Instrument-induced biases in open-path CO$_2$ flux measurements

I. Bogoev$^1$, M. Helbig$^2$, O. Sonnentag$^2$, K. Wischnewski$^2$

$^1$Campbell Scientific, Inc., UT, USA, $^2$Université de Montréal, QC, Canada

16-19 November, 2015. Hobart, Australia
Sensor-specific uncertainties affect inter-site comparability

Different designs, geometries, shapes, performance, strengths, weaknesses, limitations
Open-path, co-located, separated, horizontally symmetrical, omnidirectional
Motivation for this study: is it feasible to measure CO$_2$ flux with open path sensors?

- Systematic biases in CO$_2$ fluxes measured by open- and closed-path analyzers (Norunda?)
- Open-path systems measure more negative daytime uptake during cold season
- Ecologically unreasonable observations of net ecosystem exchange with open-path analyzers

Motivation for this study (continued)

- Instrument-induced surface heating issues in cold climates
  Grelle et al., (2007)

- Semi-empirical, site- and orientation-specific correction
  Burba et al., (2008)

- Is surface heating affecting other open-path gas analyzers?
Challenges of open-path CO$_2$ flux measurements

\[ F_c = \rho_d w' X_c' \]

\[ F_c = \overline{w' \rho_c'} + \mu \frac{\rho_c}{\rho_d} \overline{w' \rho_v'} + (1 + \mu \frac{\rho_v}{\rho_d}) \frac{\rho_c}{T_a} \overline{w'T_a'} \]

- The **WPL** terms should accurately represent the conditions in the **sensing path** of the gas analyzer.
- The **magnitude of the interferences** ($T'$ and $\rho_v'$) is large especially temperature!
- All sensors need to have **adequate and similar frequency response** to capture the fast fluctuations of $T_a$, $w$, $\rho_v$ and $\rho_c$. 
Challenges of open-path CO$_2$ flux measurements

\[ F_c = \rho_d w' X_c' \]

\[ F_c = \overline{w' \rho_c'} + \mu \frac{\rho_c}{\rho_d} \overline{w' \rho_v'} + (1 + \mu \frac{\rho_v}{\rho_d}) \frac{\rho_c}{T_a} \overline{w'T_a'} \]

- To preserve the covariance all measurements need to be well **synchronized in time and space**
- Increased requirements for **absolute accuracy** of $T_a$, $\rho_v$, $\rho_d$ and $\rho_c$ measurements
Challenges of open-path CO$_2$ flux measurements

\[
F_c = \rho_d w' X_c'
\]

\[
F_c = \bar{w}' \rho_c' + \mu \frac{\rho_c}{\rho_d} \bar{w}' \rho_v' + (1 + \mu \frac{\rho_v}{\rho_d}) \frac{\rho_c}{T_a} \bar{w}' T_a'
\]

- The sensor is in-situ and exposed to the elements
- Adverse effects of weather (rain, snow, dust, condensation, solar radiation) can change the calibration
- Large range of ambient temperatures can cause calibration drifts
Why would you use an open-path CO$_2$ flux system?

- Simple and reliable (no pump, no filter, no tubing)
- Good frequency response (no tube delays, minimal spectral attenuation)
- Low power (<6W)
Winter time CO$_2$ flux measurements over snow-covered surface

- Air temperature in the gas-analyzer sensing path same as the CSTA3
- Similar sensible heat flux measured with the IRGASON and the CSTA3
- No apparent CO$_2$ uptake observed

Bogoev, EGU (2014)
Is instrument surface heating a problem?

- Air temperature in the gas-analyzer sensing path same as the CSTA3
- Similar sensible heat flux measured with the IRGASON and the CSTA3

Picture by Manuel Helbig at Scotty Creek
The tale of two nearby flux sites at Scotty Creek watershed

by Manuel Helbig and Oliver Sonnentag

Site A – Forested peat plateaus landscape
Site B – Bog peatland
Winter time apparent CO$_2$ uptake observed at the forested peatland site

- Identical open-path sensors at both sites
- But different **sensible heat** regimes due to differences in the surface albedo (0.75-0.9 for fresh snow, 0.15-0.3 conifer forest with snow)
Comparison of CO$_2$ mixing ratios and fluxes measured by open- and closed-path gas analyzer

During periods with significant **sensible heat:**

- IRGASON measures increased CO$_2$ variance compared to the CPEC200
- IRGASON measures more CO$_2$ uptake
Comparison of CO$_2$ fluxes measured by open- and closed-path gas analyzer
Comparison of CO$_2$ spectra measured by open- and closed-path gas analyzer

Power Spectrum of CO$_2$

IRGASON CO$_2$ measurements converted to mixing ratio using humidity corrected sonic temperature

OK

?
Inadequate correction for fast temperature related spectroscopic effects?
Spectroscopic effects (for Campbell analyzers)

\[ A = \frac{N}{(\Delta \nu)} \int_{v_1}^{v_2} \left\{ 1 - \exp \left( -\frac{S_i \alpha_i c L}{\pi [(v - v_0)^2 + \alpha_i^2]} \right) \right\} dv \]

- \( A \) = Absorbed light energy in the spectral interval
- \( N \) = Number of absorption lines in the spectral interval
- \( \nu \) = Wave number of the individual spectral line
- \( c \) = Density of the absorbing gas
- \( L \) = Path length
- \( S_i \) = Strength of the individual line
- \( \alpha_i \) = Half-width of the individual line

\[ \alpha(P, T) = \alpha_0 \frac{P}{P_0} \left( \frac{T_0}{T} \right)^{1/2} \]

- \( \alpha(P, T) \) = Absorption coefficient
- \( \alpha_0 \) = Absorption coefficient at reference conditions
- \( P \) = Barometric pressure
- \( T \) = Air temperature
- \( P_0 \) = Barometric pressure at reference conditions
- \( T_0 \) = Air temperature at reference conditions

Jamieson et al. (1963)

Fast-response air-temperature measurement

Slow-response air-temperature measurement
Results of using fast-response air-temperature in the conversion of absorption into CO$_2$ density

\[ \Delta = -0.0035314 \times H_s + 0.06371 \]

\[ \Delta = -0.014257 \times H_s + 0.066828 \]
Cumulative flux results (Scotty Creek)
Conclusions:

- Systematic biases in CO$_2$ fluxes measured with open-path analyzers can be minimized by using fast air-temperature for the spectroscopic corrections.
- No need for instrument self-heating corrections (IRGASON and EC150).
- Measuring CO$_2$ fluxes with open-path analyzers is feasible.
THANK YOU