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短 報（Note）

Development of a portable CO_2 flux observation system using a closed-path gas analyzer for intercomparison

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Abstract

A portable CO_2 flux observation system with a closed-path gas analyzer was developed as a reference system for forest ecosystems in Asia. This new system was tested against an existing routine system at the Fujiyoshida forest meteorology research site. The difference in observing the CO_2 flux between the two systems was less than 5% regardless of the fact that a high-frequency fluctuation correction was not applied to the portable system. The results suggest that the portable system can be used as a reference CO_2 flux observation system, especially for new observation sites in Asia.

Key words : AsiaFlux, closed-path gas analyzer, CO_2 flux, forest, portable observation system

Introduction

The accumulation of accurate scientific knowledge on carbon exchange in terrestrial ecosystems has become an important task for the study of global warming. A carbon flux observation network (FLUXNET) has been established, and products from tower-based micrometeorological observation systems are being consolidated (Baldocchi et al., 2001); however, methodologies to measure CO_2 flux between a terrestrial ecosystem and the atmosphere have been conducted using different types of instruments and analysis methods. Consequently, standardization of measurement methods and quality control of data are required to implement a global observation system.

Observations of CO_2 flux between a terrestrial ecosystem and the atmosphere are often based on a micrometeorological technique called the eddy covariance method using two types of infrared gas analyzers, open- and closed-path. An open-path infrared gas analyzer is generally used for grass or cropland observations; however, it is also frequently used for forest sites in some parts of Asia (Mizoguchi et al., 2009). The open-path gas analyzer system, however, often gives unreliable signals during rainfall; therefore, the continuous measurement data in pluvial areas of Asia inevitably has several data gaps. In contrast, a closed-path analyzer system can measure CO_2 concentration during rainfall but is more complex than the open-path system and requires more knowledge and experience for its operation. In addition, Ono et al. (2007) indicated that the relative difference between the two systems was considerable. Thus, there is a strong demand for standardizing measurement systems and analysis methodology in the tower flux observation network of Asia (AsiaFlux). Under similar circumstances, the flux network of the United States (AmeriFlux) has developed a portable standard observation system using both types of infrared gas analyzers, and it has been operated as a reference system both inside and outside the AmeriFlux network (Nakai et al., 2002; AmeriFlux, 2009). In contrast, the European flux network has shown less interest in using a portable system, and has used the same closed-path system and analysis methods since beginning.

In this study, a portable CO_2 flux observation system was developed and its basic performance was evaluated. The system was built with a closed-path type gas analyzer so that it could be used as a long-term CO_2 measuring method in rainy areas of Asia. The primary purpose of this system is to provide an on-site reference for quality control of observed CO_2 flux data and to standardize the measurement systems especially for new observation sites in Asia.

System design

The portable CO_2 flux observation system consists of an

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ultrasonic anemometer-thermometer (SAT, SAT-550/KAIJO), a closed-path infrared gas analyzer (IRGA, LI-7000/LI-COR), a thermo-hygrometer (HMP-45A/VAISALA), a high-speed sampling data logger (CR-3000/CAMPBELL), and an air intake switch for calibration. All devices are powered by 12 or 24 V DC converted from 100 to 240 V AC input to correspond with the wide range of electrical configurations in Asia (Table 1). It also has a DC-DC converter, which produces 24 V from 12 V for situations when only 12 V DC is available. All components are mounted in a plastic container (W 826 mm × H 521 mm × D 287 mm, 40 kg, Photo 1) to improve portability and installation convenience.

There are two gas intake methods for closed-path gas analyzers in tower flux observation systems. One involves placing a pump in front of the gas analyzer to push air into the analyzer (compressed type; Fig. 1) and the other involves placing the pump behind the gas analyzer to pull the air in by creating a vacuum (decompressed type). Under normal circumstances, the latter is more stable against fluctuations in atmospheric pressure. However, when comparing the compressed and decompressed types during the early stage of system design, air pressure in the sampling cell of the gas analyzer dropped to a low of about 700 hPa, and the resulting CO_2/H_2O concentration readout was incorrect, contrary to our expectation. It is possible that the long length of air tubing, which exceeds 50 m in actual observations using towers, affected the data. The compressed type method (Fig. 1) was adopted for this portable system to avoid the large depression in the gas analyzer observation cell. With compressed type, the difference in gas pressure between the inside and outside of the sampling cell was less than 5 hPa, which had negligible effects on the readout.

Performance test and system intercomparison

The Fujiyoshida forest meteorology research site (AsiaFlux site code: FJY) of the Forestry and Forest Products Research Institute is located in a temperate red pine forest. Long-term and continuous flux monitoring is performed (Ohtani et al., 2005a;

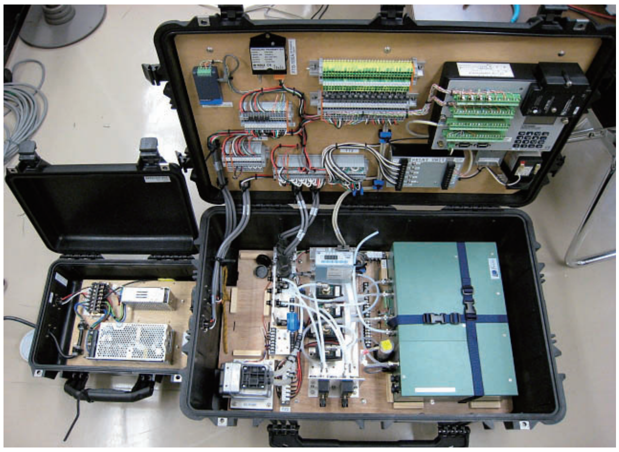

Photo 1. The portable CO_2 flux observation system. Right (main unit): Infrared gas analyzer, air pump, mass flow controller, and solenoid valve are mounted in the lower part; data logger and terminal block are installed on the upper lid part. Left (power unit): Supporting 100–240 V AC and providing 12 or 24 V DC to the main unit through an electric cable.

Table 1. Specifications for the major sensors installed in the portable CO_2 flux observation system

		Manufacturer	Model	Supply voltage	Consumption current	Remarks
Main unit	**Sensors**					
	Infrared gas analyzer	LI-COR (USA)	LI-7000	10.5 to 16VDC	4A max.	
	Ultrasonic anemometer-thermometer	KAIJO (Japan)	SAT-550	24VDC	0.17A	
	Thermo-hygrometer	VAISALA (Finland)	HMP-45A	7 to 35VDC	less than 4mA	
	Barometer	VAISALA (Finland)	PTB-110	10 to 30VDC	less than 4mA	
	Data logger	CAMPBELL (USA)	CR-3000	10 to 16VDC	10mA at 100Hz sampling	
	Other equipments					
	Draft fan for thermo-hygrometer	NIPPON BLOWER (Japan)	CF825D-12M	12VDC	170mA	
	Air pump	PANASONIC (Japan)	MVP03V12BA1	8 to 15VDC	2.5A	
	Mass flow controller	YAMATAKE (Japan)	CMQ0020	15 to 24VDC	300mA max.	
	Solenoid valve	CKD (Japan)	AG31-02-2-03A	12VDC	0.9A	
	Flow meter	KOFLOC (Japan)	RK1650	-	-	
	Filter	BLASTON (USA)	9922-05	-	-	PTFE
	Air intake tube	-	-	-	-	4mm inner, 6mm outer diameter
Power unit	Switching power supply	COSEL (Japan)	PAA150F-12A	-	-	Input: 100 to 240VAC Output: 12V13A (max.)
	Switching power supply	SANKEN (Japan)	HWA050-24	-	-	Input: 100 to 240VAC Output: 24V2.1A (max.)

Ohtani et al., 2005b) at the 30-m observation tower, which mainly observes CO_2 flux between the forest and atmosphere. The routine observation system consisted of a SAT (DA-600-3T/KAIJO), closed-path IRGA (LI-6262/LI-COR), data logger (DR-M3b/TEAC), and other micrometeorological instruments.

The portable system performance test was conducted at this site between September 20 and 25, 2007, and the system operated without complain throughout the period. SAT and air intake of the portable system were installed at a height of 26 m of the tower 1-m horizontally away from SAT of the existing routine system (Ohtani et al., 2001). The main unit was 4 m below SAT and securely placed on the tower landing. Air was introduced from an air intake into the IRGA inside the main unit through an 8-m long polyethylene tube (4 mm inner and 6 mm outer diameter) at a flow rate of 8.5 $Lmin^{-1}$. The signal time lag due to air intake was calculated to be 1.9 s based on a cross-correlation of vertical wind velocity and CO_2 concentration fluctuations.

Since the main unit of the portable system can be installed on the tower, the tube length is much shorter; thus, the signal time lag becomes much smaller than the routine system, which is optimized for long-term measurement and draws air down from 30 m to a cabin underneath the tower. Shorter tubing reduces the attenuation of high-frequency fluctuations in CO_2 concentration, which results in a more accurate measurement.

Data obtained from the performance test were analyzed to determine parameters such as signal time lag, and then the main comparison between the portable and routine systems was done over the measurement period between October 31 and November 8, 2007. Again the portable system was installed 1 m away from the routine system at a height of 26 m on the tower (Photo 2), and the main unit was also placed 4 m below SAT and air intake. The main and power units were covered with a silver sheet to reduce the effects of radiation, rise in temperature, and rainfall. The same 8-m tube, such as used in the performance test, was used to introduce air into the gas analyzer at a rate of 8 $Lmin^{-1}$. The signal sampling rate was 10 Hz for the portable system and 5 Hz for the routine system.

Flux was calculated every 30 min. Post processing of quality control and signal time lag correction was applied for each measurement (Ohtani et al., 2005a). However, the high-frequency correction based on cospectral CO_2 similarity and sensible heat fluxes (Watanabe et al., 2000) was applied only to the routine system data to confirm that the high-frequency spectral attenuation for the portable system was significantly smaller than the existing routine system due to its shorter intake distance (8 m).

Results and discussion

Figure 2 shows fluctuations in the power spectra for vertical wind velocity and CO_2 concentration before high-frequency correction. It is an example of data that were obtained during a sunny day when absolute flux values were relatively large. The power spectra of vertical wind velocity fluctuations matched well, except for a small difference in the lower frequency band. In contrast, the CO_2 concentration power spectra clearly demonstrated that the portable system with its shorter air intake distance detected fluctuations in the

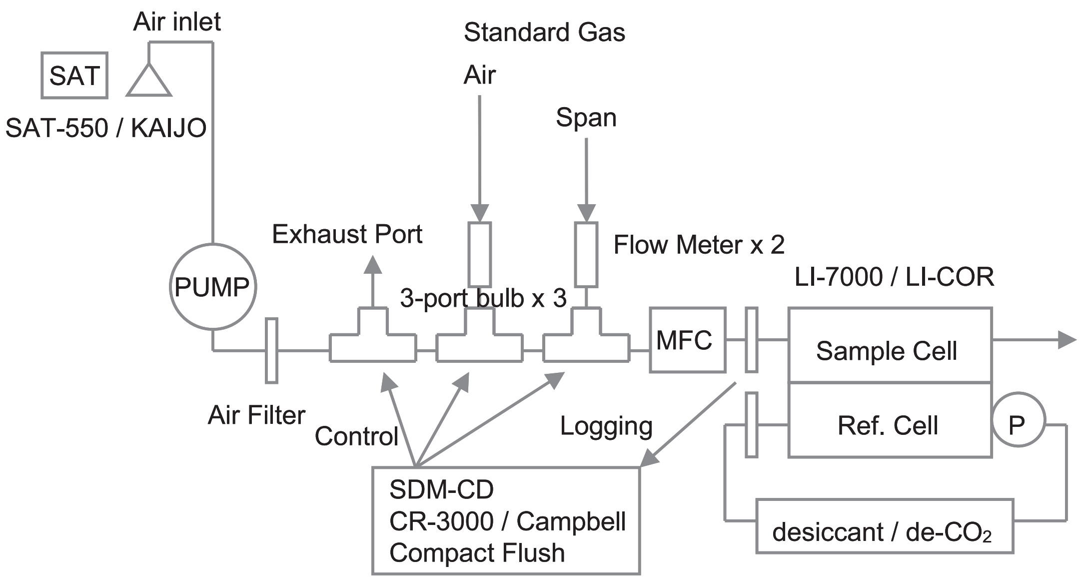

Fig. 1. Block diagram of the portable CO_2 flux observation system.
(SAT: sonic anemometer-thermometer, MFC: mass flow controller, P: pump)

Photo 2. System comparison: SAT and air intake of the portable system (left) and the routine system (right).

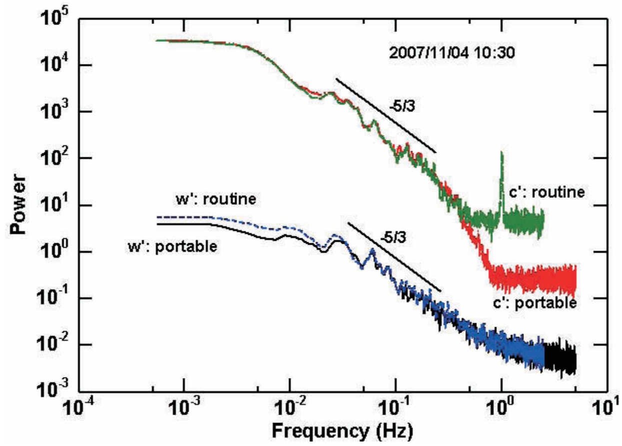

Fig. 2. Fluctuations in the power spectra (before high-frequency correction) of vertical wind velocity (w′) and CO_2 concentration (c′) for the existing routine and portable systems.

higher frequency region and was better able to record actual fluctuations in CO_2 concentration. Dissipation of the spectral information became noticeable at frequencies above 0.4 Hz for the routine observation system and 1 Hz for the portable system. Accordingly, attenuation of the CO_2 concentration signals in the portable system was smaller than that in the routine system.

Figure 3 shows flux correlation diagrams for sensible heat (*Fh*) and CO_2 (*Fc*) of the portable system against those of the routine system. Data were filtered by friction velocity with a minimum threshold of 0.2 ms^{-1} (Ohtani et al., 2005a). Sensible heat flux is calculated from wind velocity and temperature (sound virtual temperature) measured by SAT; therefore, there should be little difference in these values except for the small effects of measurement displacement or instrument characteristics. The difference in the two systems was less than 20 Wm^{-2}, and both values were in good agreement overall. When the sensible heat flux was negative, mainly from evening to nighttime, the absolute values of the portable system tended to be smaller than the routine system. The SAT in the portable system (SAT-550/KAIJO) contains an electrical circuit vertically below its sonic transmitters and receivers, and this component generates a small amount of heat during operation. Heat convection may affect the wind and thermal fields among the sensors resulting in a lowering of the sensible heat flux absolute values at night. During daytime, wind velocity was generally higher; hence, slight heat from SAT did not have considerable effect.

CO_2 flux is calculated from the wind velocity (obtained by SAT) and CO_2 concentration (obtained by IRGA). During daytime, when the flux was negative, values of both the systems corresponded well, and the difference was less than 5%. Deviations in a small part of the data were most likely caused by the friction velocity value, which was very close to the threshold value, and by some CO_2 concentration fluctuations. Although the portable system values tended to be slightly smaller than the routine system during night, both values were in good agreement overall.

Differences in latent heat and CO_2 fluxes between the portable and routine system were small despite the fact that high-frequency corrections were not applied to the portable system data. The shorter tubing in the portable system may have provided this result.

Concluding remarks

A portable flux observation system using a closed-path type infrared gas analyzer was developed. The performance test showed its efficiency and reliability as a reference system for the intercomparison of routine observation systems. The slightly heated element found in the bottom of the initial SAT (SAT-550/KAIJO) may have affected fluxes in some cases, and the SAT also had a relatively large power consumption, which may prevent observations depending on the power supply to the site. Hence, the SAT has now been replaced by another instrument with lower power consumption (WindMaster-Pro II/GILL). In addition, high-frequency band correction will be examined for the case of a long air intake tube.

In the near future, this new portable system will be tested after improvements and will be used for system intercomparisons in Asia.

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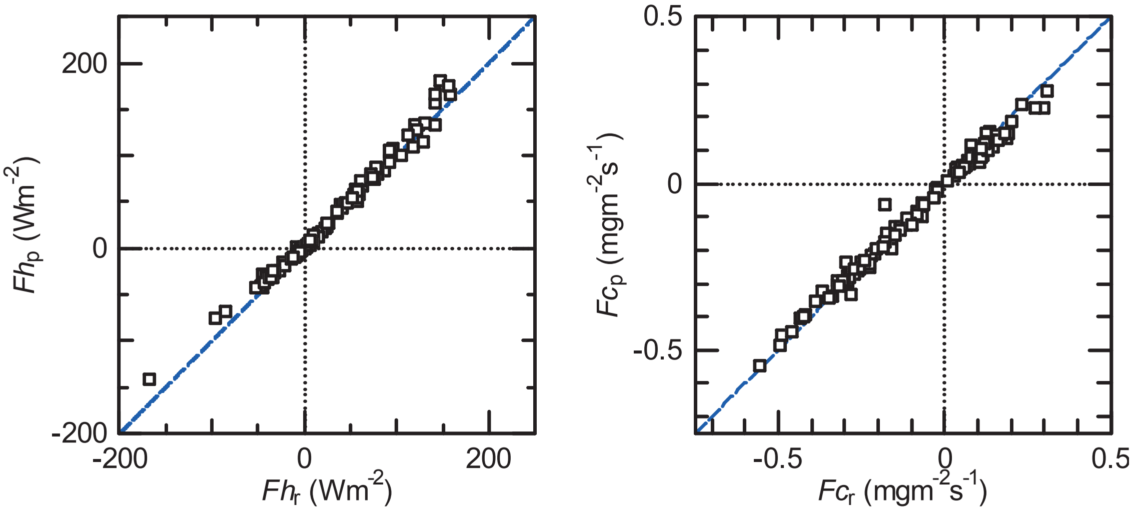

Fig. 3. Correlation diagrams for sensible heat (*Fh*, left) and CO_2 (*Fc*, right) fluxes observed using the portable and routine systems The subscript letter “r” and “p” indicates the value for the routine and portable system, respectively.

managing the flux observation systems at the Fujiyoshida site. This study was supported in part by the Special Coordination Funds for Promoting Science and Technology from the Japanese Ministry of Education, Culture, Sports, Science and Technology, and the Global Environment Research Account from the Japanese Ministry of the Environment.

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観測システム間相互比較のための
ポータブル CO_2 フラックス観測システムの開発

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要 旨

森林生態系の CO_2 フラックス観測精度の向上を目的に、クローズド型のガス分析計を使用した比較観測用のポータブルフラックス観測システムを開発した。森林を対象とする長期 CO_2 フラックス・モニタリングサイトである富士吉田森林気象試験地で比較観測を実施した結果、経常観測システムとの CO_2 フラックスの違いは 5% 以下に収まり、ポータブルシステムが比較観測用の測器として使用可能なことが確認できた。今後、このシステムをフラックス観測の精度検証に用いるとともに、アジア地域で新規に観測を開始するサイトに対して標準的な観測手法を示すためにも役立てる。

キーワード： アジアフラックス、クローズドパス型赤外線ガス分析計、CO_2 フラックス、森林、ポータブル観測システム

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