Can CO_2 concentration at one level of eddy covariance measurement be used to estimate storage term over forest?

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CO_2 concentration profile was measured to investigate whether CO_2 concentration at one level (i.e., eddy covariance measurement level) can be used to estimate storage term without significant uncertainty at broadleaf deciduous forest at Kwangneung experiment forest in Korea. Based on t-test with significance level of 5%, there was no statistical difference between storage term from one-level CO_2 concentration and one from CO_2 profile measurement. Storage term constitutes on average 5% of half hourly net ecosystem exchange (NEE) even at unstable stability (i.e., well mixed condition), indicating that storage term should be considered even at daytime, which is sometimes neglected.

Key words: Net ecosystem exchange, Eddy covariance method, Storage term, Forest

1. Introduction

Net ecosystem exchange (NEE) is a net loss or net gain of atmospheric carbon by ecosystem. Eddy covariance method has been used to quantify NEE based on conservation equation at various ecosystems through FLUXNET[2]. When the budget equation is applied to forests, storage term (which is neglected over short vegetation) may be significant in evaluating NEE, especially at nighttime under stable condition[4]. It requires practically much effort to compute storage term through measurement of CO_2 concentration profile. That is why storage term has been estimated from CO_2 concentration at one level (i.e., eddy covariance system level) at some sites[3]. While its contribution to NEE could be negligible when NEE is integrated over long term, compared to turbulent CO_2 flux term, it may be important when NEE is parameterized with controlling factors such as light or air temperature using half-hourly NEE. Therefore it needs to examine whether there is any significant difference between storage term evaluated by CO_2 concentration at eddy covariance level (F_{s_s}) and one evaluated by from CO_2 profile measurement (F_{s_m}). The objective of the study is to examine whether CO_2 concentration at eddy covariance system level can be used to estimate storage term over temperature broadleaf deciduous forest at Kwangneung experiment forest in Korea.

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2. Experimental Methods

2.1 Theoretical consideration

The CO_2 storage equals the integration, with respect to height, of the time rate of change of the CO_2 concentration profile:

$$F_{storage} = \int_0^{z_r} \frac{\partial \rho_c(z)}{\partial t} \partial z \qquad (1)$$

where, ρ_c is CO_2 density (mgm^{-3}), z_r is the measurement height of eddy covariance system and t is the time. In practice the time derivatives is approximated using finite differences between two successive concentration measurements and the integral is approximated as the sum of CO_2 at multiple levels as below[1].

$$F_{storage} \approx \frac{\Delta \rho_c(z)}{\Delta t} z_r \qquad (2)$$

2.2 Site description

The measurement site is located at Kwangneung experiment forest near Seoul, Korea (37° 45' 25.37" N, 127° 9' 11.62" S: elevation 340 m). The terrain around the tower site has a valley-like topography with ~ 10% slope along the eastwest direction. Adequate fetch (of about 2km) is limited to east wind (90°±45). The forest has not been disturbed since mid 15^{th} and the age of trees ranges from 60 to 400 years. Main species are *Quercus serrata* and *Carpinus laxiflora* and the mean canopy height is 18m. More detailed description on canopy structure, species composition and soil properties are given in other papers[5].

2.3 Measurements

Half-hourly turbulence fluxes of CO_2, water vapor and sensible heat together with the corresponding concentrations have been measured above the forest by eddy covariance method since mid September in 2001. Eddy covariance system is consisted of a fast response three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc.) and an open-path infrared gas analyzer (LI7500, LI-COR) and was installed on a 30-m walk-up tower (i.e. 31m measurement level). Sampling rate is 10Hz and half-hourly fluxes and concentrations are calculated on-line and recorded at a data logger (CR5000, Campbell Scientific Inc.). For CO_2 profile measurement, three closed-path infrared gas analyzers (LI7600, LI-COR) were installed at 16, 8 and 0.7 m above the forest floor at 1800 on July 10, 2003 and operated until 0500 on July 12. CO_2 concentration was sampled every five-minute and averaged over half hour. Before measurement, they were zero- and span-calibrated and the uncertainties for the concentration measurement were less than 1%.

2.4 t-test

To evaluate whether there is statistical difference between F_{s_s} and F_{s_m}, we apply t-test whose null hypothesis is $F_{s\_s} = F_{s\_m}$. Since CO_2 concentration at eddy covariance system level is used in calculation of both F_{s_s} and F_{s_m}, F_{s_s} and F_{s_m} are not independent each other. Therefore, we use new variable, d defined by the difference between F_{s_s} and F_{s_m} and calculate

$$t = \frac{\bar{d}}{s_d \sqrt{n}}, p = P[T \geq t]$$

where $\bar{d} = 1/n \sum_{i=1}^{n} d_i$ and $s_d = 1/\sqrt{(n-1)} \sum_{i=1}^{n} (d_i - \bar{d})$ accept the null hypothesis if p-value is larger than 0.0025, which sets the significance level at 5%. The symbol t and p are used here following common statistical practice.

3. Results and Discussion

During the study period, wind blew from SE ~ SW with wind speed of 1 ~ 3m/s at 0730 ~ 1430 on July 11. Wind from NE was the dominant with wind speed of 0~2m/s at the remaining periods (Fig. 1). Since the study site has enough fetch to the east, NEE is evaluated when wind blows from the east. Therefore, the main target period is from 0730 to 1430 on July 11, when wind direction is 78 ~ 120°. However, since storage term plays a more important role in NEE at nighttime, same analysis will be made for nighttime data, independently. From 0730 to 1430 on July 11, wind speed is stronger in the afternoon than that in the morning. Since $2ms^{-1}$ has been used as criteria to evaluate the quality for turbulence flux data, additional analysis will be performed under wind speed with < $2ms^{-1}$. For comparison between storage terms, the whole period is divided into four cases. Case 1 corresponds to the period with 0700 ~ 1430 on July 11 and Case 2 to 0700 ~ 1200, when wind is relatively weak. Case 3 and 4 correspond to nighttime period and are separated, depending on the number of measurement levels; three levels for Case 3 and four levels for Case 4 since measurement at 0.7 m high were not made over some period.

Fig. 2 shows the diurnal variation of CO_2 concentration profile. While CO_2 concentration changes significantly with time and with height at upper three levels, CO_2 concentration near forest floor is always higher than ones at the other levels due to active emission of CO_2 emission from the surface. The variability of CO_2 concentration at 16 m level is the largest due to photosynthesis at daytime and respiration from leaves, where leaf area index is the maximum. Since storage term is based on the rate of change of concentration, measurement near maximum leaf area index should be considered in evaluating storage term.

The variations of two storage terms for Case 1 are shown in Fig. 3a. During this period, there was no measurement of CO_2 concentration at 0.7 m level. Therefore, during this period, F_{s_m} is evaluated from CO_2 concentrations at three levels (31, 16 and 8 m). Computed storage term is less than 0.1 $mgm^{-2}s^{-1}$ in absolute magnitude. There is good agreement between two storage terms. From 1300 to 1430, when wind speed is larger than 2

ms^{-1}, two storage terms are about 0 in magnitude.

Fig. 3b shows variations of NEE. Fco_2 indicates NEE without storage term, $NEE_{31} = Fco_2 + F_{s\_s}$, $NEE_{31\_8} = Fco_2 + F_{s\_m}$. While Fco_2 is in the range of -0.1 ~ -1.0 $mgm^{-2}s^{-1}$, NEE_{31_8} is 88 ~ 130 % of Fco_2 and storage term results in on average 6% increase, compared to Fco_2. This means that storage term is important in evaluating NEE even at unstable stability.

Table 1 summarizes statistics related with t-test case by case. Since p-values are larger than 0.0025 for all cases, we accept the null hypothesis, indicating that there is no ground to judge that there is any difference between two storage terms and CO_2 concentration at eddy covariance level can be used to evaluate storage term. It is encouraging that there is no statistical difference between F_{s_s} and F_{s_m} under week wind speed indicating that the criteria for quality test for turbulence fluxes may be lowered to 1 ms^{-1} and more turbulence fluxes under wind speed with < 2 ms^{-1} can be available in evaluating NEE without significant uncertainty at the study site. In addition, although there were no data at nighttime when wind blew from around the east, comparison between two storage terms under different wind direction may give us justification to use storage term using CO_2 concentration at eddy covariance measurement level.

Fig. 4 shows that the difference between two storages divided by NEE Even though there is no difference between two storages in terms of statistics, there is difference on half-hourly time scale and it is required to quantify them. In half-hourly time scale, the difference amounted up to 15% of NEE for some cases.

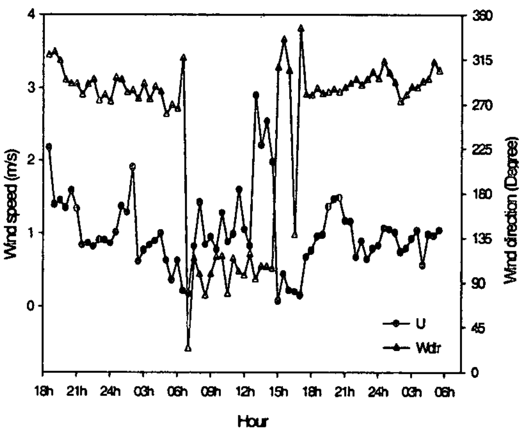

Fig. 1 Wind direction and wind speed during the whole period

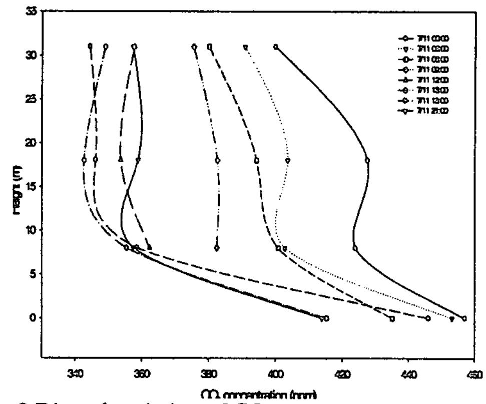
Fig. 2 Diurnal variation of CO_2 concentration profile

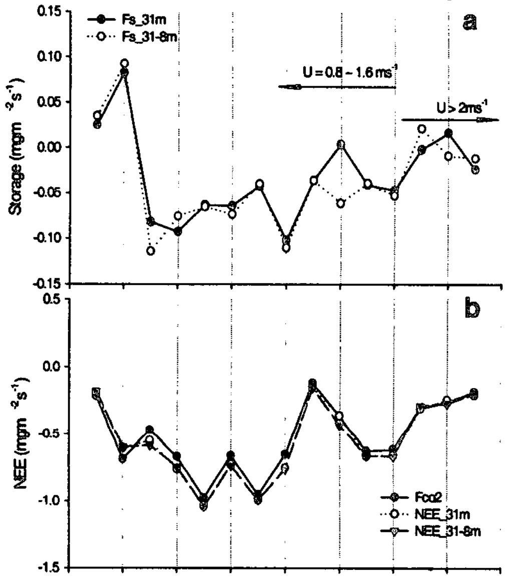

Fig. 3 The variations of two storage terms (a) and NEE with storage term and without storage term with time (b)

4. Conclusions

CO_2 profile at three or four levels was made with addition of additional closed path infrared gas analyzer to the existing eddy covariance system. Based on t-test with significance level of 5%, there is no ground that there is any difference between two storage terms, indicating that CO_2 concentration at eddy covariance level can be used to evaluate storage term. Storage term constitutes on average 5% of half hourly net ecosystem exchange (NEE) even at unstable stability (i.e., well mixed condition), indicating that storage term should be considered even at daytime, which is sometimes neglected.

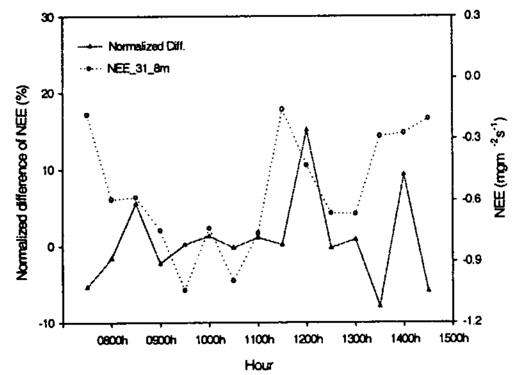

Fig. 4 Variations of normalized difference between two storage terms by NEE and the corresponding NEE

Table 1. Summary of statistics related with t-test with significance level of 5%.

Case	*n*	$\bar{d}$	s_d	*t*	*p*
D1	15	0.005	0.022	0.841	0.41
D2	11	0.007	0.023	0.992	0.34
N1	24	0	0.029	-0.148	0.88
N2	20	0.009	0.060	0.684	0.50

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