Simultaneous Carbon Dioxide and Methane Eddy-Covariance Flux Measurements Using a High-Speed WS-CRDS Analyzer: *Field Comparisons to Conventional AmeriFlux Systems*

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Abstract

The well-known eddy-covariance flux method is commonly employed to study biogeochemical scalar fluxes of greenhouse gases between the land surface and the atmosphere. Its use has so far been limited mainly to flux measurements of CO_2 and water vapor due to the lack of adequate instrumentation for other greenhouse gases. The carbon exchange of gas species between terrestrial ecosystems and the atmosphere, particularly in areas with stagnant water or poorly drained and heavy soils, represents a substantial portion of the atmospheric budget of both CO_2 and methane (CH_4), and so quantifying such exchanges of both gases is critical in adding to our understanding of the carbon cycle. Recently, a novel closed-path analyzer has been evaluated against conventional instrumentation for performing not only CO_2 flux measurements, but for making simultaneous CO_2 and CH_4 flux measurements. We present field data evaluating the performance of a high-frequency fast-response (10Hz) gas analyzer based on Wavelength-Scanned Cavity Ring Down Spectroscopy (WS-CRDS) that was developed for simultaneous, dual-gas eddy-covariance flux measurements. The performance of this analyzer was evaluated in terms of what is required for appropriately high-quality measurements involving the exchange of both CO_2 and CH_4 between terrestrial ecosystems and the atmosphere. The WS-CRDS analyzer was deployed at Hyslop Crop Science Field Research Laboratory outside of Corvallis, OR and was compared in real-time with the AmeriFlux Portable Eddy Covariance System for measuring CO_2 fluxes using conventional infrared open- and closed path CO_2 and water vapor analyzers. Data comparing the performance of this WS-CRDS analyzer against this currently-used AmeriFlux instrumentation is presented.

Instrumentation

A 1st-generation 10-Hz eddy-covariance flux analyzer which simultaneously measures CO_2 and CH_4 was developed by Picarro and evaluated against both open- and closed-path NDIR-based CO_2 LiCOR analyzers. Both closed-path (Li7000) and open-path (Li7500) analyzers were used to compare to the closed-path Picarro instrument. For CH_4 however, no such instruments were available for comparison with the 10Hz CH_4 measurements made with the Picarro system. The Picarro analyzer is based on the existing WS-CRDS technology (described below) but has enhanced speed, enabling its application to flux measurements.

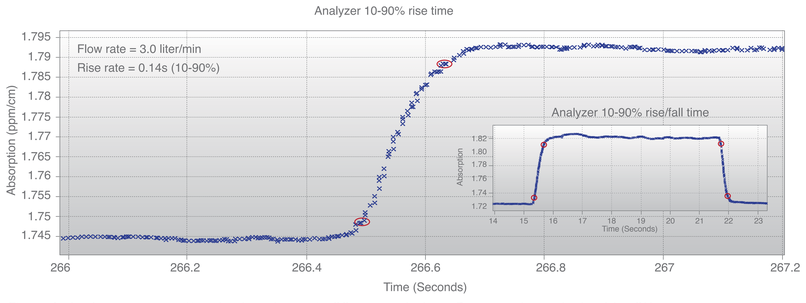


Figure 1. Analyzer response time to step change in CO_2 concentration. Response time identical for CH_4.

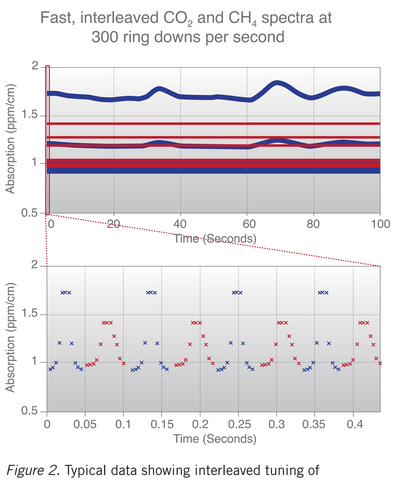


Figure 2. Typical data showing interleaved tuning of dual-laser system over CO_2 and CH_4 spectral lines used to measure concentration. Inset shows Individual ring down measurements taken at specific locations along each peak, actively targeted by wavelength monitor control loop.

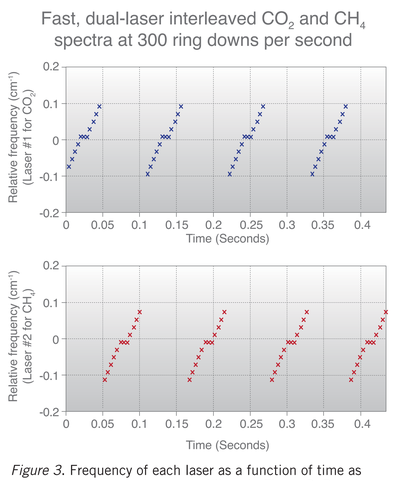
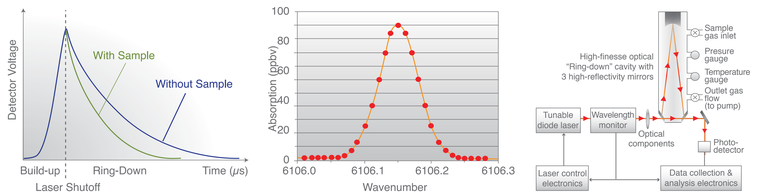


Figure 3. Frequency of each laser as a function of time as each is tuned across the spectral lines in Figure 2. Rapid switching between lasers allows high-speed measurements while maintaining high measurement precision.

Wavelength-Scanned Cavity Ring Down Spectroscopy (WS-CRDS) – How it Works



Light intensity as a function of time in a WS-CRDS system with and without a sample having resonant absorbance. This demonstrates how optical loss (or absorption by the gas) is rendered into a time measurement (left). By using a patented wavelength monitor, this measurement is continuously repeated at a number of well-controlled points in wavelength (right). The concentration is determined by a multi-parameter fit to this lineshape and is proportional to the gas concentration.

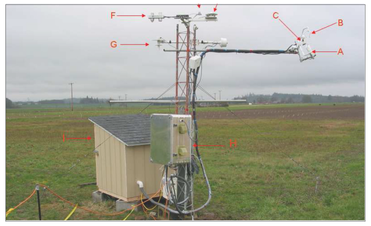


Figure 4. The field-site setup of the AmeriFlux portable system (PS) and the Picarro prototype analyzer at the Hyslop Crop Science Field Research Laboratory. The Picarro analyzer was housed in the weatherproofed box in the background (I), whereas the electronics and the closed-path infrared gas analyzer (Li7000) of the PS were located in the aluminum box in the foreground. Other instrumentation: anemometer (B), open-path Li7500 (A), closed-path Li7000 (C), radiometer (F), pyranometer (D), radiation sensor (E), temperature sensor (G), pressure transducer (H).

Figure 5. Close-up picture of the eddy-covariance complex consisting of sonic anemometer (Campbell Scientific CSAT3), open-path infrared gas analyzer (Licor, Li7500), and separate inlets for gas samples analyzed by the closed-path analyzers (Licor, Li7000; and Picarro). The inlet lines are protected from rain by a small funnel to prevent water droplets being sucked into the sample tube. The sample tube is insulated and heated over its entire length to dampen temperature fluctuations in the air stream and to prevent condensations when water vapor saturated air is sampled.

Field Measurements of CO_2 & CH_4 Flux

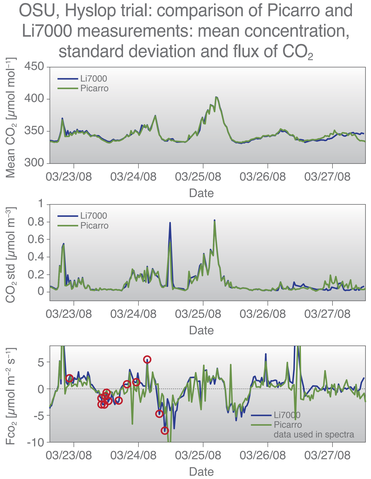


Figure 6. Time series plots of selected statistics and vertical flux of CO_2 for both closed-path analyzers. Circles in the bottom panel indicate data used in the computation of power- and cospectra in Figures 8 & 9.

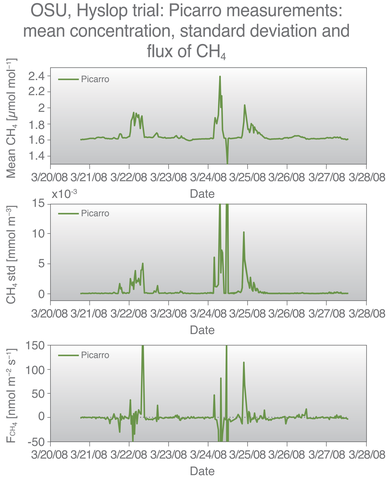


Figure 7. Time series plots of selected statistics and vertical flux of CH_4 for both closed-path analyzers. Circles in the bottom panel indicate data used in the computation of power- and cospectra in Figures 8 & 9.

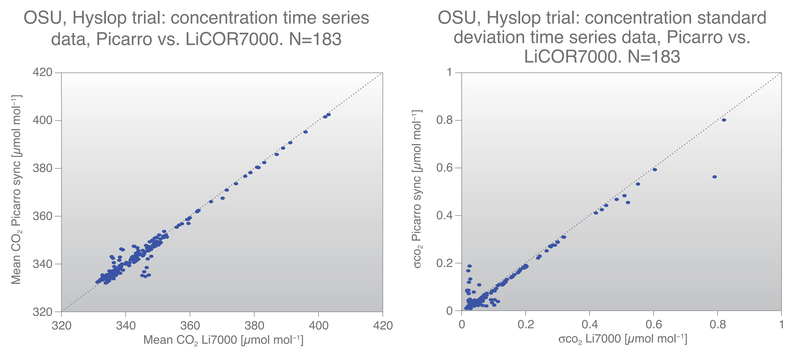


Figure 6a & 6b. Scatter plot of data shown as time series plot in Figure 6. The dotted lines indicate unity.

Data Analysis

Analysis of both the powerspectra of the and cospectra of the observables during the measurement campaign was carried out (results presented in figures below). These field results are also presented along with the theoretically-predicted characteristic features of atmospheric turbulence spectra. Overall, the observed discrepancies in the measurements between the analyzers (and deviation from ideal response) is attributable to differences in sample delivery which were addressed subsequent to this analysis. The loss in spectral energy at the highest frequencies arises through transport of the air sample through the tubing (in the case of the close-path analyzers) which results in attenuation of the smallest eddy sizes and therefore highest frequency perturbations. Higher flow rates, shorter tubing, and better tubing geometry can ameliorate this effect.

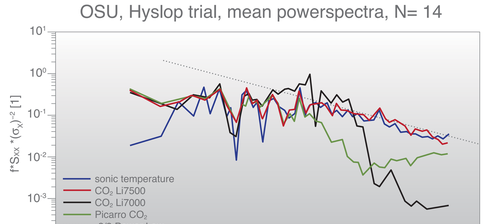


Figure 8. Mean, bin-averaged power-spectra of atmospheric turbulent variables of the selected fourteen 30-min periods used for spectral analysis. Spectral densities were multiplied by natural frequency f and normalized by their variances to check for spectral power laws. One expects a -2/3 power law in the spectral decay of power-spectra. The power spectral analysis for the methane data yields similar results. (The attenuated high-frequency response of the Li7000 beyond 1Hz is anomalous and likely due to inadvertent use of a cutoff filter.) The attenuated high-frequency response of the Picarro analyzer is likely due to insufficient sample flow rate through the instrument resulting in laminar rather than turbulent flow in the tubing and measurement cavity.

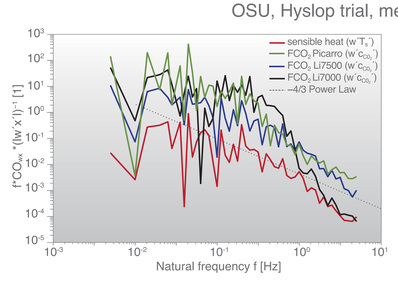


Figure 9. Mean, bin-averaged cospectra of turbulent fluxes of sensible heat and carbon dioxide (CO_2) using the signals from different gas analyzers. Spectral densities were normalized by their covariance. The dashed line indicated the expected -4/3 power law of cospectral decay.

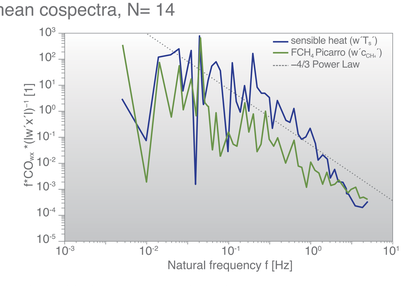


Figure 10. Same as Figure 9 but for turbulent methane fluxes. No other methane flux instrument similar to the Li7000 was available to enable a comparison (similar to that in Figure 8) to the Picarro methane data.

Summary & Conclusions

- Setup and operation of Picarro analyzer is remarkably straight-forward, no long-term drift of the mean concentrations of CO_2 and CH_4. No repeated field calibrations were necessary
- Spectrally integrated statistical moments (mean, variance, etc.) agree very well over the entire measurement period when compared to the Li7500 and Li7000
- Flux estimates for CO_2 in Picarro prototype are significantly less than those of the Li7000 by approximately 30% due to a poor spectral response in the frequency range beyond 0.2 Hz due to the attenuation from the non-fully turbulent flow in the sampling tube
- Sampling system is currently being redesigned to keep flow turbulent
- Precision of instrument (230 ppbv CO_2, 1.2 ppbv CH_4 in 0.1s) appears adequate for measuring fluxes from a wavelet analysis of magnitudes of concentration fluctuations