CARBON DIOXIDE EFFLUX FROM THE FOREST FLOOR IN A DECIDUOUS FOREST IN JAPAN -- AN IMPROVED METHOD OF FLUX CALCULATIONS BASED ON THE CO_2 SENSOR RESPONSE

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ABSTRACT

Some infrared CO_2 sensors, such as GMD20 and GMT222 (VAISALA), are widely used for soil CO_2 efflux measurements despite the fact they have a slow response rate. The output signal is delayed both from diffusion processes in the sample cell and internal averaging calculations necessary for stable data output. For accurate estimations of CO_2 efflux, we therefore need to know the actual increase in CO_2 concentration in a chamber without composite delays. To parameterize these delays, we conducted laboratory experiments to determine the response characteristics of sensors under diffusion and flow-through conditions. Next, we developed a backward calculation method for estimation of the actual CO_2 concentration increase using the delayed sensor output (BCDC: Backward calculation for delay compensation). The results showed that the slow response of sensors caused large estimation errors in CO_2 efflux measurements. In the case of GMT222, a 10% underestimation was suggested when the soil CO_2 efflux was calculated with non-corrected data using a nonlinear regression method with sampling intervals of 300 seconds. Thus, correction of the sensor response with a backward estimation might be effective. We also calculated and evaluated the CO_2 efflux from a forest floor in a deciduous forest employing the BCDC method.

INTRODUCTION

A large number of sampling points are required to estimate a representative value of the soil CO_2 efflux in a forest because of the high spatial variability. Although small infrared CO_2 sensors are conveniently used in the chamber method, some sensors have a slow output response. This slow response becomes a problem when the soil CO_2 efflux is calculated using the increasing CO_2 concentration in the chamber. In this study, we conducted laboratory experiments to determine the response characteristics of sensors and investigated a method of backward calculation for estimating the actual increase in CO_2 concentration from the delayed sensor output. Field experiments were also conducted and the soil CO_2 efflux in a deciduous forest was evaluated.

SITE AND METHODS

Kawagoe forest meteorology research site is located at 35°52'N and 131°29'E on a flat area of land with an elevation of 30m [*Mizoguchi et al*., 2003]. CO_2 efflux measurements were conducted four times using a CO_2 sensor (GMT222, Vaisala) and large chambers 20cm in diameter from May 2001 to February 2002. The output signal of the CO_2 sensor includes delays both from diffusion processes in the sample cell and internal averaging calculations necessary for stable data output. Laboratory experiments on the response characteristics of sensors were conducted under diffusion and flow-through conditions. First, the sensor was set in a calibration tube, which was consequently filled with low concentration standard gas (C_0 ppm). Next, the gas was replaced by higher concentration gas (C_1 ppm) under a flow-through condition. In the diffusion condition, the high concentration gas was injected into the tube using a syringe. The output signals of the sensor were expressed by the following equation and the constants, a and b, were calculated by the least squares method:

$$k_t = k_t'(1-\exp(-aT))$$

where $k_t = (C_{t+b} - C_0)/(C_1 - C_0)$, $k_t' = (C_t' - C_0)/(C_1 - C_0)$, and C_t' is the expected concentration in the tube if the output of the sensor is not delayed.

RESULTS AND DISCUSSION

Fig.1 shows the results of the response experiments under diffusion and flow-through conditions. The constants, a and b, of GMT222 under the diffusion condition were 0.015 and 17s, respectively (R^2=0.80) while under the flow-through condition they were 0.057 and 23s, respectively (R^2=0.97). The response time of GMT222 under the flow-through condition was shorter than that under the diffusion condition.

The F_{obs} / F_{exp} ratio was compared between measuring intervals (*dt*) (Table 1), where F_{obs} is the CO_2 efflux calculated with the sensor output and F_{exp} is the CO_2 efflux calculated with the expected concentration in the chamber under the diffusion model. The maximum ratio calculated using linear regression was 0.81 at *dt* = 300s. The maximum ratio calculated using nonlinear regression was 0.99 at *dt* = 1800s. A long measuring interval reduces errors in the case of nonlinear regression; however, it is inefficient and sometimes has a negative effect because the chamber is closed for a long time and thus the chamber environment changes.

The soil CO_2 efflux in a deciduous forest was also calculated and the F_{obs} / F_{exp} ratios on each observation date were compared (Table 2). The measuring interval, *dt*, was 120s and the efflux was calculated using nonlinear regression. The efflux calculated with the sensor output was smaller than that calculated with the modified CO_2 concentration, suggesting that the efflux calculated using the sensor output is an underestimate.

Tables 1 and 2 suggest that a short measuring interval leads to soil CO_2 efflux underestimates when the efflux is calculated with non-corrected data using nonlinear regression. Thus, correction of the sensor response with a backward estimation might be an effective solution.

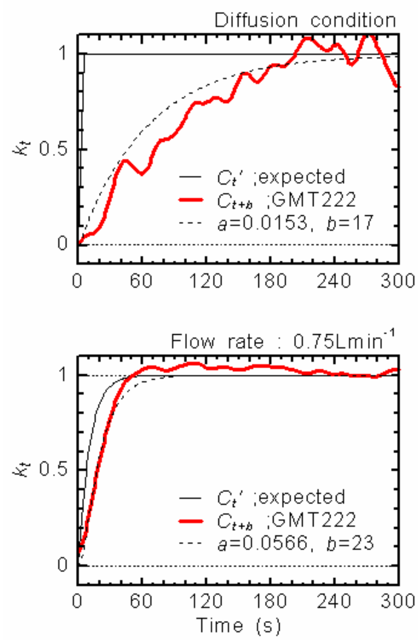

Fig.1 Comparisons of the sensor outputs in the response experiments and the CO_2 concentrations estimated using the proposed equation (see text for details)

dt (s)	Linear method	Nonlinear method
60	0.338	0.192
120	0.647	0.527
300	0.811	0.896
600	0.736	0.962
1200	0.578	0.983
1800	0.462	0.989

Table 1. The F_{obs} / F_{exp} ratio of the CO_2 efflux calculated with the sensor (F_{obs}) and that calculated using the ideal concentration in the chamber under the diffusion model (F_{exp})

Date	F_{obs} ($mgm^{-2}s^{-1}$)	F_{exp} ($mgm^{-2}s^{-1}$)	F_{obs} / F_{exp}
May 28,2001	0.176	0.220	0.841
Aug. 23,2001	0.197	0.275	0.749
Nov. 20,2001	0.096	0.143	0.797
Feb. 19,2002	0.056	0.063	0.830

Table 2. Soil CO_2 efflux in the forest and comparisons of F_{obs} and F_{exp}.

REFERENCE

Mizoguchi, Y., Ohtani, Y., Watanabe, T., Yasuda, Y., and Okano, M. (2003), Long-term continuous measurement of CO_2 efflux from a forest floor using dynamic closed chambers with automatic opening/ closing capability (in Japanese with English summary), *Jpn. J. Ecol.*, *53*, 1-12.