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CO_2 Flux Measured by an Open-path System Over a Larch Forest During the Snow-covered Season

By

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Key words: NEE (net CO_2 exchange), energy balance, open-path system, snow-covered season, WPL correction.

Summary

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In the northern part of Japan, snow covers the land for several months in winter. It is necessary to estimate the CO_2 flux during the snow-cover season to evaluate annual net CO_2 exchange between the atmosphere and ecosystems (NEE); CO_2 flux is probably small because of snow accumulation and low temperature. This paper reports NEE, as measured using an open-path system (NEE_O) over a larch forest during the snow-cover season. NEE_O ranged from -2 to -6 µmol m^{-2} s^{-1} under sunshine conditions, whereas NEE measured with a closed-path system was always slightly positive. Such negative NEE_O was unexpected because the forest canopy had no leaves and floor vegetation was under snowpack. One reason for negative NEE_O under sunshine conditions is that the CO_2 resolution of the open-path analyzer was low when CO_2 fluctuation was small. During the snow-cover season, eddy energy flux accounted for 70% of available energy. Therefore, incomplete WPL correction of CO_2 flux resulting from underestimated sensible heat flux would partly explain the unexpected negative NEE_O.

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Introduction

In Japan's northern areas, snow covers the land for several months in winter. Therefore, it is necessary to estimate CO_2 flux during the snow-cover season to properly evaluate annual net CO_2 exchange between the atmosphere and ecosystems (NEE). The CO_2 flux is probably small because of snow accumulation and low temperature. However, unexpected negative NEE have been measured frequently using the eddy covariance technique with an open-path system above a larch forest on sunny days during the snow-cover season. We examine the winter negative NEE through comparison with NEE measured with a closed-path system. Thereby, we investigate the cause of such unexpectedly negative NEE.

Material and Methods

Site description

The study site was the Tomakomai FRS, a Japanese larch (*Larix kaempferi* Sarg.) plantation in Tomakomai, Hokkaido, Japan (42°44'N, 141°31'E). The terrain was almost flat, with a slope between 1° and 2°. The larch forest area was about 100 ha; its canopy height was 15–16 m. The canopy LAI reached about 5.5 $m^2\ m^{-2}$ at the maximum in summer. The site had scattered deciduous broadleaf trees (*Betula ermanii*, *Betula platyphylla*, and *Ulmus japonica*) and sparsely distributed spruce (*Picea jezoensis*). A 42-m tower was built near the forest center for flux and meteorology measurements. The fetch was between 300 m for the north and 800 m for the west; it was 350 m for the south, which was the dominant wind direction. The forest floor was covered thickly with understory species, which mainly comprised fern (*Dryopteris crassirhizoma*) and *Pachysandra terminalis* with maximum height of 0.9–1.4 m and maximum LAI of 3.6 $m^2\ m^{-2}$ in July. HIRANO & al. 2003 described site characteristics in detail. The forest canopy had few leaves during the snow-cover season because of defoliation. The forest floor was covered with snow continuously from 30 November 2001 to 1 April 2002 and from 17 December 2002 to 19 April 2003 (TANAKA & al. 2003). The snow depth was 0.5–1.0 m from January through March 2003.

Flux measurements

Since 2000, the eddy covariance technique has been used to measure NEE, sensible heat flux (*H*) and latent heat flux (lE) over the canopy (HIRANO & al. 2003). Wind speed and virtual temperature were measured with a 3D sonic anemometer-thermometer (DA600; Kaijo Corp.), and CO_2 and water vapor densities were measured with open-path and closed-path CO_2/H_2O analyzers (LI7500 and LI6262; Li-cor Inc.) at 27 m height. The open-path analyzer was calibrated approximately every 2 mo using CO_2 gas standards (0 and 500 ppm). The closed-path analyzer was calibrated once a day with CO_2 gas standards (320 and 420 ppm) (WANG & al. 2004). Data were sampled at 10 Hz through a low-pass filter with a cut-off frequency of 5 Hz; half-hourly averages of fluxes were calculated without trend removal. Double rotation and WPL corrections (WEBB & al. 1980) were applied, and sensor span and separation between sensors were corrected. Net ecosystem CO_2 exchange (NEE) was calculated as the sum of CO_2 flux and CO_2 storage change in spaces below the flux measuring height. HIRANO & al. 2003 described details of flux and meteorological measurements. WANG & al. 2004 provides closed-path system details.

Results and Discussion

We found an important discrepancy in NEE results for open-path and closed-path systems during the snow-cover season. Fig. 1(a) shows a typical example of diurnal variation in half-hourly mean NEE. NEE measured with the open-path system (NEE_O) often ranged between -2 and -6 μmol m^{-2} s^{-1} in sunshine, whereas NEE measured with the closed-path system (NEE_C) was always slightly positive (1–2 February 2002). CO_2 storage change was small during the daytime within ±0.6 μmol m^{-2} s^{-1}; we used it to calculate both NEE_O and NEE_C. As a result, the negative NEE was attributable to open-path CO_2 flux. CO_2 release by respiration from soil and stem was measured using the chamber method, even during the snow-cover season (MALHI & al. 1999). Moreover, the forest canopy had no leaves except for those of a few spruce trees; floor vegetation was covered by the snowpack. For that reason, such negative NEE above the canopy was unexpected. Fig. 1(b) shows diurnal variations in half-hourly mean energy fluxes. *H* accounted for most net radiation; consequently, WPL correction depended on *H*. Variation of NEE_O before WPL correction (Fig. 1(a)) is a mirror-image of that of *H* in the daytime.

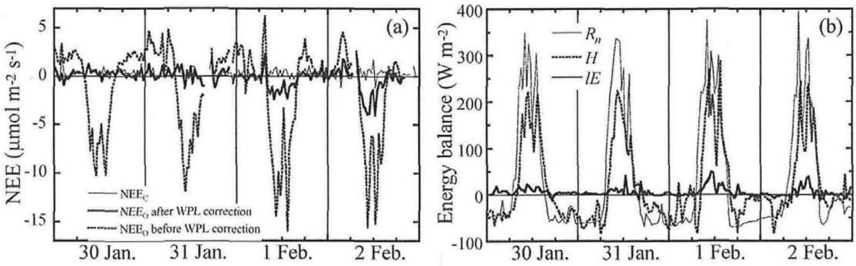

Fig. 1. Diurnal variations in (a) half-hourly mean NEE measured with open-path (NEE_O) and closed-path systems (NEE_C), (b) half-hourly mean net radiation (R_n), sensible heat flux (*H*), and latent heat flux (lE), on sunny days, 30 January to 2 February 2002, in the snow-cover season.

Fig. 2 shows 5-min time series of (a) virtual temperature, (b) open-path CO_2 density before WPL correction, (c) open-path CO_2 density after WPL correction, and (d) closed-path CO_2 density. Fluctuations in CO_2 density before WPL correction and virtual temperature showed similar ripples, but reverse. This similar pattern shows that CO_2 density fluctuations before WPL correction were considerably affected by air density fluctuations caused by temperature fluctuations. On the other hand, both fluctuations in open-path CO_2 density after WPL correction and closed-path CO_2 density were small and obscure. During the sunny daytime in the snow-cover season, the open-path CO_2 flux was a small difference between two relatively large fluxes: CO_2 flux before WPL correction and WPL correction term, which have reverse signs. If WPL correction is incomplete because of *H* underestimation, the CO_2 flux will be negative even though there is no CO_2 sink on the ground. Moreover, the CO_2 resolution of the open-path analyzer should be low when CO_2 the fluctuation is small.

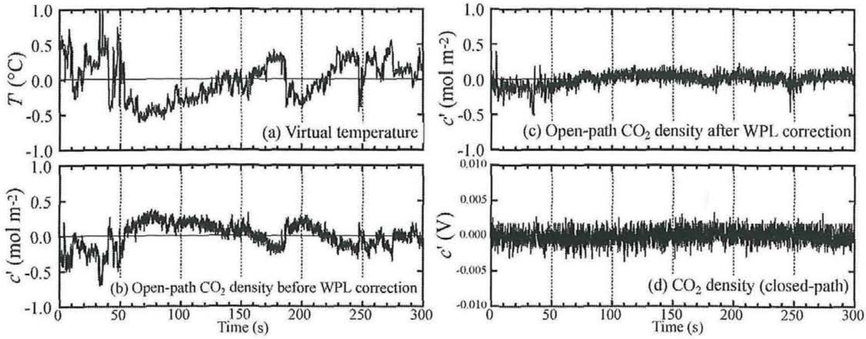

Fig. 2. Time series of (a) virtual temperature, (b) open-path CO_2 density before WPL correction, (c) open-path CO_2 density after WPL correction and (d) closed-path CO_2 density for 5 min from *1000* to *1005* on *1* February 2002. Closed-path CO_2 density was not WPL-corrected. Data were sampled at 10 Hz through a low-pass filter with cut-off frequency of 5 Hz. Half-hourly mean NEE estimated from the open- and closed-path data between 1000 and 1030 were -2.41 and 0.81 $\mu mol\ m^{-2}\ s^{-1}$, respectively.

In the snow-cover season, energy balance closure was about 70% based on a half-hourly mean, whereas it was almost closed in the snow-free season. The latent heat of snowmelt and freeze was negligible (KODAMA 2001). H calculated from the virtual temperature from the 3D sonic anemometer-thermometer was identical with air temperature from a thin t hermocouple thermometer. Additional H of 50–60 W m^{-2} was necessary to pull NEE_O from negative to positive on an average around noon. The difference between NEE_C and NEE_O was about 2.5 $\mu mol\ m^{-2}\ s^{-1}$. The daily maximum R_n was about 300–400 W m^{-2}. Therefore, the missing eddy energy flux was about 90–120 W m^{-2}. If H and lE were adjusted for energy balance closure (TWINE & al. 2000), NEE_O and NEE_C would become almost equal. Therefore, incomplete WPL correction of CO_2 flux resulting from underestimated H would at least partially explain the unexpected negative NEE_O.

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