B-4.3 Improvement of Carbon Budget Evaluation at Forest Ecosystem by Means of Micrometeorological Methods

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Abstract

Eddy correlation method is used worldwide as a standard technique to measure CO_2 exchange between terrestrial ecosystems and the atmosphere in flux network sites such as Ameriflux, EUROFLUX and AsiaFlux. In order to improve the evaluation of carbon budget in forests, we examined practical problems of eddy correlation method in data processing, analysis and corrections. Eddy correlation data collected at 41 m height of Tomakomai flux research site (42°44'N, 141°31'E, 115-140 m ASL, Larch forest) using an open-path infrared gas analyzer were provided for the study, and the following results were found: 1) Accurate zero adjustment of sonic anemometer is required to apply coordinate rotation. 2) Trend removal should be applied after eliminating spiky noises and should not be applied when stepwise changes are found in data set. 3) Correction for high-frequency spectral losses due to sensor line averaging and separation was insignificant at the forest site. 4) Correction for the density effects due to heat and water vapor transfer is essential. The magnitude of the density correction often exceeded 50 % of raw flux even in mid-July when the leaves were fully developed. In order to promote inter-site comparison of CO_2 budget between flux network sites using different instruments, a campaign measurement for comparing eddy correlation systems using different sonic anemometers and open-path infrared gas analyzers was conducted at 25 m height of the Tomakomai site in mid-July, 2000. Results showed that specific sonic probes possibly underestimate longitudinal wind component, and that differences (standard errors) in CO_2 flux between different eddy correlation systems were about 12 % of the daytime maximum CO_2 uptake rate.

Key Words Eddy correlation, CO_2 flux, Open-path analyzer, Density correction, Larch forest

1. Introduction

In order to get scientific data for intergovernmental discussion to regulate CO_2 emission, it is highly required to assess CO_2 exchange between terrestrial ecosystems and the atmosphere. Recently, flux network activities, such as Ameriflux, EUROFLUX and

AsiaFlux, have started continuous monitoring of CO_2 exchange at various ecosystems worldwide. In the flux network sites, eddy correlation method is used as a standard technique to measure CO_2 flux. In this study, in order to improve evaluation of CO_2 budget in forest ecosystems, we examined practical problems in applying eddy correlation method to forest ecosystems.

2. Research Objective

Practical problems of eddy correlation method are categorized into those caused by site topography and sensor installation, influences of imperfect sensors (response, span length, etc.), and problems in data recording, post-processing and analysis. Corrections for some of those problems have been proposed. Those are corrections for density effects of heat and water vapor transfer (density correction; Webb *et al.*, 1980), for high frequency spectral losses due to sensor line averaging and separation (Moore, 1986), and for water vapor sensitivity of CO_2 sensor (Leuning and Moncrieff, 1990). In this study, we examine these corrections as well as basic procedures in data processing such as coordinate rotation of sonic anemometer and trend removal, and discuss the influence of each on CO_2 flux evaluation in forest ecosystem. In addition, to promote inter-site comparison of CO_2 budget between flux network sites, it is a critical requirement to know errors originating from the use of different eddy correlation systems. For this objective, we made comparison of three different eddy correlation systems, all of which use open-path infrared gas analyzers.

3. Research Method

3.1 Examination of practical problems of eddy correlation data in post-processing, analysis and corrections

Tomakomai flux research site (42°44'N, 141°31'E, 115-140 m ASL) is located in a larch forest (about 40 years old, 18-20 m height) near Lake Shikotsu, Hokkaido, Japan. To monitor CO_2 exchange between the forest ecosystem and the atmosphere in the long term, CO_2 flux was measured continuously at the top of a 41-m high tower using a sonic anemometer (DA-600, Kaijo) and an open-path infrared gas analyzer (OP2, Data Design Group). The data sampled at 10 Hz were provided for this study and processed as follows: 1) Coordinate rotation of sonic anemometer; 2) Linear trend removal; 3) Statistical calculation; 4) Correction for sensor line averaging and separation; 5) Density correction. Influences of each processing or correction on CO_2 flux evaluation were examined.

3.2 Intercomparison of eddy correlation systems using different sonic anemometers and open-path infrared gas analyzers

An intercomparison was conducted on another tower ("Eco-tower") in Tomakomai flux research site from July 10 to 14, 2000. Three types of sonic anemometers and open-path infrared gas analyzers were arrayed at the top of the tower (25 m height) in the following combinations: 1) DA-600 (Kaijo, Tokyo, Japan; two horizontal probes with 120° separation and a vertical probe; 10 cm in span length) and E009B (Advanet Inc., Okayama, Japan; 10 cm in path length). 2) Solent Model 1012R (Gill Instruments Ltd., Lymington, UK; three non-orthogonal probes; 15 cm in span length) and LI-7500 (LICOR, Lincoln, NE, USA; 12 cm in path length). 3) CSAT3 (Campbell Scientific Inc., Logan, UT, USA; three non-orthogonal probes; 10 cm in span length) and OP2 (Data Design Group, San Diego, CA, USA; 20 cm in path length). Data were sampled at 10 Hz using synchronized two data loggers (Teac, DR-M3a), and processed. Sonic anemometers were calibrated in a wind tunnel before the campaign and no systematic differences among them were found. Since we could not make reliable calibrations of the gas analyzers at the site because of drift in signal output due to ambient temperature variations, calibration constants determined in a laboratory before the campaign were used for the data processing and analysis.

4. Results and Discussion

4.1 Examination of practical problems of eddy correlation data in post-processing, analysis and corrections

Coordinate rotation of sonic anemometers is applied for adjusting sonic tilt, but it is reported that the applications under low wind conditions result in unrealistic rotation angles and unacceptable flux values. We found unrealistic rotation angles even under moderate wind conditions, which was caused by the offset error of sonic anemometer. It is therefore recommended not only to check the offset of the anemometer regularly but also to confirm zero adjustment of data recording system.

Trend removal from raw signals of wind velocities and gas concentrations is required for statistical calculation. When a data set to be processed contains spiky noises, we have to eliminate them before trend removal by setting appropriate criteria, otherwise calculated statistical variables are incorrect. Not only electric power source but also weather conditions, such as fog and rain, may cause spiky noises. Open-path gas analyzers is more susceptible to the latter than closed-path analyzers.

At the forest site, correction for sensor line averaging and separation was < 1% even under stable conditions. This is in contrast to at short crop sites, in which the correction generally raises nocturnal CO_2 efflux by 20-40 %. The smaller correction at the forest site is attributed to higher measurement height (41 m).

In mid-May, in which larch trees were developing and sensible heat flux was as much as 400 W m^{-2}, the density correction for CO_2 flux was so large that the correction changed the sign of raw flux from negative (uptake) to positive (efflux). The correction often exceeded 50 % of raw flux in mid-July when the leaves were fully developed. Correction for the influence of water vapor sensitivity of CO_2 analyzer (E009B) was also significant in the daytime (0.15 mgCO_2 m^{-2} s^{-1} at maximum).

4.2 Intercomparison of eddy correlation systems

Time courses of raw signal output from the three sonic anemometers were quite similar. Comparison of half-hourly statistical variables showed that lateral (v) and vertical wind components (w) and acoustic temperature from the three anemometers agreed well, but that the average and standard deviation of longitudinal wind component (u) of DA-600 were smaller than those from the other two anemometers (Solent and CSAT3) by 14 % and 19 %, respectively. This suggests the shape of the probe of DA-600 possibly disturbed horizontal wind measurement under variable wind direction in the field.

Time courses of raw signal output of water vapor (q) and CO_2 concentrations (c) from the three gas analyzers showed similar variations, but that high-frequency noises in the signal were much different each other; the largest in E009B and the smallest in LI-7500. Trends in both q and c signals were apparent in E009B output. Half-hour standard deviations of q and c of E009B were larger than those of LI-7500 by 10 % and 20 %, respectively, owing to high-frequency noises. Contrary, standard deviations of OP2 were smaller than those of LI-7500 by 13 % and 15 %, respectively. In addition, half-hour averages of c of E009B were smaller than those of LI-7500, and showed large scattering. These results indicate calibration constants of OP2 were incorrectly determined or changed during the campaign.

Momentum flux determined by DA-600 was smaller than that by the other two anemometers by 21 %, principally because of underestimation of u. Sensible heat fluxes by the three anemometers agreed each other within 10 %. Despite larger standard deviations of q and c by E009B, water vapor and CO_2 fluxes by the DA-600 & E009B system agreed with those of the Solent & LI-7500 system because high-frequency noises in E009B signals were random and not correlated with w. Water vapor and CO_2 fluxes by the CSAT3 & OP2 system also agreed with the Solent & LI-7500 system by correcting underestimated calibration constants of OP2, which is suggested by the comparison of standard deviation of q and c. Standard errors in sensible heat, latent heat and CO_2 fluxes between the three eddy correlation systems were 15 W m^{-2}, 20 W m^{-2} and 0.12 mg CO_2 m^{-2} s^{-1} (about 12 % of the daytime maximum uptake rate), respectively. These uncertainties should be taken into account when we make inter-site comparison of eddy correlation data obtained using different eddy correlation instruments. From the results of the intercomparison, it is recommended that open-path infrared gas analyzers should be calibrated regularly and accurately, although the calibration of open-path infrared gas analyzers in the field is more difficult than that of closed-path ones.

References

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