Performance Evaluation of an Innovative Sampling System for Closed Path Eddy Covariance Measurements

Rex Burgon[a], Steve Sargent[a], Benjamin Conrad[a]
[a]Campbell Scientific, Inc., USA

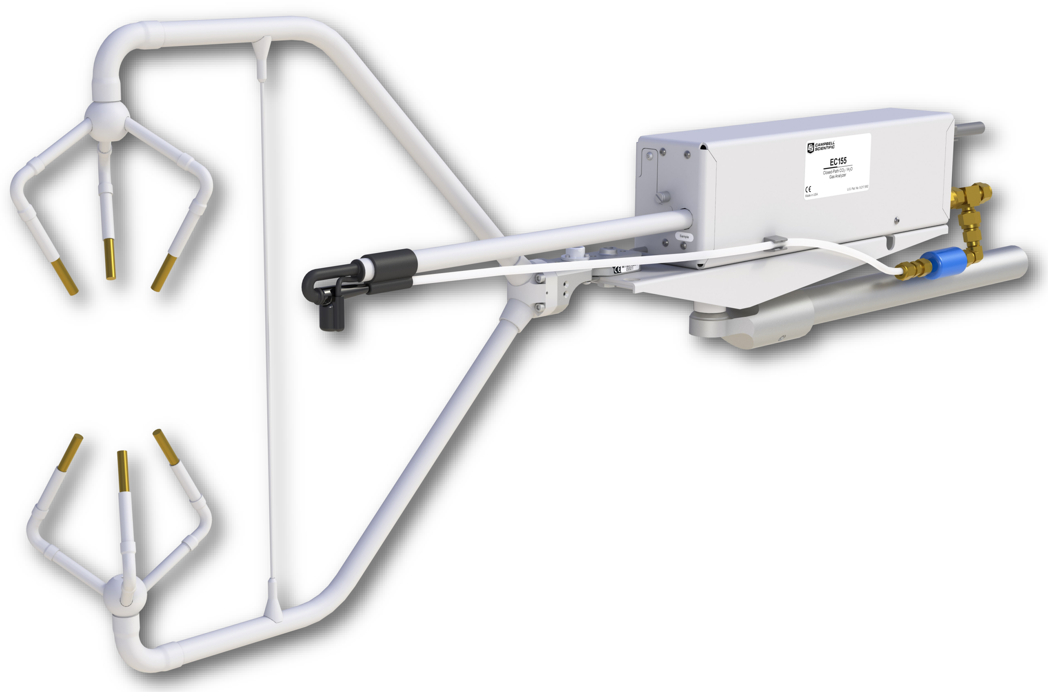
AMS 32nd Conference on Agricultural and Forest Meteorology

Poster #140

Abstract #295682

Introduction

A well-designed, closed-path eddy covariance (EC) system has good frequency response, needs little maintenance, and performs well in a variety of environmental conditions. The EC155 design was revised recently to include a Vortex Intake with a stainless steel sample cell. Each component influences overall system performance.



Objective

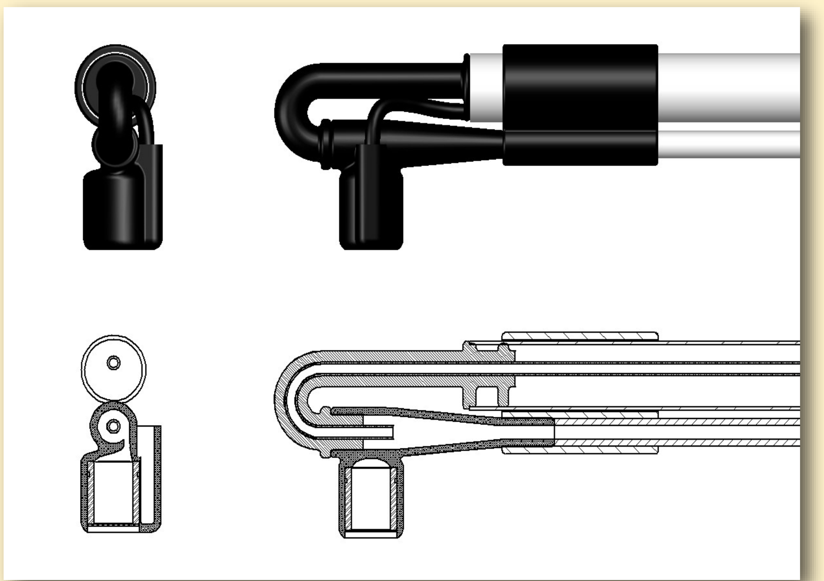
This work presents some of the system performance testing for the new EC155 design.

- Thermal damping of sample air
- Maintenance and reliability with a Vortex Intake
- Frequency response for CO_2 and H_2O vapor

Vortex Cleaner

A novel EC system that includes a vortex air cleaner (United States Patent No. 9,217,692) has been developed and field tested. The vortex intake keeps the analyzer windows clean and eliminates the requirement for a filter upstream of the gas analyzer.

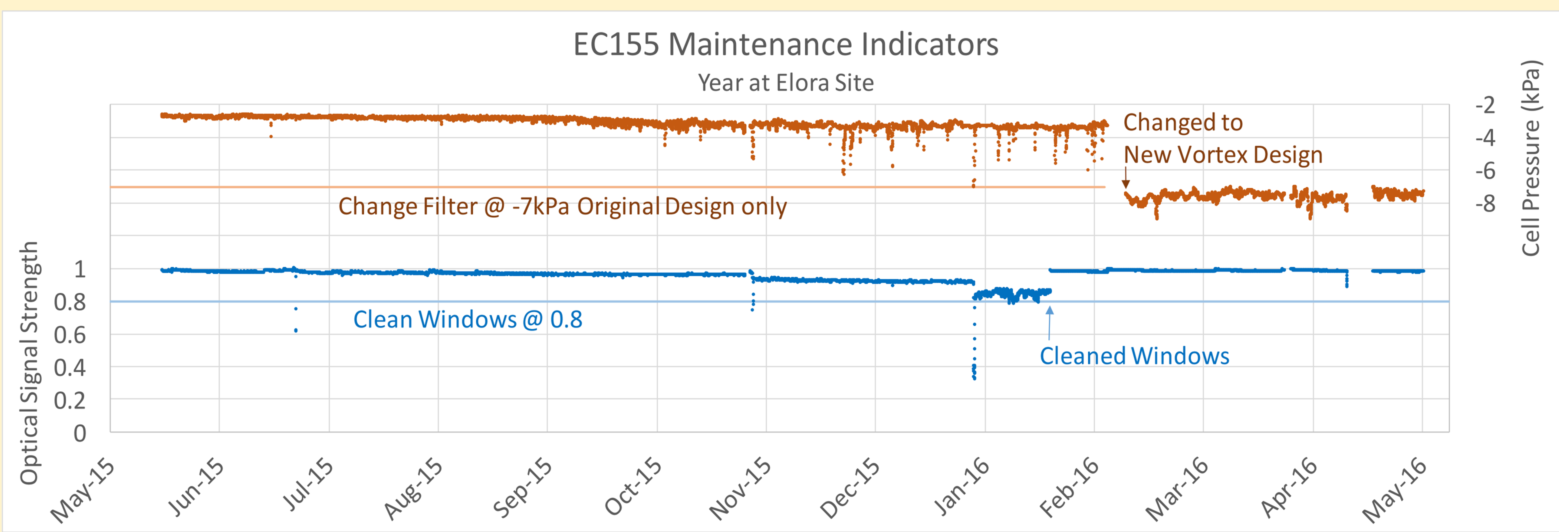
Dirty air enters the vortex chamber through a tangent port inducing vortex flow. Momentum keeps heavier dust particles away from the center where clean sample air is drawn.



Details of Vortex Intake for CPEC200/EC155 and TGA Eddy Covariance

Elora, Ontario, Canada

An EC155/CPEC200 is running as part of a larger flux study (Brown, et al., 2016). The system was first deployed in May, 2015 with the original design. It ran for 8.5 months before cleaning windows. The filter was never changed. In February, 2016 the system was upgraded to the new vortex design.



Logan, Utah, USA

An EC155 with a prototype vortex intake was tested in a field north of Campbell Scientific, Inc. in Logan, Utah, USA where the air quality is generally good. The test began December 17, 2013. **No maintenance** was required on the intake or sample cell windows for the entire **307 day test** (Burgon, et al., 2015).

Extreme Dirty Air Performance

Two sites in China (Olympic Park, Beijing and Badaling) were used to compare maintenance of inline filters and prototype vortex intakes. Both sites suffer from notoriously dirty air and filters plug relatively quickly. The **vortex intakes extended maintenance intervals** by **factors of 16 and 40** relative to inline filters (Burgon, et al., 2015).

Thermal Damping

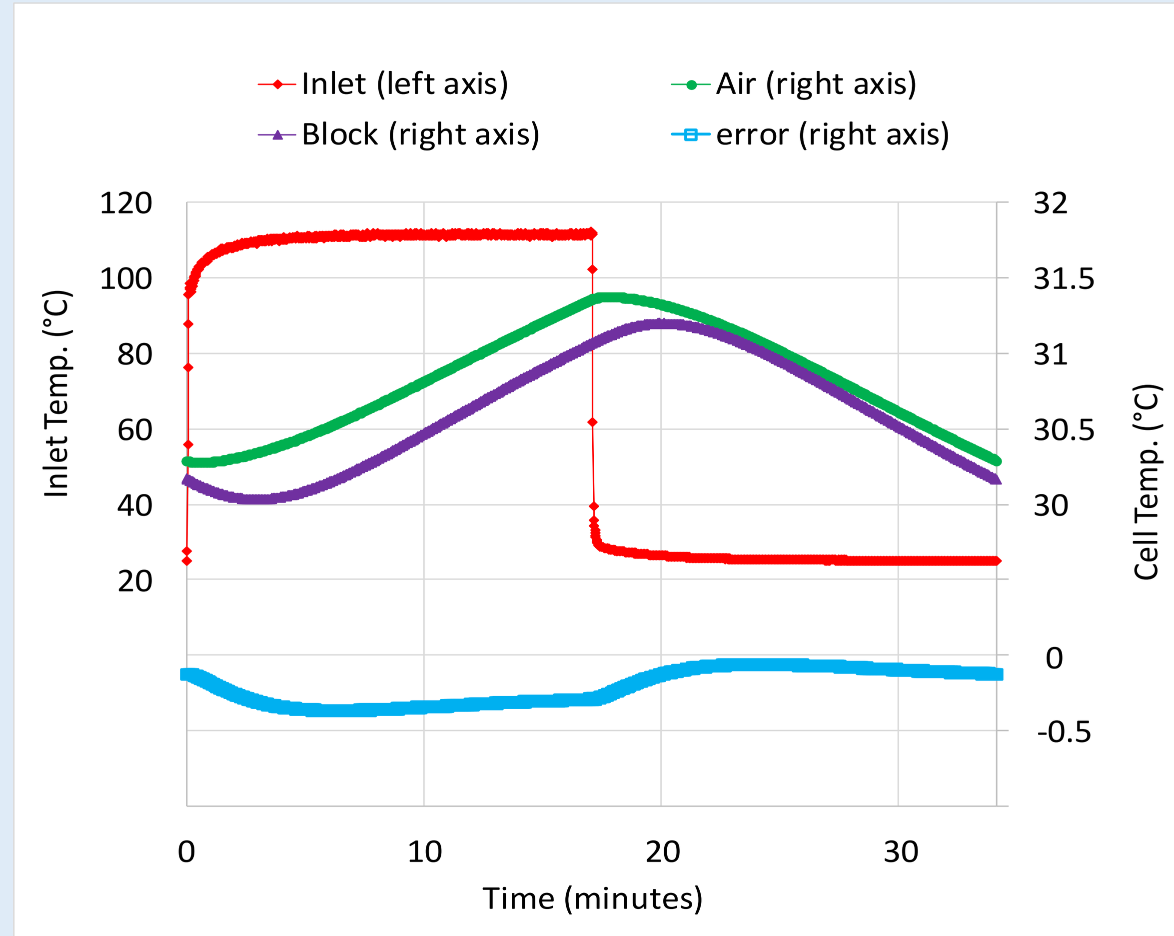
Background

Rannik, et al. (1997) used a simple, steady-state model to assess tubing length required to damp temperature fluctuations sufficiently to neglect the WPL (Webb, 1980) temperature term. They found the Reynolds number inside the tube to be an important factor, noted that fluctuations would damp more quickly than the steady state, and suggested the importance of experimental verification of physical intake tubes. Their Figure 3(a) showed L/D of 300 to be sufficient for the conditions that most closely describe the EC155. Their often referenced statement that L/D should be on the order of 1000 is a conservative upper bound on the tube length required, not a minimum requirement.

Temperature damping in the original EC155 intake/sample cell was measured by Sargent (2015), and was shown to reduce the sensible heat flux of the air within the sample cell compared to ambient by more than a factor of 100, even for cospectra with very low frequencies.

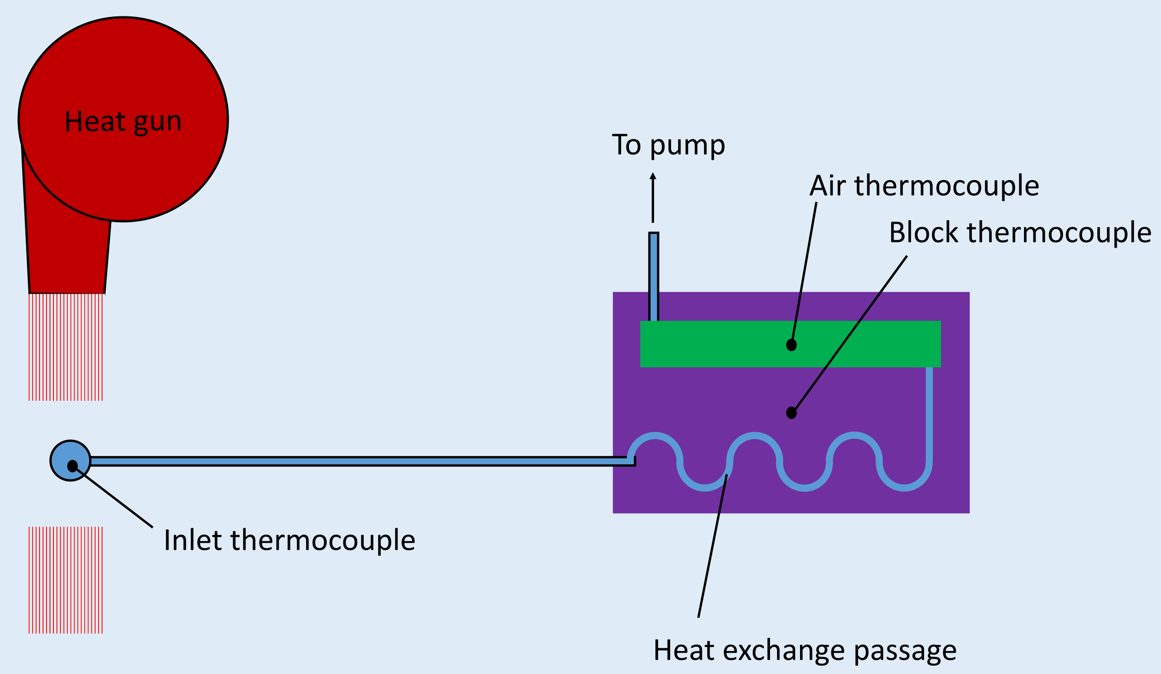
The new design includes two changes to further improve temperature damping:

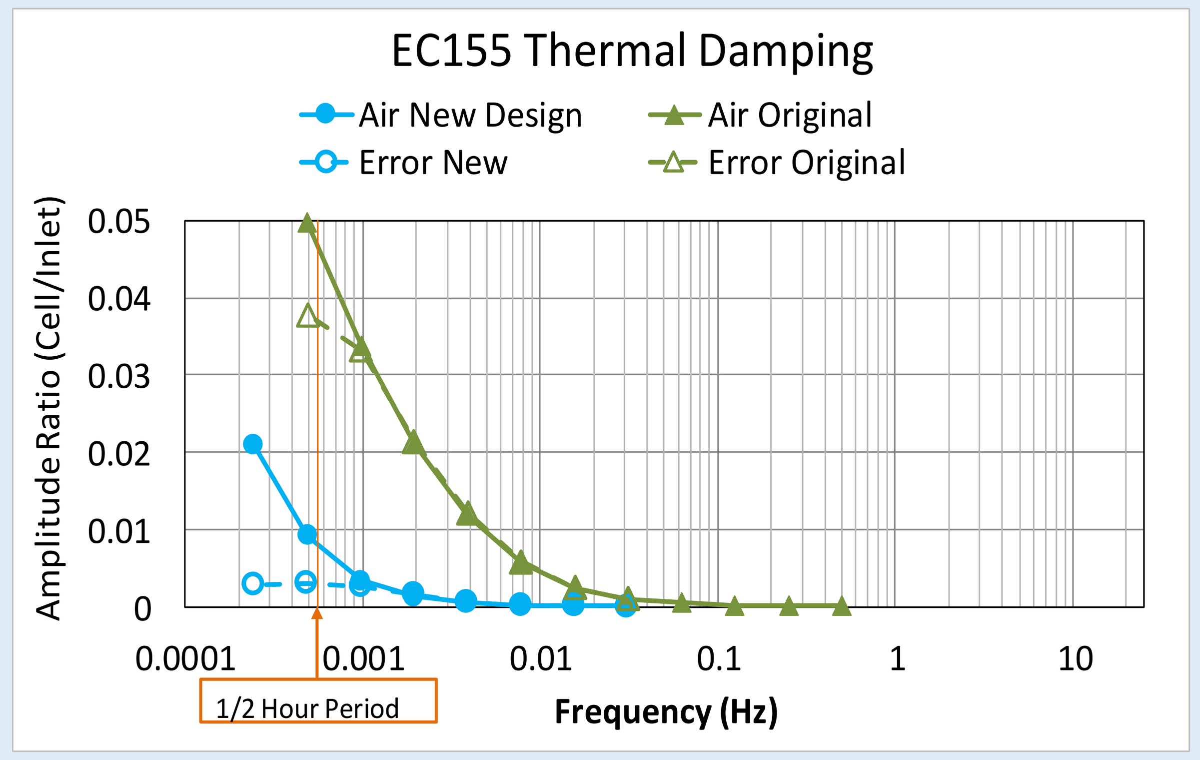
- An intake tube with a smaller ID (0.085" compared to 0.105"), giving a higher Reynolds number for better heat transfer from the air to the tube wall, increased L/D ratio (220 to 290), and more thermal mass (thicker wall) for increased damping of fluctuations
- A heat-exchange passage milled into the sample cell block (large thermal mass) to bring the air even closer to the block temperature before entering the sample cell



Method

The new design was tested using the method of Sargent (2015). A heat gun was directed at the inlet and cycled on and off for several cycles at a controlled period. Several test runs provided results over a series of frequencies. Fast response thermocouples measured temperatures of the inlet air, air in the cell, and the cell block. The cell used for thermal testing was modified to position a thermocouple (air) in the optical path.





Conclusions

- Thermal damping and equilibration to cell block is even better with New EC155 design
- WPL temperature correction term not necessary for EC155 (original or new)
- Temperature error < 0.3% of inlet fluctuations for all frequencies
- Zero maintenance with Block temperature sensor
- No delicate thermocouples exposed to sample air stream
- No complications related to weighting multiple dynamic thermocouple readings

System Frequency Response

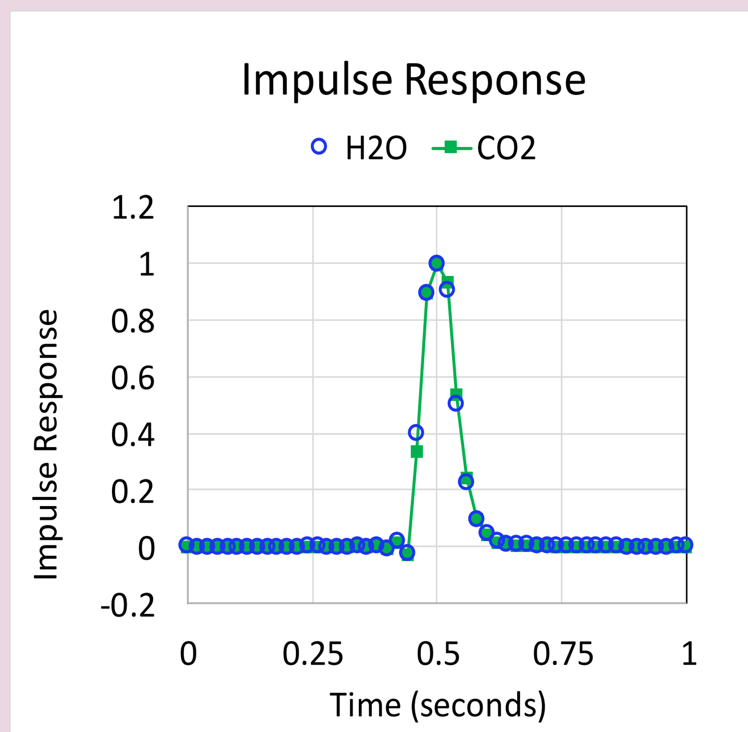
System frequency response depends on details of the gas sampling components such as rain cap, filter and intake tube as well as flow rate (Aubinet, 2016). The new EC155 design replaces the filter with a vortex cleaner that splits the total flow (2 LPM bypass and 6 LPM sample). The original sample flow was 7 LPM. Frequency response performance was verified for both designs including the complete gas sampling systems.

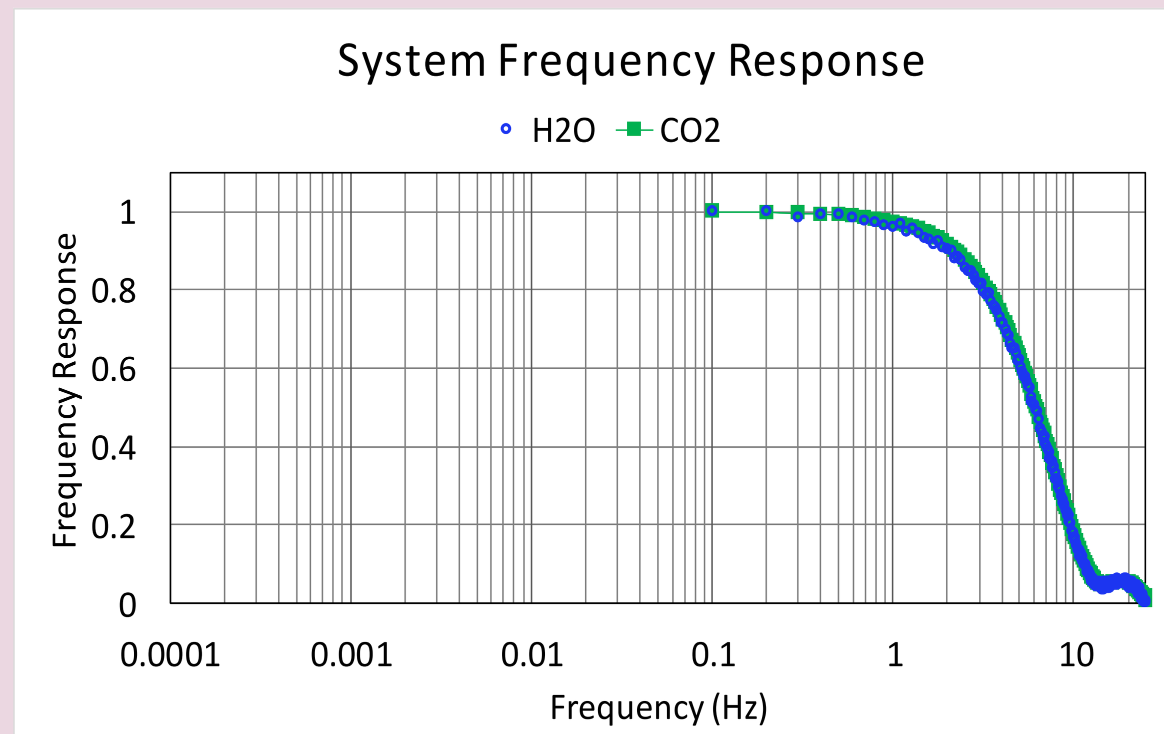
Method

The technique of Sargent (2012) was used to measure frequency response. The otherwise steady CO_2 and H_2O concentrations were pulsed by injecting a short (< 5ms) burst of "tank" air into the sample flow just upstream of the rain cap. The system response was recorded at a sample rate of 50 Hz with a 25 Hz digital filter.

Conclusions

- Excellent system response, difference consistent with slight change in sample flow.
- New design cutoff frequency = 4.3 Hz
- Original design cutoff frequency = 5.1 Hz





References

Aubinet, M., Joly, L., Loustau, D., De Ligne, A., Chopin, H., Cousin, J., Chauvin, N., Decarpenterie, T., and Gross, P. (2016) Dimensioning IRGA gas sampling systems: laboratory and field experiments. *Atmos. Meas. Tech.*, 9, 1361-1367, doi:10.5194/amt-9-1361-2016.

Brown, S., Sargent, S., Somers, J., Wagner-Riddle, C., (2016) A long-term field trial of a lower-powered eddy covariance system for measuring N_2O fluxes. *AMS 32nd Conference on Agricultural and Forest Meteorology,* Oral Presentation 7.4

Burgon, R., Sargent, S., Zha, T., Jia, X,. (2015) Field-Performance Verification of Carbon Dioxide, Water, and Nitrous Oxide Closed-Path Eddy Covariance Systems with Vortex Intakes. *AGU Fall Meeting 2015* Poster B33C-0669

Rannik, Ü., Vesala, T., and Keskinen, R. (1997) On the damping of temperature fluctuations in a circular tube relevant to the eddy covariance measurement technique. *J. Geophys. Res.* 102, Issue D11, 12789-12794.

Sargent, S. (2015) Damping Temperature Fluctuations in the EC155 Intake Tube. *https://s.campbellsci.com/documents/us/technical-papers/ec155%20damping.pdf*

Sargent, S. (2012) Quantifying Frequency Response of a Low-power, Closed-path CO_2 and H_2O Eddy-covariance System. *http://s.campbellsci.com/documents/us/technical-papers/cpec200_frequency_response.pdf*

Webb, E.K., Pearman, G.J., and Leuning, R. (1980) Correction of Flux Measurement for Density Effects due to Heat and Water Vapor Transfer. *Quart. J. Roy. Meteor. Soc.* 106, 85-100.

Acknowledgement: We thank Karen Wolfe for technical editing.