Development and deployment of a compact eye-safe scanning differential absorption lidar (DIAL) for spatial mapping of carbon dioxide for monitoring/verification/accounting at geologic sequestration sites

Project Number: DE-FE0001156

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
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Presentation Outline

- Program and Project Benefits
- Technical Status
  - Brief Introduction to differential absorption lidar (DIAL)
  - DIAL instrument 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

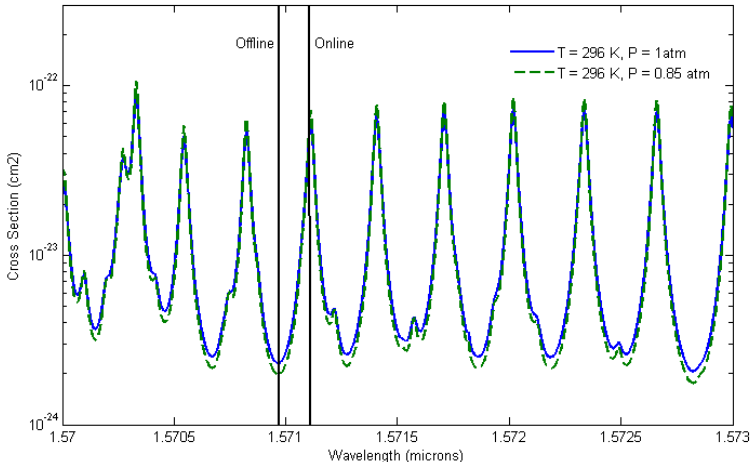
  The research project is developing a scanning differential absorption lidar for spatial mapping of CO_2 number densities for near surface large area monitoring. This technology contributes to the Carbon Storage Program's effort to ensure 99% CO_2 storage permanence.

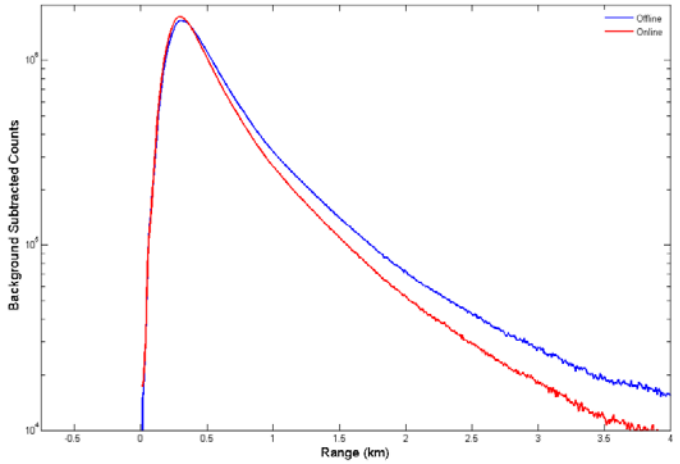
Project Overview: Goals and Objectives

- The project objectives for the proposed work include the development, testing, and deployment of a scanning eye-safe diode laser based differential absorption lidar (DIAL) for near surface mapping of carbon dioxide (CO_2) number densities.
  - Relates to the development of technologies to demonstrate that 99% on CO_2 remains in the injected zones.
  - Success criteria: Demonstration of instrument from a laboratory setting.
- Horizontal testing of the instrument will be conducted to determine the performance of the CO_2 DIAL instrument at the Zero Emission Research Technology (ZERT) field site during a controlled release experiment.
  - Relates to conducting field tests for site operations.
  - Success criteria: Demonstration of instrument during a ZERT controlled release experiment. Validation with in-situ Licor detector.
- Testing at the Big Sky Carbon Sequestration Partnership to deploy the CO_2 DIAL instrument at a regional carbon sequestration demonstration project.
  - Relates to conducting field tests for site operations.
  - Success criteria: Deployment at the Big Sky Carbon Sequestration Partnership Site in north-central Montana for one month.

Technical Status: DIAL Technique

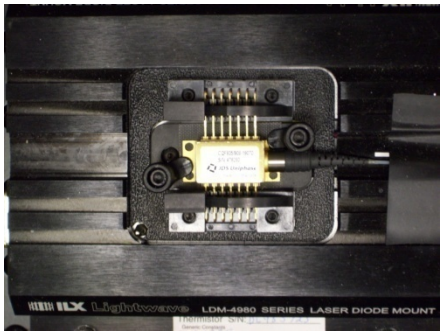
- The DIAL technique uses two closely spaced wavelengths and does not rely on an instrument calibration.
- The difference between the return signal for the two closely spaced wavelengths is related to the molecular number density.
- The number density can be calculated using the DIAL equation.

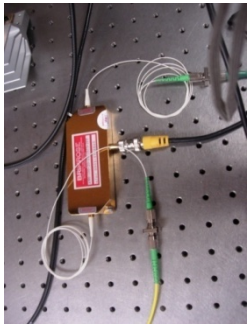


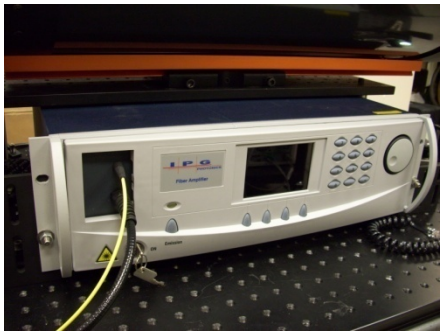


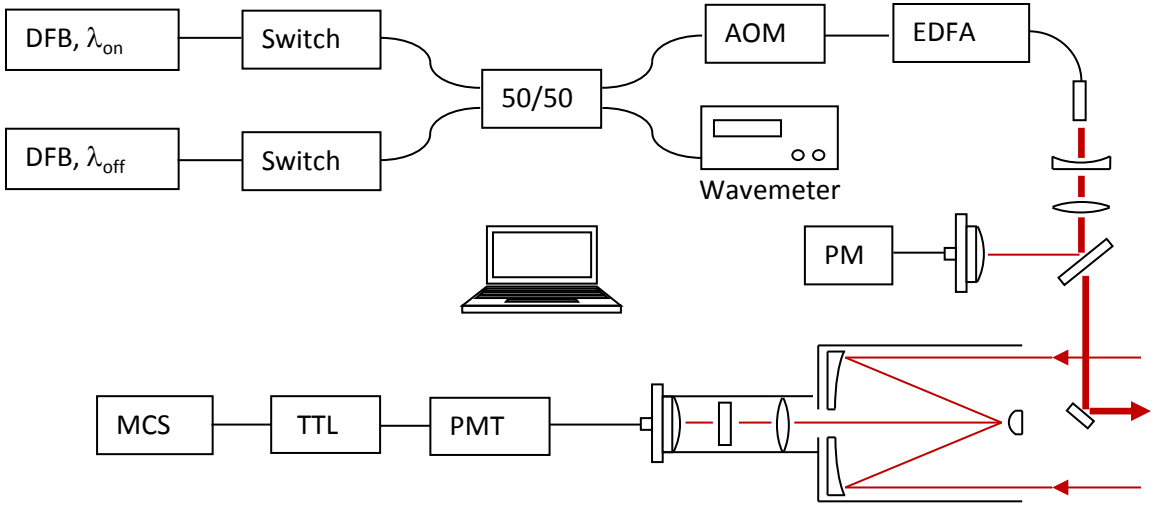
$$N(r) = \frac{1}{2\Delta r(\sigma(\lambda_{on},r) - \sigma(\lambda_{off},r))}\left[ln\left(\frac{P(\lambda_{on},r)P(\lambda_{off},r+\Delta r)}{P(\lambda_{on},r+\Delta r)P(\lambda_{off},r)}\right)\right]$$

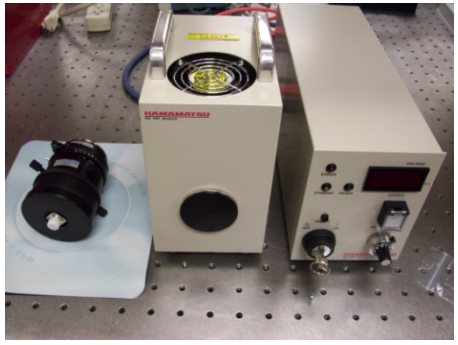
Technical Status: Instrument Schematic

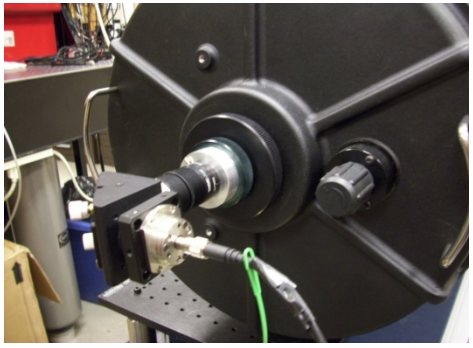










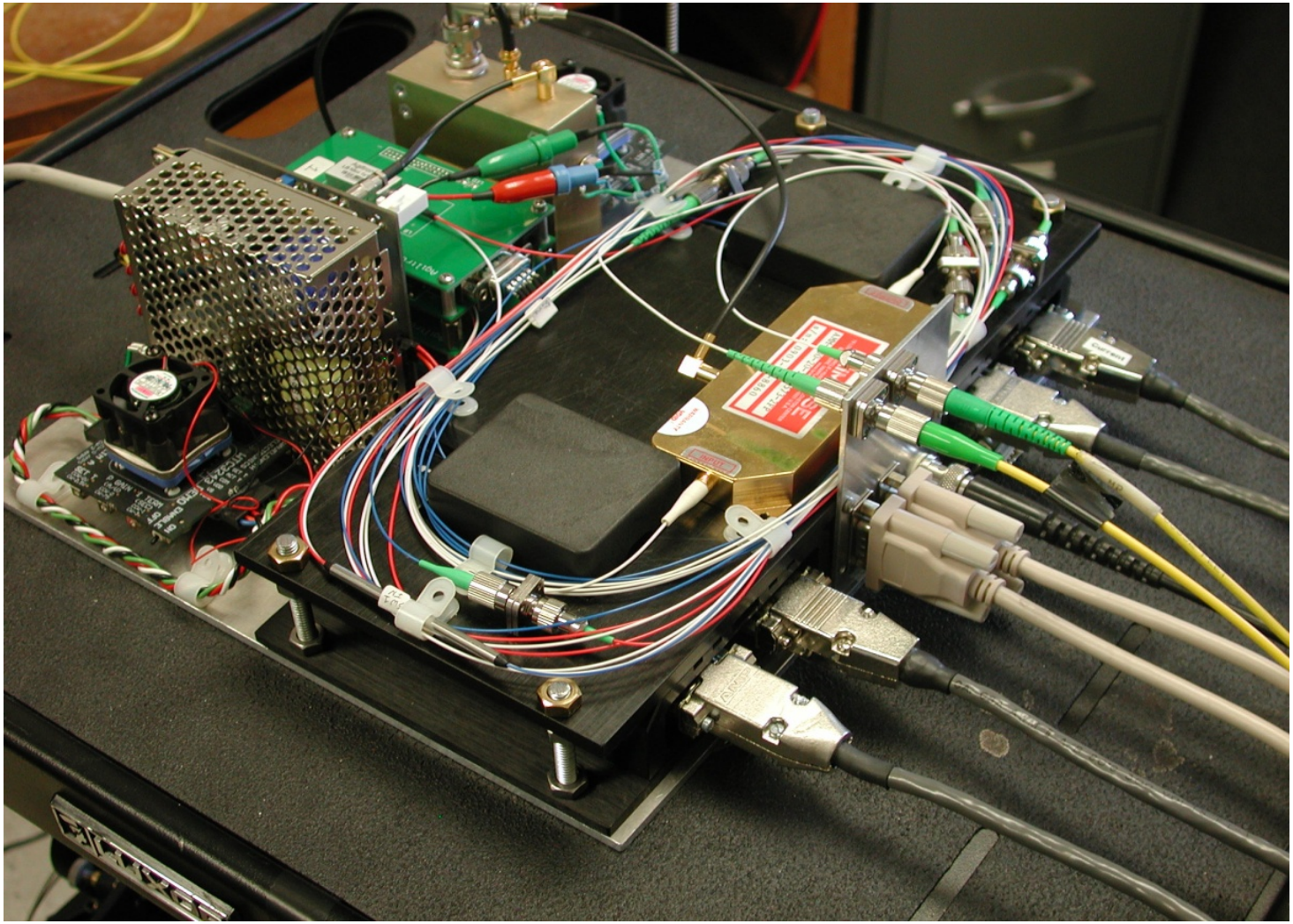


DFB Lasers	
Manufacturer	Eblana
Packaging	14 pin
Output Power	10 mW
Linewidth	<2 MHz
Side Mode Suppression	>40 dB

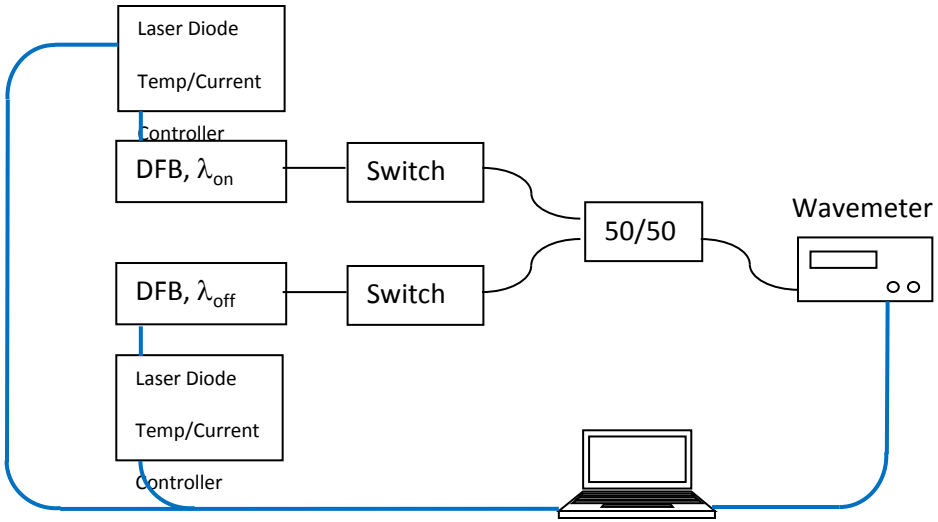
EDFA	
Manufacturer	IPG Photonics EAR-0.5K-1573-MT
Max. Output Power	0.5 W
Power Stability	0.54%
Wavelength Range	1.570 – 1.575 μm

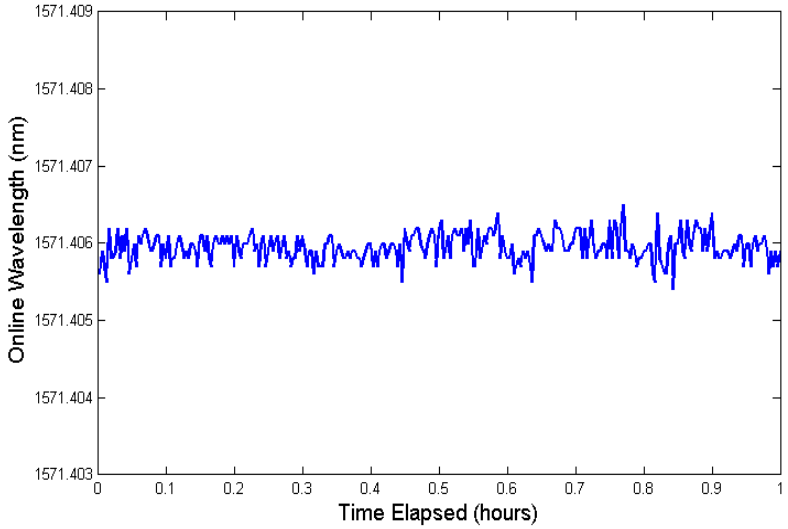
PMT	
Manufacturer	Hamamatsu H10330-075A
Wavelength	0.95 – 1.70 μm
Gain (@-800 V)	$1X10^6$
Dark Current	300 nA
Quantum Efficiency	2%
Operating Temp.	TEC Cooled to -60 C

Technical Status: DIAL Laser Transmitter



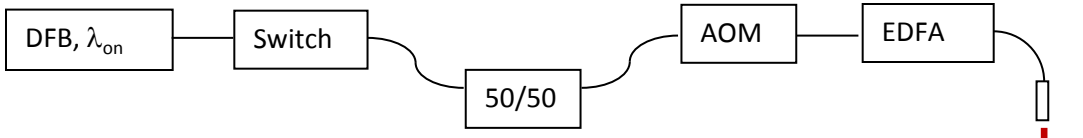
Technical Status: Wavelength Control

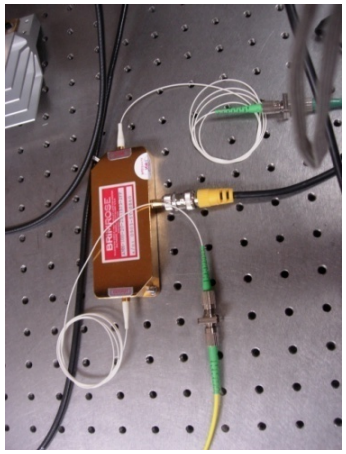


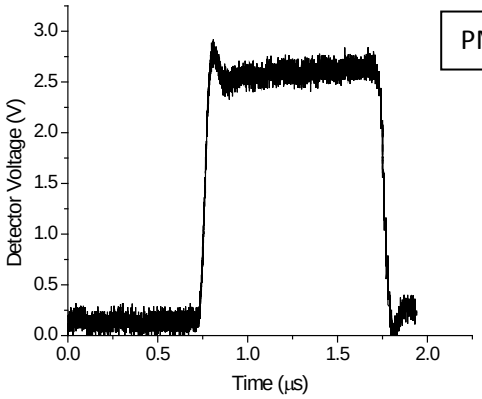


- A two laser scheme was developed so that switching times between on-line and off-line can be on the order of seconds.
- This locking scheme always ensures seed power to the EDFA to prevent damage due to stimulated Brillioun scattering.
- This locking is robust, operating unattended over a period of 12 hours with this instrument and up to seven days on a water vapor DIAL.
- Locking stability is +/- 0.18 pm (+/- 20 MHz)

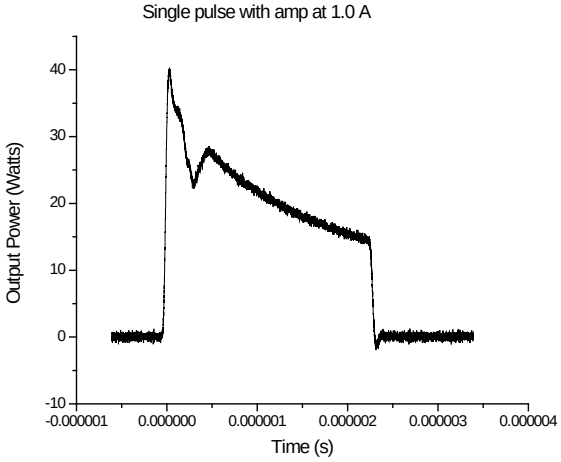
Technical Status: Pulse Generation

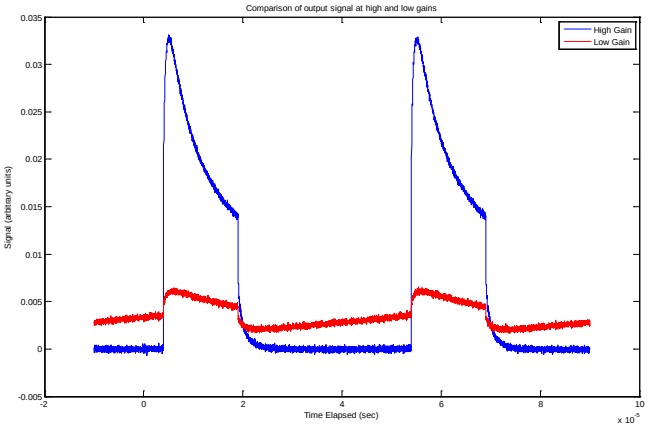


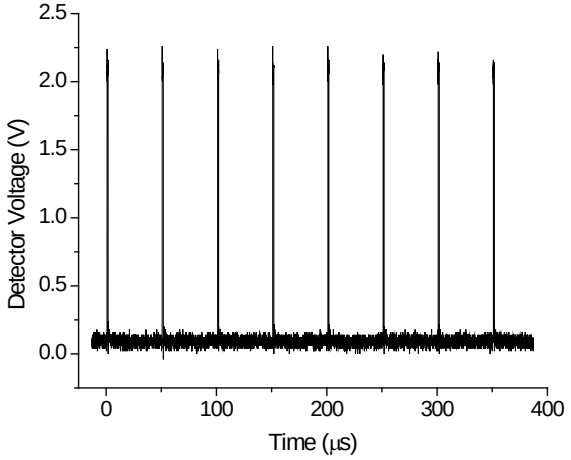




- Pulses between 0.2 and 2 μs generated using the AOM.
- Pulse repetition frequency of up to 25 kHz demonstrated.
- A pulse repetition frequency of 15 kHz provides a maximum range of 10 km.





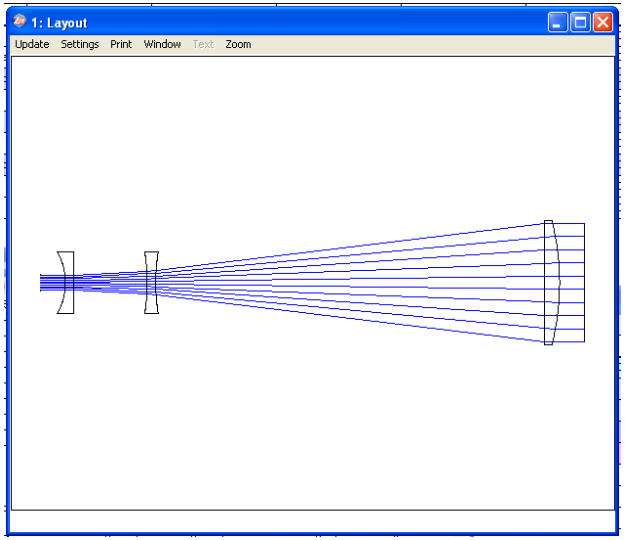


Technical Status: Optical Modeling

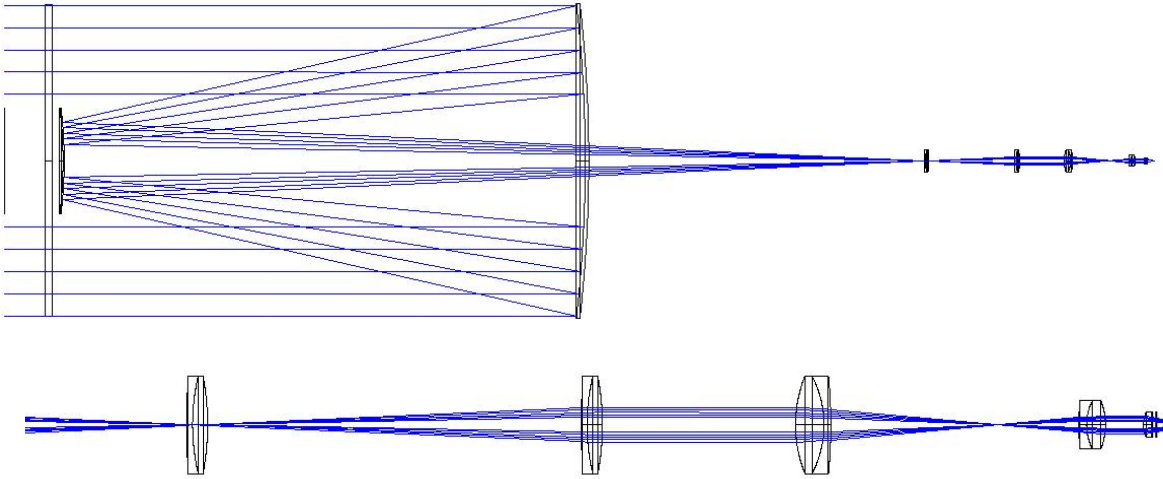
Lens Data Editor

Edit Solves View Help

Surf:Type		Comment	Radius	Thickness		Glass		Semi-Diameter		Conic
OBJ	Standard		Infinity	Infinity				0.000		0.000
STO	Standard	input beam	Infinity	10.000				2.900		0.000
2*	Standard	expander	-25.700	3.500		N-BK7		12.500	U	0.000
3*	Standard		Infinity	30.020	V			12.500	U	0.000
4*	Standard		-77.900	3.500		N-BK7		12.500	U	0.000
5*	Standard		77.900	159.298	V			12.500	U	0.000
6*	Standard	collimator	Infinity	6.200		N-BK7		25.400	U	0.000
7*	Standard		-103.360	10.000				25.400	U	0.000
IMA	Standard		Infinity	-				24.334		0.000



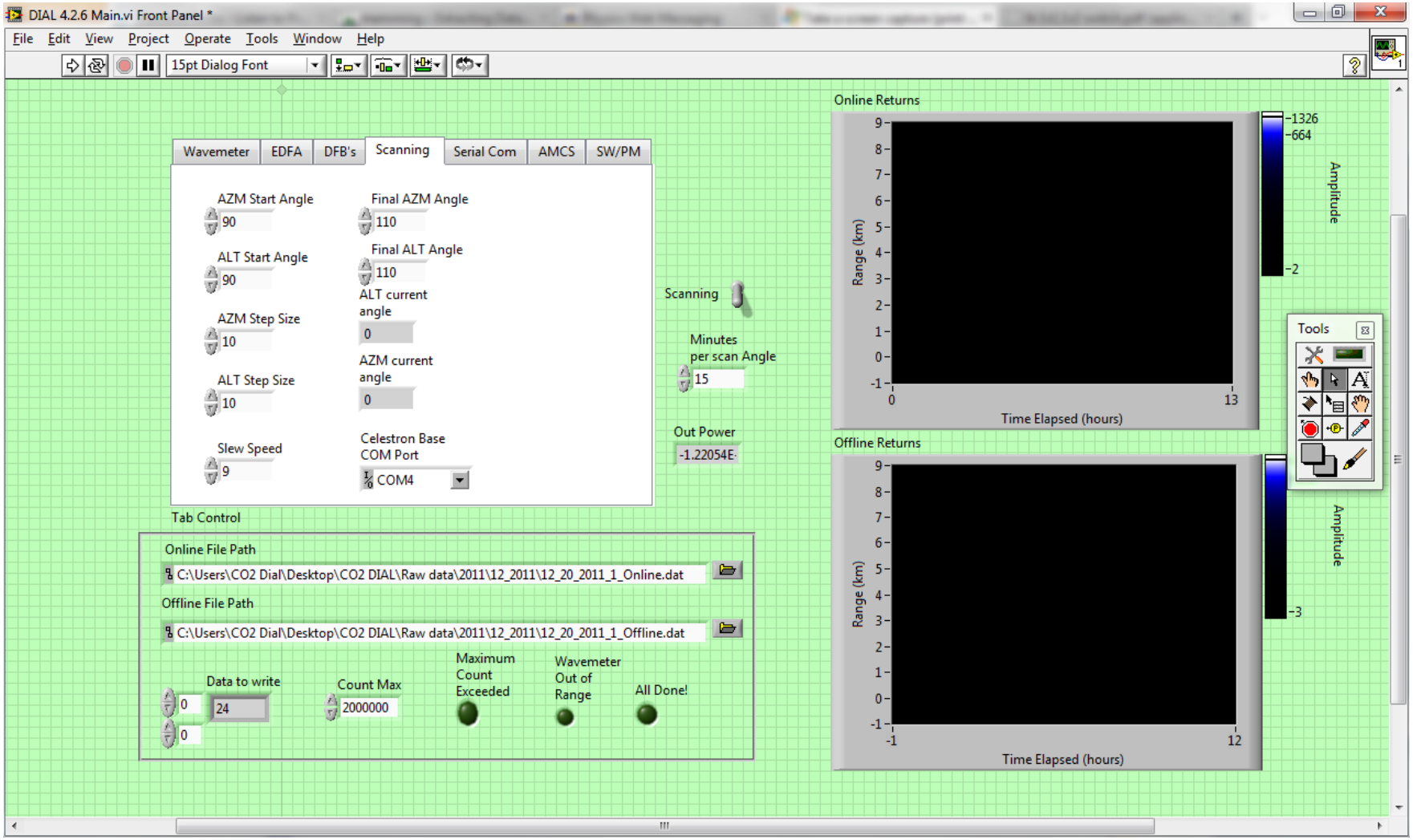
Collimation of the outgoing beam is key to achieving accurate on-line and off-line returns. Measuring the M^2 and beam diameter of the outgoing beam, a collimation optical train was designed.



The receiver optical train images the telescope focus at the fiber input which acts as the receiver field stop.

Range, overlap, and signal to noise performance depends on a well executed receiver design.

Technical Status: Labview Control Program



Technical Status: CO_2 DIAL -- Scanning

Using existing telescope mount with motor drives provides a stable scanning method.

DIAL instrument, supporting electronics, and data acquisition computer in the cargo trailer at the ZERT site.

Technical Status: Eye Safety

American National Standard for Safe Use of Lasers
ANSI Z136.1-1993

Wavelength: 1.571 μm
Pulse Repetition Frequency: 15 kHz
Pulse Duration: 200 ns

The Maximum Permissible Exposure (MPE) for a Non-Ocular-Eye-Hazard distance of 0 m is

MPE = 6.67 μJ/cm²

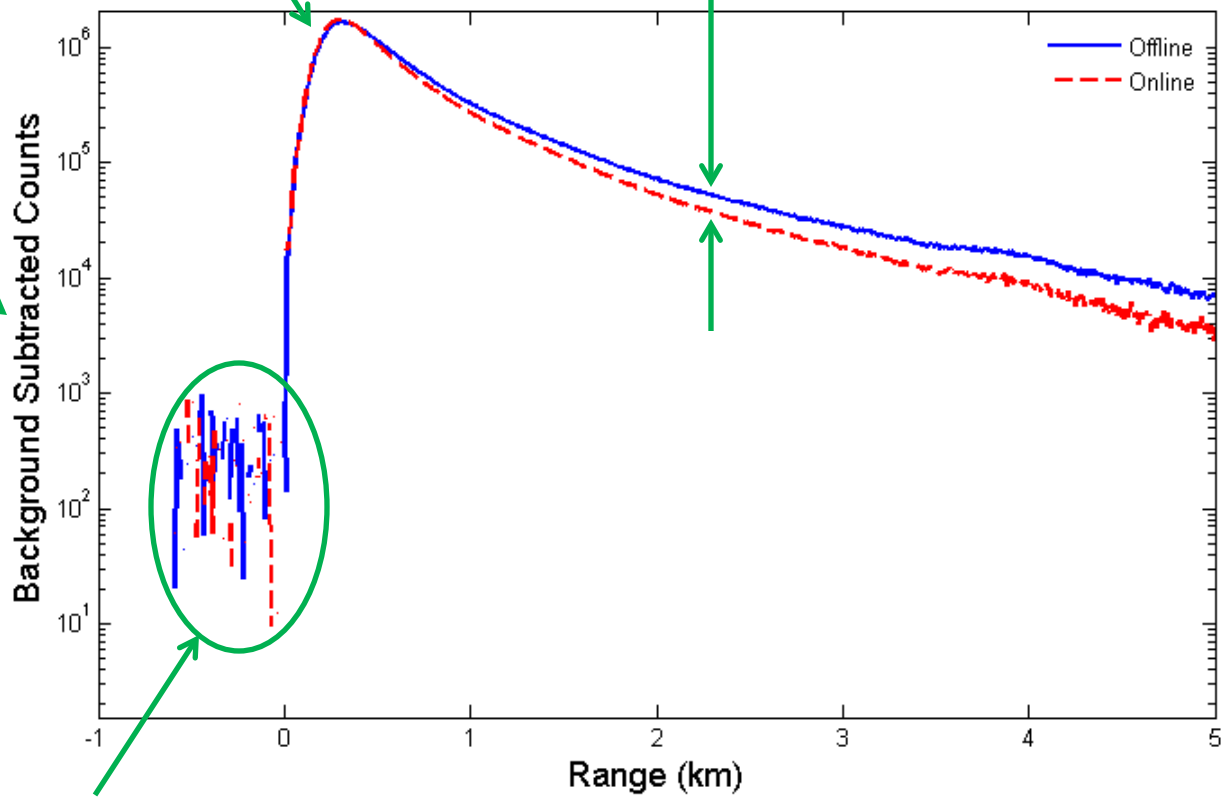
For the 5.0 cm diameter laser transmitter beam, the maximum pulse energy of 130 μJ must be maintained for the Non-Ocular-Eye-Safe distance of 0 m.

Technical Status: On-line and Off-line

Initial overlap

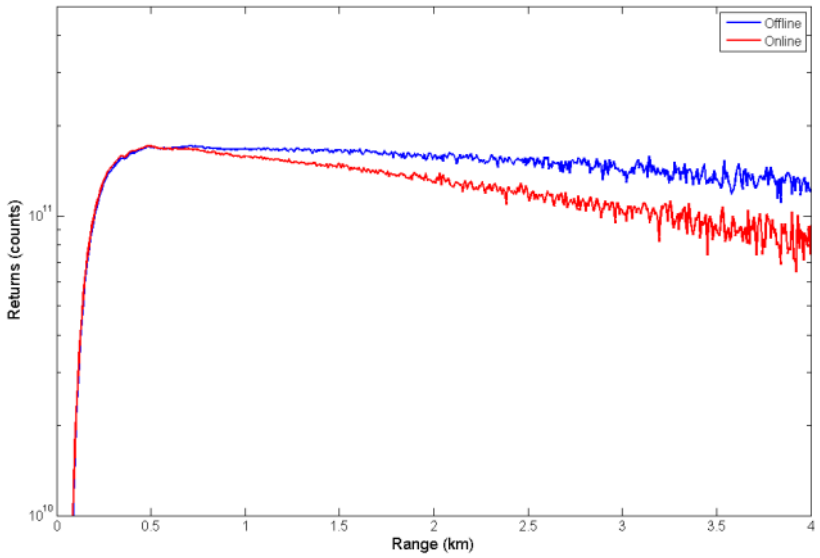
Difference in return signal is directly related to the CO_2 number density

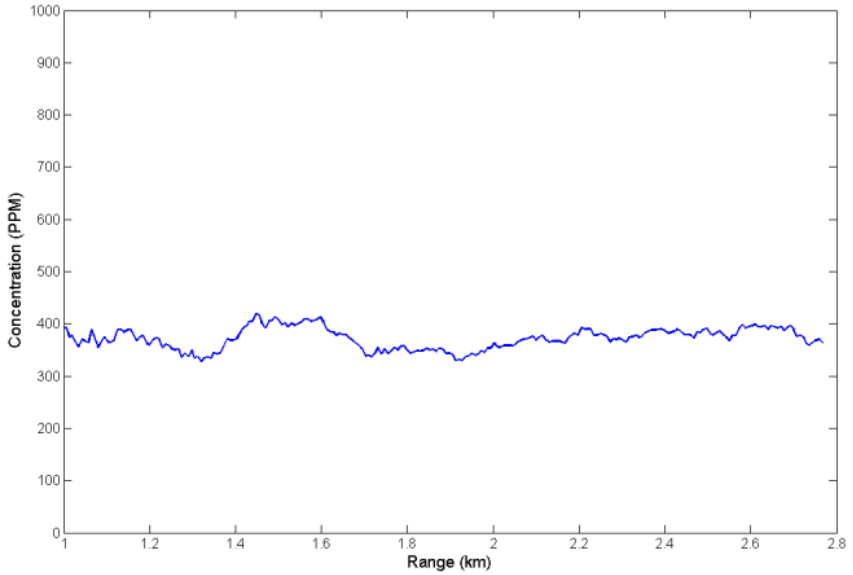
Shown on a log scale due to $1/r^2$ dependence

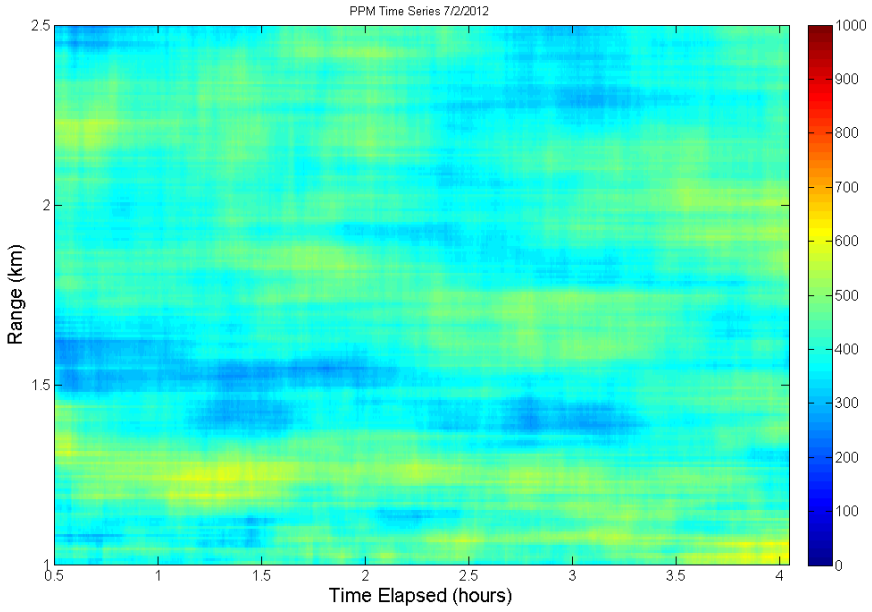


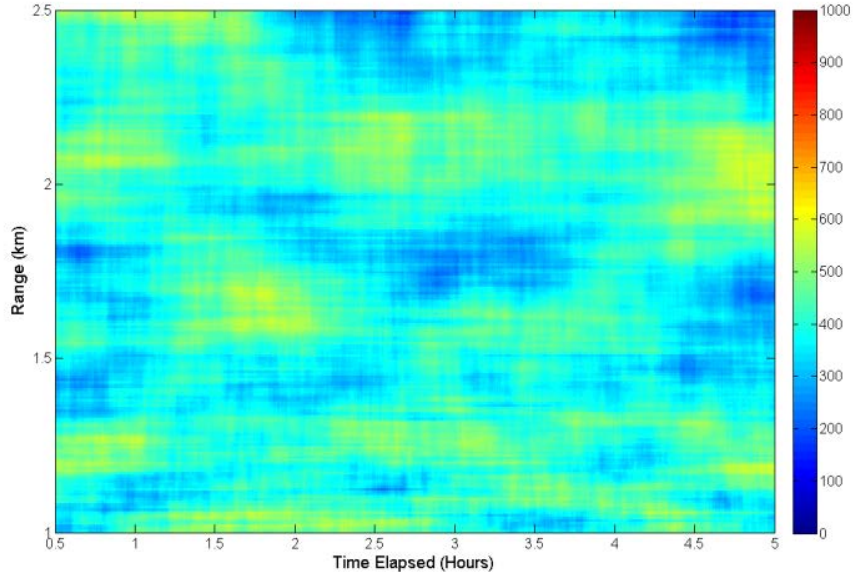
4 μs of background collected before laser pulse fires. Used for background subtraction

Technical Status: Data









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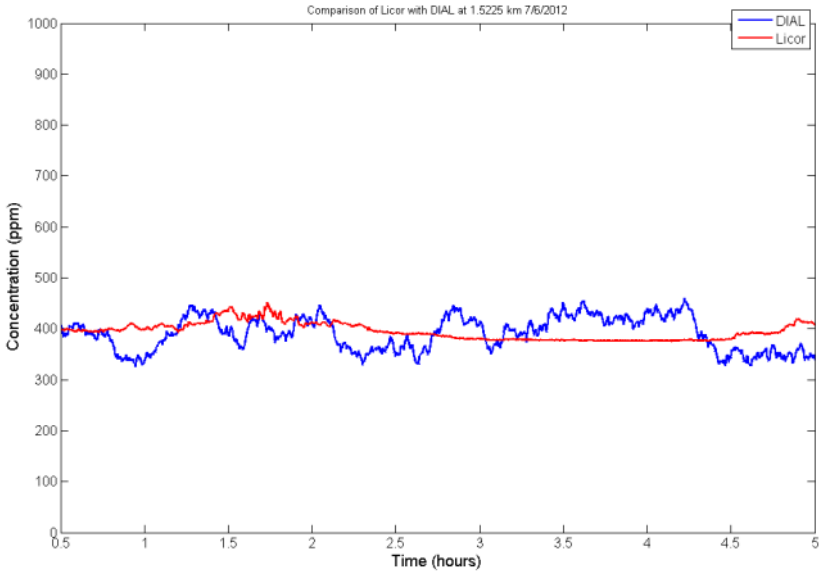

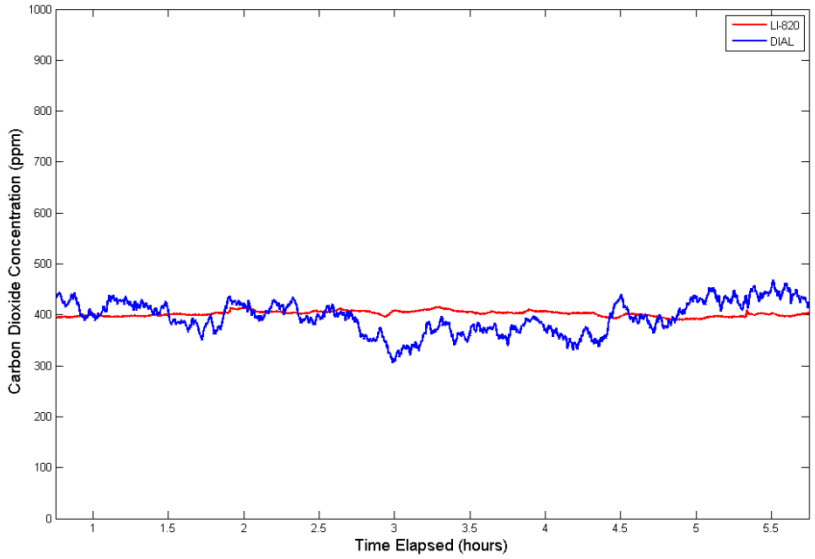

Technical Status: Big Sky Carbon Sequestration Site

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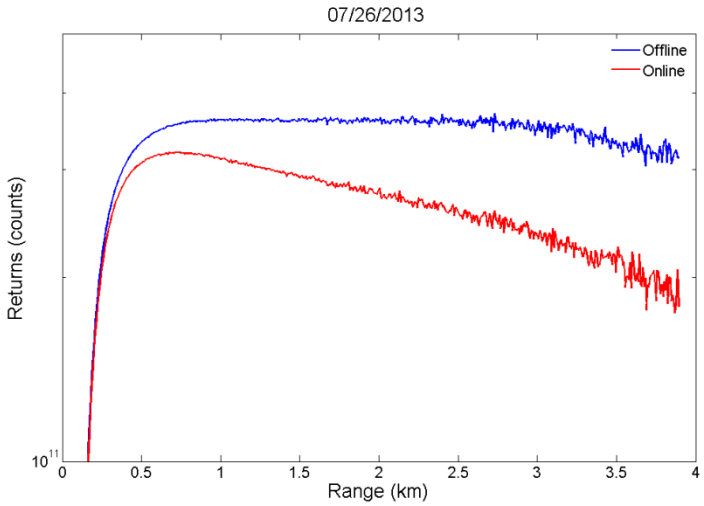
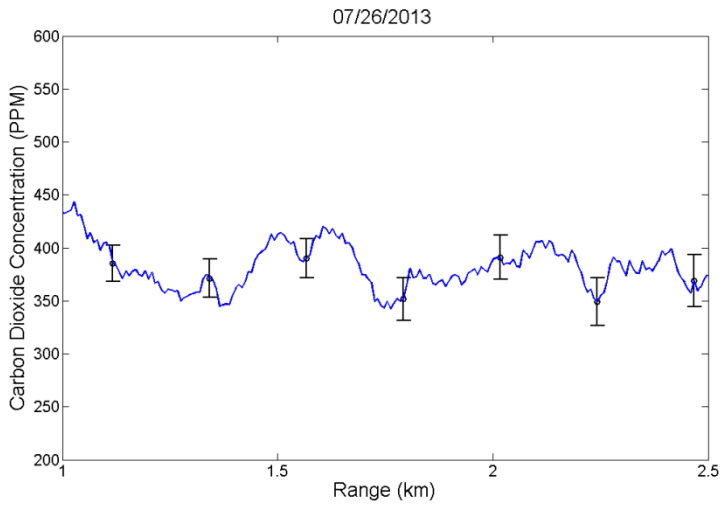
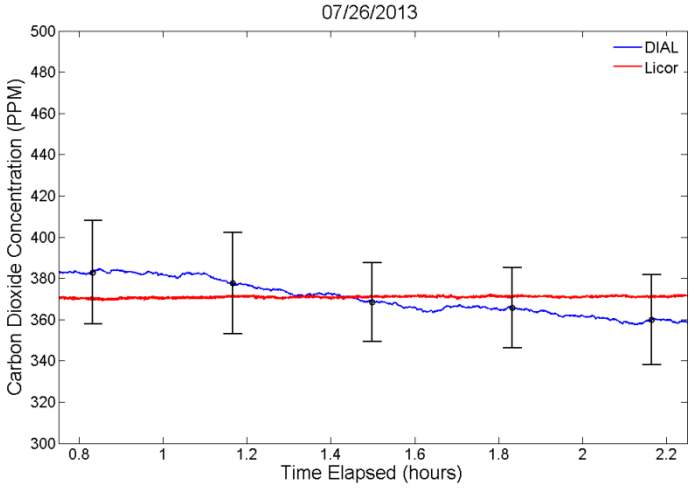
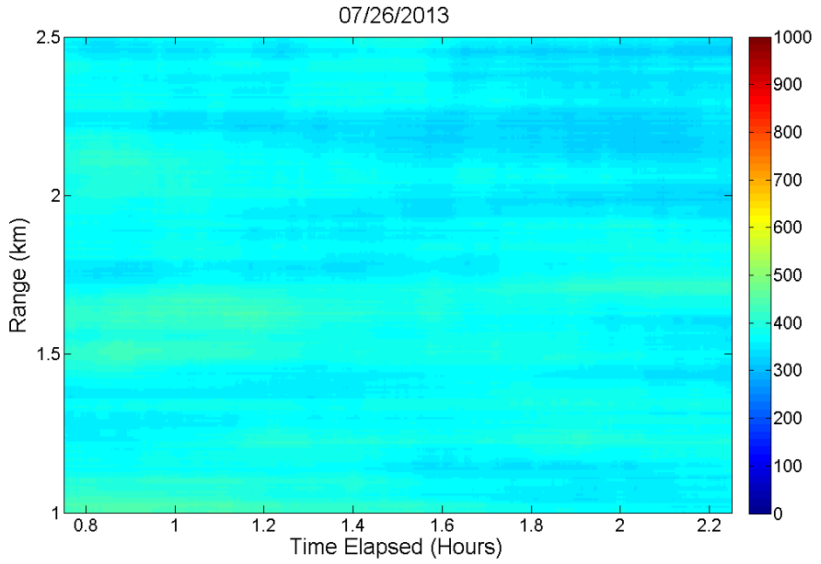
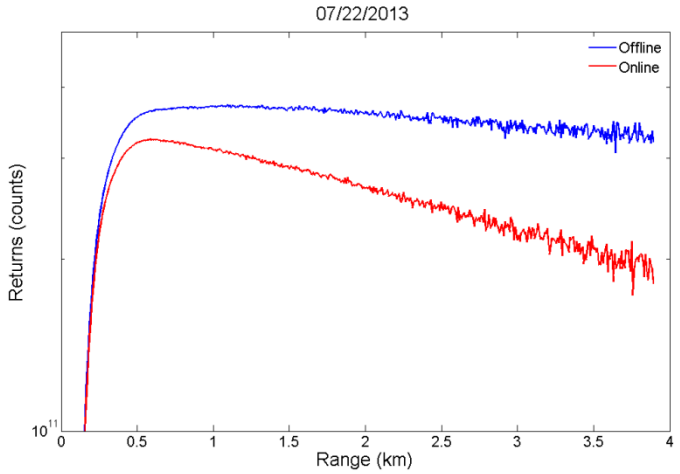


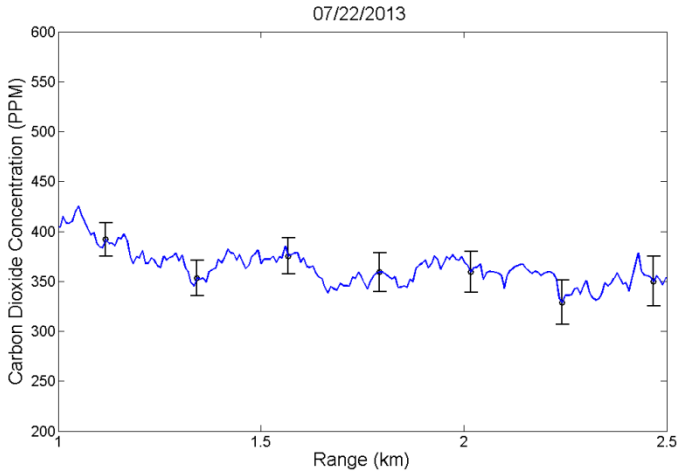


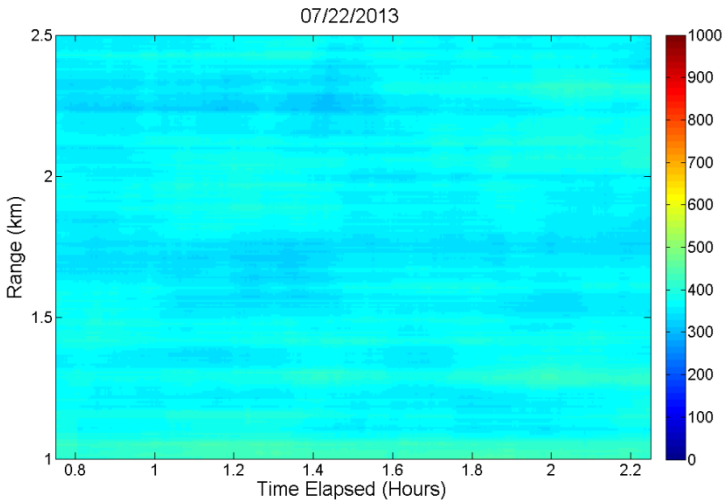


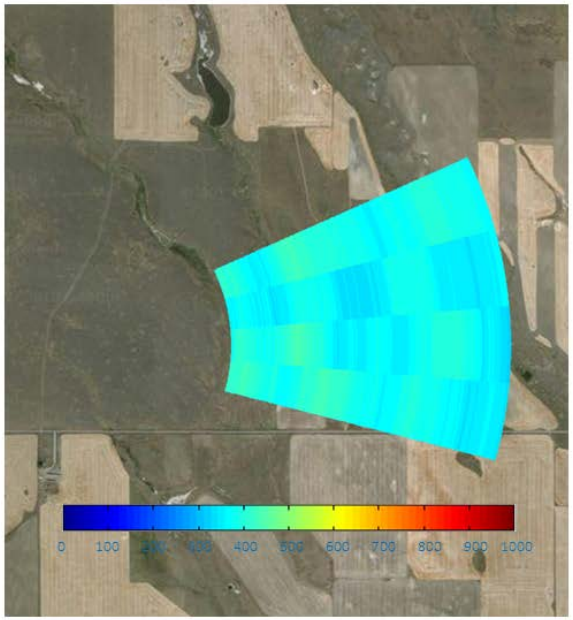


Technical Status: Big Sky Carbon Sequestration Site









Accomplishments to Date

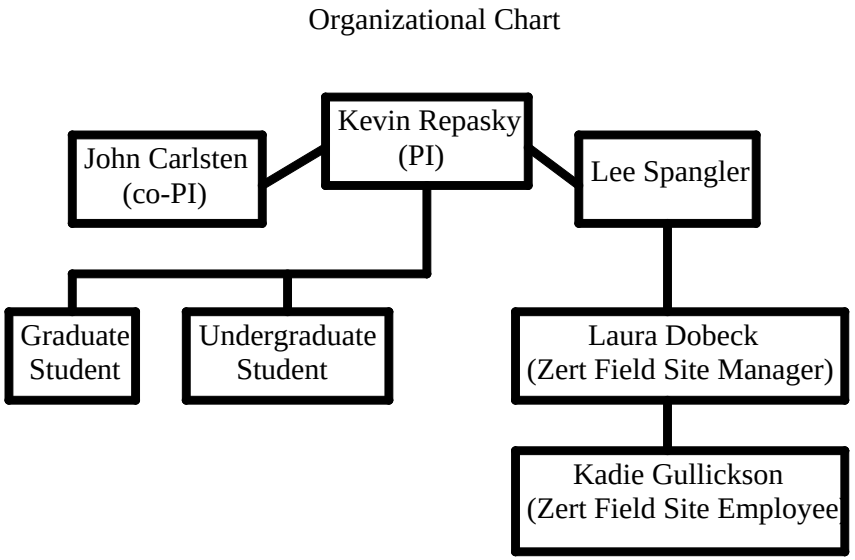
- A field deployable DIAL for spatial mapping of CO_2 has been developed.
- CO_2 profiles have been demonstrated with continuous operation over 8 hours.
- CO_2 profiles have been validated using a co-located point source Licor detector.
- Instrument has been demonstrated at the ZERT field site.
- Instrument has been successfully deployed at the Big Sky Carbon Sequestration Partnership site for a one month period.

Summary

- The DIAL offers a potential large area monitoring technology for surface monitoring for carbon storage facilities.
- The DIAL has been successful deployed at the ZERT field site and data validated using in-situ point detectors.
- The DIAL has been successfully deployed at the Big Sky Carbon Sequestration Partnership site in north-central Montana.
- Future Plans
  - Incorporate and finish testing APD.
  - Collaboration with NASA on CO_2 detection at 1.571 μm and 2 μm (Upenrda Singh and Jirong Yu, NASA LaRC, Langley, VA). Proposal Pending.
  - Technology transfer: photon upconversion techniques for more efficient detection techniques (Advr, Bozeman, MT)

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: Hear of ZERT and BSCSP. Coordinate field work
- Laura Dobeck: Coordinate ZERT field experiments.

figure 5.

Appendix: Gantt Chart

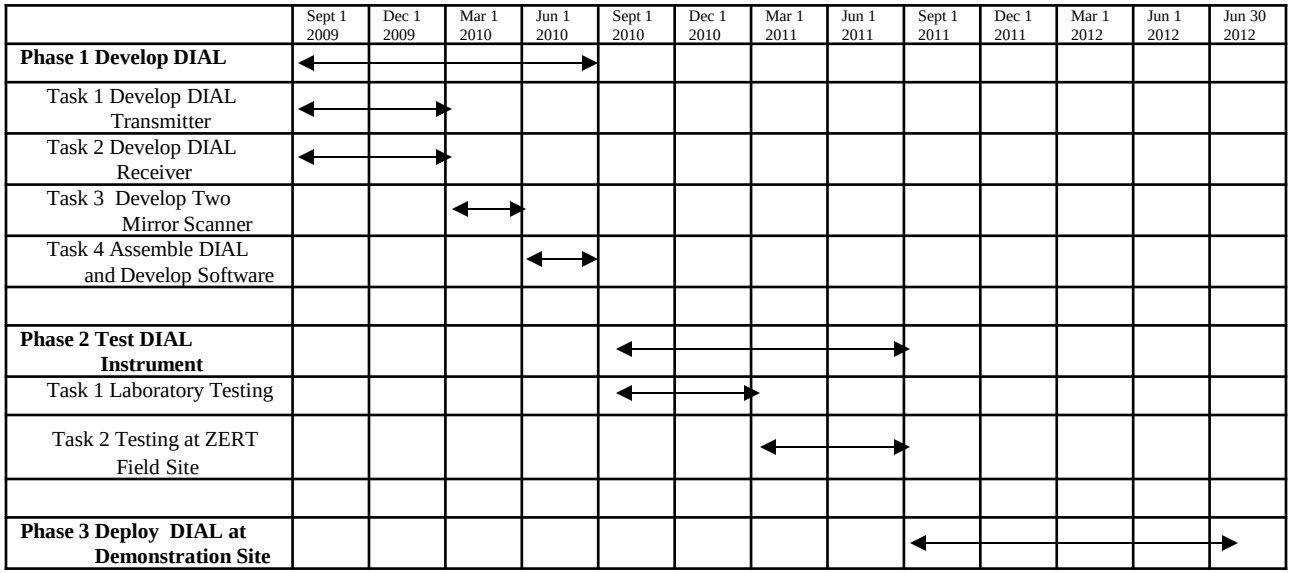


Figure 5 (From Proposal) Gantt Chart showing the proposed timeline to complete each task and phase of the proposed project.

Note: Due to permitting issues, A second summer of ZERT field work is being completed in the summer of 2012 and the instrument will be deployed at the BSCSP site in the summer of 2013.

figure 5.

Appendix: Presentations and Publications

- Presentations
  - "Development of a Differential Absorption Lidar (DIAL) for Carbon Sequestration Site Monitoring", William Johnson, Amanda Bares, Amin R. Nehrir, Kevin S. Repasky, and John L. Carlsten, American Geophysical Union, San Francisco, California, 2011, (contributed).
  - "Laser based detection of atmospheric carbon dioxide", K.S. Repasky, National Institute of Standards and Technology, Gaithersburg, MD, March 2012 (invited).
  - "Large area detection of CO2 for carbon sequestration", IEAGHG: Environmental Impacts of CO2 Storage Workshop, Bozeman, MT, July 2012 (invited).
- Papers:
  - "Differential Absorption Lidar (DIAL) for Carbon Dioxide Monitoring", William Johnson, Kevin S. Repasky, and John L. Carlsten, Applied. Optics, Vol. 52 Issue 13, pp.2994-3003 (2013).