Frequency Response of a New Closed-Path, Trace-Gas Analyzer for Eddy-Covariance Flux Measurements

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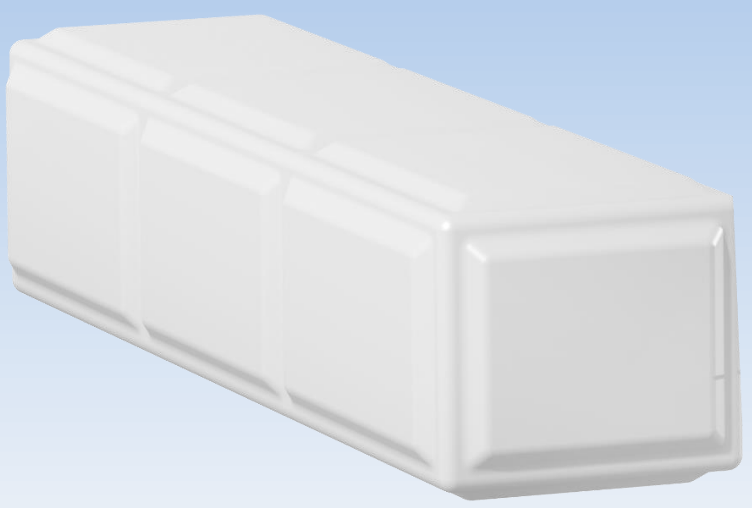


Introduction

Building upon 20 years of experience designing trace gas analyzers, Campbell Scientific, Inc. has recently introduced the TGA200A—a trace gas analyzer designed to measure nitrous oxide or methane mixing ratios, or carbon dioxide isotope ratios.

While similar to the earlier generation TGA200, key changes to the TGA200A include a thermoelectrically cooled laser, eliminating the need for liquid nitrogen, and a smaller sample cell volume which improves frequency response.

Objective

Using an impulse-response technique as described earlier[1], the goal of this study was to measure frequency response in a laboratory setting using Campbell Scientific's new nitrous oxide analyzer as part of a complete system for eddy-covariance (EC) measurements.

TGA200A Features and Specifications

Design Features

- Low noise: 1.5 ppb typical noise (Allan deviation with 100 ms averaging time)
- Fast response
- Field rugged—requires no instrumentation hut and can be placed near mounting structure to minimize sample tube length
- High measurement rate (500 Hz) gives excellent synchronization to the sonic anemometer
- Digital filter preserves frequency response and reduces noise

TGA200A Sample Cell

- Configuration: single pass, 1.46 m length x 12.7 mm inner diameter
- Volume: 200 ml
- Residence time: 43 ms at 15 slpm flow and 54 mb pressure

Other EC System Components

Combining a TGA200A with a CPEC200 (Campbell Scientific, Inc.), sample pump, dryer, intake assembly, and tubing, will create a complete EC system for CO_2, H_2O, and N_2O measurements.

- CPEC200 closed-path EC system
  - CSAT3A sonic anemometer
  - CR3000 datalogger
  - EC155 CO_2/H_2O infrared gas analyzer
- Busch B0021 pump with special oil return line
  - 950 W power
  - 18 slpm pumping speed at 50 mb
- PD200T dryer
  - Nafion® dryer element, 200 tubes, 1.2 m long, 0.64 mm inner diameter
  - Low-volume filter holder
  - Eliminates the WPL water vapor[2] term and avoids spectroscopic corrections
- Intake assembly
  - Rain diverter with insect screen
  - 0.5 m stainless steel tube
  - Mounting bracket for easy installation
- Intake tube: Synflex type 1300, 1/4-in outer diameter, 0.17-in inner diameter
  - 0.5 m length, intake assembly to dryer
  - 3.3 m length, dryer to TGA200A
  - Reynolds number: 4900

Literature

1. Sargent, S. (2012) Quantifying Frequency Response of a Low-power, Closed-path CO_2 and H_2O Eddy-covariance System. *https://s.campbellsci.com/documents/us/technical-papers/cpec200_frequency_response.pdf*
2. 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.
3. Horst, T.W. (1997) A simple formula for attenuation of eddy fluxes measured with first-order-response scalar sensors. *Boundary-Layer Meteorol.* **82**: 219-233.

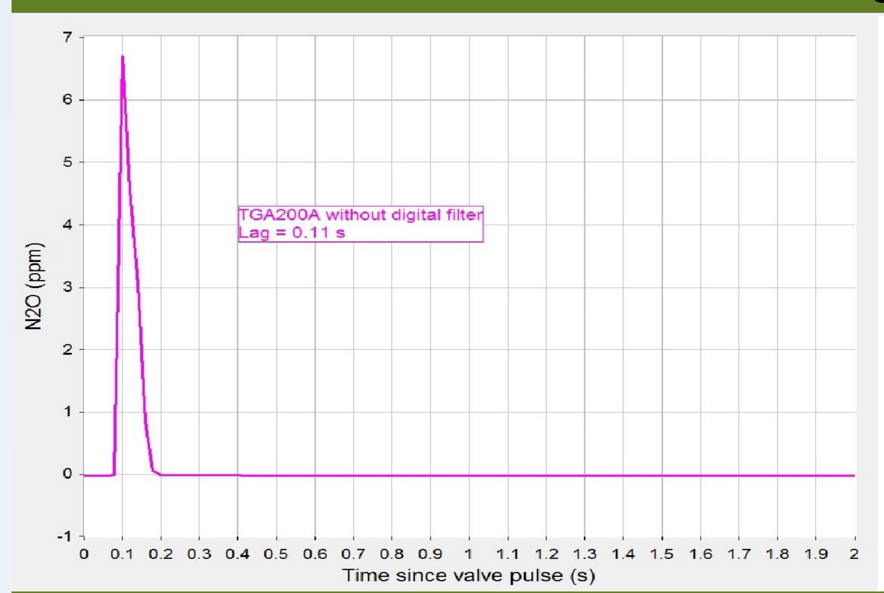
Methods

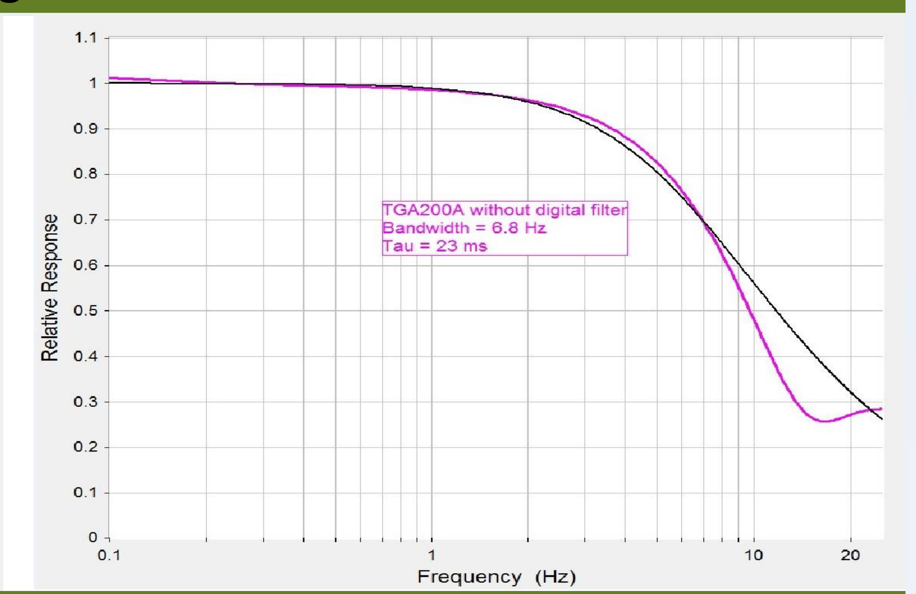
- Inject fast pulses of N_2O into sample flow (ambient air) every 10 seconds
- Sample the TGA200A response at 50 Hz with CR3000 datalogger
- Impulse response
  - Remove trend (10 s moving average)
  - Overlay multiple pulses
  - Compute ensemble average
  - Calculate lag time
- Frequency response
  - Fourier transform the impulse response
  - Normalize to 1 at low frequency
  - Graphically determine half-power bandwidth f
  - Calculate the characteristic time: $\tau_c = \frac{1}{2\pi f}$
- Inject pulses at the inlet of the TGA200A, with and without digital filtering, and at the inlet to the EC system

Results

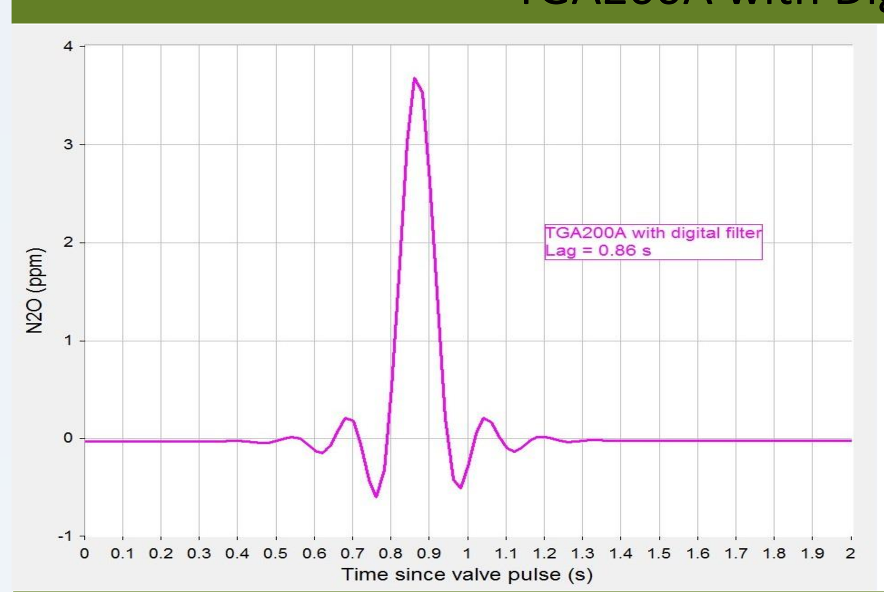
Impulse responses and frequency responses are shown below for the TGA200A with and without digital filtering, and for the complete EC system. The first-order model corresponding to the characteristic time constant is overplotted in black.

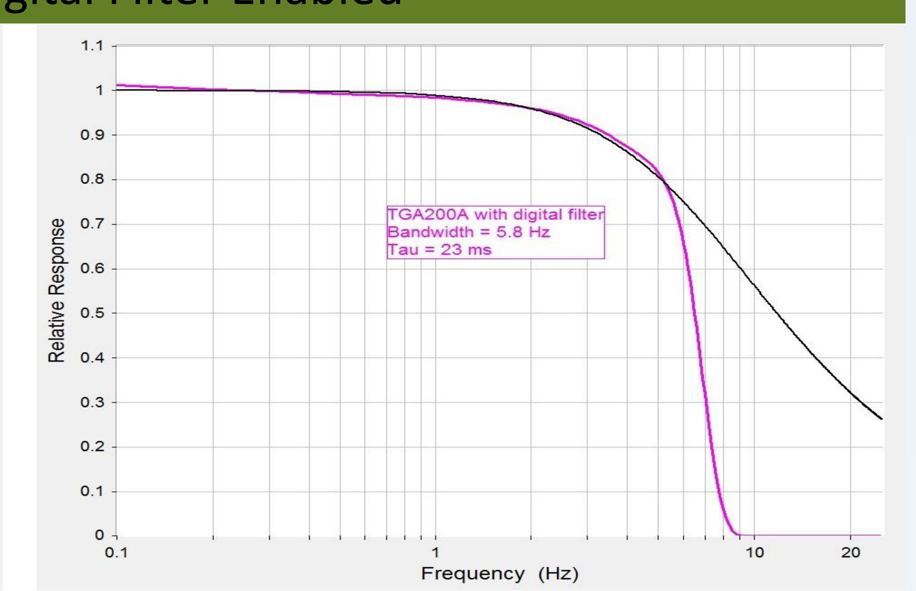
TGA200A with Digital Filter Disabled



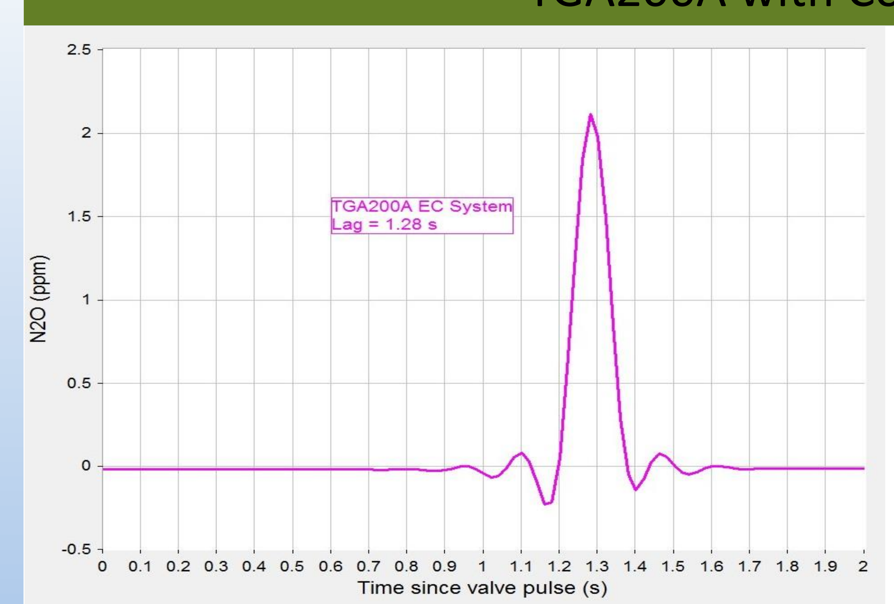


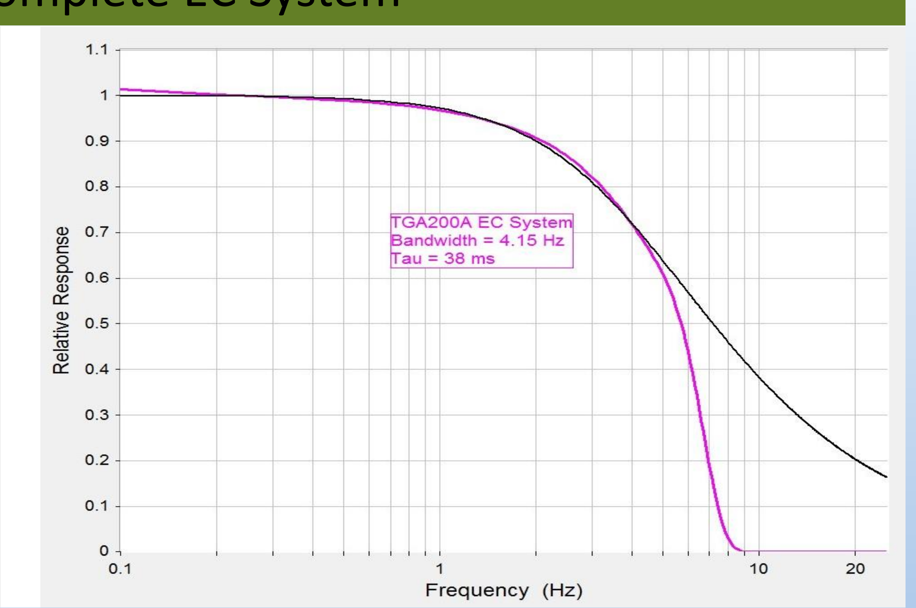
TGA200A with Digital Filter Enabled





TGA200A with Complete EC System



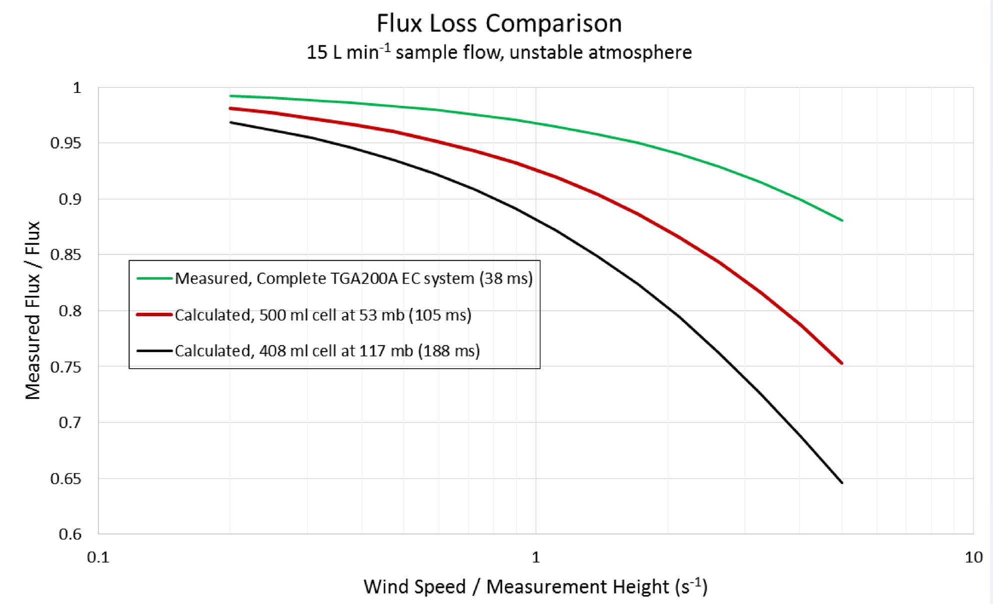


Flux Loss

The simple model proposed by Horst[3] gives the flux attenuation as a function of the characteristic time constant τ_c, measurement height z, and mean wind speed $\bar{u}$.

$$\frac{F_m}{F} = \frac{1}{1+(2\pi n_m \frac{\bar{u}}{z} \tau_c)^{\alpha}}$$

n_m is 0.085 and α is 7/8, corresponding to unstable atmospheric conditions. The ratio of measured flux to true flux, Fm/F, is plotted as a function of the ratio of $\bar{u}/z$. Also shown for comparison, are two sample cells assumed to have characteristic time constants equal to their residence times.



Conclusions

- TGA200A has excellent frequency response: 6.8 Hz bandwidth; 23 ms characteristic time constant
- Complete system has excellent frequency response: 4.15 Hz bandwidth; 38 ms characteristic time constant
- EC system flux loss is very low: 97% of flux measured at the typical condition, wind speed is approximately equal to measurement height

Ongoing Work

- Field verification (May – July 2015).
- Develop an optimal EC system (dryer, intake assembly, filter, and pump) to take full advantage of the TGA200A's small sample cell. This will preserve the excellent frequency response with a lower-power sample pump.

Acknowledgments

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