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Characteristics of the Gas Exchange of a Tropical Rain Forest in Peninsular Malaysia

By

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Summary

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Understanding the energy/H_2O/CO_2 exchange processes of tropical rain forests is very important for evaluating their roles in climate change. We measured sensible heat, latent heat, and CO_2 fluxes above a tropical rain forest in Peninsular Malaysia using the eddy covariance method for the year 2003. The average daily sensible and latent heat fluxes were 3.0 and 6.1 MJ, respectively. After considering the calculated heat storage terms, energy budget closure was estimated to be approximately 65%, even during the day. The average daily CO_2 flux was –2.1 g C m^{-2} in 2003. The average diurnal change of CO_2 flux ranged from –18.0 to 10.0 µmol m^{-2} s^{-1}, and no significant seasonal changes were observed. In the night time, CO_2 efflux measured using the eddy covariance method increased with friction velocity, suggesting an underestimation of ecosystem respiration under poor mixing conditions.

Introduction

Understanding the energy/H_2O/CO_2 exchange processes of tropical rain forests is very important for evaluating their roles in climate change. Ecosystems absorb carbon dioxide by photosynthesis and release it by autotrophic and heterotrophic respiration. The rates of photosynthesis and respiration constitute very large units in tropical rain forests; therefore, a high level of accuracy and a carefully thought out strategy at the experimental design stage are necessary in order to ex-

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amine the balance of absorption and emission in terms of small differences in the gross values of both. These rates vary diurnally and seasonally in response to interactions between the physical environment and physiological factors. A flux measurement above the forest canopy using a micro-meteorological method permits direct computation of gas exchange in the forest ecosystem and analysis of the characteristics at various time scales. Flux measurements using the eddy covariance method have been conducted for various vegetation types and ages (e.g., VALENTINI & al. 2000, BALDOCCHI & al. 2001). However, in Southeast Asia very few studies have been initiated for estimating net ecosystem exchange (NEE) from micro-meteorological observations, although net ecosystem production has been estimated from ecological studies at sites such as the Pasoh Forest Reserve (HOSHIZAKI & al. 1999, 2001). Only a short term observation of CO_2 flux was conducted in March 1998 at Pasoh (YASUDA & al. 2003). In order to describe and explain the temporal patterns of gas exchange in tropical rain forests there is a clear need for further data sets and analyses, especially with regard to long term CO_2 flux. In this paper, we present long term observations of sensible heat, latent heat, and CO_2 fluxes related to environmental factors, including solar radiation, air temperature, vapour pressure deficit, rainfall, and soil moisture, as well as their diurnal and seasonal changes for the year 2003.

Material and Methods

Site description

Observations were conducted at the Pasoh Forest Reserve near Simpang Pertang in Negeri Sembilan, about 140 km southeast of Kuala Lumpur, in Peninsular Malaysia (2°58'N, 102°18'E). The core area (600 ha) of the reserve is covered with a primary lowland mixed dipterocarp forest, which consists of various species of *Shorea* and *Dipterocarpus*. The continuous canopy height is approximately 35 m, although some emergent trees exceed 45 m. Based on empirical equations obtained for the Pasoh Forest Reserve by KATO & al. 1978, the leaf area index (LAI) estimated from tree diameter observations (Niiyama, unpublished) was 6.52.

Observations

Fluxes of sensible heat, water vapour, and carbon dioxide were measured at a height of 54 m on an observation tower. Wind velocity and temperature were observed with a three-axis sonic anemometer (SAT-550, Kaijo). Carbon dioxide concentration was monitored with an open path CO_2/H_2O analyzer (LI-7500, Licor). Data were sampled at 10 Hz and sent to a data logger (CR-5000, Campbell). Fluxes were calculated for the momentum, heat, H_2O, and CO_2 at an averaging time of 30 minutes. The wind field coordinates were rotated so that the mean vertical wind was zero. Spike and range over data were interpolated and counted. If the number of spikes or out-of-range data exceeded 1% of the total number of data points for each element, then the 30-minute flux data were considered to be invalid. The linear trends of temperature, water vapour, and CO_2 concentration were removed. We also corrected for the effect of air density fluctuation (WEBB & al. 1980).

Meteorological variables monitored at a height of 52 m on the tower included downward and upward ranges of short-wave radiation (MR22, Eko), ranges of long-wave radiation (PIR, Eppley), air temperature, humidity (HMP45A, Visala), wind velocity (AC750, Makino), and rainfall. Soil water content at depths of 10, 20, and 30 cm (CS515, Campbell), and soil heat flux at a depth of 2 cm (HFP01, HukuseFlux), were monitored at three points around the tower.

Results and Discussion

Daily mean values of meteorological variables and monthly mean diurnal changes in fluxes, air temperature, and vapour pressure deficit monitored at this site, for the year 2003, are shown in Fig. 1a. The mean air temperature (25.9 °C) and vapour pressure deficit (6.2 hPa) at 52 m showed little seasonal change. The absolute daily maximum air temperature was 33.9 °C on 5 March (day 64 day of the year 2003) and the absolute daily minimum air temperature was 20.8 °C on 25 October (day 298). Relatively cool air temperatures and low vapour pressure deficits in January-February and October-December coincided with a cloudy period. Annual rainfall in 2003 (1,896 mm) was larger than the four-year average (1,571 mm) from 1996 to 1999, including the El Niño event from 1997 to early 1998, but slightly larger than that of a normal year in FELDA Pasoh Dua (1,804 mm; TANI & al. 2003). Soil water content was comparatively constant throughout the year.

The average daily sensible and latent heat fluxes were 3.0 and 6.1 MJ m^{-2}, respectively. After considering the heat storage terms, calculated using an empirical equation for this study site (OHTANI & al. 1997), energy budget closure was estimated to be approximately 65%, even during the day. Non-closure of the energy budget is consistent with observations in many other forests, and the closure deficit of about 35% is larger than that of other tropical rain forest sites (e.g., KUMAGAI & al. 2004, DA ROCHA & al. 2004). Various causes may have influenced this result, but recent studies (LEE 1998, WATANABE & KANDA 2002) have shown that such an imbalance may inevitably occur owing to mass flow, even when the measurement includes the minimum errors, and the data represent the spatially averaged fluxes. Further analyses (e.g., mass flow rate, horizontal advection) are needed, therefore, to solve this problem. The evapotranspiration rate was directly calculated at 2.50 mm day^{-1} using an eddy covariance latent heat flux. If the Bowen ratio calculated by eddy covariance was correct, and the closure deficits were divided into sensible and latent heat fluxes by the Bowen ratio, then the evapotranspiration rate was recalculated as 3.04 mm day^{-1}. This value is similar to those reported in other tropical rain forests (3.45 mm day^{-1}, SHUTTLEWORTH & al. 1984; 3.45 mm day^{-1}, DA ROCHA & al. 2004; 2.86-3.48 mm day^{-1}, KUMAGAI & al. 2004).

The average diurnal changes in CO_2 flux ranged from –18.0 to 10.0 μmol m^{-2} s^{-1}, and did not show clear seasonal changes corresponding to soil moisture and air temperature conditions (Fig. 1b). Under relatively cool and wet conditions in January-February and October-December, no significant changes in CO_2 fluxes were observed. These diurnal changes are similar to those reported for other tropical forests (GRACE & al. 1996, GOULDEN & al. 2004). The average daily eddy covariance CO_2 flux was –2.1 g C m^{-2} in 2003. This value was larger than the value of NEE reported in other tropical forests (–0.60 g C m^{-2}, FAN & al. 1990; –0.95 g C m^{-2}, GRACE & al. 1996; –1.5 g C m^{-2}, GOULDEN & al. 2004), but similar to NEE obtained from short term observations at this forest (–2.4 g C m^{-2}, YASUDA & al. 2003). In the night time, CO_2 efflux measured using the eddy covariance method increased with friction velocity rise, suggesting an underestimation of ecosystem respiration under poor mixing conditions (Fig. 2). Uncertainties in CO_2 fluxes under poor mixing conditions influence the absolute accuracy. Taking energy imbalance into account, accuracy would be influenced by vertical mass flow rates and/or horizontal advection terms, even under good mixing conditions. Therefore, the absolute value of daily net CO_2 exchange should be precisely analyzed and corrected by cross-checking other techniques, including process-based models, chamber CO_2 flux observations of all components of the forest, and both biomass and necromass increment observations.

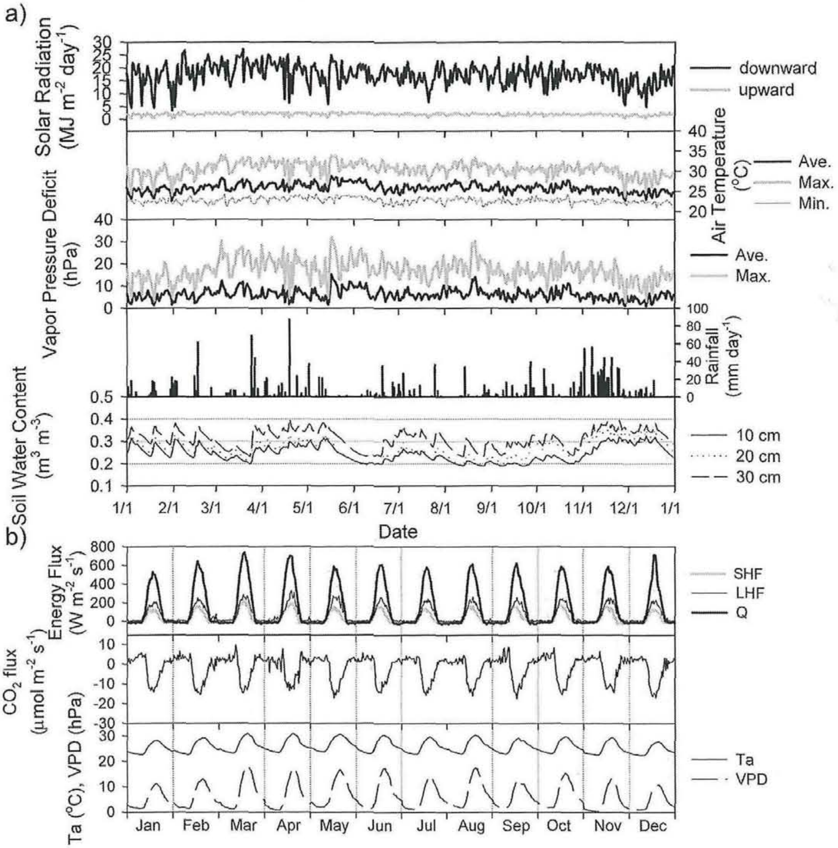

Fig. 1. Seasonal fluctuations in the daily total downward and upward solar radiation, daily average, maximum, and minimum air temperatures, daily average and maximum vapour pressure deficits, daily total rainfall, and volumetric soil water content at depth of 10, 20, and 30 cm (a). Seasonal changes in average diurnal course of the available energy (Q), sensible and latent heat fluxes (SHF, LHF), eddy covariance CO_2 flux, air temperature (Ta), and vapour pressure deficit (VPD) at 52 m (b).

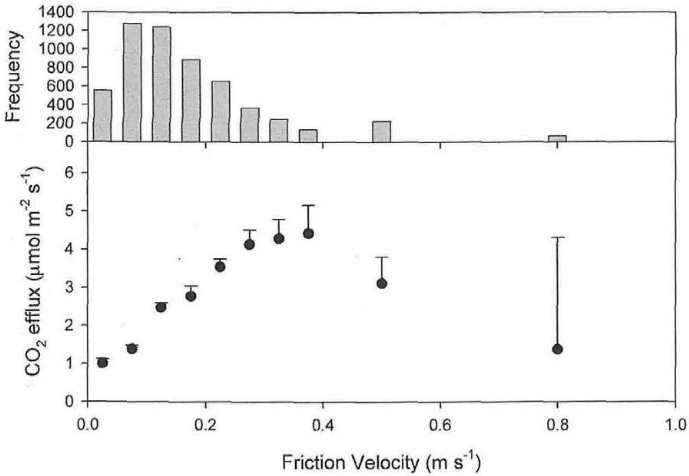

Fig. 2. Relationship between friction velocity and nighttime CO_2 efflux, with the frequency of each friction velocity (u_*) class (class 1-8, in the range of 0.05 m s^{-1} u_*<0.4 m s^{-1}; class 9, 0.4≤u_*<0.6 m s^{-1}; class 10, 0.6≤u_*<1.0 m s^{-1}). The circles represent the average eddy covariance data in each friction velocity class, and the error bars represent standard error.

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