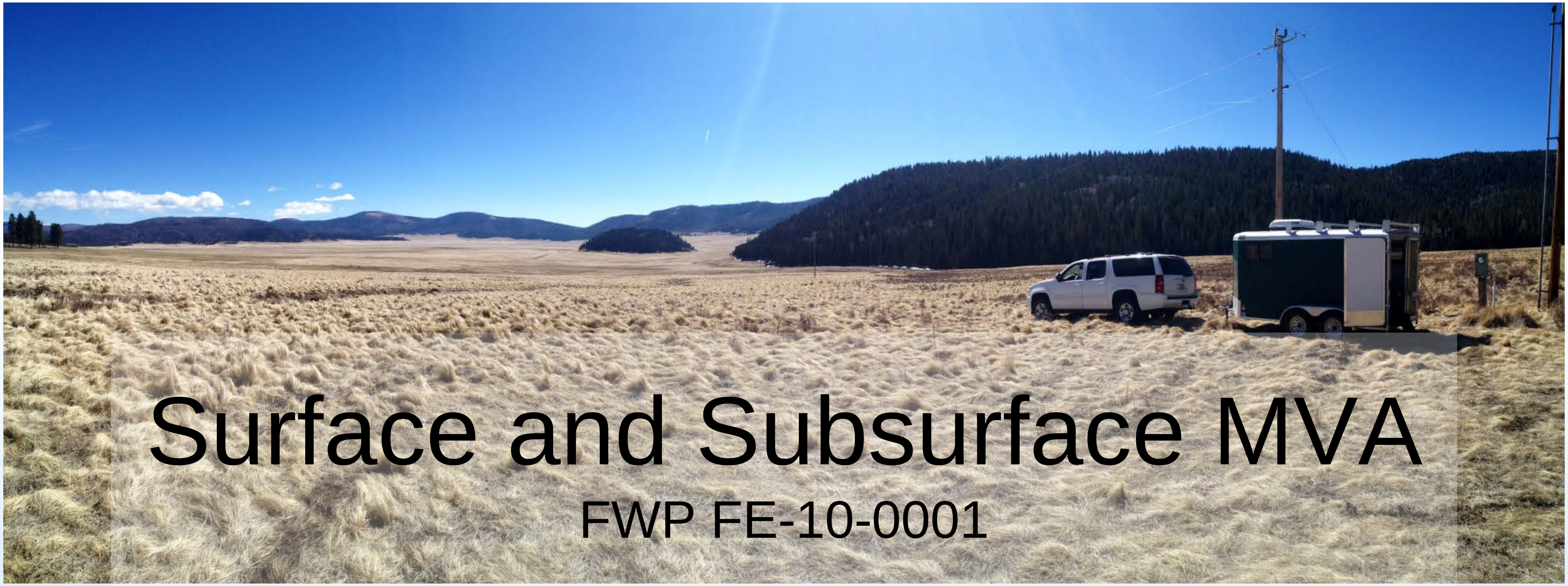

Surface and Subsurface MVA

FWP FE-10-0001

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Los Alamos National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 12-14, 2014

Presentation Outline

- Project Overview
  - Goals and Objectives
- Benefit to the Program
- Technical Status
  - Surface MVA
  - Subsurface MVA
- Accomplishments to Date
- Summary

Project Overview: Goals and Objectives

- Surface MVA – Frequency Modulated Spectroscopy
  - Quantitatively identify CO_2, H_2S and CH_4 seepage from geologic sequestration sites
  - Distinguish anthropogenic CO_2 from natural CO_2 emissions
    - CO_2 carbon stable isotope measurements
    - H_2S sulfur and CH_4 carbon stable isotope measurements
  - Real-time *remote and in situ* CO_2, H_2S and CH_4 monitoring
  - Integrated into Single Instrument
- Subsurface MVA – Advanced Seismic Imaging
  - Quantify reservoir geophysical properties changes Using Joint Waveform Inversion of Time-Lapse Seismic Data
  - Design optimal, cost-effective surveys for time-lapse seismic monitoring

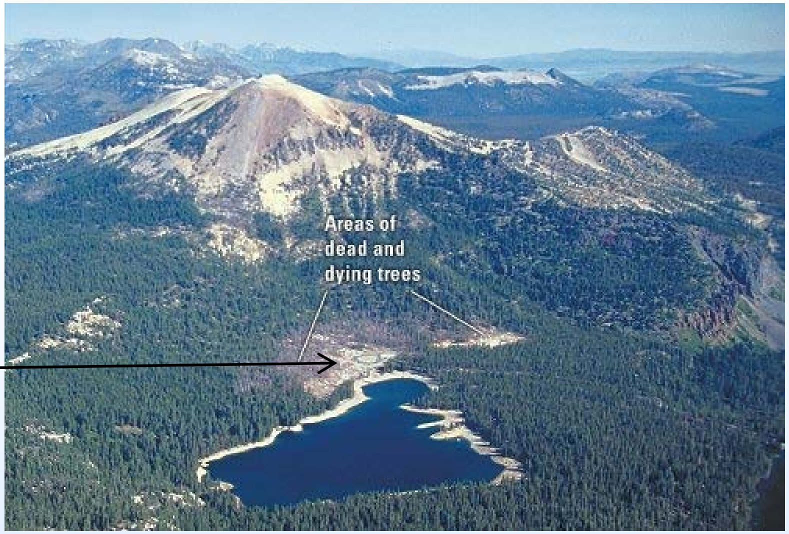
Benefit to the Program

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Advanced Seismic Reservoir Imaging
- Develop and validate technologies to ensure 99% storage permanence.
  - FMS CO_2, H_2S, and CH_4 Monitoring
  - Advanced Seismic Reservoir Imaging
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
  - FMS CO_2, H_2S, and CH_4 Monitoring
  - Advanced Seismic Reservoir Imaging
- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.
  - FMS CO_2, H_2S, and CH_4 Monitoring
  - Advanced Seismic Reservoir Imaging

MVA Field Experiments

- 2008 - 2014 Field Experiments
  - Mammoth Springs, CA
  - Valles Caldera, NM
  - Sevietta Long Term Ecological Research, NM
  - Farmington, NM
  - Soda Springs, UT
  - LANL Juniper-Pinion Field Site
  - ZERT, MSU, Bozeman, MT

    - Controlled CO_2 Flow & Release Rate



LANL MVA Program

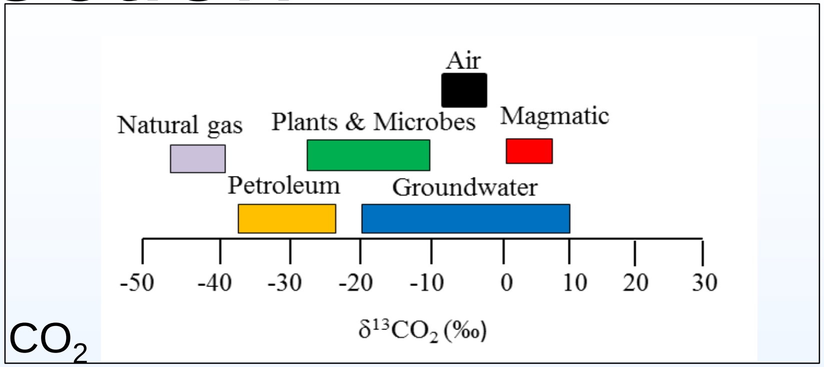
- Frequency Modulated Spectroscopy
  - In situ
  - Remote
  - LIDAR
  - CO_2, CH_4, H_2S (isotopes)

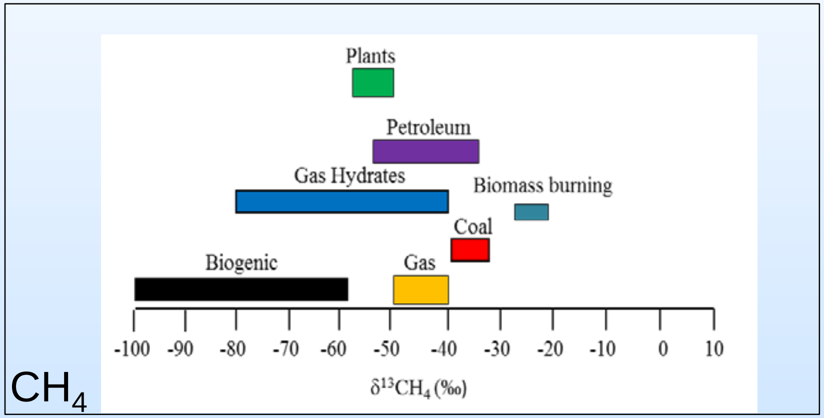
- Flask Collects, Mass Spectroscopy
- Water Stable Isotope Analysis

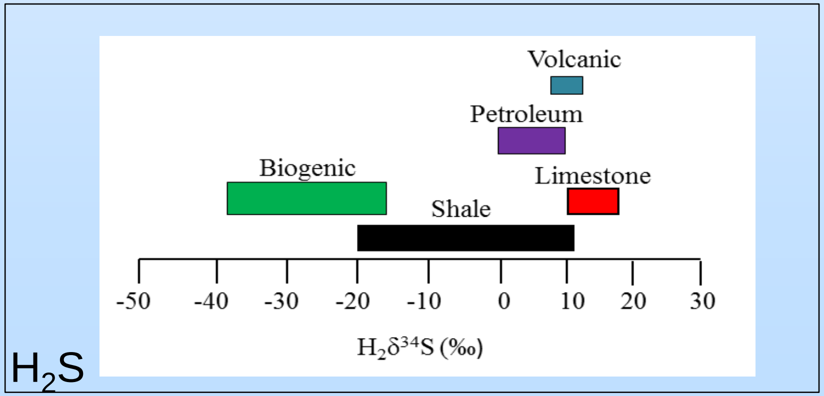
Stable Isotope Detection

- Detect Seepage of CO_2, CH_4, H_2S at sequestration sites
- Isotopic Signatures for source identification
- Frequency Modulated Spectroscopy
  - 100x to 1000x more sensitive than absorption spectroscopy
- Generally, the Atmosphere Contains
  - 98.9% $^{12}C^{16}O_2$
  - 1.1% $^{13}C^{16}O_2$
- Calibration Gases Prepared In House
  - Available vendors were too expensive and took too long

$$\delta^{13}C_{sam} = \left(\frac{13C_{sam}/12C_{sam}}{13C_{std}/12C_{std}} - 1\right)x1000$$

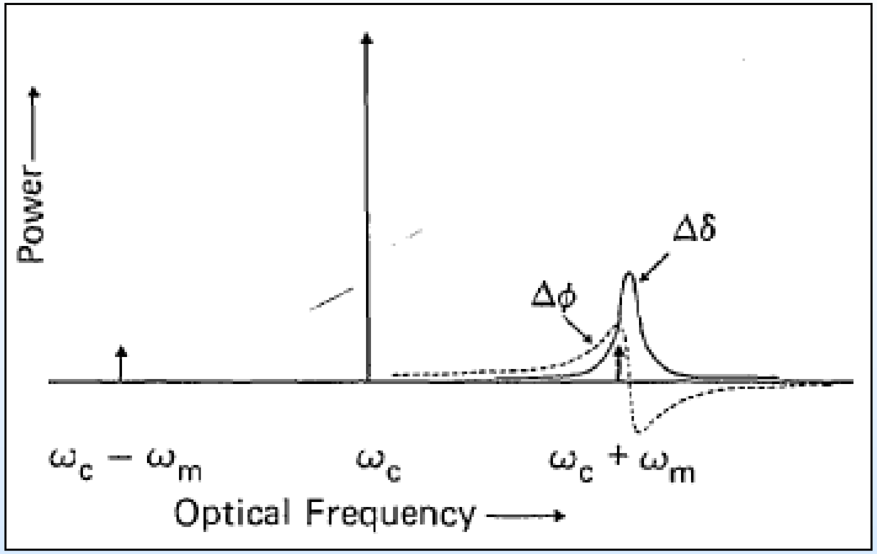




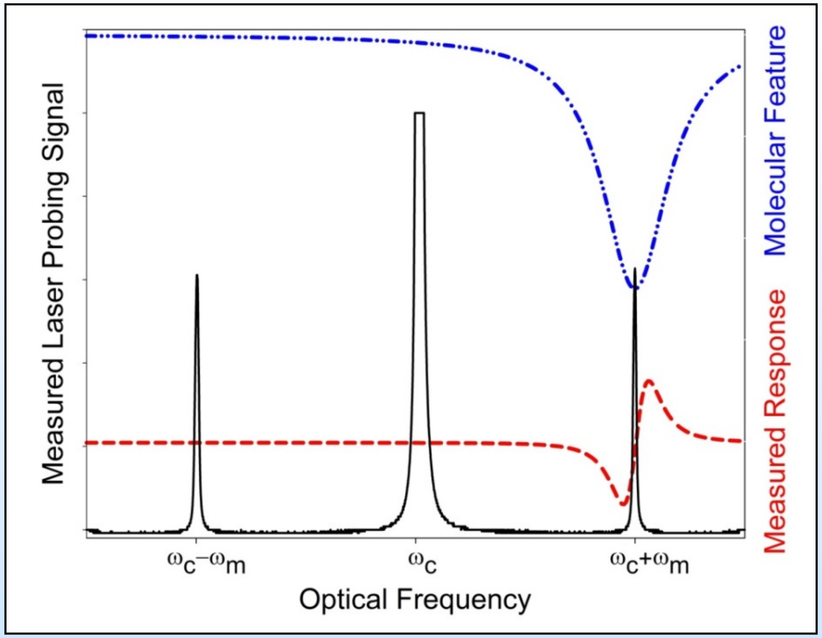


Frequency Modulated Spectroscopy

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



Frequency Modulation Spectroscopy

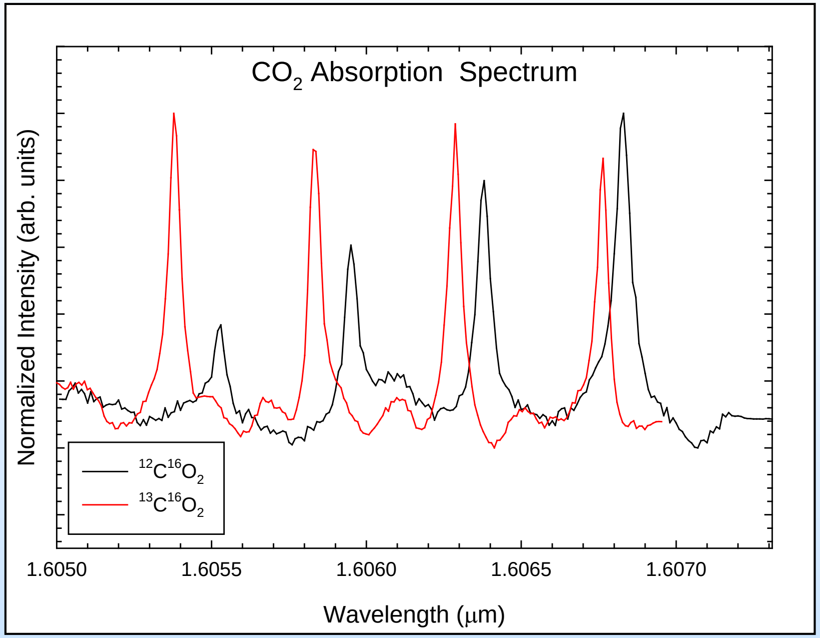


Absorption Spectroscopy Maximum Line Strengths (HITRAN)

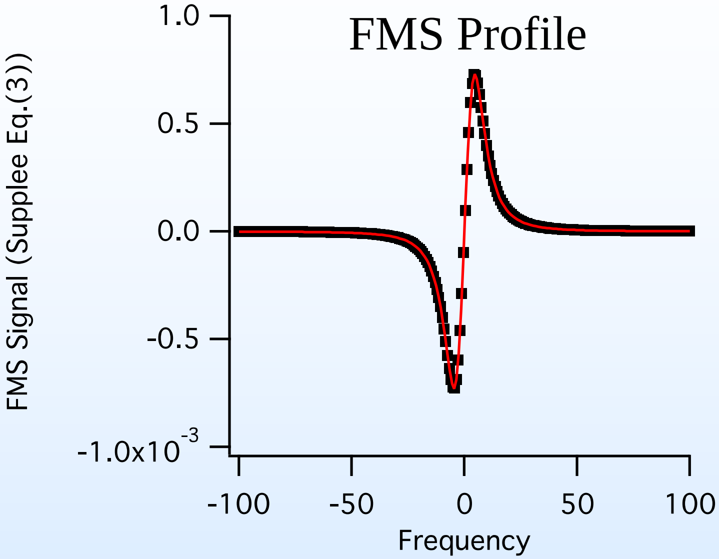
$^{12}C^{16}O_2$ = 1.83x10^{-23}	$^{12}CH_4$ = 1.00 x10^{-21}	$H_2{}^{32}S$ = 1.3x10^{-22}
$^{13}C^{16}O_2$ = 2.10x10^{-25}	$^{13}CH_4$ = 1.59x10^{-23}	$H_2{}^{34}S$ = 1.8x10^{-24}

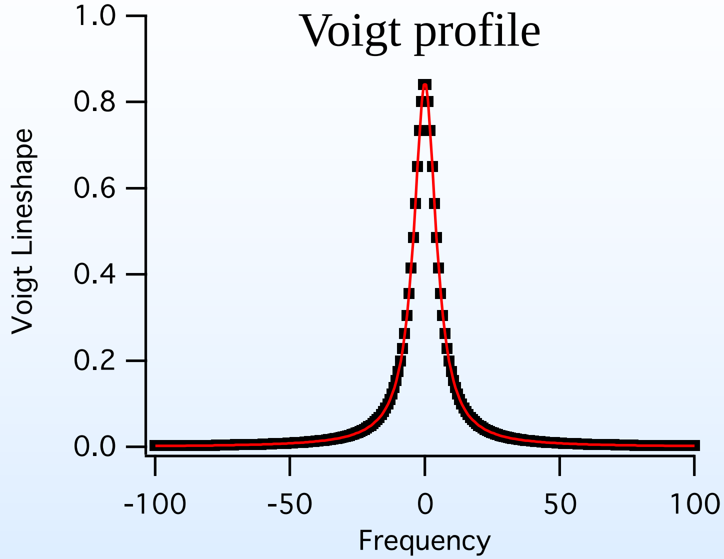
Frequency Modulated Spectroscopy

- Why 1570 – 1680nm range?
  - Telecom Electronics (1550nm)
  - Absorption Cross Section for Remote (hundreds of meters)
  - No spectral interferences.
    - H_2O or CO
- Why 1604 – 1609nm range?
  - $^{13}C^{16}O_2$ Peaks between $^{12}C^{16}O_2$ Sub-Bandheads.
  - $^{12}C^{16}O_2$ Peaks ~10x $^{13}C^{16}O_2$
  - Multiple species detection with same hardware



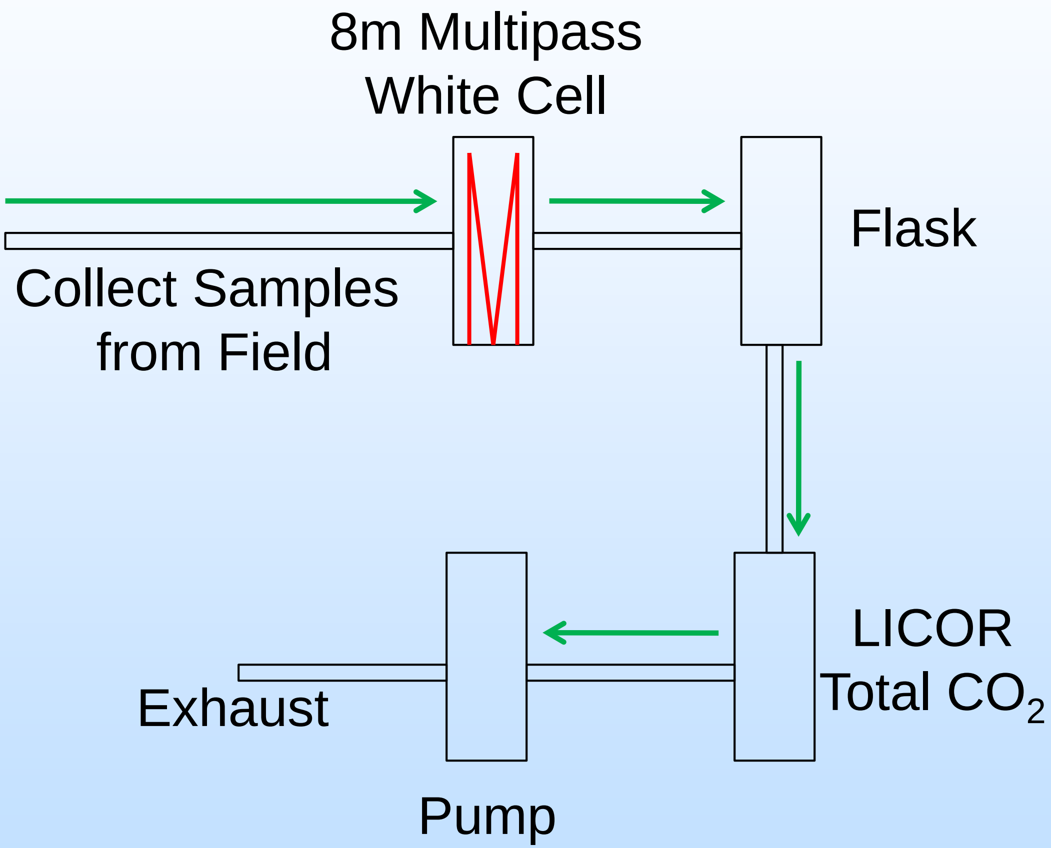
Forward-Backward FMS Systems Model

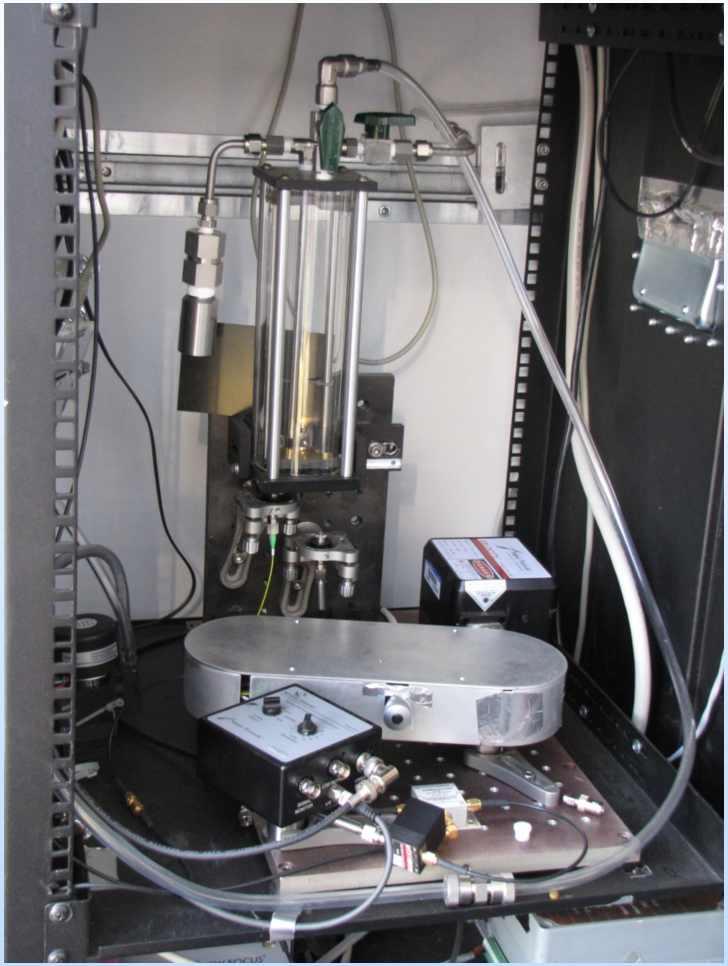




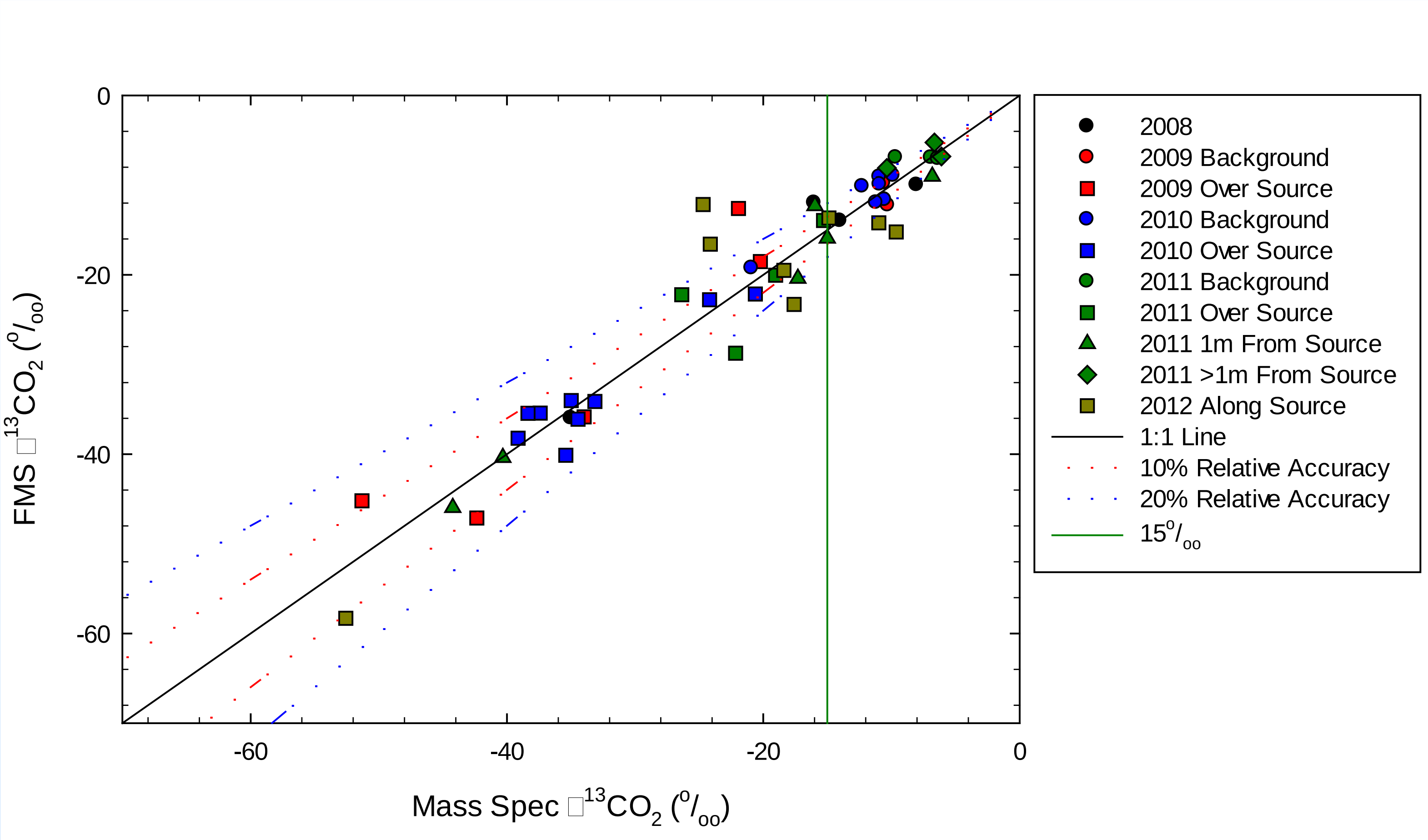
- The Voigt profile shown on the right as black squares was used to generate simulated FMS signal as a function of carrier frequency (shown as black squares in the left-hand plot). The theoretical equation for the FMS signal was then fit to that simulated FMS signal.
- The resulting fit to the simulated FMS signal is shown as a red line in the left-hand plot.
- The Voigt line shape corresponding to the best-fit parameters determined during that regression is then shown as a red line on the right. It accurately reproduces the original Voigt feature.
- The agreement is excellent in both forward and backwards fitting. For this calculation, M=0.1 and ω_m =0.1.

In Situ FMS Instrument





In Situ Observations

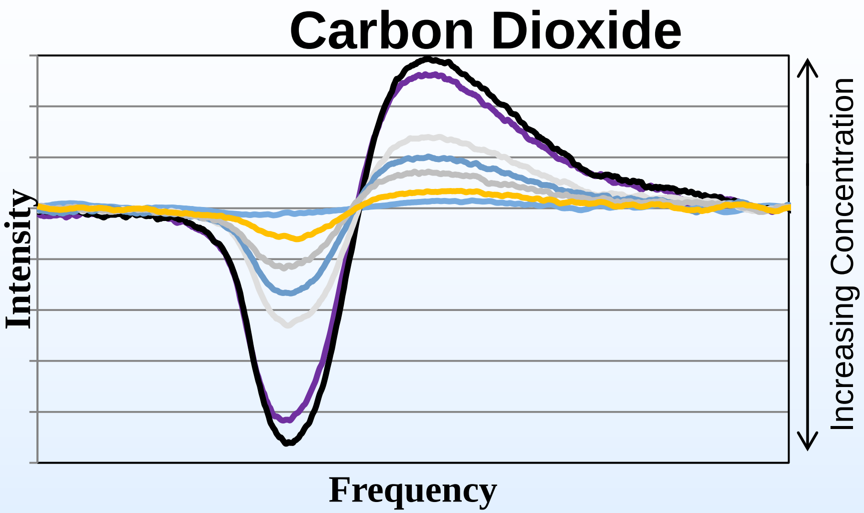


<u>Historical Trends</u>

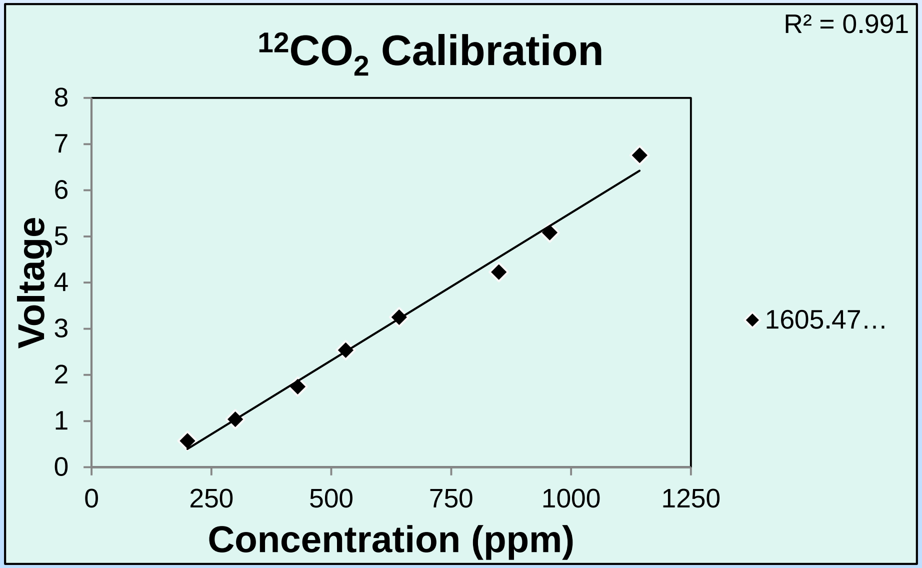
Background > -15 $^{o}/_{oo}$

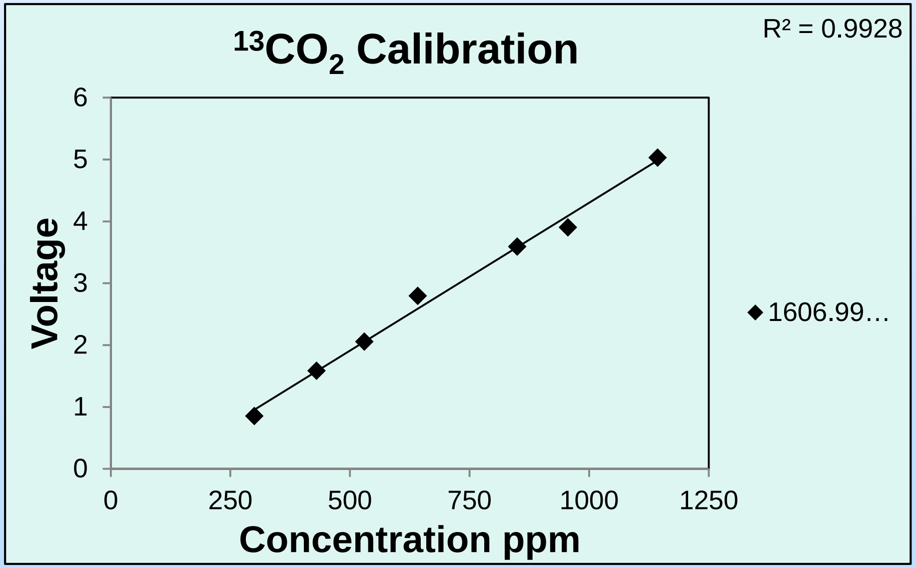
Seepage < -15$^{o}/_{oo}$

Carbon Dioxide Calibration

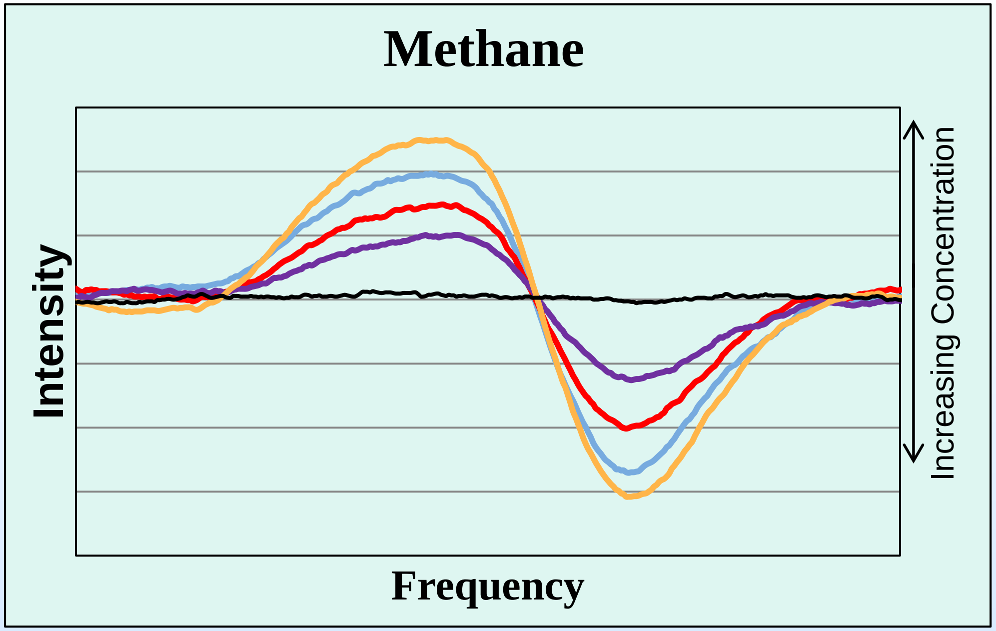


Estimated Detection Limit
$^{12}CO_2$ and $^{13}CO_2$ < 1 ppb

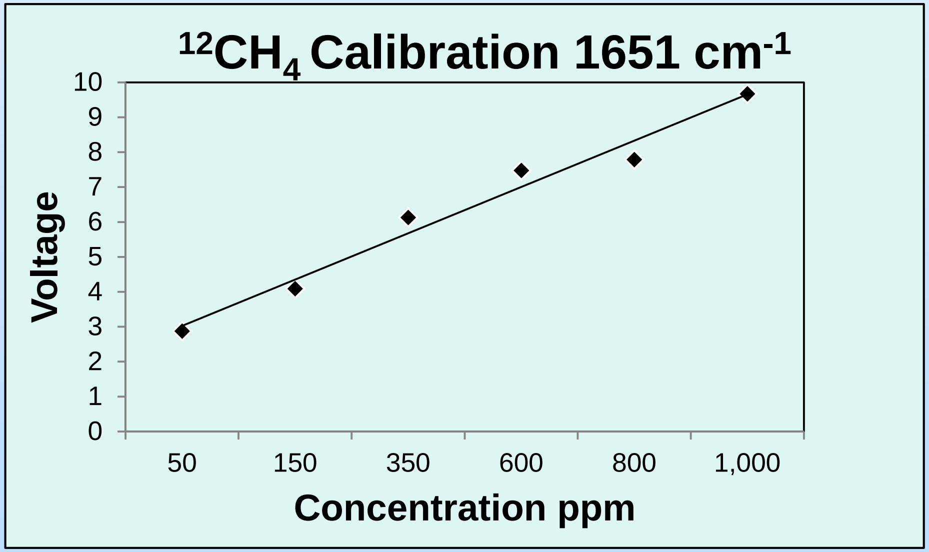




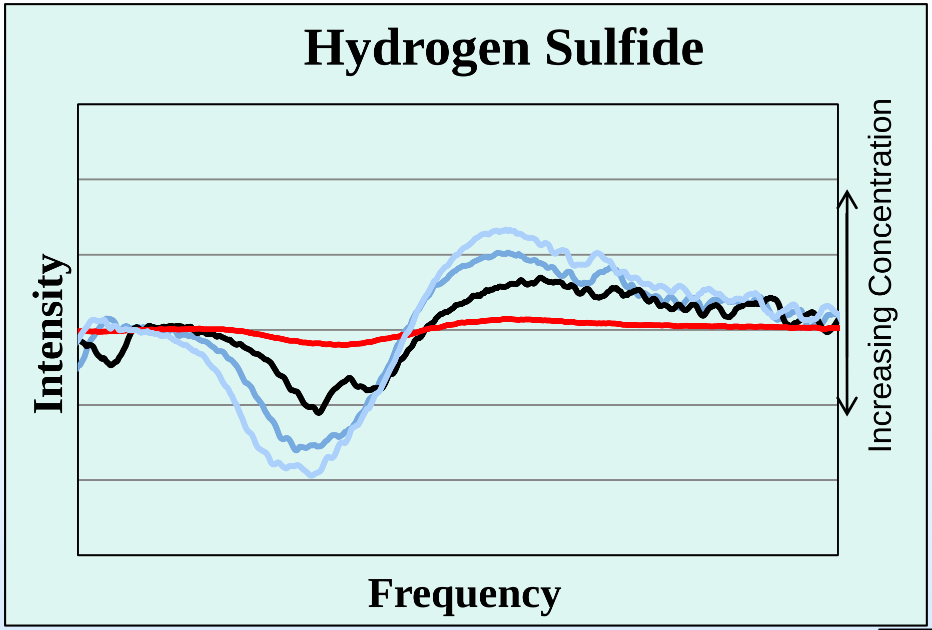
Methane Calibration



Estimated Detection Limit
$^{12}CH_4$ and $^{13}CH_4$ < 1 ppb



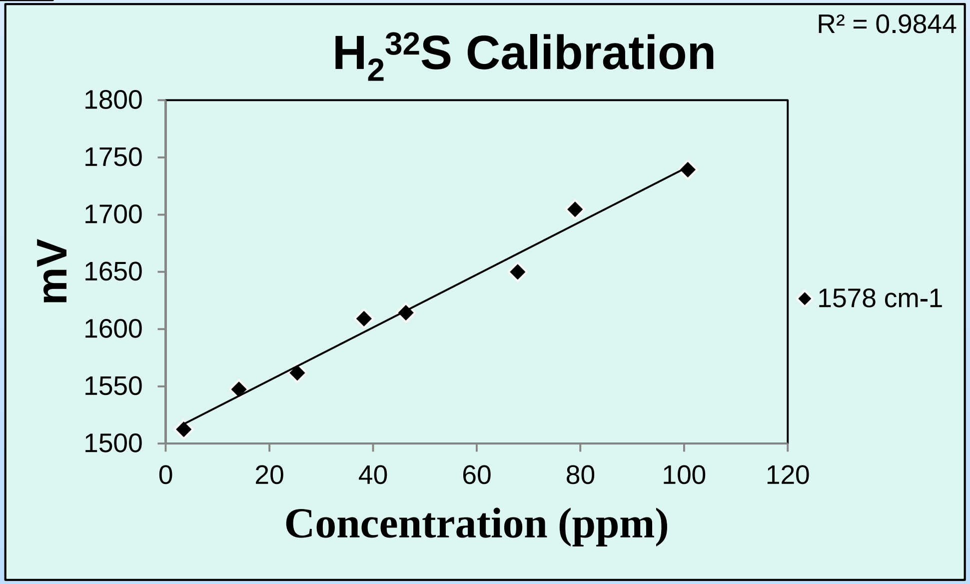
Hydrogen Sulfide Calibration



Estimated Detection Limit

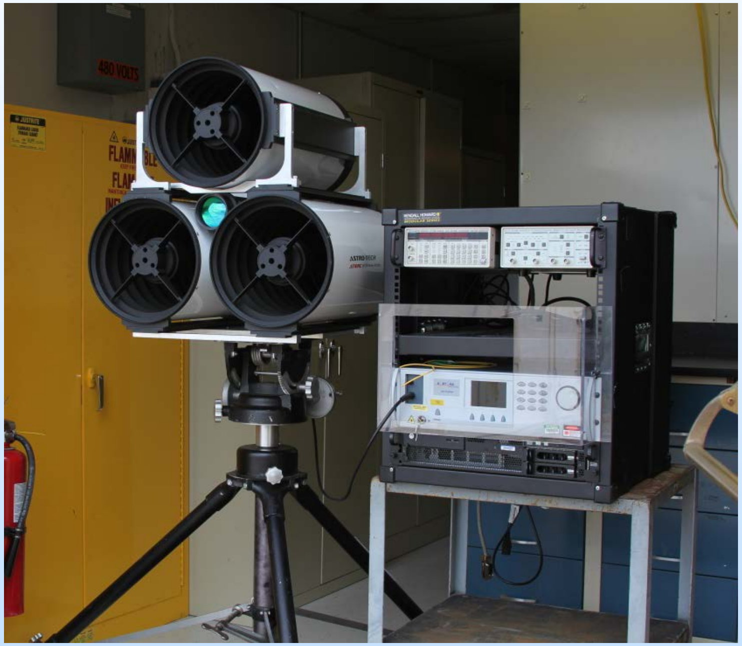
$H_2{}^{32}S$ < 1 ppb

$H_2{}^{34}S$ < TBD



Integrate into LIDAR Instrument

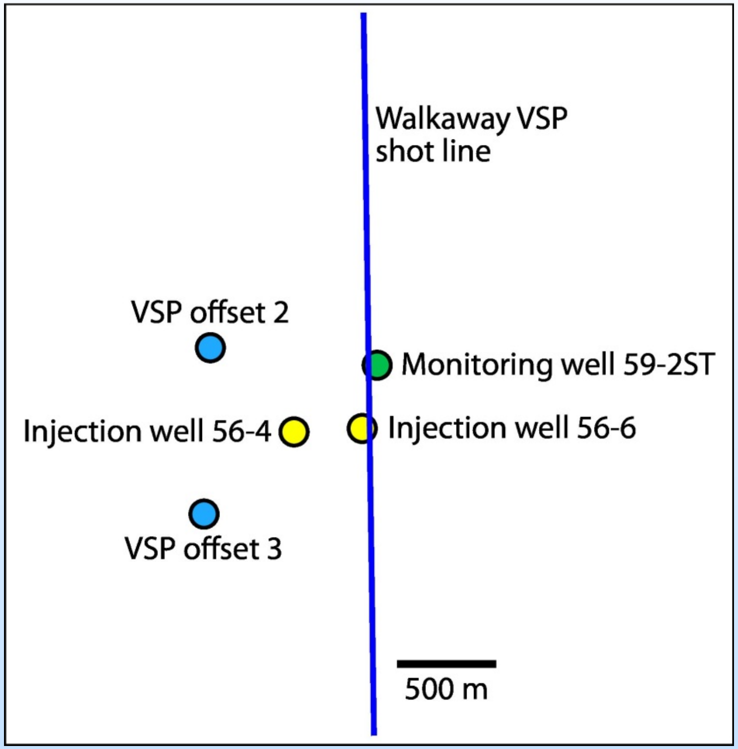
Add CH_4 and H_2S detection to CO_2 LIDAR instrument



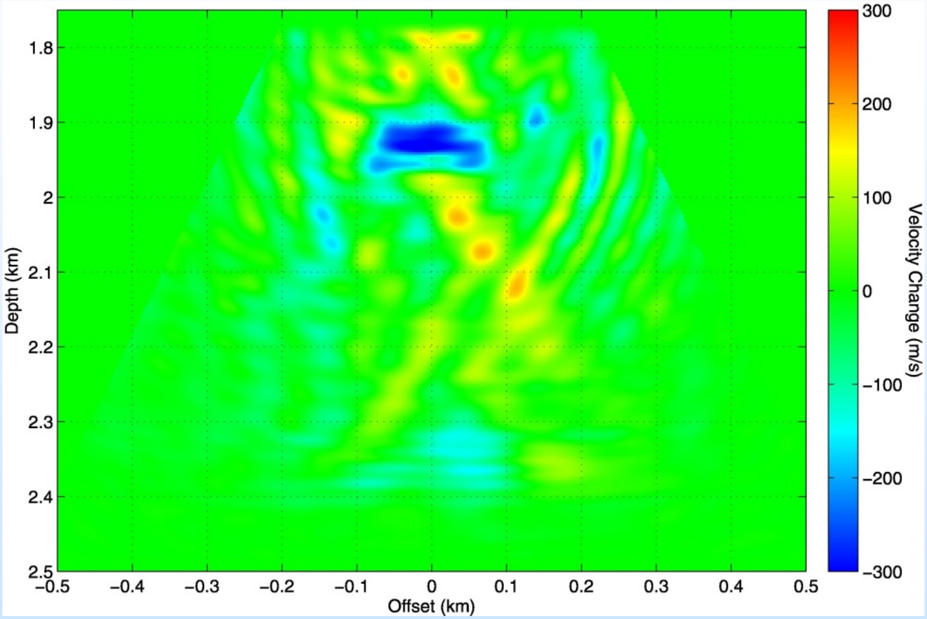
Quantify Reservoir Changes Using Joint Waveform Inversion of Time-Lapse Seismic Data

- **Motivation**
  - Accurate quantification of reservoir changes can be used as a non-invasive tool for tracking CO_2 plume, and is crucial for long-term MVA for geologic carbon storage.
- **Objective**
  - Study the field applicability of our recently developed algorithm for joint waveform inversion of time-lapse seismic data.
- **Field Data:** Time-lapse walkaway vertical seismic profiling (VSP) surveys at the SACROC EOR field
  - As part of efforts of SWP Phase II to acquire the data
  - A baseline VSP data were acquired before CO_2 injection
  - A repeat VSP data were acquired about six months after CO_2 injection

Quantify Reservoir Changes Using Joint Waveform Inversion of Time-Lapse Seismic Data



100 shot points along the blue line were used to acquire VSP data recorded at 15 levels of geophone in the monitoring well.



Joint waveform inversion result of time-lapse walkaway VSP data from SACROC reveals a <u>low velocity zone</u> near the CO_2 injection locations.

Quantify Reservoir Changes Using Joint Waveform Inversion of Time-Lapse Seismic Data

- Joint waveform inversion algorithms can quantify changes of geophysical properties within CO_2 reservoirs.
- Algorithms can quantifying reservoir changes with either:
  - time-lapse surface seismic data or
  - time-lapse VSP data
- Our algorithms can be combined with optimal survey designs for cost-effective monitoring.
  - We have developed a seismic-wave sensitivity analysis method for optimal designs of time-lapse seismic surveys.

Accomplishments to Date

- Frequency Modulated Spectroscopy
  - Developed CH_4 and H_2S detection methods
  - Integrated CH_4 and H_2S detection into existing in situ CO_2 FMS instrument
  - Developed CH_4 and H_2S calibration curves
  - Developed Forward-Backward System Model
- Advanced Seismic Imaging
  - Quantify reservoir geophysical properties changes Using Joint Waveform Inversion of Time-Lapse Seismic Data
  - Design optimal, cost-effective surveys for time-lapse seismic monitoring

Summary

- Key Findings
  - FMS
    - Stable isotopes are sensitive signatures of seepage from carbon sequestration and EOR sites.
    - Detection of these stable isotope signatures can be integrated into the same instrument.
  - Advanced Seismic Imaging
    - Joint Waveform Inversion of Time-Lapse Seismic Data can Quantify changes in reservoir geophysical properties
    - Design optimal, cost-effective surveys for time-lapse seismic monitoring
- Lessons Learned
  - Field experiment are critical tests to validate the instruments and algorithms developed under this program
- Future Plans
  - Integrate the CH_4 and H_2S detection methods into the LIDAR instrument and to field test the integrated instrument.