P1.17 *Comprehensive Relationship Between Atmospheric-Land Surface Interaction for Energy, Water Vapor Fluxes over Tropical Asian Monsoon Environment.*

Motomu Toda
Japan Society for the Promotion of Science, Japan. and Ohte Nobuhito.
Nobuhito Ohte, Yoshiko Kosugi
Graduate School of Agriculture, Kyoto University, Japan
Tsutomu Watanabe
Forestry and Forest Research Institude, Ibaraki, Japan.

1. Introduction

Long-term observation of turbulent heat and water vapor fluxes in association with meteorological and hydrological variables has been carried out over terrestrial complex land cover in tropical regions as part of the fundamental framework of the GAME (GEWEX Asian Monsoon Experiment, in which GEWEX stands for Global Energy and Water cycle Experiment) since May 1998 to investigate the energy and water cycles in Asian monsoon environment. In the present paper, two findings to enhance our understandings about the atmospheric-land interaction in tropical monsoon area are presented.

One of the significant aims of the present study is to clarify the seasonal energy and water vapor behavior and to quantitatively evaluate the total amount of energy balance, and evapotranspiration during the observation period. Other is the extraction for parameters related with the evaporative and photosynthesis activities using canopy conductance model and the biochemical model (*Farquhar et al.*, 1980).

2. Site information

A surface flux station (99^{o} 25”792 E, 16^{o} 56”392 N) 121 m above sea level was established in the Chao Phraya river basin about 60-km east from Tak province, Thailand.

The land surface features of the surrounding area within 20 km of the tower in the dominant E – S - W wind directions were evaluated by the land use digital map produced from a Landsat TM scene taken on 12 Nov., 1998 [*Nishida*, 2000] and were found to consist of evergreen and deciduous forests (82%) with variable height in the range of 5 to 20 m, paddy fields (8%), grasslands and farmlands (9%), bare soil (1%), water reservoirs and small villages (<1%). In all other wind directions, the land use is essentially the same as shown in Table 1 of *Toda et al.* [2002].

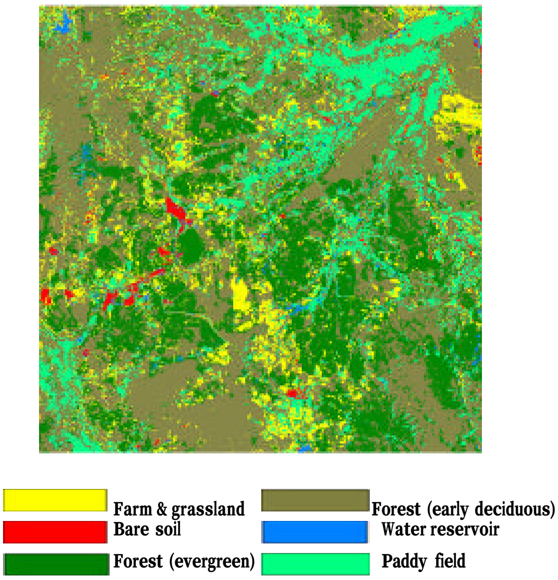

Figure 1. Map of land cover around the observation tower.

Sensible heat and latent heat fluxes were calculated by eddy correlation and bandpass covariance method using sonic anemometer thermometer (GILL, R3A) and with platinum-resistance temperature transducers and capacitive relative humidity (model 50Y, Vaisala) using ventilated psychrometers (Type S-301, Yoshino) mounted on 60m high, respectively.

3.Results

3.1 The seasonal variation of the surface fluxes.

Figure 2 shows the seasonal variations in daily averaged surface energy flux components. The maximum value of net radiation reached 18.33 MJ m^{-2} day^{-1} in June 1998.

During the middle of June 1998, the sensible heat reached nearly 10 MJ m^{-2} day^{-1}, and it

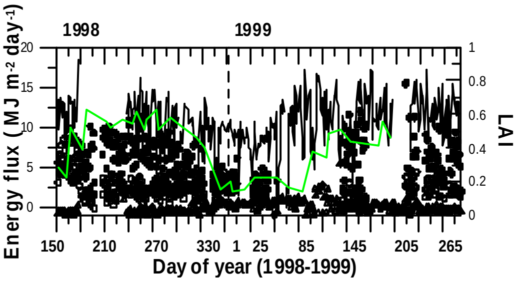

Figure 2. Seasonal variations of the surface energy fluxes; net radiation (R_{net}; —), sensible heat (H; ○), latent heat (LE; ●) and ground heat (G; △) throughout the observation period ([DOY 152] 1998 to [DOY 294] 1999). The solid line with green color also designates the seasonal variation of Leaf Area Index (LAI).

indicated 3 times greater than that of latent heat flux during the corresponding period. The increase of precipitation in the corresponding season already has started. The partitions of the sensible and latent heat fluxes to net radiation changed after the soil near the surface became wet enough due to the precipitation. In the onset of monsoon, the sensible heat held the value 2.5 MJ m^{-2} day^{-1} approximately.

In contrast, the maximum of latent heat flux reached 11.11 MJ m^{-2} day $^{-1}$ on 5 September [DOY 248] 1998, and 11.56 MJ m^{-2} day $^{-1}$ on 28 June [DOY 179] 1999 during rainy season, and they corresponded with 5.36 mm day $^{-1}$ and 5.58 mm day^{-1} for daily evapotranspiration, respectively. The ratio of latent heat flux to available energy (net radiation minus ground heat flux) was 0.96 in August 1998. Latent heat flux became equivalent to sensible heat at the end of January 1999, and re-increased in latent heat flux and re-decreased in sensible heat flux appeared in April 1999, corresponding with the decrease of surface temperature, and the increase of specific humidity.

The seasonal change of LAI is shown using LAI-NDVI empirical equation for broadleaf forest proposed by Nemani and Running (1989) with LANDSAT-TM data for the 20 × 20 square kilometer regions during the observation period. The value of NDVI was calculated from brightness of the two wavelength bands.

As shown in Figure 2, the seasonal cycle of LAI has quietly corresponded with the changes of the latent heat flux throughout a year.

The ratios of turbulent fluxes to the subtraction of the ground heat from the net radiation flux were 0.73 (for wet season) and 0.79 (for the dry season), respectively. The unclosure of energy balance is often called the energy imbalance, and a number of causes of imbalance have been reported at many experimental sites. In the simulated results with large simulation model (LES), for instance, *Watanabe and Kanda* [2002] and *Kanda et al.* [2002] indicates that the time-averaged value of the surface fluxes obtained from a point-scale measurement is not correspondence with the spatial-averaged ones on the same level as a measured height for any stability conditions. Using LES, Figure 3 (a) to (b) represent the spatial turbulence structures (a) for the horizontal wind u in the neutral condition behind $10ms^{-1}$ of geostrophic wind U_g and (b) for the vertical wind w in the unstable atmospheric condition, respectively. Spatial Inhomogeneity of each predictive variable was seen clearly in both of the figure ((a) streaky pattern (b) spoke pattern).

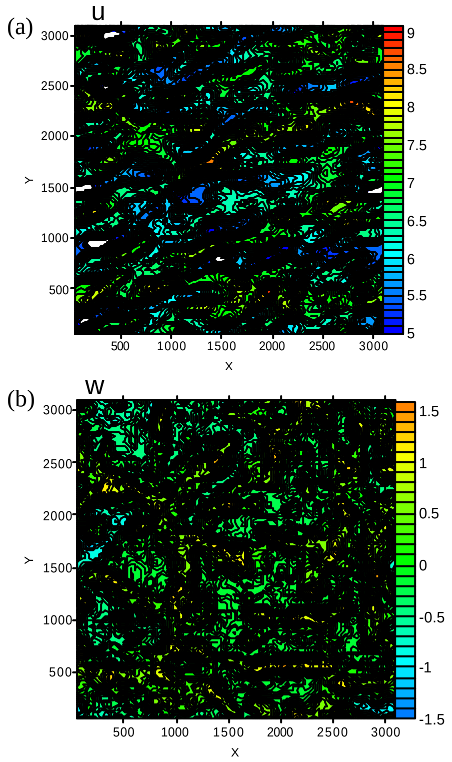

Figure 3. Simulated results of the x-y cross-section on z=150m using Large Eddy Simulation model (LES). (a) designates the horizontal wind u in the neutral and (b) the vertical wind w in the unstable stability condition, respectively.

Table 1 Monthly estimations of the surface energy flux components and evapotranspiration on a daily integrated basis from July 1998 to February 1999. Δ represents the residual of energy balance closure.

Month	R_{NET} (MJ)	G (MJ)	H (MJ)	LE (MJ)	Δ (MJ)	E (mm day $^{-1}$)
1998. 6	11.91	-0.46	6.25	4.16	1.95	1.71
7	-	-	1.6	6.63	-	2.72
8	12.82	-0.35	1.67	8.01	3.49	3.29
9	11.77	-0.47	1.53	7.08	3.63	2.9
10	10.07	-0.45	1.91	5.6	3.02	2.3
11	10.09	-0.16	1.75	4.25	4.26	1.75
12	9.19	0.37	3.02	2.64	3.16	1.08
1999. 1	8.12	0.38	3.13	2.84	1.77	1.16
2	8.72	0.46	3.28	1.53	3.44	0.63

Based on the consideration with the theoretical and observational approaches for linear decrease of the surface fluxes with a height, it found that the value of flux obtained from the instruments mounted on 60m level in the present study can almost be regarded as the surface flux in the daytime, but as an underestimate by less than 6% of the flux at the ground. At any rate the energy imbalance is still unresolved, and approximately 70 to 80 % of energy closure obtained on a daily-integrated basis was similar to that of many other flux measurement fields.

The total energy balance and evapotranspiration were calculated during June 1998 to February 1999 in which the turbulence fluxes were measured sufficiently, and both dry and wet period were included during these nine months. The 5-day mean data was computed for all of the components with data obtained for 222 of the 303 days of this period.

Monthly average values of daily integrated energy balance components, and evapotranspiration, are shown in Table 1. Annual observation results show the turbulent fluxes varied remarkably in response to the meteorological changes that characterize the tropical monsoon climate and the vegetative cycle. As shown in Table 1, the energy closure $\Delta = (R_{net} - LE - H - G)$ was greater during the wet season, when latent heat is the predominant energy flux, and the result corresponded with that of Tanaka et al. (2001). As indicated in Table 1, evapotranspiration in the averaged dry and wet season were 1.14 and 2.33 mm day^{-1}, respectively. Figure 4 shows the cumulative evapotranspiration and precipitation during the nine-month period. The sum of the evapotranspiration reached 526 mm, while the total precipitation was 641 mm. This indicates that more than 80 percentage of precipitation replaced by the evapotranspiration loss. One of another findings is that the evaporation in dry condition was 75mm with 5mm of the precipitation. It found that the evaporation of the water reservoir around the observational tower attributed to the total evaporation [*Toda et al.*, 2002]. Inhomogeneity in the land surface appears to make it complex to evaluate the behavior of surface fluxes.

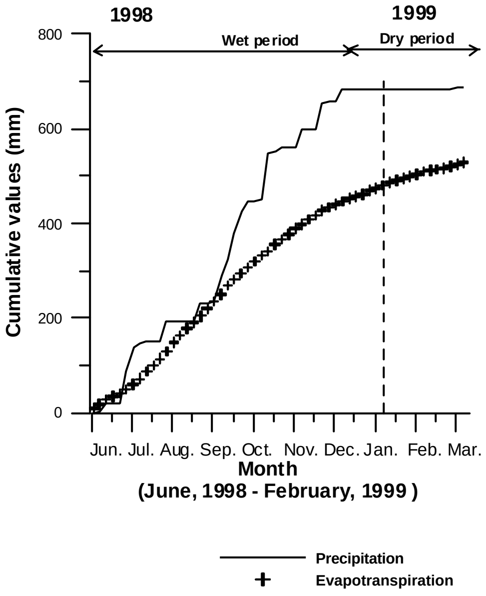

Figure 4. Cumulative values for precipitation and evapotranspiration throughout the observation period from June 1998 to February 1999. Plus sign denotes the amount of evapotranspiration, and solid line indicates the amount of precipitation.

3.2 The extraction and comparison of evaporative and photosynthesis parameters over two typical land covers in tropical monsoon Asia.

Additional field observation was conducted to make clear the seasonal and diurnal changes of carbon dioxide exchange processes between atmosphere-terrestrial land covers in tropical monsoon region under drastic dry and wet periods. Figure 5 (a) to (b) show the CO_2 flux from March 1998 to February 1999.

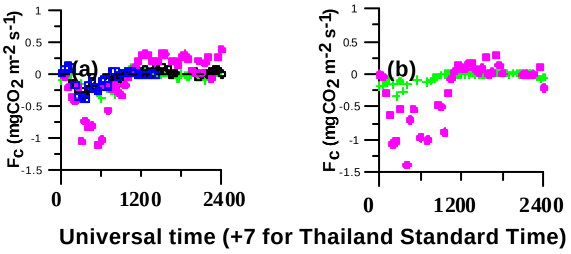

Figure 5 The seasonal and diurnal variations of carbon dioxide flux (F_c) over two land covers. The result of (a) was obtained over the terrestrial terrain and (b) is the over the paddy field 80km away from the site (a). The plus sign denotes March in 1998, and the empty and filled circles with black and pink is in May and August in 1998, and the square with blue is in February in 1999. Note that the negative values indicate the transfer from atmosphere to the surface.

In wet season (August in 1998), high carbon uptakes were obtained over both land surfaces from -1.2 to -1.5 mgCO_2 m^{-2} s^{-1}. Even dry season (March to May) in absence of rainfall, small carbon uptake (-0.2 mgCO_2 m^{-2} s^{-1}) was observed in complex terrain. This result supports that the evaporative activity of the terrestrial vegetation plays role on the evaporative contribution in dry condition.

In order to evaluate the relationships between the fluxes and the environmental factors, the extraction of parameters in rainy season (August to September 1998) was made related with evapotranspiration and carbon assimilation rate for two typical terrestrial land covers with canopy conductance model and the photosynthesis model. Based on the modified version of the model proposed by *Jarvis* [1976], canopy conductance g_s can be described as the form of multiplication of each individual function of photosynthetic active radiation (*PAR*), vapor pressure deficit (*VPD*),

$$g_s = g_{s\max} f_1(PAR) f_2(VPD)$$

where

$$f_1(PAR) = \frac{PAR}{PAR + \dfrac{g_{s\max}}{a}}, \quad f_2(VPD) = 1 - bD \quad ,$$

g_{smax} is maximum canopy conductance , a represents the initial slope at *PAR*=0. Unknown three parameters (g_{smax}, *a*, *b*) are optimized with a non-linear least squares optimization procedure based on Marquardt's maximum neighborhood method (Marquardt, 1963).

Figure 5 (a)-(b) show the relationship between (a) *PAR*-g_s and (b) *VPD*-g_s, and the high dependence on the meteorological variables in paddy field was clearly seen compared to that in the terrestrial terrain under the same meteorological condition.

Figure 6. The relationship between canopy conductance g_s and the meteorological variables in rainy season.

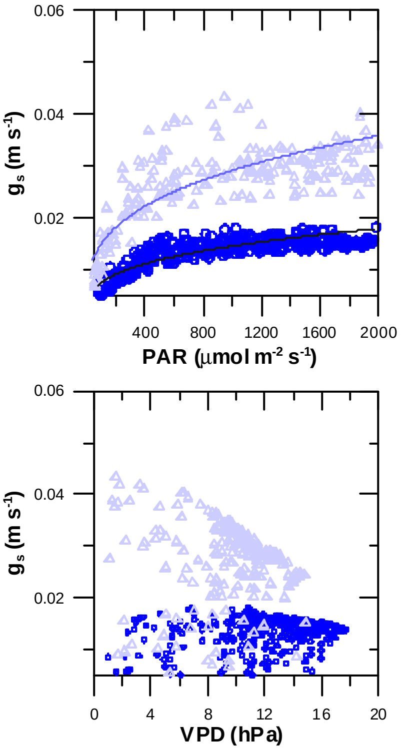

Table 2. Summary of the extracted parameters in canopy conductance model.

Paramters	Complex terrian Rainy	Paddy filed Rainy
g_{smax}	2.84×10^{-2}	5.84×10^{-2}
a	8.55×10^{-5}	2.28×10^{-5}
b	0.023	0.035

Next, the net carbon assimilation rate (F_c) in the photosynthesis model proposed by Farquhar et al. [1980] also can be written as

$$F_c = -m_c[V_c(1-0.5j)\ R_d] = -m_c\left[V_c\left(1-0.5\frac{V_0}{V_c}\right) R_d\right]$$

$$= -m_c\left[V_c\left(1-\frac{p(\Gamma_*)}{p(C_c)}\right) - R_d - R_{soil}\right]$$

where V_c is the rate of carboxylation in the PCR cycle, R_d is the dark respiration rate, R_{soil} is the soil respiration, V_o is the rate of oxygenation, $p(\Gamma_*)$ is the CO_2 compensation point without dark respiration, and C_c is the intercellular CO_2 concentration. Assuming the following condition,

$$e(1-f)=0.22, C_c/C_a=0.75$$

where ε is the leaf absorptance to *PAR* and *f* the fraction of *PAR* not absorbed by chloroplasts, two parameters (ρ:density of chlorophyll, R_d) herein are extracted, where ρ reflects the physiological characteristics.

Figure 7 indicates the relationship between F_c and *PAR* over two land covers in rainy season. The dependence of F_c to *PAR* in paddy field was retained higher than that in terrestrial terrain under the same meteorological condition as shown in Figure 6. The comparison of the parameters in conjunction with the evaporative and photosynthesis activities was summarized in Table 2 and table 3.

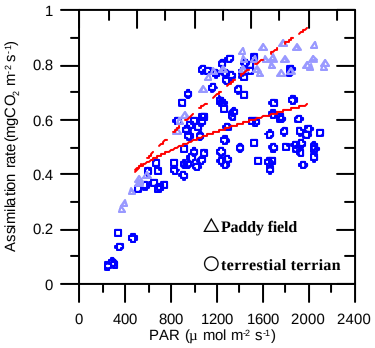

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Figure 7. Relationship between PAR and net assimilation in photosynthesis model using rate observed data in rainy season.

Table 3. Summary of the extracted parameters in photosynthesis model

Paramters	Complex terrian Rainy	Paddy filed Rainy
ε (1-f)	0.22	0.22
ρ	0.25	0.3
R_d	0.03	0.05

4.Concluding remarks

The surface energy flux balance and total evapotranspiration were estimated using the eddy correlation, and bandpass covariance technique over a tropical monsoon environment within the framework of GAME. One of the aims of this present study is to obtain information on the seasonal variation of heat and water vapor exchanges between the atmosphere and terrestrial land cover (complex area) in tropical monsoon environment. The result indicated the daily integrated values of net radiation, sensible heat, latent heat and ground heat flux during the observation period from July 1998 to February 1999 were 10.76 MJ m^{-2}, 2.32 MJ m^{-2}, 5.18 MJ m^{-2} and 0.03 MJ m^{-2}, respectively. Sensible and latent heat fluxes were the dominant energy partitioning components throughout the year. The seasonal difference in surface fluxes between wet and dry seasons was seen, and the latent heat flux was dominant in the monsoon season, corresponding with the increase of specific humidity after frequent precipitation. Whereas the sensible heat flux increased as the surface temperature increased in the absence of rainfall during the dry season. However, the closure of energy balance remained unresolved as with the foregoing experimental studies. The estimated amount to evapotranspiration was 526 mm versus 641 mm of actual precipitation, and accounted for about 80% of the precipitation during this period.

Over typical land uses in monsoon region the short-term observation was conducted to measure the CO_2 flux. The results suggested that both of land uses might work as the carbon sink throughout a year even in the crucial dry condition. The comparison of model parameters, which indicate the intensity for evaporation and the net assimilation rate, indicated that the activities of the paddy field was more vigorous rather than that of the terrestrial terrain.

5. References

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