Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation

Project Number DE-FE-00026517

[1]**Julia Correa**, [1]Barry Freifeld, [1]Jonathan Ajo-Franklin, [1]Michael Commer, [2]Scott McDonald

[1]Lawrence Berkeley National Lab

[2]Archer Daniels Midland

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Collaborators

- Scott McDonald (Project PI), Archer Daniels Midland Company
- Michael Commer, Michelle Robertson, Todd Wood, Barry Freifeld and Jonathan Ajo-Franklin, Lawrence Berkeley National Laboratory
- Joern Kaven, United States Geological Survey
- Nick Malkewicz, Schlumberger
- Sallie Greenberg, Illinois State Geological Survey
- Thomas Coleman, Silixa LLC
- David Larrick, Richland Community College

Presentation Outline

- Technical overview
- Project highlights
- Latest accomplishments
- Project Summary
  - Key Finding
  - Next Steps

SOV and DAS technology

New vs. Conventional Technology

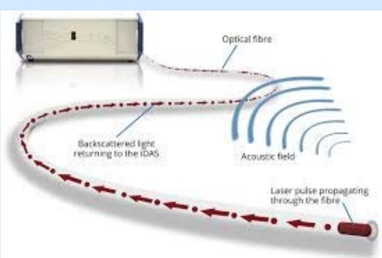
Seismic surveys are considered the backbone technique for CO_2 storage monitoring programs.

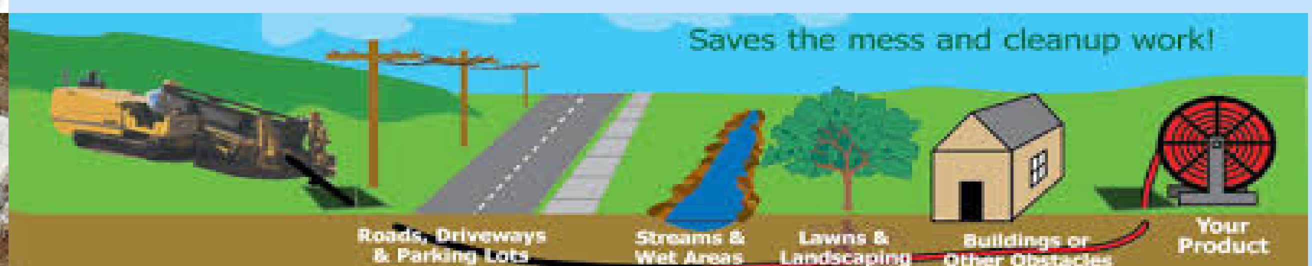
Stringing thousands of cables and running thumper trucks every few years can test the limits of good neighbors. Costs are high.

Permanent reservoir monitoring offers a way to obtain higher quality information with minimal intrusion into surrounding lands –

- DAS provides high spatial and temporal resolution.
- Installation can be in horizontal directionally drilled boreholes beneath bodies of water, existing infrastructure.
- Excitation of DAS cables can be achieved through permanent fixed rotary sources for continuous monitoring.

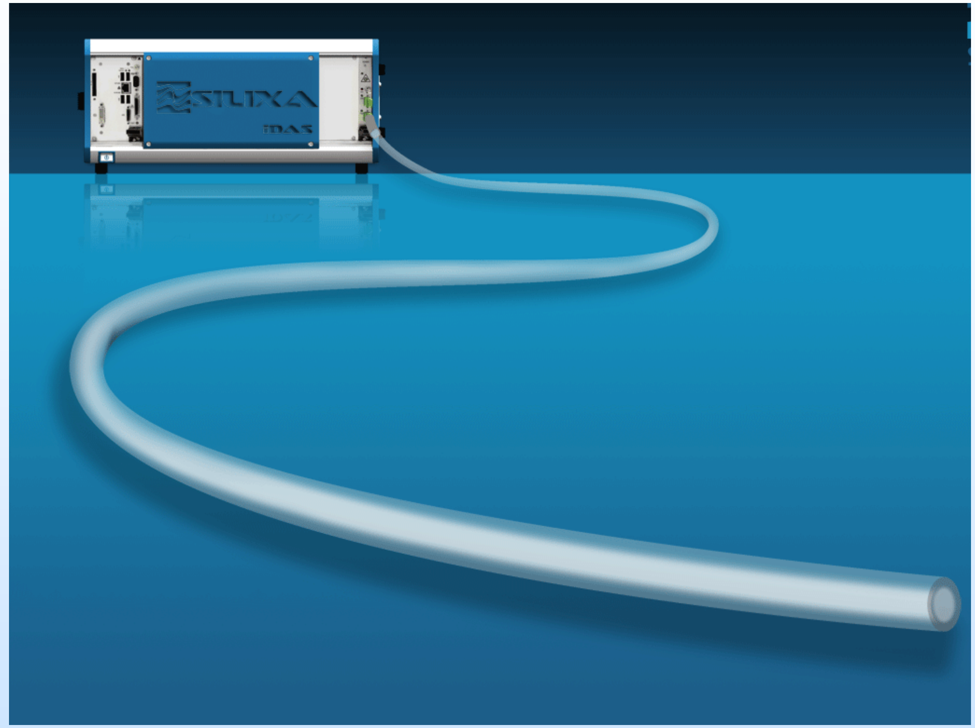
DAS Seismic

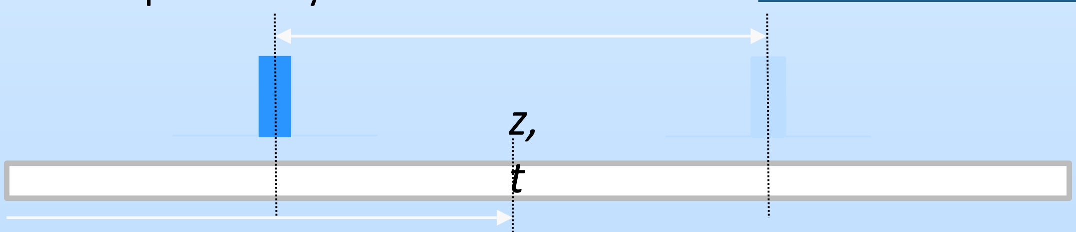




Distributed Acoustic Sensing

- 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



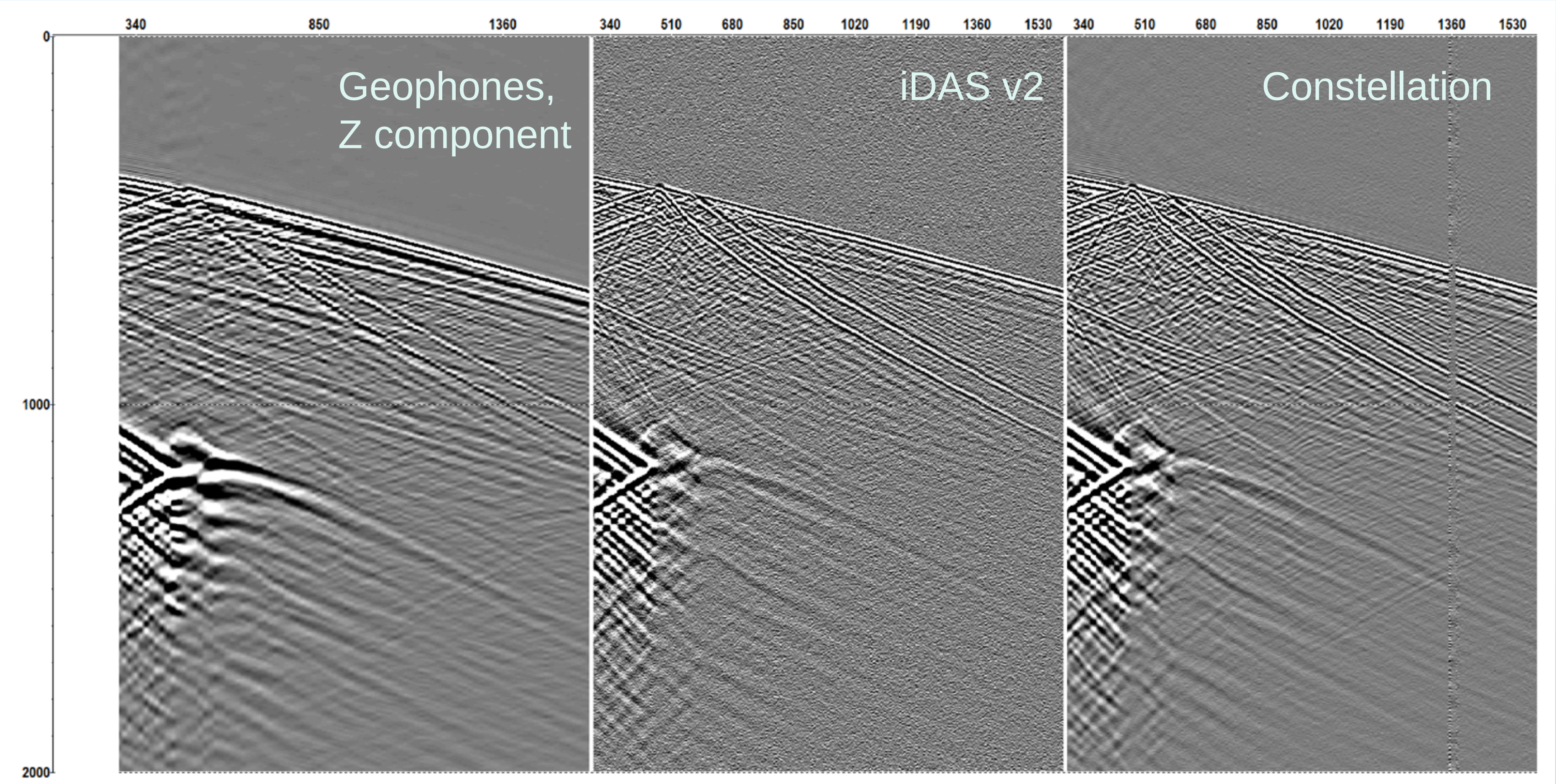


$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

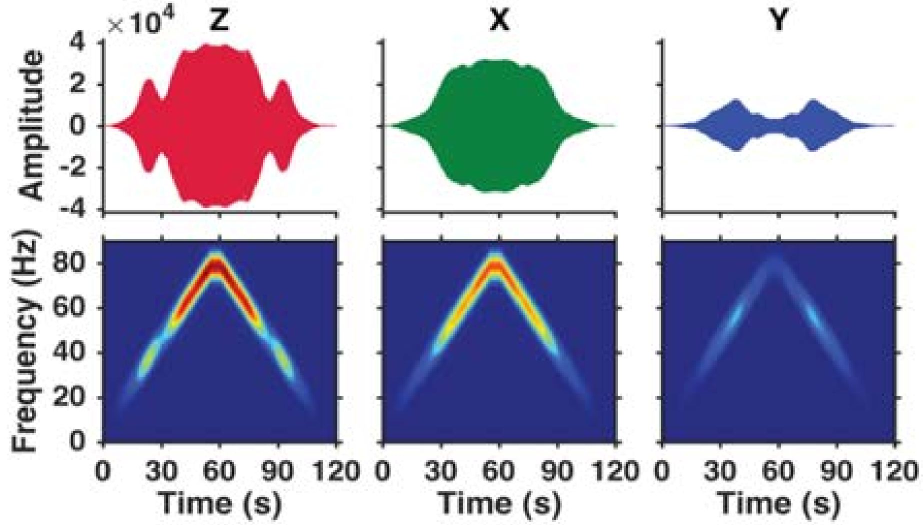
Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, *first break* (32), February 2014

ADM IMS cable contains new Silixa Ltd. Carina technology – significantly lower noise floor

CO_2CRC Otway – SP0, 700 m offset, 5 sweeps, data courtesy R. Pevzner



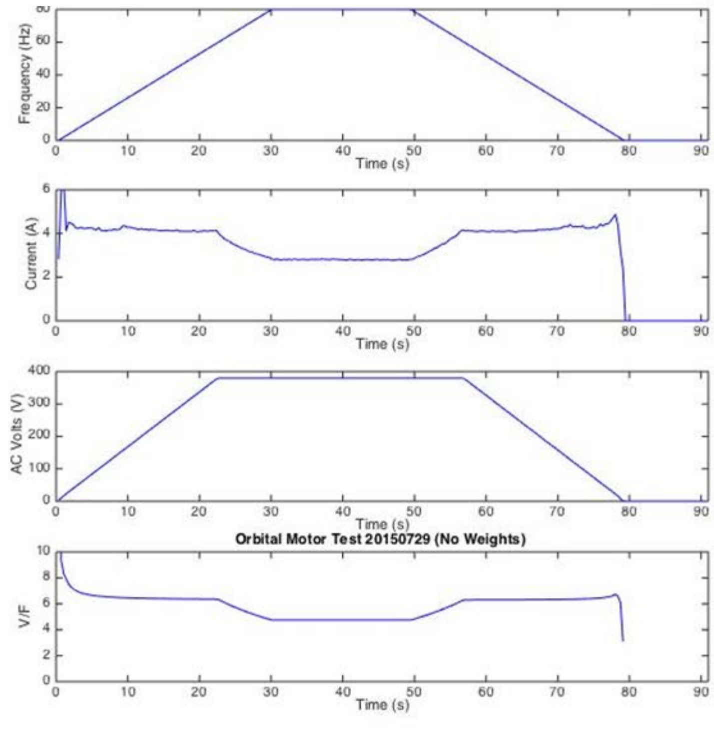
Surface Orbital Vibrator (SOV) – Controlled AC Motor



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

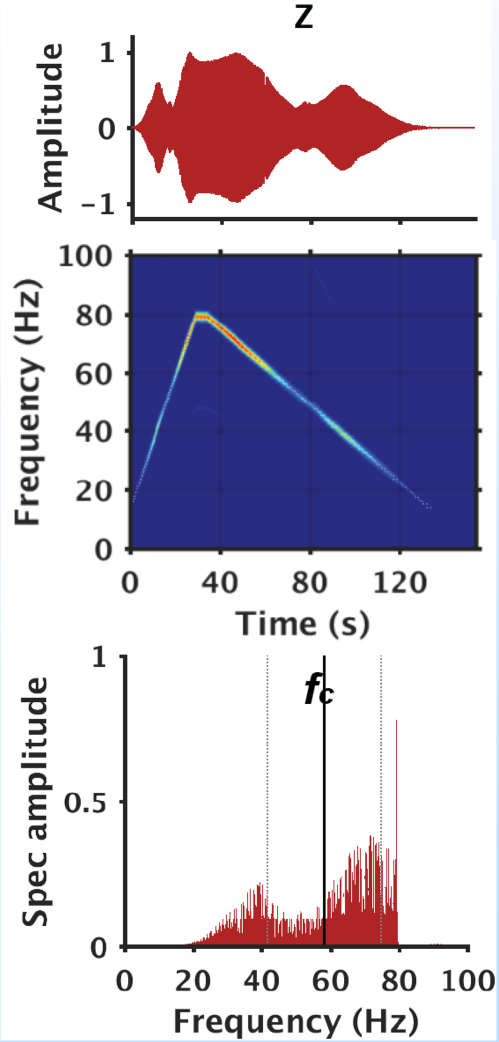
Force is adjustable

$F = m\omega^2 r$



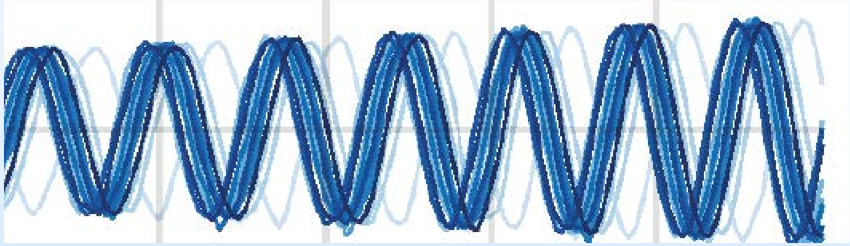
SOV for permanent reservoir monitoring

Sweep-based:
controlled release of seismic energy

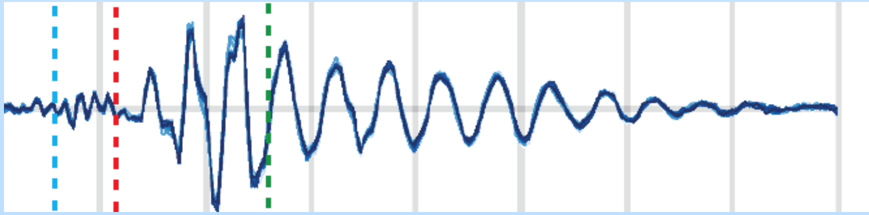


Not phase-controlled:
simpler system

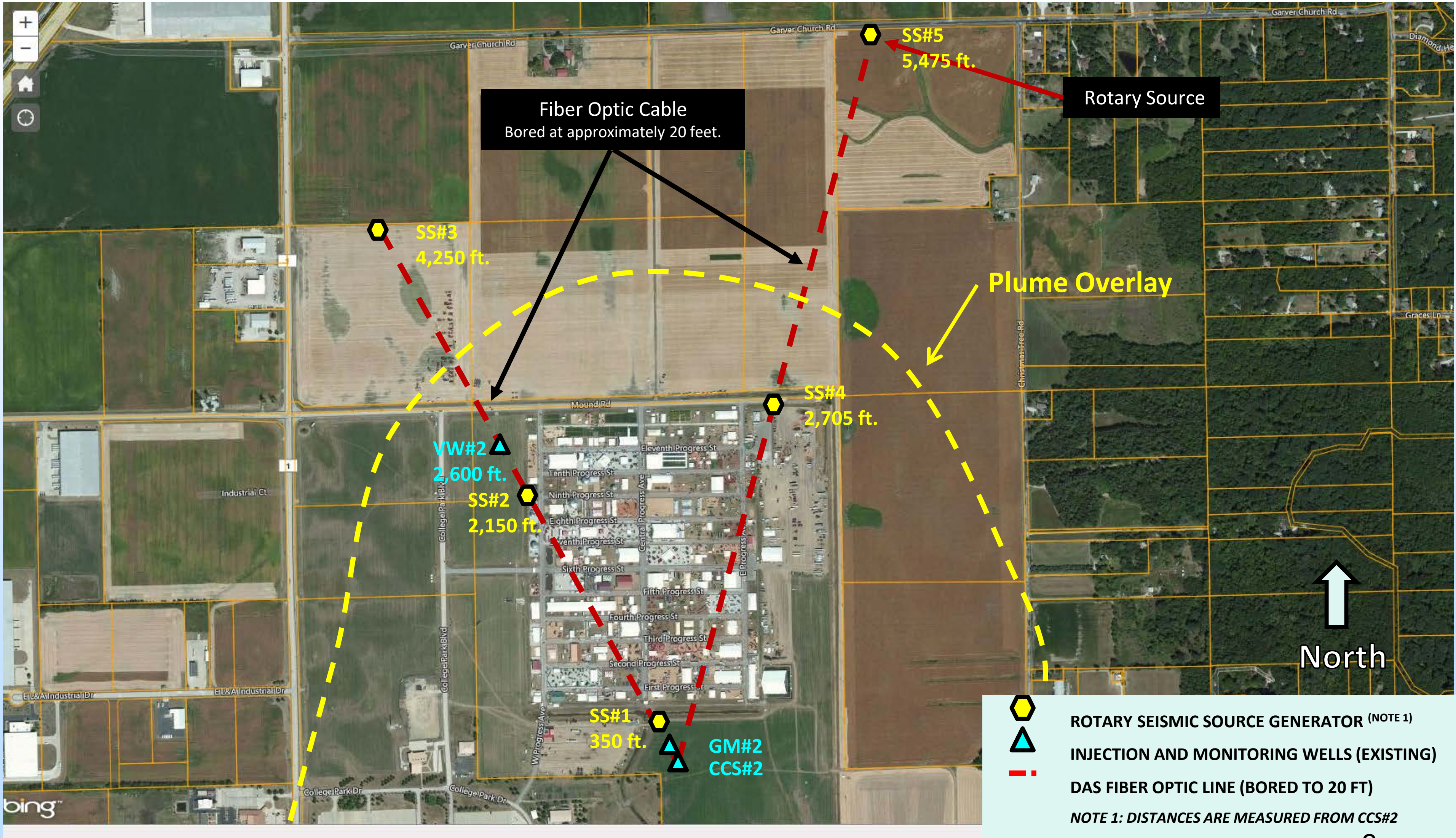
DAS records before deconvolving source sweeps (t_{shift} up to 20 ms)



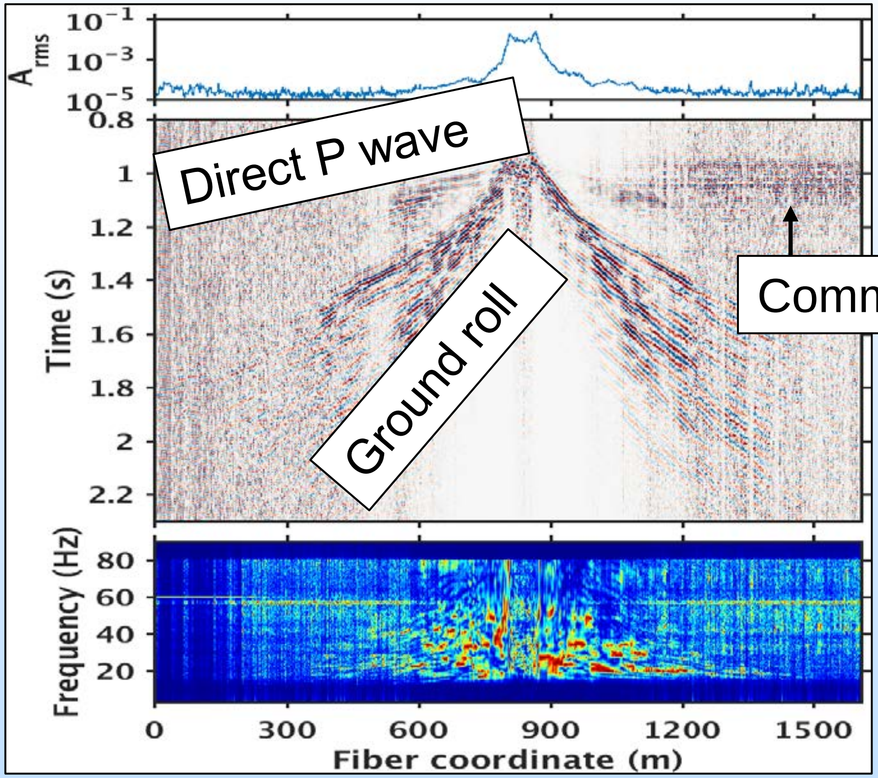
Same records after deconvolving source sweeps (t_{shift} < 1 ms)



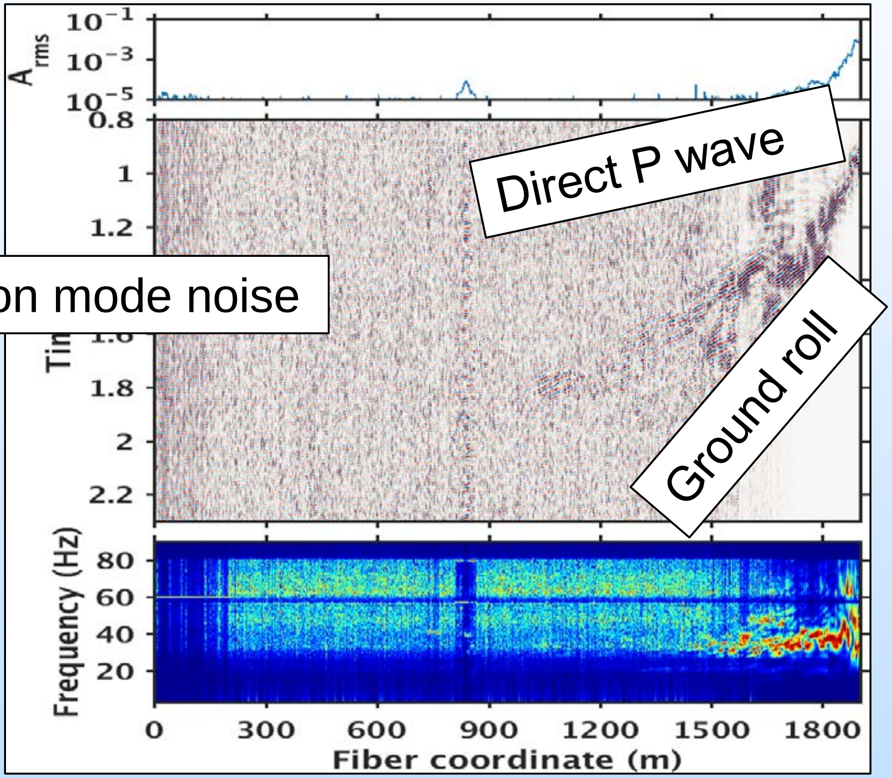
ADM site in Illinois
IMS Fiber Optic and SOV Layout



SOV sweep recorded by the permanent N/E DAS surface array



SOV4 sweep recorded by the northeast DAS surface array.

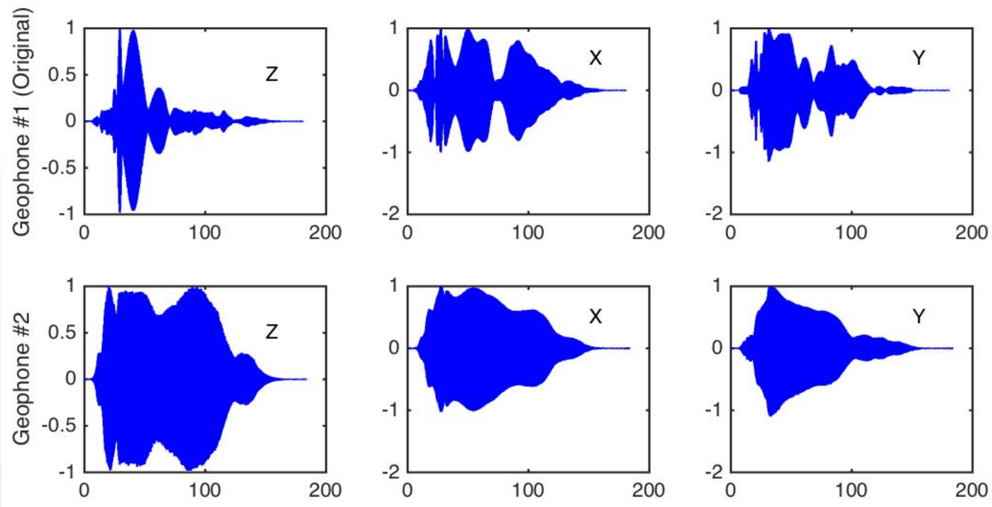


SOV5 sweep recorded by the northeast DAS surface array.

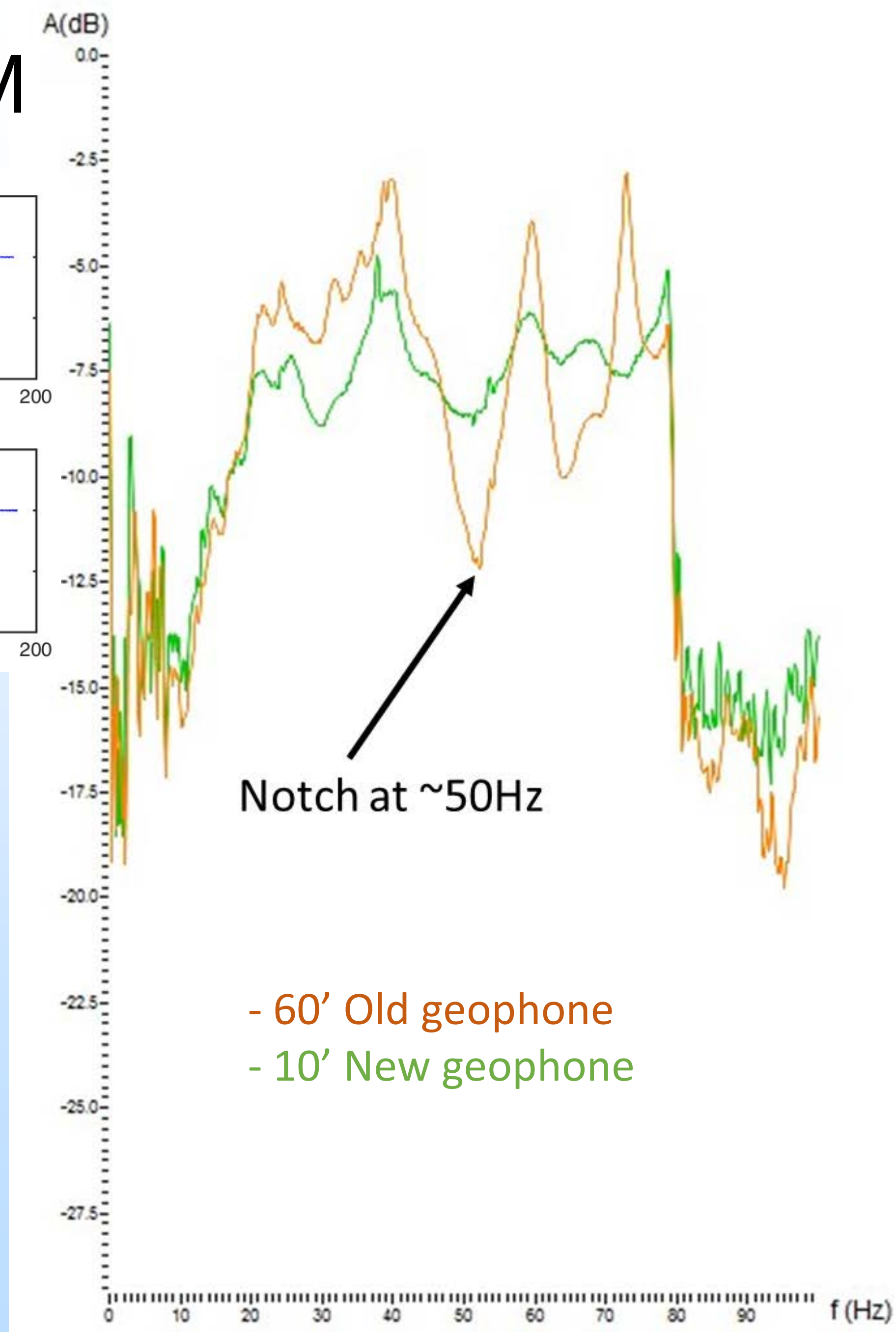
Lessons Learned at ADM

- **Testing different set-ups** in order to increase signal response:
  - Changed **fiber length** and **adjusted laser repetition rate**
  - Changed **depth of the geophone** that records the SOV
  - Increased **different force** of the SOV source
  - Tested **different sweeps designs**

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**

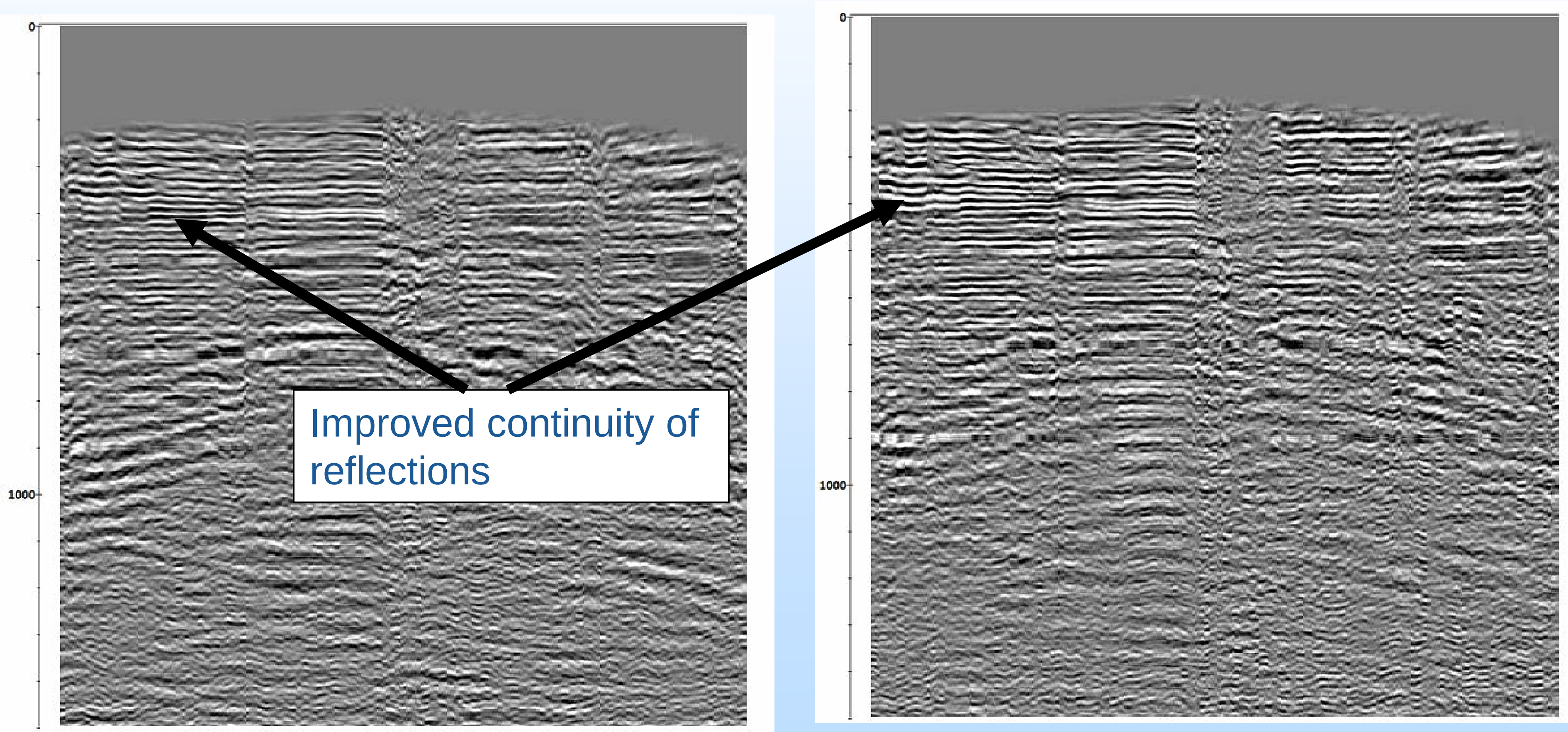


Lessons Learned at ADM

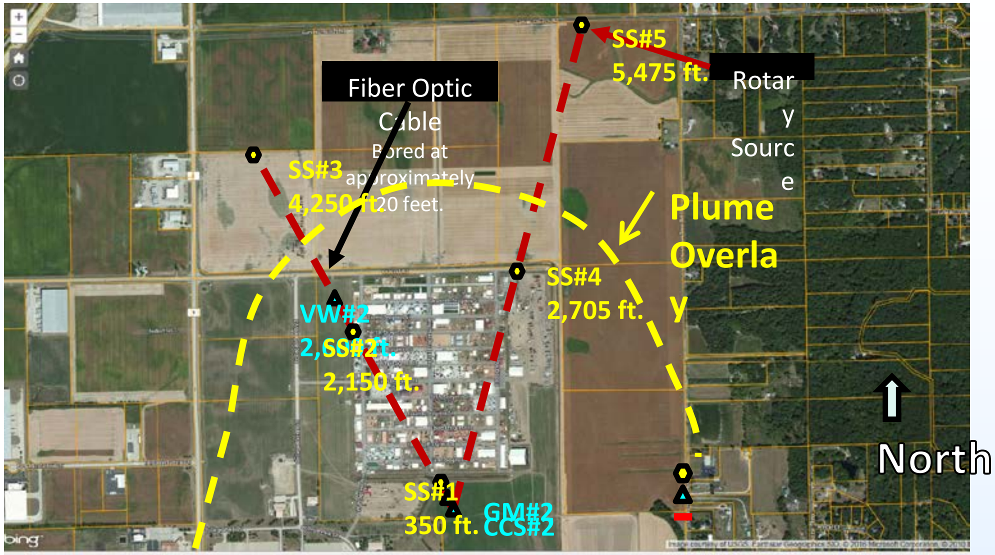
Increased the force of the SOV to 100%

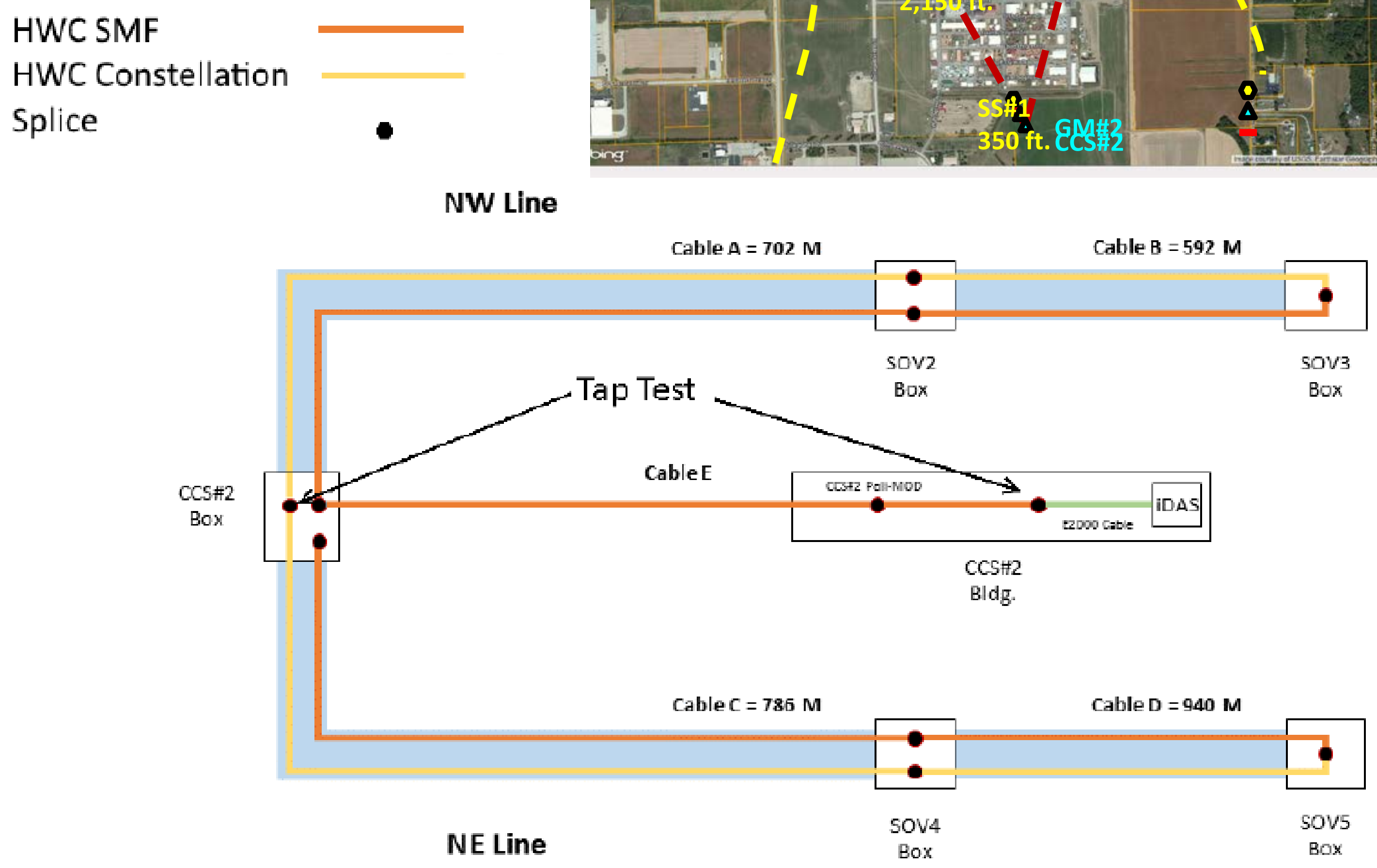
70% force

100% force



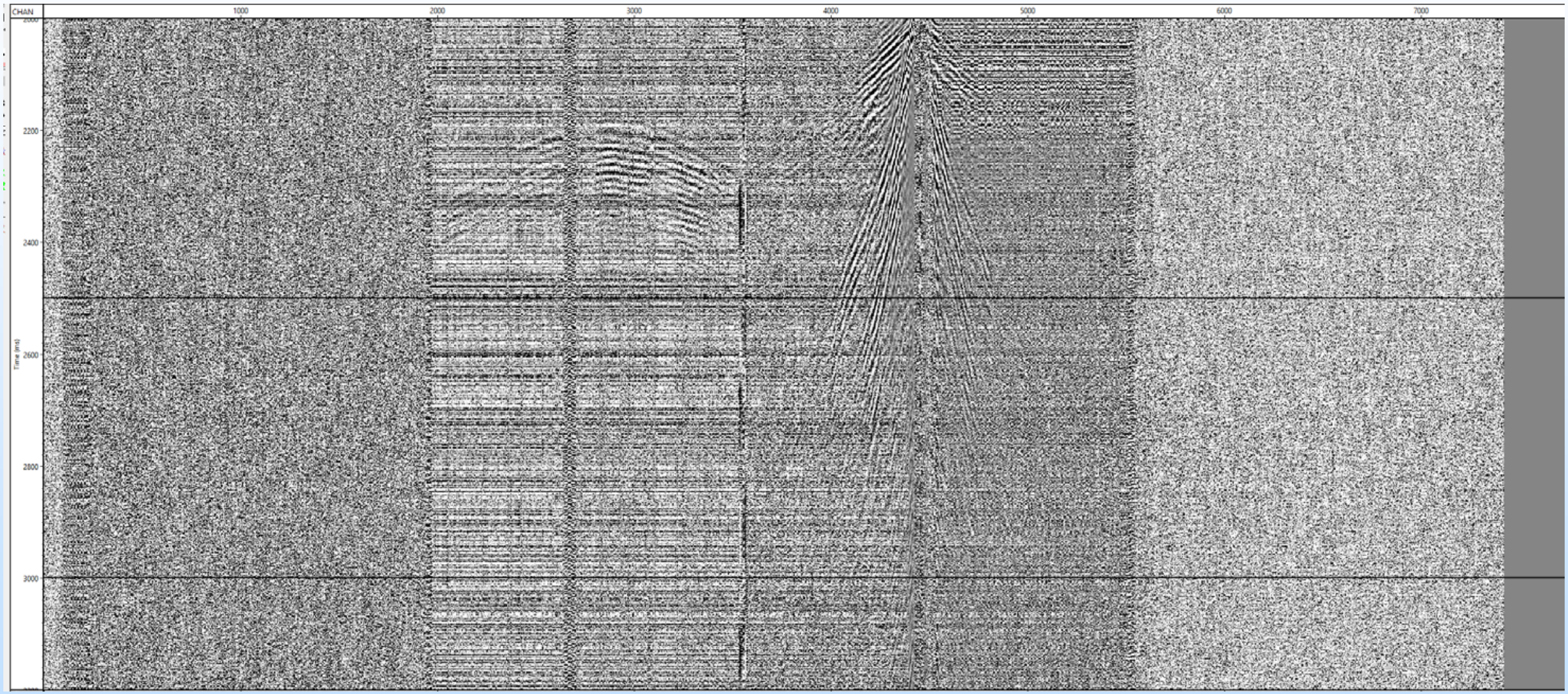
Fiber deployment





FOC cable depth=10 meters

Fiber deployment
SM vs Carina



Single-mode fiber NW line

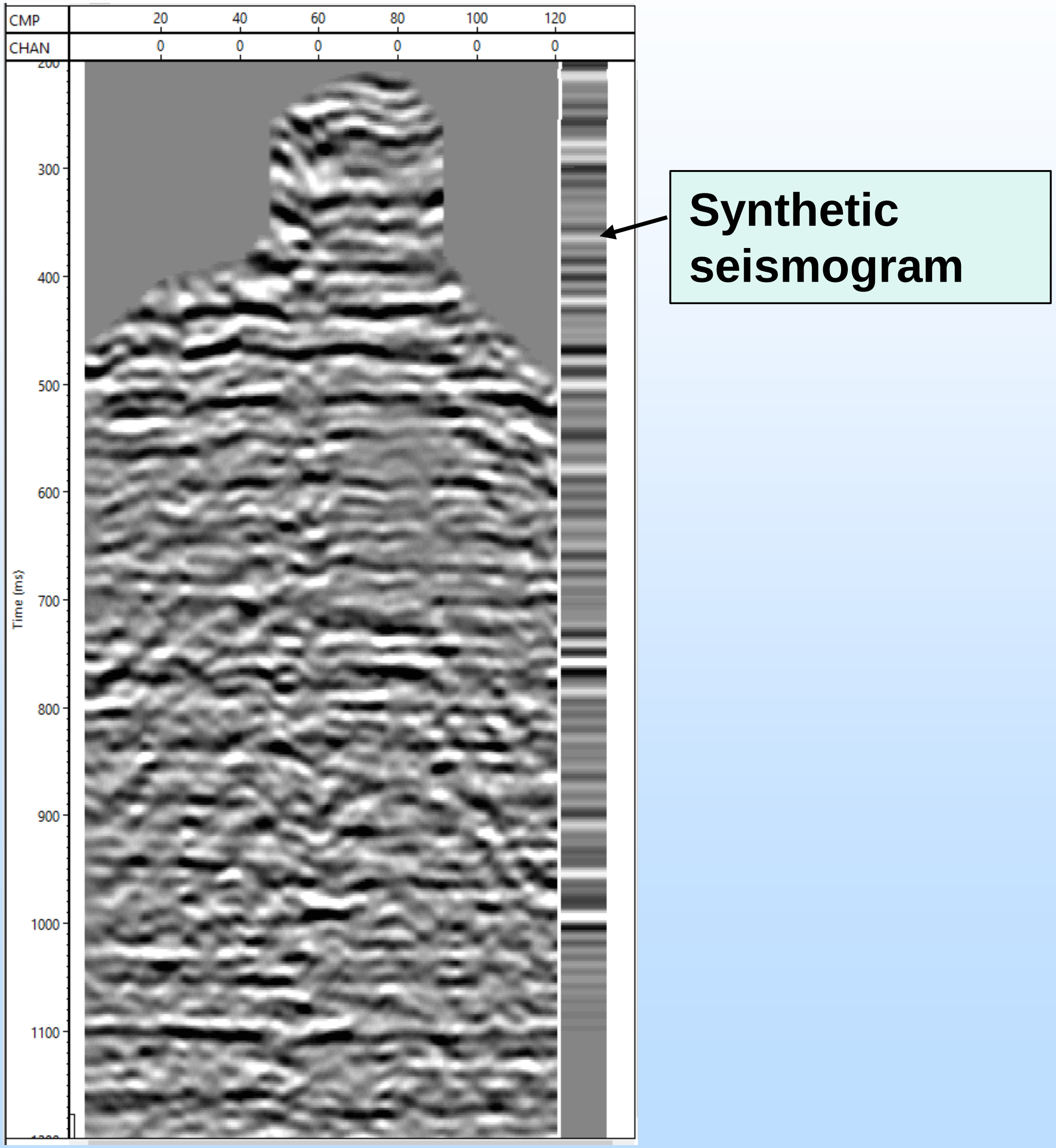
Constellation fiber NW line

Constellation fiber NE line

Single-mode fiber NE line

Well tie to 2D seismic – SOV4 on NW line

- Migrated stack was used for well tie
- There strong reflections along the area of interest
- After well tie, the reflections in the seismic could be associated with the monitoring zone and seal



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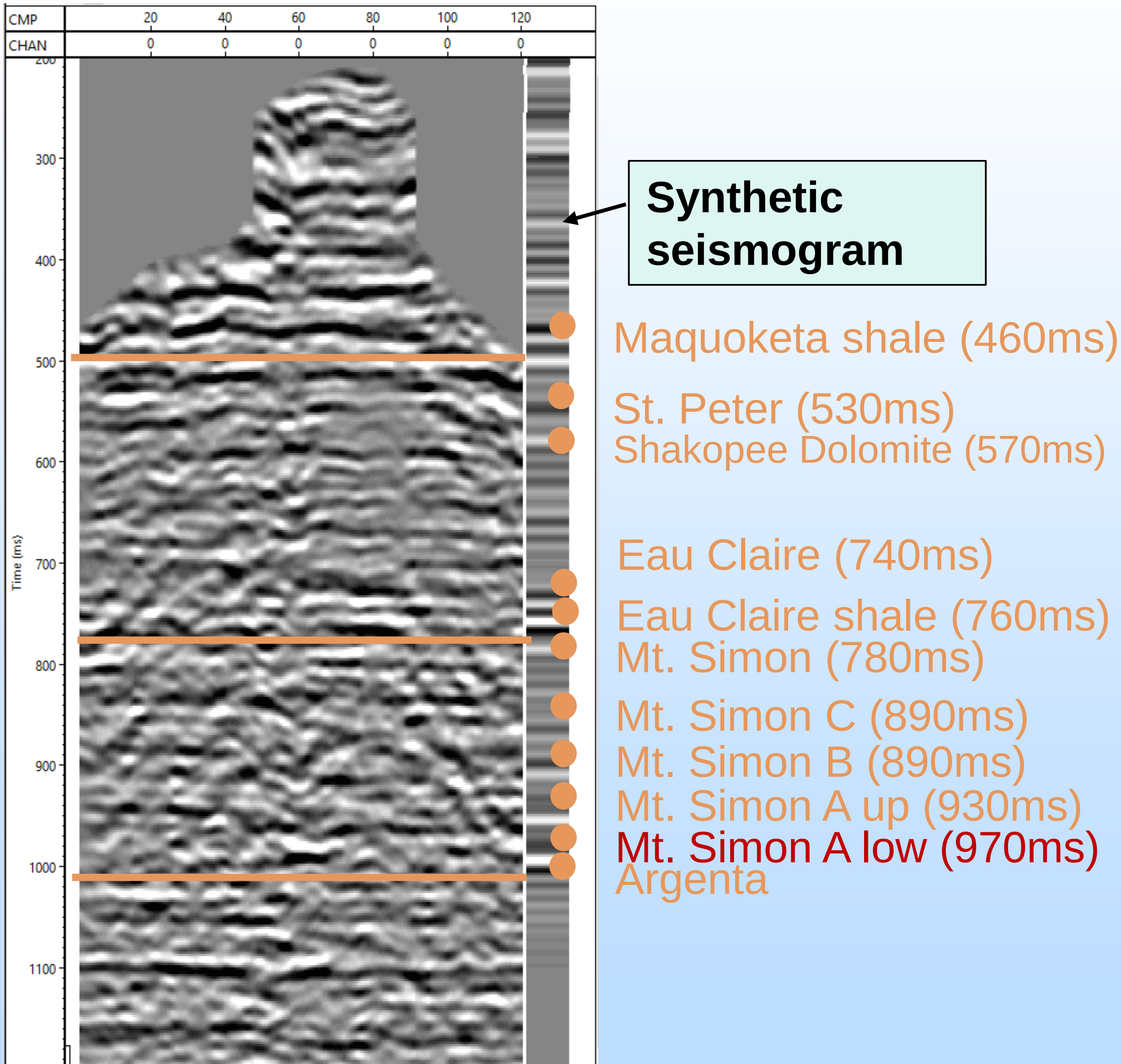
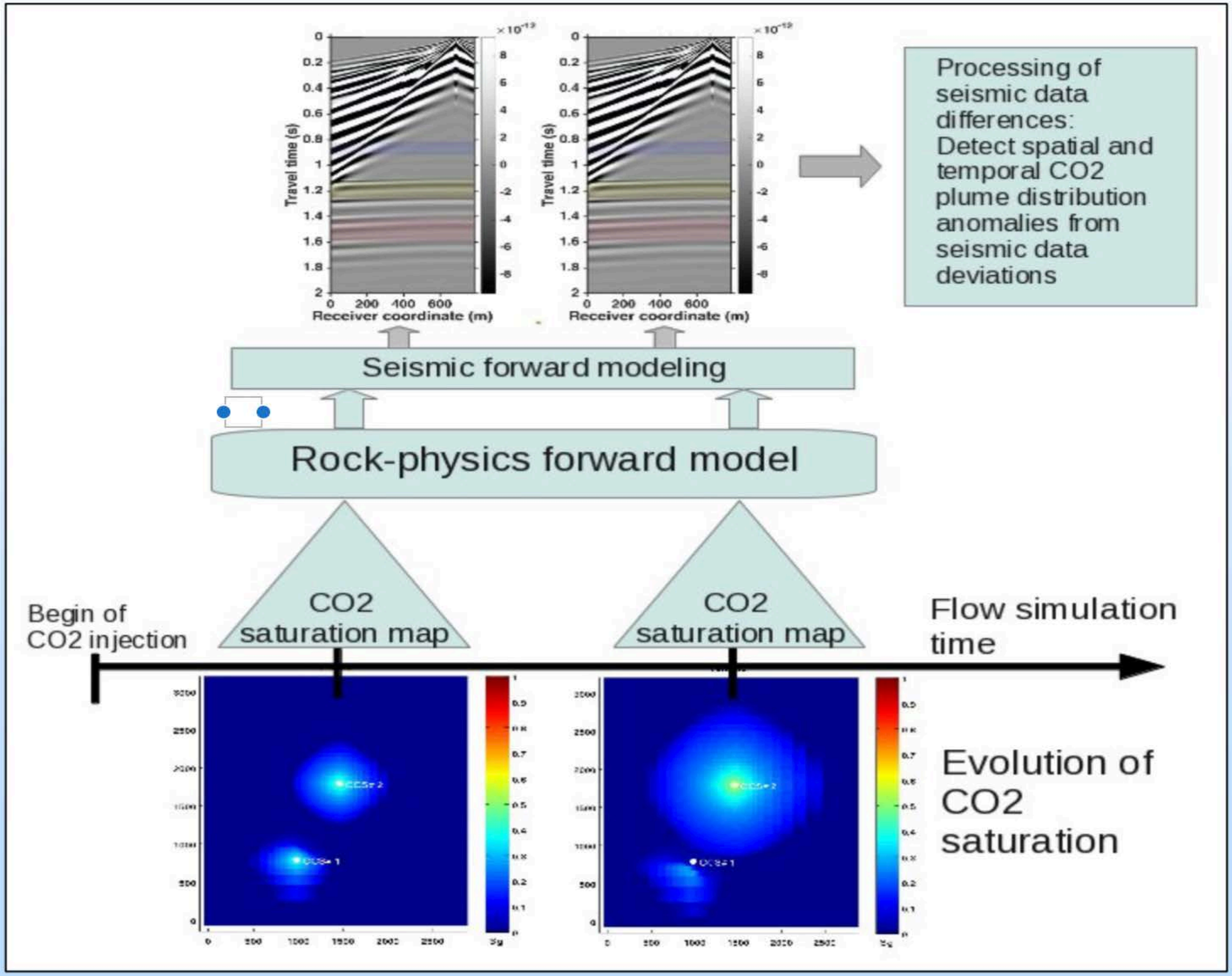
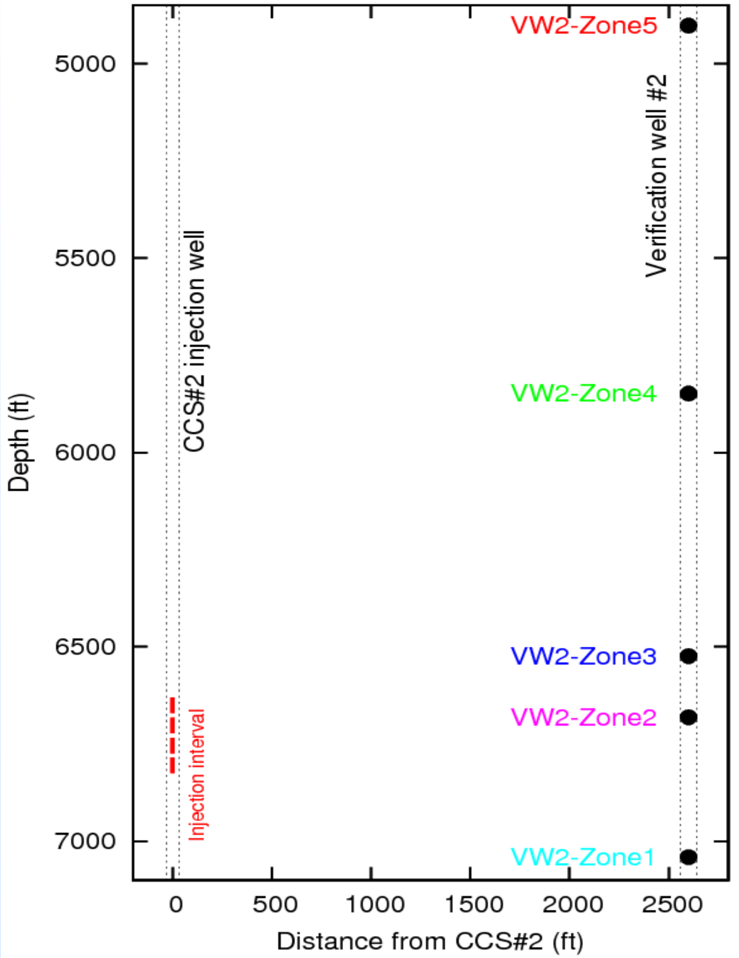


Outlook: Joint inversion of flow and seismic data

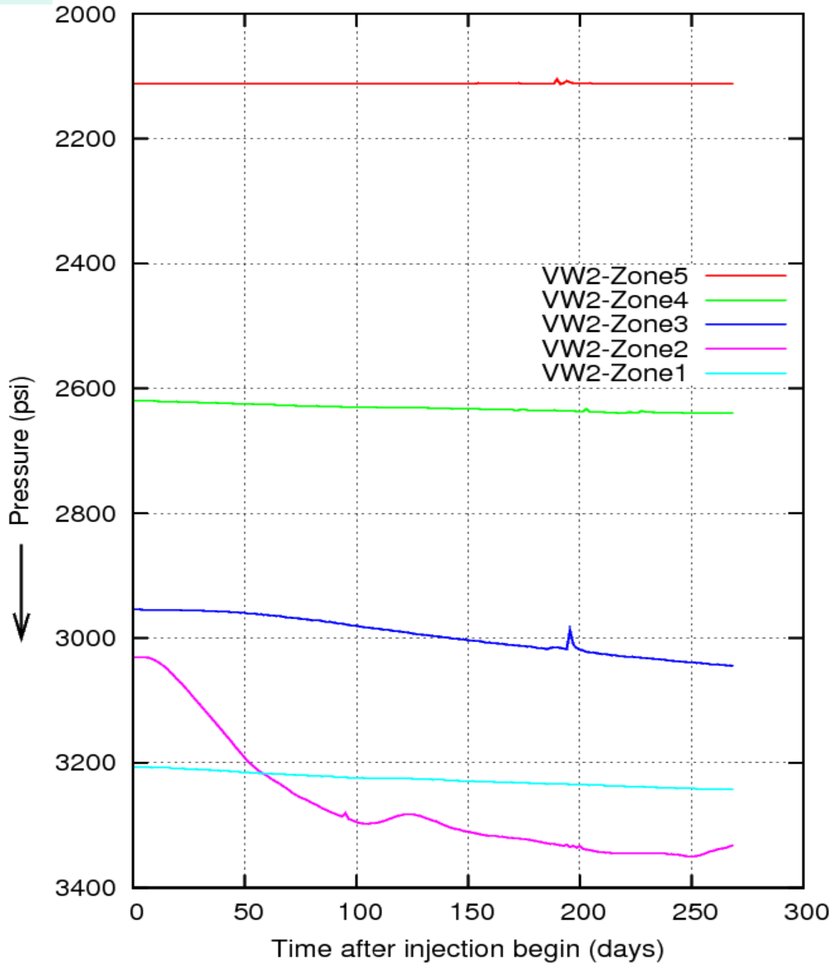


Flow-data inversion using a radial model

Reservoir zone between injection well CCS#2 and monitoring well VW#2

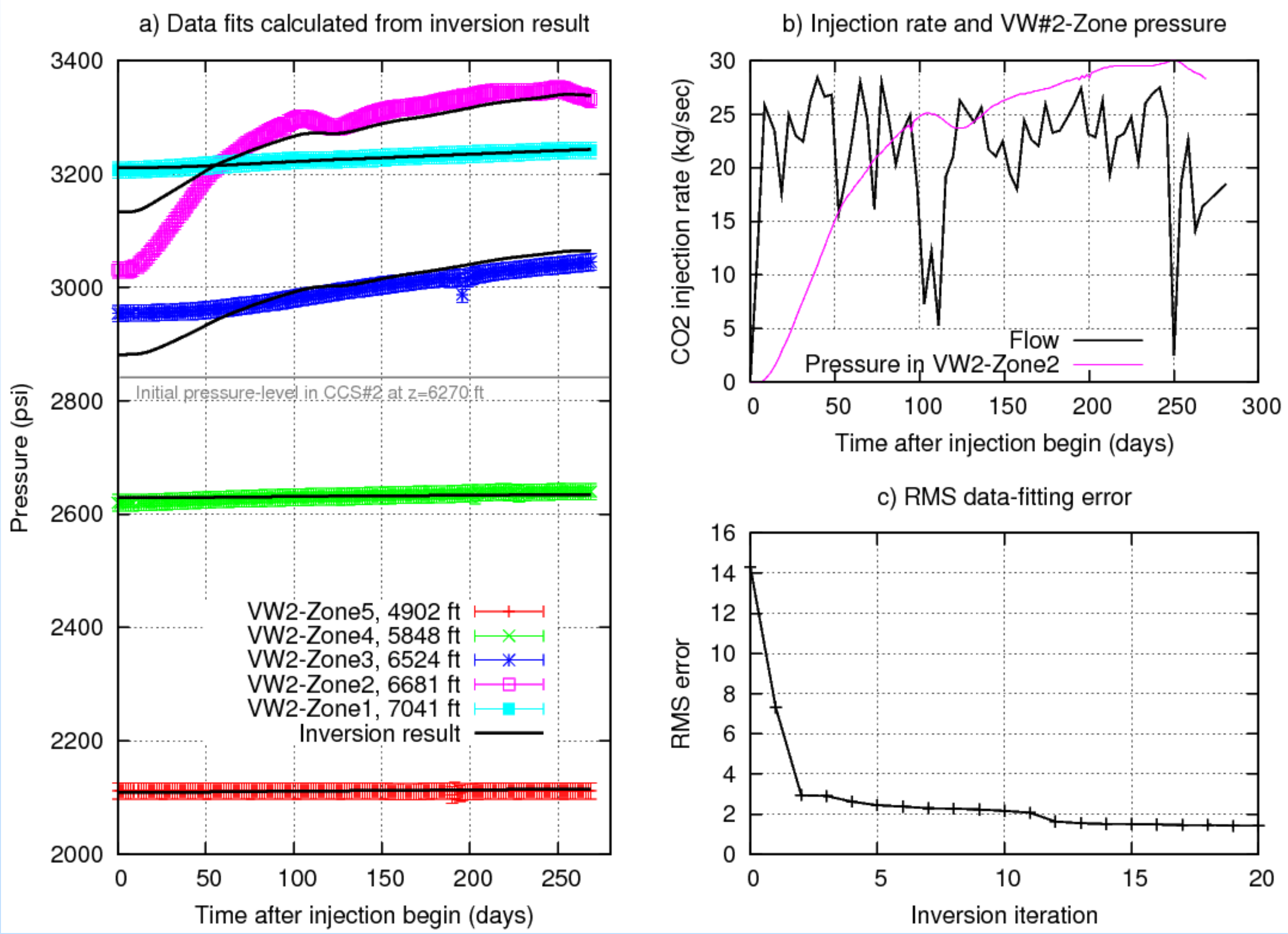


Pressure development over 268-day injection period



Flow-data inversion using a radial model

a. Data fits produced by 6-layer permeability model
b. Injection rate and pressure in VW#2-Zone 2
c. RMS data fitting error over inversion iterations



Accomplishments to Date

- Design and specification DAS cable, SOV, instrumentation, data acquisition and associated subsystems
  - Horizontal directional drilling (HDD) for fiber deployment to minimize disturbance on the land
- Development of an IMS architecture and the demonstration of its operation using synthetic data feeds
- Detail real-time DAS cross-correlation and stacking algorithm and provide analysis of synthetic data evaluation with different levels of synthetic noise
- Testing engineered fiber as an alternative in order to increase sensitivity of DAS measurements

Lessons Learned

- The use of engineered fibers increase signal sensitivity, being an alternative to projects where single-mode fibers provides low signal-to-noise ratio
    - Major potential for imaging deep reflectors in projects where only surface fibers can be used
- Larger SOV that will provide higher force can increase signal strength and improve reflections continuity
- The geophone installed deeper showed a ghost reflection in the pilot signal, which degraded the final deconvolution result
- Challenges with data transfer and network latency

Synergy Opportunities

- Initial trialing of DAS helical wound cables supported by Otway Project
- Further testing of novel Constellation optical fiber
- Development of surface cable DAS data processing flows and HDD. Linkages to the CO2CRC Otway Project Stage 3, CMC CaMI, and PTRC Aquistore

Project Summary

- **Key Findings.**
  - *We are making steady progress on the operation of the DAS-SOV network. Our latest tests with the engineered fibers gives us hope that we can monitor the injection interval*
- **Next Steps**
  - *Installation of larger SOVs to improve signal*
  - *Operation of IMS equipment and related controls*
  - *Optimization of system with respect to data quality and processing speed*
  - *Comparison of real time IMS data with state of the art detailed models*
  - *DAS data feed integration into the passive seismic monitoring system and system optimization*

Appendix

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

Benefit to the Program

- **Carbon Storage Program Goal Support:**
- **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.**
- **Goal (4) Contributing to the Best Practice Manuals for monitoring, verification, and accounting (MVA) with regard to IMS.**

Benefit to the Program

- Reduce overall storage cost.
- Increase monitoring sensitivity.
- Increase monitoring reliability by using an integrated system.
- Optimize operation and maintenance activities.
- Reduce project risk during and after the injection of CO_2.

Project Overview
Goals and Objectives

- **Develop an integrated IMS architecture that utilizes a permanent seismic monitoring network, combines the real-time geophysical and process data with reservoir flow and geomechanical models.**
- **Create a comprehensive monitoring, visualization, and control system that delivers critical information for process surveillance and optimization specific to the geologic storage site.**
- **Use real-time model calibration to provide reservoir condition forecasts allowing site optimization.**

Project Overview

Specific Project Objectives

1. **Design an IMS using a real-time multi-technology architecture that fully integrates and enhances the site's existing monitoring infrastructure that includes multi-level 3D seismic arrays, distributed acoustic sensing (DAS), multi-level pressure/temperature sensors, distributed temperature sensing (DTS), borehole seismometers, and surface seismic stations**
2. **Augment the sites monitoring capabilities by installing several rotary seismic sources and integrating a network of surface DAS with the existing seismic system to create a continuous active source seismic monitoring (CASSM) array covering over two square kilometers and extending to a depth of 6,300 feet.**
3. **Develop terabyte level data processing solutions for real time monitoring of reservoir conditions and time lapse imaging of the CO2 plume.**

Project Overview

Specific Project Objectives

4. **Commission and operate the monitoring system in an industrial setting under actual conditions.**
5. **Validate and document the economic and environmental benefits of the monitoring system.**
6. **Update the monitoring verification and accounting best practices guide to include IMS and CASSM monitoring systems.**
7. **Incorporate DAS channels in routine location of microseismicity using the combination of borehole and surface seismic stations.**
8. **Develop near real-time data processing techniques to overcome passive seismic monitoring limitations of low signal-to-noise ratio on DAS array.**

IMS Organization Chart

- ADM has overall project responsibility and is accountable for:
  - Task 1 Project management and planning
  - Task 3 IMS Installation
  - Task 4 IMS Commissioning and Operation

- LBNL's team will be accountable for:
  - Task 2 IMS Design
  - Subtask 3.3 IMS DAS Surface Cable and Rotary Sources CASSM
  - Subtask 3.4 IMS Control, Monitoring, and Data Acquisition Software
  - Subtask 4.2 Function test of IMS DAS Surface Cable and Rotary Sources CASSM
  - Subtask 4.5 Validate IMS real-time reduced order models

- USGS's team will be accountable for:
  - Subtask 2.4 Design of Passive Microseismic Monitoring System
  - Subtask 4.6 Operation Passive Microseismic Monitoring System

IMS Organization Chart

- **Silixa's team will be accountable for:**
  - **Subtask 2.1 IMS Data Acquisition and Processing Equipment,**
  - **Subtask 3.2 IMS Data Acquisition and Processing Equipment,**
  - **Subtask 4.1 IMS Instrumentation, Controls, and Data Network,**

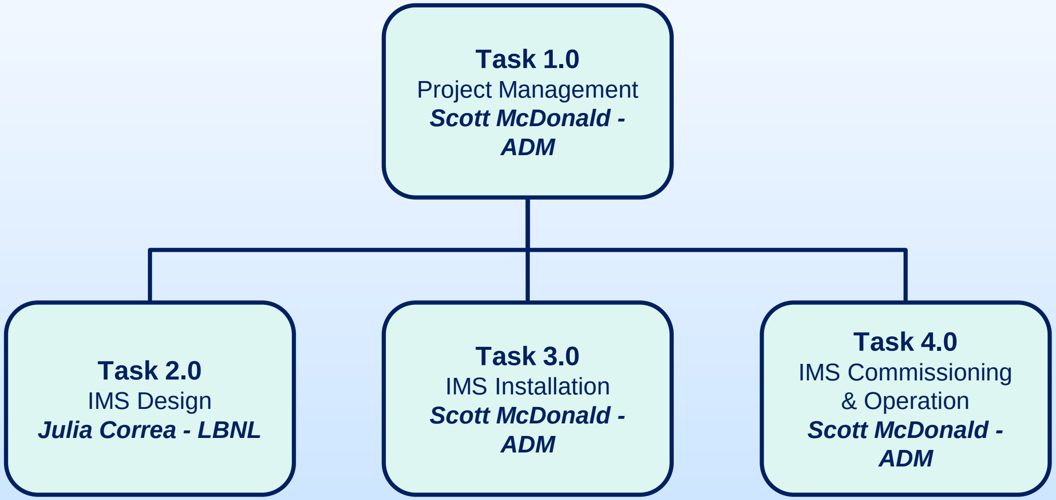
- **RCC's team will be accountable for:**
  - **Subtask 1.4 Project Outreach and Education.**

- **ISGS's team will participate in:**
  - **Subtask 1.4 Project Outreach and Education,**
  - **Subtask 2.4 Design of Passive Microseismicity Monitoring System**
  - **Subtask 4.6 Operating Passive Microseismicity Monitoring System**

- **SLB's team will participate in:**
  - **Subtask 2.1 Data Acquisition and Processing Equipment**
  - **Subtask 4.5 Validate IMS real-time reduced order models**

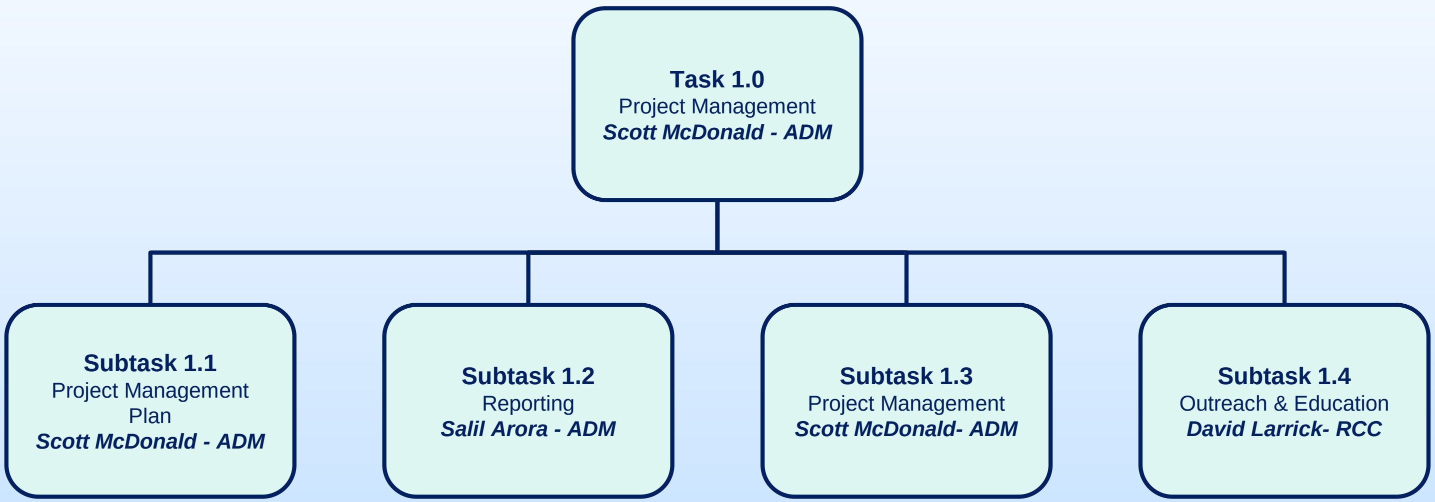
IMS Organization Chart

General Task Overview



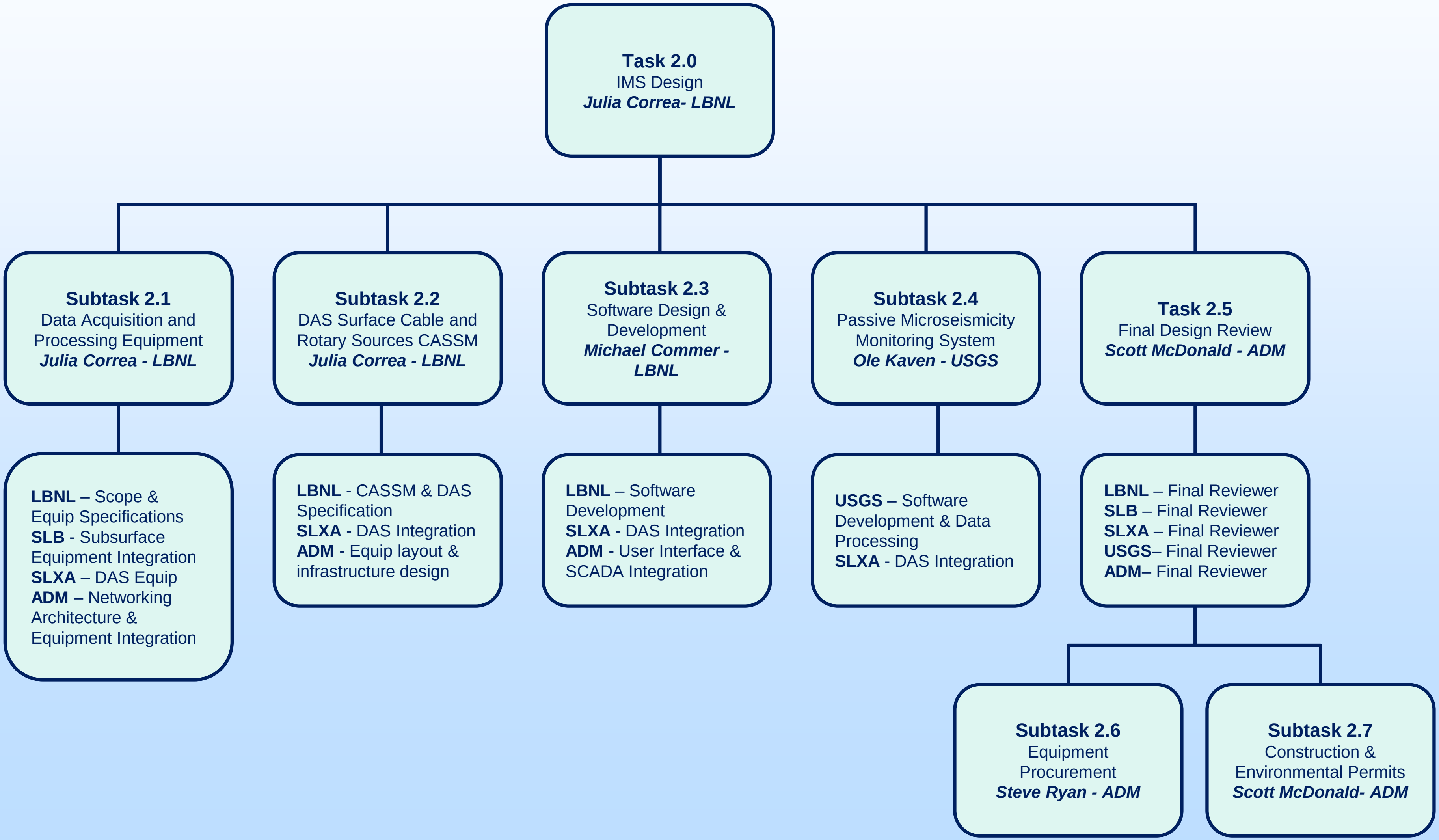
IMS Organization Chart

Task 1.0 - Project Management



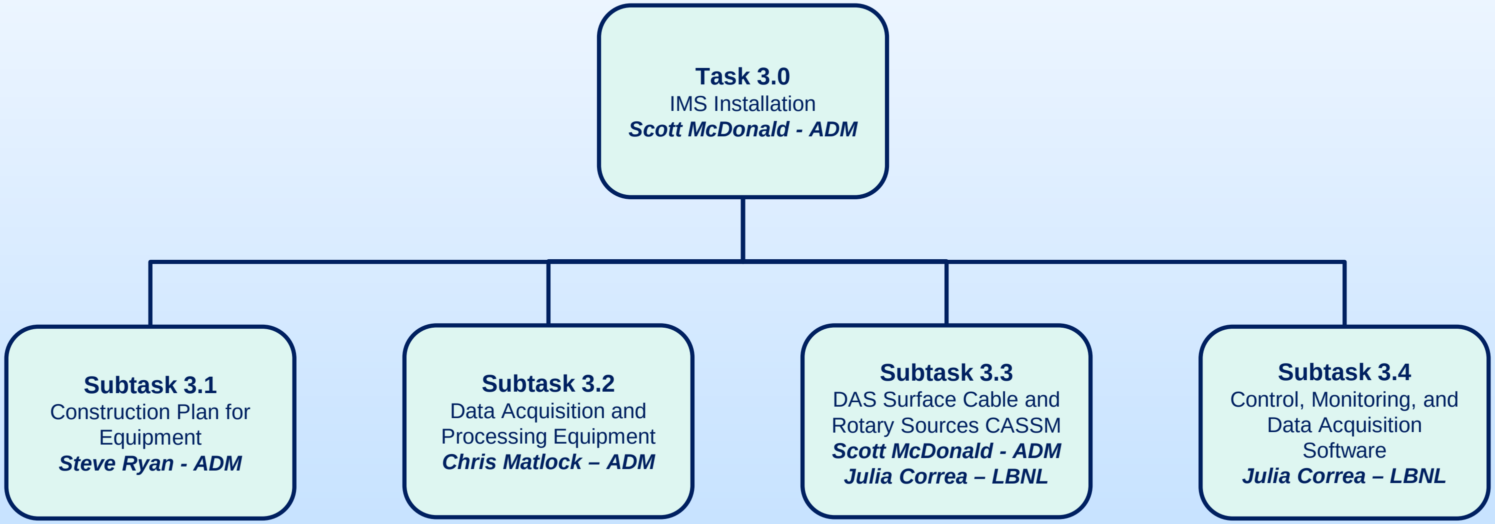
IMS Organization Chart

Task 2.0 - IMS Design



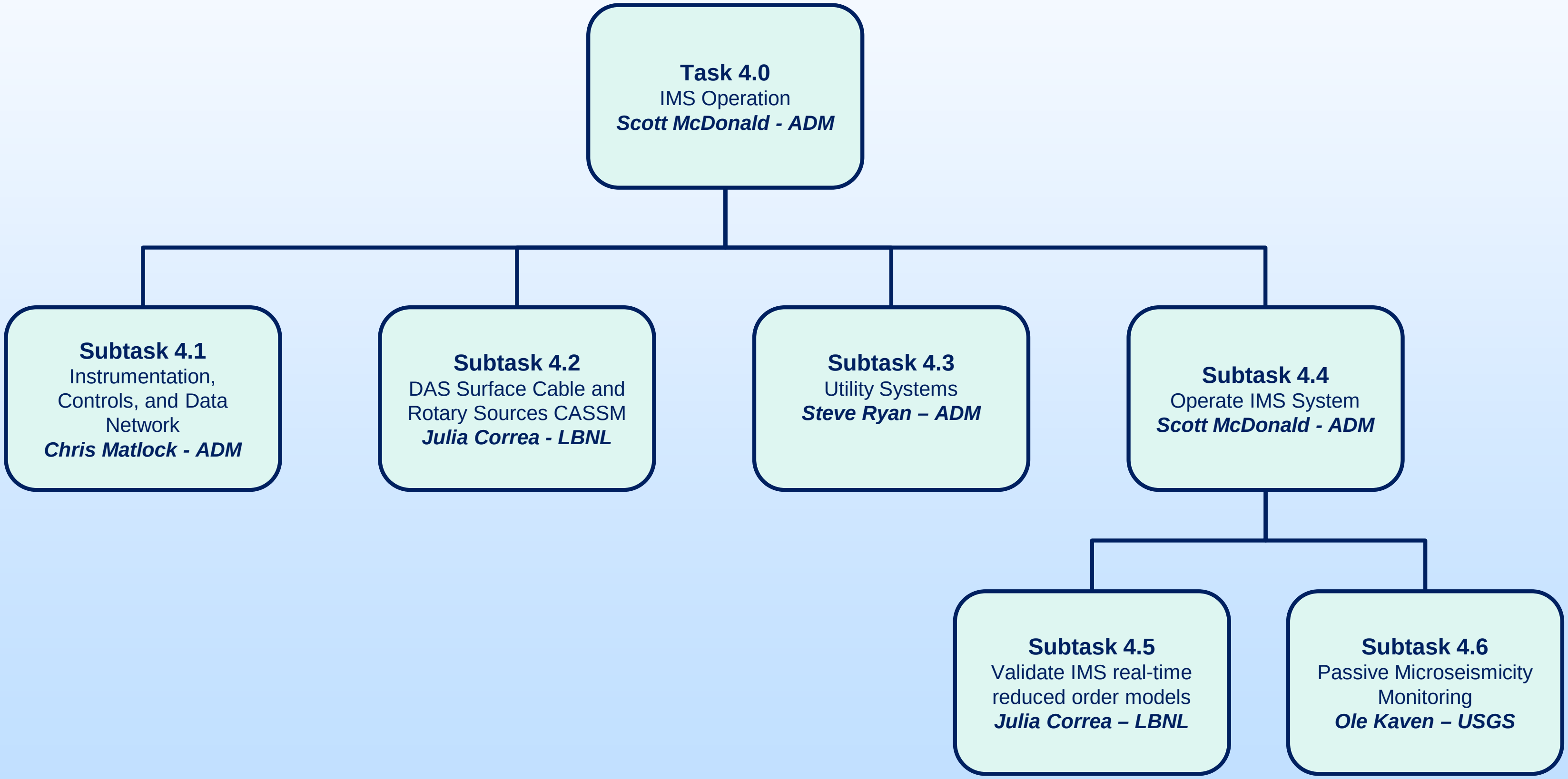
IMS Organization Chart

Task 3.0 - IMS Installation



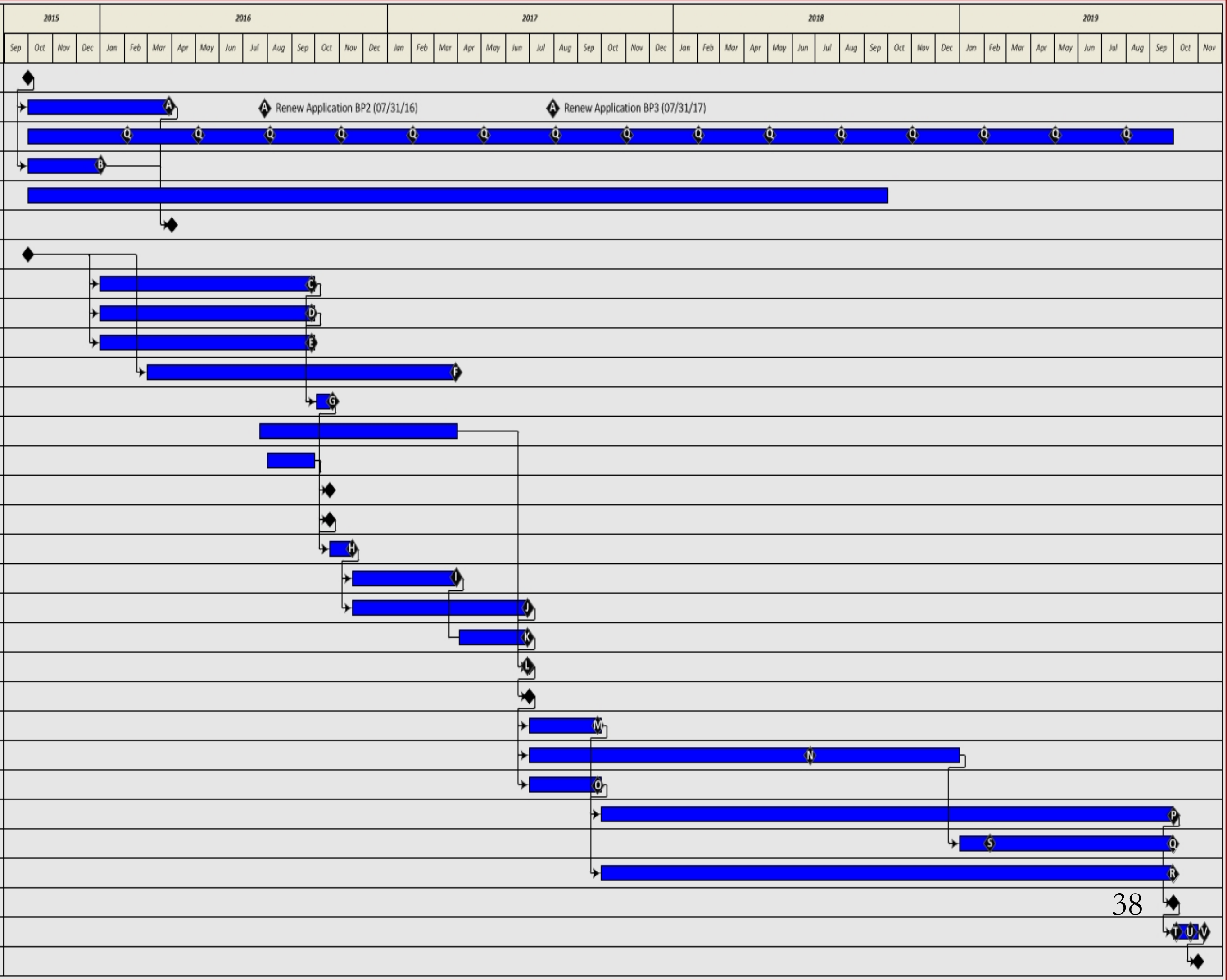
IMS Organization Chart

Task 4.0 - IMS Operation



IMS Gantt Chart

ID	Task Name	Resource Names	Start	Finish	Duration
1	Task 1.0 – Project Management and Planning		10/01/2015	10/1/2015	0d
2	Subtask 1.1: Project Management Plan	ADM	10/01/2015	03/31/2016	183d
3	Subtask 1.2: Reporting	ADM	10/01/2015	09/30/2019	1461d
4	Subtask 1.3: Kickoff Meeting	ADM	10/01/2015	12/31/2015	92d
5	Subtask 1.4: Project Outreach and Education	RCC	10/01/2015	09/30/2018	1096d
6	Complete Project Prerequisites		04/01/2016	04/01/2016	0d
7	Task 2.0 – IMS Design		10/01/2015	10/01/2015	0d
8	Subtask 2.1: IMS Data Acquisition and Processing Equipment	LBNL	01/01/2016	09/30/2016	274d
9	Subtask 2.2: Design CASSM	LBNL	01/01/2016	09/30/2016	274d
10	Subtask 2.3: IMS Software Design and Development	LBNL	01/01/2016	09/30/2016	274d
11	Subtask 2.4: Design Passive Microseismicity Monitoring system	USGS	03/01/2016	03/31/2017	396d
12	Subtask 2.5: IMS Final Design Review	ALL	10/03/2016	10/19/2016	17d
13	Subtask 2.6: IMS Equipment Procurement	ADM	07/22/2016	03/31/2017	253d
14	Subtask 2.7: Construction and Environmental Permits	ADM, RCC	08/01/2016	09/30/2016	61d
15	Complete IMS Design		10/20/2016	10/20/2016	0d
16	Task 3.0 – IMS Installation		10/20/2016	10/20/2016	0d
17	Subtask 3.1: Develop Construction Plans	ADM	10/20/2016	11/17/2016	29d
18	Subtask 3.2: IMS Data Acquisition and Processing Equipment Installation	ADM, LBNL	11/18/2016	03/31/2017	134d
19	Subtask 3.3: IMS DAS Surface Cable and Rotary Sources CASSM Installation	ADM, LBNL	11/18/2016	06/30/2017	225d
20	Subtask 3.4: IMS Control, Monitoring, and Data Acquisition, Software Installation	LBNL, ADM	04/03/2017	06/30/2017	89d
21	IMS Installation Complete		07/01/2017	07/01/2017	0d
22	Task 4.0 – IMS Commissioning and Operation		07/01/2017	07/01/2017	0d
23	Subtask 4.1: Commissioning of DAS, SOV, Instrumentation, Controls, & Data Acquisition	ADM	07/01/2017	09/30/2017	92d
24	Subtask 4.2:Commissioning of CASSM System and Joint Inversion Module	ADM	07/01/2017	12/31/2018	549d
25	Subtask 4.3: Commission of Passive Seismic Monitoring Network	ADM	07/01/2017	09/30/2017	92d
26	Subtask 4.4: Operation of IMS Equipment and Data Acquisition System	ALL	10/01/2017	09/30/2019	730d
27	Subtask 4.5 Operation of integrated CASSM System with Joint Inversion Module		01/01/2019	09/30/2019	273d
28	Subtask 4.6 Operation of Passive Seismic Monitoring Network	USGS, ADM	10/01/2017	09/30/2019	730d
29	IMS Commissioning and Operation Complete		10/01/2019	10/01/2019	0d
30	Final Project Reporting		10/01/2019	10/31/2019	31d
31	PROJECT COMPLETE		11/01/2019	11/01/2019	0d



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- Correa, J., Cheng, F., Freifeld, B. M., Ajo-Franklin, J., Pevzner, R., Tertyshnikov, K., Yavuz, S., Wood, T., Robertson, M., Daley, T., McDonald, S., Guerra, D. and Hill, D., 2019, Continuous on-demand reservoir monitoring using DAS and permanent surface vibrators: case studies and preliminary results. Presentation in SEG International Conference 2019 Post-Convention Workshop

BACKUP

CCS#2 synthetic seismogram

- Use density and sonic logs to generate reflectivity series
- Convolved the reflectivity series with a synthetic wavelet
  - Zero phase wavelet
  - Ormsby filter with frequencies 10-15-70-80 Hz