Instrument-induced biases in open-path CO_2 flux measurements

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Sensor-specific uncertainties affect inter-site comparability

Different designs,
geometries,
shapes,
performance,
strengths,
weaknesses,
limitations

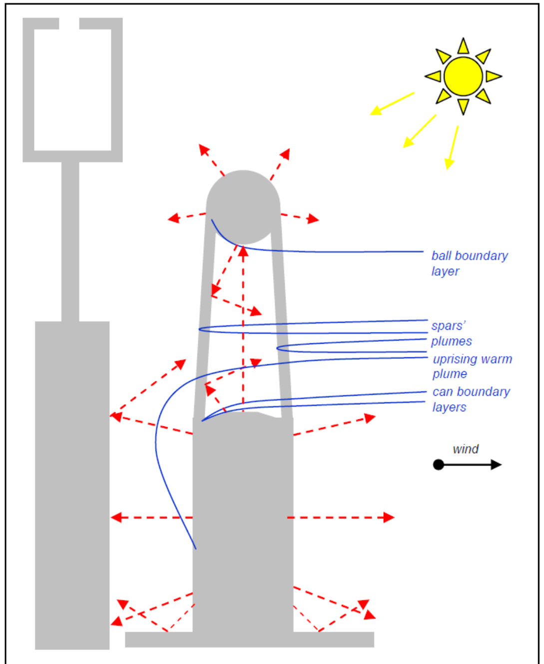
Open-path,
co-located,
separated,
horizontally
symmetrical,
omnidirectional

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

Amiro, (2006); *Hirata et al.*, (2007); *Ono et al.*, (2008); *Amiro*, (2010); *Hommeltenberget al.*, (2014)

Motivation for this study (continued)



In blue – flow patterns of warmed air (boundary layers & wakes)
In dotted red – thermal heat dissipation (longwave)

Burba et al./ AMS (2006)

- 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

$$F_c = \rho_d \overline{w'X_c'}$$

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

- 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, ρ_v *and* ρ_c

Challenges of open-path CO_2 flux measurements

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- To preserve the covariance all measurements need to be well **synchronized in time and space**
- Increased requirements for **absolute accuracy** of T_a, ρ_v, ρ_d *and* ρ_c measurements

Challenges of open-path CO_2 flux measurements

$$F_c = \rho_d \overline{w'X_c'}$$

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- 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)

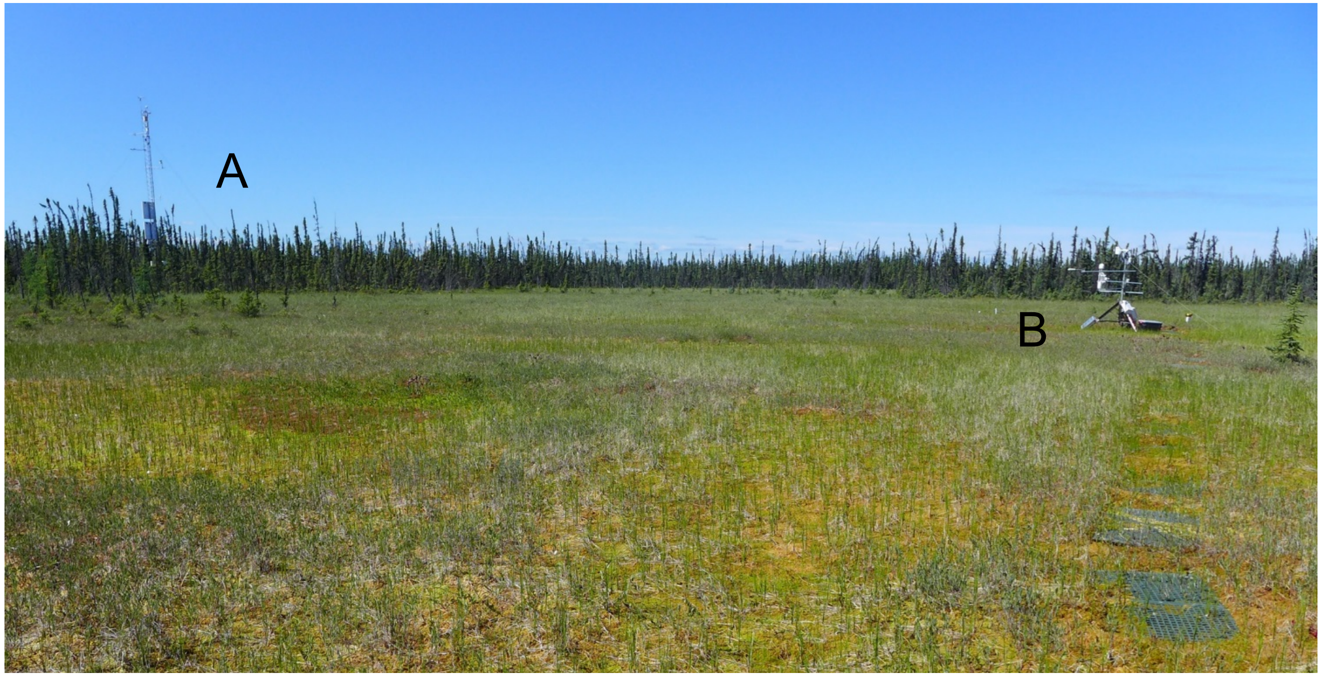
Is instrument surface heating a problem?

- 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

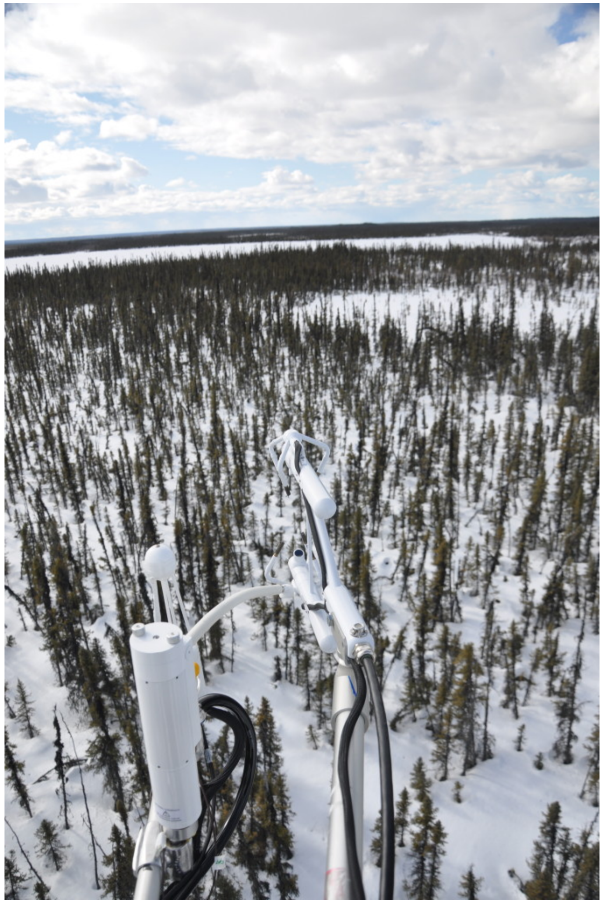
by Manuel Helbig and Oliver Sonnentag



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)

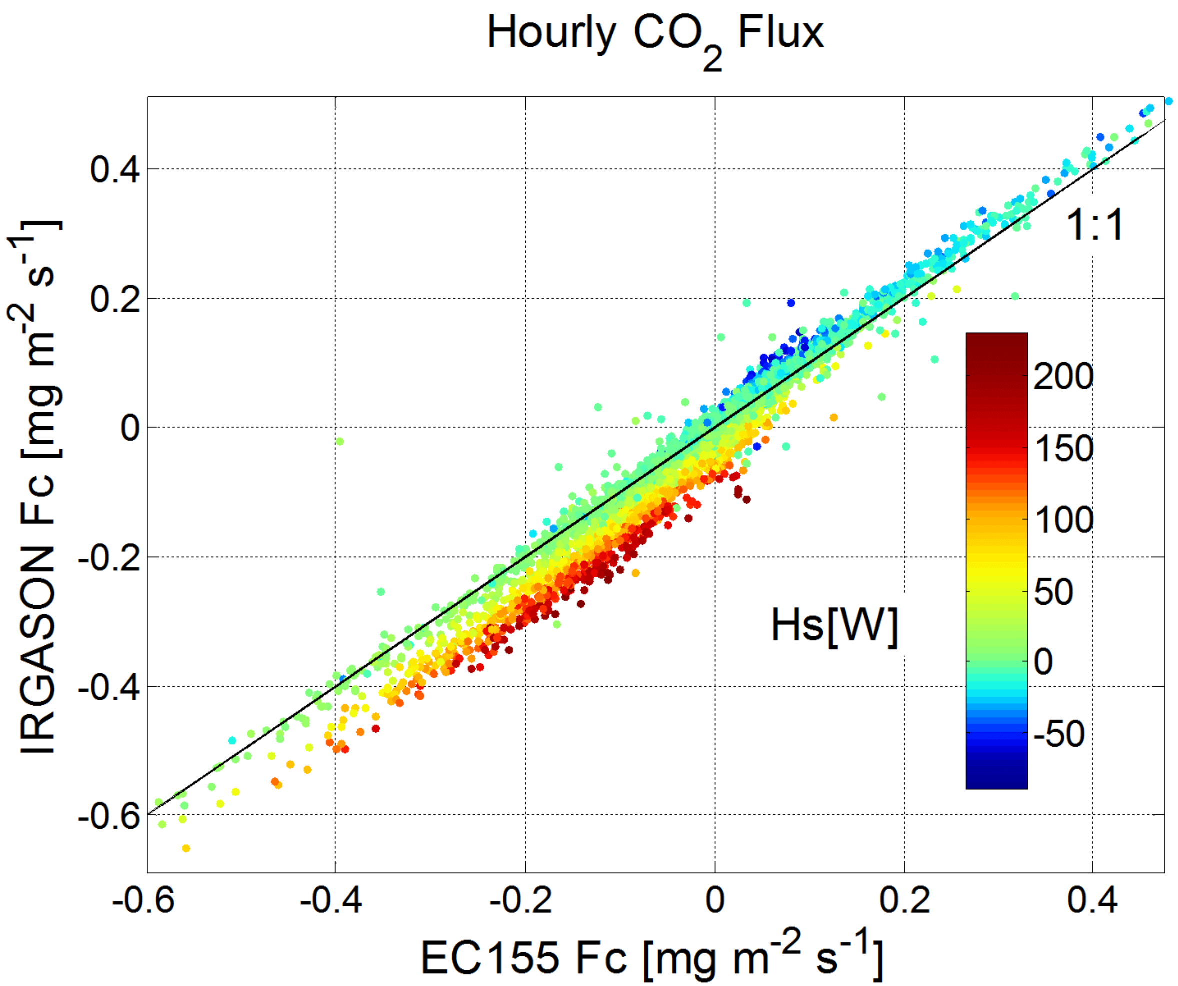


Comparison of CO_2 mixing ratios and fluxes measured by open- and closed-path gas analyzer

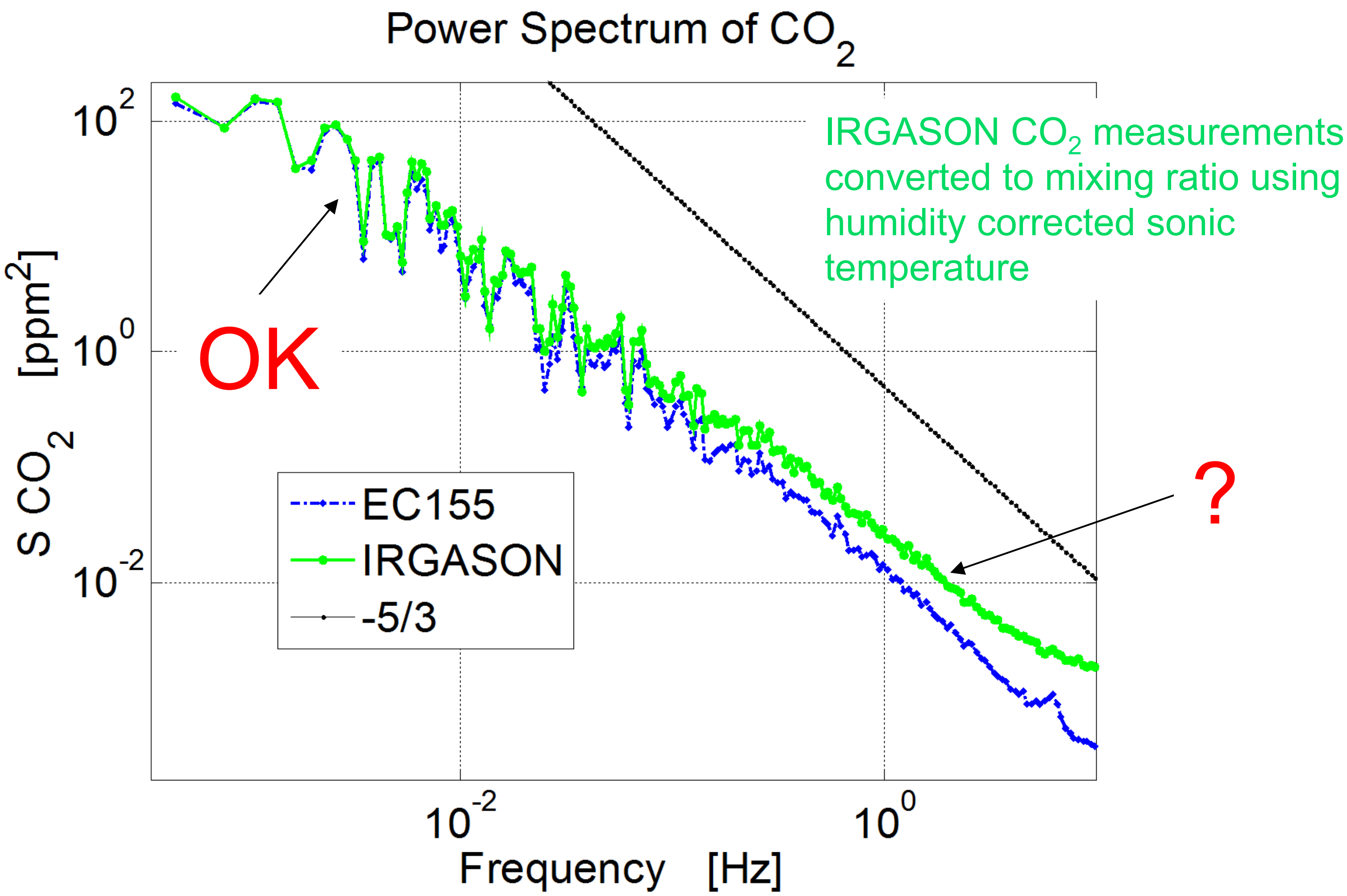
During periods with significant **sensible heat:**

- IRGASON measures increased CO_2 variance compared to the CPEC200
- IRGASON measures more CO_2 uptake

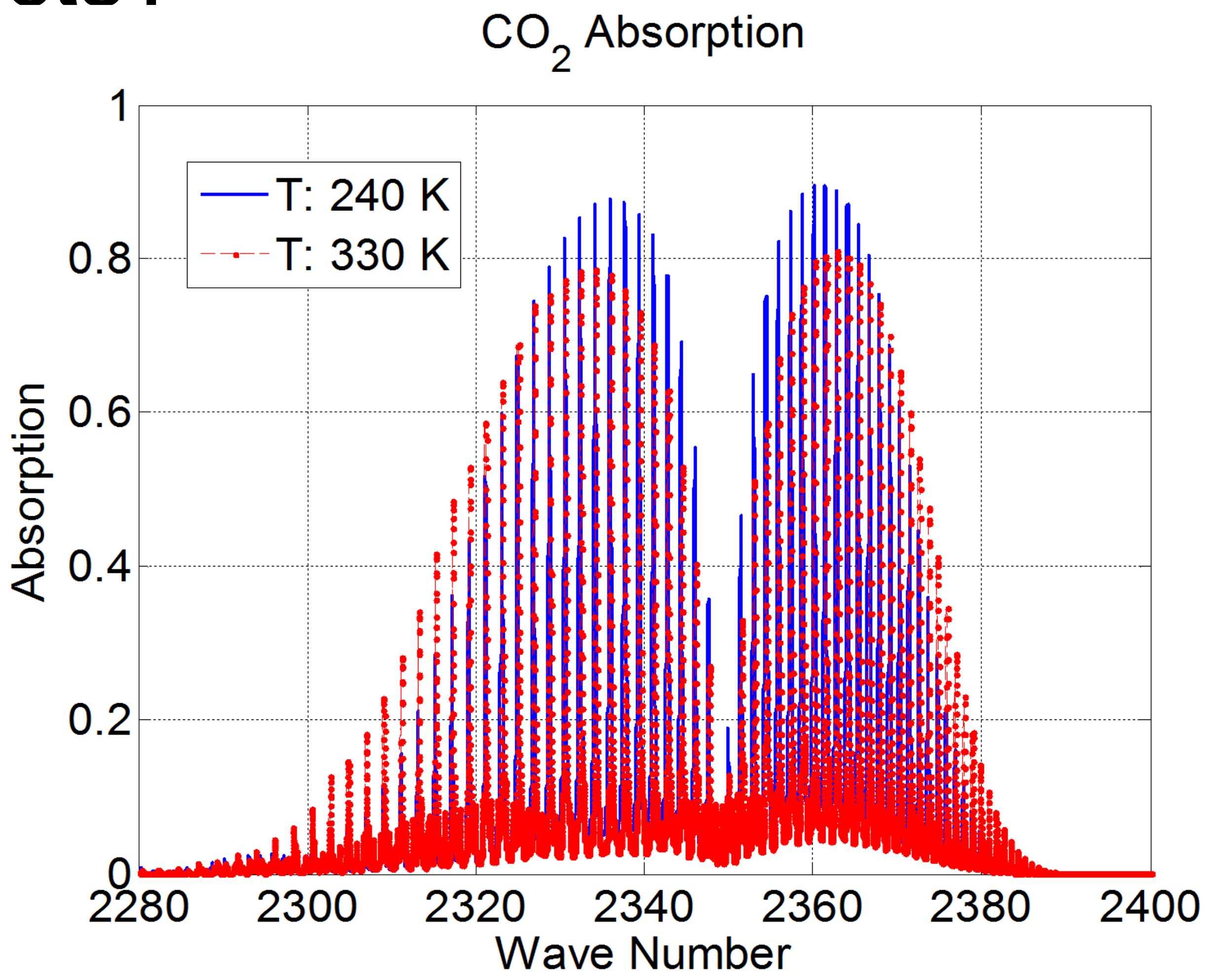
Comparison of CO_2 fluxes measured by open- and closed-path gas analyzer



Comparison of CO_2 spectra measured by open- and closed-path gas analyzer



Inadequate correction for fast temperature related spectroscopic effects?



Spectroscopic effects (for Campbell analyzers)

$$A = \frac{N}{(\Delta\nu)} \int_{\nu_1}^{\nu_2} \left\{ 1 - \exp\left(- \frac{S_i \alpha_i c L}{\pi\left[(\nu - \nu_0)^2 + \alpha_i^2 \right]} \right) \right\} d\nu$$

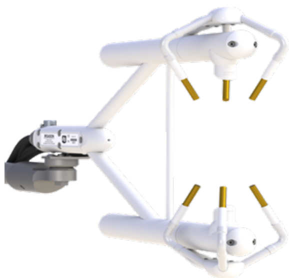
A = Absorbed light energy in the spectral interval
N = Number of absorption lines in the spectral interval
v = Wave number of the individual spectral line
c = Density of the absorbing gas
L = Path length
S_i = Strength of the individual line
α_i = Half-width of the individual line

$\boldsymbol{S_i = f(T,P)}$ $\boldsymbol{\alpha_i = f(T,P)}$

T = Air temperature, P = barometric pressure

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

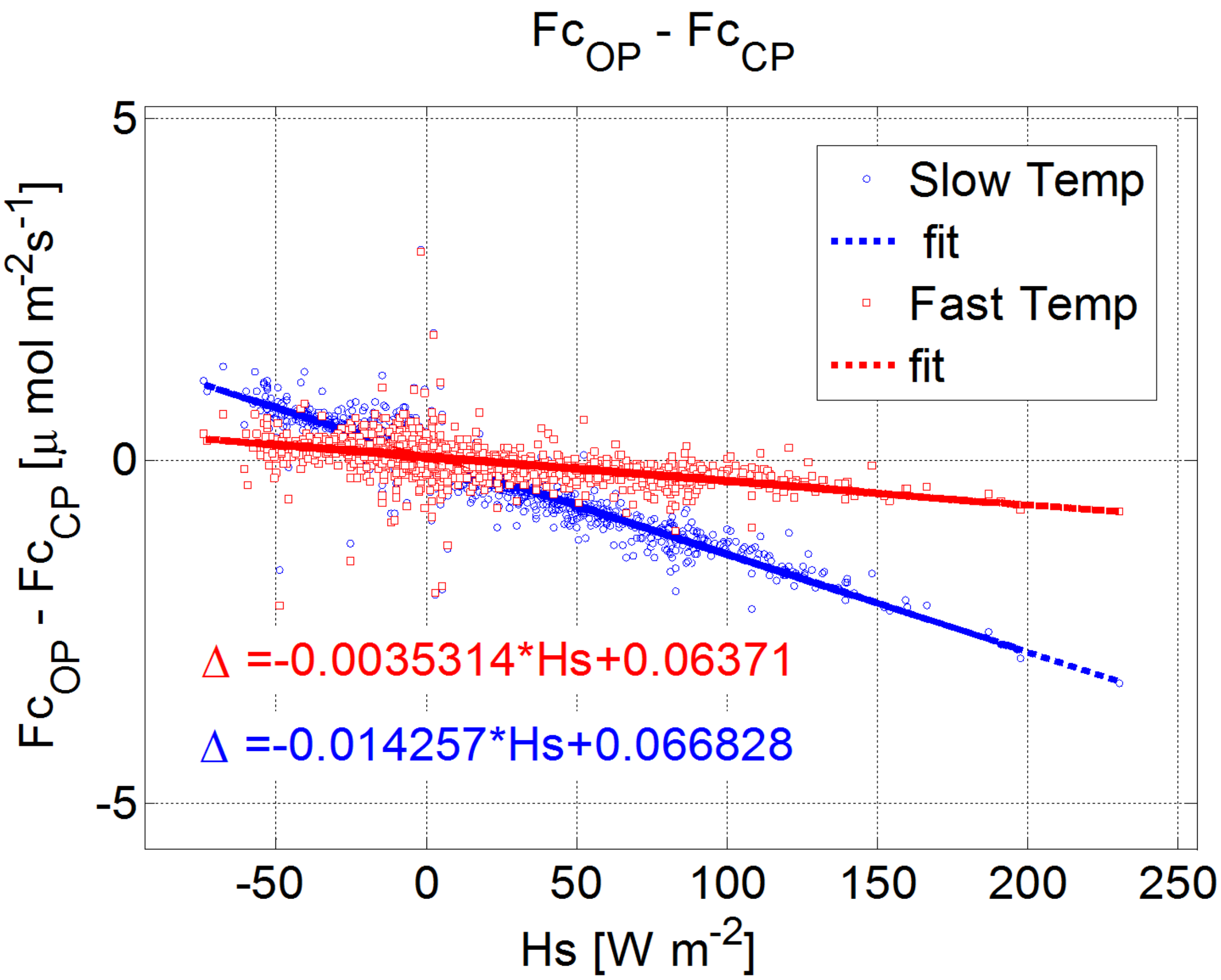
Jamieson et al. (1963)

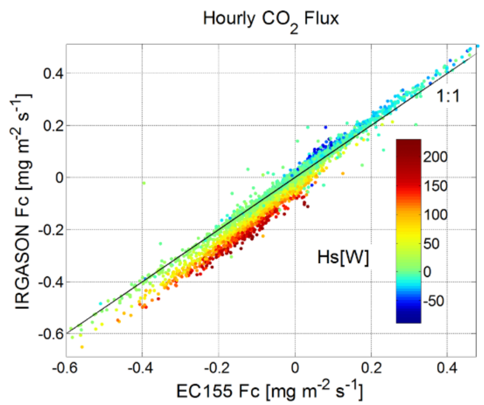


Fast-response air-temperature measurement

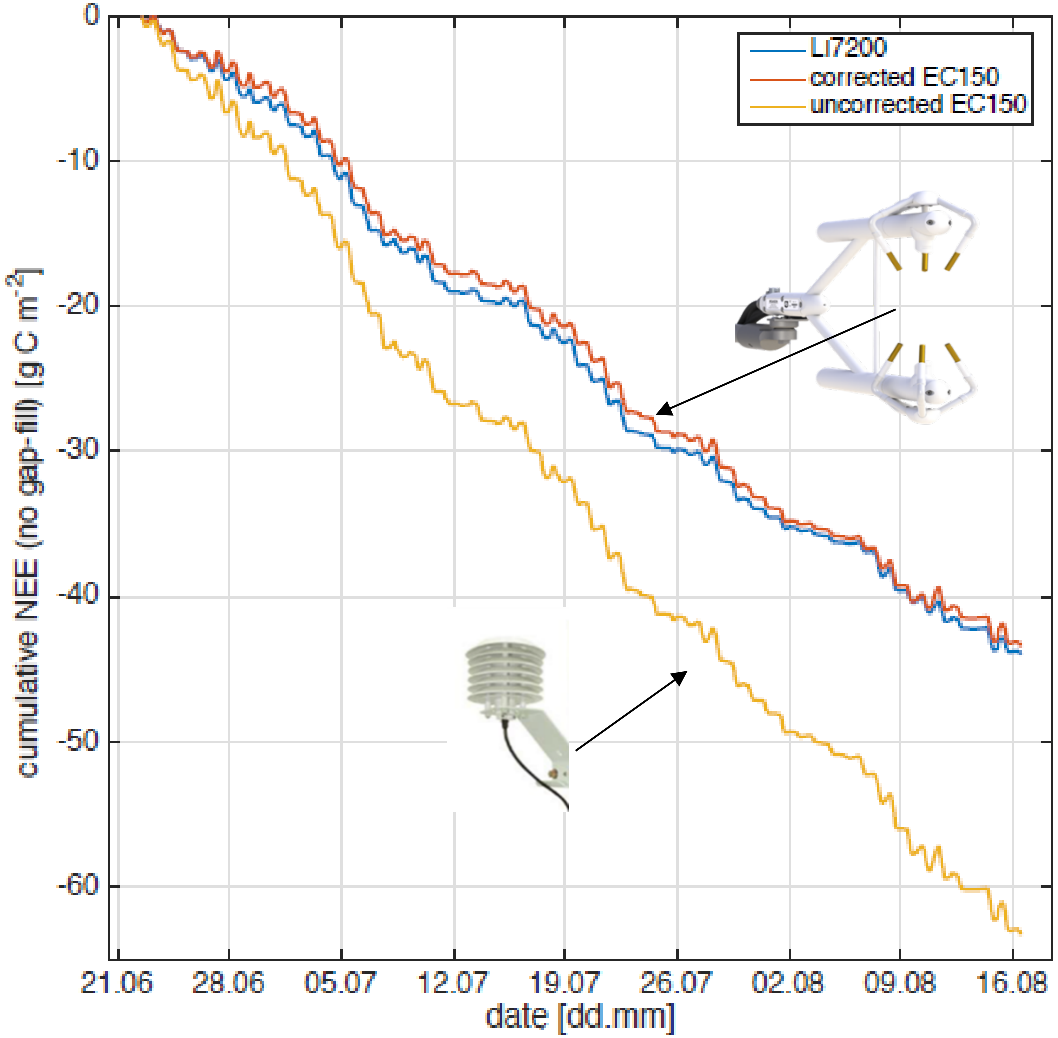
Slow-response air-temperature measurement

Results of using fast-response air-temperature in the conversion of absorption into CO_2 density





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