Surface-Atmosphere CO₂ Exchange in a Northern Hardwood Forest: Evaluation of an Open-Path Eddy Covariance Instrument

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Abstract: Carbon exchange measurements within northern forested ecosystems are needed to address the functional diversity within these ecosystems and to assess their response to changing environmental situations, including climatic change. Towards this goal, we report here initial evaluations of an advanced sensor under development by Physical Sciences, Inc. (PSI; Andover, MA) that provides simultaneous eddy covariance-based measures of ambient ¹²CO₂, ¹³CO₂ and H₂O fluxes between the surface and the atmosphere. Based on advanced TDL (tunable diode laser) and signal processing technologies, this field-portable sensor offers capabilities to address process-level studies of ecosystem functioning beyond that currently available.

Introduction: Climatic change projected over the next several decades is expected to dramatically impact the structure, carbon dynamics and ecological functioning of northern forests on regional to global scales. In anticipation, various national and international programs have called for the development of improved data sets characterizing surface-atmosphere interactions that influence or are a measure of process-level dynamics in these ecosystems. The prototype instrument developed by PSI is one of the first of a new generation of sensors that can contribute to such high quality databases.

Background: Although the eddy covariance technique represents the only direct measure of surface-atmosphere exchange, technological challenges have limited its application to only a few biogeochemical trace gas species. Spectroscopic approaches based on the use of tunable diode lasers offer the promise of numerous advantages over existing sensor technologies. To this end, Physical Sciences, Inc. has integrated a near-IR diode laser absorption spectrometer with an open-path in situ probe. By taking advantage of evolving laser, fiber optic, detector and signal processing technologies, PSI has developed a prototype field-portable instrument that operates at ambient temperatures, has low power demands and which can be configured to many applications.

Methods: Field measurements were carried out in a mature northern hardwood forest managed by UVM’s Proctor Maple Research Center. Eddy covariance measurements were made ~7-8m above the canopy from a 24m aluminum walk-up tower (right). Fast response (10Hz) measures of CO₂, water vapor, heat, and momentum fluxes were made using PSI’s prototype instrument, LiCOR’s open-path, non-dispersive near-IR sensor (Model 7500) and a commercial sonic anemometer (Applied Technologies, Inc.).

Results: Field results from 2002 demonstrated the successful integration of the data acquisition, TDL sensor and commercial micrometeorological modules to monitor ¹²CO₂ and H₂O fluxes. Sensitivity (power spectra) and precision measures were well within predetermined tolerances for both PSI and LiCOR instruments. PSI measured rates of CO₂ uptake by the forest canopy correlated well with coincident measures of incident photosynthetically active radiation (Figure 1). Differences in measured fluxes between the PSI TDL and LiCOR NDIR instruments, however, were often significant (Figure 2) suggesting one or both require further evaluation. Additionally, the results demonstrated an over-sensitivity of the prototype PSI sensor to scattered sunlight and that ¹³CO₂ absorption was insufficient at the wavelength chosen for quantitative analyses at ambient concentrations.

Conclusions and Outlook: Initial results suggest that the advantages offered by TDL technologies to measure trace-gas ambient fluxes in situ are close at hand. Measurement issues remaining with the PSI instrument are being addressed. To date, an isolated and stronger ¹³CO₂ absorption line has been selected, the appropriate laser procured and the detector configuration redesigned. Additionally, discussions are underway to identify observed differences between the responses of the PSI and LiCOR instruments, to extend the instrument to additional gas species, and to design follow-on field evaluations.

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