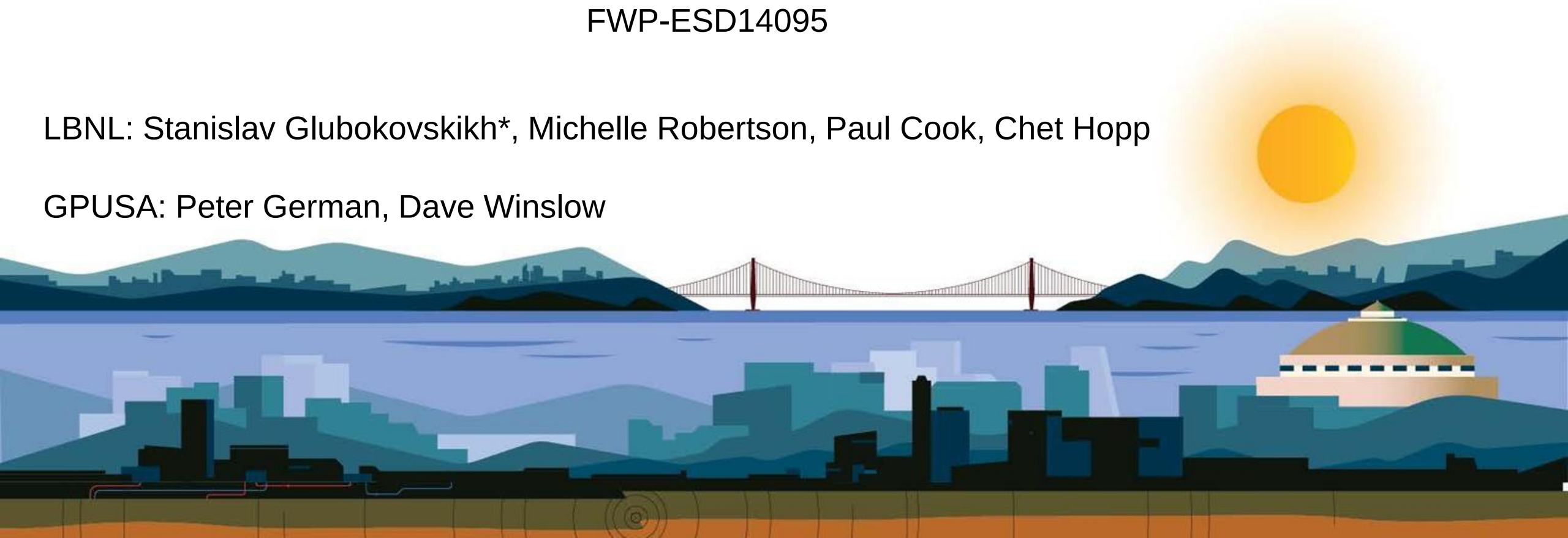
CCSMR Task 4: Optical Monitoring Technology for Deep CO_2 Injection

FWP-ESD14095

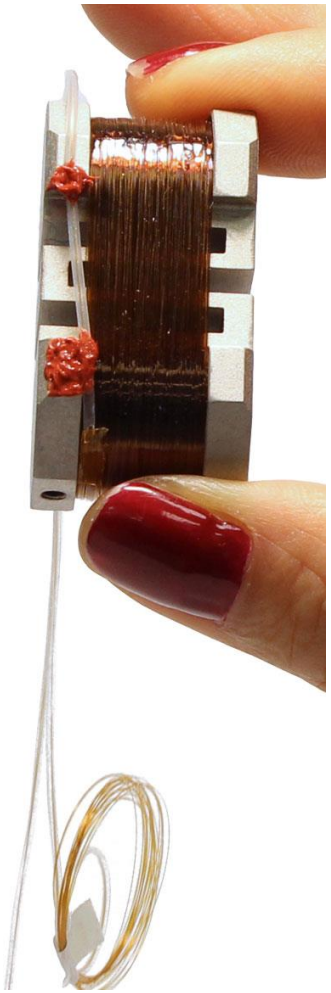
LBNL: Stanislav Glubokovskikh*, Michelle Robertson, Paul Cook, Chet Hopp

GPUSA: Peter German, Dave Winslow



High-Sensitivity Vector Optical System (HS-VOS)

Seismic sensing system for *high-precision* tracking of injected CO_2/pressure

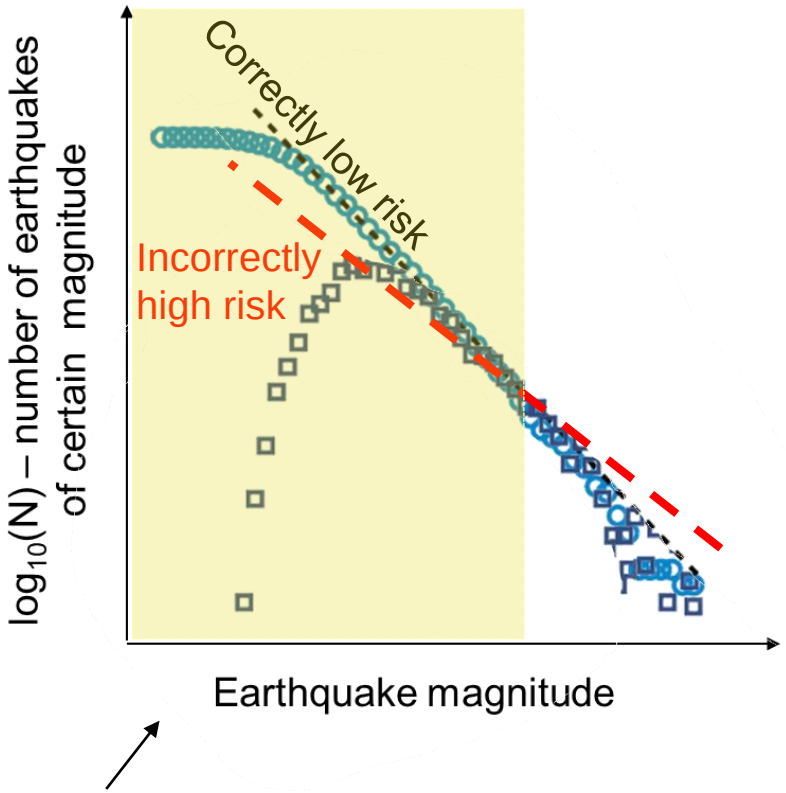


- Refining and applying a system of resilient high-fidelity seismometers
  - On hybrid wireline cable (4x copper and 18x single-mode fiber)
  - Electronics: 9-laser interrogator/demodulator recording system, w/GPS
  - Passive optical sensing, no power downhole, for up to ~3.5km depth / 200°C

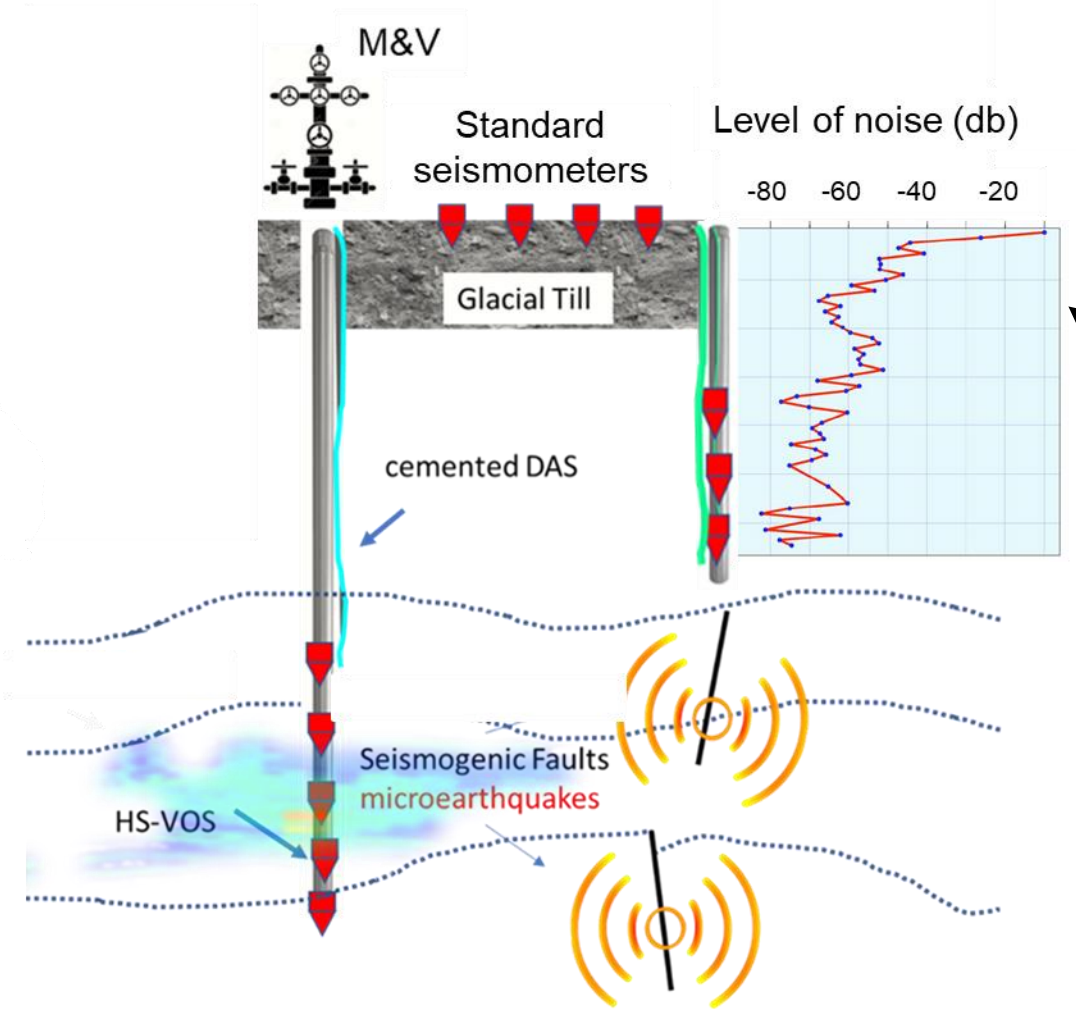
- A few semi-successful field deployments in the past
- Preparing the system for deployment at a Carbon SAFE III site

Why optical seismometers?

… sensitivity + longevity + coupling with DAS
…for cost-effective seismic monitoring of CCS



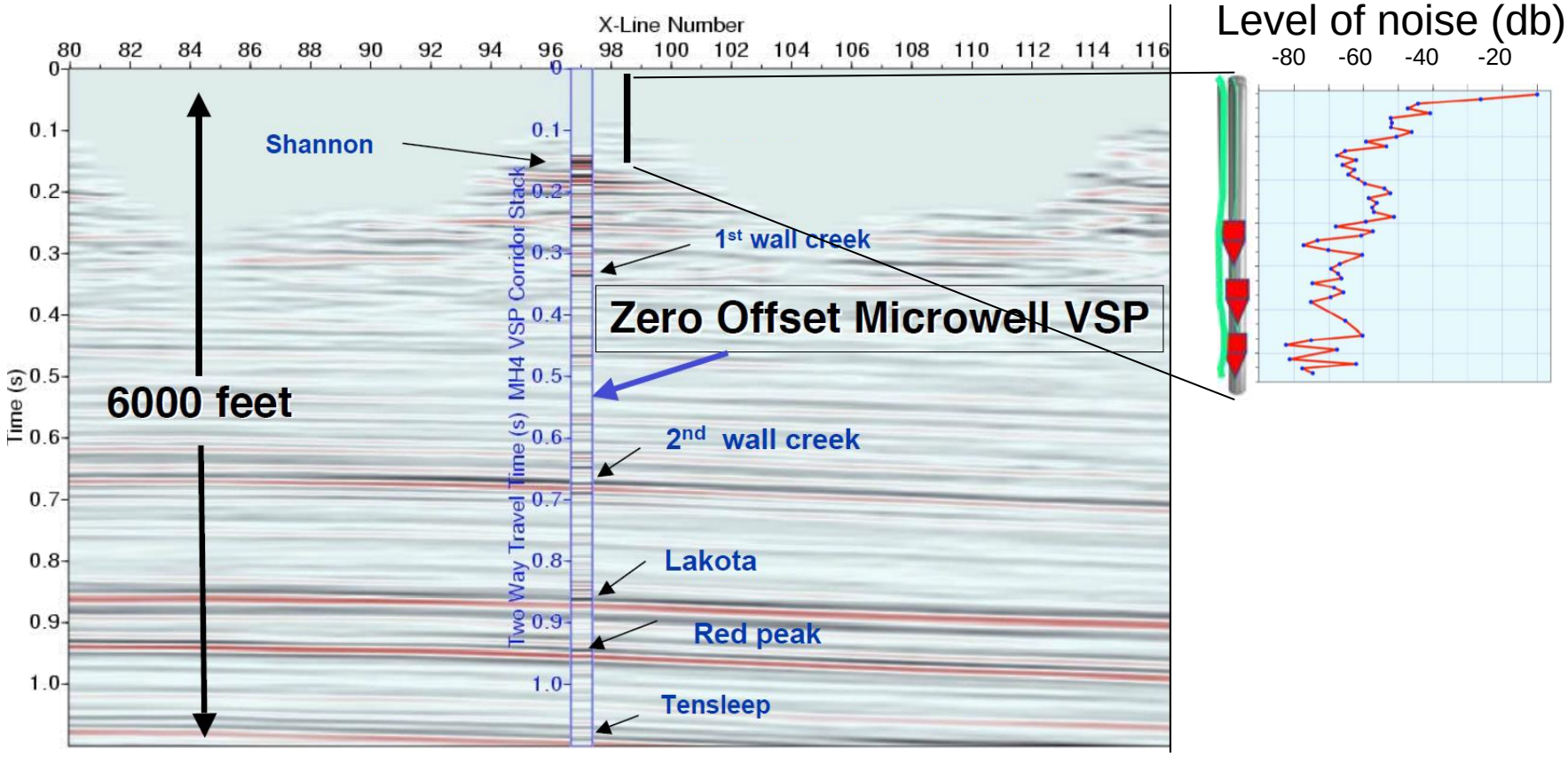
Early forecasting felt seismicity needs low-magnitude detections



SNR in shallow holes may enable μ-VSP monitoring

Development of high-repeatability m-VSP in shallow boreholes

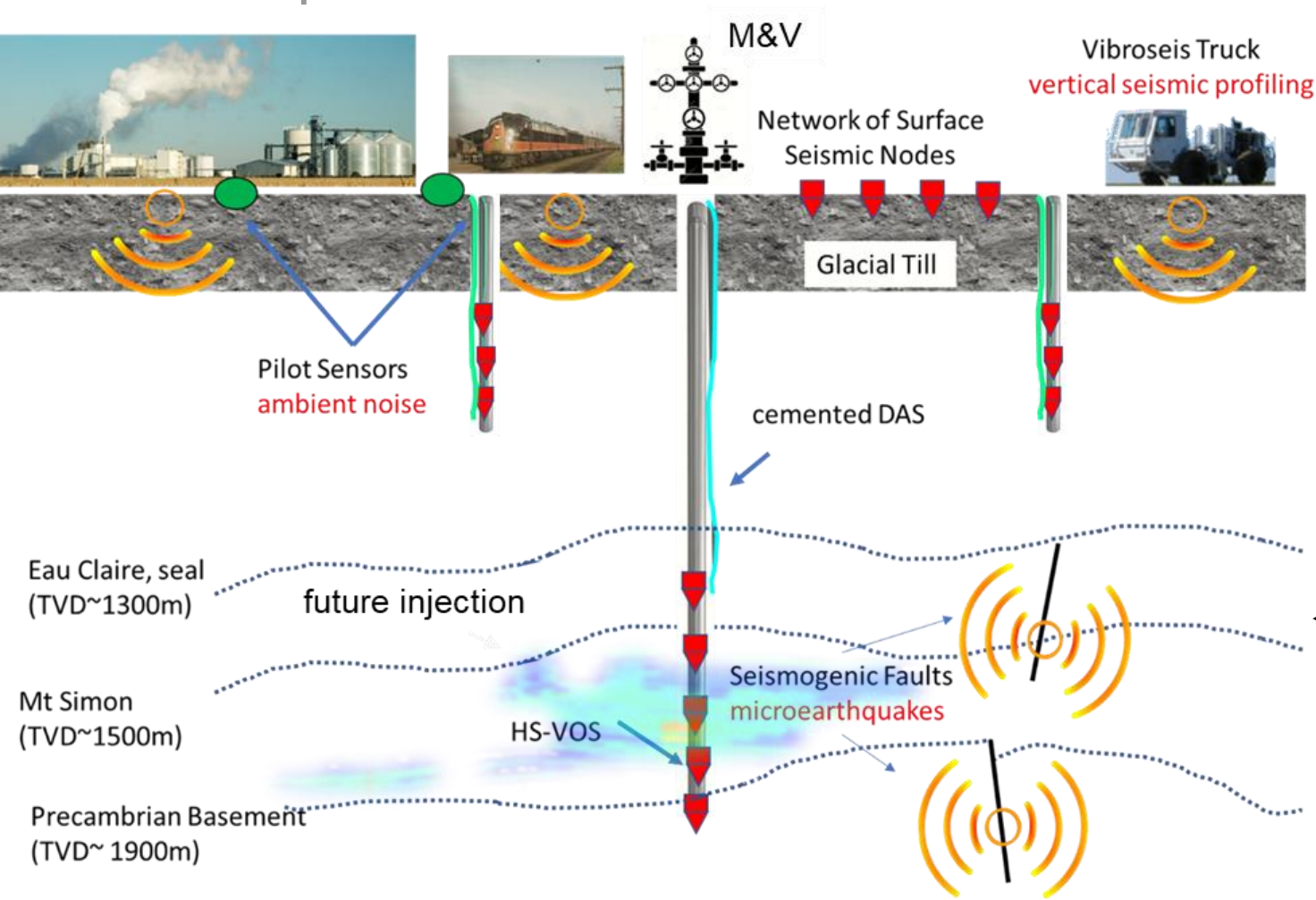
Shallow, slim, cemented boreholes can monitor the subsurface well



Case study in West Texas: *Majer, Daley et al. 2008*

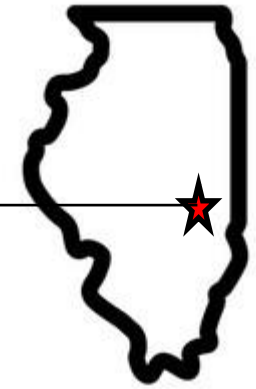
Field deployment at a Carbon SAFE III site

Support FWP: a comprehensive borehole seismic characterization using shallow and deep boreholes



1. 3D VSP for reservoir characterization + optimization of the 4D seismic
2. Passive recording for natural seismicity and ambient noise
3. Development of high-repeatability μ–VSP in shallow boreholes
4. Benchmarking seismic sensors

One Earth Sequestration, near Gibson city, IL



ISGS

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Modified statement of work and schedule due to site access issues

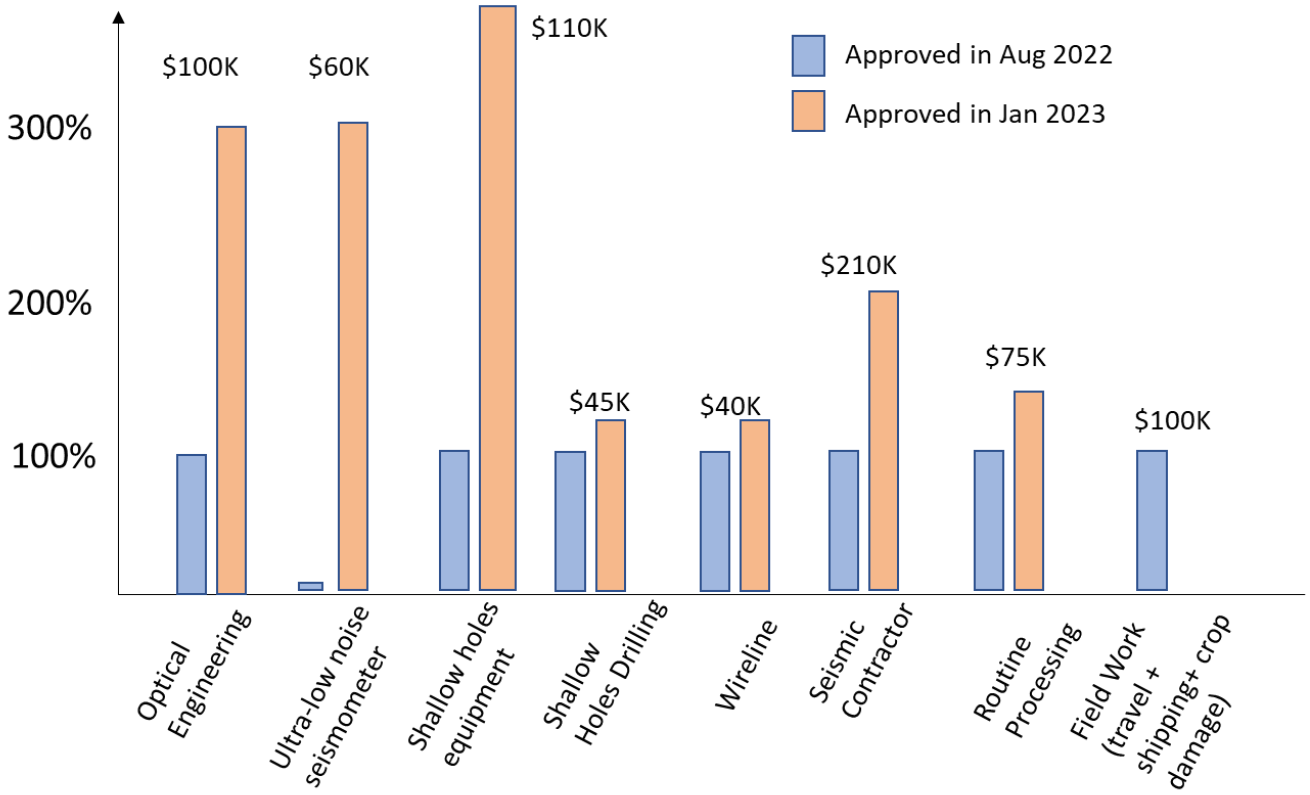
Re-focus on instrumentation engineering and synthetic feasibility analysis

CCSMR_T4 ($390K) + Support_FWP ($673K)=$**1,163K**

Costs increased, total outside LBNL **$780K + …**

+ … issues with site access = …

Modified SOW

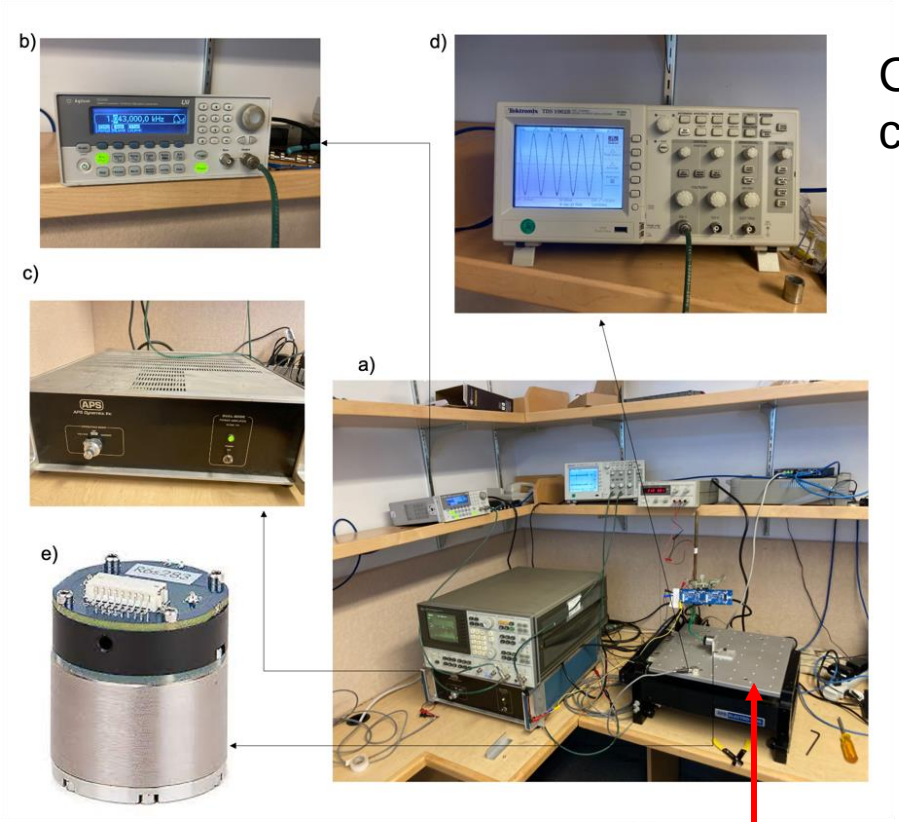


Proposed activities in FY22:

1. Save money for the prime-time in FY23
2. Finalize the HS-VOS engineering work ($110K)
3. Shallow borehole tests of the optical seismometers at the Richmond Filed Station ($50K)
4. Modeling-driven optimization of the data processing/interpretation ($60K)

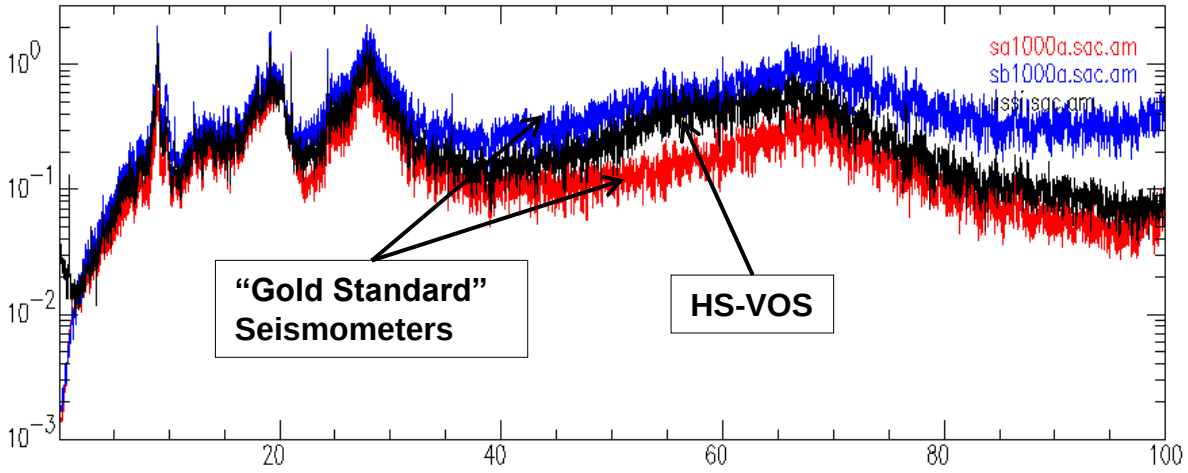
HS-VOS: sensors calibration on a vibration table

Preliminary results: the sensors compares well with the best commercial analogs



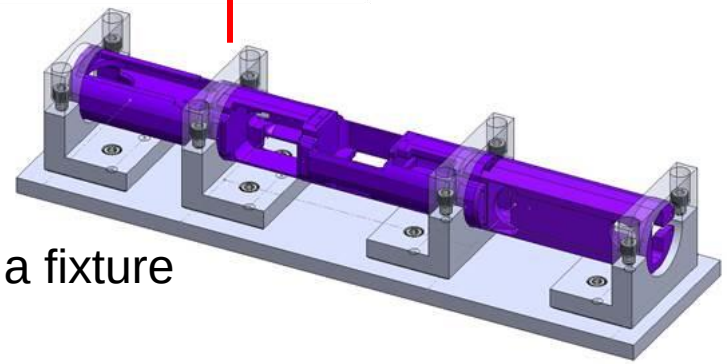
Components of the calibration system

Normalized acceleration spectra



Frequency (Hz)

SAULN accelerometer



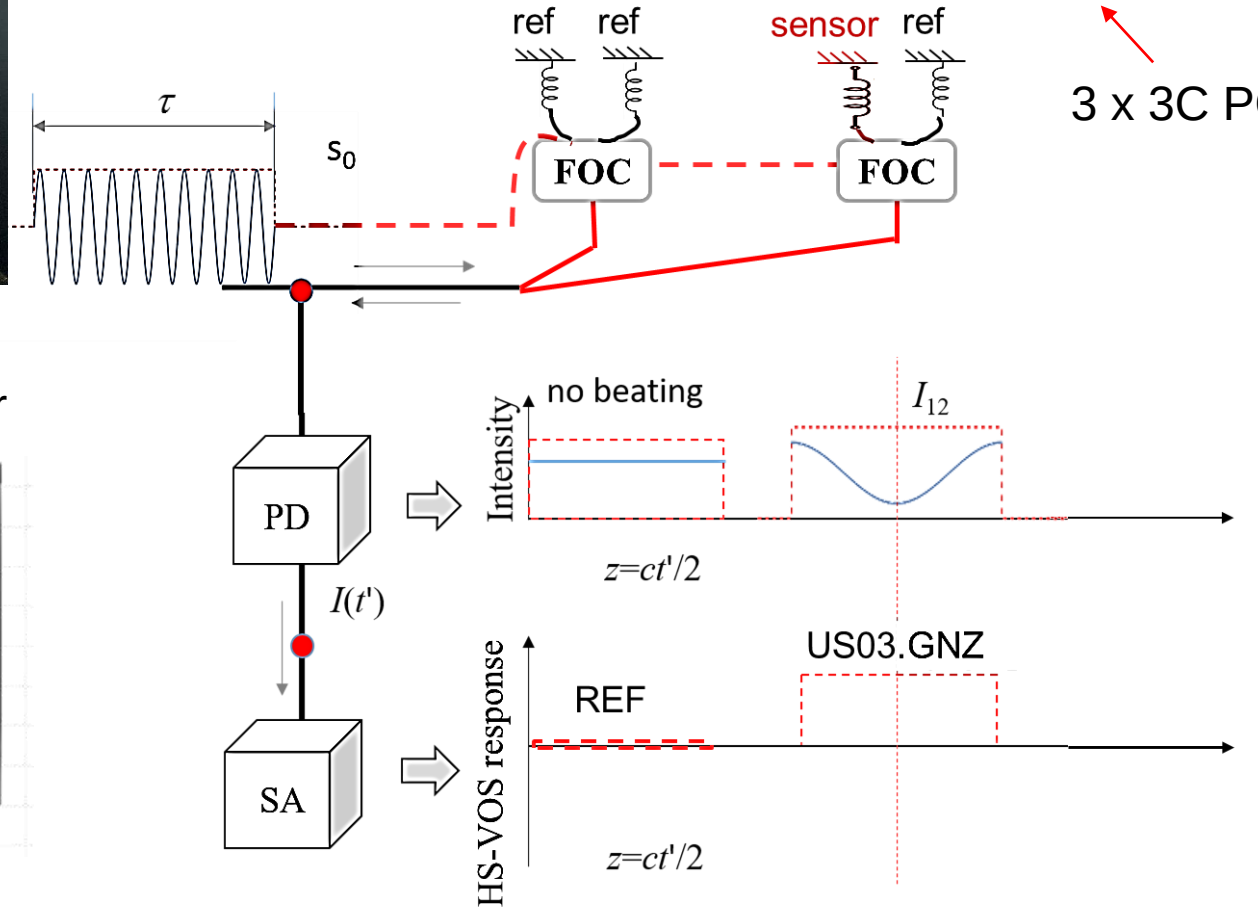
Open HS-VOS pod in a fixture

Field deployment at a Carbon SAFE III site

A comprehensive borehole seismic characterization using shallow and deep boreholes

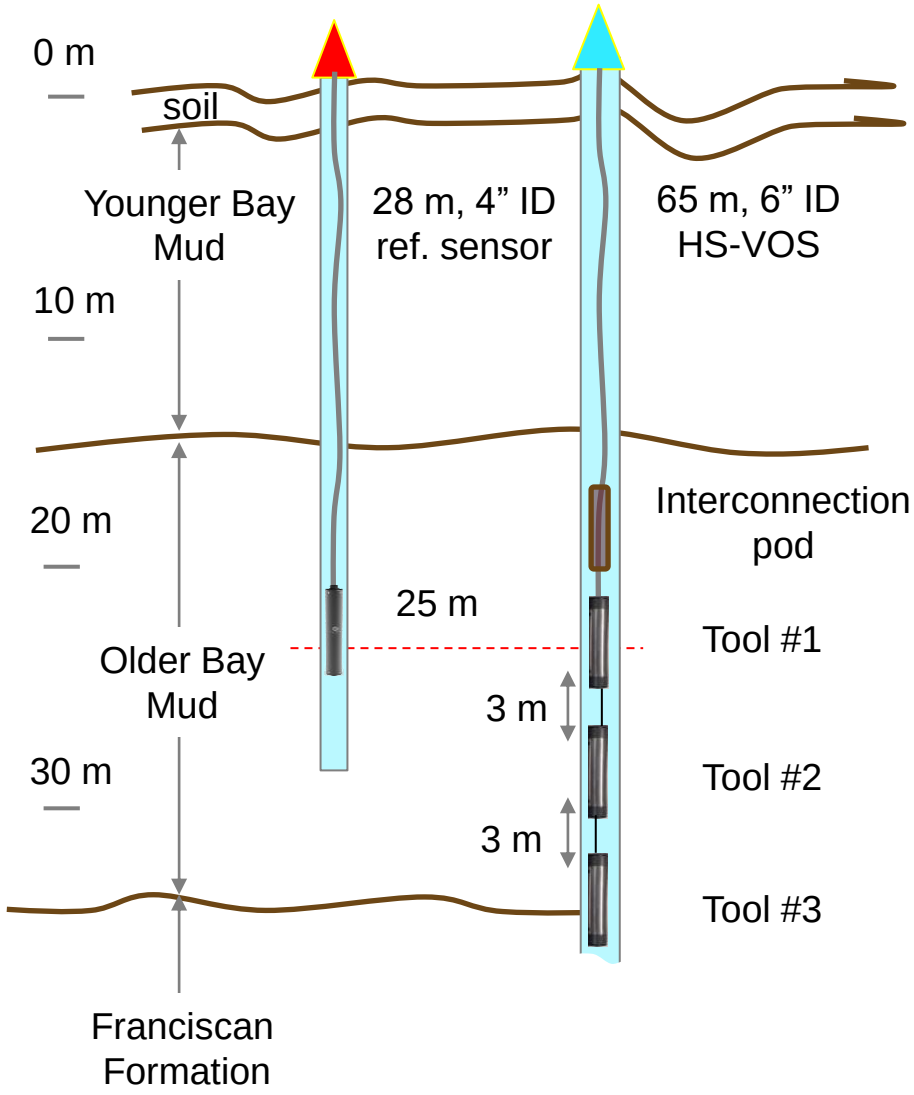
laser source

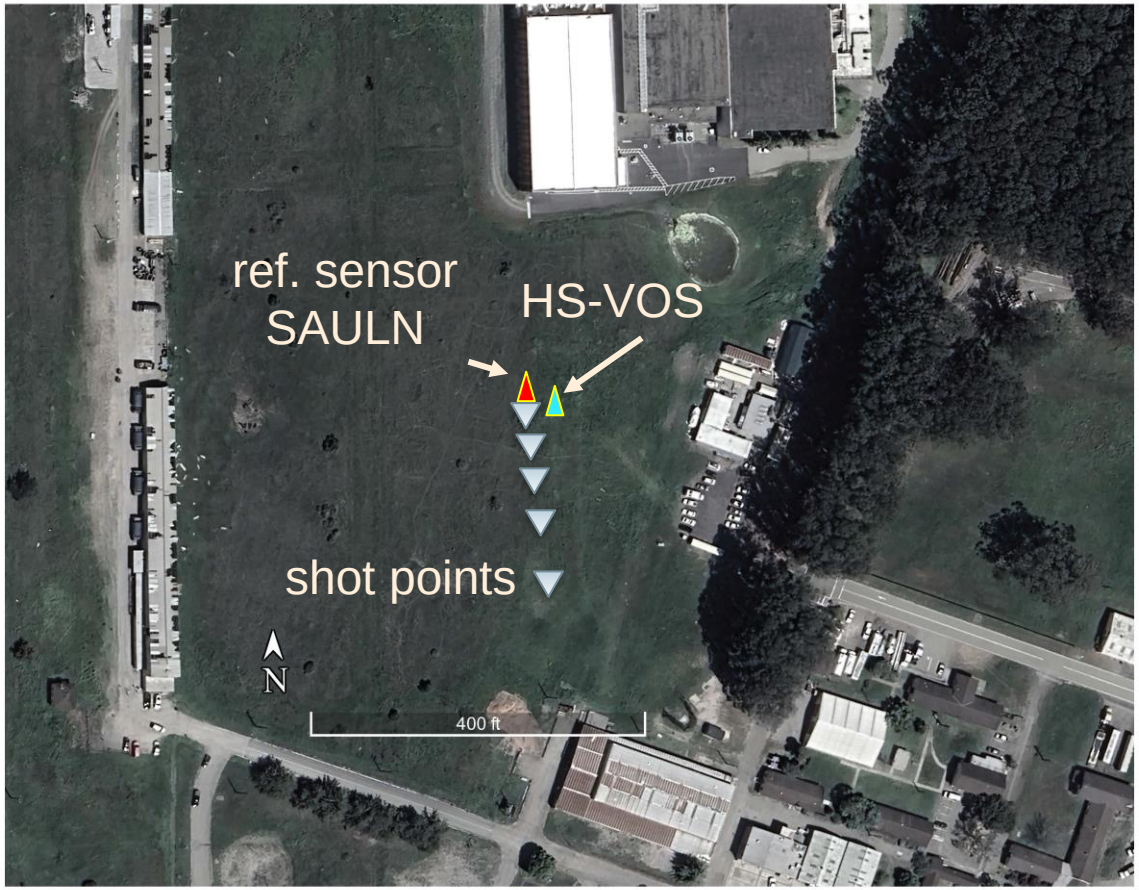
optical interrogator



HS-VOS: field testing in shallow boreholes

Outline of the test at the Richmond Field Station, LBNL's testing facility

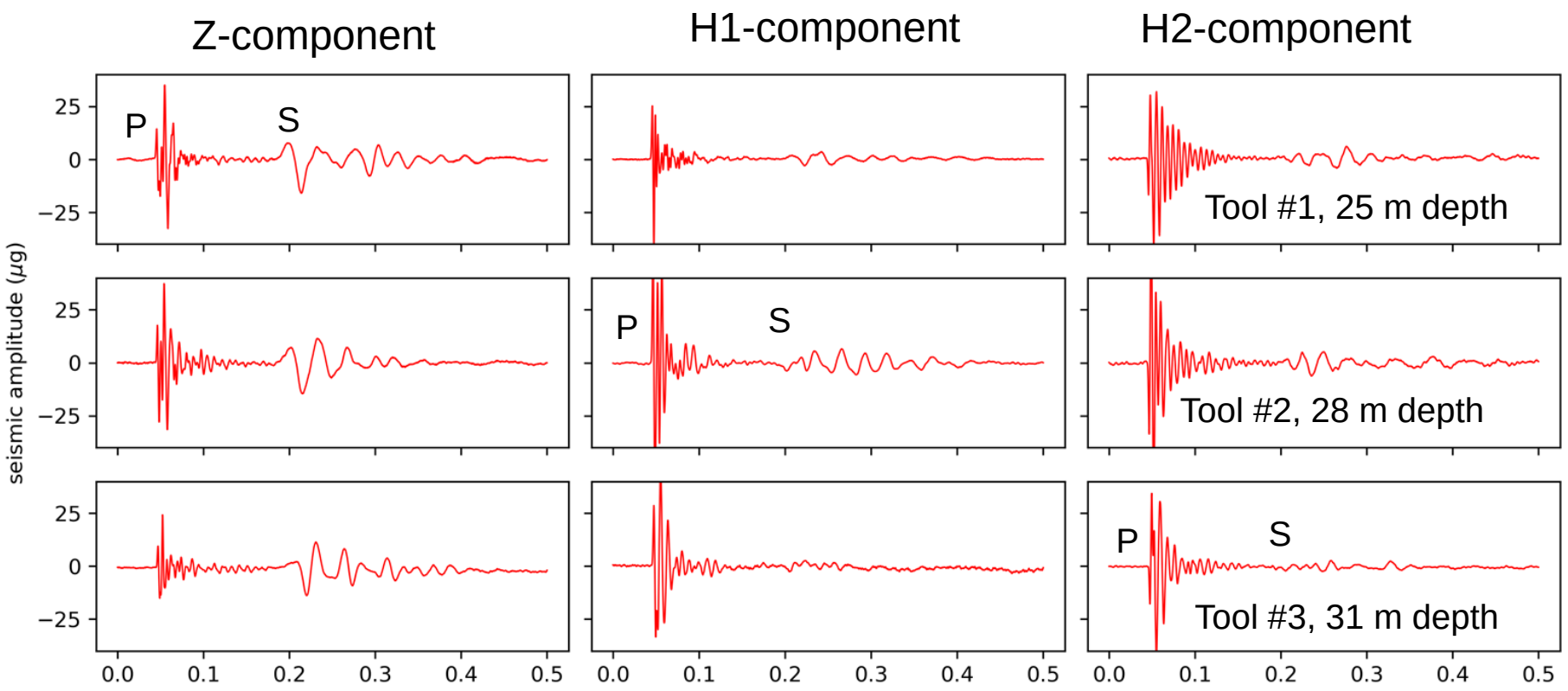


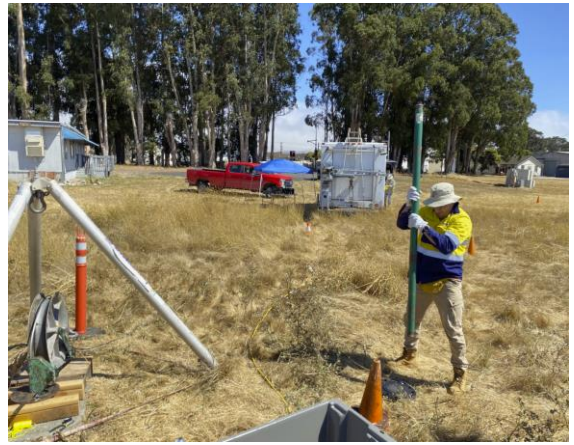


HS-VOS: field testing in shallow boreholes

Preliminary results: uphole electronics and downhole sondes are stable+…

… +signal-to-noise ratio is high





Weight-drop 48 m form the wellhead

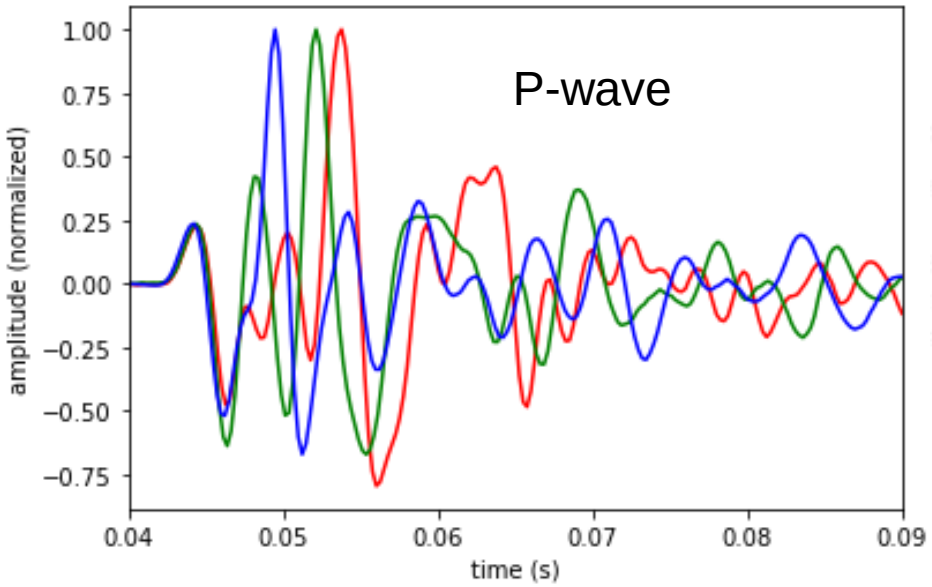
Clamping: inflatable bladder

HS-VOS: field testing in shallow boreholes

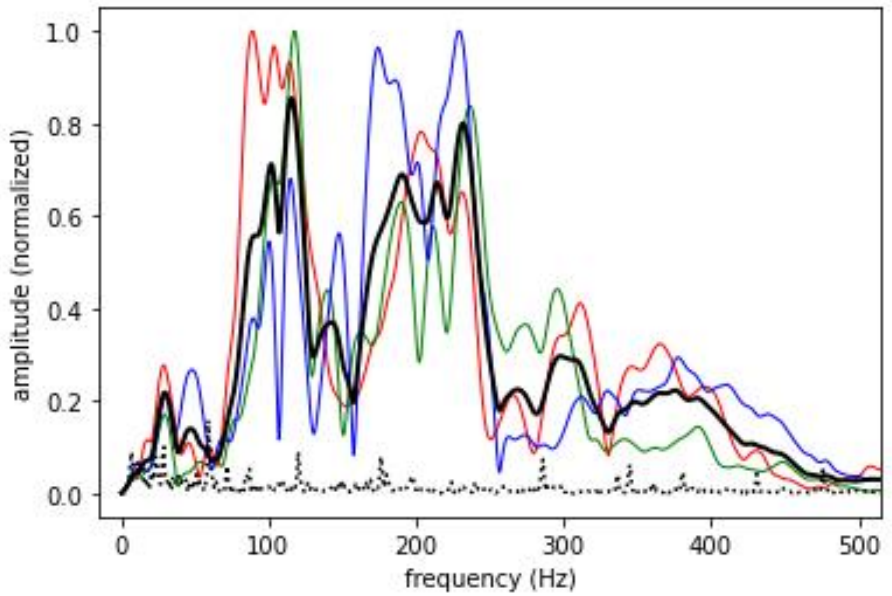
Preliminary results: consistent records among the sensors +…

… + but still a good example of repeatability of the VSP data

Vertical component, waveform+….



…+ spectra

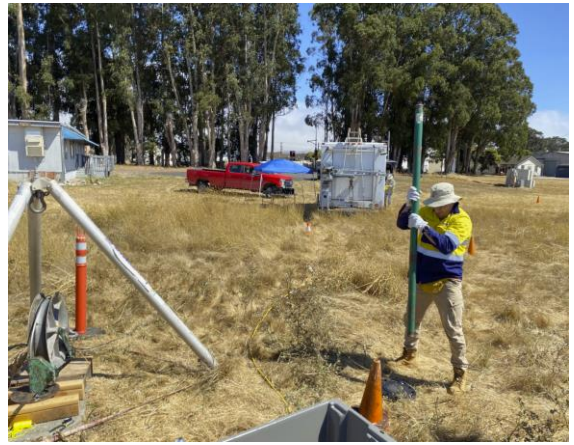


Tool #1, 25 m

Tool #2, 28 m

Tool #3, 31 m

Mean spectrum



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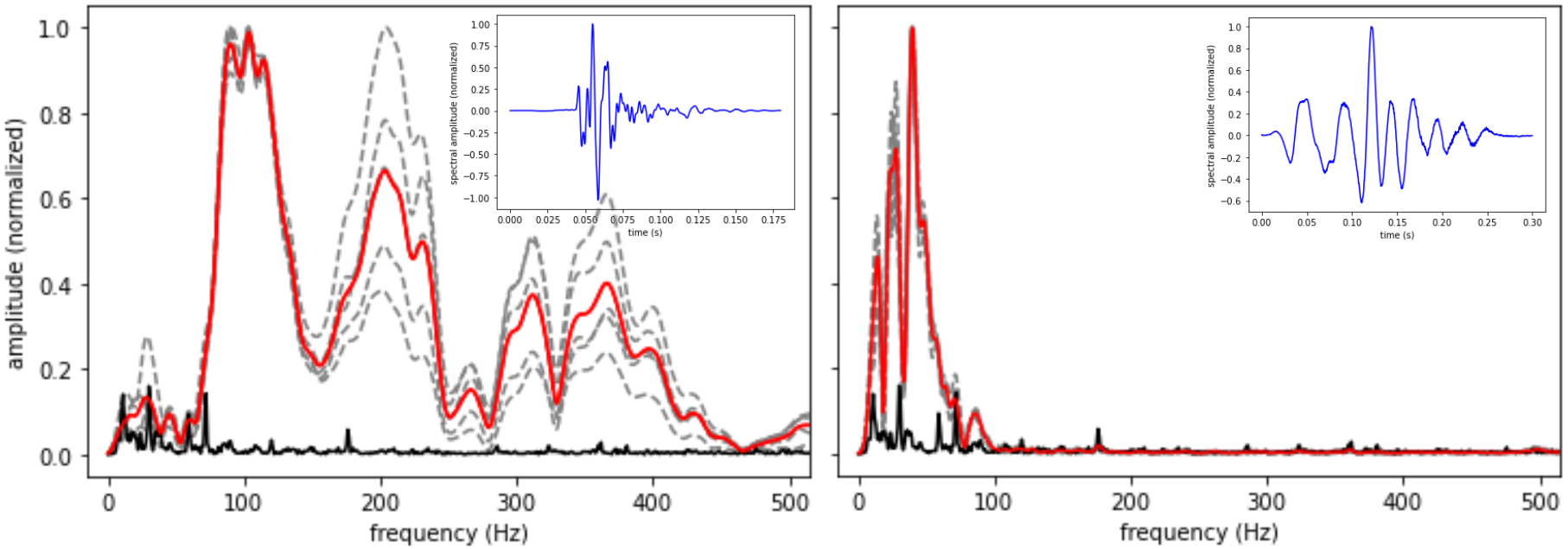
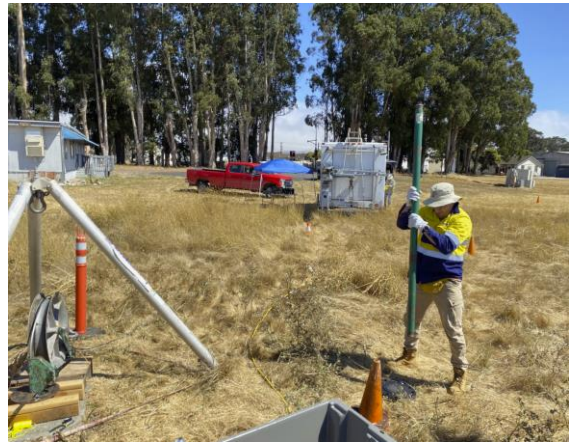
HS-VOS: field testing in shallow boreholes

Preliminary results: HS-VOS gives either comparable or superior signal-to-noise…

… compared with the reference accelerometer

P-wave, ‘vertical’ spectra **HS-VOS** S-wave, ‘vertical’ spectra





Weight-drop 48 m form the wellhead

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Mean spectrum

Spectrum, each shot

Spectrum noise

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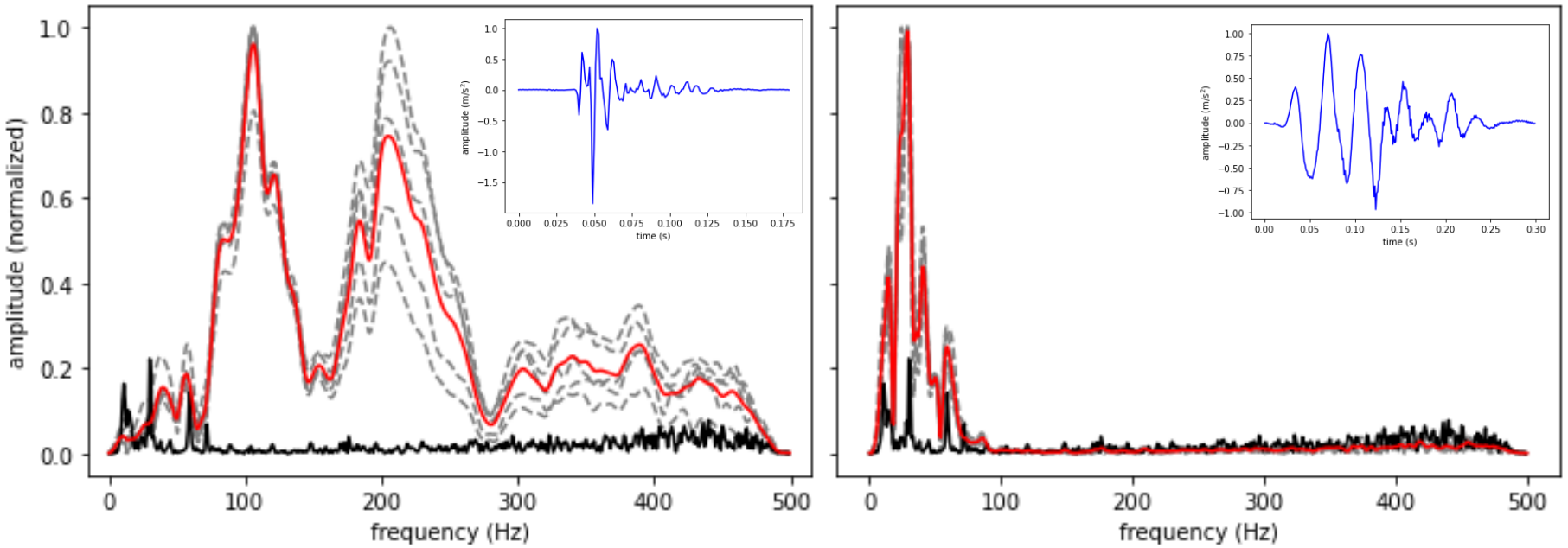
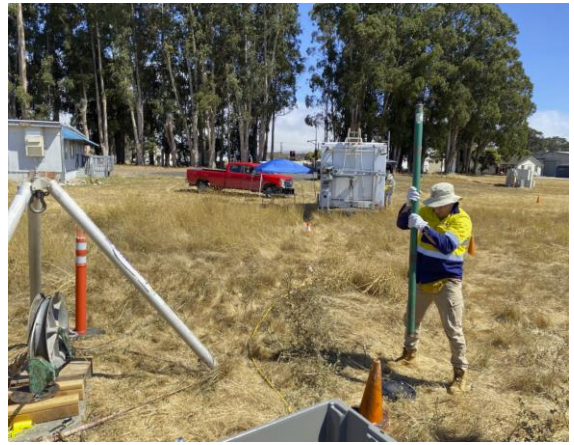
HS-VOS: field testing in shallow boreholes

Preliminary results: HS-VOS gives either comparable or superior signal-to-noise…

… compared with the reference accelerometer

P-wave, ‘vertical’ spectra **SAULN** S-wave, ‘vertical’ spectra





Weight-drop 48 m form the wellhead

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Mean spectrum

Spectrum, each shot

Spectrum noise

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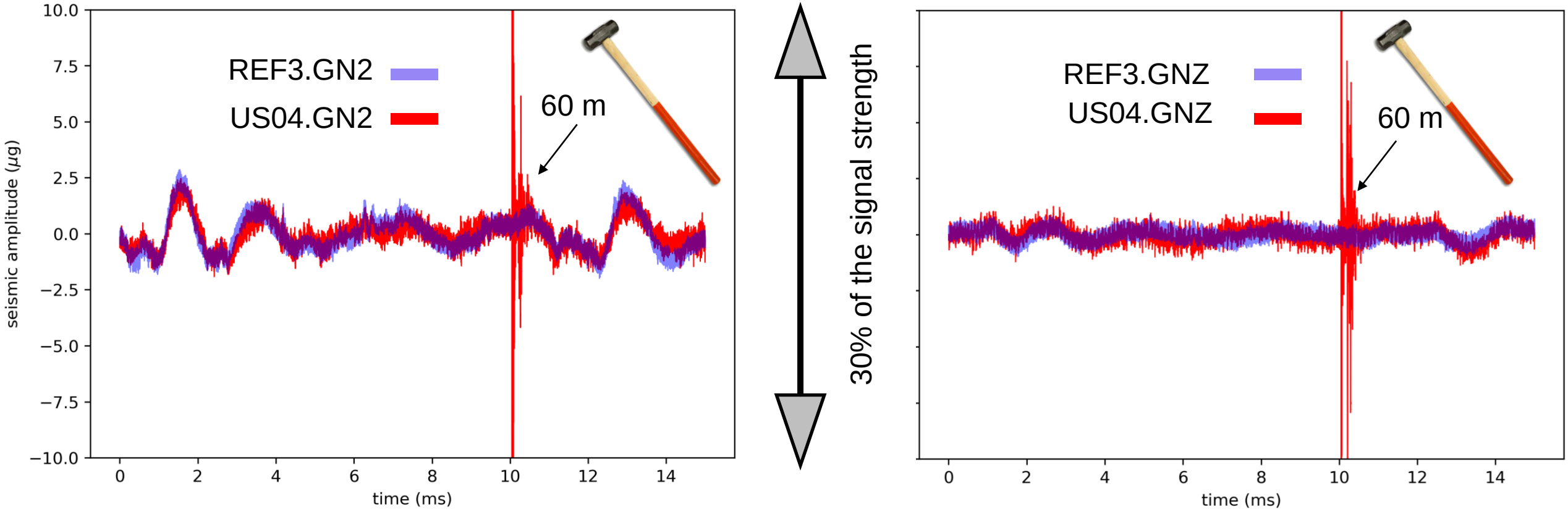
HS-VOS: field testing in shallow boreholes

Preliminary results: Reference sensors in the pod record optical noise →

… → can be used for denoising



Preparation to the field deployment at the One Earth Sequestration site

Designed the seismic acquisition system including the instrumentation and survey design

Nodal stations

DAQLink 4

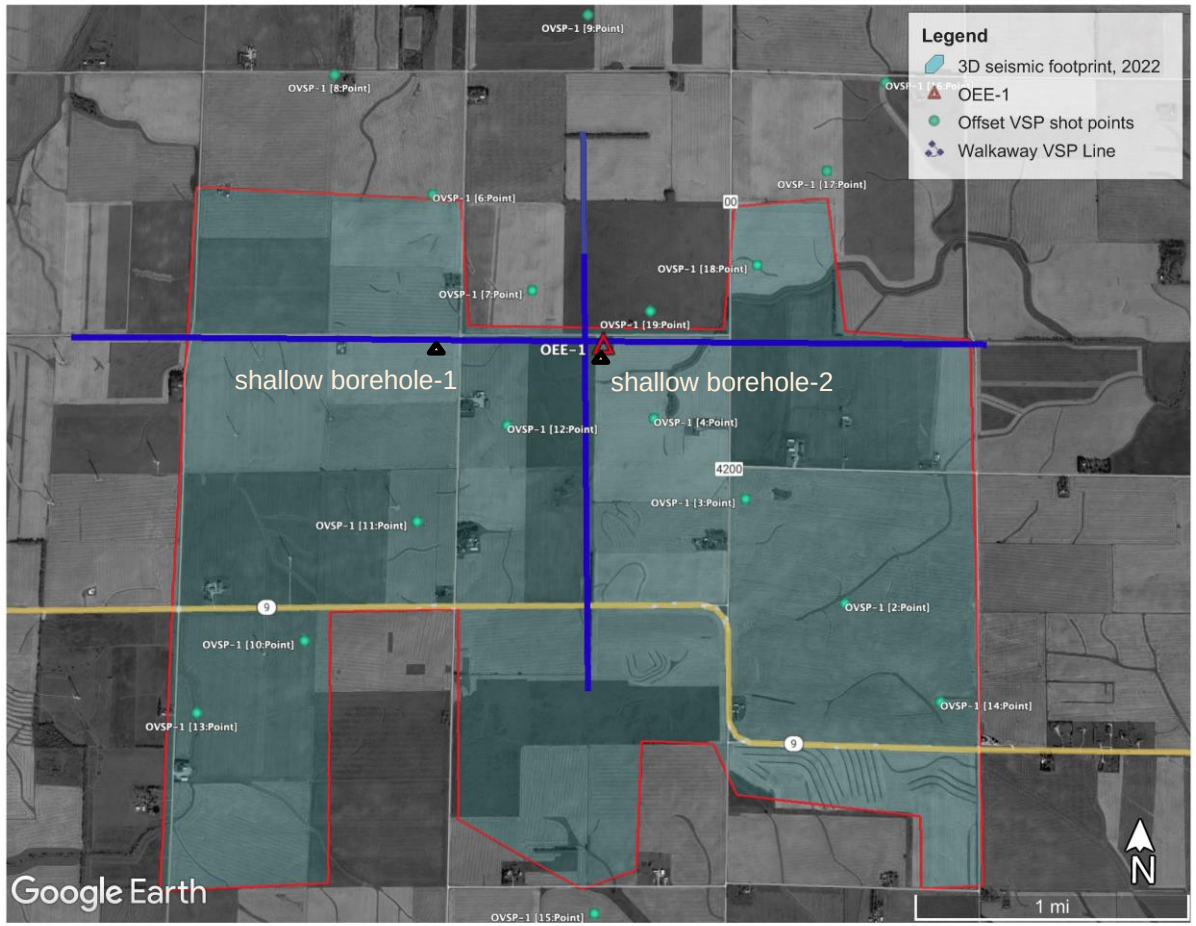
Helical DAS

ProSeismic

3C geophones

Silicon Audio
Ultra low-noise
broadband
accelerometer

150-200 m dedicated seismic borehole.
Fully-cemented seismic sensors



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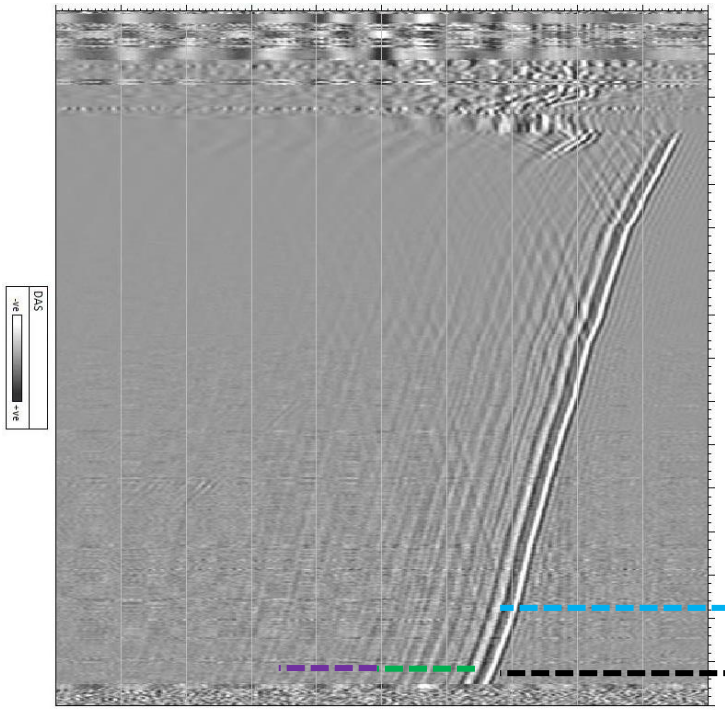
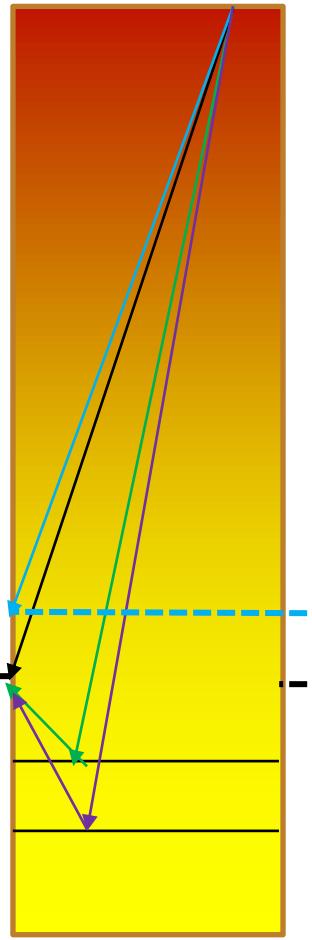
Preparation to the field deployment at the One Earth Sequestration site

Fast-track analysis of the by-product VSP suggests that the target reflections might be detectable

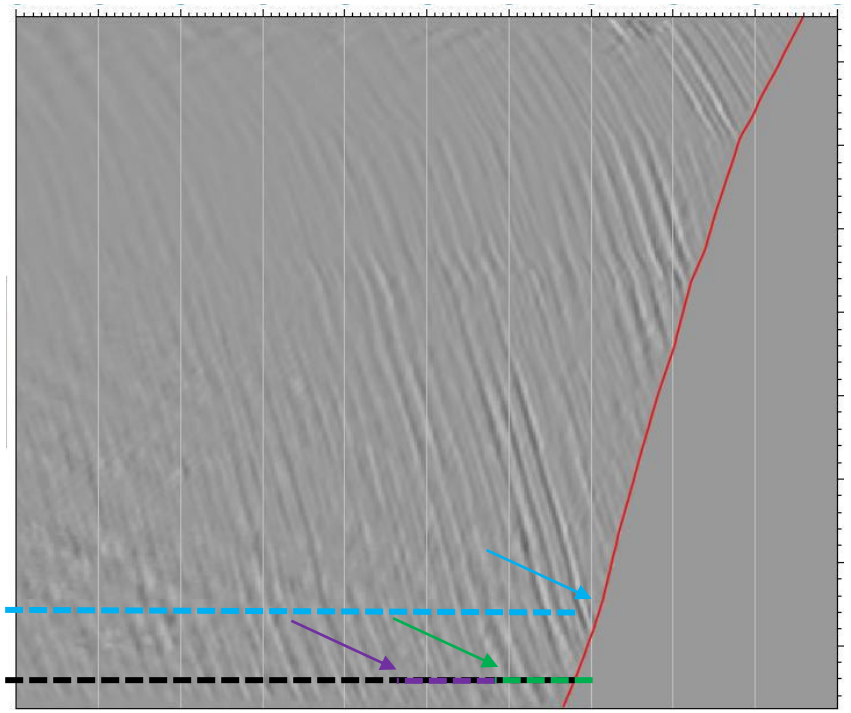
Raw, correlated shot



A smoothed velocity model



Stack 30x, correlated shot, wavefield separation



Project Summary

Full-on preparation to the field deployment at Carbon SAFE III

- HS-VOS system is operational as confirmed by:
  - Tests in the workshop
  - Deployment in the shallow boreholes
- Seismic survey design is done:
  - Procured the equipment for permanent deployment
  - Contract with seismic/wireline contractor is close to full execution
- Commenced the modeling-driven optimization of the data analysis:
  - Analysis of the legacy VSP data
  - Building a numerical seismic model

Potential Synergies

- Other Carbon Storage and monitoring projects in the US and abroad
  - Dry Fork CarbonSAFE Phase III (Wyoming)?
- Passive/active monitoring using shallow boreholes:
  - Full proposal submitted to DOE for a long-term monitoring at a commercial storage site in the Bay Area
- Induced seismicity monitoring and/or crosshole seismic at hot injection similar to CarbFIX 2 (Iceland)
  - Our 200C sondes are interchangeable with the 200C test sondes

Organization Chart

- **Lawrence Berkeley National Laboratory:**
  - Task PI, Data Lead: Stanislav Glubokovskikh
  - Field Lead: Michelle Robertson
  - Senior Engineer: Paul Cook
  - Software Systems: Sung Choi

- **Illinois State Geological Survey:**
  - Illinois Storage Corridor PI: Roland Okwen
  - Geological modeling: Sherilyn William-Stroud
  - Seismic Acquisition: Curt Blakely

- **PROJEO**
  - Support of the field work: Nick Malkiewicz

- **GPUSA:**
  - Seismologist: Peter German
  - Optical Engineer: David Winslow

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 at an operational CarbonSAFE sites
  - Broader learnings from leveraged international research opportunities
  - Rapid transfer of knowledge to domestic programs

Gantt Chart

Task	Milestone Description*	Fiscal Year 2023					Planned Start Date	Planned Completion Date (Reporting Date)**	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
		FY23	Q1	Q2	Q3	Q4					
Milestone 4-1 (A)	Milestone 4-1: Design of the shallow seismic boreholes, optimized for the microhole VSP monitoring	Q1FY23	x				July-22	12/31/2022 (1/31/2023)	April-22	Dec-23	Completed as reported in FY23Q1 report.
Milestone 4-2 (B)	Preparation of the HS-VOS system for the deployment in a test borehole	Q2FY23		x			Aug-22	03/31/2023 (04/30/2023)	Aug-22	Aug-23	Completed as reported in FY23Q2 report.
Milestone 4-3 (C)	Analysis of selected VSP shots recorded at the OEE site in March-22	Q3FY23			x		May-23	6/30/2023 (7/31/2023)	July-23	→	Partially completed as reported in Q3FY23
Milestone 4-4 (D)	Synthetic feasibility study of the borehole seismic monitoring system at the OEE site.	Q4FY22				x	Aug-23	9/30/2023 (10/31/2023)	Aug-23	→	Commenced. Geological and geophysical data sets are assembled.

Bibliography

- Currently in the instrument development and testing stages, with substantial delays in 2020-2023 due to COVID-19 restrictions and issues associated with post-COVID supply chains delays and cost increases.

- No Journal publications yet for this subtask, two are in preparation