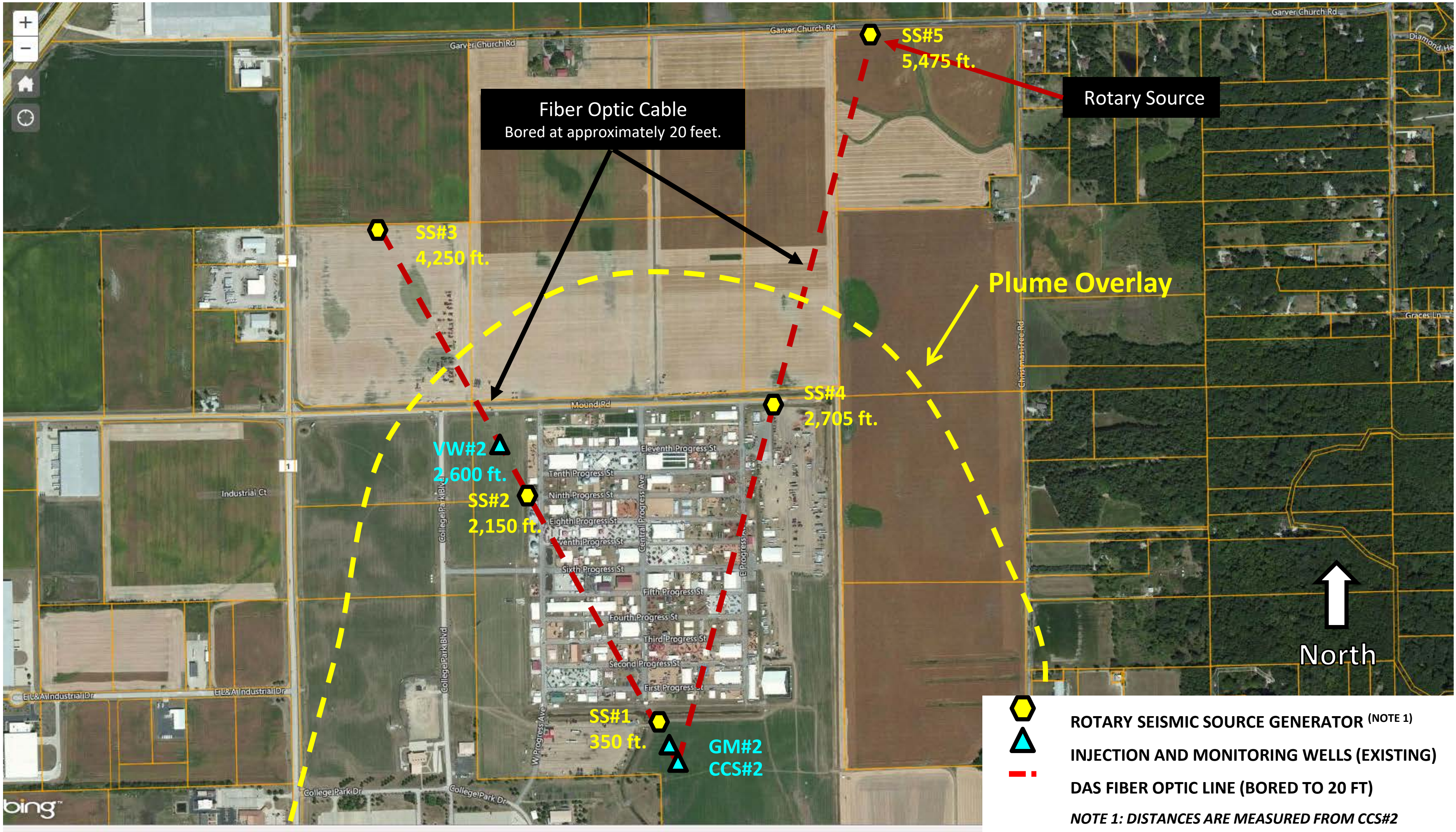
DAS/SOV1 2D line


CDP
10 20 30 40 50 60 70 80 140 130 120 110 100 90 80 70 60 50 40 30 20 10
0
1000
2000
SOV2
SOV1

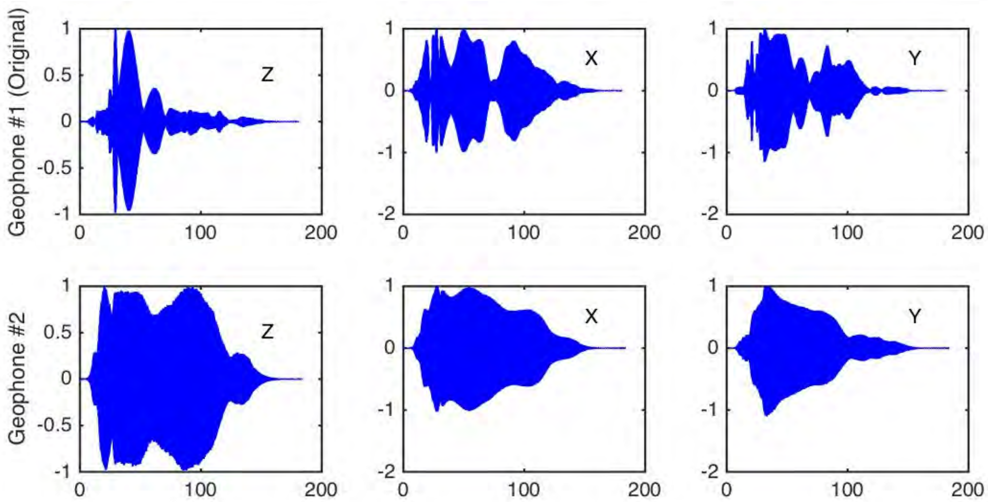


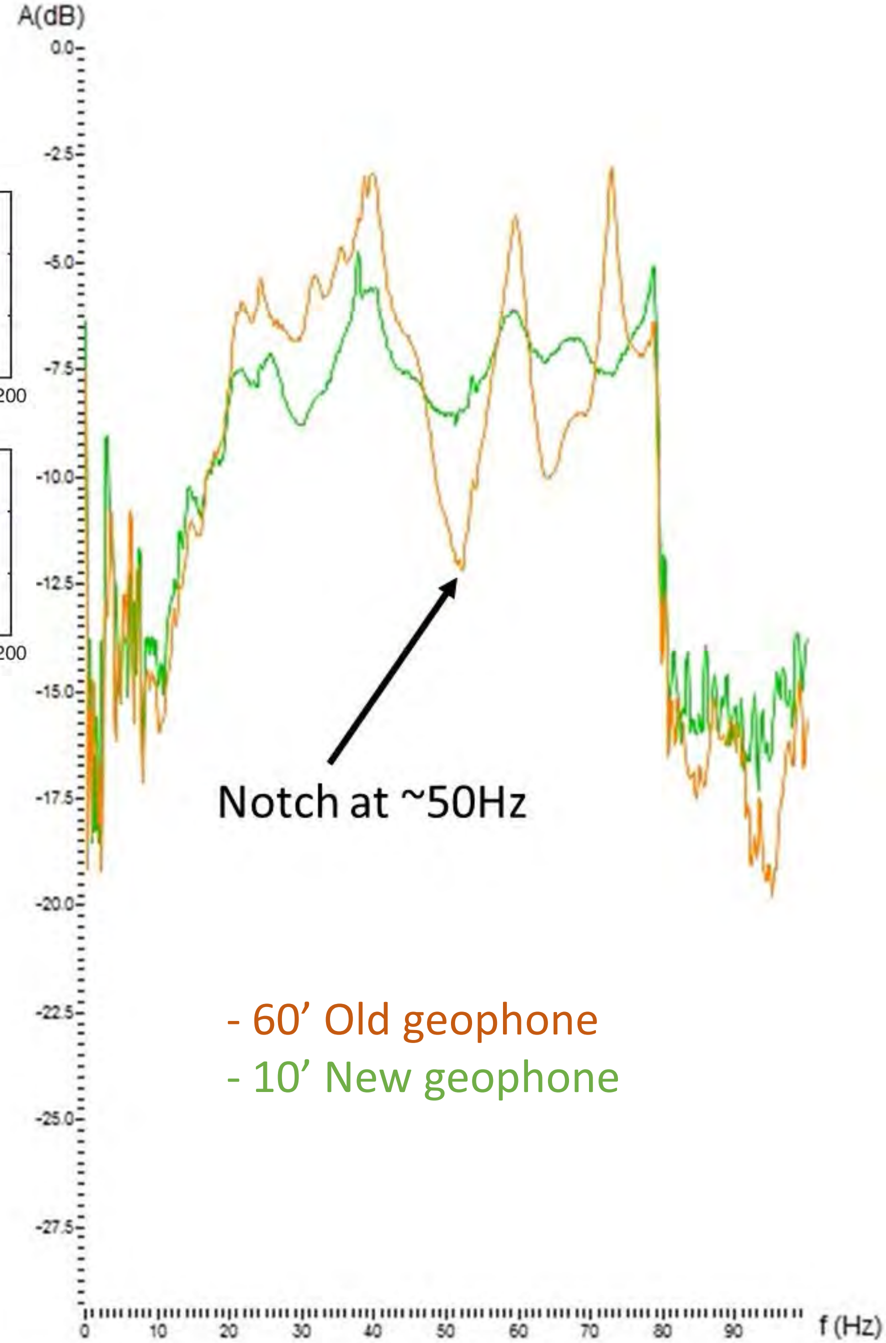
Geophone
DAS v3
DAS v2
Signal to Noise Ratio
DAS v3
DAS v2
Geophone
50m
SP7
600m
SP0
1 km
SP5
2 km
SP6
Depth (m)
Time (ms)
SNR (dB)
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
CF
iDAS v3
SMF
iDAS v2
DAS&DTS
cable 1
Constellation
fibre
1 CF, 3 SMF, 2
MMF
DAS&DTS cable 2
2 SMF, 2 MMF,
1430m MD
1640m MD
[Correa et al., 2017]

ADM IMS Fiber Optic and CASSM Layout



Lessons Learned at ADM



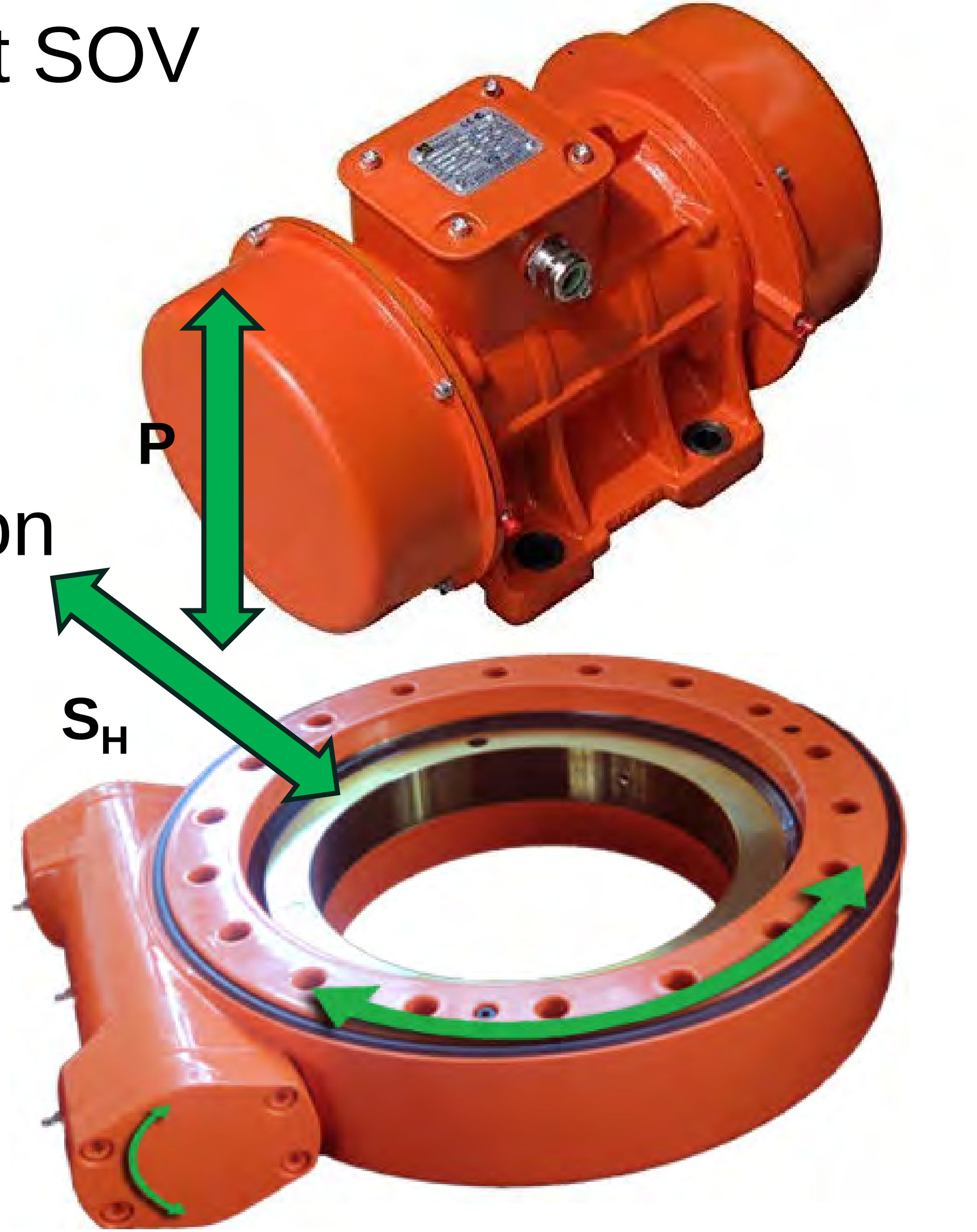


- **The old geophone presents a strong notch at ~50 Hz and at ~65 Hz**
- **Geophone buried at 60’ (~18m)**
- **Velocity of S-wave at this depth is ~1000 m/s (from well log; empirical overburden)**
- **Ghost notch frequency = Velocity/depth = 1000/18 = 55 Hz**
- **The notch with the old geophone is probably a source ghost from the S-wave**

NEW!

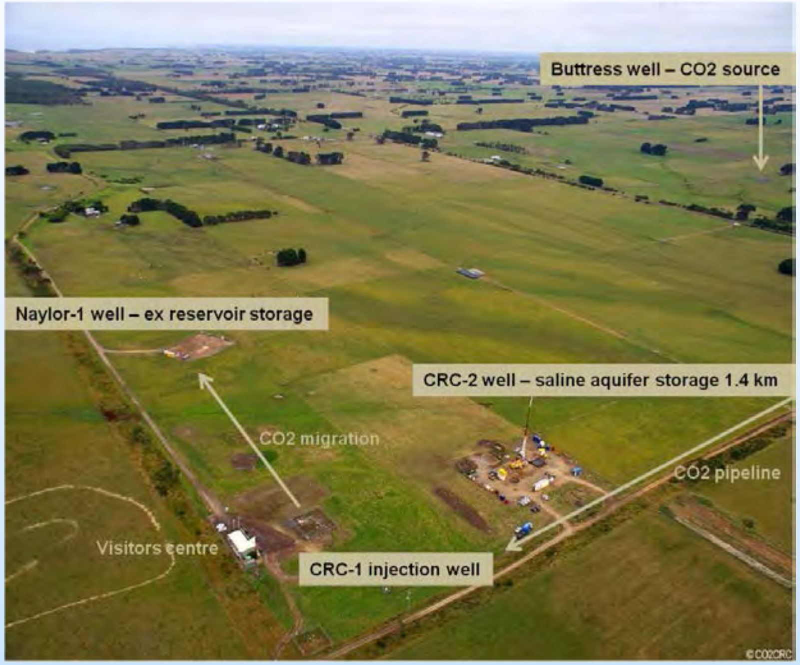
Swept SOV

- Allow for swept azimuthal orientation of S_H
- Detect anisotropy using shear wave splitting

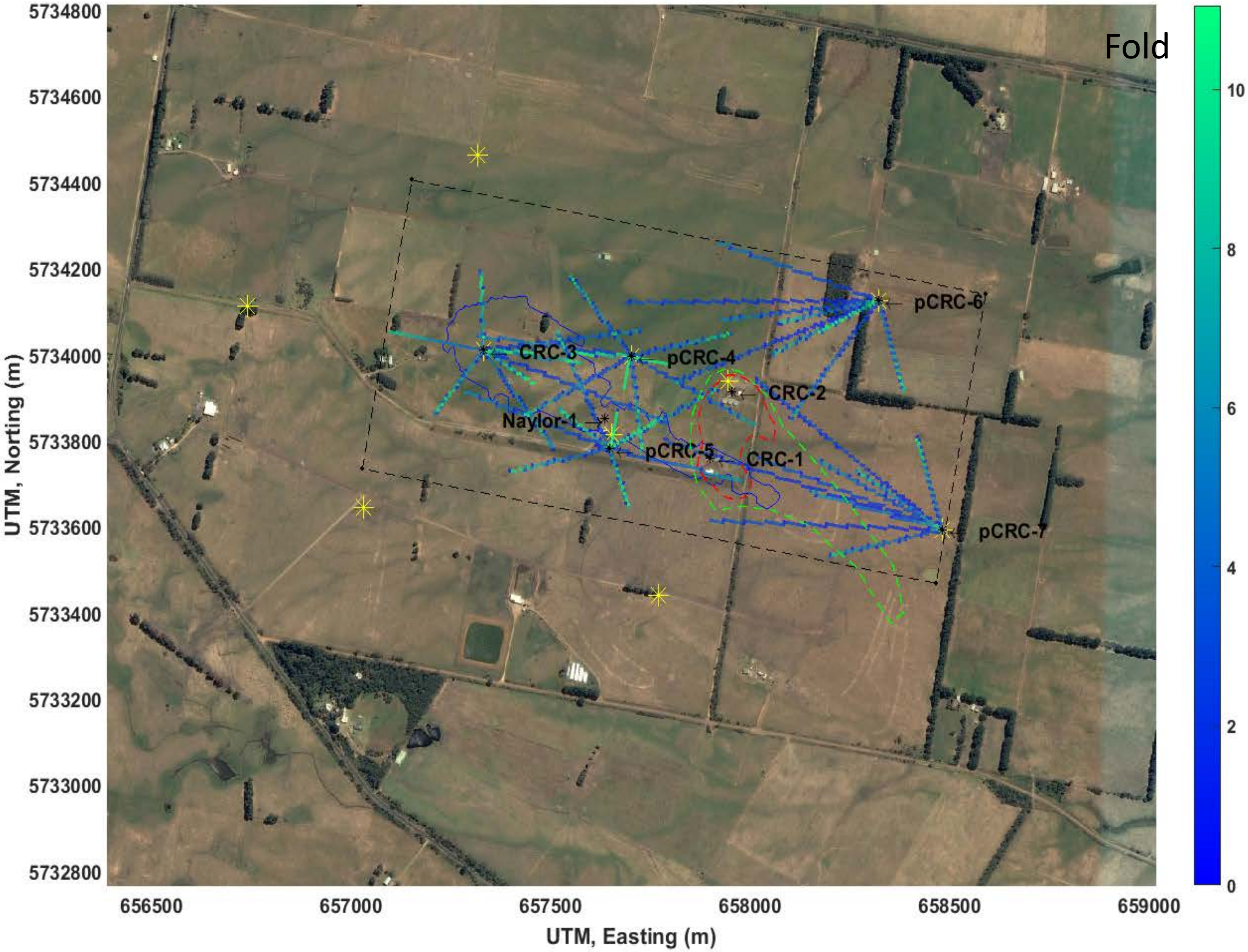


Otway Stage 3 Concept

- Build on previous experience and infrastructure at the site (2 large, 2 small injections)
- Drill 4 -5 new wells at the CO2CRC Otway test site, to form a subsurface monitoring array
- Injection of 15 – 30 kt will simulate a leak and track migration
- Install 10 SOVs and use HDD for surface fiber installation below water table



Seismic coverage by 10 permanent sources / DAS / vertical wells



Accomplishments to Date

- Tested Silixa Carina Fiber at CRC-3 using SOVs
- Compared 80 Hz 10 T-f SOV with 160 Hz 2.5 T-f
- Currently building the first SOV with swept S_H
- Plan to install 10 SOVs at Otway Project Site for multi-well VSP and surface reflection survey.

Lessons Learned

– Optimal source signature depends upon local geology and conditions such as location of the water table.
  - Geophones located too deep can lead to ghosting and notches in the source signature
  - Further work is needed to identify optimal placement and processing techniques for source-receiver deconvolution
– Moving data from the DAS system located in the field to offsite for analysis faces bandwidth limitations (snail mail common method)
– Operation of the SOVs under extreme low temperatures (<-15 ºC) should be avoided
– SOV-DAS in the VSP geometry yields good SNR whereas surface reflection SOV-DAS needs greater sensitivity

Synergy Opportunities

- SOVs are planned to be used in the Eagle Ford Shale Laboratory project (Texas A&M, LBNL and Wildhorse Resources LLC)
- Planning is underway for deploying an SOV with an oil & gas operator in the California central valley to monitor tertiary recovery
- EGS projects, such as at FORGE, could benefit from the oriented S_H SOV to identify anisotropy and evaluate fracture stimulation

Project Summary

- Time-lapse VSP acquired with SOV can be used to conduct continuous reservoir monitoring (with automated acquisition and data processing);
- Acquiring VSP surveys using DAS and SOV sources offers an alternative to surface vibroseis surveys for TL monitoring;
- DAS/SOV provide datasets sufficient to image injection depth;
- Large motors (high force) provide better signal to noise ratio than higher frequency smaller sources.

Appendix

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

Benefit to the Program

- Goal (1) Develop and validate technologies to ensure 99 percent storage permanence by reducing leakage risk through early detection mitigation.
- Goal (2) Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness by advancing monitoring systems to control and optimize CO2 injection operations.
- Successful development of SOV-DAS will enable more cost effective monitoring and can serve to either reduce or replace more expensive traditional 4D seismic methods.

Project Overview

Goals and Objectives

- Project Goal: To improve the performance of SOV-DAS by trialing new field hardware and data processing methodologies. Develop best practice and guidance for incorporating SOV-DAS into permanent reservoir monitoring programs.
- This project will be considered a success if it is able to improve SOV-DAS performance such that it provides equal or better quality data as compared to current state-of-the-art approaches to seismic acquisition.

Organization Chart

- Barry Freifeld, LBNL PI
- Julia Correa, LBNL and Curtin University, Data processing and analysis
- Todd Wood, LBNL, Electrical engineering and software development
- Paul Cook, LBNL, Mechanical engineering
- Michelle Robertson, Project Scientists – field logistics and operations management

- Collaborators:
  - Australian CO2CRC and Curtin University (Roman Pevzner lead scientist for Otway Stage 3 experiment
  - ADM IMS Project, Scott McDonald PI

Gantt Chart for LBNL Target Research Program

Milestone Reporting accompanies Quarterly report	Q1 FY18			Q2 FY18			Q3 FY18			Q4 FY18		
Subtask Description	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Task 1 Project Management and Planning												
Task 2 SOV-DAS						A*						B
Task 3 Monitoring Leakage: Joint EM and Seismic						C			D			
Task 4 Monitoring Technology for Deep CO_2 Injection						E			F			
Task 5 US-Japan CCS Collaboration on Fiber-Optic Technology									G			H
Task 6 Fault-Leakage and Security						I						J*

Task	Milestone Description*	Fiscal Year 2018 Q1	Q2	Q3	Q4	Planned Start Date	Planned Completion Date (Reporting Date)**	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
Milestone 2-1 (A)	Stage 3 SOV-DAS installation – field architecture and data processing plan		x			1/1/2018	3/31/18 (4/30/18)			AOP Tracked
Milestone 2-2 (B)	Data analysis report for CRC-3 installation SOV data				x	1/1/2018	9/30/18 (10/31/2018)			
* No fewer than two (2) milestones shall be identified per calendar year per task (per previously separate project)										**Note: Milestone reporting accompanies quarterly report, one month after end of quarter.

Bibliography

- Correa, J., Egorov, A., Tertyshnikov, K., Bona, A., Pevzner, R., Dean, T., Freifeld, B., Marshall, S., Analysis of signal to noise and directivity characteristics of DAS VSP at near and far offsets - A CO2CRC Otway Project data example, The Leading Edge December 01, 2017, Vol.36, 994a1-994a7. doi:10.1190/tle36120994a1.1
- Correa, J., Freifeld, B., Robertson, M., Pevzner, R., Bona, A., Tertyshnikov, K., and Daley, T., (2018) 3D vertical seismic profiling acquired using fibre-optic sensing DAS – results from the CO2CRC Otway Project, AEGC 2018: Sydney, Australia.
- Freifeld, B., Dou, S., Ajo-Franklin, J., Robertson, M., Wood, T., Daley, T., White, D.J., Worth, K., Pevzner, R., Yavuz, S., dos Santos Maia Correa, J., McDonald, S., Using DAS for reflection seismology – lessons learned from three field studies (invited talk) AGU Fall Meeting, New Orleans, 11-15 Dec 2017.