
EERC
Critical Challenges. Practical Solutions.

CO_2 INJECTION MONITORING WITH A SCALABLE, AUTOMATED, SEMIPERMANENT SEISMIC ARRAY (SASSA)

DE-FE0012665

Amanda Livers

Energy & Environmental Research Center

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

Critical Challenges. Practical Solutions.

PRESENTATION OUTLINE

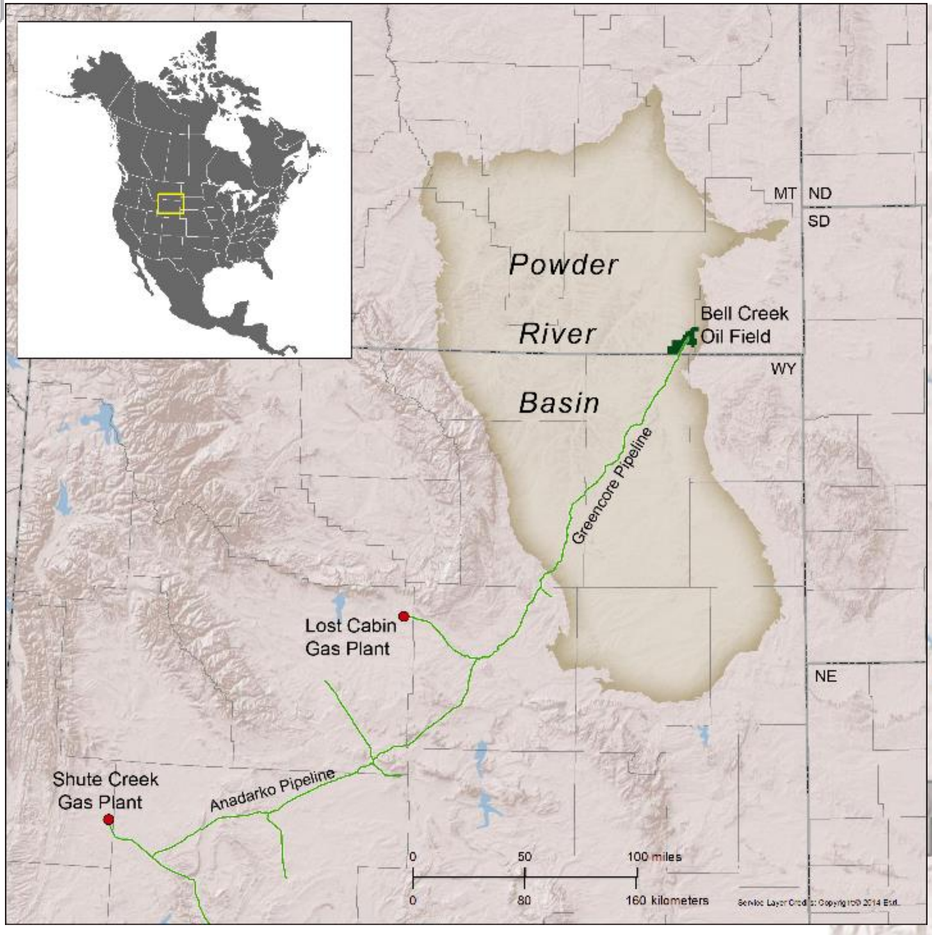
- Project Overview
  - Study area
  - SASSA concept
- Reservoir Simulations and 2-D Line
- Array Design and Acquisition
- Data Processing and Interpretation
- Accomplishments
- Lessons Learned
- Synergy Opportunities
- Summary

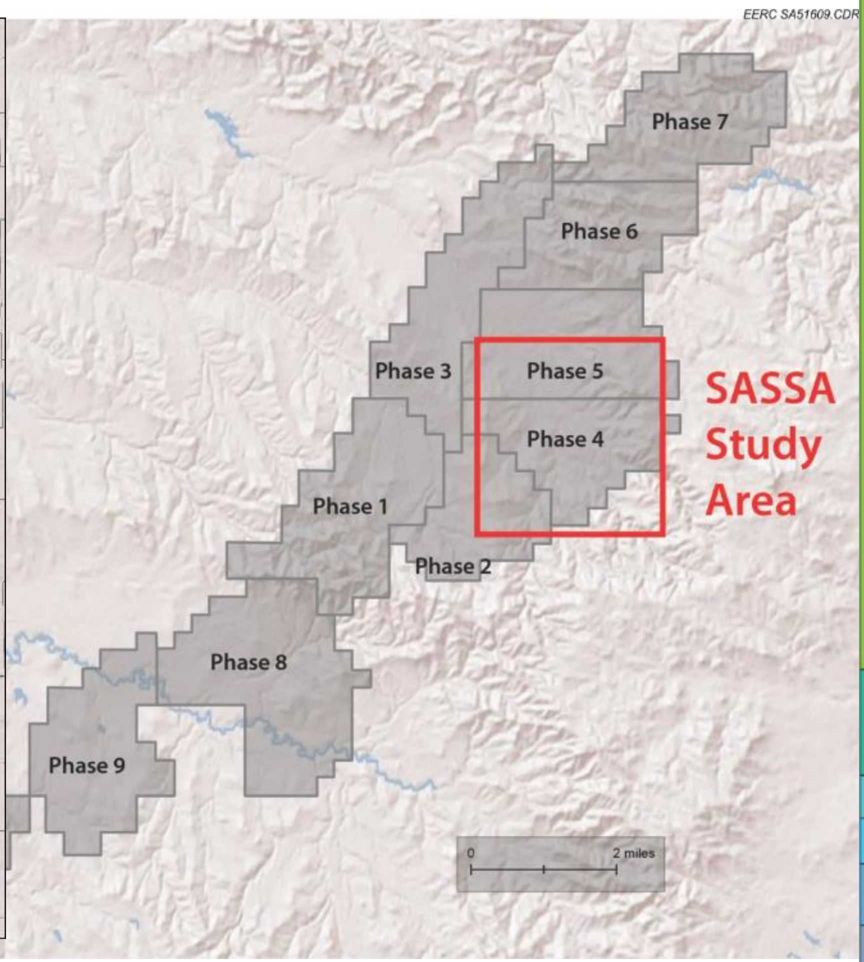

Active Receiver Location


Before Reclamation

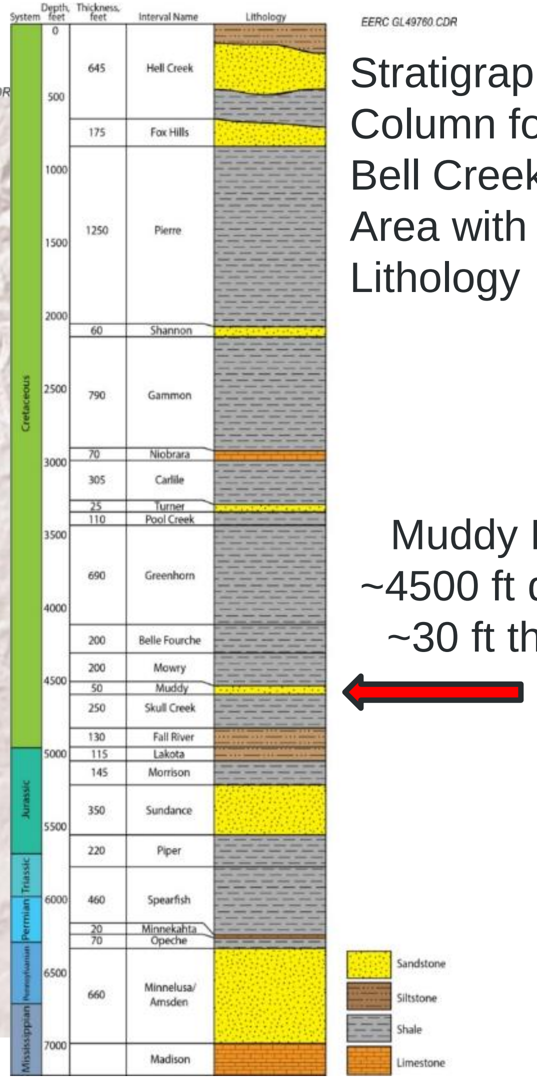

After Reclamation

STUDY AREAS AND TARGET





Bell Creek Oil Field



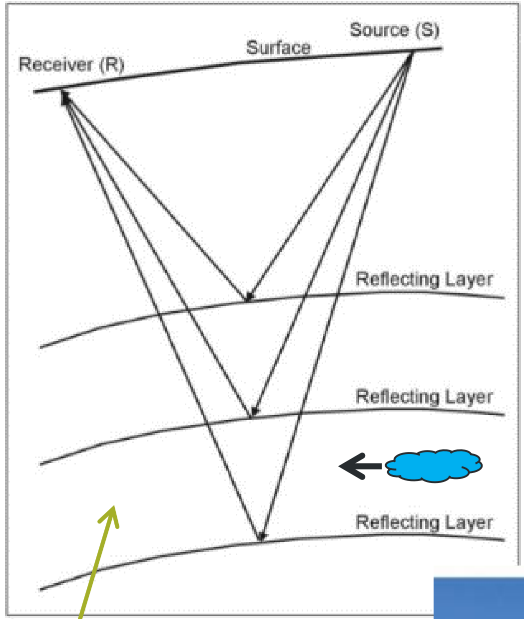
Stratigraphic Column for the Bell Creek Area with Lithology

Muddy Fm
~4500 ft deep
~30 ft thick

SASSA CONCEPT

- Applying the seismic method to track CO_2 movement in the reservoir.
  - Sparse array and one stationary source.
  - Monitor discrete locations in the reservoir (weekly).
  - Changes to the reservoir reflection character may indicate the passing of CO_2.
  - Validation with dynamic reservoir simulations and 2-D time-lapse seismic.

- Why: Incremental results, actionable information, low impact, possibly cheaper cost, relocate and reuse.



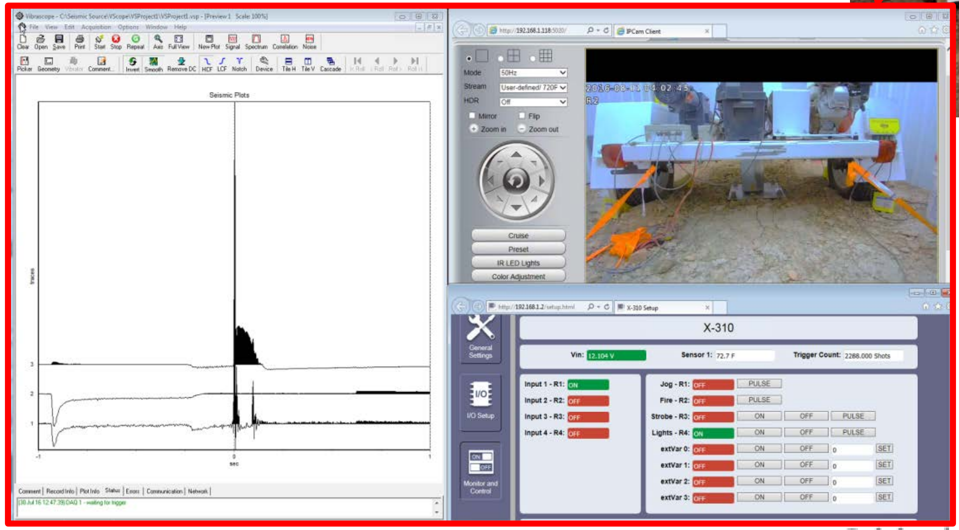
Reservoir Layer

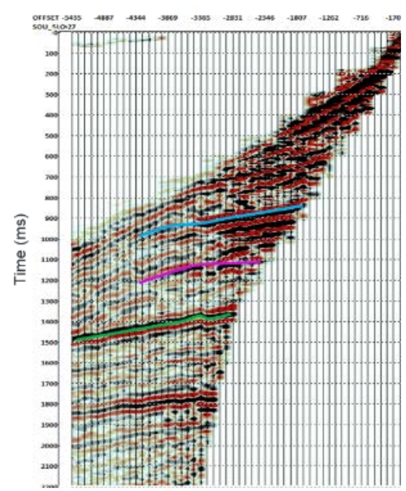
EERC SB51472.CDR

SEISMIC SOURCE

- **Gisco ESS 850**
  - 850-lb (385-kg) weight accelerated with a slingshot.
  - Powerful, flexible, electrically powered.
  - Safe remote operation within a locked structure.

EERC SA51610.CDR





RECORDING SYSTEM

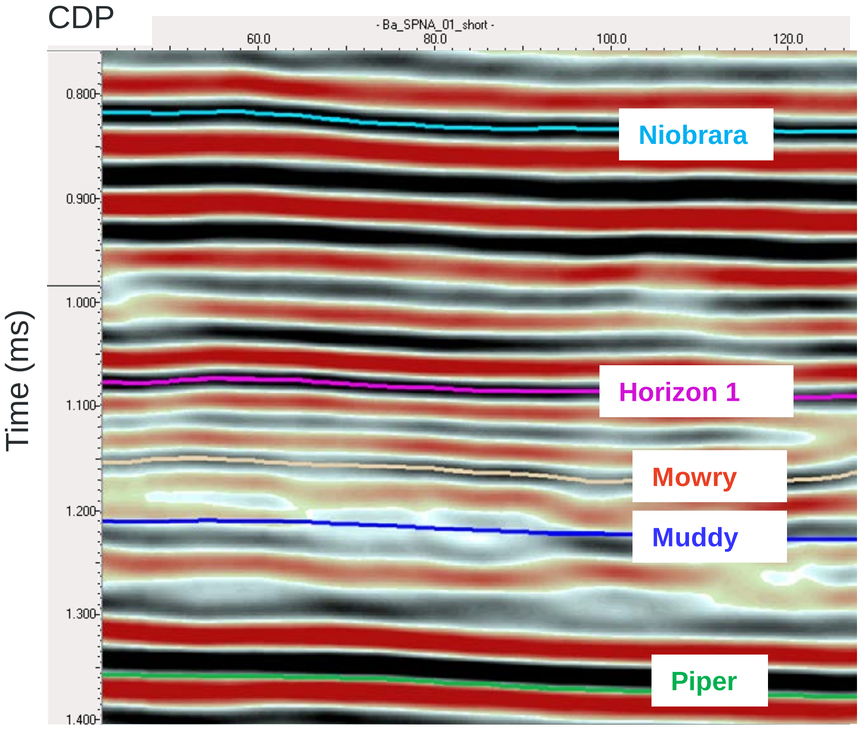
- **Fairfield Zland system**
  - 96 autonomous nodes – three-component 5-Hz geophones.
  - Programed to wake and receive data on weekends.
  - Handheld units for node deployment, GPS location, and mapping.
  - Data Management server.
  - Charger and data download racks.

Seismic Management System

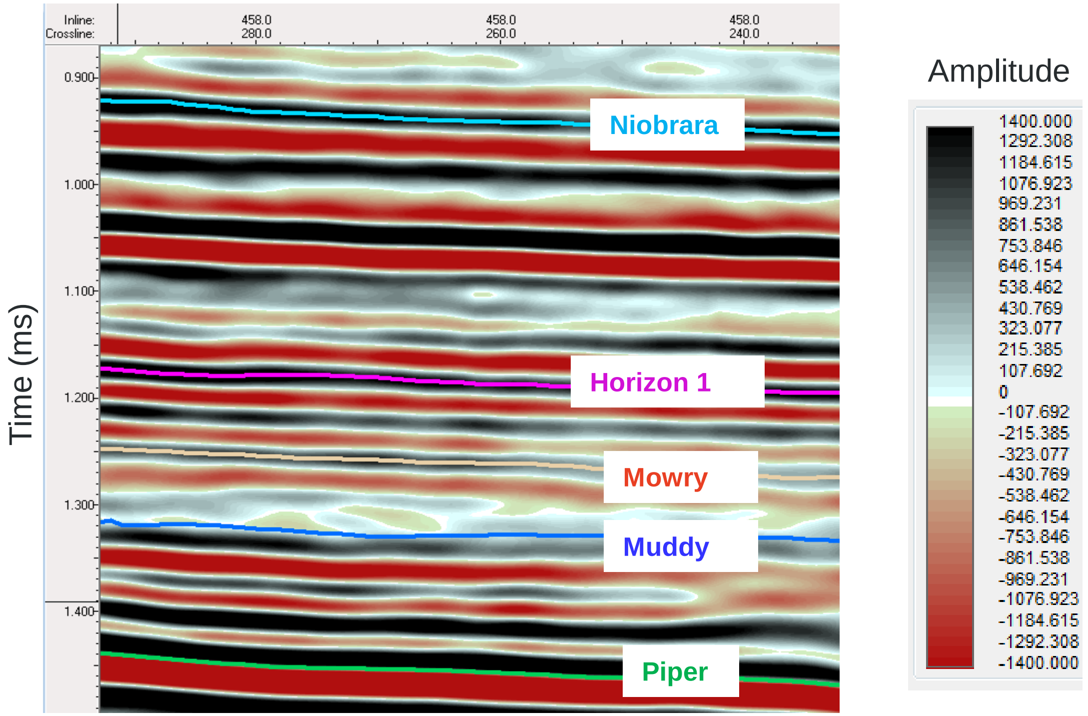
DATA QUALITY

- 2-D data have reflection characteristics similar to the conventional 3-D survey in the same area.
- Reflections from the reservoir are weak or intermittent in this area.

SASSA 2-D Baseline

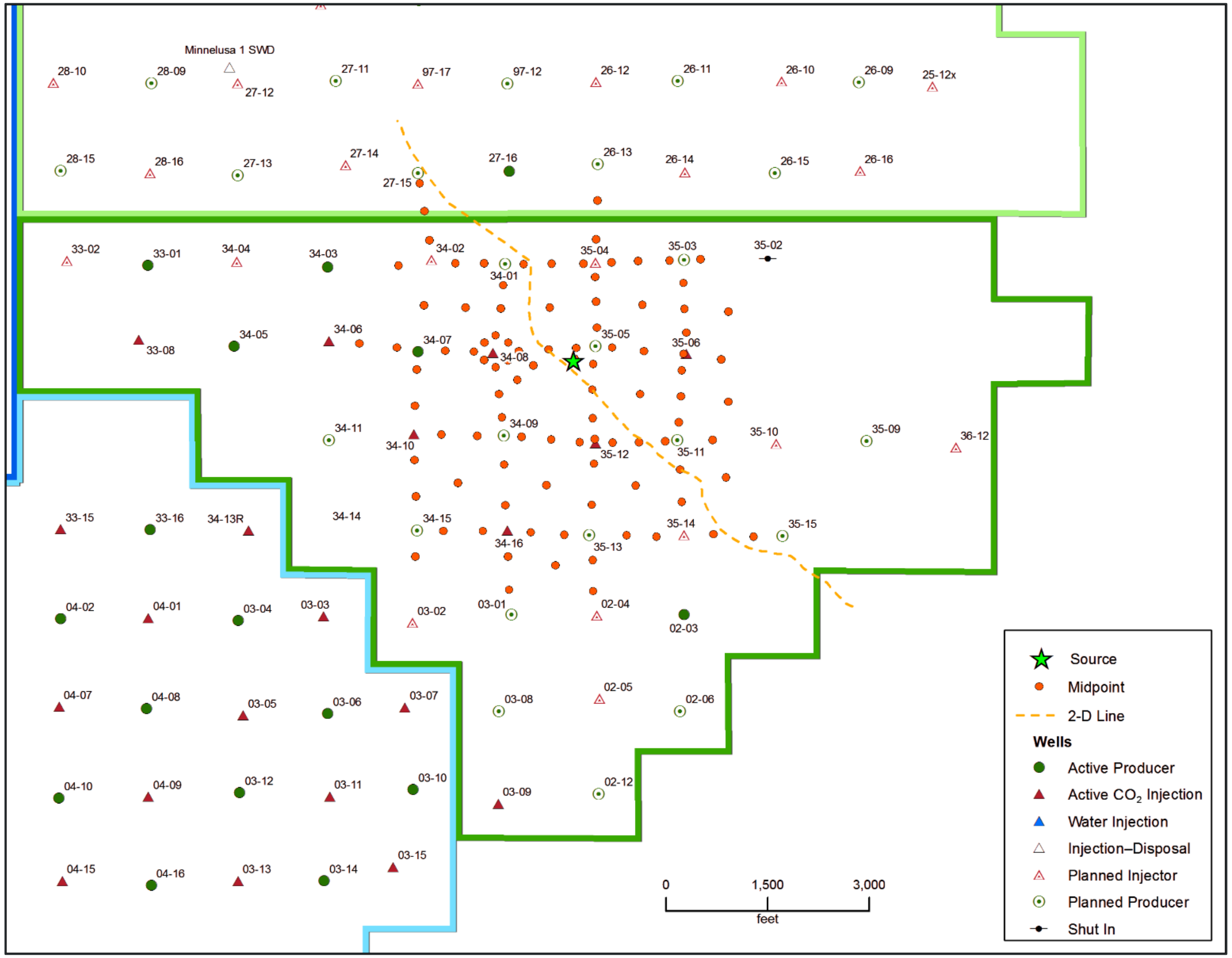


Bell Creek 3-D Baseline – Nearest Inline



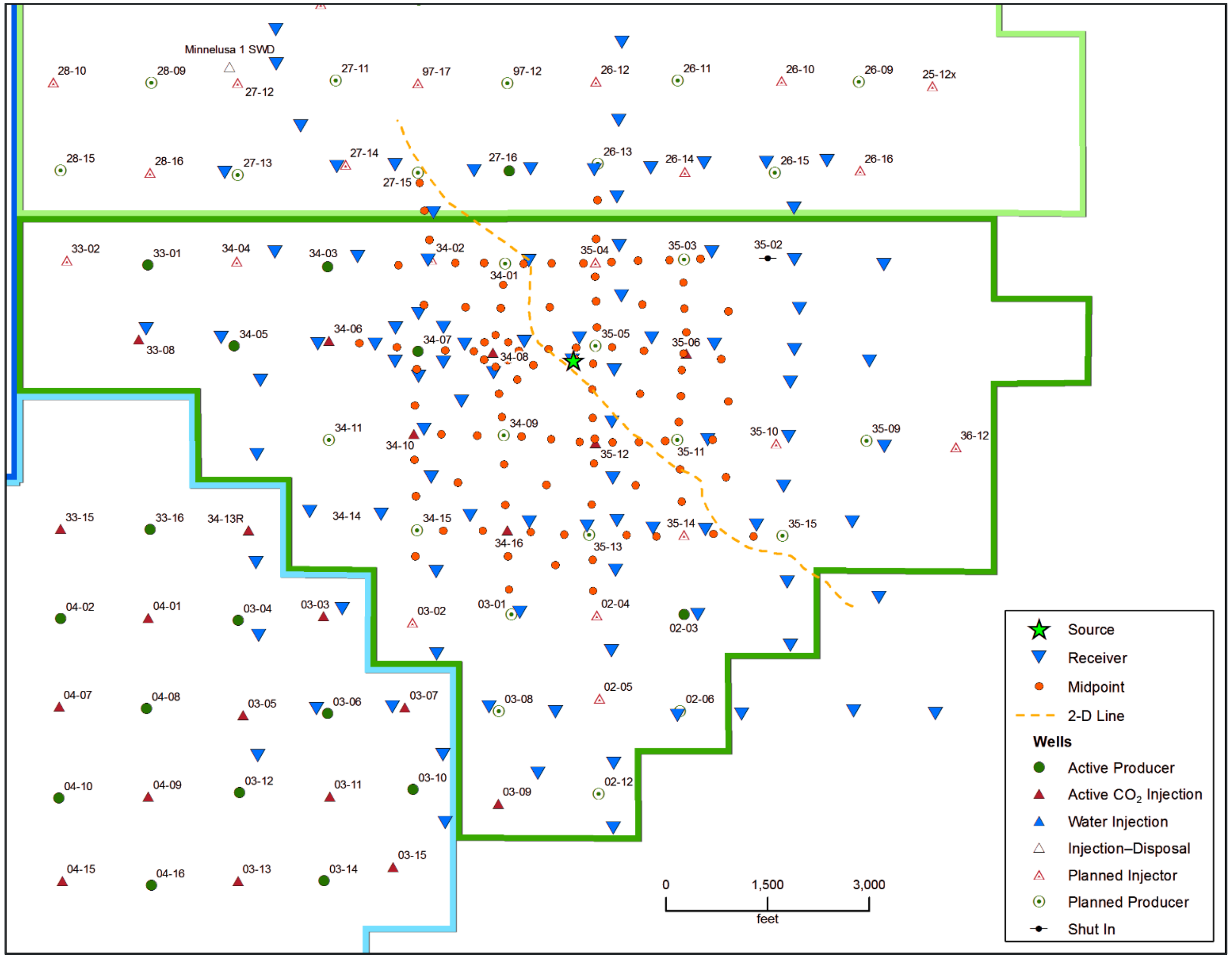
ARRAY LAYOUT

- Monitoring focuses on four injector–producer patterns covering about 1 square mile.
- Orange dots represent monitored points.



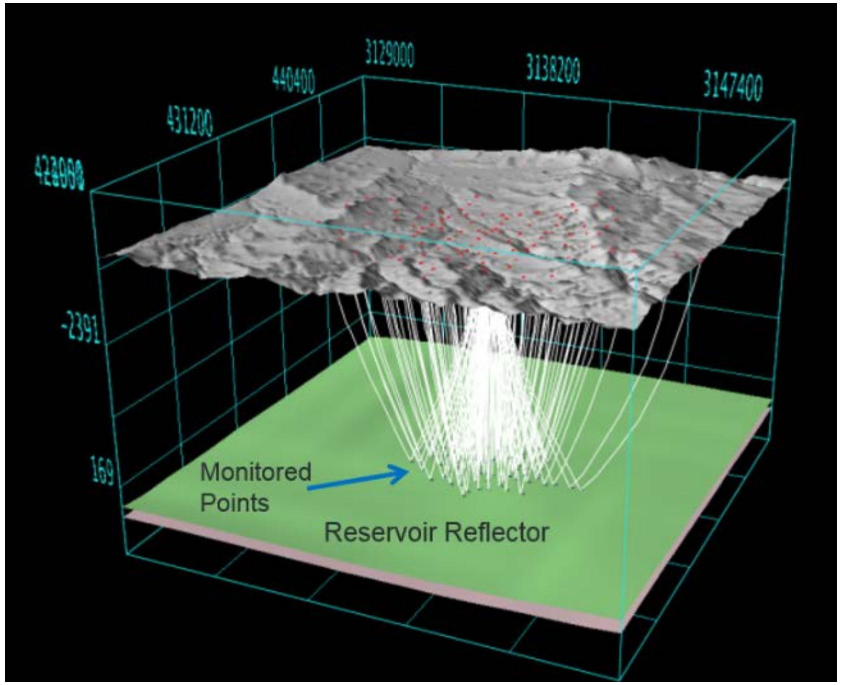
ARRAY LAYOUT

- Monitoring focuses on four injector–producer patterns covering about 1 square mile.
- Orange dots represent monitored points.
- Blue triangles represent receiver locations.

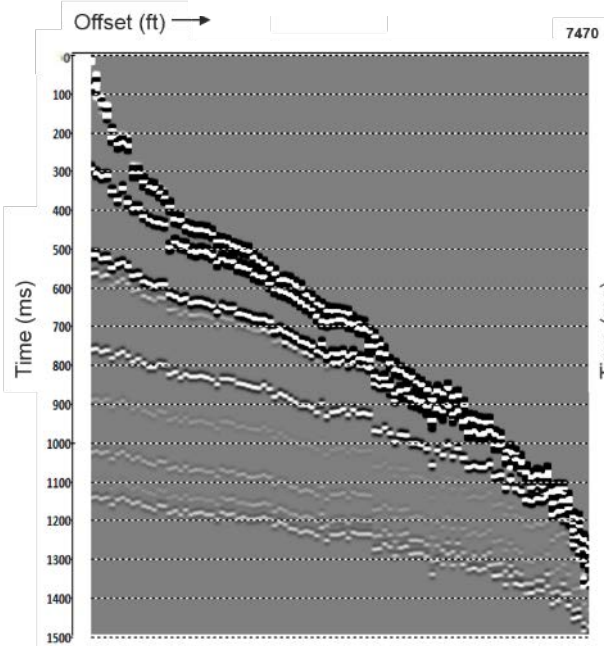


DETERMINING RECEIVER LOCATIONS

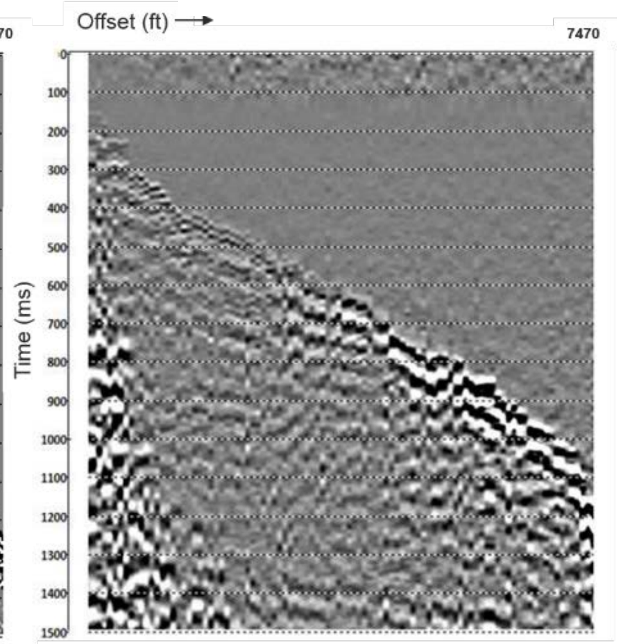
- Because of dip and structure, locating receivers required…
- 3-D velocity modeling:
  - Layered velocity model based on 3-D seismic depth volume
  - Lidar elevation data
- Iterative ray-tracing to locate geophone positions that illuminate the desired reflection point locations.



Model Data



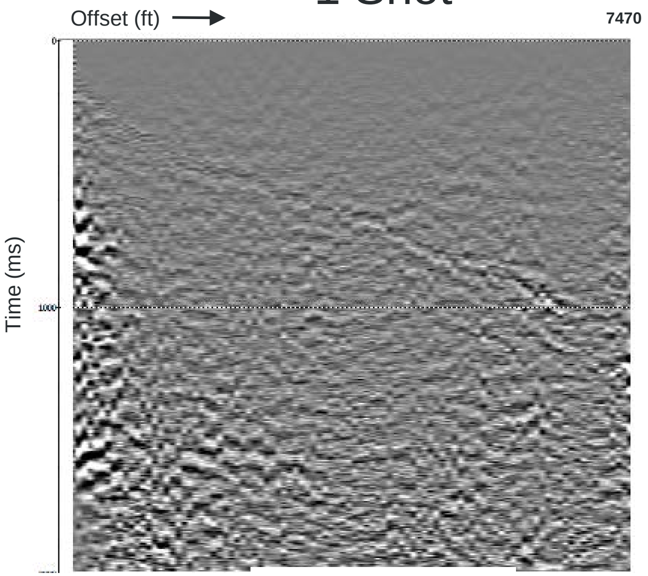
Field Data



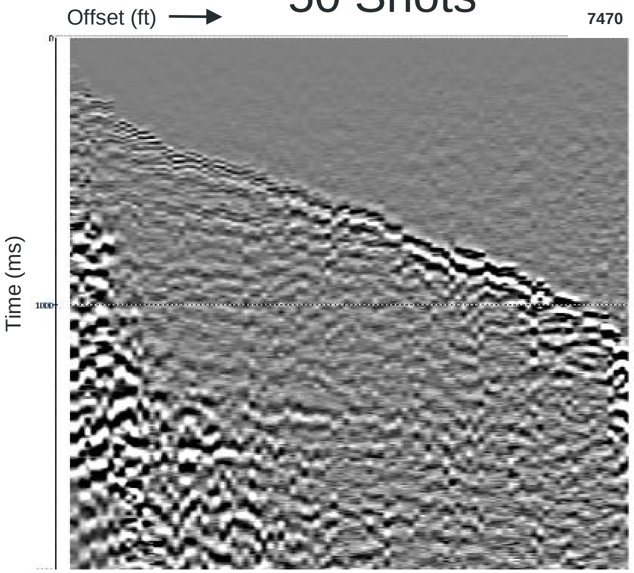
ARRAY DATA ACQUISITION

- 41 data sets harvested.
- Some data collections missed because of:
  - Internet outage.
  - Equipment repair.
  - Abstention due to weather.
- Source fired remotely ~50 to 100 times.
  - Increased signal-to-noise through vertical stacking.
  - Receiver domain processing prior to stacking.

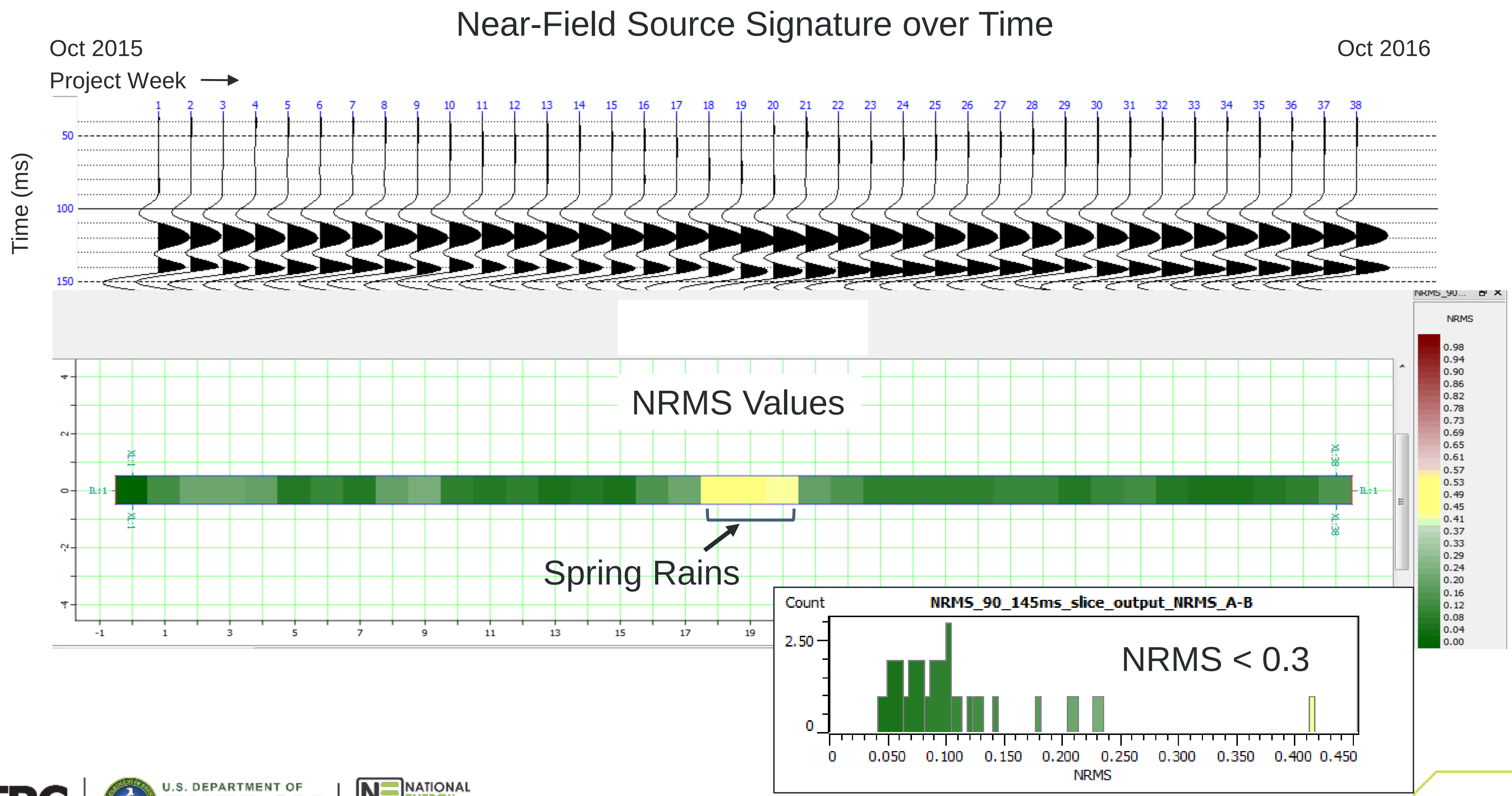
1 Shot



50 Shots

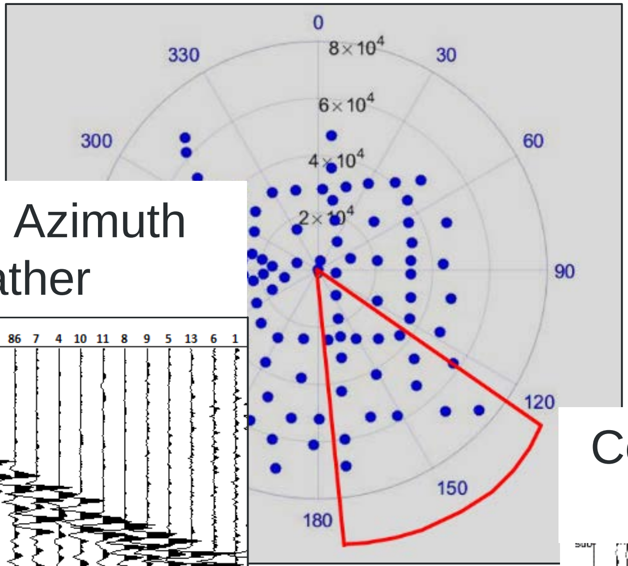


SOURCE REPEATABLITY

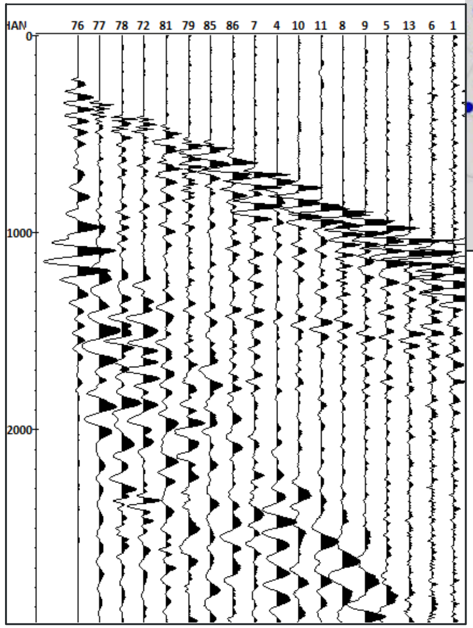


MULTIDOMAIN APPROACH

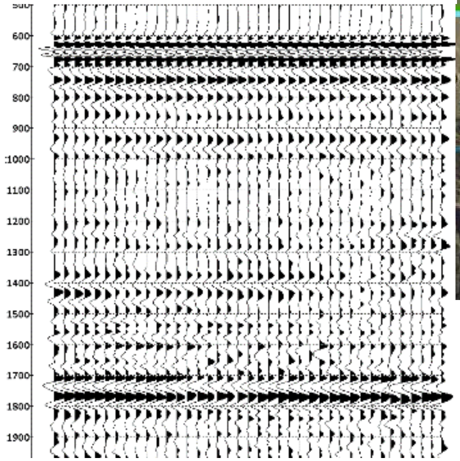
Common Azimuth



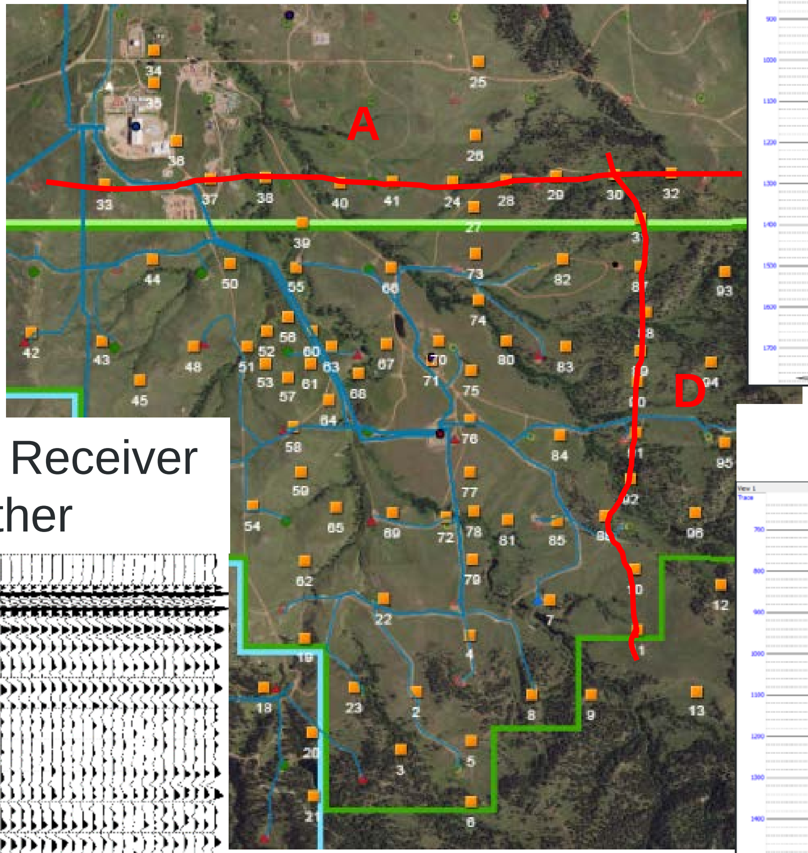
Common Azimuth Gather



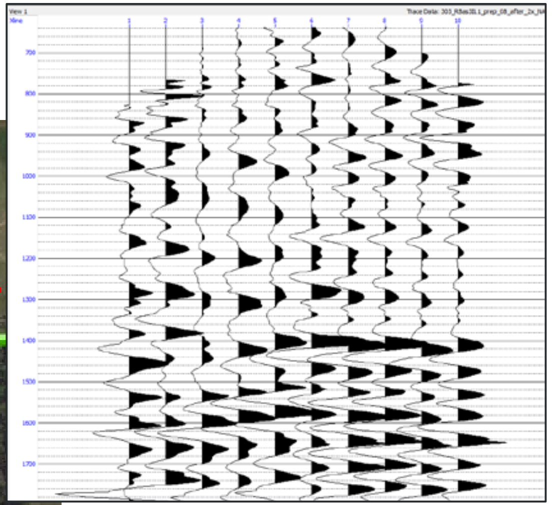
Common Receiver Gather



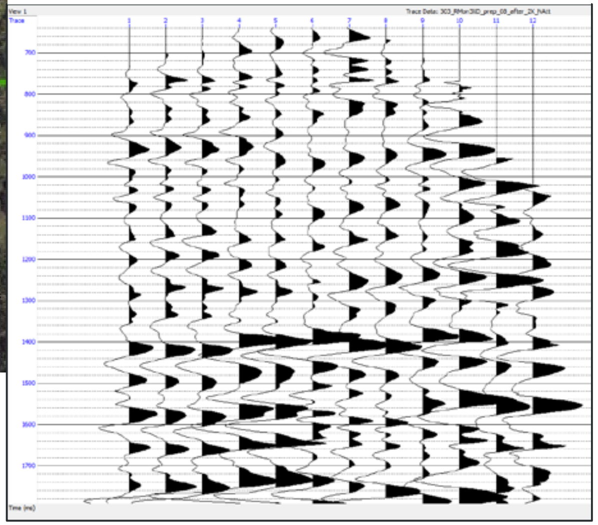
Pseudo Inline and Crossline



Inline A



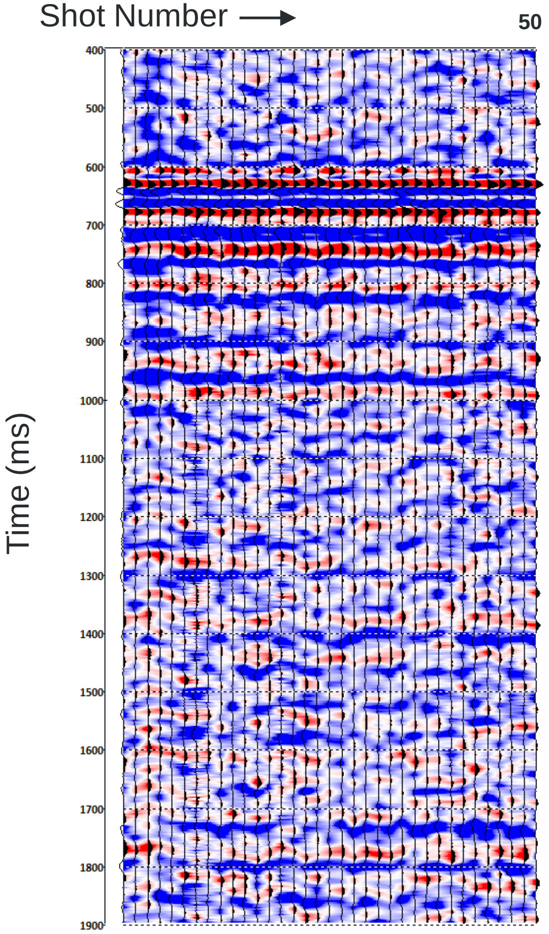
Crossline D



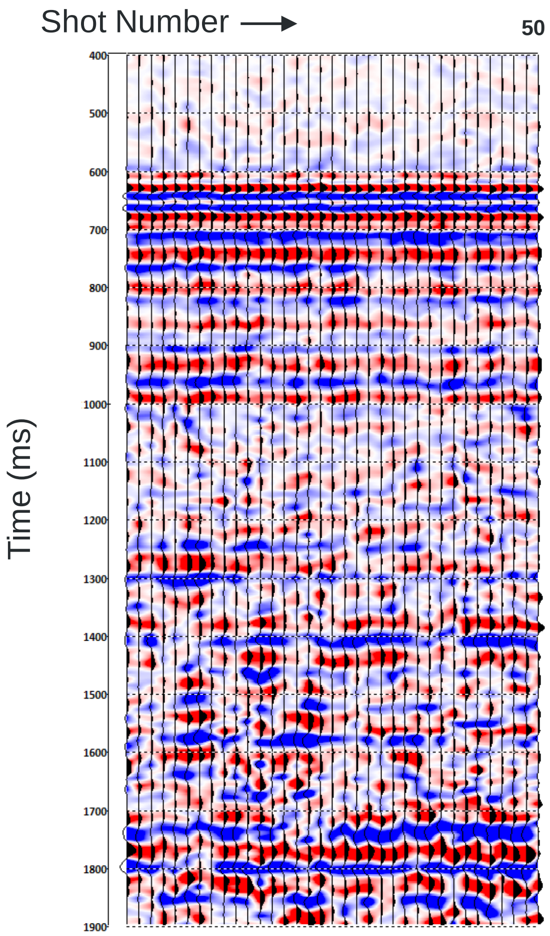
RECEIVER DOMAIN PROCESSING

Channel 92

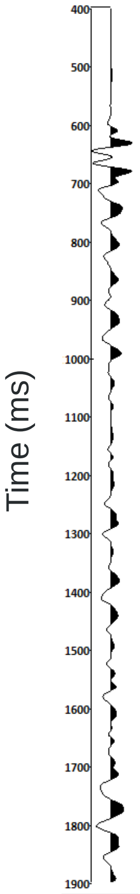
Raw Data



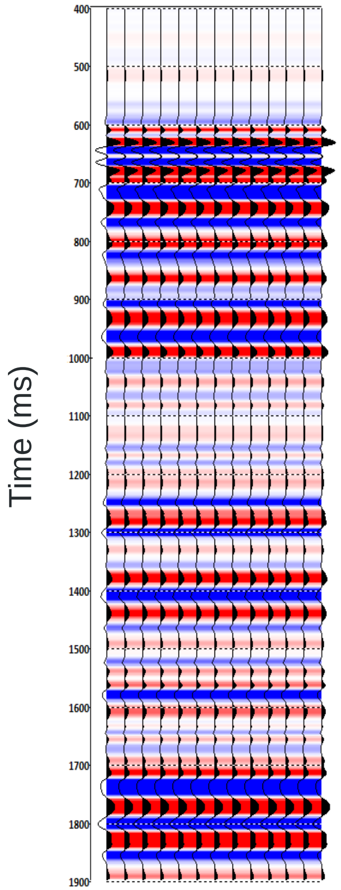
Processed Data



Vertical Stack



Stacked Trace Repeated

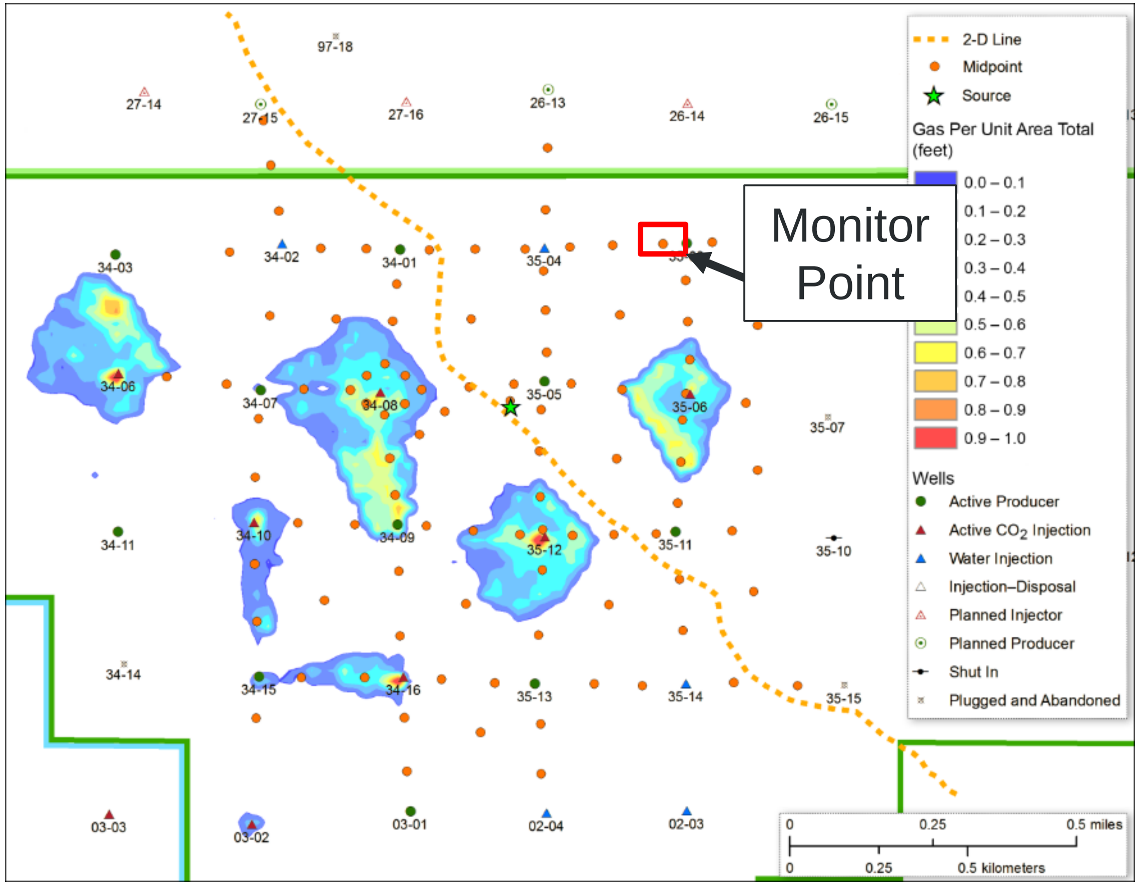


Simple Processing Flow:

- Spherical divergence
- Trace editing
- Bandpass (4-8-56-64-Hz)
- 30-Hz notch

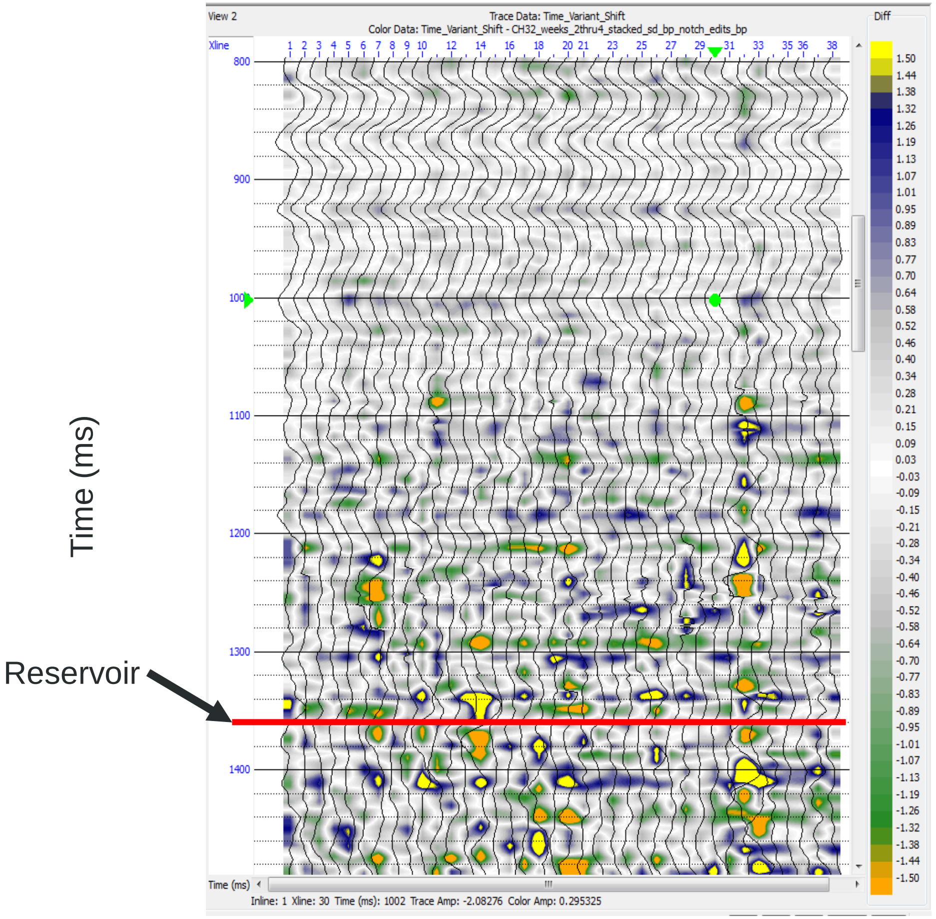
TIME-LAPSE DIFFERENCING

Channel 32



Difference Display

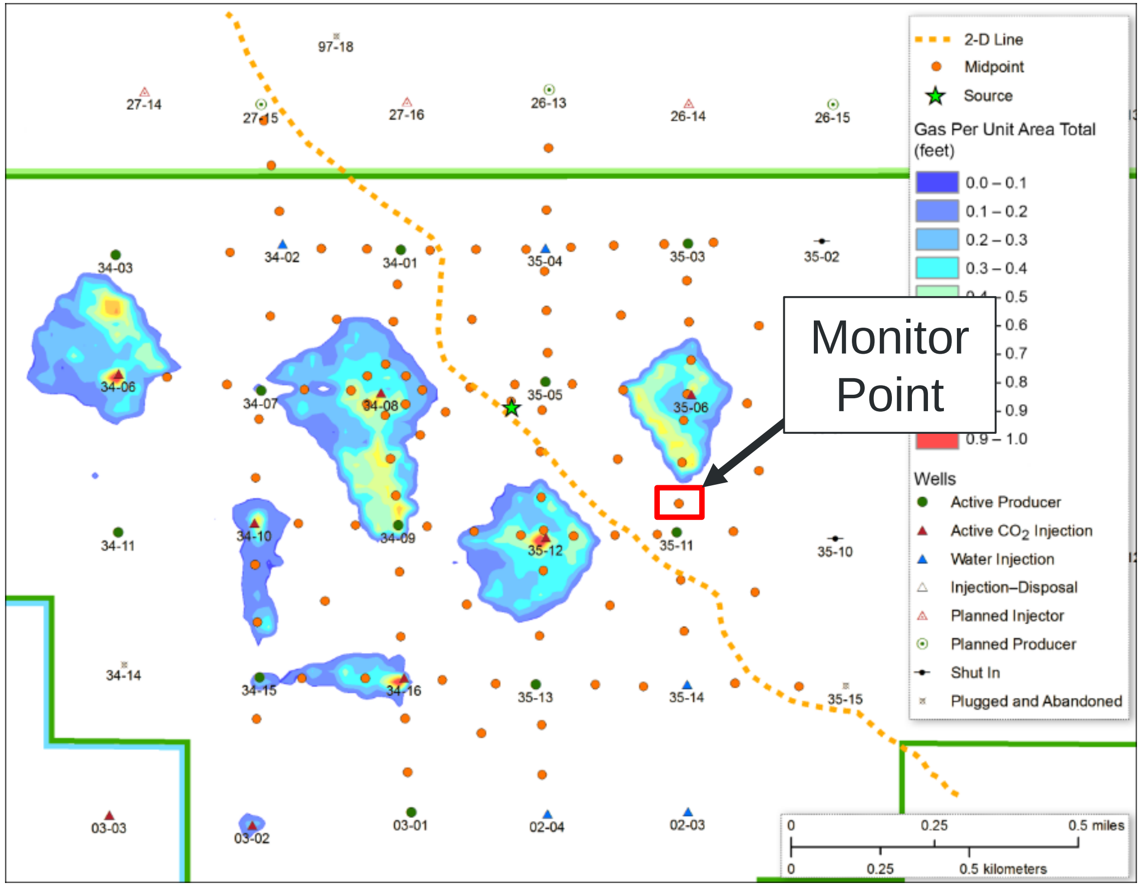
Week Number →

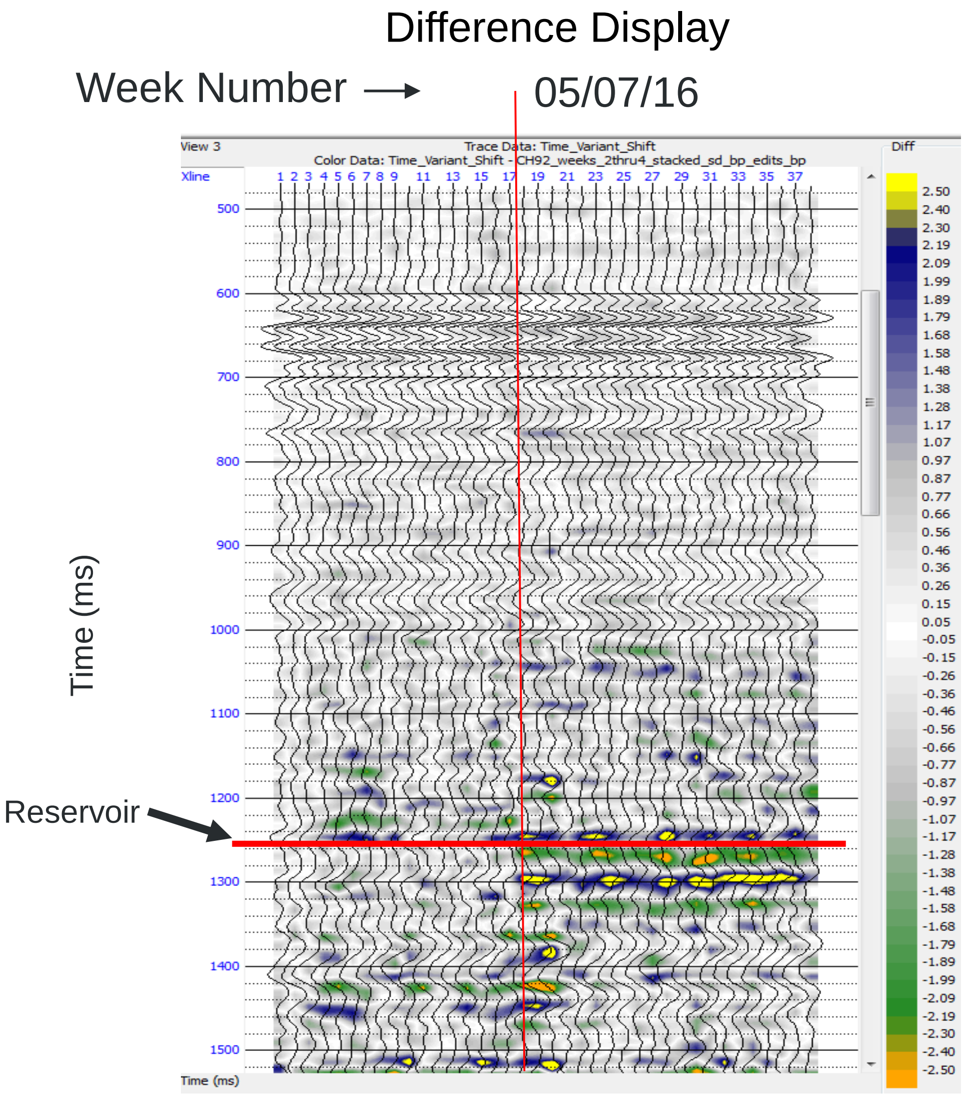


Critical Challenges. **Practical Solutions.**

TIME-LAPSE DIFFERENCING

Channel 92

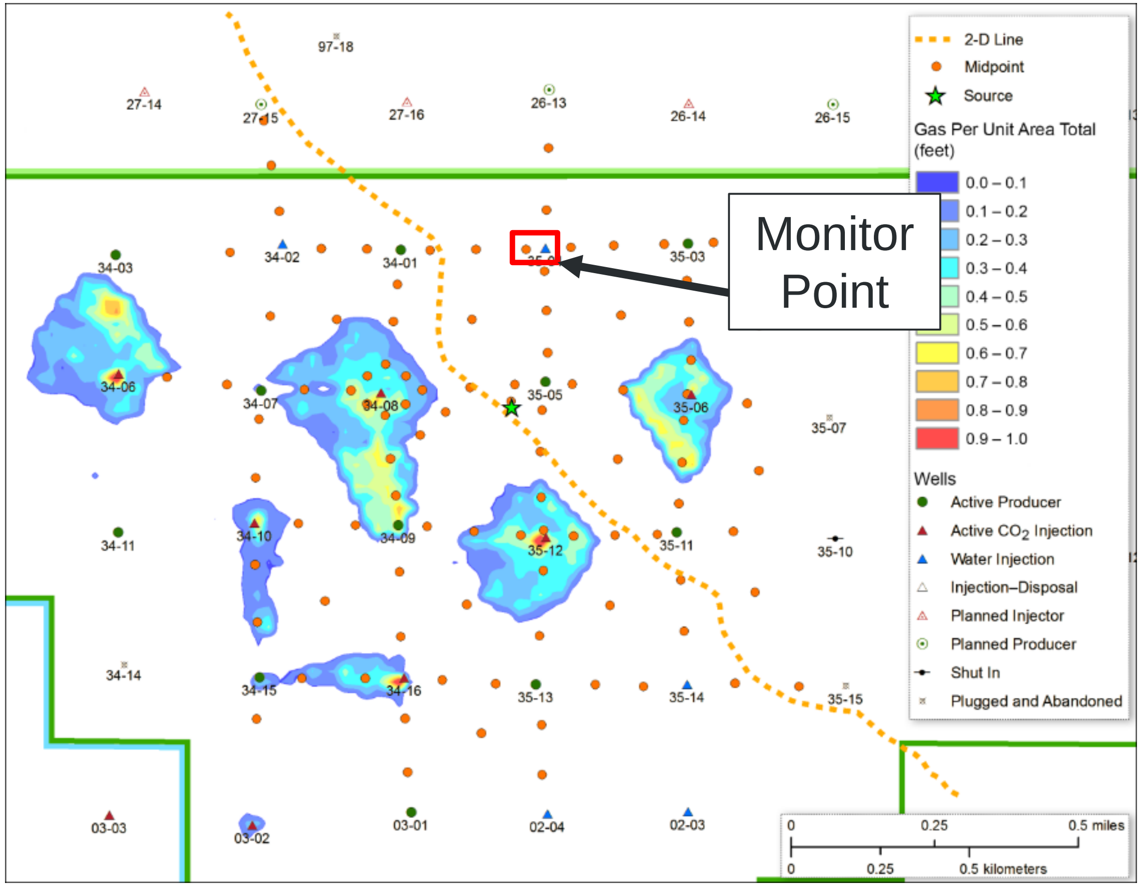




Critical Challenges. Practical Solutions.

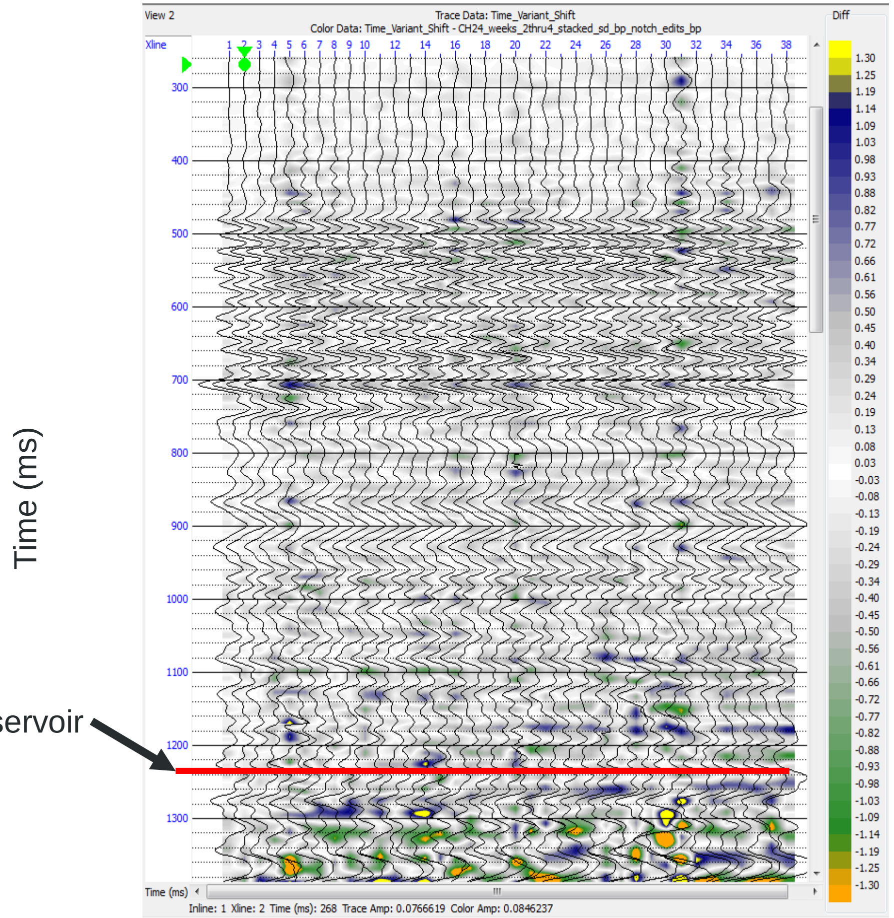
TIME-LAPSE DIFFERENCING

Channel 24

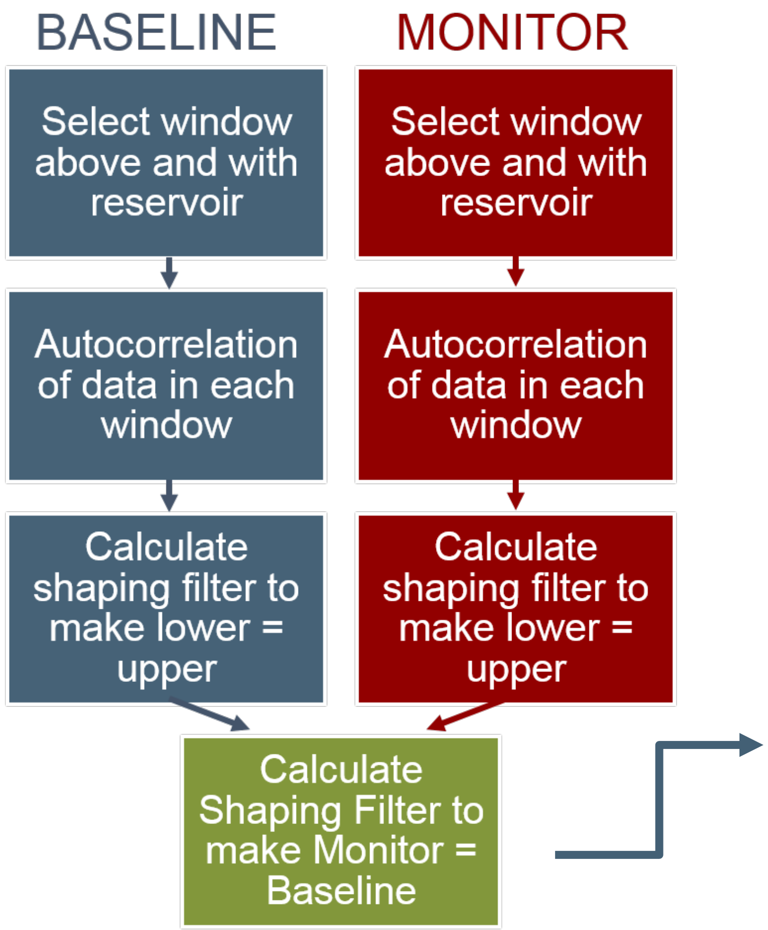


Difference Display

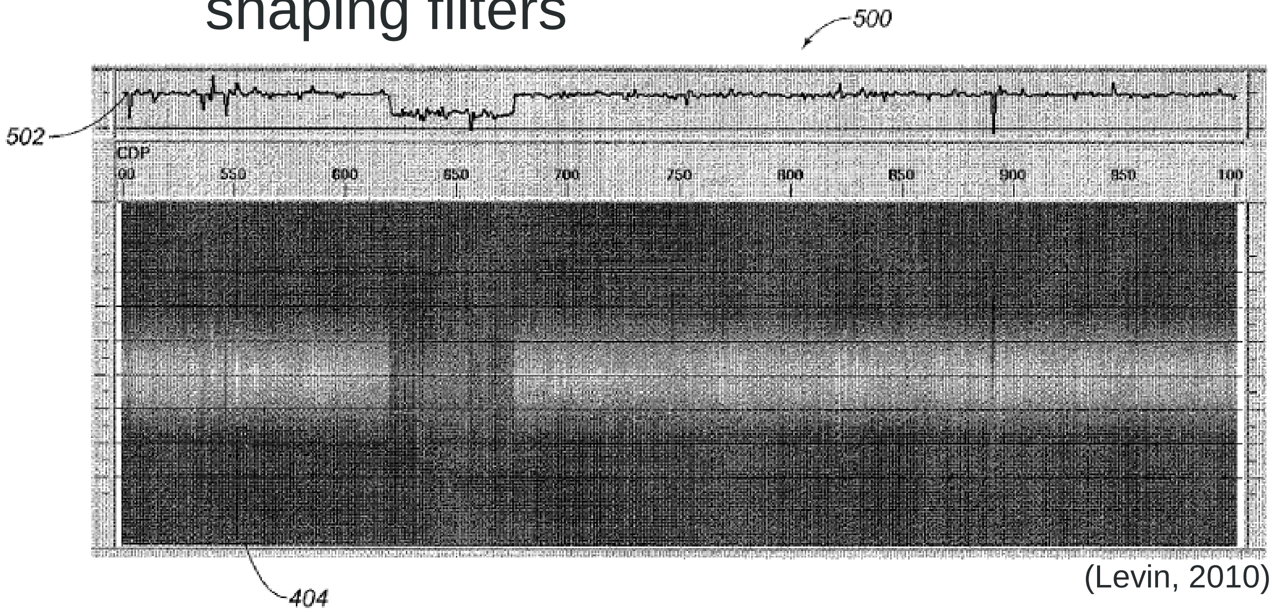
Week Number →



COMPLEMENTARY TIME-LAPSE ANALYSIS



- Levin 4-D quick look method
  - Calculation and comparison of shaping filters



(Levin, 2010)

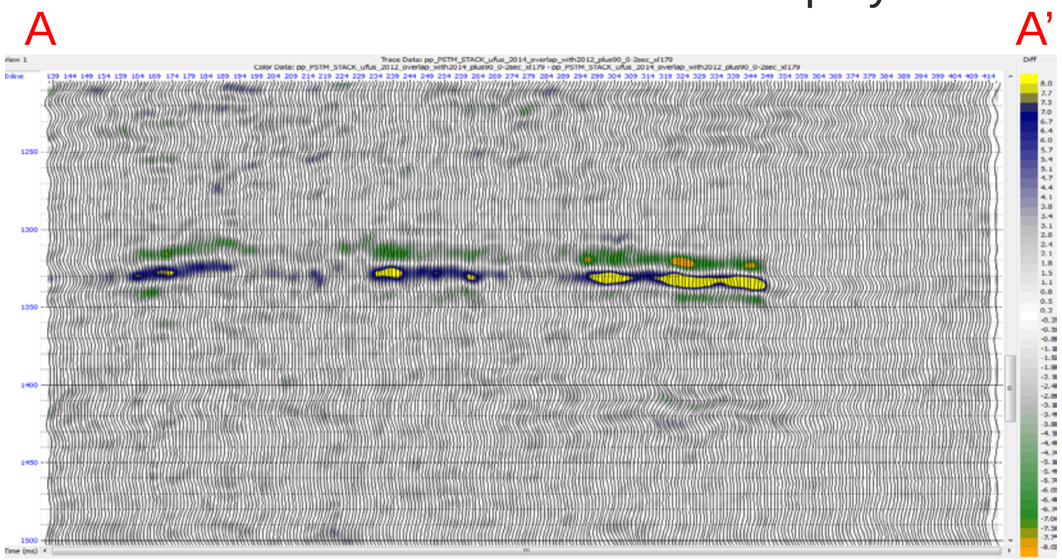
Levin, S. A., 2010, Systems and methods for monitoring time-dependent subsurface changes: U.S. Patent 7,843,766 B2.

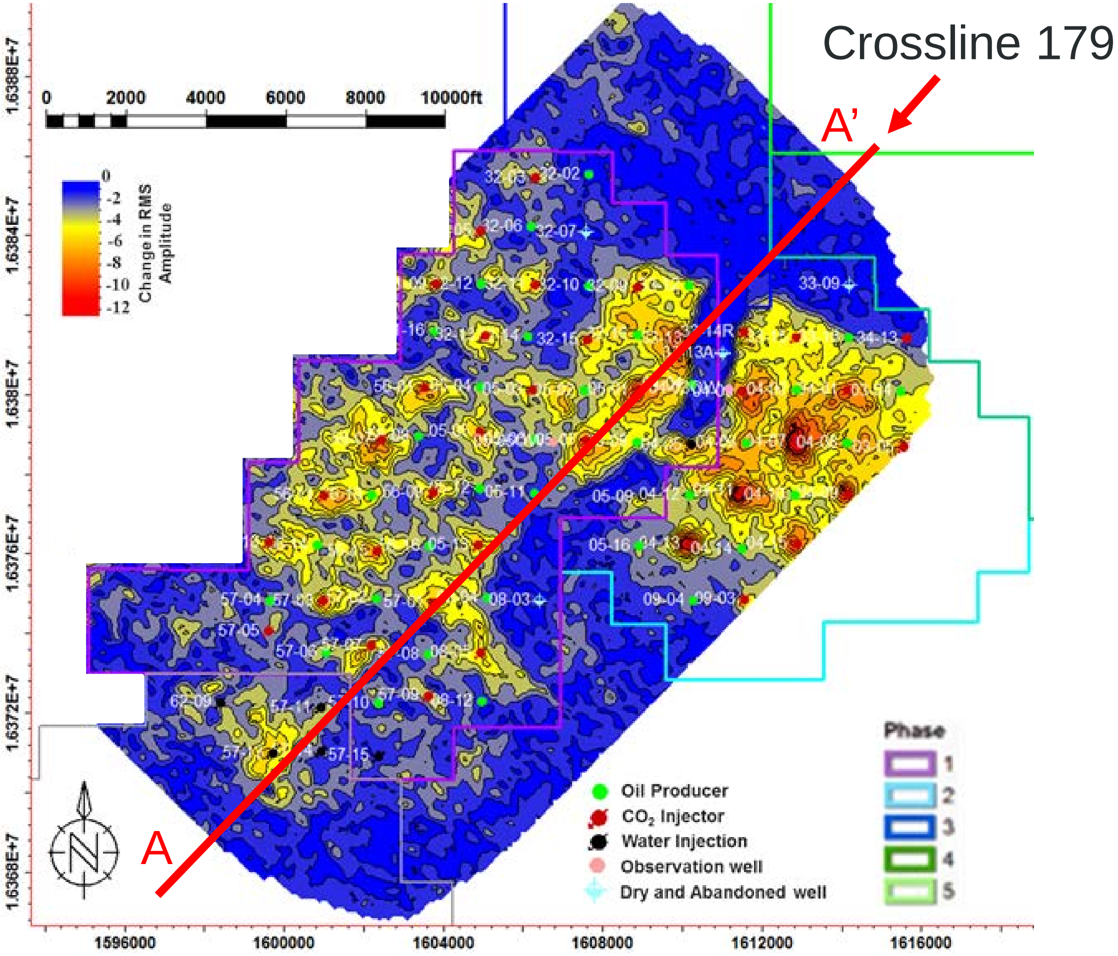
Levin, S. A., 2009, 4-D: from mainstream to Main Street: Presented at the Society of Exploration Geophysicists Houston 2009 International Exposition and Annual Meeting, Houston, Texas, October 26–30, 2009.

LEVIN METHOD TEST

- To test the Levin method and refine parameters, it was applied to a 4-D time-lapse crossline known to encounter areas with and without CO_2.

Crossline 179 Difference Display





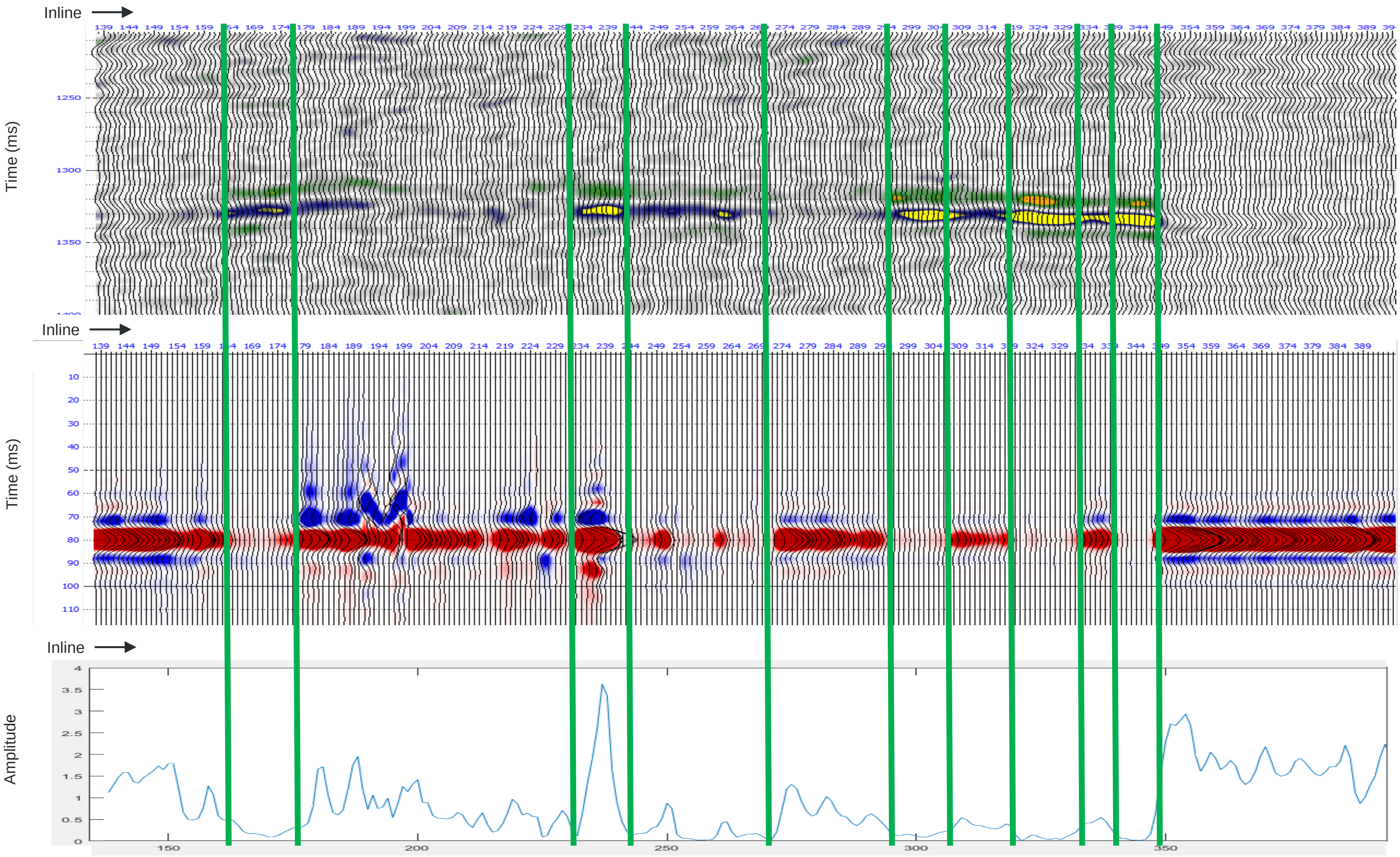
Time-lapse difference map of the reservoir displaying RMS amplitude changes.

LEVIN METHOD RESULT ON 3-D CROSSLINE

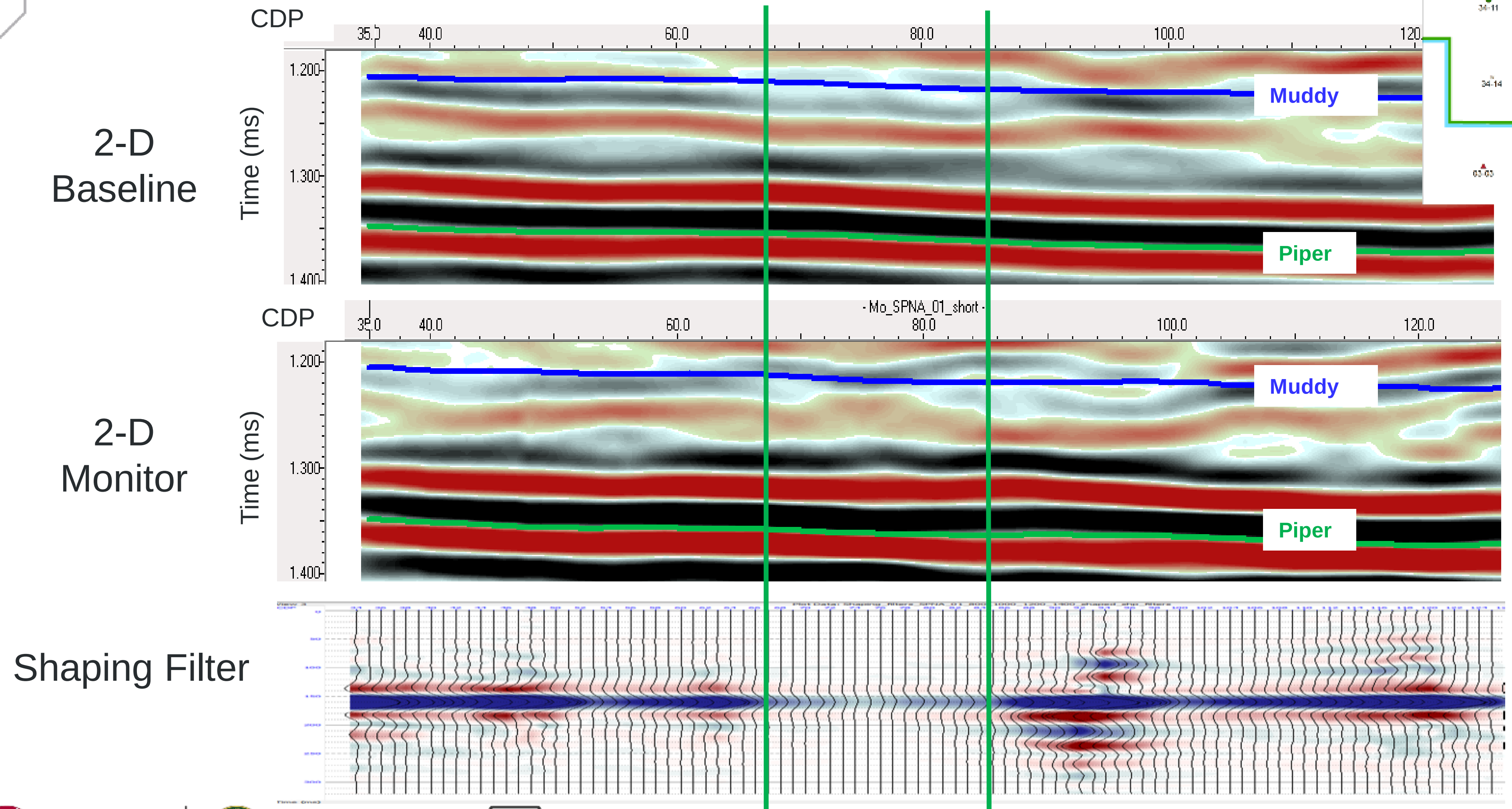
Crossline 179 Difference Display

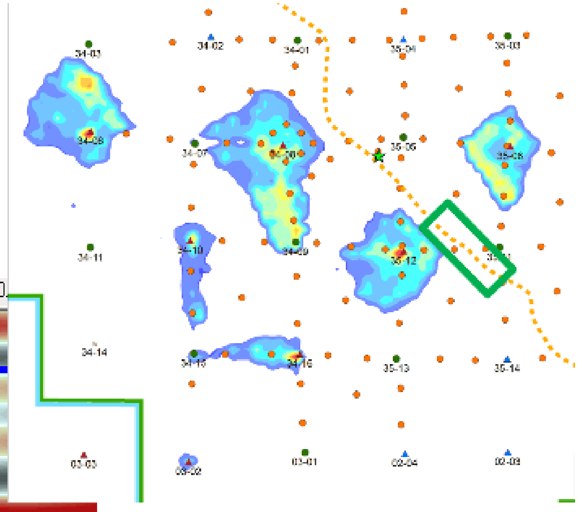
Shaping Filter

Shaping Filter Center Sample Amplitude



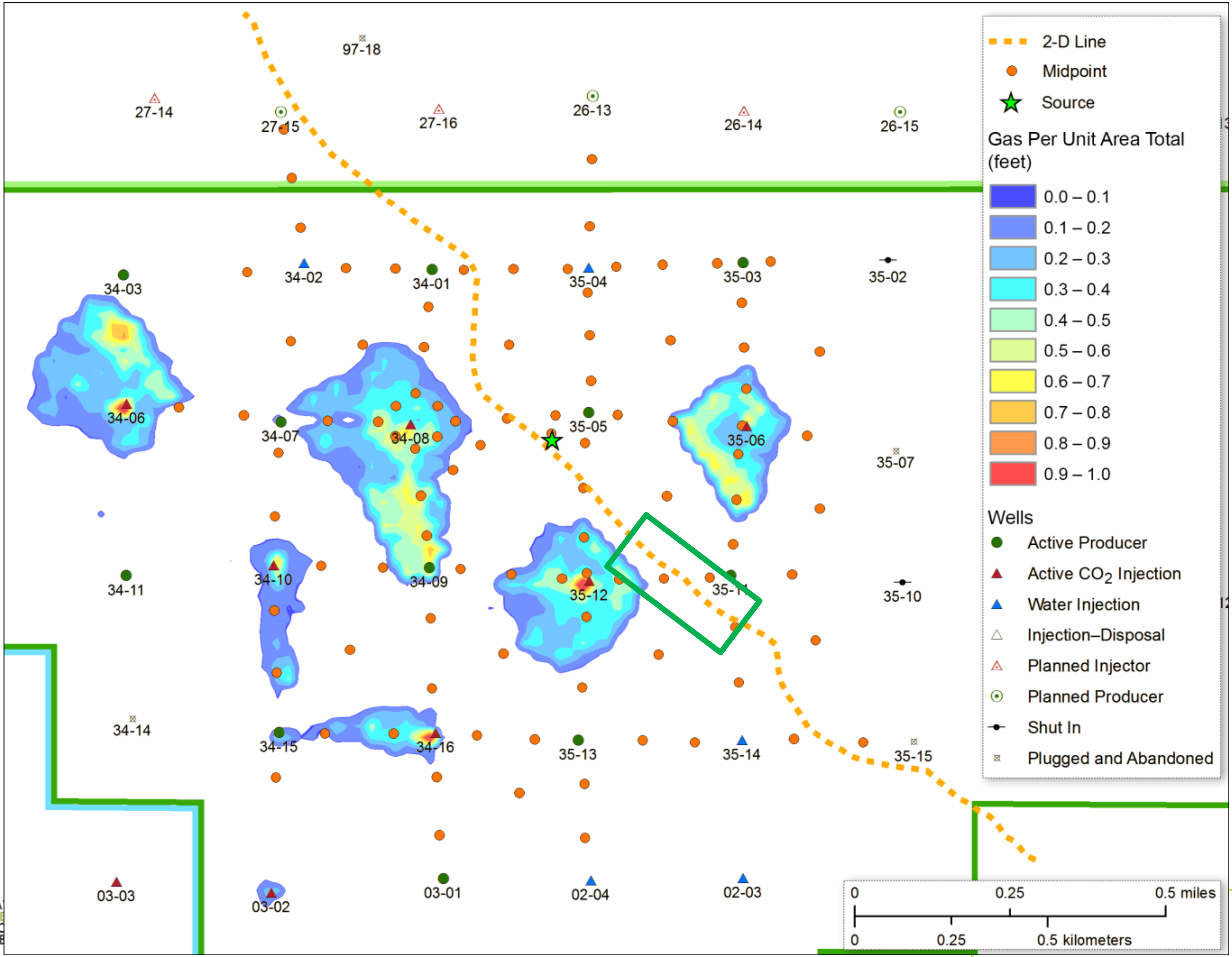
APPLICATION OF LEVIN METHOD





DYNAMIC RESERVOIR SIMULATIONS

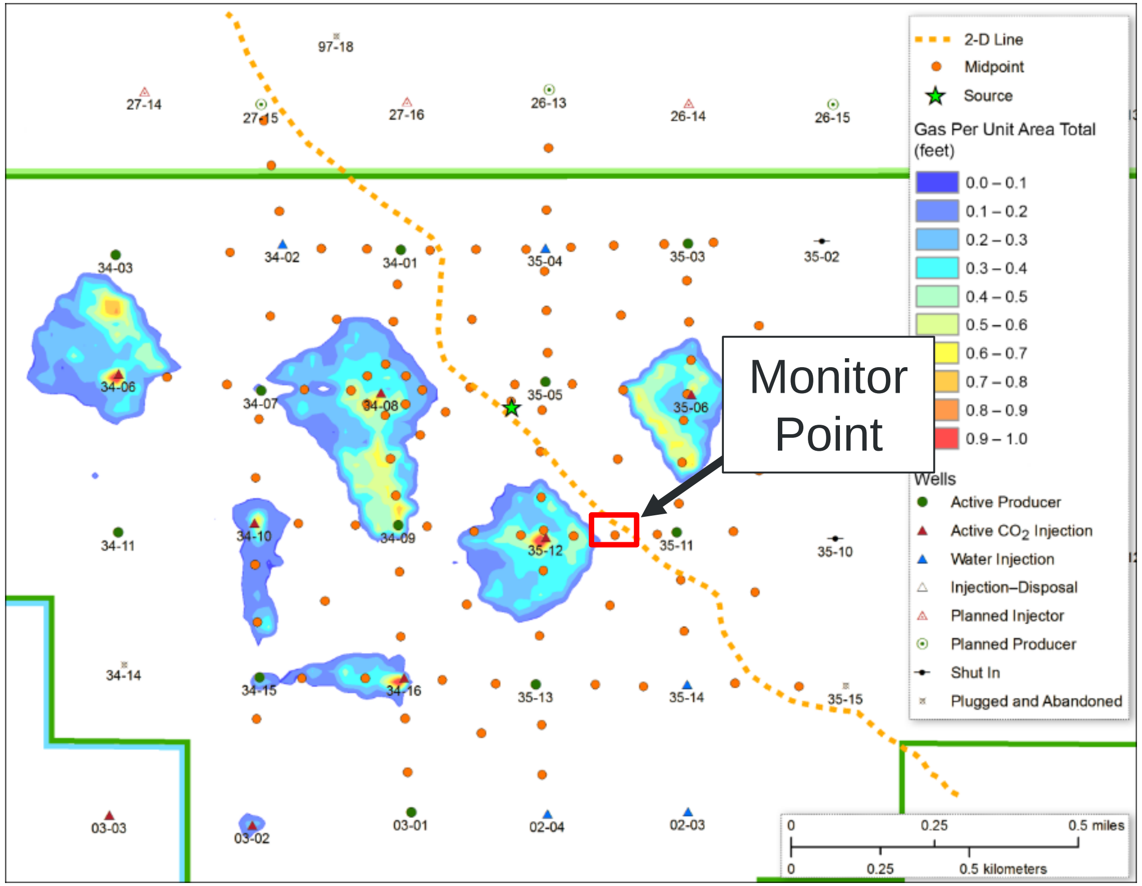
- Predictive simulations of CO_2 saturation using Computer Modelling Group (CMG) software to corroborate and help evaluate SASSA results.
- 2-D line for validation appears to skirt the saturation fronts.



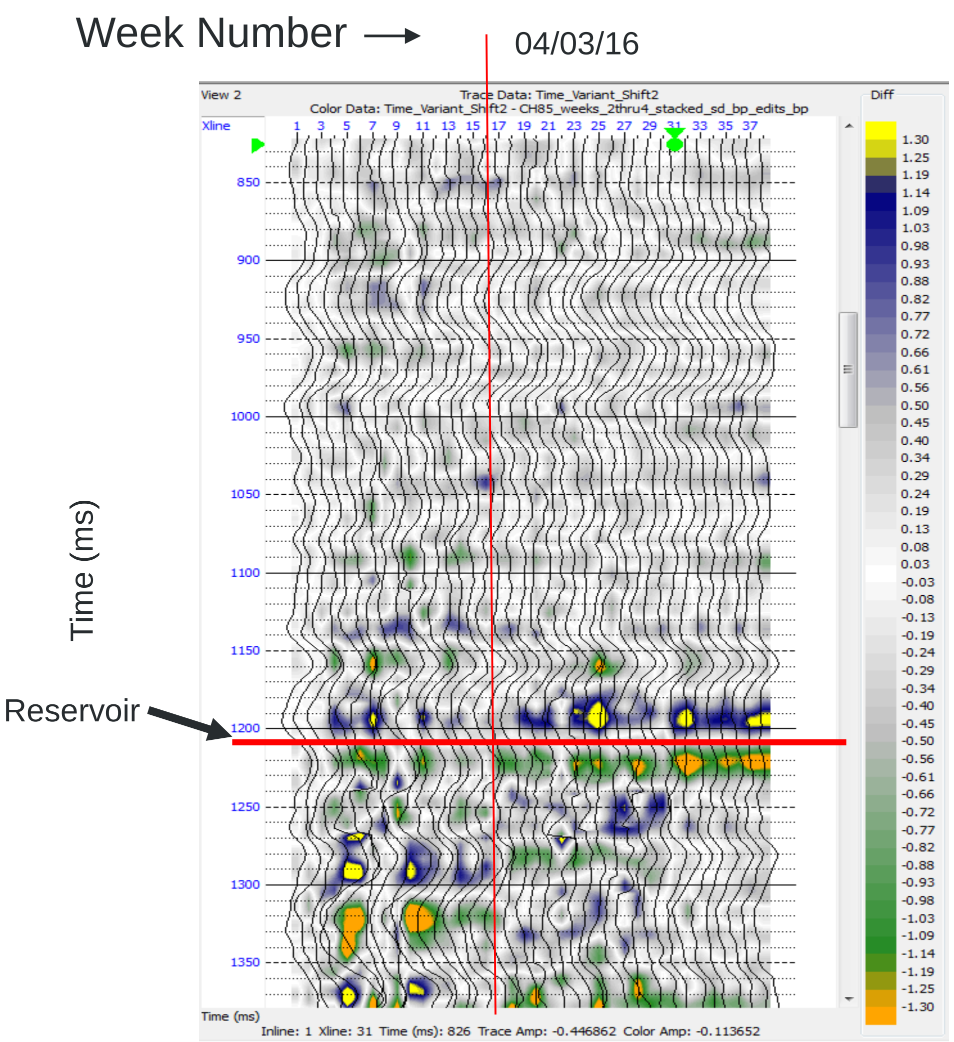
EERC U.S. DEPARTMENT OF ENERGY NETL

TIME-LAPSE DIFFERENCING

Channel 85



Difference Display



APPLICATION OF LEVIN METHOD

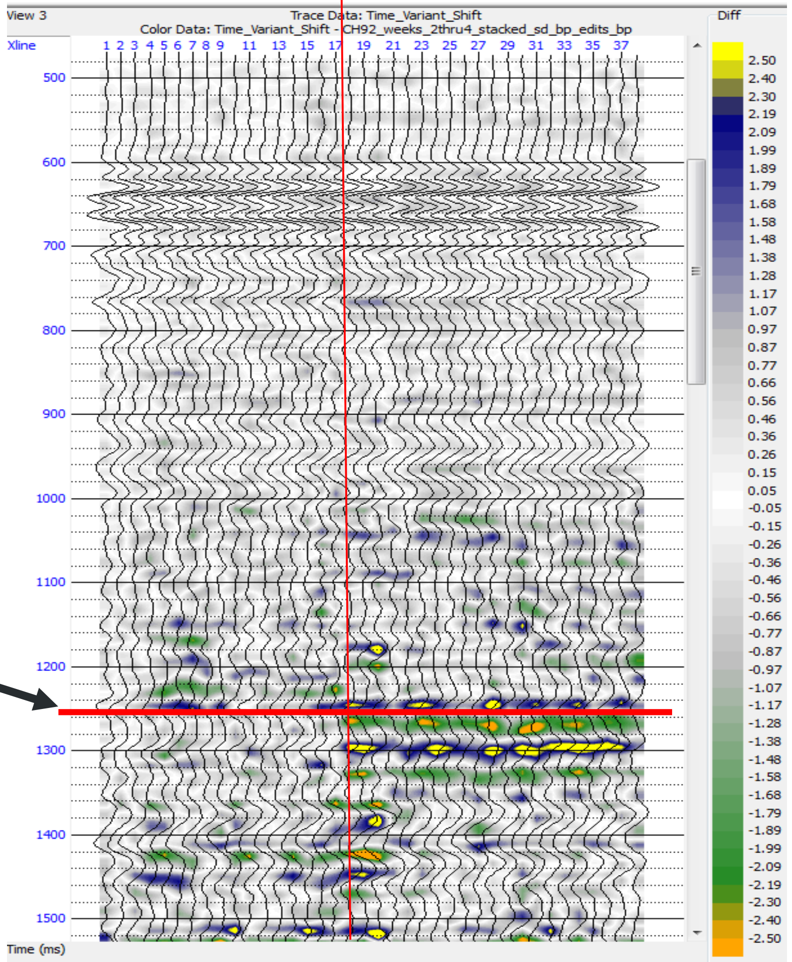
Channel 92

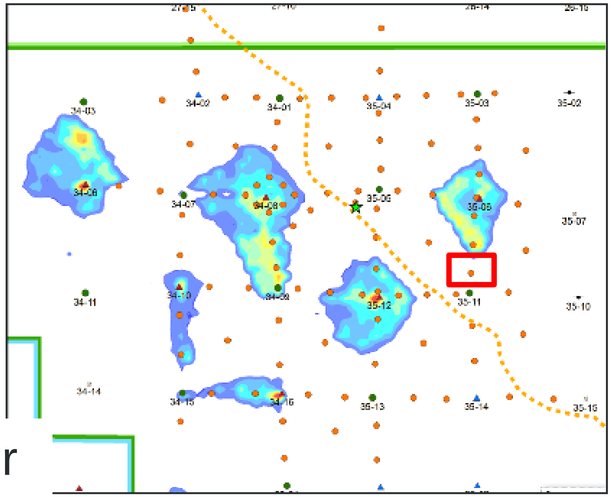
Difference Display

Week Number → 05/07/16

Time (ms)

Reservoir

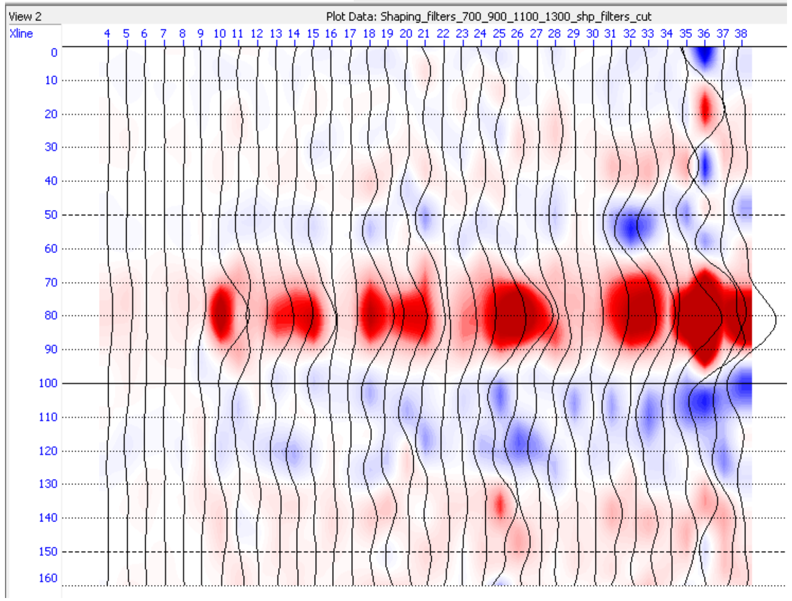




Shaping Filter

Week Number →

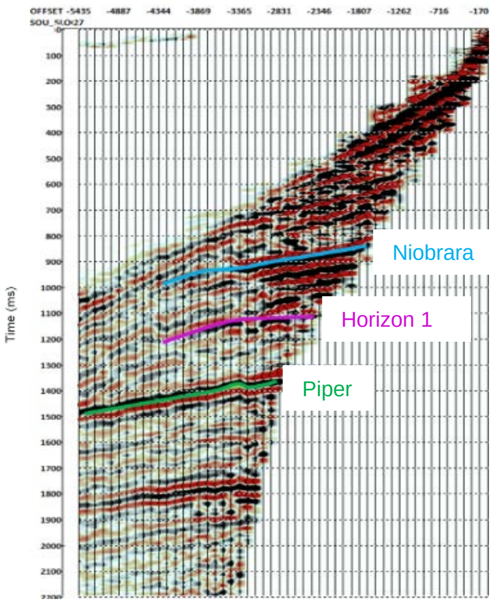
Time (ms)

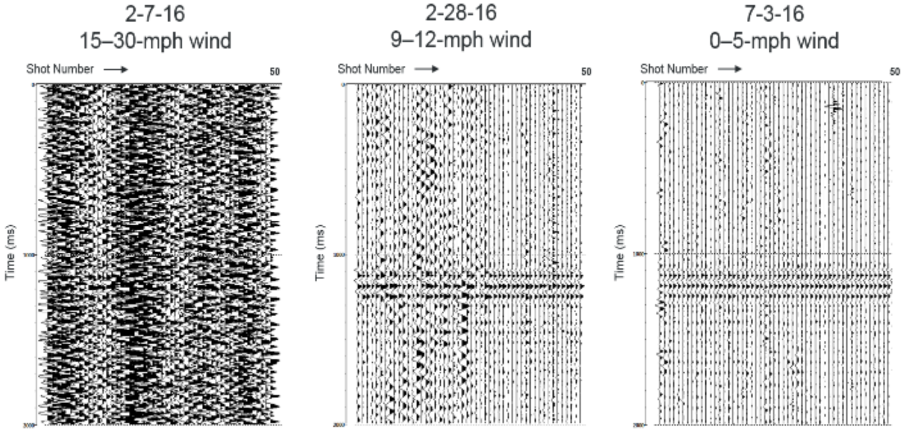


KEY CONSIDERATIONS

- Main factors contributing to the success of the SASSA method
  - Source repeatability
  - Noise attenuation
  - Identification of time-lapse changes not associated with changes in CO_2 saturation

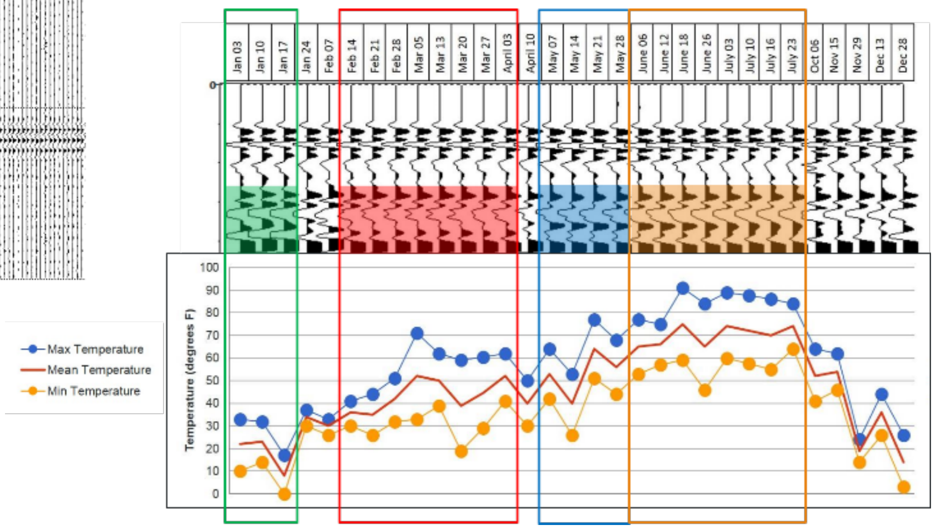
Horizon Interpretation





Changing Noise

Seasonal Changes



ACCOMPLISHMENTS TO DATE

- System implementation and data acquisition complete
  - Equipment was procured – seismic source, recording system, remote control system, source structure and footing hardware. Geophysical modeling software and data processing software were purchased.
  - Source location was selected – geophysical modeling was completed, monitor locations (midpoints) chosen, and receiver locations determined.
  - Physical system was implemented in the field. Source structure and footing built, 2-D baseline acquired, semipermanent main array installed.
  - Baseline data acquired prior to CO_2 injection. Monitor data acquired on a weekly schedule for 1 year and periodically harvested.
  - Final monitor 2-D line acquired. System retrieved and stored for next use.

ACCOMPLISHMENTS TO DATE

- Data collection, processing, interpretation, and validation
  - Data collection is complete – 41 weeks of data collected.
  - 2-D baseline and monitor seismic data acquired, processed, and interpreted.
  - Wells in the study are history-matched and predictive simulations computed, providing an indication of where CO_2 saturations exist in the study area.
  - Processing workflow developed, refined, and applied. Several innovations have been devised to working with this unique data set, including...
    - Common receiver gather processing
    - Azimuth gathers
    - Pseudo inlines and crosslines
    - The Levin 4-D quick look method to computationally assist in identifying gas-affected locations
  - In-depth analysis and validation of the results are in progress.

ACQUISITION LESSONS LEARNED

- Ground roll presented a data-processing challenge.
  - Interferes with reflections on nodes offset <2200 feet from the source.
- General noise levels varied from week to week and required counteraction.
  - Wind is a big variable – burying the nodes and shooting earlier in the day may help.
  - Gauging current weather conditions before shooting would be an advantage. Rain is noticeable.
  - More cultural noise occurred than expected. Power line noise, pipeline noise, and pump motor noise near producing wells have presented challenges.
  - Individual nodes require individual attention based on noise proximity.
- The source shed was protected with a lightening rod, but not from a voltage surge.
  - An overvoltage surge entered on the power wires, traveled along the battery charger cables, and damaged ALL electronics connected to the source batteries, and more through an Ethernet port.
  - Note: Fuses protect against CURRENT surges, not overvoltage conditions.
  - If the chargers were plugged into the UPS, damage would have been limited to the UPS.
  - The source signature recorder memory was corrupted by the surge. Best practice would be to harvest shot data after each weekly salvo to eliminate data lost to SSR damage.

SYNERGY OPPORTUNITIES

- Several international CO_2 storage projects are experimenting with fixed sources and permanent or semipermanent receiver arrays.
  - Aquistore (Canada)
  - Otway (Australia)
  - Tomakomai (Japan)

  Lessons learned from each may be applicable.

- Complementary monitoring method used in combination with the CO_2 EOR monitoring using the Krauklis wave presented later today.

SUMMARY

- Key findings
  - Results are not black and white, but confidence is high that the data show changes due to CO_2.
  - Reservoir simulations show where effort should be concentrated.
  - Ambiguity in identifying changes due to CO_2 exists because of noise levels.
  - Solutions involving data-processing techniques and interpretation methods are being explored to remove ambiguity.
- Future plans
  - Finalize analysis, and validate if possible. Prepare the final report.
  - Submit for publication findings from the study to a scientific journal.

ACKNOWLEDGMENTS

- Thank you to…
  - Denbury Onshore LLC: for field access and assistance in the Bell Creek Field.
  - CGG GeoSoftware: for the donation of HRS-10 software that was used in generating some of the results for this project and presentation.
  - DOE Project Management: Andrea McNemar
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APPENDIX

- Benefit to the Program
- Project Overviews, Goals, and Objectives
- Organization Chart
- Gantt Chart
- Bibliography

BENEFIT TO THE PROGRAM

- Program goals addressed:
  - Develop and validate technologies to ensure 99% storage performance.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
  - Develop best practice manuals for monitoring, verification, accounting, and assessment.

- The SASSA method is a novel application of existing technology with the potential to track the location of a CO_2 saturation front in the subsurface in a timely and cost-effective manner:
  - To improve measurement and accounting of storage performance.
  - Provide a means of remotely detecting out-of-zone migration of CO_2 (ensuring containment effectiveness).
  - Contribute to best practices for monitoring, verification, and accounting (MVA).

BENEFITS STATEMENT

The project will address Area of Interest 1, “Tools and technologies that provide accurate, high-resolution measurement of CO_2 saturations, plumes, and pressure fronts in the subsurface,” by using commercially available technology to create an innovative, scalable, automated monitoring system for the purpose of detecting the movement of a CO_2 plume and pressure front resulting from the injection of CO_2 into the subsurface. The project goals will be accomplished by deploying the proposed technology at an existing commercial CO_2 enhanced oil recovery and storage project. The results of this effort will validate the use of existing technology to effectively monitor the migration of CO_2 in the subsurface in a cost-effective, noninvasive (both to the environment and the operator) way. These results will contribute to the Carbon Storage Program’s goal of developing and validating technologies to measure and account for 99% of injected CO_2 in the injection zones.

PROJECT OVERVIEW
GOALS AND OBJECTIVES

- Demonstrate and evaluate a novel seismic deployment method that can be operated remotely (and potentially automated) to show where and when a carbon dioxide (CO_2) miscible front passes a particular subsurface location.

- Goals
  1. Install a semipermanent seismic system in the field that includes a safe and remotely operated seismic source.
  2. Collect and process data records to identify time-lapse changes that can be verified as being due to the presence of CO_2.

ORGANIZATION CHART

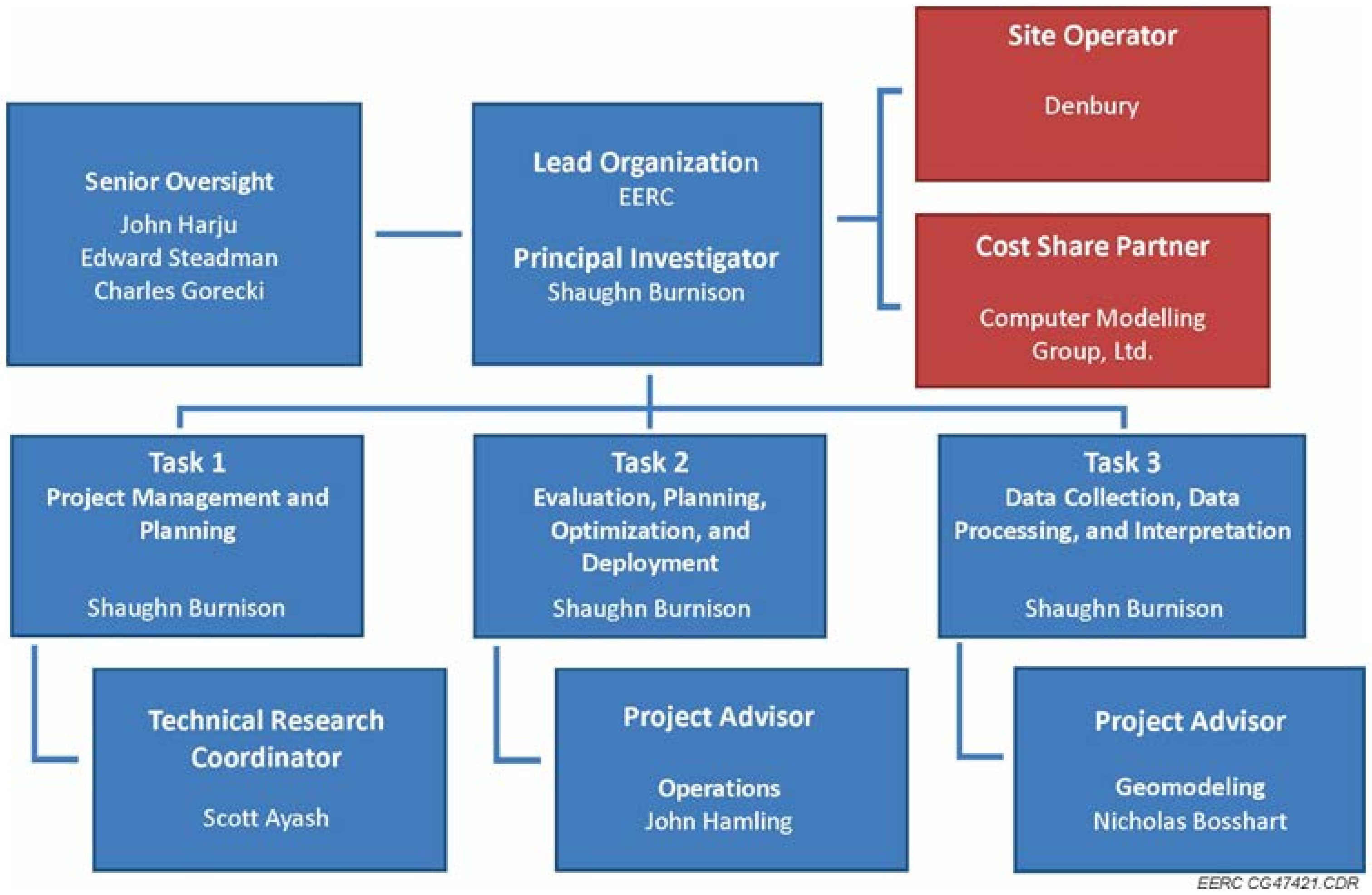
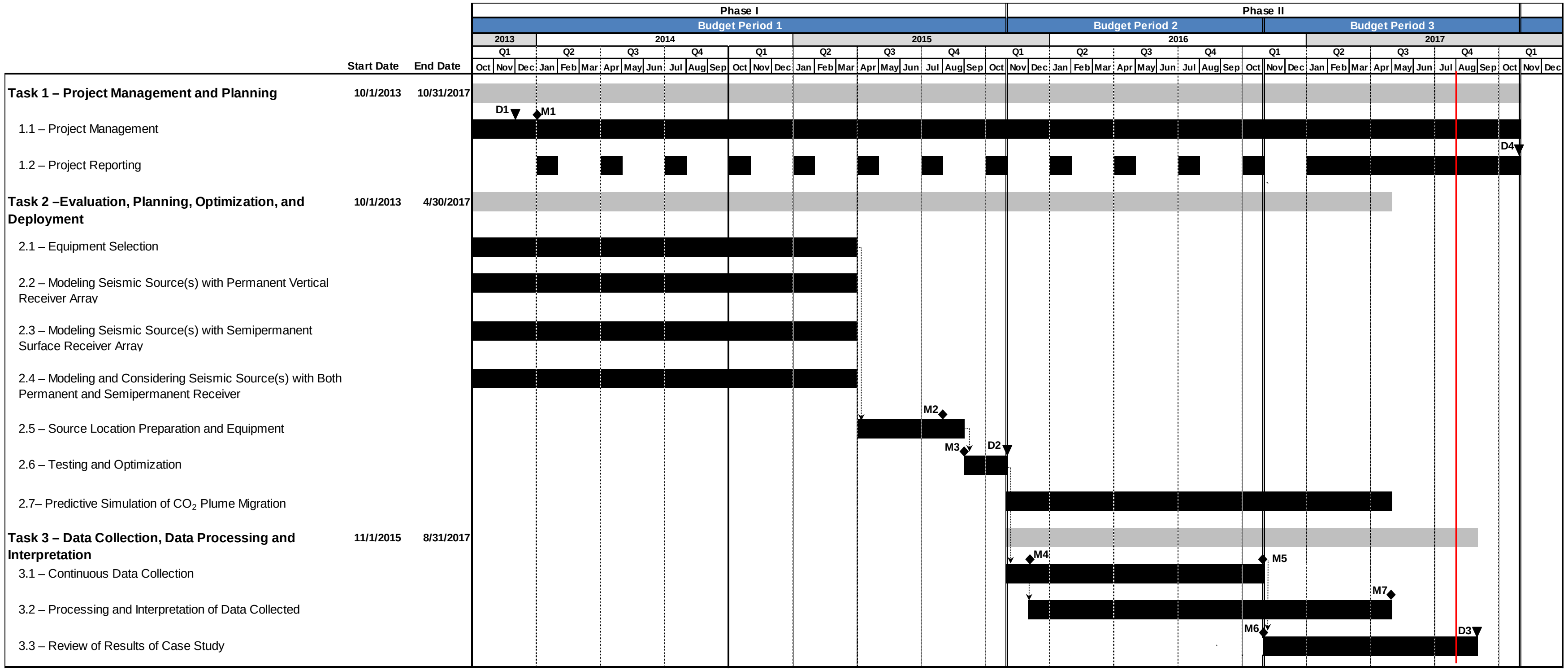
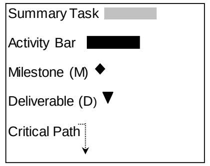


Figure 1. Project organization chart.

GANTT CHART





Key for Deliverables (D) ▼	Key for Milestones (M) ◆
D1 – Updated Project Management Plan (PMP)	M1 – Project Kickoff Meeting Held
D2 – Interim Report on Completion of Technical Design	M2 – Source Location Preparation Initiated
D3 – Technical Paper or Journal Article Based on Processing and Modeling Results and Overall Recommendations	M3 – Start Optimization and Testing of Equipment
	M4 – First Data Available for Processing
D4 – Final Report	M5 – Data Collection Completed
	M6 – Comparison to Conventional Seismic and History Match to Geological Model and Simulation Initiated
	M7 – Data Processing Completed

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THANK YOU!

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