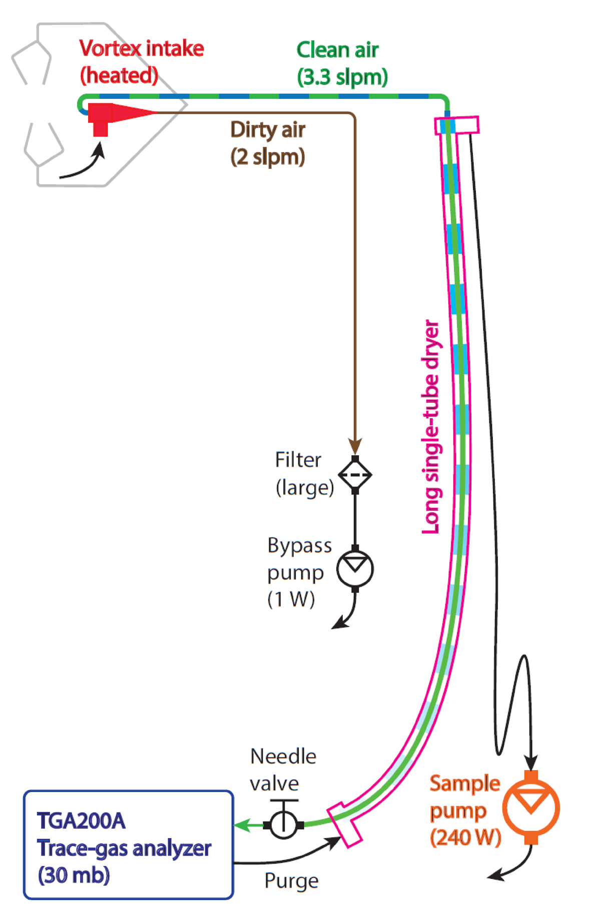
A Novel Low-Power, High-Performance, Zero-Maintenance Closed-Path Trace Gas Eddy-Covariance System with No Water Vapor Dilution or Spectroscopic Corrections

B33C-0668

James Somers and Steve Sargent, Campbell Scientific, Inc. Logan, Utah, USA

Introduction

Trace-gas eddy covariance (EC) flux measurement can be made with open-path or closed-path analyzers. Traditional closed-path trace-gas analyzers use multipass absorption cells that behave as mixing volumes, requiring high sample flow rates to achieve useful frequency response. The high sample flow rate and the need to keep the multipass cell extremely clean dictates the use of a fine-pore filter that may clog quickly. A large-capacity filter cannot be used because it would degrade the EC system frequency response. The high flow rate also requires a powerful vacuum pump, which will typically consume on the order of 1000 W. The analyzer must measure water vapor for spectroscopic and dilution corrections.



Open-path analyzers are available for methane, but not for nitrous oxide. These methane analyzers have low power consumption but are very large which degrades frequency response and disturbs air flow near the sonic anemometer. They require significant maintenance to keep exposed optical surfaces clean. Water vapor measurement for dilution and spectroscopic corrections require a separate water vapor analyzer.

A new closed-path EC system for measuring nitrous oxide or methane fluxes provides an elegant solution. The analyzer (TGA200A, Campbell Scientific, Inc.) uses a thermoelectrically cooled interband cascade laser (ICL). The small volume (200 ml) and unique configuration (1.5 m single pass) of the sample cell provide excellent frequency response with a low-power scroll pump (240 W).

A single-tube Nafion® dryer removes most of the water vapor and attenuates fluctuations in the residual water vapor. A vortex intake assembly eliminates the need for an intake filter without adding volume that would degrade system frequency response. Laboratory testing shows the system attenuates the water vapor dilution term by more than 99% and achieves a half-power bandwidth of 3.5 Hz.

TGA200A Trace Gas Analyzer

Design Features:

- New thermoelectrically cooled interband cascade laser (no LN_2 required)
- Low noise: 1.5 ppb (N_2O), 7 ppb (CH_4) typical (Allan deviation with 100 ms averaging time)
- 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

TGA200A Sample Cell:

- Configuration: single pass, 1.46 m length x 12.7 mm inner diameter
- Volume: 200 ml
- Residence time: 99 ms at 3.7 standard LPM flow and 31 mb pressure

Power:

90 to 264 Vac, 47 to 63 Hz

- Electronics: 34 W (max), 22 W (typical)
- Temperature control: 170 W (max), 60 W (typical)

References

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Vortex Intake Assembly

A novel vortex intake design (U.S. Patent No. 9,217,692) removes particulates from the sample air stream with no filter to clog and no additional mixing volume that could degrade frequency response. The filter in the dirty air bypass can be made arbitrarily large to extend the maintenance interval almost indefinitely. Laboratory tests and field trials show excellent performance used with an EC155 CO_2/H_2O analyzer (Campbell Scientific, Inc.; Burgon, et al., 2015). A field trial of the vortex intake with a TGA200A has been underway since June 2015 (Brown, et al., 2015).

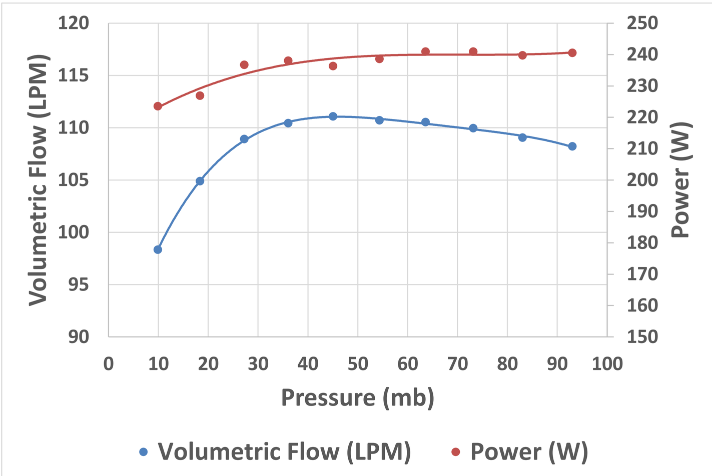
The integral rain diverter has very small volume (1.3 ml) to avoid frequency response degradation and is heated (0.7 W) to prevent accumulation of dew or frost.

A low-power (1 W) diaphragm pump provides the bypass flow (2 LPM) to pull the dirty air from the vortex chamber.

Sample Pump

Earlier trace-gas analyzers from Campbell Scientific used an oil-sealed rotary pump (Busch RB0021, modified for continuous operation). The new TGA200A has a smaller sample cell to deliver excellent frequency response with a smaller pump. A dry scroll pump (Edwards nXDS6i) was chosen for better power efficiency and lower maintenance (no oil changes). Its flow, pressure, and power consumption were measured to verify the vendor specifications:

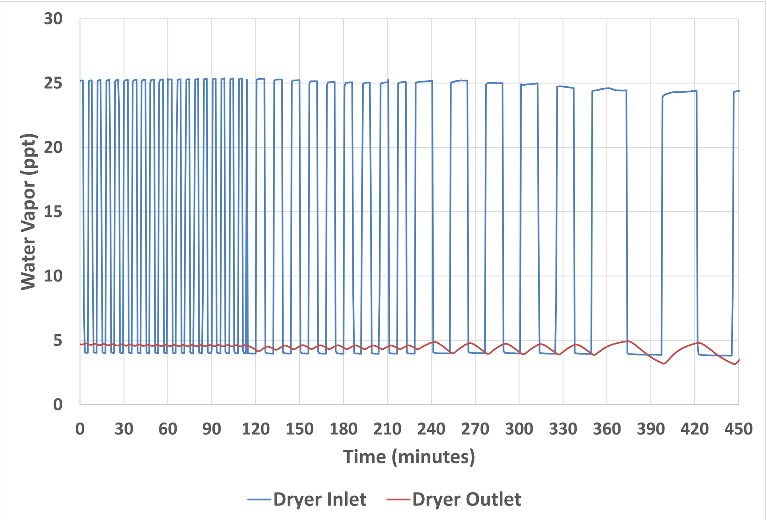
- Measured volumetric flow: 110 LPM (5% higher than vendor specification)
- Measured power consumption: 240 W (15% lower than vendor specification)



Dryer

A trace-gas EC system must either remove or measure water vapor fluctuations to account for the latent heat flux (Webb, et al., 1980). Early systems from Campbell Scientific used a large-capacity dryer (PD200T, Campbell Scientific, Inc.) which is optimized for high flow; typically 15 and 3 LPM for the sample and purge. This dryer gave excellent frequency response with the TGA200A, but required a large-capacity sample pump (Sargent and Somers, 2015). The smaller sample cell volume of the TGA200A achieves excellent frequency response at lower flow, enabling the use of a lower-capacity dryer. This new dryer uses a single Nafion® tube of 2.2 mm inner diameter, 7.5 m long. Its flexible purge shell has a large inner diameter (25.4 mm) allowing it to be used in reflux mode without excessive pressure drop. The length of the dryer is used to carry the sample flow from the intake to the analyzer, replacing the sample tube entirely for low EC measurement heights.

The dryer was tested in the laboratory to ensure it damps water vapor fluctuations sufficiently to avoid errors in the trace gas flux due to latent heat flux.

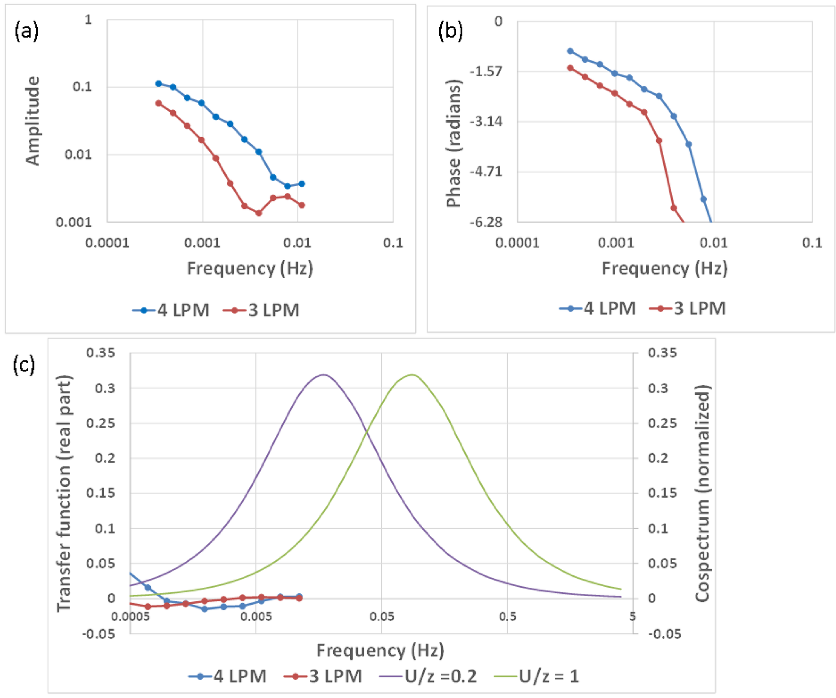


- Switch between humidity at a range of periods from approximately 1 to 48 minutes
- Repeat with flow at 3 and 4 standard LPM
- Measure humidity at inlet and outlet of dryer, using an AP200 atmospheric profile system (Campbell Scientific, Inc.)

Example time series for 3 slpm flow, 6, 12, 24, and 48 minute periods. The fluctuation amplitude at the dryer outlet is very small at the shorter periods. The amplitude is measureable at the longer periods, but is out of phase, so it does not contribute to the covariance with vertical wind in an EC system.

The amplitude and phase of the water vapor fluctuations were determined using Fourier analysis, and the (complex) transfer function was calculated as the ratio: dryer outlet/dryer inlet.

The amplitude and phase of the complex transfer function are shown in (a) and (b) at right.

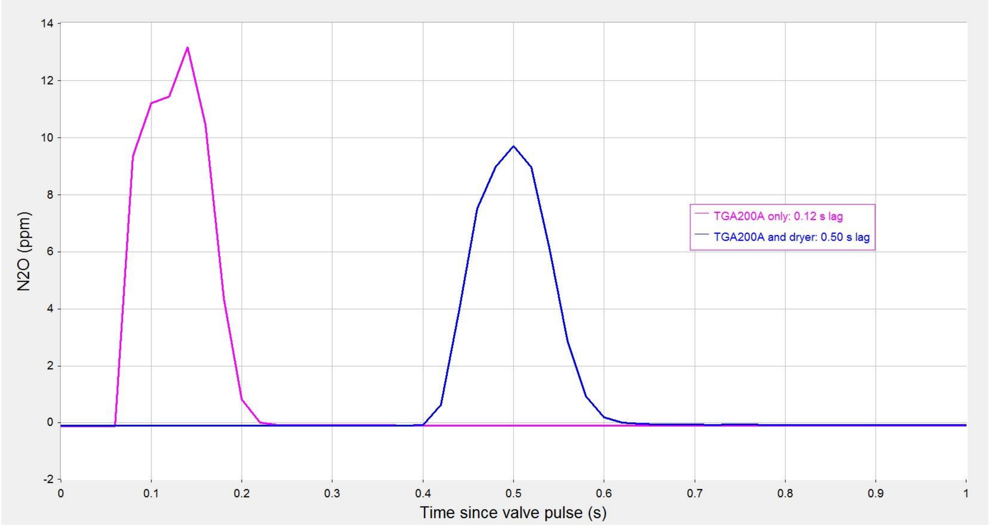


The real part of the transfer function is shown in (c) overplotted with logarithmic cospectral models (Horst, 1997) representing typical conditions (U/z = 1) and low-frequency conditions (U/z = 0.2). The X axis is scaled from 0.0005 Hz (approximately 30-minute period). The water vapor fluctuations are effectively damped at all frequencies that transport significant flux.

System Frequency Response

The frequency response of the TGA200A and the EC system was measured with the impulse response method (Sargent, 2012). Impulse responses are shown below, for the impulse injected at the inlet of the TGA200A and at the inlet of a simulated dryer (7.5 m of 2.2 mm ID stainless steel tubing).

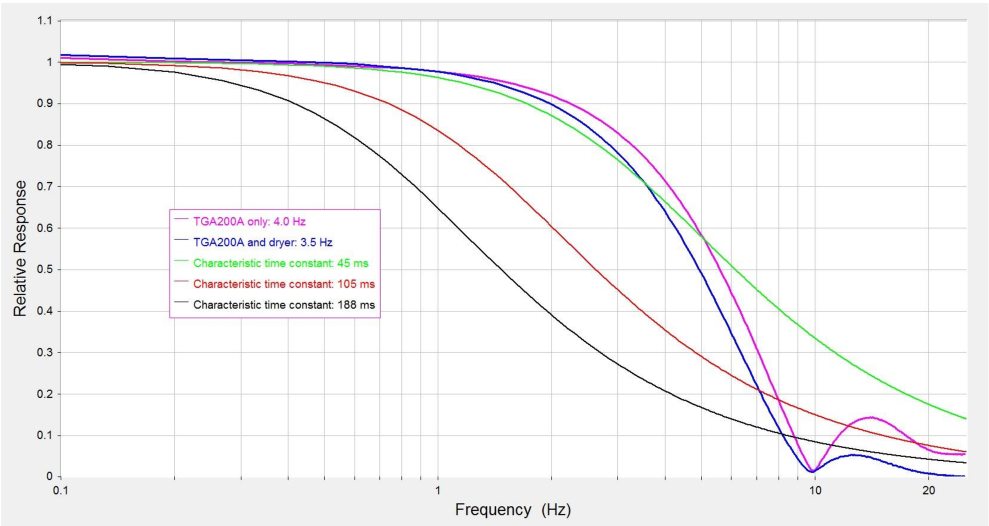
- Flow: 3.7 LPM; TGA200A cell pressure: 31 mb; calculated residence time: 99 ms



The corresponding frequency responses are shown below. The dryer degraded the frequency response very slightly, reducing the cutoff frequency from 4.0 to 3.5 Hz. The green line is the first-order model with a characteristic time constant that gives the same cutoff frequency as the TGA200A and dryer.

Also shown for comparison are first-order models for other analyzers with these characteristics:

- Flow: 15 LPM; volume: 500 ml; pressure: 53 mb; time constant: 105 ms
- Flow: 15 LPM; volume: 408 ml; pressure: 117 mb; time constant: 188 ms



Conclusions

The TGA200A achieves excellent frequency response with a relatively low-power sample pump. The new dryer is optimized for the TGA200A's smaller sample cell, taking the place of the sample tube while damping water vapor fluctuations to eliminate trace gas flux error due to latent heat flux. The new vortex intake assembly removes particulates without the need for a traditional filter in the sample path.

Future Work

- Continue field trials
- Investigate the tradeoff of frequency response versus sample pump capacity to demonstrate feasibility for solar power options

Acknowledgments

Karen Wolfe for technical editing, layout, and design support.