CO_2 and CH_4 Leak Detection Using Eddy Covariance Methods

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SWP Eddy Covariance

The Southwest Carbon Partnership (SWP) has been investigating the eddy covariance method for CO_2 and CH_4 surface leak detection. Two separate eddy tower deployments, one on the University of Utah campus and one at the Farnsworth Unit, TX (Phase III Field Test Site), have collected data that indicate eddy covariance methods are useful as surface monitoring tools.

A 20 day deployment of a Picarro gas analyzer at the tertiary EOR site at the Farnsworth Unit, Texas yielded potential point source detection of CO_2 and CH_4, sufficient to exam additional methods and approaches for quantifying potential point source leaks from CCS/CCUS sites.

For more control during testing, a small field-scale deployment on the campus of the University of Utah consisted of a single eddy covariance tower equipped with a 3-D sonic anemometer and LiCor CO_2 and CH_4 gas analyzers. The tower was deployed around a known source of CO_2 and CH_4 (a natural gas cooking vent from a cafeteria). The eddy covariance data was analyzed to determine trends of CO_2 and CH_4 as a function of time, space and wind speed. With a single eddy covariance system, the compass direction of a CO_2 /CH_4 source can be identified. With 2 or more eddy systems, leaks can be located (via triangulation methods) with a greater degree of certainty.

Instrumentation

Instrumentation

The SWP maintains two eddy covariance systems. Each can be readily deployed to CCS/CCUS field sites for short- or long-term monitoring of surface flux and/or point source leakage. Each operates at a nominal sampling frequency of 10 Hz, collecting 10 CO_2, CH_4, H_2O, temperature and wind speed/direction data points every second.

- LiCor System
  - Gill HS-50 3D sonic anemometer
  - LI-7200A Open-path CO2 analyzer
  - LI-7700 Open-path CH4 analyzer
  - Smartflux Integrated data-logger
  - Tripod for sensor mounting
  - Power Source (solar, if necessary)
- Picarro System
  - Applied Technologies 3D sonic anemometer
  - Picarro Cavity Ring-Down Spectrometer (CRDS) for CO_2 and CH_4 (integrated data-logger)
  - Tower for sensor mounting
  - Power source (110 VAC)

Field Testing

Initial deployment of the Picarro eddy covariance system was the CO_2 EOR field site at the Farnsworth Unit, Texas. The system was placed adjacent to a CO_2 injection well where it continually monitored CO_2, CH_4 and wind speed/direction for 20 days (withdrawn prematurely due to technical issues). Statistical analysis of the data suggested a nearby road was a larger contributor of CO_2 and CH_4 than the EOR operations. Atmospheric CO_2 flux analysis also suggests no detectable diffuse leakage of CO_2 and/or CH_4 from the subsurface.

Secondary deployments of the Picarro and LiCor eddy covariance systems were on the University of Utah campus, to evaluate methods using a consistent and quantifiable emission of CO_2 and CH_4. In particular, the LiCor system was deployed on the roof of the Student Union building, near a duct that emits exhaust from an eatery that utilizes a natural gas cooking stove. CO_2 and CH_4 are in abundant concentrations within the exhaust gas.

Location of the Farnsworth Unit, TX (SWP Phase III field site

Picarro eddy tower installation near CO_2 injection well, Farnsworth Unit

REFERENCES

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Ameriflux. (2016). Ameriflux. Retrieved from http://ameriflux.lbl.gov/

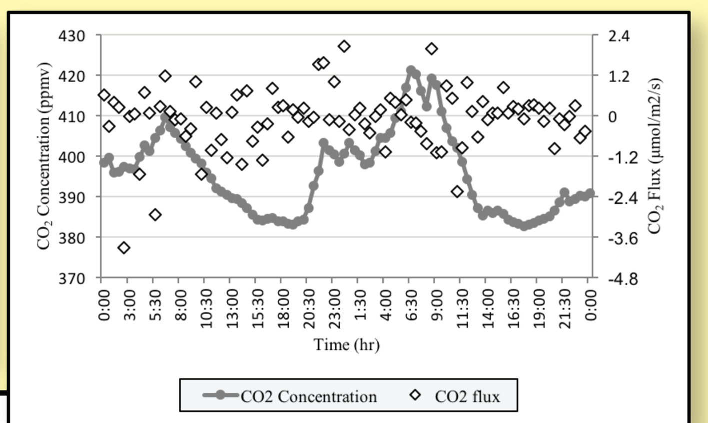
Walsh, M. (2016). Analysis of Temporal and Spatial Trends of Greenhouse Gas Emission Sources with Conditional Bivariate Probability Functions. (Unpublished Doctoral thesis). University of Utah, Salt Lake City, UT.

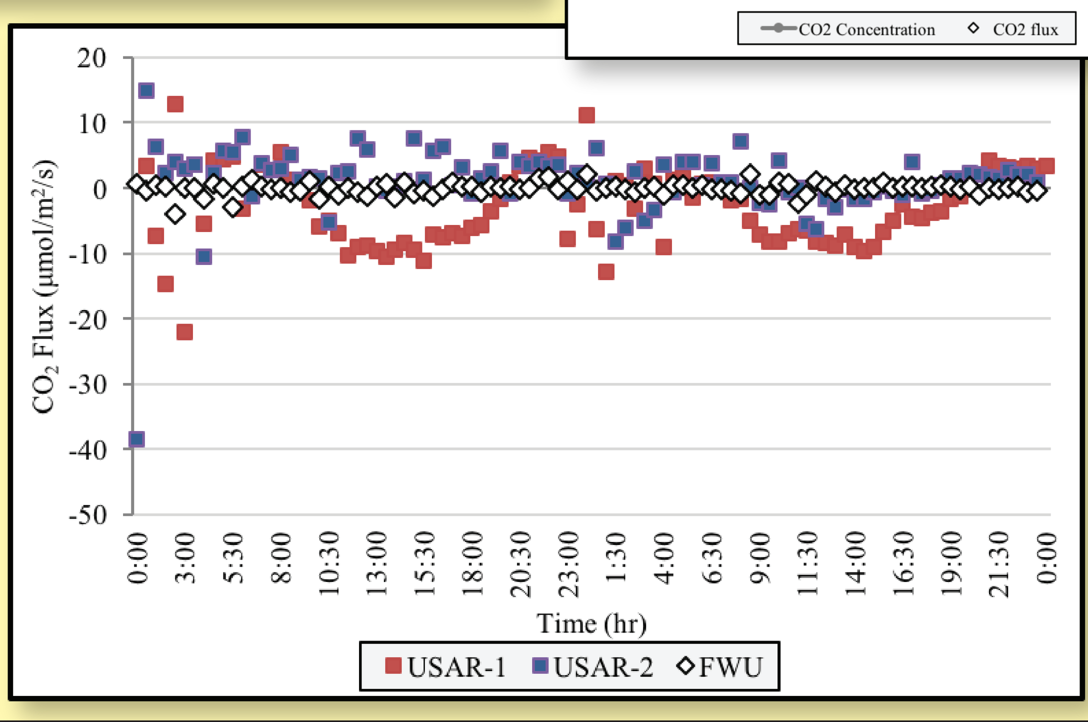
Coutinho, L. (2017). Analysis of Near-Surface and Atmospheric Monitoring Results from the Storage and CO_2-Enhanced Oil Recovery Project at Farnsworth Unit, Texas. (Unpublished Masters thesis). New Mexico Tech, Socorro, NM.

Farnsworth Unit - CO_2 Flux

Because of the long-term, continuous and stable attributes of eddy covariance systems, they can be used for quantifying diffuse flux as well as qualifying point source leaks. Coutinho (2017) used the eddy covariance data from the initial field deployment at the Farnsworth Unit to evaluate atmospheric CO_2 flux (as a measure of surface flux). Despite transient increases in carbon dioxide concentration (likely from passing vehicles, there was no elevated CO2 flux and the values were in-line with other flux values for the region (Ameriflux, 2016).

Eddy tower (Farnsworth Unit) CO_2 flux (30-minute intervals) and CO_2 concentration variation over 48 hrs (plot to right). Flux values range from -3.97 to 2.09 μ mol/m²/s, with a mean of -0.10 μmol/m²/s, indicating the absence of a strong source of CO_2 for this time period. Flux values for the Farnsworth Unit are also comparable (though more stable) for flux values elsewhere in the region for the same time period (plot below).





University of Utah - CO_2 Point Source Location

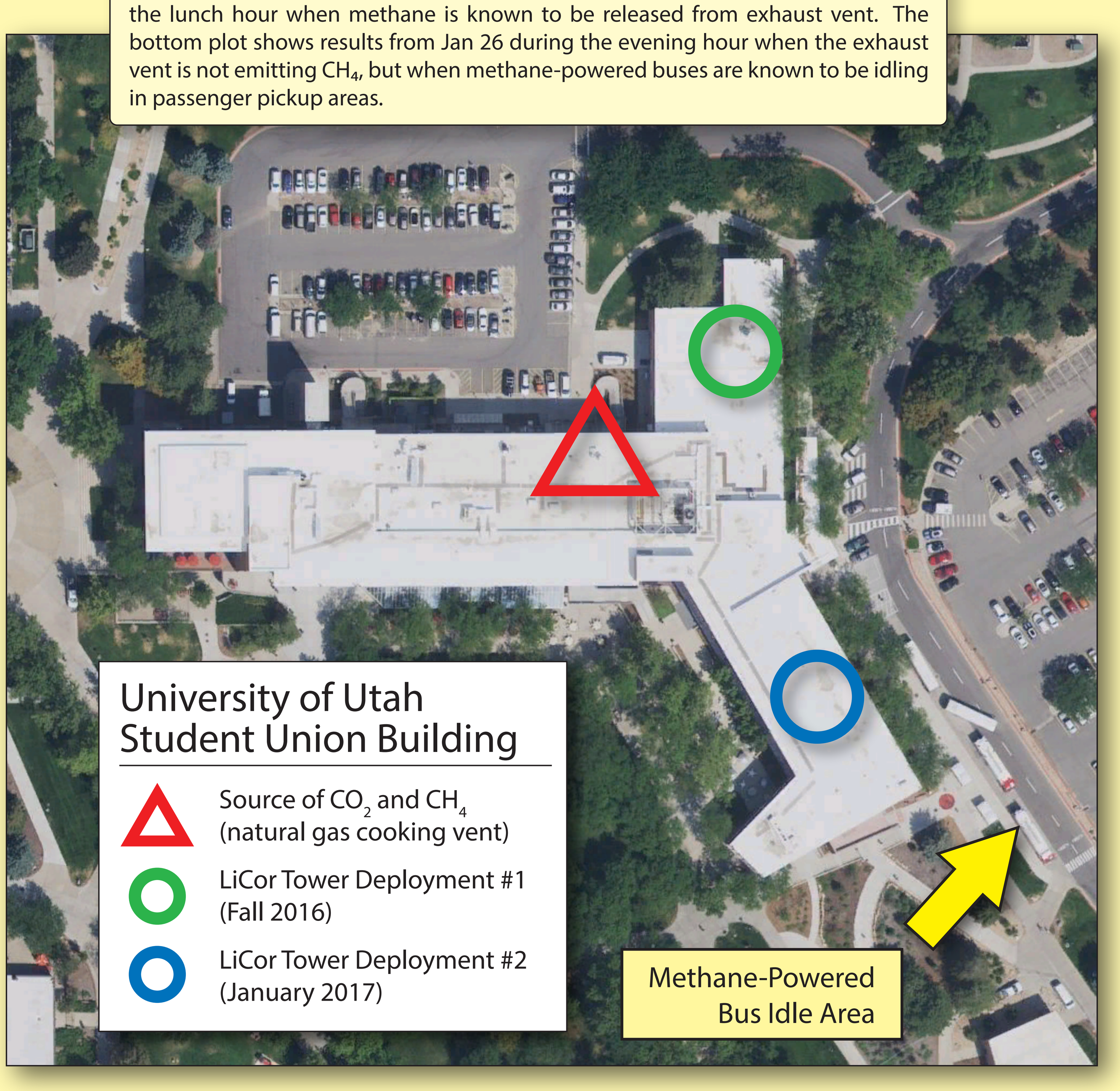
The satellite photo on the right shows the roof of the Student Union building on the University of Utah campus. The red triangle shows the exhaust vent for a natural gas cook stove that emits CO_2 and CH_4 during weekday lunch hours (approximately 10 AM to 3 PM). Two separate deployments of the LiCor eddy system to the northeast and southeast (green and blue circles, respectively) were used to collect data for statistical analysis and verification of eddy methods for the potential of point source leak detection. A second intermittent source of CO2 and CH4 is from the parking lot to the east, which includes an idle and passenger pickup area for methane-powered Salt Lake City commuter buses (yellow arrow).

The primary statistical analysis that was used to evaluate the data was the Conditional Bivariate Polar Function (CBPF) of the OpenAir pollution analysis package (Carslaw, 2012). This function is integrated into polar diagram plots that show the probability of a high concentration reading (CO_2 or CH_4, 99th percentile or above) occurring in a specified compass direction. CBPF's have proven to be effective at quantifying and locating emissions of air pollutants (SO_2, NO_x, and PM2.5) and are showing potential for CCUS applications.

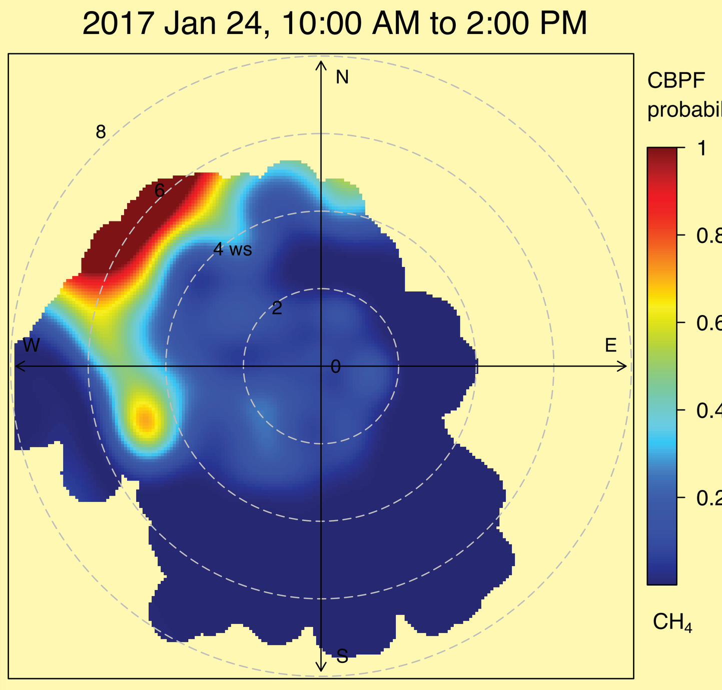
Methods
- Data
  - MySQL, RStudio
- Data Cleaning
  - Over 1.7 million data pts/day
  - Erroneous, negative values
  - Wind direction & speed calculations
- Summary Statistics
  - Descriptive statistics
  - Hourly, daily, weekly trends (box plots)
  - Time series
  - Wind speed variance
- Wind Rose Diagram
  - Circular histogram

Caveats
- Data quality/accuracy is highly dependent on
  - Requires at least two concurrent eddy covariance systems for accurate source location identification
  - Data volume (weeks/months of data is necessary to reduce statistical noise)
  - Wind speed and direction (variability is preferred to maximize source input)
  - Currently, data reduction is time-consuming and requires human analysis. Machine Learning is being investigated as an option for "big data" analyses of eddy covariance deployments

Conditional Bivariate Polar Function plots for methane (right) for two days in January 2017 from southern-most tower deployment (blue circle), showing strong correlations to known CH_4 sources. The top plot shows results from January 24 during the lunch hour when methane is known to be released from exhaust vent. The bottom plot shows results from Jan 26 during the evening hour when the exhaust vent is not emitting CH_4, but when methane-powered buses are known to be idling in passenger pickup areas.



2017 Jan 24, 10:00 AM to 2:00 PM



2017 Jan 26, 8:00 PM to 12:00 AM