Development of a 1 x N Fiber Optic Sensor Array for Carbon Sequestration Site Monitoring

Project Number: DE-FE0001858

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Developing the Technologies and Building the Infrastructure for CO_2 Storage
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MONTANA STATE UNIVERSITY BOZEMAN

ZERT Zero Emissions Research and Technology

Presentation Outline

- Program and Project Benefits
- Technical Status
  - Brief Introduction to integrated path differential absorption concentration measurements
  - 1 x N fiber sensor array description
  - Experimental results
- Program accomplishments and summary

Benefit to the Program

- Program Goals Addressed:

  Develop and validate technologies to ensure 99% storage permanence.

- Project Benefits

  The research project is developing a scalable, cost effective, reconfigurable fiber sensor array for large sub-surface monitoring of CO_2. This technology contributes to the Carbon Storage Program's effort to ensure 99% CO_2 storage permanence.

Project Overview: Goals and Objectives

- The project objectives for the proposed work include the development, testing, and deployment of a 1 x N fiber sensor array for subsurface CO_2 monitoring.
  - Relates to the development of technologies to demonstrate that 99% of CO_2 remains in the injected zones.
  - Success criteria: Demonstration of instrument from a laboratory setting.
- Testing of the instrument will be conducted to determine the performance of the fiber sensor array at the Zero Emission Research Technology (ZERT) field site during a controlled release experiment and at the Big Sky Carbon Sequestration Partnership Site.
  - Relates to conducting field tests for site operations.
  - Success criteria: Demonstration of instrument during a ZERT controlled release experiment and for a one month deployment at the BSCSP site.

Technical Status: Integrated Path Differential Absorption (IPDA) Technique

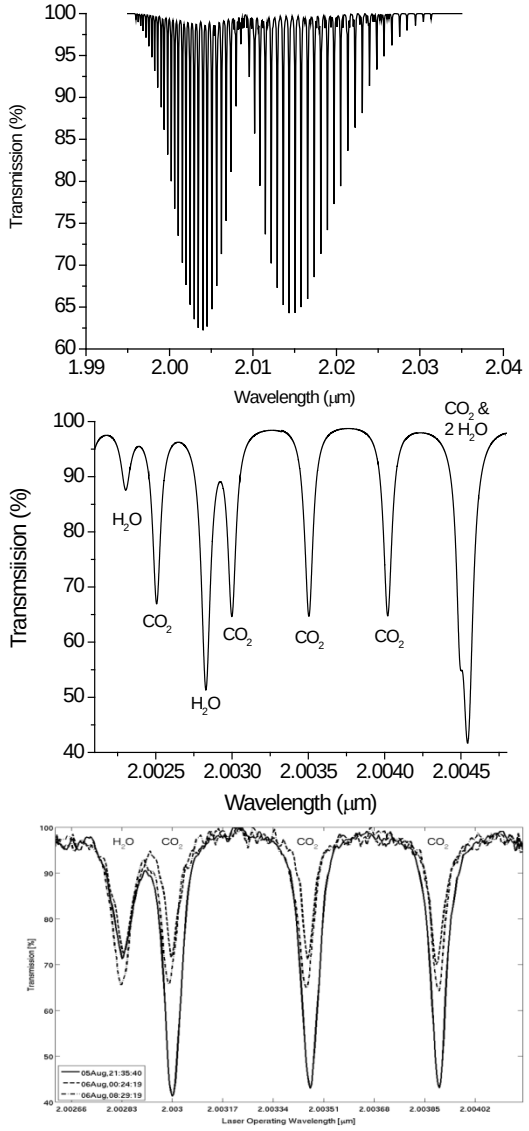
- The number density for carbon dioxide is related to the amount of light absorbed as a function of wavelength.

- Working near the 2 μm wavelength provides strong absorption features which allow subsurface CO_2 concentration measurements to be made in as little as 0.5 m.

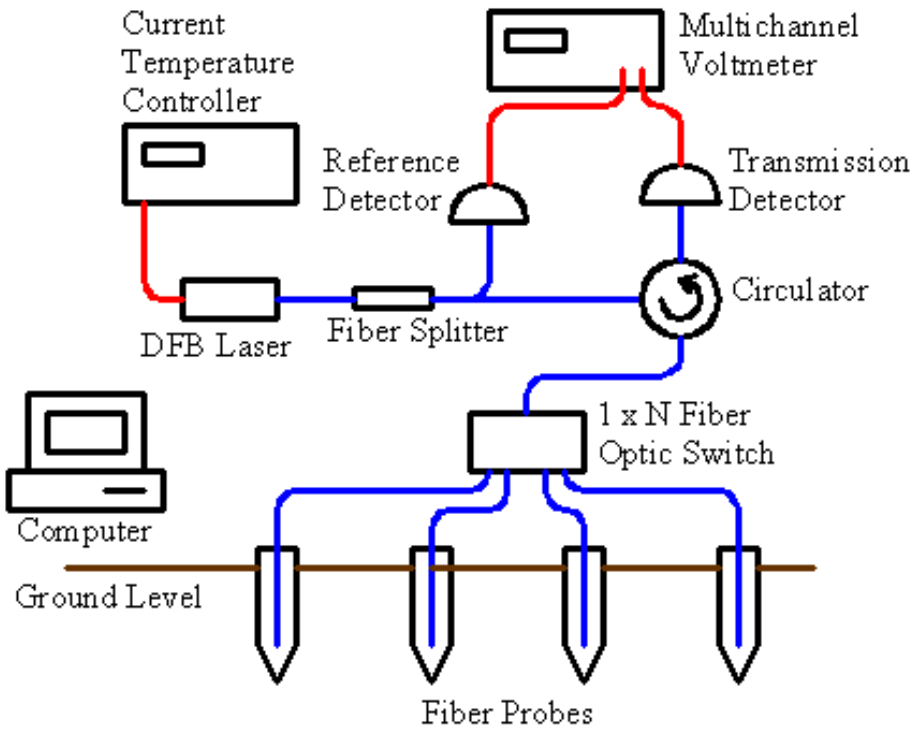
- Measuring the normalized transmission allows on to calculate the number density.

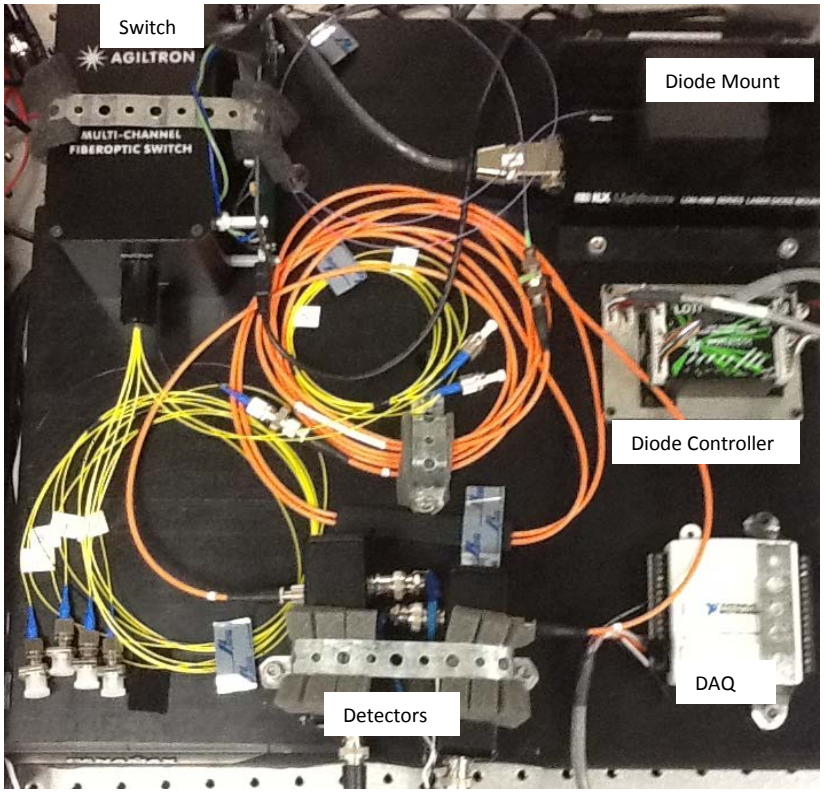
- Using the line strength and line shape parameters, the concentration can be calculated from the IPDA equation:

$$C = \frac{-\ln(T)}{Sg(\nu - \nu_0)\left[N_L(296/T_a)\right]P_T L},$$

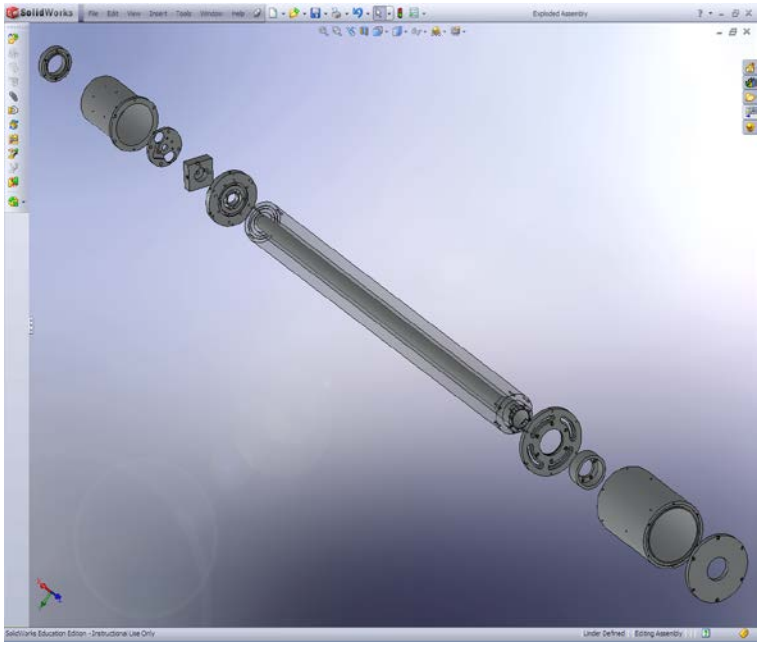


Technical Status: Instrument Design

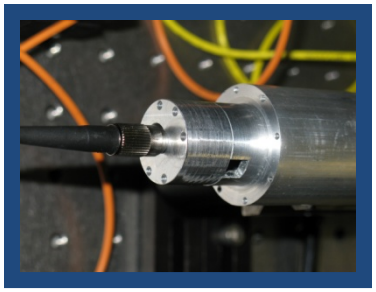




Technical Status: Probes

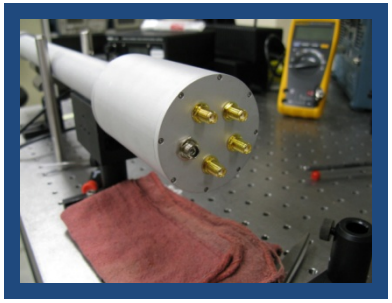


Solidworks CAD drawing of the probe design. The probe was designed to contain all passive optical components and is inexpensive to manufacture.



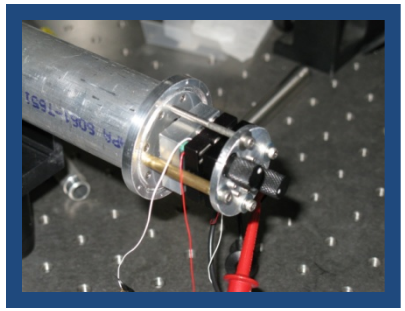
Fiber coupler details

Electronic Feed-through



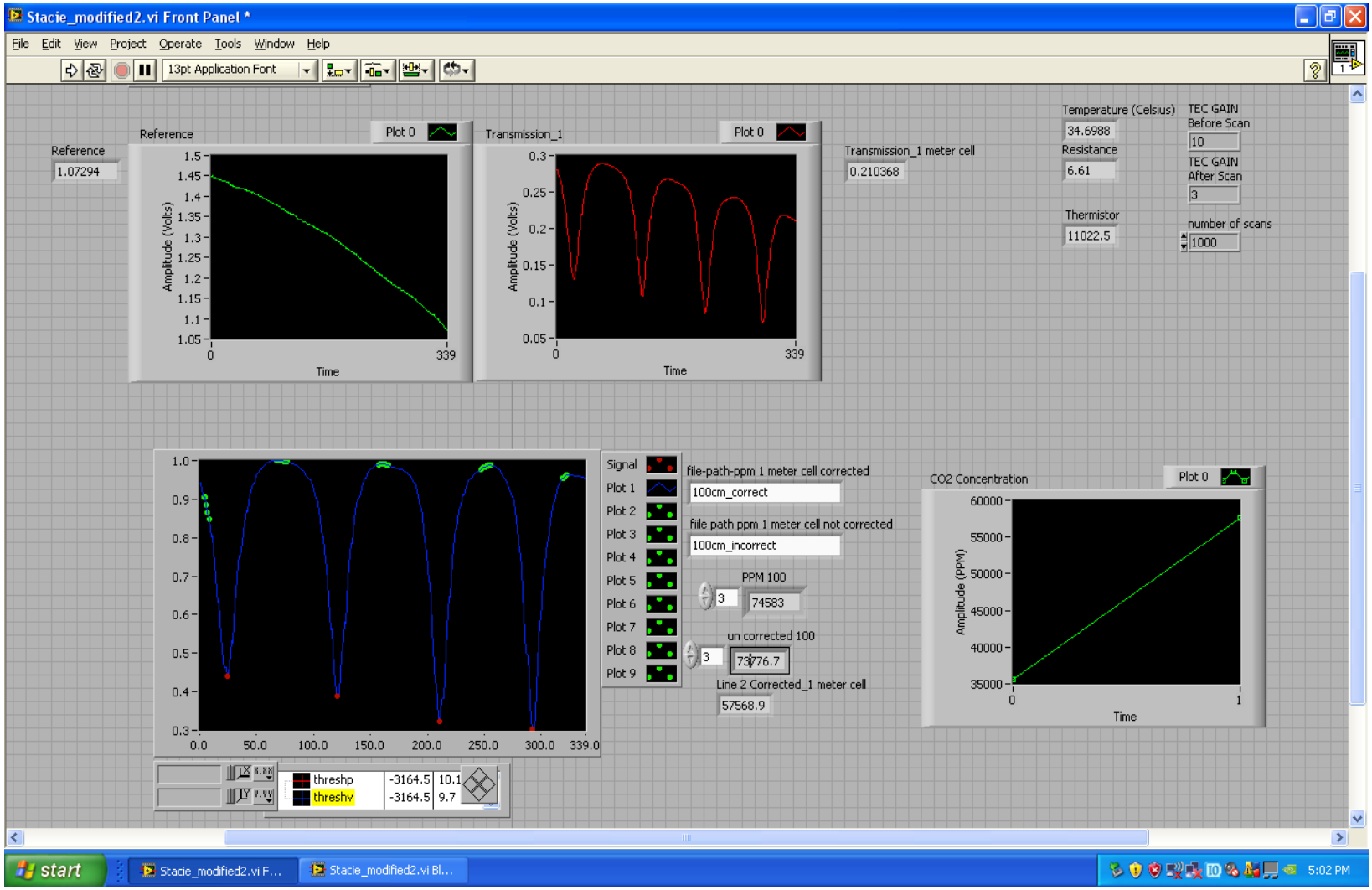
Gas permeable membrane

Retro-reflector details

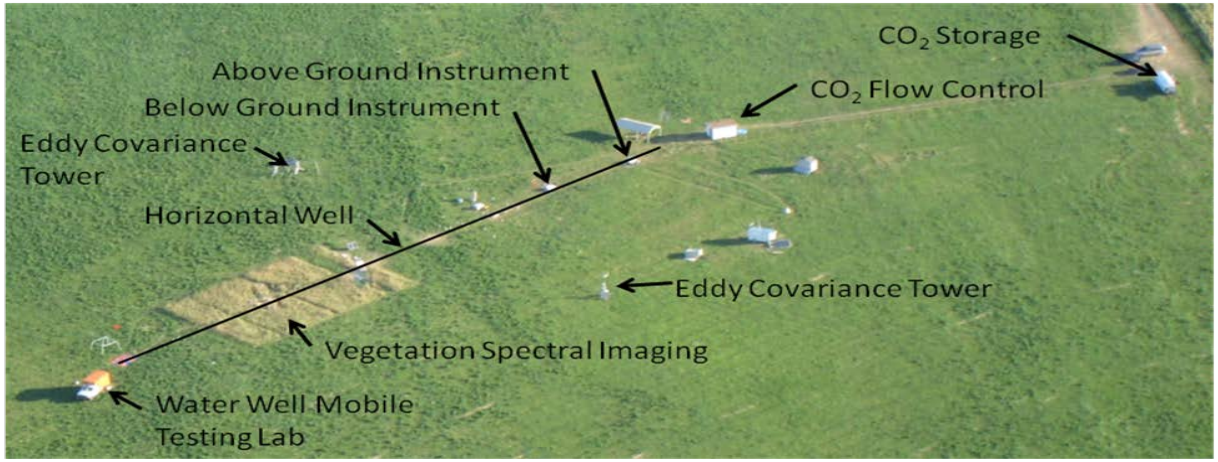


Four completed fiber probes

Technical Status: Data Acquisition Software



Technical Status: Field Experiment



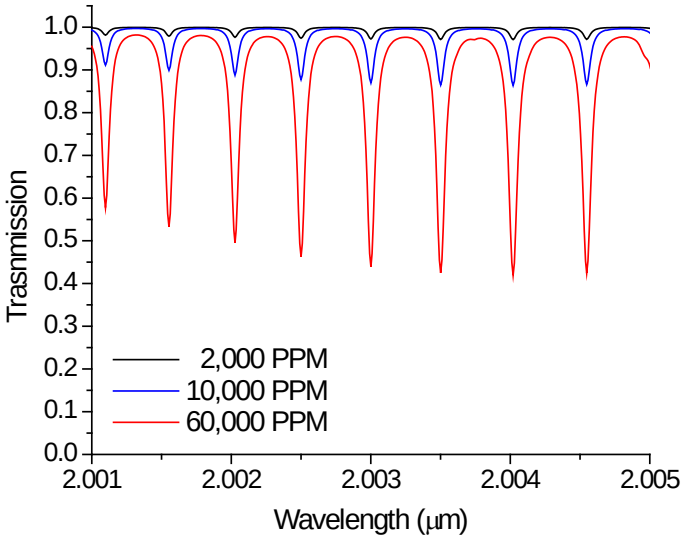
Aerial view of the ZERT controlled release site.

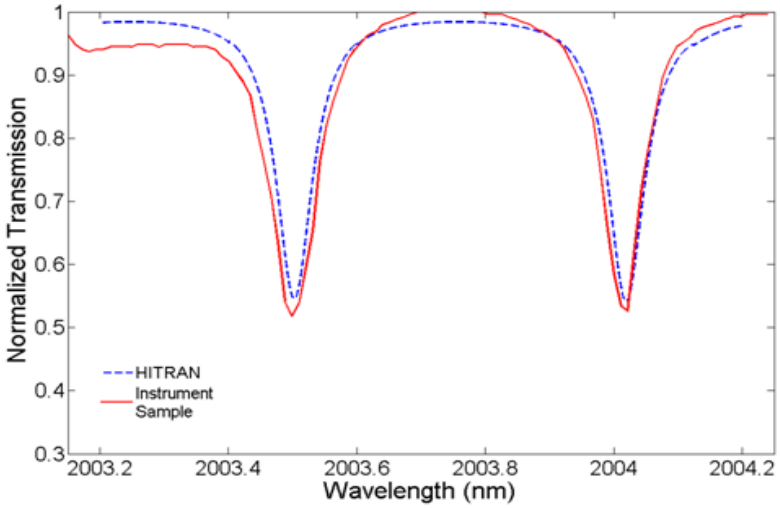
Electronics and optics packaged in a weatherproof enclosure for field studies.

Instrument deployed at the ZERT site with sun shade.

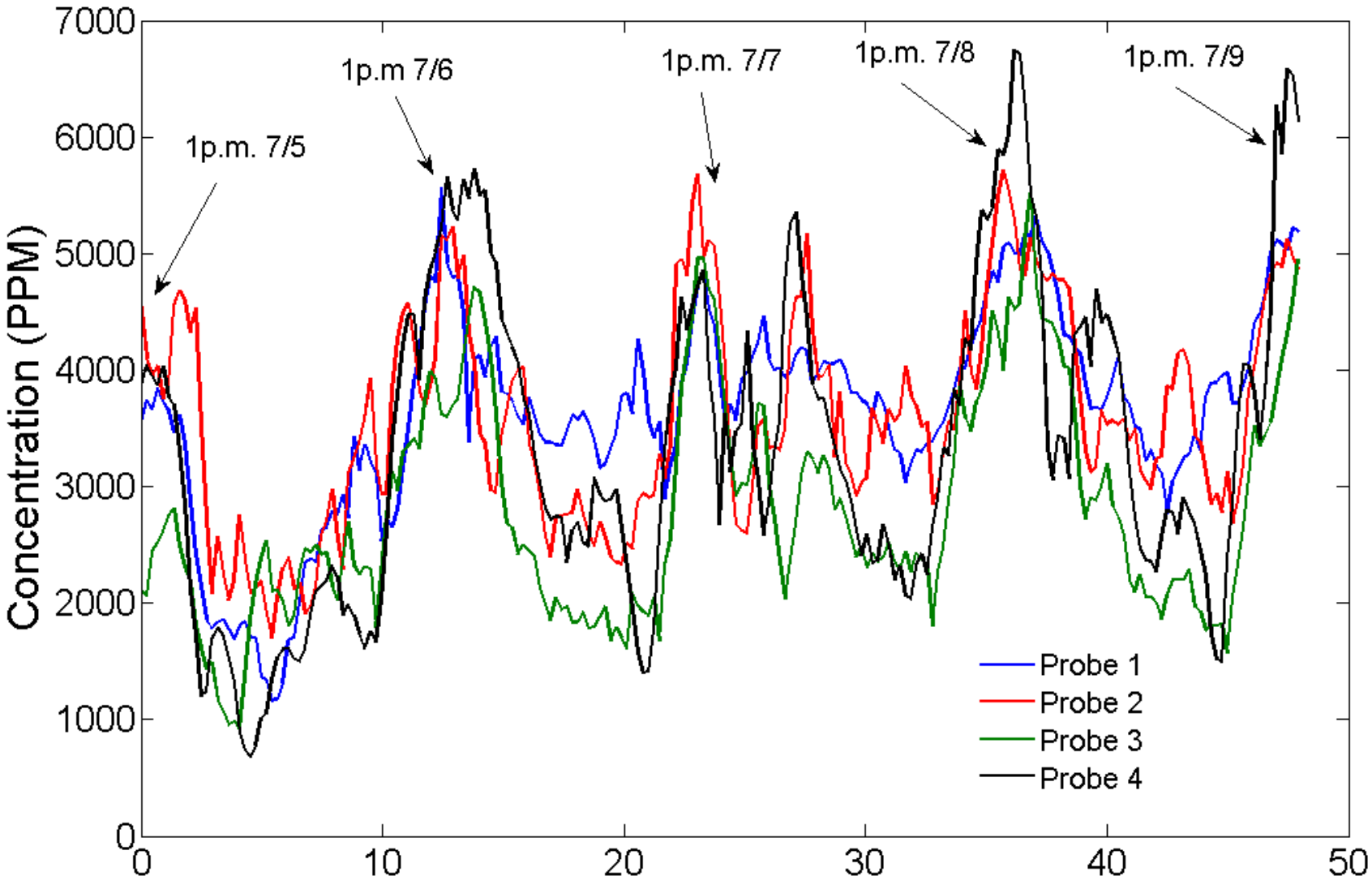
Technical Status: ZERT Field Data

Wavelength mm	Linestrength 10^{-21} molecules/cm	Normalized Lineshape Cm
2.001 102 0	0.811 2	1.160 0
2.001 557 7	0.931 6	1.151 6
2.002 025 5	1.048	1.140 1
2.002 505 7	1.153	1.130 4
2.002 998 0	1.241	1.116 1
2.003 502 6	1.302	1.102 2
2.004 019 2	1.332	1.084 2
2.004 548 2	1.322	1.0653

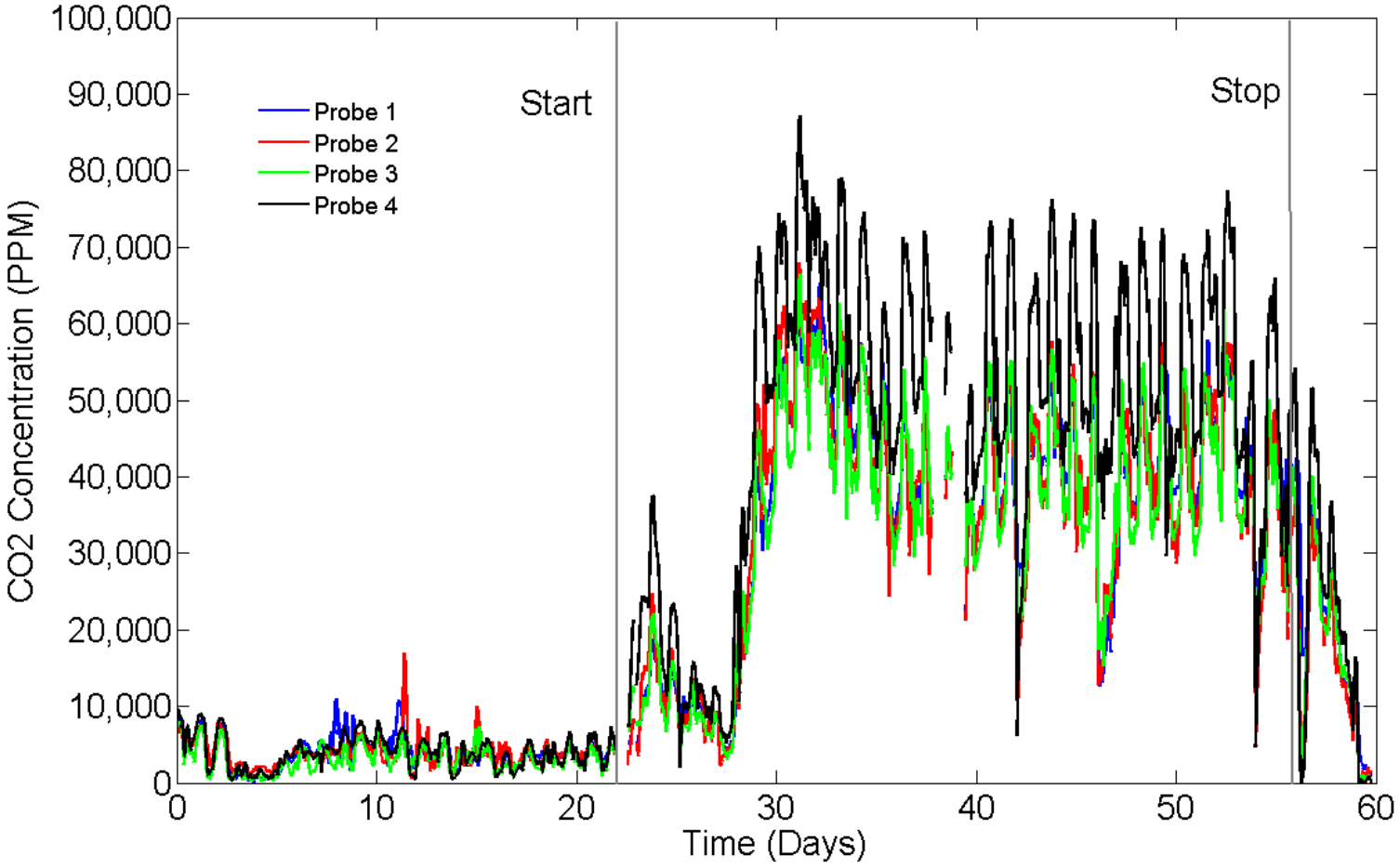




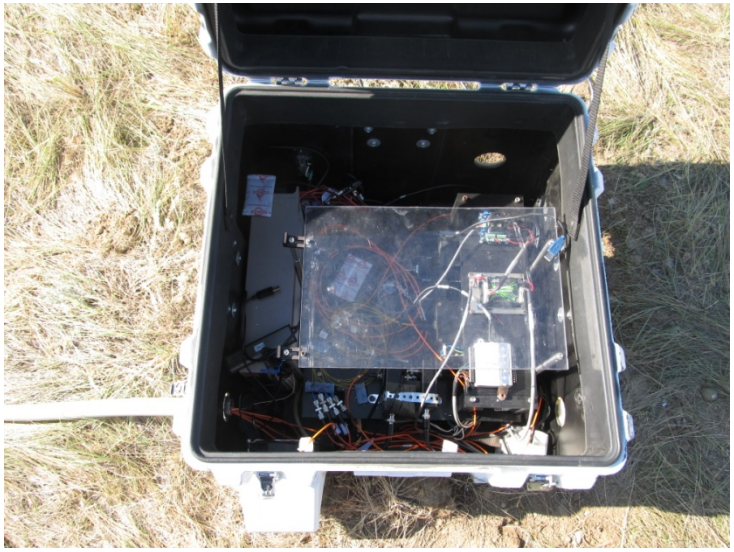
Technical Status: ZERT Field Data

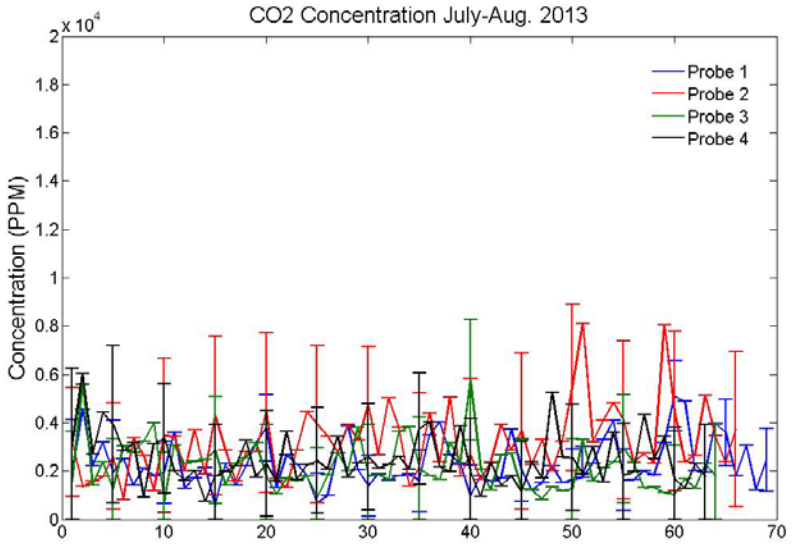


Technical Status: ZERT Field Data



Technical Status: BSCSP Field Data





Scalability and Large Area Coverage

A commercial 1 x 100 fiber optic switch allows up to 100 probes to be deployed. Using standard telecommunications fiber, these 100 probes can be located up to 1 km away from the central electronics box.

Because the cost of the probes is kept low, scaling to 100 probes will not greatly increase the cost providing a cost effective sensor array.

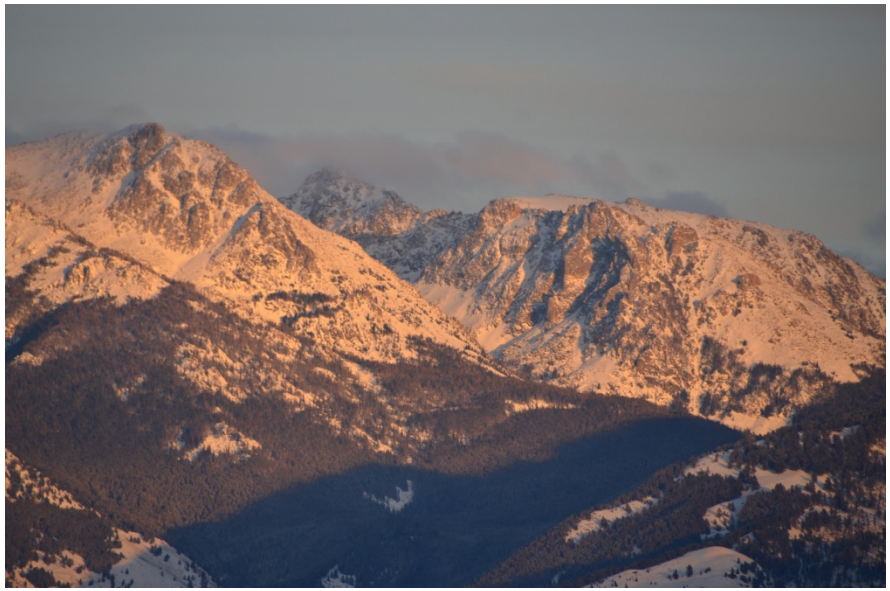
Accomplishments to Date

- A 1 X N fiber sensor array architecture has been developed.
- Subsurface CO_2 concentration measurements have been made continuously for over 40 days.
- Instrument has been demonstrated at the ZERT field site where the elevated subsurface CO_2 concentration from the subsurface release is clearly evident.
- Instrument has been successfully deployed at the BSCSP site.

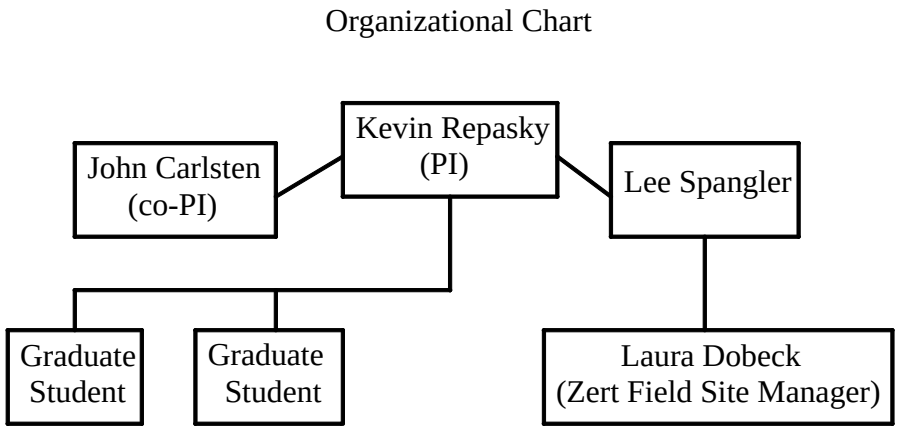
Summary

- The fiber sensor array has been successfully deployed at the ZERT controlled release experiment.
- The fiber sensor array offers a scalable, reconfigurable, cost effective monitor for large area coverage with autonomous operations.
- Future Plans
  - Include a second DFB laser for sensing oxygen to provide the potential to distinguish sources of subsurface CO_2.
  - Working with Integrated Optical Systems on transfer technology of fiber sensors into the commercial market.

Thanks Kindly for Your Time



Appendix: Organization Chart



- Kevin Repasky: (PI) responsible for overall project.

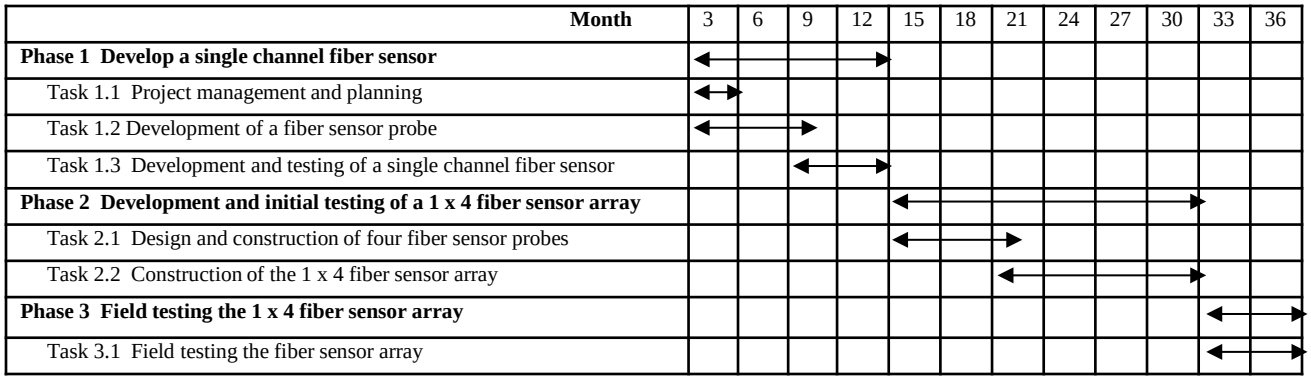
  John Carlsten: (Co-PI) work with Dr. repasky to manage project and students.

  Lee Spangler: Head of ZERT and BSCSP. Coordinate field work

  Laura Dobeck: Coordinate ZERT field experiments.

figure 5.

Appendix: Gantt Chart



Month	3	6	9	12	15	18	21	24	27	30	33	36
Phase 1 Develop a single channel fiber sensor	◄	─	─	►								
Task 1.1 Project management and planning	◄	►										
Task 1.2 Development of a fiber sensor probe	◄	─	►									
Task 1.3 Development and testing of a single channel fiber sensor			◄	►								
Phase 2 Development and initial testing of a 1 x 4 fiber sensor array					◄	─	─	─	─	►		
Task 2.1 Design and construction of four fiber sensor probes					◄	─	►					
Task 2.2 Construction of the 1 x 4 fiber sensor array							◄	─	─	►		
Phase 3 Field testing the 1 x 4 fiber sensor array											◄	►
Task 3.1 Field testing the fiber sensor array											◄	►

figure 5.

Appendix: Presentations and Publications

- Presentations:
  - "Large area detection of CO2 for carbon sequestration", IEAGHG: Environmental Impacts of CO2 Storage Workshop, Bozeman, MT, July 2012 (invited).
  - "Subterranean Carbon Dioxide (CO_2) Concentration Analysis Utilizing an Optical Fiber Probe Array for Carbon Capture and Storage (CCS) Site Monitoring", Benjamin Soukup, Kevin S. Repasky, and John L. Carlsten, American Geophysical Union, San Francisco, California, 2011.
  - "Sub-Surface Carbon Dioxide Concentration Measurement Using a Fiber Based Sensor in a Send/Call Geometry for Carbon Sequestration Site Monitoring", Geoffrey Wicks, Benjamin Soukup, Kevin S. Repasky, John L. Carlsten, Jamie L. Barr, and Laura Dobeck, American Geophysical Union Meeting, San Francisco, California, 2010.
- Papers:
  - "Development of a 1 X N fiber sensor array for subsurface carbon sequestration site monitoring", Benjamin Soukup, Geoffrey Wicks, Kevin S. Repasky, and John L. Carlsten, in preparation for submission to the Journal of Applied Remote Sensing.