Field Trials of Trace-Gas Analyzers for Eddy Covariance Flux of Methane (CH_4) and Nitrous Oxide (N_2O)

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Introduction

The Eddy Covariance (EC) Gas Flux method makes challenging demands on the gas analyzers used in the field, particularly for the trace gasses CH_4 and N_2O. The analyzer must have sufficient frequency response, low noise, and measurement stability. For practicality, it must be field rugged, low power, and require minimal maintenance. The aerodynamic footprint of the instruments near the sample volume of the 3D anemometer is a paramount concern for quality science data.

Tunable diode laser absorption spectroscopy (TDLAS) is a proven method for measuring the low concentrations of trace gasses in natural air and is effective for EC (Somers and Sargent, 2015, Brown, et al, 2016). A closed-path TLDAS gas analyzer employs a low sample gas pressure to isolate the mid-infrared absorption lines while also providing sufficient flow rate to preserve instrument frequency response.

The TGA300 series of closed-path trace-gas analyzers is new instrumentation developed at Campbell Scientific specifically to meet the requirements of trace-gas EC flux measurements. This field study evaluated the TGA300s alongside other instruments used for the same purpose. The TGA310 measures methane (CH_4) and was compared alongside an LI-7700 open-path analyzer. The TGA320 measures nitrous oxide (N_2O) and was compared to a TGA200A closed-path analyzer. To complete the fluxes, the TGA300 instruments utilized sonic data from an IRGASON. The TGA200A and LI-7700 use a CSAT3B for sonic data. A Young 81000RE anemometer and a variety of additional sensors were also present.

Accuracy and Noise

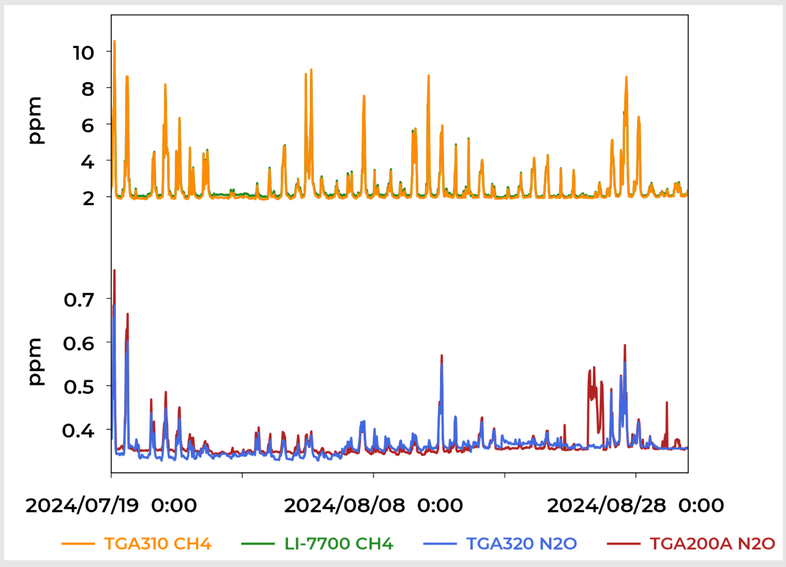

Figure 1: These plots show a times series of the scalar measurements of the gas analyzers over a period of a month. Plot A is CH_4 from the TGA310 and LI-7700. Plot B is N_2O from the TGA320 and TGA200A. For clarity of the image, the data has been smoothed with a 1-hour block average to illustrate the general correlation of absolute concentrations measured by the devices. Setting aside minor offset differences that do not impact the flux calculations, the amplitude gain is well correlated. The instruments all responded to dynamic cultivation activities. Data availability was similar between the open and closed path instruments at this site except for the regular window wash cycles of the LI-7700 every few hours. Missing data due to precipitation events was inconsequential because this site receives little rainfall and is flood irrigated.

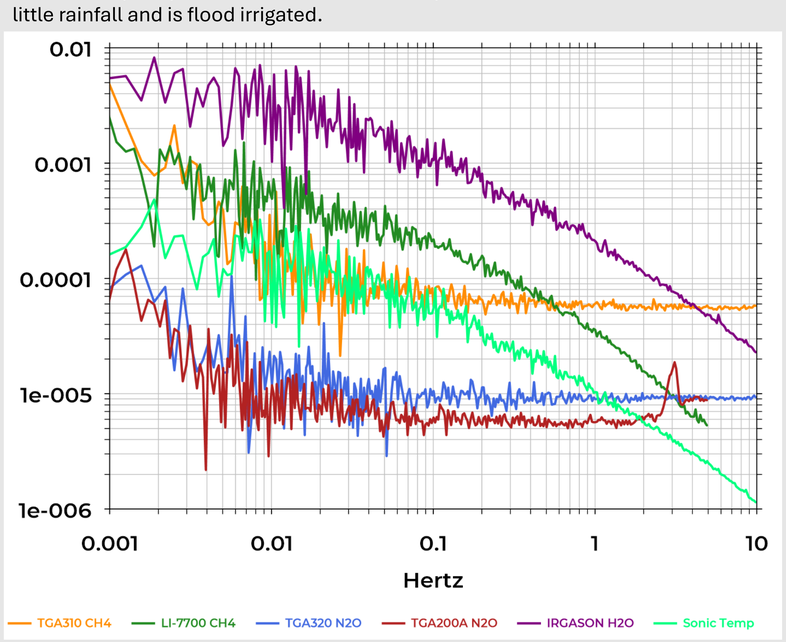

Figure 2: Normalized noise spectra of the primary output for all analyzers. Dry mixing ratio is shown for the TGAs and wet mixing ratio for the LI-7700. This data was from a 4-hour data sample taken during calm hours of the day with insignificant variations in CH_4 and N_2O concentration. The TGA instruments transition from 1/f noise to broadband white noise approximately around 0.02 Hz. The intake design of the TGA dampens the fluctuations of temperature and water yielding dry mixing ratio directly without corrections. The spectral profile of the sonic temperature and water vapor are also shown for substantiation. In this view, the LI-7700 exhibits elevated noise behavior because it lacks a collocated high-frequency-response air temperature measurement so temperature fluctuations could not be removed for the conversion to a mixing ratio.

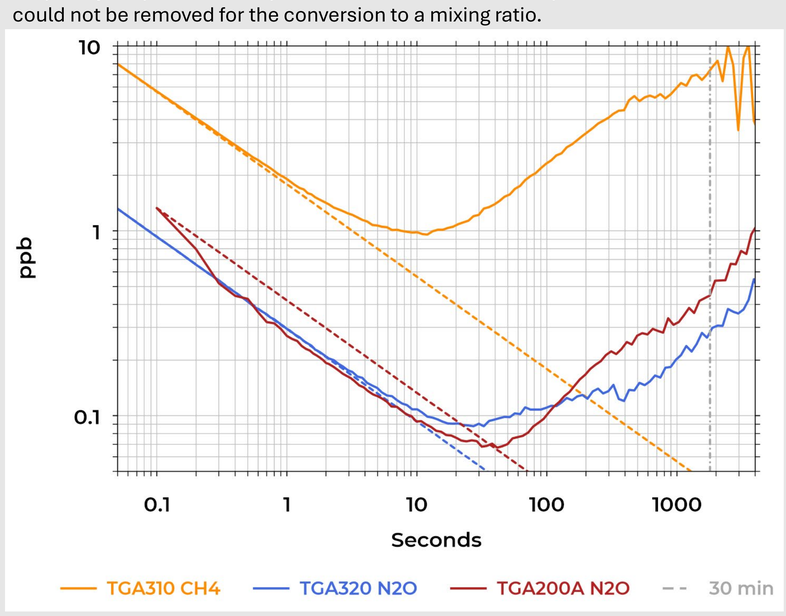

Figure 3: Allan deviations (Allen, 1966) computed to a 4-hour interval for all analyzers. The TGA instruments exhibit deviation smaller than the 10 Hz noise floor out to 30 minutes indicating stability for EC flux calculations.

Measurement Campaign

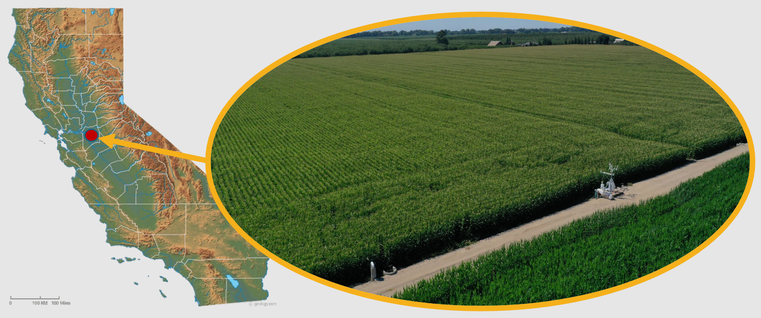

Figure 4: Test site located in San Joaquin Valley, CA. Campaign dates Aug 2023- Sept 2024. Crops were silage corn and winter wheat.



Figure 5: Test site equipment. TGA310, TGA320, TGA200A, CSAT3B, IRGASON, LI-7700, LI-7500, Young 81000RE, CR6, radiometers, soil sensors, etc.



Figure 6: Fully integrated instrument cluster measures N2O, CH4, CO2, H2O, and 3D sonic all with Campbell Scientific sensors



Figure 7:Hybrid instrument cluster measures N2O, CH4, CO2, H2O, and 3D sonic with Campbell Scientific, Li-Cor, and RM Young

Conclusions

1. The field trial has shown the TGA300 to be a significant advancement in the tools available for EC measurements of methane and nitrous oxide. The instruments met the critical benchmarks of noise, stability, frequency response, and aerodynamic footprint necessary for the technique. Practical features such as field installation, maintenance schedule, and power draw of the TGA300 surpassed other currently available instrumentation.
2. The effectiveness of the intake dryer assembly of the TGA was evident. It sufficiently removed fluctuations of air temperature and water vapor yielding dry mixing ratio without corrections. The field noise performance matched the results from testing in a controlled laboratory environment.

References

1. Somers, J., Sargent S. (2015) A Novel Low-Power, High-Performance, Zero-Maintenance Closed-Path Trace Gas Eddy-Covariance System with No Water Vapor Dilution or Spectroscopic Corrections, AGU Fall Meeting Poster B33C-0668.
2. Brown, S.E., S. Sargent, J. Somers, and C. Wagner-riddle (2016) A Long-Term Field Trial of a Lower powered Eddy Covariance System for Measuring Nitrous Oxide Fluxes, 32nd Conference of Agricultural and Forest Meteorology.
3. Allan, D. W. (1966) Statistics of atomic frequency standards. Proc. IEEE 54: 221-231.
4. Burgon, R., Sargent, S., Zha, T. and 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.

Trace-Gas Analyzers: TGA300

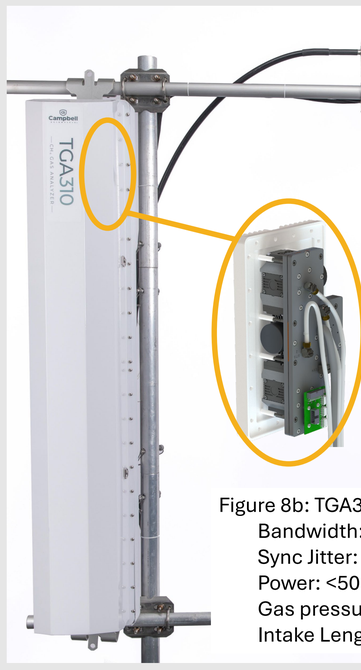

Figure 8a: The TGA300 operates at a higher sample cell pressure than earlier generations of TDLAS. Also, the gas pathways are designed with small diameters reducing the required volume of gas flow. The result is a miniaturized vacuum pump that is integrated inside the instrument and draws only a fraction of the power of its predecessors.

Figure 8b: TGA310/320 Specifications

Bandwidth: >3 Hz	Noise CH_4 : <7 ppb rms
Sync Jitter: ±10 ms	Noise N_2O : <1.5 ppb rms
Power: <50 W	λ CH_4 : 4534 nm
Gas pressure: 30 kPa	λ N_2O : 3221 nm
Intake Length: 5 m	

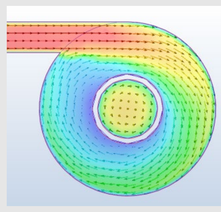

Figure 9: The vortex air cleaner reduces filter maintenance without impacting frequency response. Airborne particles are thrown to the outside of the vortex and carried away while the sample tube pulls cleaner air from the center of the vortex. (Burgon, et al. 2015)

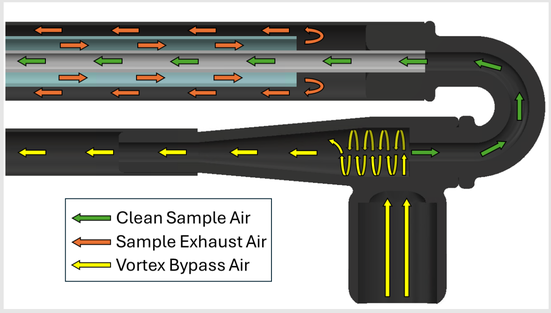

Figure 10: The external intake line houses a 4 m multi-layer dryer structure with a Nafion membrane tube at the center. After the vortex cleaner, sample air passes down the center of the Nafion tube. The opposite side of the tube has counterflow air provided by the exhaust sample air. The counterflow draws water out of the sample due to its lower pressure and higher temperature. More importantly, the dryer dampens the variations in water and temperature sufficiently to eliminate the need for a WPL correction. (Somers, et al. 2015)

Frequency Response and Fluxes

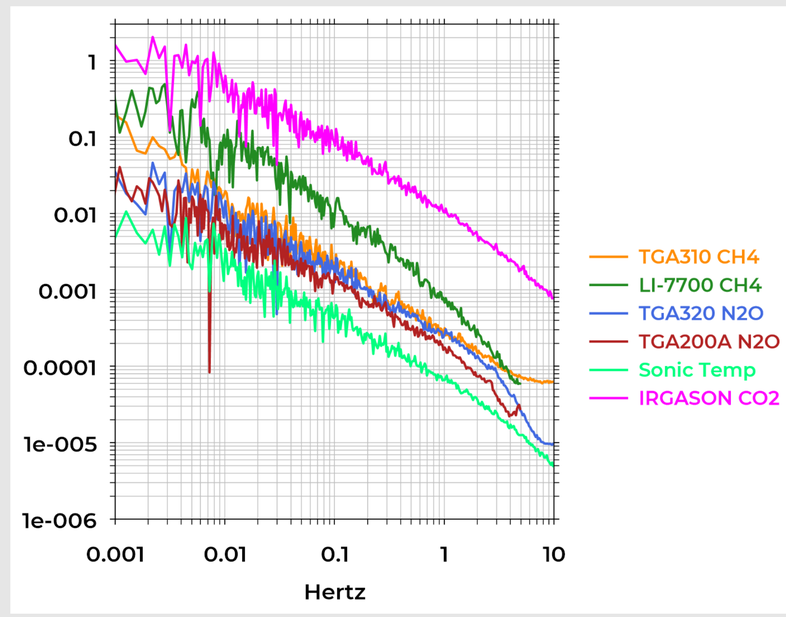

Figure 11: Normalized spectra for the gas analyzers and anemometer. This was examined during a period of high turbidity and available gas fluxes. For a spectral reference, the open-path IRGASON was used to measure sonic temperature and CO2 which both exhibit unattenuated frequency response to at least 10 Hz. The closed-path TGA300s show bandwidth beginning to roll off above 3-4 Hz. The response attenuation for the TGA200A becomes noticeable around 2.5 Hz. The LI-7700 starts attenuating around 0.5 Hz requiring a significant spectral correction to the fluxes.

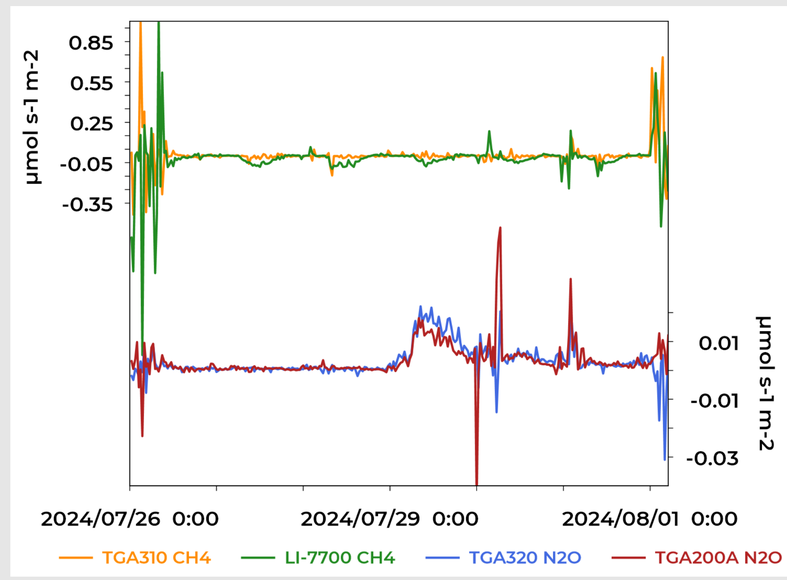

Figure 12: Shown is one week of fluxes calculated by each of the instruments. The TGA300s both used the IRGASON for the anemometer covariance, while the TGA200A and LI-7700 used the CSAT3B. This is given as a demonstration of reasonable flux results and the discrepancies between instruments can be largely attributed to a lack of refinement in the EddyPro processing setup. Detailed analysis of the flux data is the focus of separate studies.