Development and Deployment of MVA Tools

Samuel M. Clegg
Los Alamos National Laboratory

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Developing the Technologies and Building the Infrastructure for CO₂ Storage
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Presentation Outline

• Benefit to the Program
• Project Overview
• Technical Status
  – Frequency Modulated Spectroscopy (FMS)
  – $\Delta O_2/\Delta CO_2$ Ratio
  – Quantitative Seismic Monitoring
• Accomplishments
• Summary
• Appendix
Benefit to the Program

• Carbon Storage Program Major Goals
  1. Develop technologies that will support industries’ ability to predict CO₂ storage capacity in geologic formations to within ±30 percent.
  2. Develop technologies to demonstrate that 99 percent of injected CO₂ remains in the injection zones.
  3. Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.

• Project Benefits Statement.
  - The Project Goals were designed to directly meet the program major goals through Monitoring, Verification, and Accounting (MVA) technology development including; 1. Advanced Seismic Subsurface Imaging; 2. Surface seepage detection by Frequency Modulated Spectroscopy and O₂/CO₂ Ratios; and 3. four field experiments per year.
Project Overview:
Goals and Objectives

- **Surface MVA Monitoring**
  - Distinguish Natural and Anthropogenic CO2 Sources
  - Stable Isotope Detection by Frequency Modulated Spectroscopy
  - $\Delta$O2/$\Delta$CO2 Ratio
  - Field Demonstration of the Instruments

- **Subsurface Monitoring**
  - Quantitative Seismic Monitoring
  - Identification of Fractures and Seepage Pathways
  - Design Seismic Field Experiments
  - Techniques will be employed by the Big Sky Partnership
Frequency Modulated Spectroscopy (FMS)

- **Detect CO$_2$ Seepage**
  - At Natural CO$_2$ Emissions

- **Generally, the Atmosphere Contains**
  - 98.9% $^{12}$C$^{16}$O$_2$
  - 1.1% $^{13}$C$^{16}$O$_2$

- **Absorption Spectroscopy**
  - Maximum Line Strength (HITRAN)
    - $^{12}$C$^{16}$O$_2$ = 1.83x10$^{-23}$
    - $^{13}$C$^{16}$O$_2$ = 2.10x10$^{-25}$

- **Frequency Modulated Spectroscopy**
  - 100x to 1000x more sensitive than absorption spectroscopy
Fundamental Frequency Modulated Spectroscopy

From G.C. Bjorklund Optics Letters, 5, 15, 1980

From LANL in situ instrument

\[ \omega_c = 1607 \text{ nm} \]
\[ \omega_m = \pm 2 \text{ GHz} \]
Collect Samples from Field

10m Multipass White Cell

Flask

LICOR Total CO\textsubscript{2}

Exhaust

Pump

In Situ FMS Instrument Development
In Situ Observations

- Background = -8 to -11°/oo
- Seepage < -15°/oo

- Background = -4 to -7°/oo
- Over Source ~ -20°/oo
- 1m Away ~ -15 to -46°/oo
- >1m Away = -4 to -7°/oo
Remote Instrument Development

At ZERT,
2010: $\delta^{13}$C $\sim$ -9 $-$ -28 \%/oo
2011: $\delta^{13}$C $\sim$ -6 $-$ -28 \%/oo
FM-LIDAR

- Direct a CW Laser Across Sequestration Site
- 10ns Modulator Pulse
- Record Time Resolved Return Signal
- Convert Time to Distance
ΔO₂/ΔCO₂ Ratio

accumulation of CO₂ in the boundary layer. Attributing this CO₂ to plant and soil respiration vs. industrial sources is essentially impossible with CO₂ measurements alone.

Deviation of ΔO₂:ΔCO₂ from the nominal value of 1.1 along with the known value of CO₂ concentration allows calculation of the amount of excess CO₂ not attributable to natural sources...
Quantitative Seismic Monitoring

- Developed and implemented a double-difference waveform inversion method with a total-variation regularization scheme.
- Improved our double-difference waveform inversion method with a modified total-variation regularization scheme.
- Developed and implemented a wave-energy-weighted double-difference waveform inversion method.
- Studied the capability for quantifying reservoir changes caused by CO2 injection using time-lapse seismic data acquired with an optimally designed sparse array.
- Will investigate the field applicability of double-difference waveform inversion for quantitative seismic monitoring.

- Methods transitioned to the Big Sky Regional Partnership!
Time-Lapse Model with CO2 Leakage Through a Fault Zone

Initial Model

Time-Lapse Model

Time-Lapse Change
Inversion Results of Time-Lapse Changes Using Sparse-Array Data

Inversion result of $P$-wave velocity change

Inversion result of $S$-wave velocity change

Vertical profile of $\Delta V_p$ along the fault zone (Red: inversion)

Vertical profile of $\Delta V_s$ along the fault zone (Red: inversion)
Accomplishments

• Surface Diagnostics
  – In Situ FMS Instrument Development
  – Remote FMS Instrument Development
  – LIDAR FMS Instrument Development
  – O2/CO2 Instrument Development

• Field Demonstration of the Instruments

• Advanced Seismic Monitoring
Summary

• Surface Measurements
  – FMS and $\Delta O_2/\Delta CO_2$ Instruments are sensitive indications of natural vs. anthropogenic sources of CO$_2$

• Subsurface Seismic Imaging
  – Quantitative Imaging of the Seismic Plume and potential fractures.
Summary

• Lessons Learned
  – Field Work is Critical. We learned a great deal every time we deploy the instruments.

• Future Plans
  – Extend FMS to Detect $\text{H}_2^{\text{34/32}}\text{S}$ (1.58 µm) and $^{13/12}\text{CH}_4$ (1.65 µm) to indicate seepage from EOR site
  – Subsurface Fiber Optical MVA System
  – Field Demonstrations of New Technologies
  – Quantitative EOR Seismic Monitoring

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The ZERT Program for Providing the Field Location and Accommodating Our Experiments
Appendix
Organization Chart

- **Frequency Modulated Spectroscopy (FMS)**
  - Sam Clegg – FMS Development Lead
  - Julianna Fessenden – Stable Isotope Geochemist
  - Rhonda McInroy – Technician
- **$\Delta O_2/\Delta CO_2$**
  - Thom Rahn – $\Delta O_2/\Delta CO_2$ Instrument Development Lead
- **Advanced Seismic Imaging**
  - Lianjie Huang - Advanced Seismic Imaging Lead
- **Field Work Coordination**
  - Thom Rahn
  - Julianna Fessenden
Recent Publications & Presentations

2012

- Carbon Dioxide Monitoring, Verification and Accounting (MVA) by Carbon Stable Isotope Measurements, Samuel Clegg et al, CCUS #409
- High Precision O2 Measurements as a Monitoring Tool for CO2 Sequestration Integrity, Thom Rahn et al. CCUS #378

2011

- Lianjie Huang organized and chaired a Special Session on CO2 Geophysical Monitoring at 2011 AGU Fall Meeting held in San Francisco, California, on December 5-9, 2011. A total of 7 oral presentations and 24 posters were given. Both oral and poster sessions were well attended.
- Sam Clegg presented an invited paper at the 2011 Fall AGU Meeting on the ZERT field work.
- Thom Rahn and Anna Trugman presented a paper at the 2011 Fall AGU Meeting on the ZERT field work.