Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE)

DE-FE0012574

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Exelis, Inc.

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

- Benefits of Program
- Project Overview
- Technical Status
- Progress to Date
- Summary
- Appendix

Benefit to the Program

- Develop and validate technologies to ensure 99 percent storage permanence.
  - Our work is aimed at providing a piece of the overall system used to validate 99 percent containment for a given carbon ground storage project.
- The Exelis instrument seeks to improve worker safety, reduce environmental and economic impact, and allow for proper accounting of CO2 flux over long-term, large scale operations. Further, the Exelis AER team seeks to accomplish this in a user-friendly, set-up-and-forget package at minimal cost to set up and only hours a month to maintain. The goals of this proposal perfectly match those of the DOE objectives outlined in section 2 of the FOA.

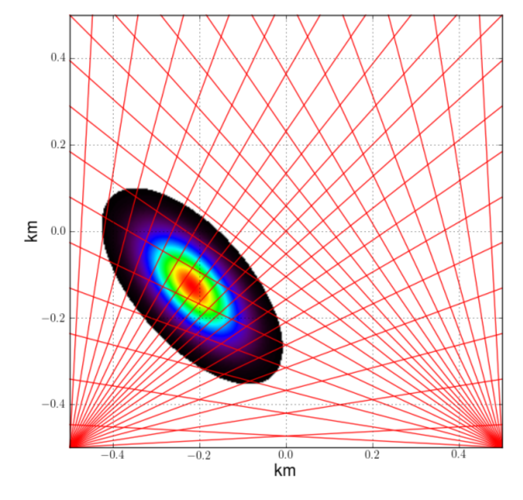
Project Overview:
Goals and Objectives

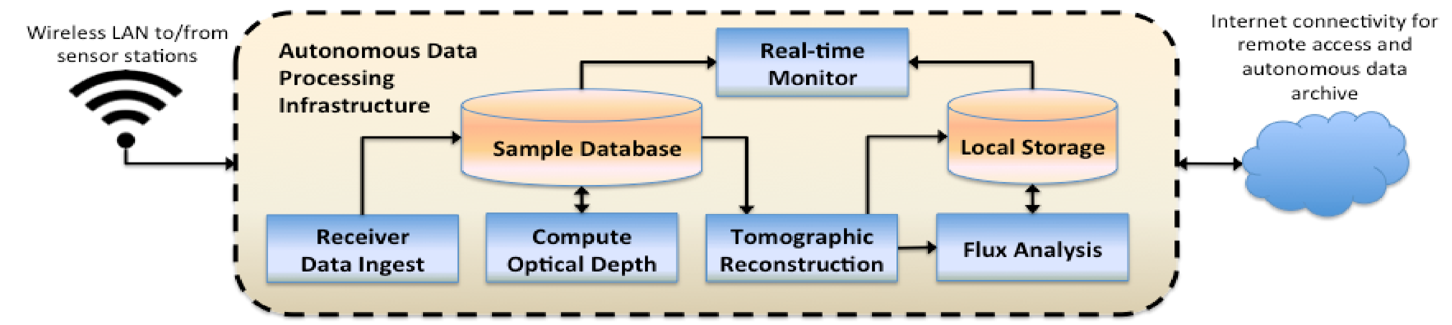
- The overall program objective is to provide a laser based measurement of carbon concentrations across a plane over ~1.6 km^2 using 2 sensors and a series of retro reflectors along with tomographic like methods to generate 2D concentration maps across the area.

BP & Phase	Task	M1 Name	Description	Planned Completion (Baseline)	Planned Completion (Revised)	Actual Completion	Status/Comments
1	4	Complete performance testing at sensor level	Complete performance testing at sensor level	3/21/2014	4/22/2014	4/22/2014	Will be met when quantified data shows the sensor meets design specifications. Proceed with system development
1	6	Complete performance assessment at system level	Complete Phase I data analysis and system level performance assessment	6/20/2014	7/31/2014		Will be met upon completion of Phase I report and updated version of algorithm description document provided to DOE including 2D concentration maps from post processing.
1	12	Complete ZERT testing	Complete testing at ZERT site and assessment of system level performance	10/31/2014	10/31/2014		Will be met when quantified assessment of 2D concentration estimates from ZERT controlled release experiments are delivered to DOE
2	16	Complete local testing of extended deployment system	Complete final retrieval software integration and test via local testing of extended deployment system	1/26/2015	1/26/2015		Will be met when autonomous operation over a full week is achieved with only remote interaction, while real time 2D CO2 concentration maps are publicly available via a web interface
2	17	Initiate testing at Decatur site	Initiate autonomous remote field testing at Decatur site	3/16/2015	3/16/2015		Will be met when remote system is collecting data autonomously at Decatur site
2	17	Complete testing at Decatur site	Complete autonomous remote field testing at Decatur site	9/30/2015	9/30/2015		Will be met when remote system has completed autonomous data collection at Decatur site

General Overview

This project serves to demonstrate a system utilizing 2 scanning laser-based differential absorption sensors, combined with a series of retro-reflectors and intelligent algorithms to generate real time 2D concentration and flux maps over a carbon sequestration storage facility. The final phase will demonstrate an autonomous, remote measurement of the entire storage field with high precision and accuracy, while making the data available in near real time via a web-based interface.



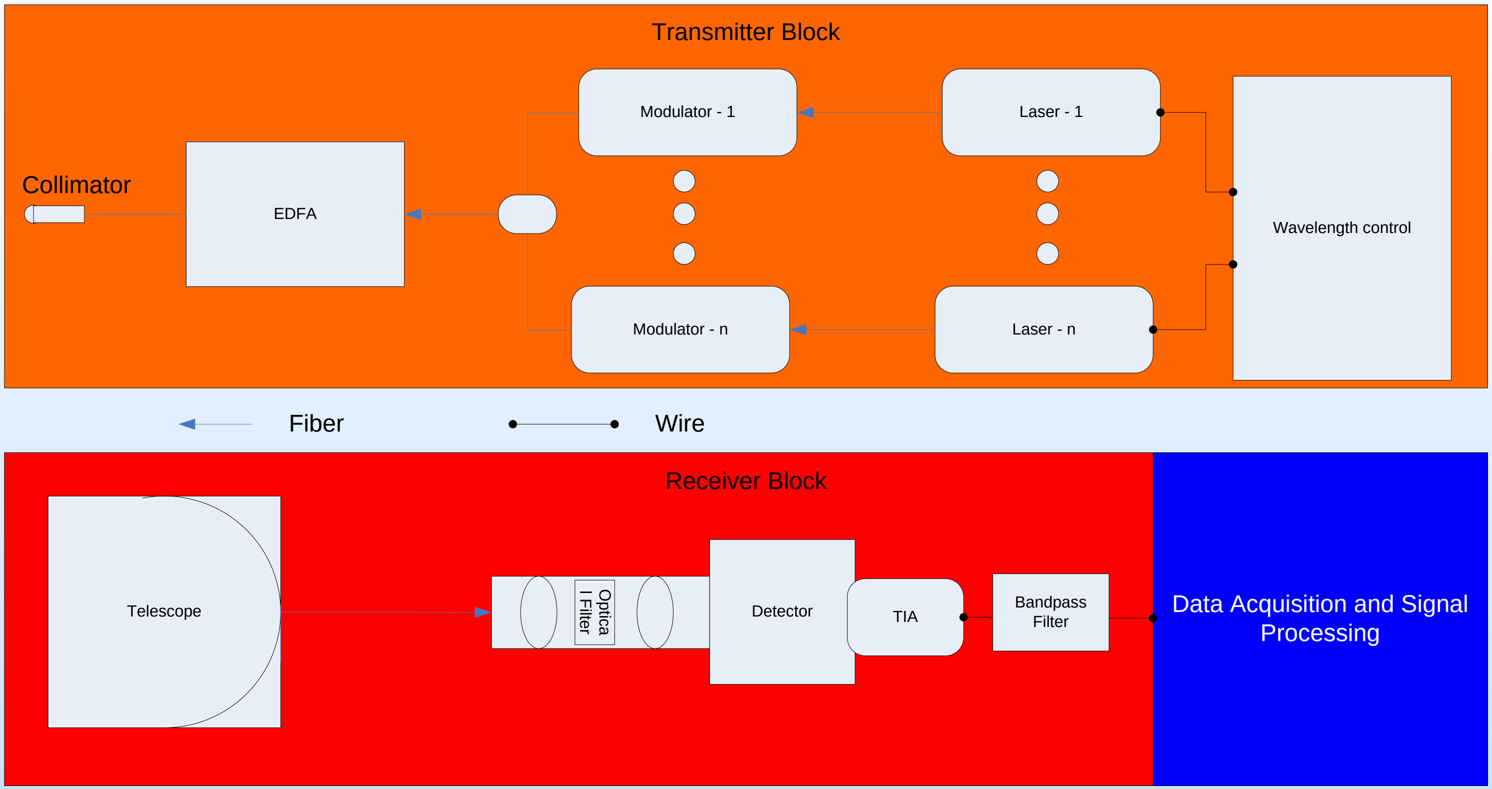


TECHNICAL STATUS

Sensor Design

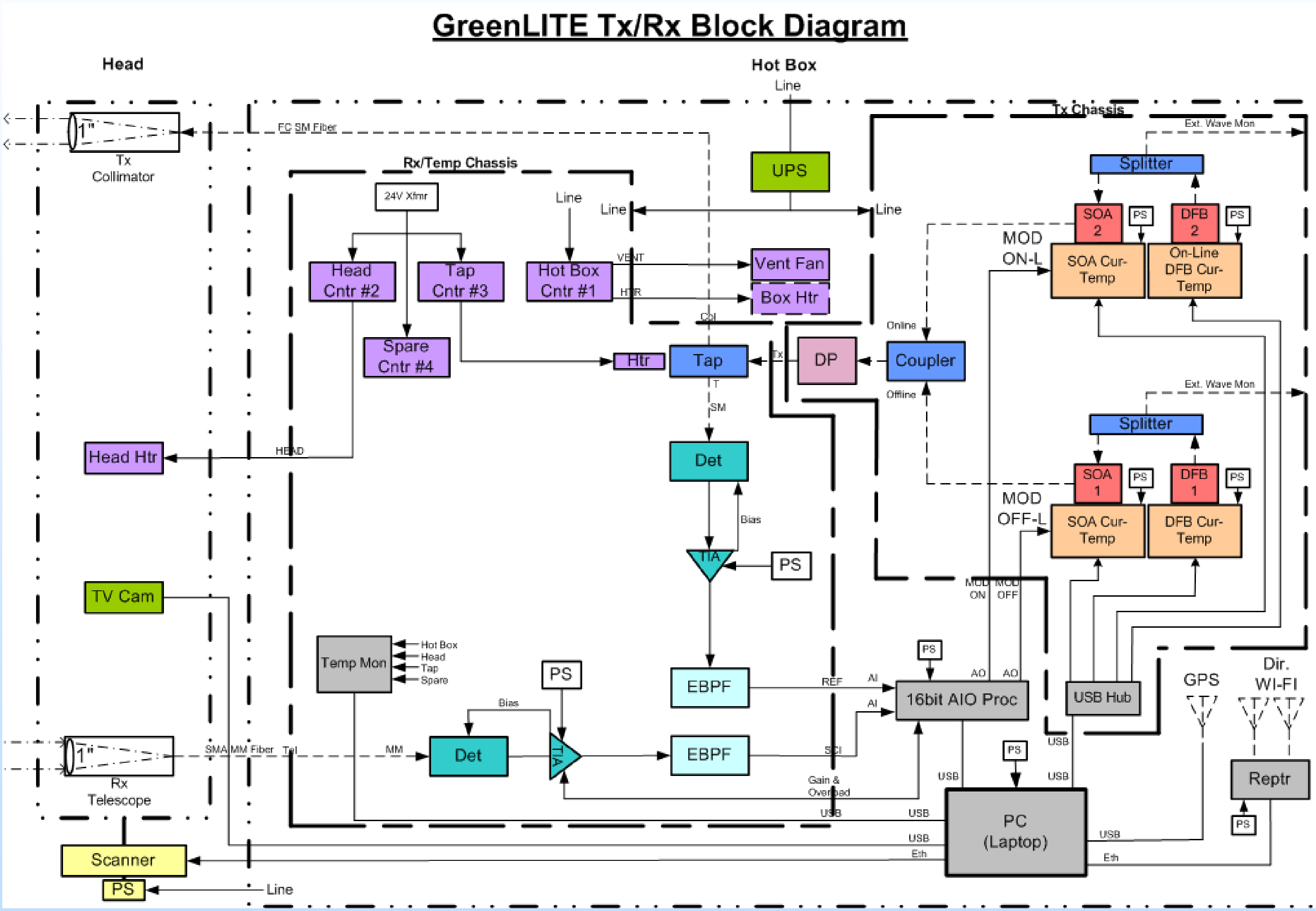
- The Green LITE sensor design was based on prior work with Exelis' airborne Multifunctional Fiber Laser Lidar (MFLL) and, more specifically, the ground-based prototype of the Laser Atmospheric Transmitter and Receiver-Network (LAnTeRN).
- The first task was to review and modify the LAnTeRN prototype design for the Green LITE specific application of Ground Carbon Sequestration monitoring.
- The design was reviewed and refined given the objectives of the Green LITE program for remote operation, and the required components were identified.

General Instrument Architecture



High reliability telecom components, CW operation requires low peak power and allows for more robust, less expensive laser components and higher system efficiency.

Sensor Detailed Block Diagram

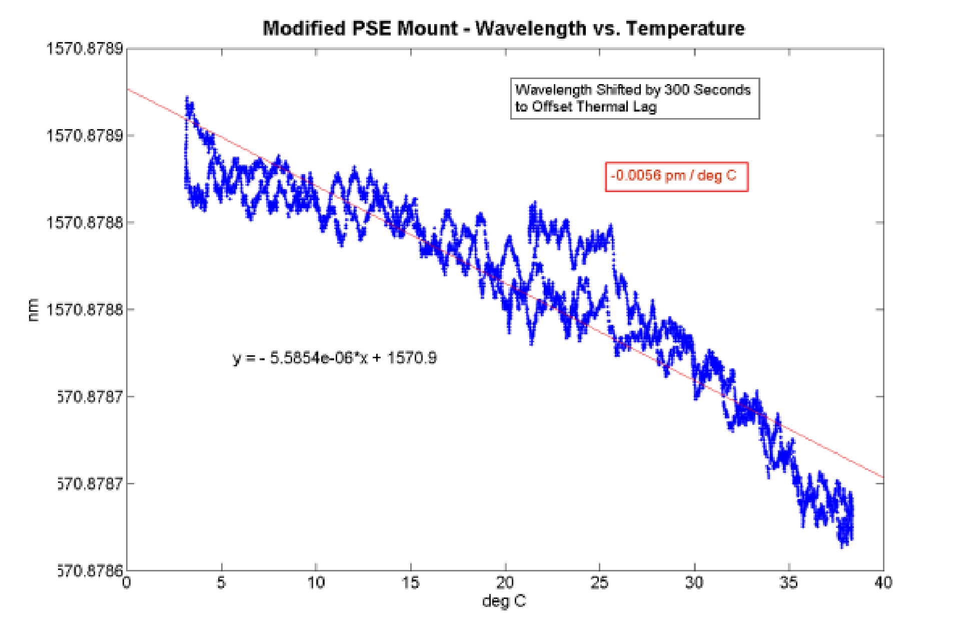


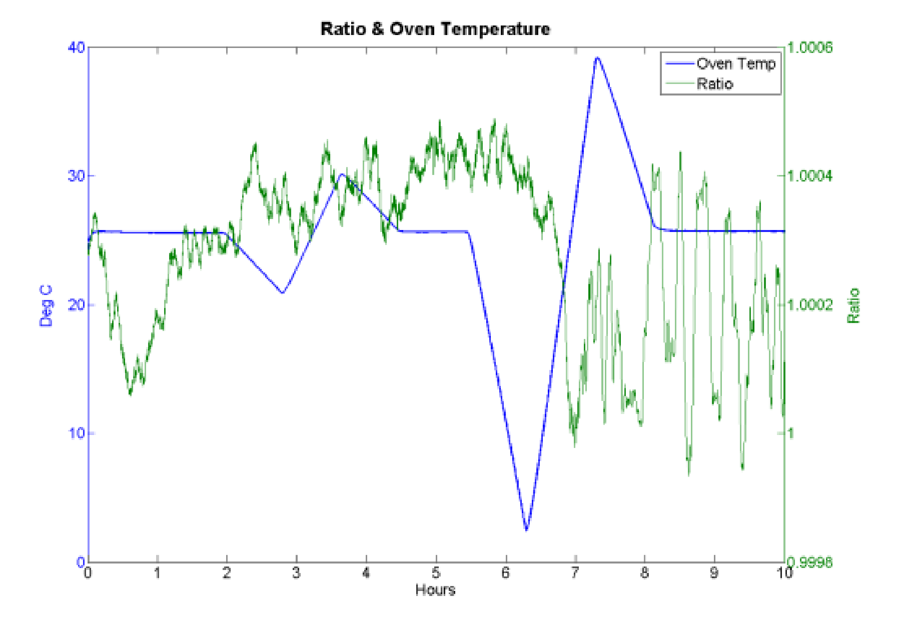
Component Selection

- As the design was refined and component specifications were developed, suitable commercial components were identified which met the design criteria and were then procured if not already on hand from prior development.
- Components were custom built if not commercially available.
- Components were characterized to verify specifications and tested for sensitivity to environmental conditions.
- Examples of characterization results are shown on next slide.

Component Characterization

Wavelength stability requirement was +/- 0.02 pm/degC



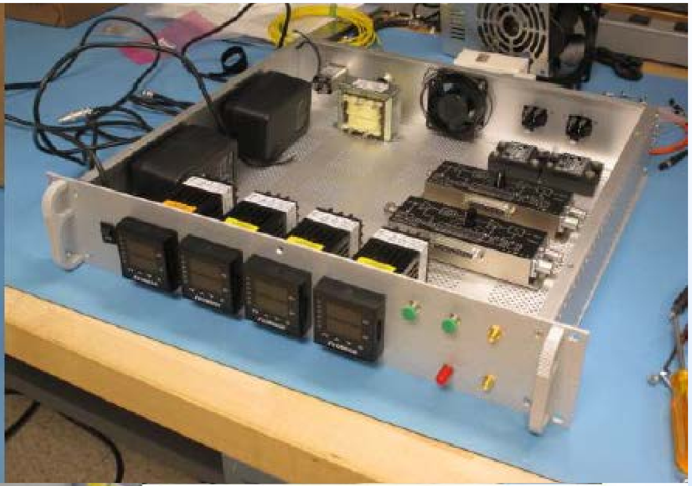


Ratio Impact Requirement for Fiber Tap Over 0-40C was 0.001

Component Integration

- Components were integrated and installed in 2 modular chassis inside a thermally controlled “hot box.”
- The hot box maintains a constant 38 °C +/-0.2 °C, which is above any ambient temperatures expected during remote deployment. This provides a constant thermal environment for the hardware components and prevents condensation from humid air.
- Temperatures of critical components also have closed loop control in addition to the controlled ambient temperature (Optics Head, Fiber taps, Lasers)

Component Integration



Hotbox maintains temperatures and prevents condensation

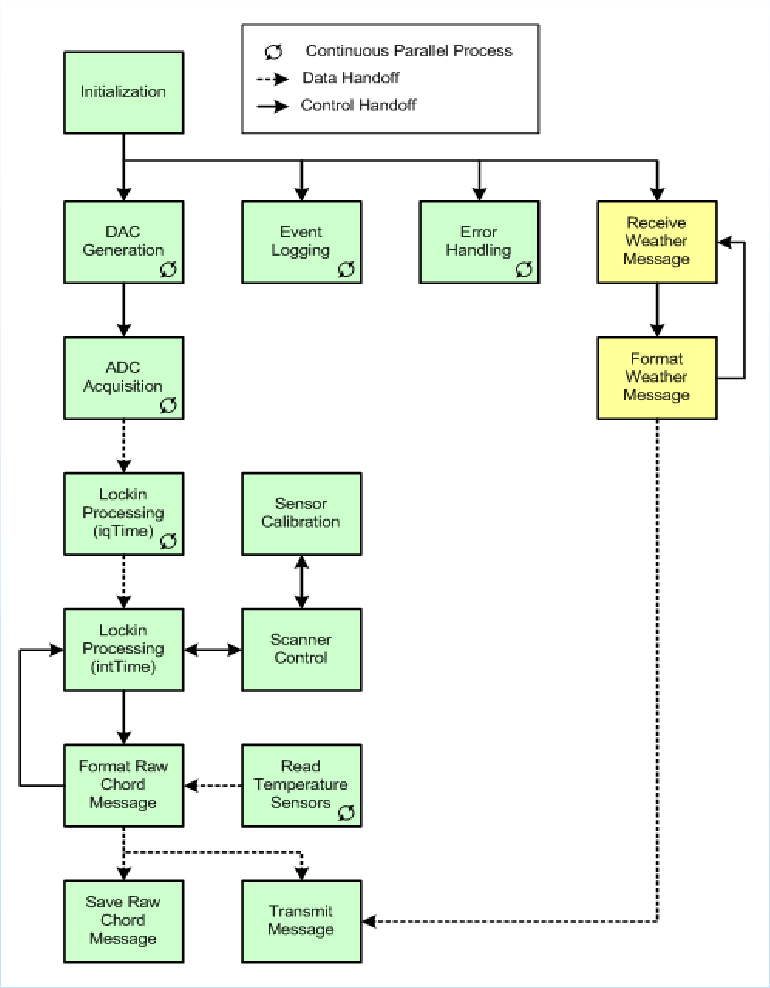
Optical Design

- The original optical design for the transmitter and receiver used refractive optics.
- Component testing revealed that refractive optics caused a variation of the wavefront significant enough to bias the measured transmission ratio.
- Further testing and several iterations of the design resulted in a reflective transmitter/receiver design that works very well.
- This design change also impacted mechanical and thermal design, and ultimately led to about a 1 month delay to the first and second milestones for the project.

Software Development

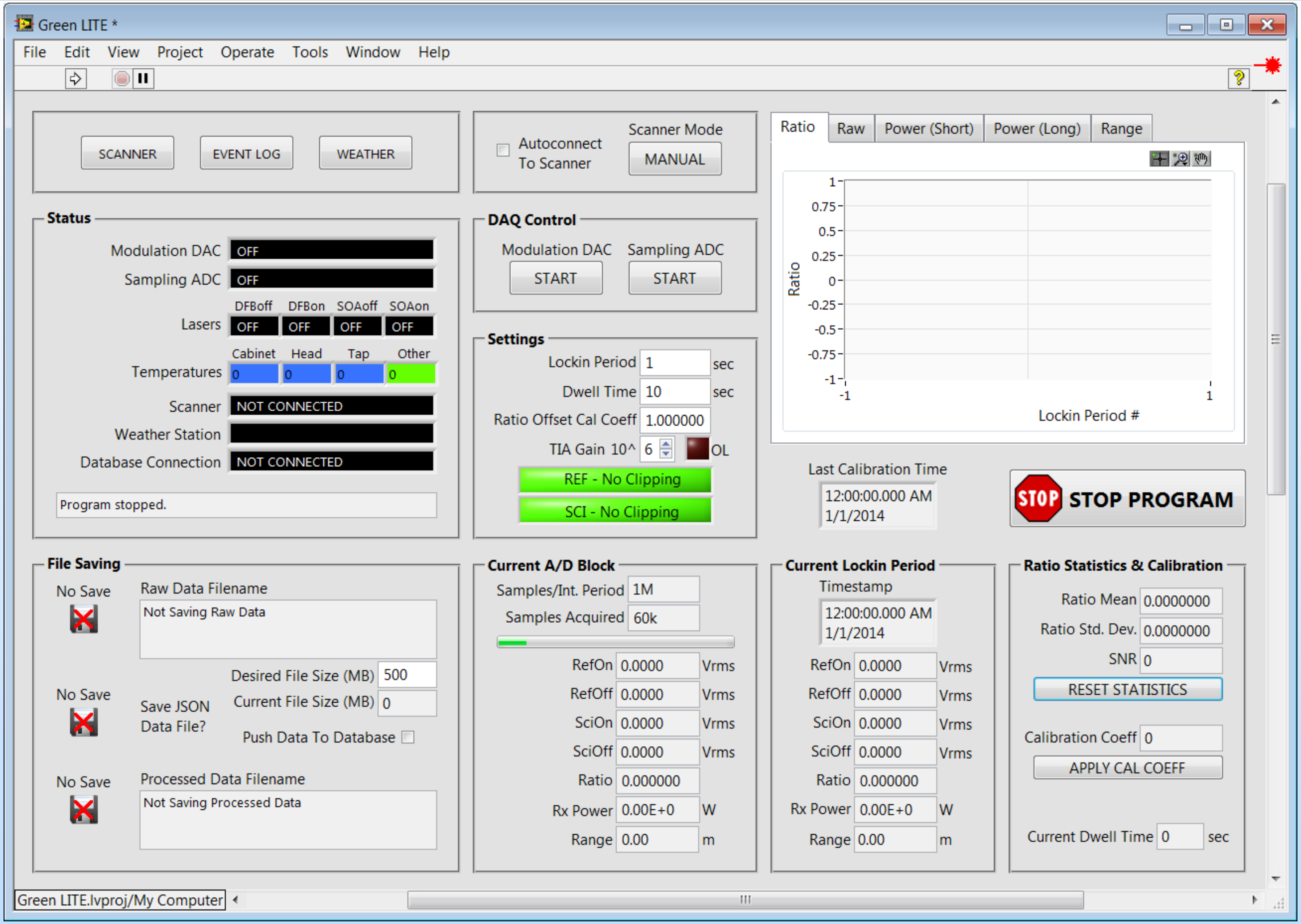
- Similarly to the hardware development, the Green LITE software development leveraged as much of the existing software from MFLL and LAnTeRN as possible.
- The software is written in LabVIEW and uses an event-based architecture.
- The software allows for 2 modes of operation:
  - Manual: no automated movement of the scanner
  - Automatic: the scanner automatically scans through a list of pre-determined pointing locations at a user-specified time interval
- Manual mode is useful for testing and debugging while automatic mode is used for normal operation.

Software Block Diagram

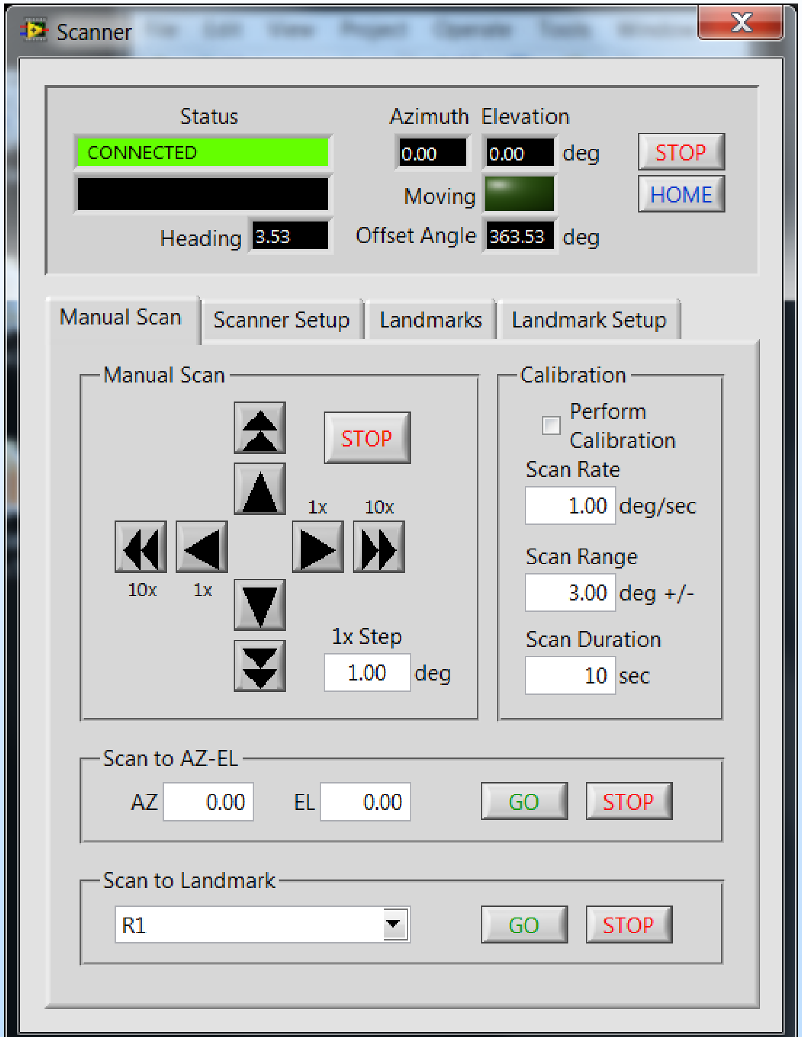


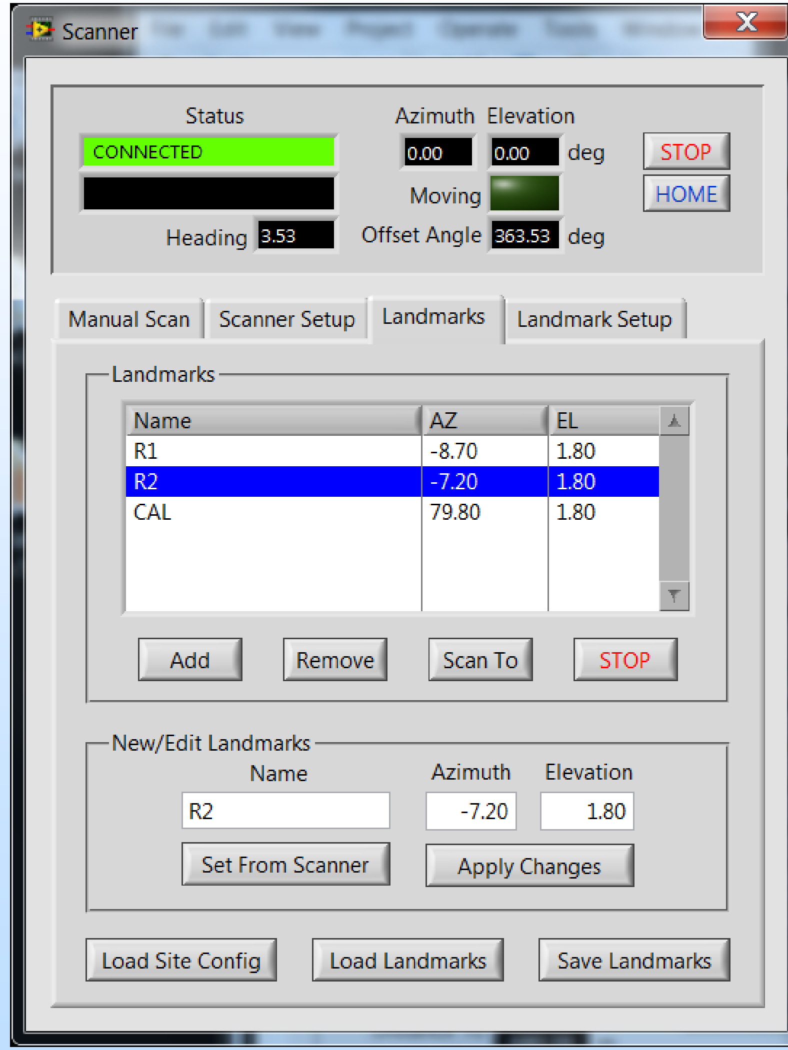
- Software functional block diagram shows different operations performed and how execution control and data are passed between operations.
- Yellow blocks are for receiving weather data from weather station and pushing to database. Another method of accessing weather data is currently being used, but this will be implemented prior to remote deployment at IBDP site.

Software Screenshots



Software Screenshots

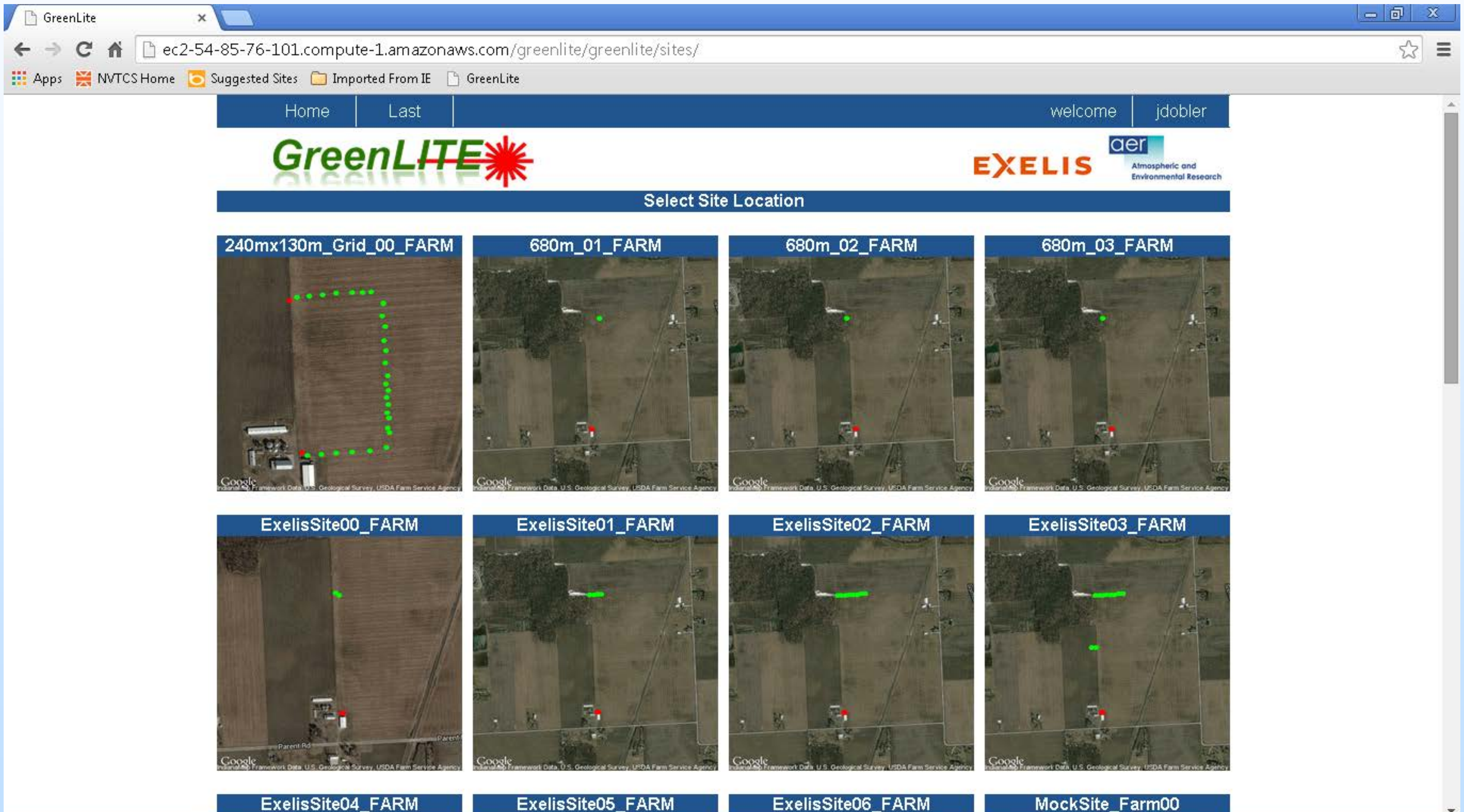




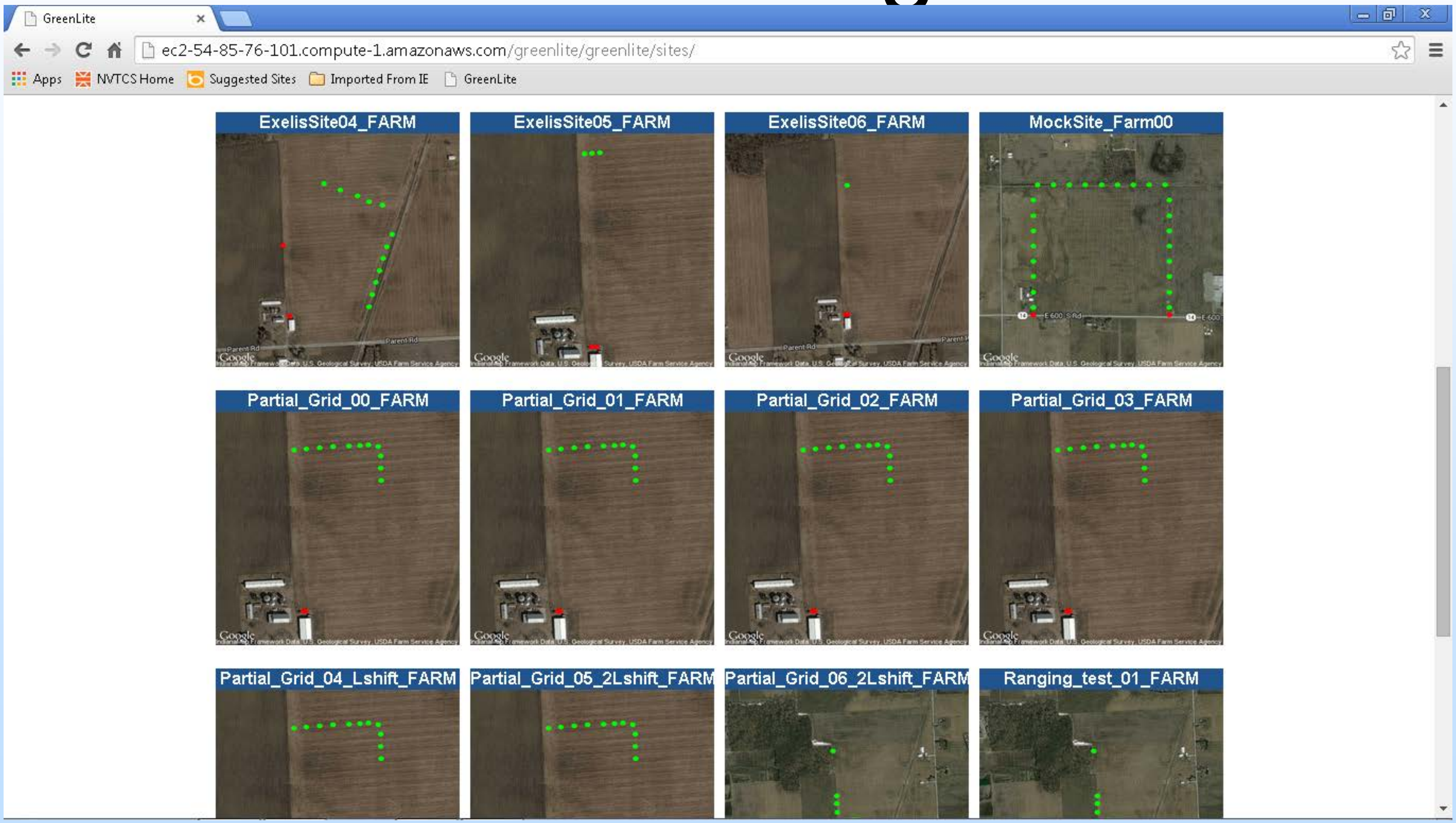
Sensor Unit Testing

- When the first sensor build was complete and the software was fully functional, the sensor was tested at the Exelis Farm test facility.
- The sensor was scanned back and forth between 2 retro-reflectors and consistently demonstrated an SNR for the differential transmission measurement of > 3000 with 10-second averages, exceeding the design specification by a factor of 3.
- All data was loaded directly to the web-based database and retrieval site via a 3G/4G wireless connection.
- Testing then progressed to system level testing consisting of both transceivers and multiple retro reflectors.

Local Sensor and System Level Testing

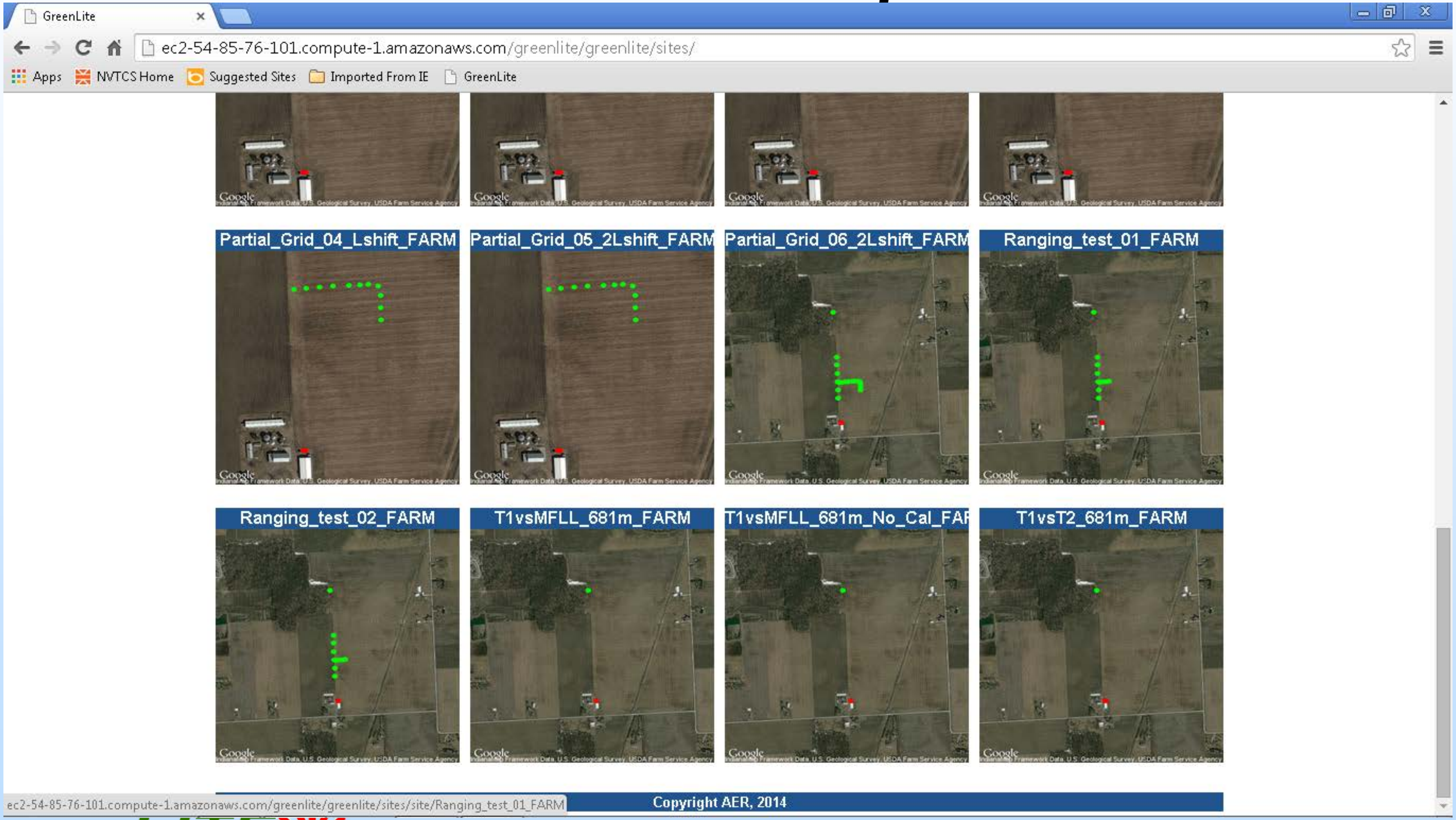


Local Sensor and System Level Testing



GreenLITE

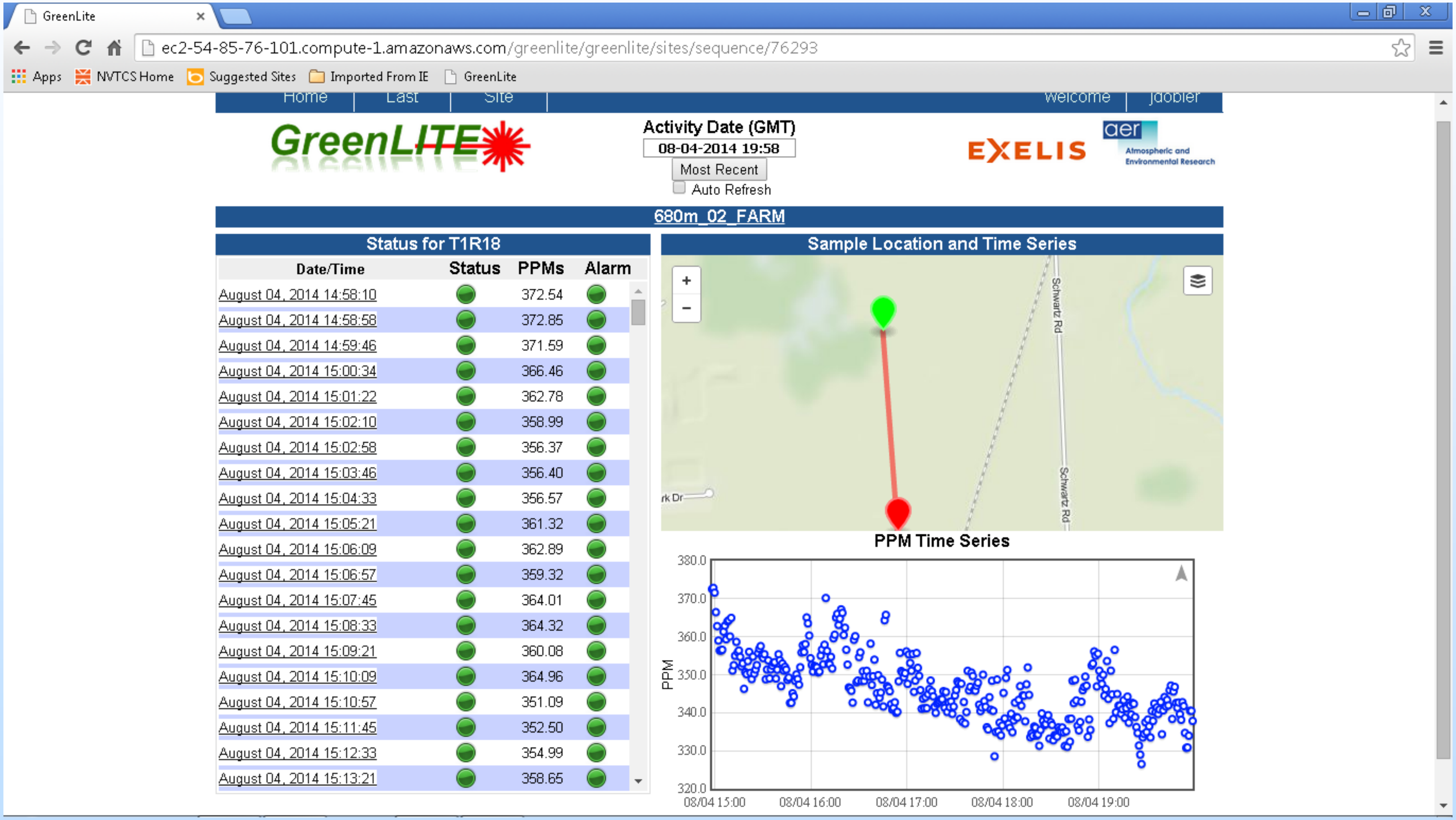
Local Sensor and System Level Testing



Local System Testing Setup

Exelis Farm Test Site Used for Preliminary Sensor and System Level Testing

Looking at Individual Chord Data on Web-based Tool



Looking at Individual Measurement Data

GreenLite

ec2-54-85-76-101.compute-1.amazonaws.com/greenlite/greenlite/sites/sample/76396

Apps NVTCS Home Suggested Sites Imported From IE GreenLite

Home | Last | Site | welcome | jdobler

GreenLITE

Activity Date (GMT)
08-04-2014 15:08

EXELIS aer Atmospheric and Environmental Research

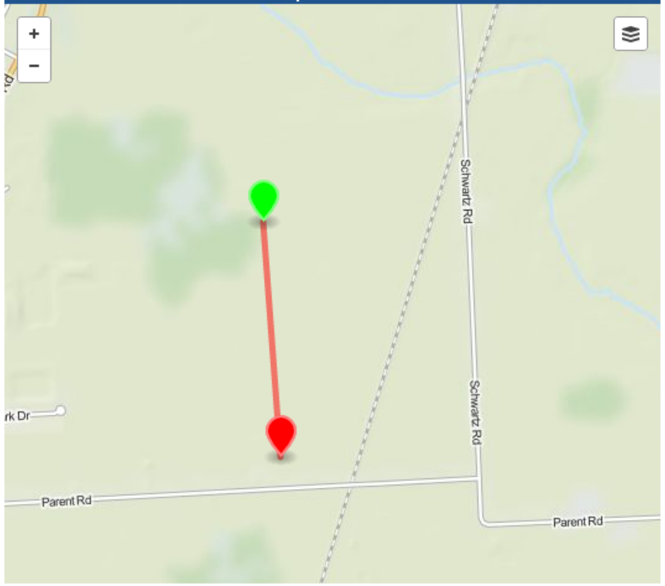
680m_02_FARM

T1R18 Status

Parameter	Value
site name	680m_02_FARM
date	August 04, 2014 15:08:33
transceiver	T1
transceiver lat	41.108394
transceiver lon	-85.010155
reflector	R18
reflector lat	41.114524
reflector lon	-85.010761
concentration ppm	364.32
delta OD	0.0674
warning status	False
error status	False
medium level flag	False
high level flag	False
metadata: temperature	25.6
metadata: pressure	991.301994083
metadata: windSpeed	0.0
metadata: relHumidity	72.0
metadata: wxDate	August 04, 2014 15:08:37
metadata: message	
metadata: windDirection	267.0

Disable

Sample Location



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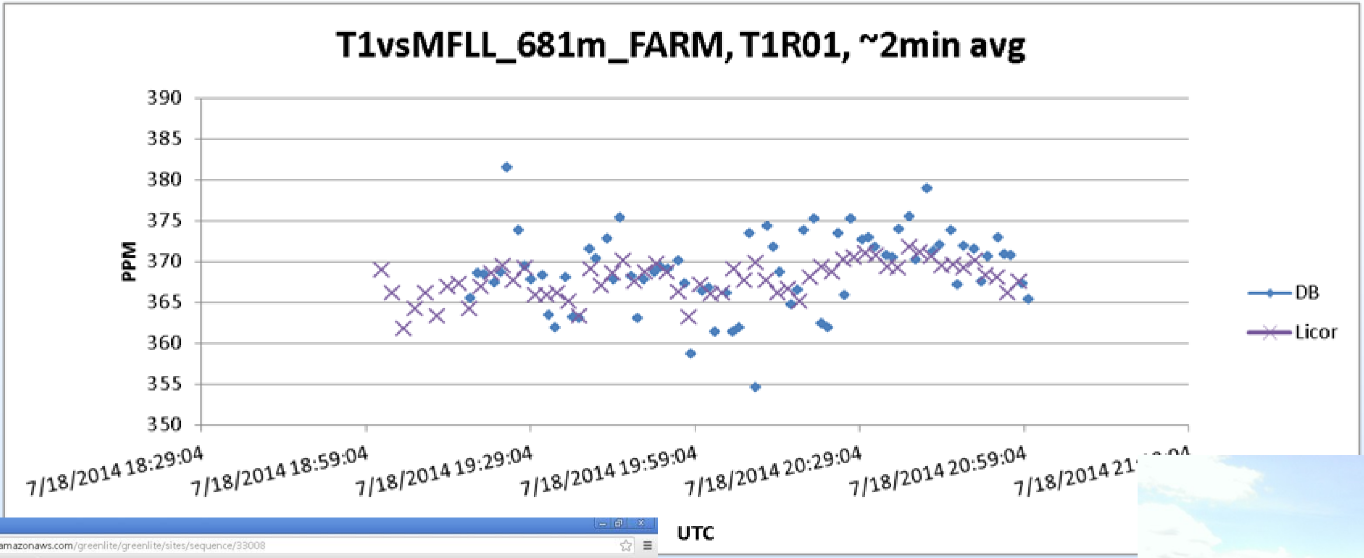
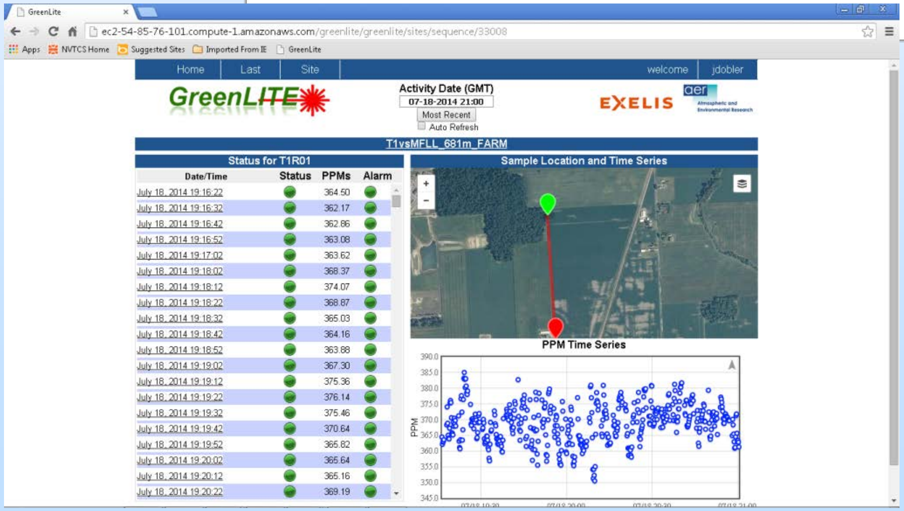
Comparison With In Situ





Weather Data Collected for Retrievals

GreenLite

ec2-54-85-76-101.compute-1.amazonaws.com/greenlite/greenlite/sites/weather/680m_02_FARM/

Apps | NVTCS Home | Suggested Sites | Imported From IE | GreenLite

Home | Last | Weather | welcome | jdobler

GreenLITE

Activity Date (GMT)

08-04-2014 19:58

Most Recent

Auto Refresh

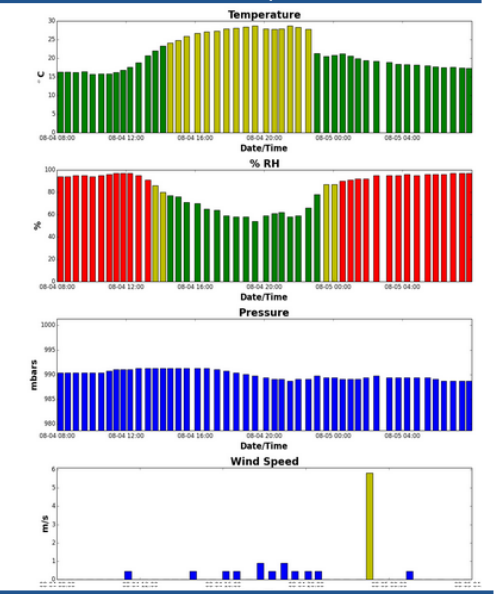
EXELIS aer Atmospheric and Environmental Research

KINNEWHA5

Status

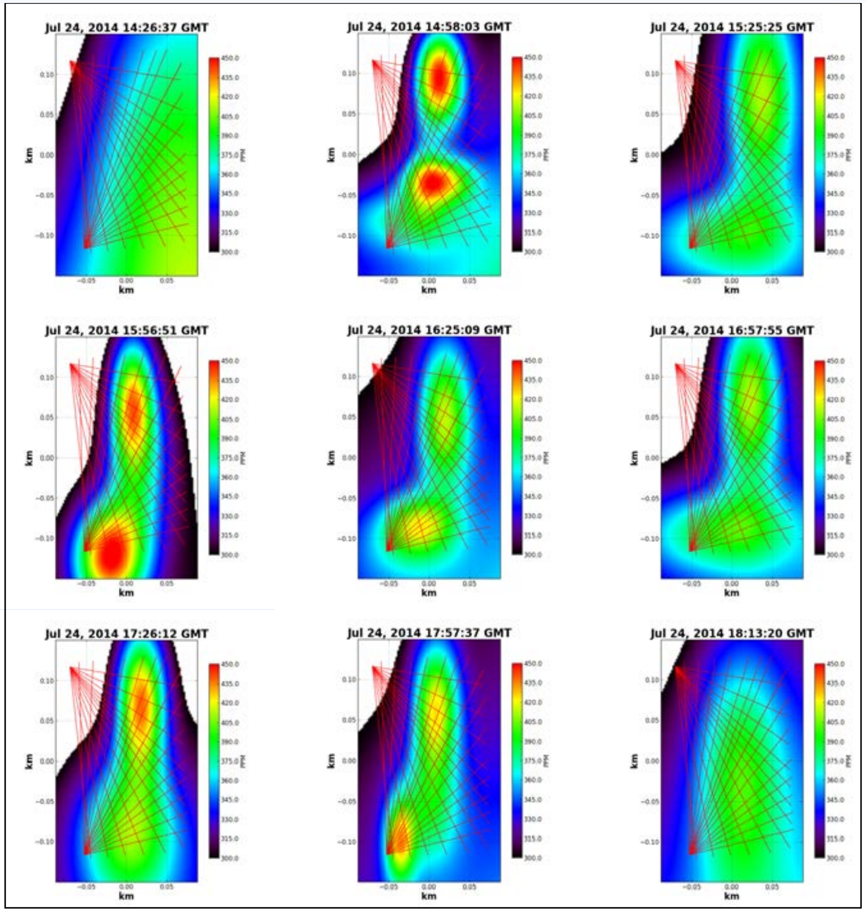
Date/Time	T °C	% RH	P (mbar)	W_{Speed}	W_{Dir}
Aug 04, 2014 08:02:08 GMT	16.30	94.00	990.3	0.000	246.0
Aug 04, 2014 08:06:08 GMT	16.40	95.00	990.3	0.000	246.0
Aug 04, 2014 08:08:08 GMT	16.40	95.00	990.3	0.000	246.0
Aug 04, 2014 08:10:08 GMT	16.50	95.00	990.3	0.000	246.0
Aug 04, 2014 08:12:08 GMT	16.50	95.00	990.3	0.000	246.0
Aug 04, 2014 08:14:07 GMT	16.50	95.00	990.3	0.000	246.0
Aug 04, 2014 08:16:07 GMT	16.50	94.00	990.3	0.000	246.0
Aug 04, 2014 08:18:08 GMT	16.50	94.00	990.3	0.000	246.0
Aug 04, 2014 08:20:07 GMT	16.50	94.00	990.3	0.000	246.0
Aug 04, 2014 08:22:08 GMT	16.50	94.00	990.3	0.000	246.0
Aug 04, 2014 08:24:07 GMT	16.50	94.00	990.3	0.000	246.0
Aug 04, 2014					

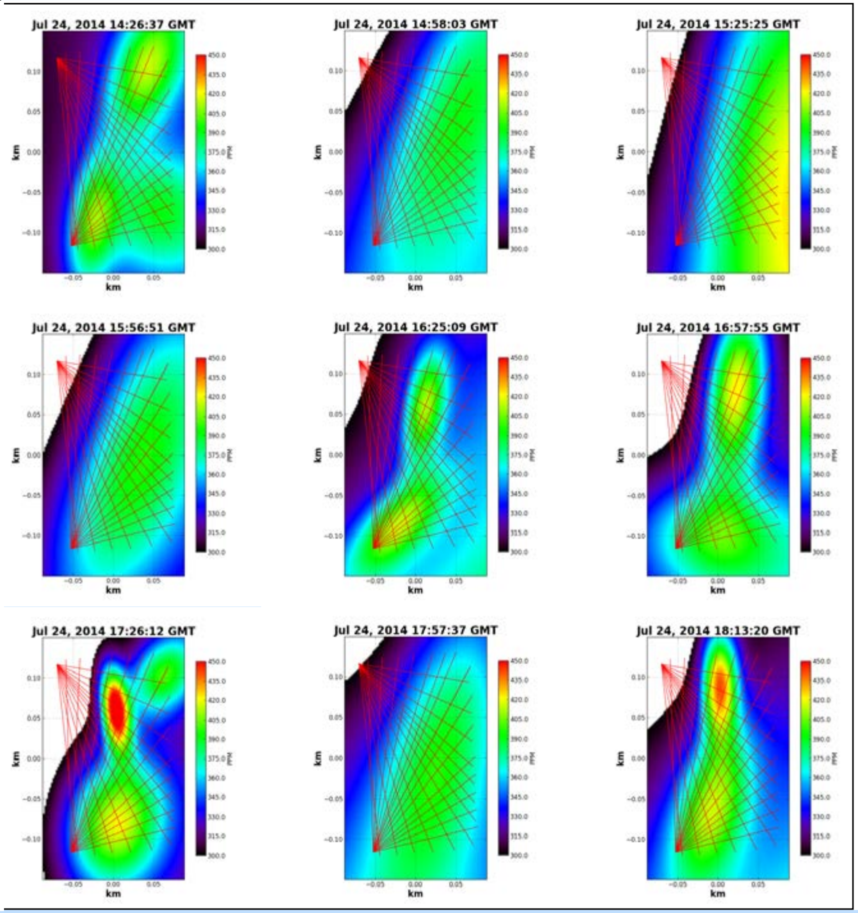
Weather Graphics



GreenLITE

Preliminary 2D Reconstructions from Local System Testing





Accomplishments to Date

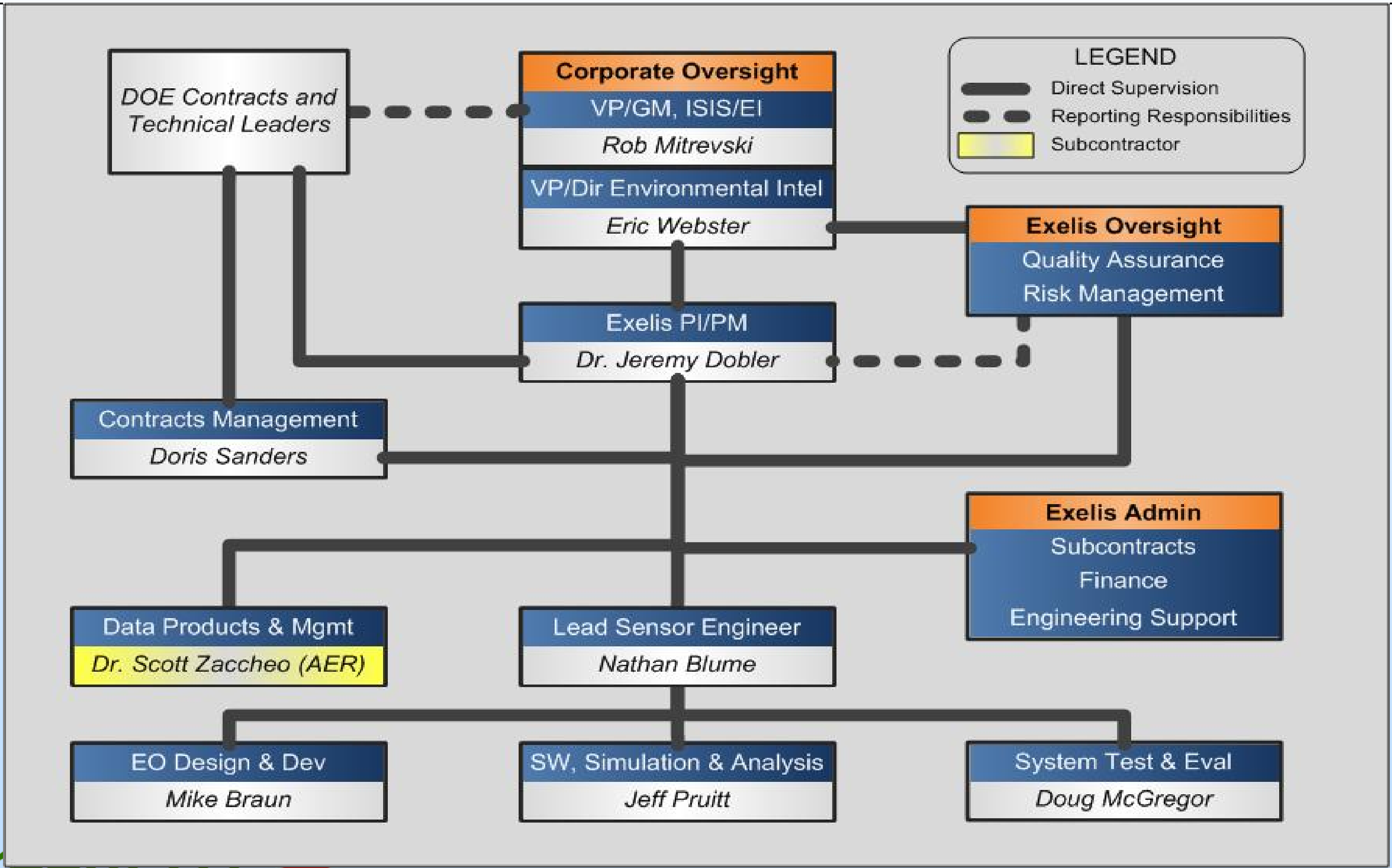
- Sensors designed and requirements specified at component level
- Component performance validated in laboratory
- System design and trade studies completed
- Sensors assembled and integrated with software
- Sensor level testing exceeded design specification by 3X
- Retrieval algorithms developed and tested
- Database and Web tools developed with user interface
- System level testing nearing completion
- Preliminary 2D mapping algorithms developed and tested with simulated and measured data

Summary

- System is capable of providing concentration and 2D maps of CO_2 concentration over hundreds of square meter area.
- Truth data is difficult to obtain using currently available hardware.
- Source determination highly dependent on wind speed and height above ground level.
- All web-based real-time processing, storage and dissemination of data is convenient and viable.

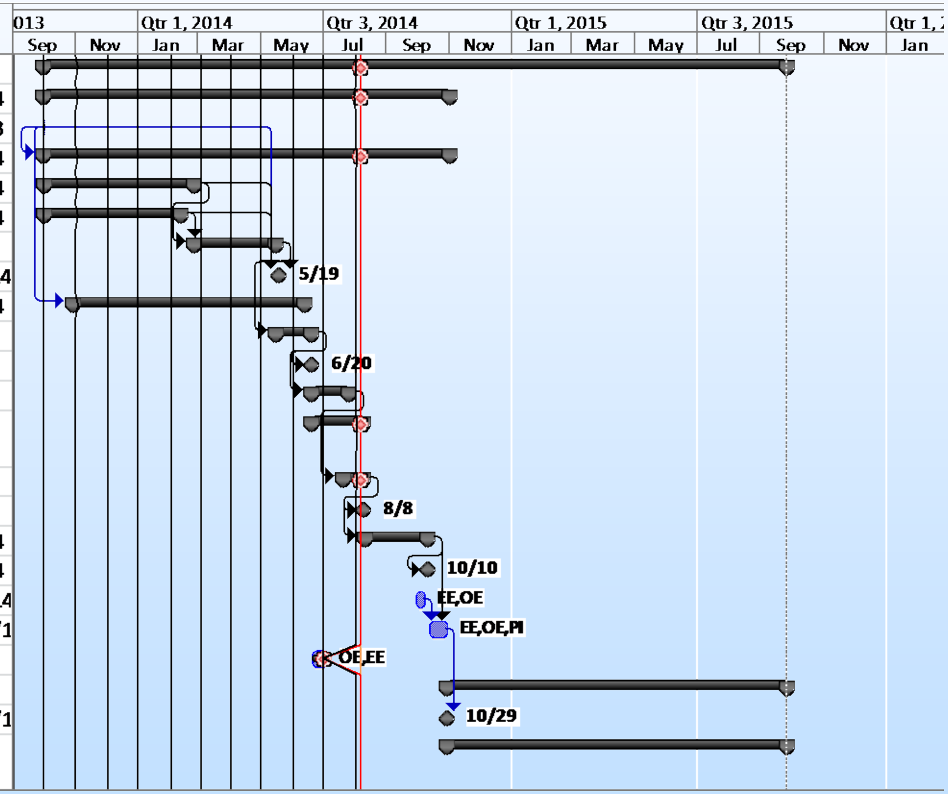
APPENDIX

Organization Chart



Gantt Chart

ID	Task Name	Start	Finish
1	DOE CO2 Sequestration Green LITE	Tue 10/1/13	Fri 9/25/15
2	Phase 1	Tue 10/1/13	Fri 10/31/14
3	Phase 1 Start Date	Tue 10/1/13	Tue 10/1/13
4	Project Management and Planning	Tue 10/1/13	Fri 10/31/14
15	HW Design and Build	Wed 10/2/13	Tue 2/25/14
21	SW Development	Wed 10/2/13	Tue 2/11/14
25	Sensor Integration	Wed 2/26/14	Fri 5/16/14
28	Sensor integration and test complete	Mon 5/19/14	Mon 5/19/14
29	CO2 Retrieval Algorithm Dev	Tue 10/29/13	Thu 6/12/14
33	System Test	Fri 5/16/14	Fri 6/20/14
36	System test with baseline algorithms complete	Fri 6/20/14	Fri 6/20/14
37	Upgrade System for Remote Deployment	Fri 6/20/14	Fri 7/25/14
43	Update, Integrate and Test Retrieval & CO2 Monitoring Subsystem	Fri 6/20/14	Fri 8/8/14
46	Local Testing of Integrated System in Field Setting	Mon 7/21/14	Fri 8/8/14
49	Local testing with integrated algorithms complete	Fri 8/8/14	Fri 8/8/14
50	ZERT Field Campaign	Mon 8/11/14	Fri 10/10/14
54	Zert testing and analysis complete	Fri 10/10/14	Fri 10/10/14
55	Decature ICCS Site Investigation	Mon 9/29/14	Wed 10/8/14
56	Phase 1 Final Report	Mon 10/13/1	Wed 10/29/1
57	Interim Report	Fri 6/20/14	Fri 7/4/14
58	Phase 2	Wed 10/29/1	Fri 9/25/15
59	Start of Phase 2	Wed 10/29/1	Wed 10/29/1
60	Project Management and Planning - Phase 2	Thu 10/30/14	Fri 9/25/15



Bibliography

No peer reviewed publications have been generated from the project yet. Several presentations are planned and peer reviewed publications will follow testing at the ZERT site and analysis of the results.

- We are submitting two abstracts for the American Geophysical Union Annual Meeting to be held in San Francisco, CA Dec. 15-19.
- “A Laser Absorption Spectroscopy System for 2D Mapping of CO2 Over Large Spatial Areas for Monitoring, Reporting and Verification of Ground Carbon Storage Sites”
- “Assessing Methods for Mapping 2D Field Concentrations of CO_2 Over Large Spatial Areas for Monitoring Time Varying Fluctuations”

- Another abstract is being submitted to the American Meteorological Society Meeting to be held in Phoenix, Arizona January 4 – 8th. We will also look for an opportunity to publish the results of the Zero Emissions Research and Technology site testing and results.
- “Intensity Modulated Continuous Wave Laser Absorption Spectroscopy for Addressing Currently Unmet Carbon Monitoring Needs”

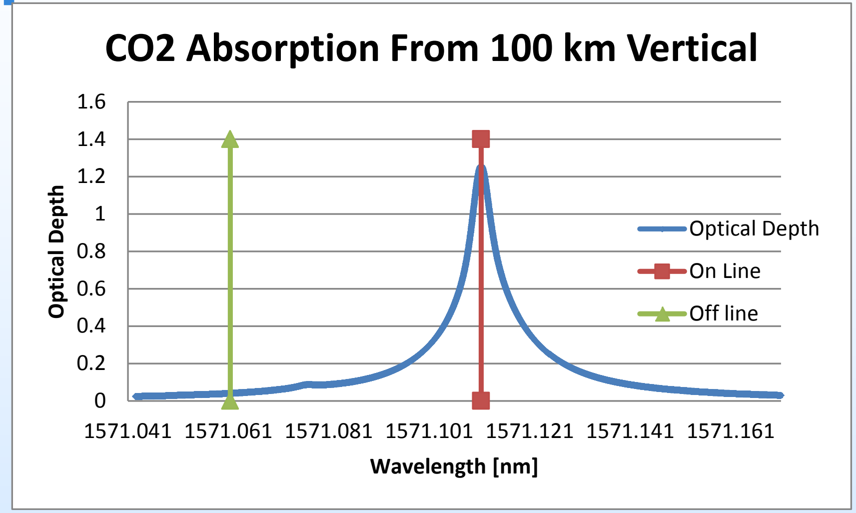
Integrated Path Differential Absorption

Starting with the basic lidar equation

$$P_{rec\lambda}(Z) = P_{o\lambda} \cdot C \frac{A}{z^2} \cdot \rho_\lambda \cdot \tau_\lambda^C(z) \cdot \tau_\lambda(z)$$

We are interested in the last term which is the transmission from range 0 to the target Z and back due to absorption.

When a simultaneous measurement is made at two closely spaced wavelengths, all other terms are common to both channels, and thus taking the ratio yields the differential transmission.



$$\Delta\tau_{\lambda on-\lambda off}(z) = \frac{\tau_{\lambda on}}{\tau_{\lambda off}} = \frac{P_{rec\lambda off}}{P_{rec\lambda on}} \cdot \frac{P_{o\lambda on}}{P_{o\lambda off}}$$

The total integrated column number density of the absorbing molecule can then be determined if the absorption cross section is known.