OPEN-PATH MEASUREMENTS OF CH_4 FLUX USING EDDY COVARIANCE TECHNIQUE

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INTRODUCTION

Methane is one of the most important greenhouse gases, and has a warming potential about 23 times that of CO_2 over 100-year cycle (Houghton *et al.*, 2001).

Prior measurements of CH_4 fluxes have mostly been made with chamber techniques, and with Eddy Covariance approach using closed-path analyzers.

Both chambers and closed-path analyzers have their advantages. However, chamber measurements are discrete in time and space, may disturb soil surface integrity and atmospheric pressure, and often are labor-intensive.

Present closed-path analyzers work under significantly reduced pressures, and require powerful pumps and grid power. Long intake tubes lead to frequency losses.

Power and labor demands may be reasons why CH_4 flux is often measured at locations with good infrastructure and grid power, and not with high CH_4 production.

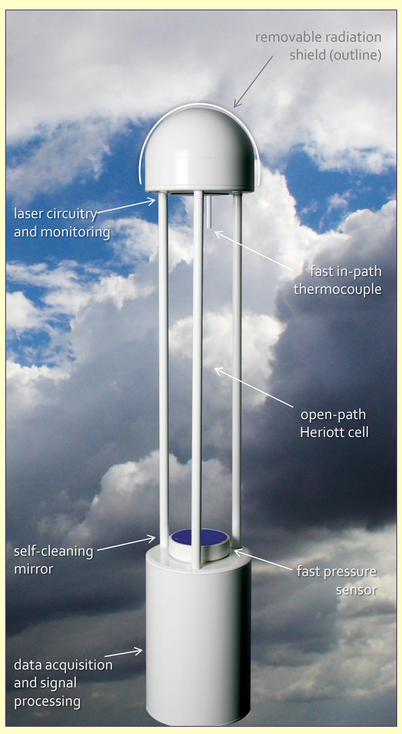
Open-path measurements could provide significant advantages for CH_4 flux research:

- **remote solar-powered deployment due to low power demand**
- **portable or mobile deployments due to light weight**
- **undisturbed *in-situ* spatially integrated flux measurements**
- **zero frequency response errors from tube attenuation**
- **confident WPL terms from co-located standard fast measurements**
- **can measure at locations of interest regardless of available infrastructure**

INSTRUMENT

The LI-7700 fast open-path methane analyzer uses TDLS (tunable diode laser spectroscopy) technology that employs a VCSEL (vertical-cavity surface-emitting laser) and an open multi-pass cell design.

CH_4 is measured with a RMS noise below 5 ppb at 10 Hz sampling in controlled laboratory conditions.



LI-7700 can provide outputs with frequencies up to 40 Hz.

In addition to CH_4 density, the air temperature in sampling path and fast air pressure are also output.

Four fast auxiliary input channels are available for sonic anemometer outputs or for any other desired fast or slow data.

Seven additional fast channels and USB data logging are available with an optional analyzer interface unit.

Field maintenance is minimized by a fully-programmable self-cleaning mechanism for the lower mirror.

Dew formation on both mirrors solved by fully programmable heaters.

Radiation shield is provided to minimize condensation and power consumption.

The stand-alone power consumption of LI-7700 is <10 Watts in steady-state, and 12 Watts during warm-up.

Field maintenance is minimized by self-cleaning lower mirror to help keep it contamination-free

EXPERIMENTS

Eddy Covariance measurements of CH_4 flux using the four prototypes of open-path methane analyzer were conducted in 2006-2009 during nine deployments in five ecosystems with contrasting weather, moisture and CH_4 production:

- Fluxes over short-hydroperiod sawgrass wetland in Florida Everglades were measured in warm and humid conditions with temperatures often exceeding 25°C
- Experiments in an arctic tundra described fluxes over coastal wetlands with frequent sub-zero temperatures, mist, and moderate winds
- Winter. Spring, and summer experiments over bare and maize agricultural fields, and over ryegrass in Nebraska tested zero-flux measurements and computations in wide range of conditions
- Deployment over pacific mangroves in Mexico examined fluxes measured in conditions of high winds, sea spray, and moderate air temperatures

Florida and Nebraska experiments were conducted using portable light tower setup, with solar panel providing power in Florida and with grid power available in Nebraska. Tundra and mangroves experiments utilized permanent towers, and were powered by small portable generator in mangroves and larger generator in the tundra.

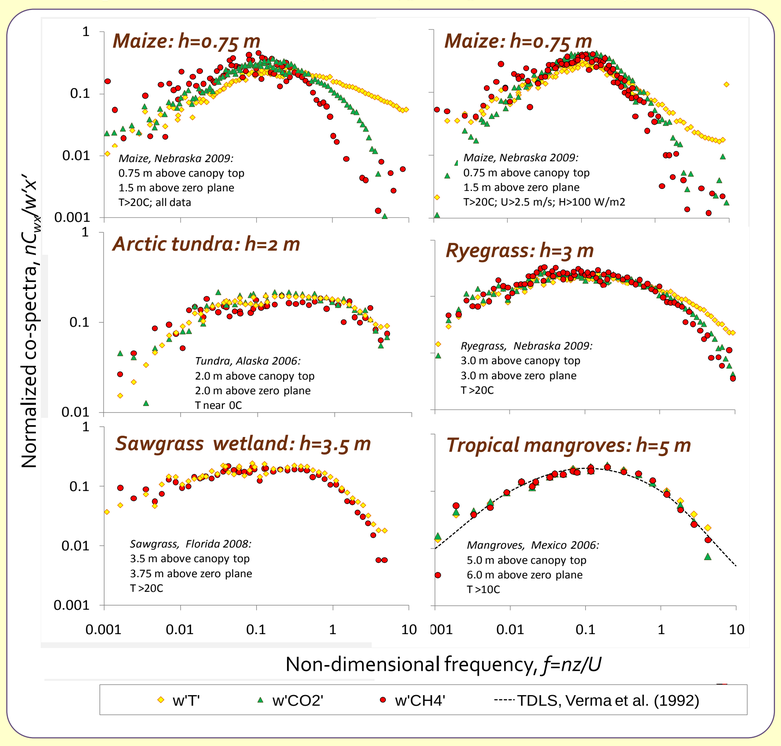
Eddy covariance flux data from a co-located open-path methane analyzer, LI-7500 and sonic anemometer were collected at a 10 Hz rate. Data were processed using EdiRe software following standard FluxNet methodology (Aubinet *et al.*, 2000).

FREQUENCY RESPONSE

Co-spectral analysis provides a powerful tool to evaluate the capability of the analyzer to detect gas fluctuations over a range of frequencies (Kaimal et al., 1972).

It is important to validate frequency response of any new sensor, open-path or closed-path, using actual field data, especially if sampling path is relatively large.

Ensemble averages of normalized midday co-spectra for the periods with sufficient wind and flux are plotted below versus non-dimensional frequency for the five contrasting ecosystems and setups, from 0.75 m to 5.0 m above canopy top.



At extremely low measurement height of 0.75 m above canopy top, there was a noticeable high frequency loss. However, with strong turbulence (U>2.5 m s^{-1} and H >100 W m^{-2}), CH_4 flux co-spectra became comparable to that of CO2 and H2O flux co-spectra from LI-7500 even at such a low height.

Co-spectral corrections for LI-7700 were still viable at this height, but such low heights are not recommended for Eddy Covariance measurements for any sensor.

In all other experiments with heights exceeding 0.75 m, CH_4 flux co-spectra behaved similar to CO_2 co-spectra from LI-7500, and was close to that of sonic temperature.

The co-spectra from the LI-7700 measurements closely followed the Kaimal model (Kaimal *et al.*, 1972), and also was in good agreement with another cospectrum from TDLS (Unisearch Associates, Inc.) over peatland (Verma *et. al.*, 1992).

At examined measurements heights above 0.75 m, the LI-7700 adequately measured CH_4 fluctuations across the whole spectrum of frequencies which contributed to turbulent transport at different surface roughness and atmospheric stabilities.

METHANE FLUXES

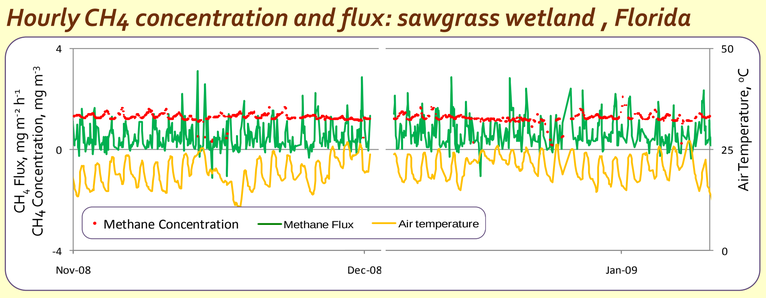
Examples of hourly CH_4 concentrations and fluxes are shown in the top two figures below.

The third figure demonstrates CH_4 emissions integrated over daytime from November, 2007, through January, 2008, in sawgrass wetland, alongside mean air temperature.

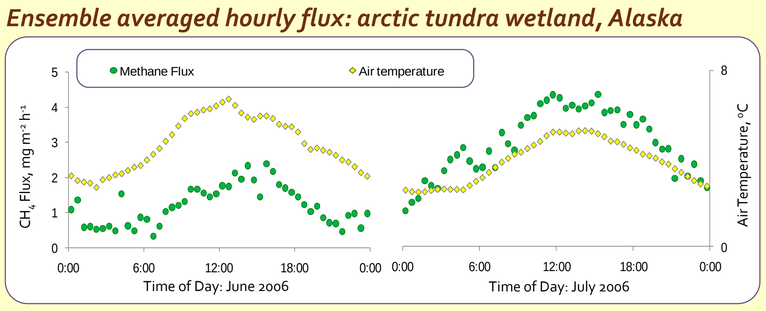
Overall, hourly CH_4 fluxes ranged from near-zero at night to 4 mg m^{-2} h^{-1} in arctic tundra (Zona *et al.*, 2008) and pacific mangroves (not shown), and to 3.5 mg m^{-2} h^{-1} in sawgrass wetland.

Observed fluxes were within the ranges reported in the literature for a number of wetlands in North America, including the Everglades wetlands in Florida (Harriss *et al.*, 1988), fen in Canada (Bubier *et al.*, 1993), peatland in Minnesota (Shurpali and Verma, 1998) and bog in Alaska (Moosavi *et al.*, 1996).

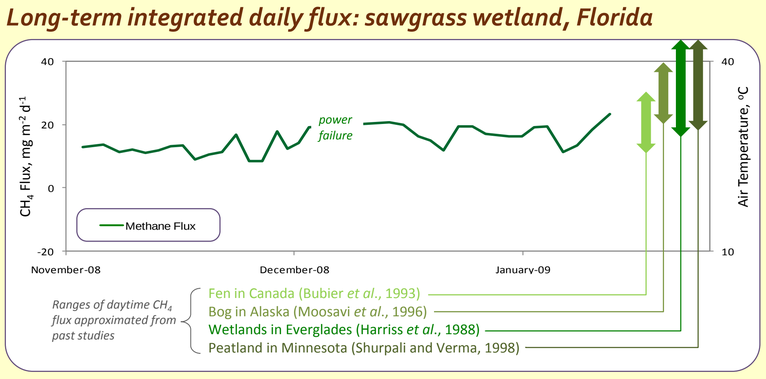
Hourly CH_4 concentration and flux: sawgrass wetland , Florida



Ensemble averaged hourly flux: arctic tundra wetland, Alaska



Long-term integrated daily flux: sawgrass wetland, Florida



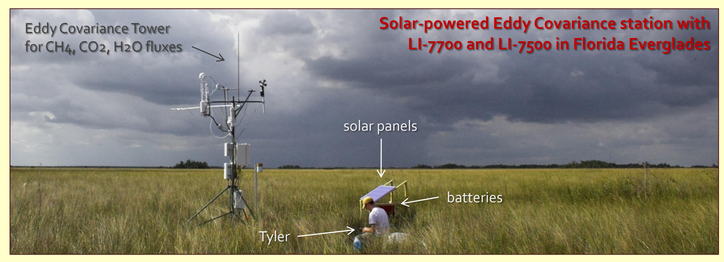
NEW OPPORTUNITIES

The stand-alone LI-7700 open-path methane analyzer requires <10 W of power.

This is 50 to 100 times below the present closed-path Eddy Covariance systems measuring methane fluxes, which also require availability of mains power grid and some type of road infrastructure for the system installation and use.

In contrast to present closed-path systems, power consumption by the whole open-path Eddy Covariance station in sawgrass wetland in Florida Everglades was about 26 Watts, including LI-7700 for CH4, LI-7500 for CO2/H2O, sonic anemometer, and air temperature/relative humidity sensors and barometer.

The 12 lbs open-path methane analyzer was carried into the wetland by one person in the backpack, along with tools, other sensors, and a laptop.



Low-power and lightweight configurations stemming from open-path design of LI-7700 provide a new and unique opportunity for measuring natural methane production and consumption where they actually occur, rather then measuring them in areas limited by available mains power grid and accessible by roads.

The areas of significant methane production and consumption, and with little available infrastructure or grid power, include remote regions of arctic and sub-arctic wetlands, boreal taiga forests, tropical mangroves, flooded plains of southeast Asia, tropical and boreal deserts and semi-deserts, *etc.*

CONCLUSIONS

- Open-path measurements of CH_4 flux using Eddy Covariance approach were conducted in seven experiments in four contrasting ecosystems
- The shape of CH_4 flux co-spectra was generally similar to those of CO_2 and H_2O from LI-7500, close to sonic sensible heat co-spectra, and to a theoretical curve from Kaimal model
- Methane concentration ranged 1.1-1.7 mg m^{-3}, with hourly variations close to those observed in similar ecosystems, and with nighttime build-ups at low winds
- Hourly fluxes ranged from near-zero at night to about 4 mg m^{-2} h^{-1} at midday in the arctic tundra
- Diurnal patterns were similar to those measured by closed-path sensors (Kim *et al.*, 1998; Hendriks *et al.*; *etc.)*
- LI-7700 open-path methane analyzer is a valuable tool for measuring long-term CH_4 fluxes in a wide range of ecosystems

Setting up Eddy Covariance station with LI-7700 and LI-7500 in pacific mangroves, powered by portable generator

- **LI-7700 enables long-term deployment of permanent, portable or mobile CH_4 flux stations at remote locations with high CH_4 production or consumption, because it is lightweight and can be powered by a solar panels or a small generator**

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