NEW CO_2 AND H_2O GAS ANALYZER DESIGN COMBINES OPEN-PATH AND CLOSED-PATH ADVANTAGES

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INTRODUCTION

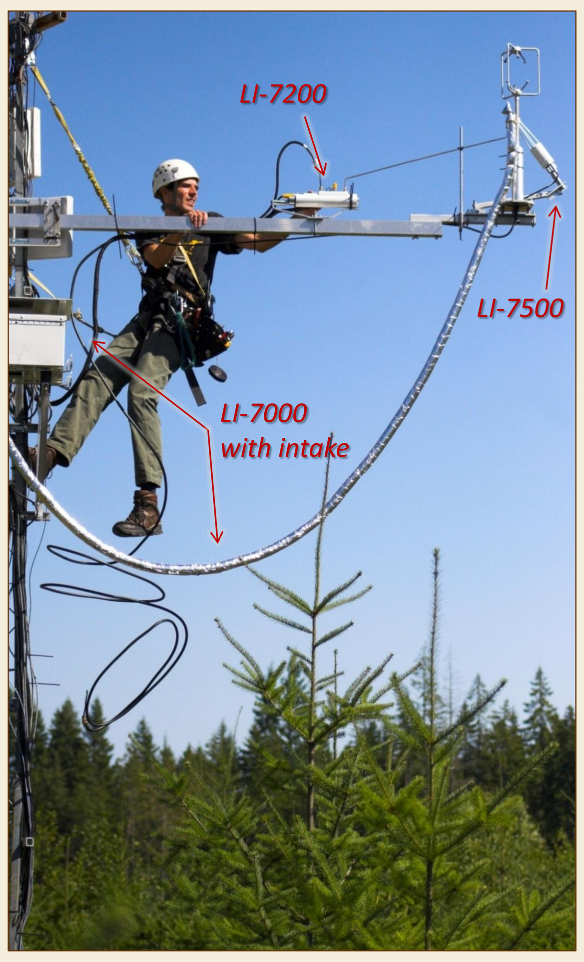
Open-path and closed-path designs of gas analyzers are well-established and widely used to measure concentrations and fluxes of CO_2 and H_2O (Lee *et al.*, 2004). Both designs have their advantages and deficiencies.

Open-path analyzers (*e.g.*, LI-7500) have excellent frequency response and long-term stability, low sensitivity to window contamination, are pump-free, and require infrequent calibrations. Yet they are susceptible to data loss during precipitation and icing-over, and some may need surface heat flux correction when used in cold conditions (Burba *et al.*, 2008).

Closed-path analyzers (*e.g.*, LI-7000) can collect data during precipitation, can be climate-controlled, and are not susceptible to surface heating issues. Yet they experience significant frequency loss in long intake tubes, especially so for H_2O flux, and may require frequent calibrations and a powerful pump.

Here we present field test results from a third type of an instrument: compact enclosed gas analyzer, enabled for operation with short intake tube, and intended to maximize strengths and minimize weaknesses of both traditional open-path and closed-path designs.

INSTRUMENT DESCRIPTION

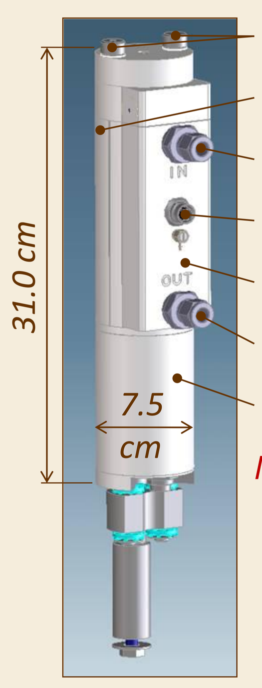


The LI-7200 is fast CO_2/H_2O analyzer enabled for operation with short intake tubes. Fast air temperatures and air pressure are measured in the cell .

Low sensitivity to contamination allows measurements without an intake filter for months at a time before cleaning is needed.

Tool-free cleanable cell configuration enables easy on-tower cell inspection and cleaning.

Four prototypes were tested in three experiments for a wide range of weather over two contrasting ecosystems during 2006 - 2009.



- *Lock screws:* hold cell in place when sampling
- *Removable cell:* plugs out-in for easy cleaning
- *Cell inlet:* can be used with short or long intake
- *Cable plug:* weather-proof, over 5 m long
- *In-cell fast T and P measurements block*
- *Cell outlet:* to pump or fan with or w/o buffer
- *Coupled metal body:* keeps cell warm and stable

Inside the cell:

- sampling cell is 12.7x1.3 cm = 16.0 cm³ volume
- fast T is on inlet and outlet, fast P is in the middle
- cell walls are made of PVC to minimize T gradient
- cell has low sensitivity to dirt, same as LI-7500

In this study, LI-7500 was used as a standard for CO_2 and H_2O concentrations, for H_2O flux, and for CO_2 and H_2O frequency response. LI-7000 was used as a standard for CO_2 fluxes. All flux data were collected at 10 Hz rate, and processed using standard FluxNet methodology after Aubinet *et al.* (2000).

WEBB-PEARMAN-LEUNING TERMS

Traditional density outputs are available in LI-7200, and can be used for applying WPL terms to half-hourly or hourly fluxes (Webb et al., 1980):

$$Fc = Fc_o + \mu \frac{E}{\rho_d} \frac{q_c}{1+\mu \frac{\rho_v}{\rho_d}} + \frac{H}{\rho C_p} \frac{q_c}{T_a} + 0$$

Dilution Term: E is computed from water vapor density measured in the cell simultaneously with CO2

Thermal Expansion Term: H in the cell is below 10% of ambient due to 1 m intake; remainder can be computed from in-cell fast temperatures

Pressure Expansion Term: it is usually neglected, but can be computed from fast measurements in the cell

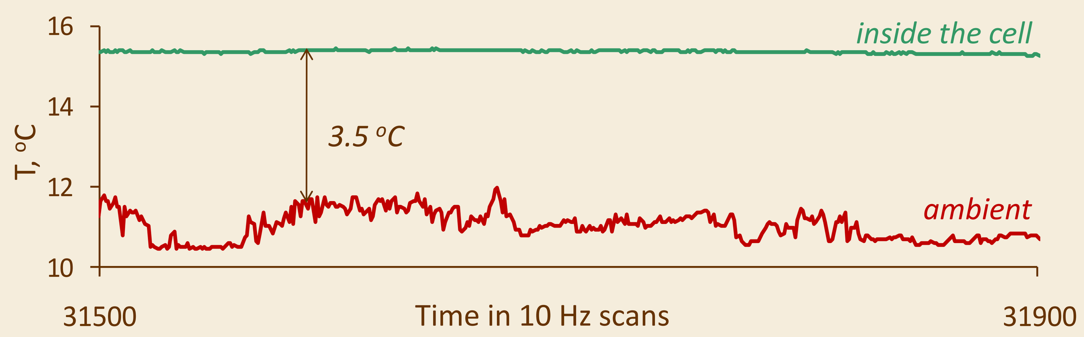
Fc – final corrected flux; Fc_o – uncorrected flux; E – evapotranspiration; H – sensible heat flux; q_c – mean CO_2 density; ρ_d – dry air density; ρ_v – H_2O vapor density; ρ – total air density; C_p – specific heat; T_a – air temperature in K ; μ – ratio of mol. masses of air to water

The LI-7200 is also capable of fast output of mixing ratios, corrected for dilution and expansion using instantaneous water, temperature and pressure measurements, so that no WPL terms are required. However, this approach was not field-tested yet, and no related data are shown.

FAST T AND P IN THE CELL

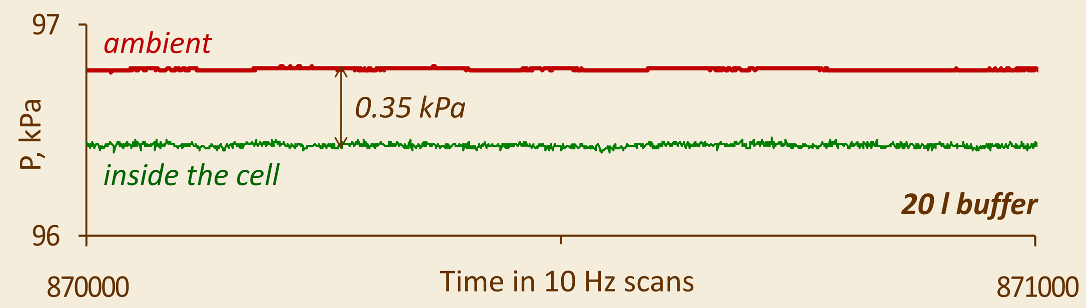
Daytime air temperature inside the LI-7200 sampling cell (typical example below) was several degrees warmer than ambient air due to solar load and internal electronics, purposely coupled to the cell to prevent condensation.

Instantaneous fluctuations were attenuated, on average, by about 85-90% with 0.5 m intake tube, and by about 90-95% with 1 m intake tube. The remainder was measured directly, eliminating open-path heating issues.



Cell air pressure was about 0.35 kPa below the ambient. Such small pressure drop was observed at 14 lpm flow, with 0.5 and 1 m intakes without filter.

Fluctuations in instantaneous cell air pressure were about 0.1 kPa without buffer volume, and were reduced to 0.02 kPa, nearly to ambient, with use of 20 l buffer downstream from the cell (typical example below).

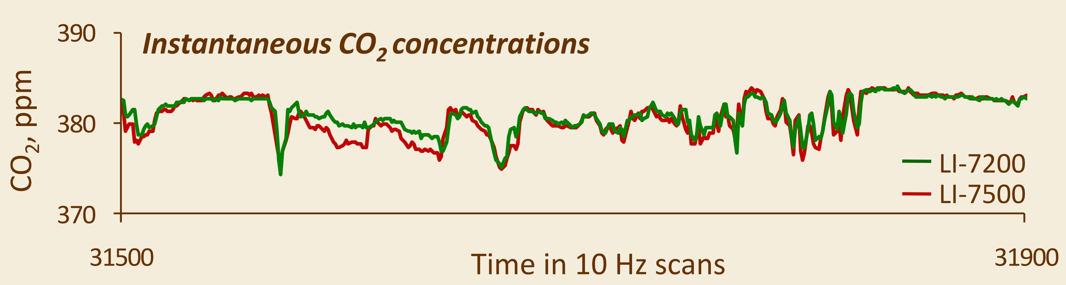


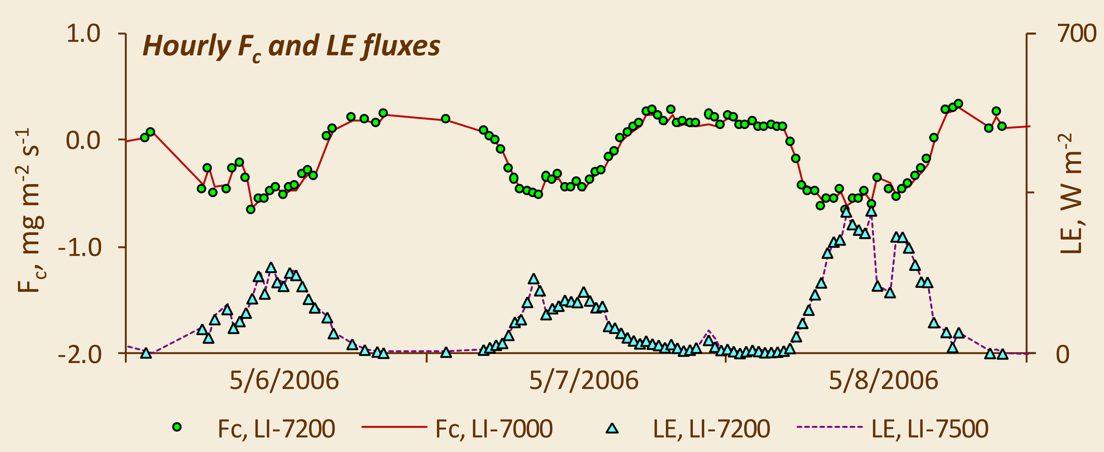
CONCENTRATIONS AND FLUXES

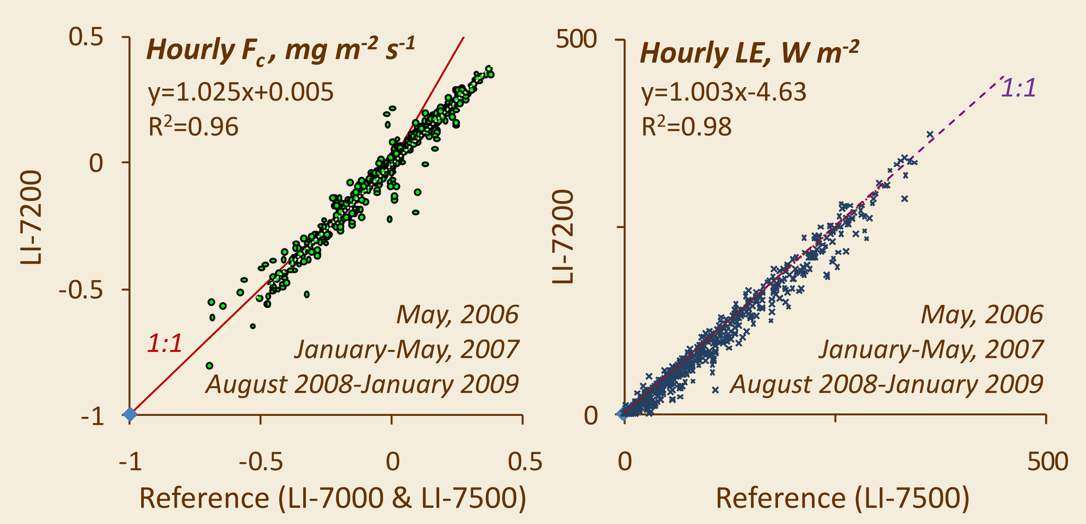
Typical examples of CO_2 concentrations and fluxes, F_c, and hourly H_2O fluxes, LE, for sample days and for the entire duration of the experiments (*e.g.*, ryegrass field in Nebraska, and wetland in Florida) are shown in figures below.

Instantaneous 10 Hz concentration values in ryegrass field experiment were within 2 ppm, and mostly within 1 ppm, of standard LI-7500, resulting in mean concentrations being within fraction of 1% from the standard LI-7500.

Hourly CO_2 and H_2O fluxes were within 2.5% of the standards (LI-7000 and LI-7500, respectively) in all experiments after appropriate corrections applied. The observed 2.5% difference was not statistically significant, for P<0.05.







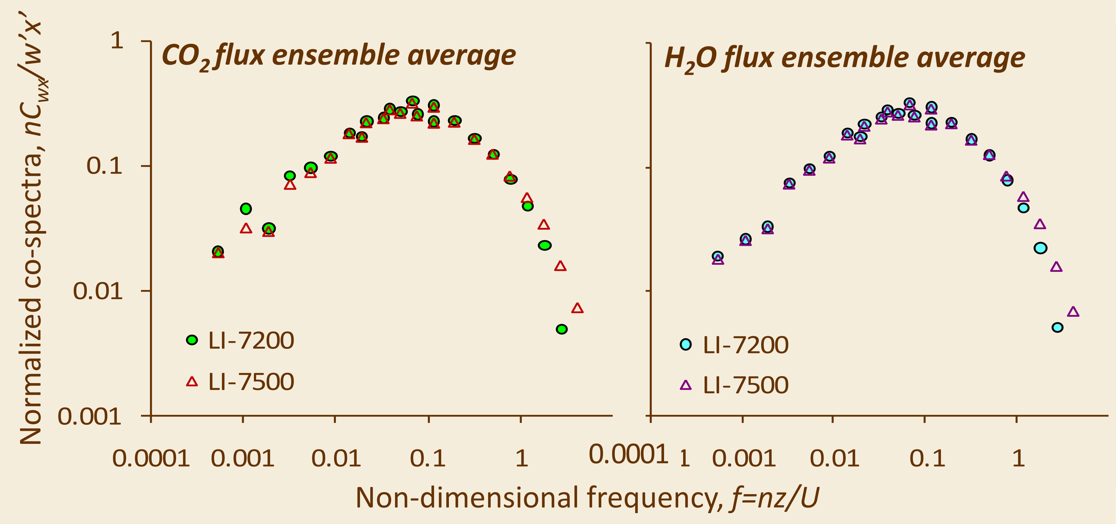
LOW POWER DEMAND

Fast T and P measured inside the cell and low sensitivity to window contamination allowed for short intake tube (0.5-1.5 m or less) with or w/o intake filter, leading to low power demand for the pump and entire system.

The optional Flow Module requires about 15 W to provide 15 lpm flow, including pump, flow control, and output circuitry. Demand could be reduced further, to about 7-10 Watts, by using a fan without flow control. Total system power demand, including LI-7200, then would be 17-30 W, making it comparable to open-path analyzers, and considerably less than power required by traditional closed-path systems (about 60-100 W).

FLUX CO-SPECTRA

Frequency loss of LI-7200 (typical example of the flux co-spectra shown below) was small, but slightly higher than that of LI-7500 (on average, 12% *vs.* 8% for 0.5 intake, 13% *vs.* 9% for 1 m intake) as expected due to some high frequency attenuation by a short intake. For comparison, frequency loss for LI-7000 with 4.5m intake was between 15 and 30%.



FIELD DATA LOSS

Flux data loss over duration of all experiments was at about 7-8% for open-path LI-7500 mostly due to precipitation (75% loss during rain; table below). For the same period, losses from closed-path LI-7000 were less than 1%. Only periods with functioning sonic anemometer and u*>0.1 were considered.

LI-7200 data loss was close to that of LI-7000, but with power and maintenance requirements close to those of LI-7500, and substantially below those of LI-7000.

CO_2 flux	LI-7500	LI-7000	LI-7200
Total for all experiments	8%	<1%	<1%
During precipitation	75%	0%	0%
H_2O flux			
Total for all experiments	7%	<1%	<1%
During precipitation	75%	0%	0%

SUMMARY AND CONCLUSIONS

Three field experiments with four LI-7200 prototypes demonstrated that the short-tube-enabled analyzer design, with fast T and P measured in the cell, utilizes strengths of both closed-path and open-path designs at the same time.

LI-7200 has following advantages, similar to closed-path analyzers:

- minimal data loss due to precipitation and icing (similar to LI-7000)
- no surface heating issues (similar to LI-7000)
- improved water specs due to absence of solar filter

and it has following advantages, similar to open-path analyzers:

- small and easily correctable flux attenuation loss in short intake
- infrequent calibration requirements (similar to LI-7500)
- minimum maintenance requirements (similar to LI-7500)
- low power configuration when used with short intake tube
- small size, light weight, and weather-proof design

Note on intake tube length:

- optimum for most applications is 0.5 to 1.0 m (Clement *et al.*, 2008)
- shorter: less temperature attenuation, difficult to mount near sonic
- longer: more water flux attenuation, stronger pump is needed
- LI-7200 works with intakes of a few centimeters to dozens of meters

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