A Low-Power Configuration for a Tunable Diode Laser Trace Gas Analyzer to Measure N2O & CO2 Fluxes using Flux Gradient Method

2016 Ameriflux PI Meeting

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INTRODUCTION

Campbell Scientific has been manufacturing tunable diode laser trace gas analyzers (TGAs) since 1993. These field-rugged instruments provide measurements with high accuracy, low noise, and the excellent frequency response required for eddy covariance applications. Widespread use of the TGA for measuring trace gas fluxes remains limited by the high power (~1000 W) pump required for eddy covariance measurements. The new TGA200A has recently shown excellent frequency response for eddy covariance with a relatively low power (240 W) sample pump (Somers and Sargent, 2015, Brown, et al, 2016) However, this power level is still difficult to provide without access to AC mains power.

An alternative to eddy covariance, the flux-gradient method (Denmead, 2008) allows the use of a much lower-power pump. Here we present the results of a field trial to evaluate the feasibility of measuring N_2O fluxes with a very low-power flux-gradient system. In addition, we investigate the tradeoff of system performance with the TGA temperature control disabled to further reduce power demand to less than 30 W, which can easily be supplied with solar panels. The resulting system provides the data integrity and reliability characteristic of closed-path analyzers with the low power normally associated with open-path analyzers.

METHODS

An N_2O/CO_2 analyzer with low-power flux-gradient sampling system was tested at the instrumentation garden located at Campbell Scientific, Inc. in Logan Utah. The equipment included (all equipment manufactured by Campbell Scientific, Inc. except as noted):

- TGA100 trace gas analyzer: This legacy analyzer, manufactured in 1994, was recently upgraded with a new thermoelectrically-cooled interband cascade laser for measuring N_2O and CO_2.
- AP200 Intake Assemblies: Ambient air was sampled through two AP200 heated intake assemblies which include a heated rain cap (0.25 W), filter, 0.007" orifice to set the flow to ~250 ml min^{-1}, and 750 ml mixing volume.
- Sampling System: A standard 16-inlet sampling system was modified for use with low-power pumps. Solenoid valves switched between intakes every 30 s. 15 s were omitted for equilibration and 15 s included in the average N_2O and CO_2.
- Pumps: A prototype pump module used three low-power, double-head diaphragm pumps (Parker BTC 11S series, Parker Hannifin Corp., Hollis, NH, USA) in a four-stage configuration. The pump speeds were controlled by a CR3000 datalogger in the sampling system to pull ~180 ml min^{-1} sample flow through the analyzer at 50 mb and bypass the remaining flow at 400 mb.
- IRGASON open-path CO_2/H_2O eddy covariance system with CR6 datalogger running EasyFlux^{TM} –DL datalogger program.
- Custom power module with AC/DC power converter (QS10.121, Puls GmbH, Munich, Germany) and a CR1000 datalogger to measure power consumption for each subsystem.

The system was operated in four different configurations:

- Measurement precision with heaters on, sampling compressed air
- Measurement precision with heaters off, sampling compressed air
- Zero Gradient with heaters off, sampling ambient air through a tee to both intakes
- Flux-Gradient with heaters off, sampling ambient air at two heights: 2.6 and 1.8 m

The open-path EC system provided CO_2 flux estimates that were used without further corrections. The TGA concentrations were averaged over 30 minutes, and the difference between the intakes was calculated. The eddy diffusivity (k-term) was calculated as the ratio of the EC flux and the CO_2 gradient. This k-term was then used to calculate an N_2O flux:

$$Fg = -K_g * \frac{[\partial pg]}{\partial z}$$

where K_g is the eddy diffusivity term, and $\frac{\partial pg}{\partial z}$ is the vertical gradient of the gas.

RESULTS

Figure 1: TGA sampling system, AP200 Intakes (in zero-gradient arrangement) and low-power sample and prototype pump module.

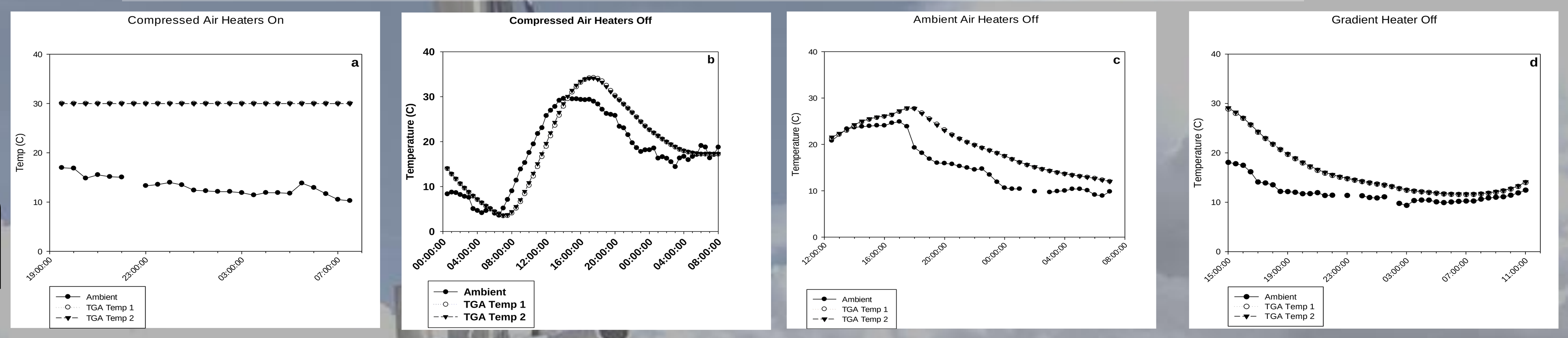

Figure 2. Ambient and TGA enclosure temperatures for a) compressed air with heaters on b) compressed air with heaters off, c) ambient air with heaters off, and d) gradient with heaters off.

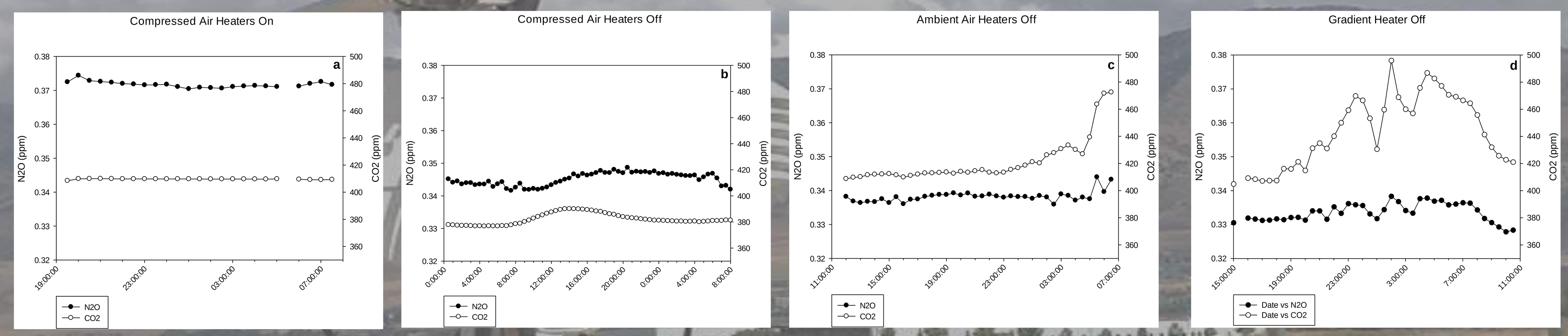

Figure 3. 30 min CO_2 and N_2O means for same conditions as Figure 2.
Note: compressed air tank was changed between a and b data collection.

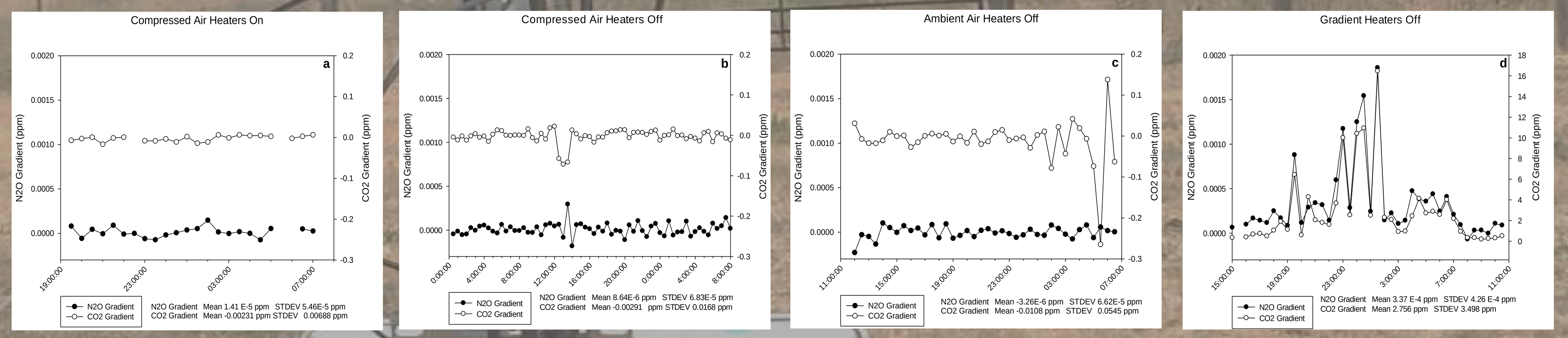

Figure 4. 30 min CO_2 and N_2O Upper – Lower Intake for same conditions as Figure 2.

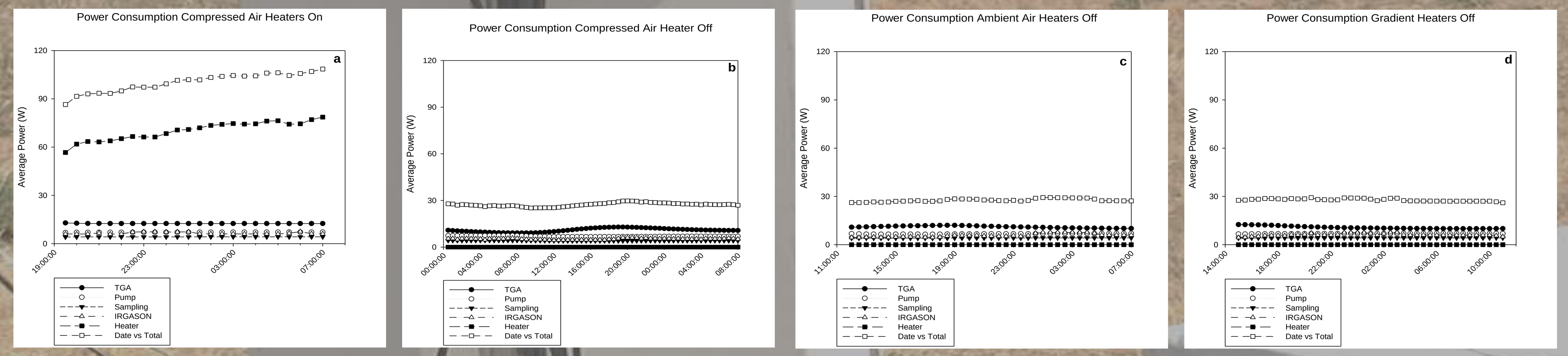

Figure 5. 30 min averages of TGA, pump, sampling system, IRGASON, heater power and total power for same conditions as Figure 2.

RESULTS

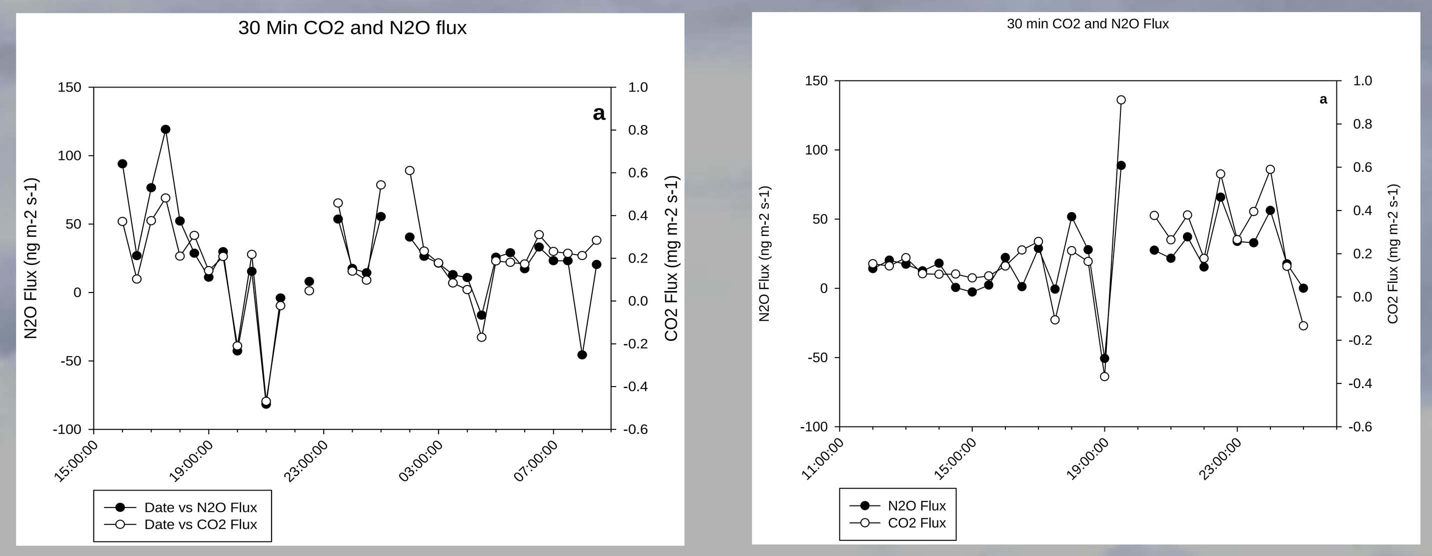

Figure 6. 30 min N_2O and CO_2 fluxes for two separate time periods: a) corresponds to a 12 mm rain event on 9/14/2016-9/15/2016 b) corresponds to a warm breezy day on 9/15/2016.

CONCLUSIONS

- The 30-minute N_2O gradient precision was 0.055 ppb with the heaters on, and increased to 0.068 ppb with the heaters off (Figure 4a-b).
- The 30-minute CO_2 gradient precision was 7 ppb with the heaters on, and increased to 17 ppb with the heaters off (Figure 4a-b).
- The N_2O and CO_2 gradient bias was much smaller than the precision with heaters on or off, sampling either compressed air or ambient air (Figure 4a-c).
- The average N_2O and CO_2 gradients were much larger than the precision (Figure 4a-d).
- Total system power with the TGA heaters on was ~100 W. This is dominated by the heater power, which depends on the temperature set point and ambient temperature (Figure 5a).
- Total system power with the TGA heaters off was <30 W (<25 W without the IRGASON) (Figure 5b-d).
- The flux-gradient method can measure N_2O fluxes at a power level which can easily be provided with solar panels.

FUTURE WORK

- Repeat the test with a new TGA200A. Its smaller sample cell volume (200 ml) would allow faster. switching to further reduce the effect of low-frequency noise.
- Test the system for multi-site gradient measurements.
- Run the system on solar panels.

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ACKNOWLEDGEMENTS

The authors would like to thank Paul Fluckiger for technical assistance.