The Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE): Measuring Ground-Based 2-D Distribution of CO_2 Over Extended Field of Interest

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This work was partially funded by a Department of Energy, National Energy Technology Grant DE-FE0012574

Abstract

This work describes the design and testing of a novel laser-based system to aid in the autonomous real-time monitoring and mapping of CO_2 concentrations over a two-dimensional field of interest. The Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE) combines real-time Laser Absorption Spectroscopy (LAS) measurements with a lightweight web-based data acquisition and product generation system to provide autonomous 24/7 monitoring of CO_2. The current GreenLITE system is comprised of two transceivers and a series of retroreflectors that continuously measure the differential transmission over a user-defined set of intersecting line-of-site paths or "chords" that form the plane of interest. These observations are first combined with in situ surface measurements of temperature (T), pressure (P) and relative humidity (RH) to compute the integrated CO_2 mixing ratios along the line-of-site paths based on an iterative radiative transfer modeling approach, grouped based on observation time and employed in a sparse sample reconstruction method to provide a tomographic like representation of the 2-D distribution of CO_2 over the field of interest. This reconstruction technique defines the field of interest as a set of idealizes plumes whose integrated values best match the observations. The GreenLITE system has been deployed at 2 primary locations; 1) the Zero Emissions Research and Technology (ZERT) center in Bozeman, Montana, in Aug-Sept 2014, where more than 200 hours of data were collected over a wide range of environmental conditions, while utilizing a controlled release of CO_2 into a segmented underground pipe, and 2) continuously since February 2015 at the Illinois Basin – Decatur Project. The system demonstrated the ability to identify persistent CO_2 sources at the ZERT test facility and showed strong correlation with an independent measurement using a LI-COR based system. Here we describe the measurement approach, algorithm design and deployment results.

Measuring Column CO_2

Approach: Retrieve CO_2 (or other trace gas) column amount from differences in observed optical depths

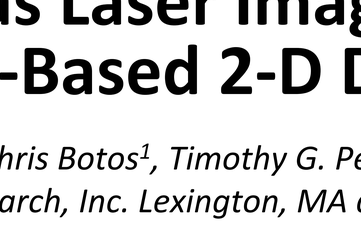
- Column amount is proportional to optical depth difference, path length and molecular density

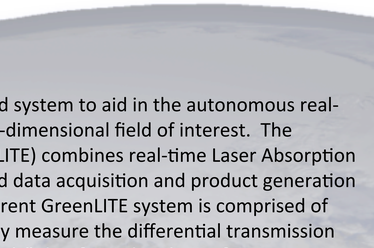
Basic Recipe

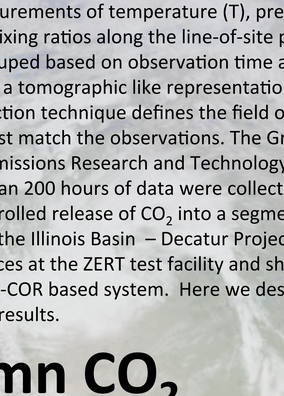
1. Measure absorption of "On"-line wavelength λ (on absorption feature of interest)
2. Measure absorption of "Off"-line wavelength λ+ Δ (in the continuum)
3. Fit estimated column value XCO_2 to observed difference given path length and local atmospheric state (T/RH/P)

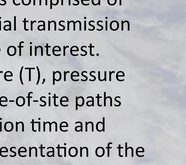
Instrument

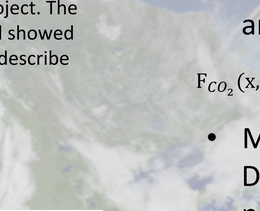
- Based on technology initially designed as demonstration system for aircraft/space-based active mission for measuring vertical XCO_2
- Employ telecommunication technology at wavelengths in a weak CO_2 feature (1.57μm)
- Designed to work in either transmission or reflection











GreenLITE

U.S. Department of Energy's (DOEs) 2015 Carbon Storage R&D Project Review Meeting

Constructing 2-D Maps of CO_2 Concentration

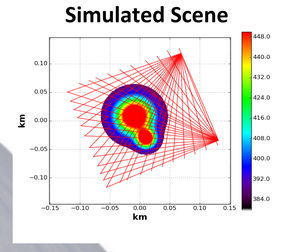
Sparse nature of GreenLITE's sampling approach is not well suited for traditional tomography techniques

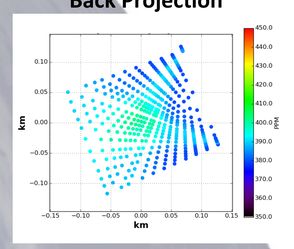
Solution: Construct 2-D views using model-based tomographic reconstruction approach

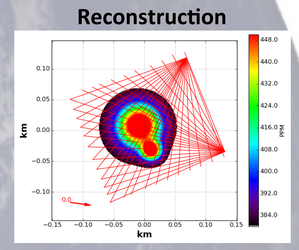
- Describes underlying field as set of analytic features and gradients

$$F_{CO_2}(x,y) = a + bx + cy + dxy + \sum_{n=0}^{N} \alpha_n e^{-\beta_n x_r^2} e^{-\gamma_n y_r^2}$$

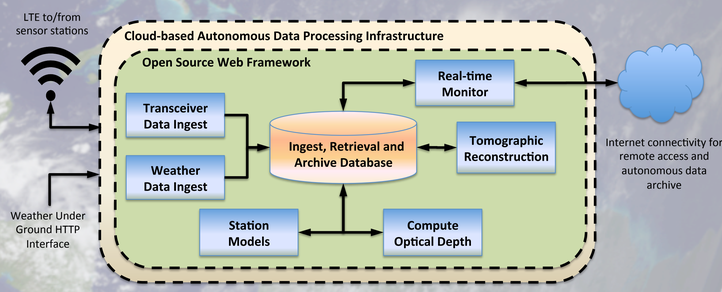
- Model source term(s) as simple 2-D Gaussians driven by source position, concentration and wind speed/direction
- Minimizing the sum of the RMSE differences between observed data and integrated model values using a Sequential Least Squares Programming (SLSQP) optimization algorithm.







Developing a Common Ground Processing Environment



Ground data processing accomplished using single common open-source web-based framework

Provides

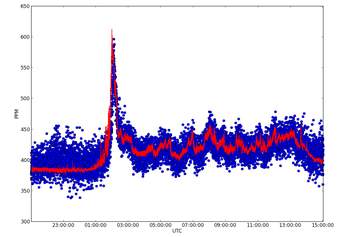
- Standardize scientific data interface: Remote instrument observation, weather information, retrievals of chord concentrations and 2-D reconstructions
- Common web-based analysis/control interface
- Facilitates allocation of computational resources
  - On-site: Instrumentation and data collection
  - Cloud-based: Web and data processing services
  - Local: Analysis and reprocessing
- Enables rapid scaling of system as required

Deploying GreenLITE

Spring 2014: Harris Farm Site Ft Wayne, IN
•12+ test configurations
Summer 2014: ZERT Bozeman, MT
•2-Weeks / 1 configuration

Feb-Aug 2015: Illinois Basin - Decatur Project (IBDP) (Decatur, IL)
- Raw Samples: 2M+
- Retrieved Samples: 1.8M+
- Site Reconstructions: 72K
- Up-time ~95%

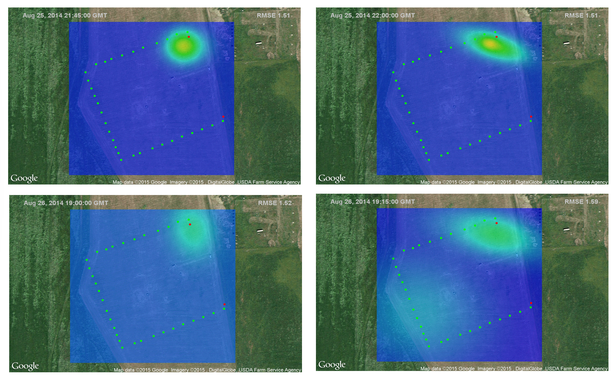
Calibrating GreenLITE



Comparison of Licor data (red) to retrieved chord values (blue)

- Both exhibit significant spatial and temporal concentration dynamics
- Observed values map very well to *in situ* measurements
- Large biogenic transients in CO_2 consistently observed at dusk in both measurements

Real-Time GreenLITE



Example time sequence of consecutive 2-D reconstructions. Persistent source in upper right corresponds to identified CO_2 source of biogenic emission. Controlled release of 0.3 T/day started 8/25 at 1722 local time and is seen in lower right image

Summary/Future

- Validate IBDP performance against independent *in situ* measurements
  - Extend analysis of IBDP ~6 month data set
- Explore clustering to locate potential persistent sources and estimate fluxes
- Develop advanced reconstructions that make better use of *a priori* information
- Monitor 2-D distributions of other GHGs (CH_4)
- Expand the scale to 5-10 km chord lengths

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