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CO₂ 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 CO₂ 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 CO₂ flux during the snow-cover season to evaluate annual net CO₂ exchange between the atmosphere and ecosystems (NEE); CO₂ 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 $\mu\text{mol m}^{-2} \text{s}^{-1}$ 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 CO₂ resolution of the open-path analyzer was low when CO₂ fluctuation was small. During the snow-cover season, eddy energy flux accounted for 70% of available energy. Therefore, incomplete WPL correction of CO₂ 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 CO₂ flux during the snow-cover season to properly evaluate annual net CO₂ exchange between the atmosphere and ecosystems (NEE). The CO₂ 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 m² 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 understorey 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 m² 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 CO₂ and water vapor densities were measured with open-path and closed-path CO₂/H₂O analyzers (LI7500 and LI6262; Li-cor Inc.) at 27 m height. The open-path analyzer was calibrated approximately every 2 mo using CO₂ gas standards (0 and 500 ppm). The closed-path analyzer was calibrated once a day with CO₂ 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 CO₂ exchange (NEE) was calculated as the sum of CO₂ flux and CO₂ 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 exam-

ple of diurnal variation in half-hourly mean NEE. NEE measured with the open-path system (NEE_O) often ranged between -2 and $-6 \mu\text{mol m}^{-2} \text{s}^{-1}$ 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 $\pm 0.6 \mu\text{mol m}^{-2} \text{s}^{-1}$; 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 day-time.

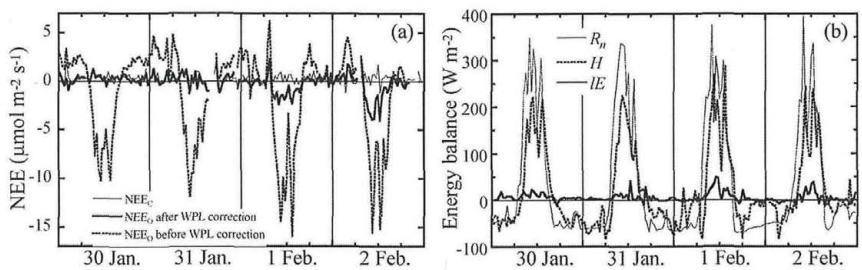


Fig. 1. Diurnal variations in (a) half-hourly mean NEE measured with open-path (NEE_O) and closed-path systems (NEE_C), (b) half-hourly mean net radiation (R_n), sensible heat flux (H), and latent heat flux (LE), on sunny days, 30 January to 2 February 2002, in the snow-cover season.

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.

(350)

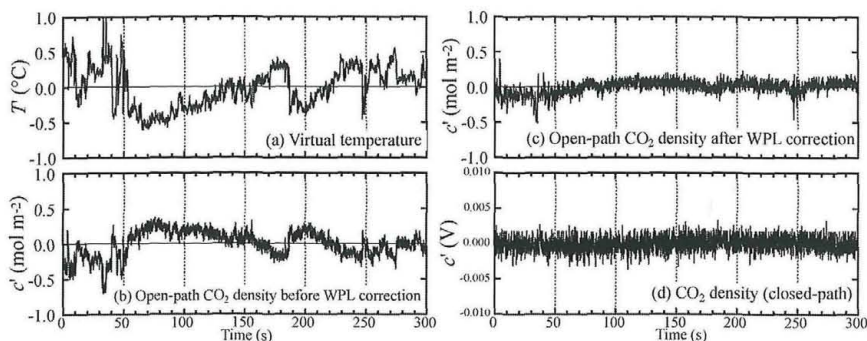


Fig. 2. Time series of (a) virtual temperature, (b) open-path CO₂ density before WPL correction, (c) open-path CO₂ density after WPL correction and (d) closed-path CO₂ density for 5 min from 1000 to 1005 on 1 February 2002. Closed-path CO₂ density was not WPL-corrected. Data were sampled at 10 Hz through 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 $\mu\text{mol m}^{-2} \text{s}^{-1}$, 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 thermocouple 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 $\mu\text{mol m}^{-2} \text{s}^{-1}$. 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 IE were adjusted for energy balance closure (TWINE & al. 2000), NEE_O and NEE_C would become almost equal. Therefore, incomplete WPL correction of CO₂ flux resulting from underestimated H would at least partially explain the unexpected negative NEE_O .

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