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Contents

Report on the AsiaFlux Training Course 2007 on Micrometeorology

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AsiaFlux Training Course 2007 on Micrometeorology was held on 17-26 July 2007 at NICEM (National Instrumentation Center for Environmental Management, Seoul National University) and Yonsei University, Korea. It was jointly organized by AsiaFlux Short Training Course Sub-workgroup (TC-SWG) and KoFlux, and it was the second AsiaFlux Training Course. In addition to 15 participants from 9 different countries and regions (India, Indonesia, Cambodia, Thailand, China, Nepal, Bangladesh, Philippines and Taiwan), several Korean supporting staffs, organizing committee members and lecturers have gathered in Seoul and spent productive 10 days together.

Background

Let us first introduce the brief background. During the first training course last year in Tsukuba, Japan, TC-SWG has realized that there is still a strong need of elementary level training program for the researchers who are interested in flux observation. Therefore we decided to hold the second AsiaFlux Training Course again to provide an opportunity to learn theories and practical skills for Asian researchers who would start long term observation or begin establishing local flux network in their countries.

KoFlux has kindly offered its support as a host. KoFlux members and TC-SWG had carefully investigated the proposed plan, then at the AsiaFlux Steering Committee meeting in November 2006, it was officially announced that AsiaFlux TC2007 would be held in Seoul in summer of 2007 with the support of KoFlux and Yonsei University.

We had made a public notification regarding TC2007 program on AsiaFlux website in December 2006 and then started calling for applications. Within the next two months, we had received almost 50 applications and many inquiries not only from Asia but also from

Europe, Africa and US.

The TC2007 organizing committee was established among TC-SWG and KoFlux members, and its first meeting was held in March 2007 in Seoul. We selected 15 participants who showed potentials to contribute to AsiaFlux as PI or new network founder. We would like to mention here that we have received much more applications than our capacity. We had to decline especially those applicants who belongs to research institutes or projects in which they can possibly get trained by their own program. We would once again like to ask those unselected applicants for their participation to AsiaFlux in other ways such as presenting their study at workshops, contributing articles to the newsletter and providing data and site information to the AsiaFlux database.

Contents

Contents of this training course were set to provide the essential theory and measurement techniques of long-term observation of energy, water and carbon fluxes by eddy covariance method. The program was divided into the following 4 sections.

1) Lectures

Several leading scientists from Korea, Japan, US and China, had lectured the basic theory on micrometeorological observation. Topics included global climate change, canopy micrometeorology, turbulent diffusion, atmospheric boundary layer and spectral analysis of turbulence with the latest research results. The up to date methods for quality control and gap-filling were also introduced.

2) Practical class

Engineers from a US-based instrument manufacturer had given a series of lectures and practices using actual instruments, data logger and PC. Trainees had a chance to learn practical operational procedures of imperative equipments for eddy covariance flux measurement such as installation and operation of ultrasonic anemometer-thermometer and infrared gas analyzer, calibration of infrared gas analyzer using standard gases, writing data logger programs for storage/retrieval of data, and data processing to obtain various fluxes from observed data.

3) Field trip

The participants took a day trip to Gwangneung KoFlux Supersite and witnessed active field observations. The site PI has explained their studies that encompass not only long term tower measurement of energy, water and CO_2 fluxes but also some inter-disciplinary researches involving biometry, chamber gas exchanges, ecohydrology, biogeochemistry and isotopic methods.

4) Open seminar

The last part of this training course was an open seminar titled “Trend and challenge in flux studies” by two authorities. The first lecturer, Prof. Shashi Verma (University of Nebraska, US), has first introduced the genesis of eddy covariance CO_2 flux measurement. He explained his experience when there were only three sets of infrared gas analyzer in the world that enabled a direct measurement of CO_2 concentration fluctuation in the atmosphere. Then he introduced his life time research on turbulent transfer over plant canopy. He passionately encouraged that we should be willing to spend time to talk about the

importance of our study to researchers in different disciplines.

Following Prof. Verma's presentation, formerly one of his best students and currently the vice chairman of AsiaFlux steering committee, Prof. Joon Kim (Yonsei University, Korea) reminded us of the urgent tasks upon aggravating global environmental conditions and importance of international collaborations. He also mentioned that we need to continue developing AsiaFlux network with spirit of self-sacrifice to contribute Asian environmental studies.

In addition to the above regular programs, we have held a couple of evening sessions with two invited Korean researchers. They introduced the latest topic and findings on groundwater hydrology and progress on remote sensing studies which deal with data from flux tower.

Throughout the course we have reaffirmed the significance of collaboration across a border when taking action toward resolving global environmental problems.

Future AsiaFlux training program

AsiaFlux Training Course 2006 and 2007 have been financially supported by MEXT (Japanese Ministry of Education, Culture, Sports, Science and Technology) and the support will end in March 2008. Although AsiaFlux has no specific plan at the moment to hold another training course of the same scale in the future, TC-SWG would like to continue to support Asian researchers based on the following two methods.

1) Learning materials

We are opening an access to the learning materials for AsiaFlux members. These materials include text, lecture notes, presentation slides and time table. We strongly encourage our Asian colleagues to use these materials when conducting training sessions in their own community.

2) Short seminar

We are going to consider having seminars as an additional program of international meetings such as AsiaFlux workshops. It will be a short program for a few days to discuss and learn observation techniques and data processing skills. The program may also deal with advanced scientific issues to exchange news and latest information.

Acknowledgement

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- Japanese Ministry of Education, Culture, Sports, Science and Technology
- National Instrumentation Centre for Environmental Management, Korea
- Sustainable Water Resources Research Centre, Korea

Productivity of a Tropical Plantation of Coconut tree (*Cocos nucifera*, L.), Compared with Tropical Evergreen Humid Forests.

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Abstract

Effects of land use and its changes on productivity and carbon balance are very important issues for Clean Development Mechanism (CDM), particularly under the tropics. A tropical plantation of coconut tree with a grass under-storey (total LAI of around 6 for the two layers) and placed in close-to-optimum growing conditions (high level of fertility, no seasonal drought, evergreen, continuous growth) displayed productivity characteristics close to tropical evergreen humid forests, *i.e.* amongst the highest levels encountered in global forest biomes. This is an appealing result, notably for other tropical perennial crops grown in fertile conditions and in absence of drought, such as *e.g.* oil palm, coffee, rubber tree. It would deserve further investigations, together with other annual tropical crops.

Introduction

Effects of land use and its changes on productivity and carbon balance are very important issues for Clean Development Mechanism (CDM), particularly under the tropics.

Ecosystem productivity is generally referred by Net Primary Productivity (NPP: the sum of annual growth and mortality), Gross Primary Productivity (GPP: CO_2 entry in the ecosystem by photosynthesis) or else Net Ecosystem Productivity (NEP: CO_2 balance of the ecosystem). Gower *et al*. (1999), Pregitzer and Euskirchen (2004) stressed the need for more productivity surveys in tropical ecosystems and forests, especially for the southern hemisphere, for young and middle-aged classes, and for the belowground compartment.

Recently, Luyssaert *et al*. (2007) released a meta-analysis of global patterns in forest CO_2 balance. They highlighted that tropical evergreen and humid forests displayed the highest levels of average annually cumulated GPP (3551 ± 160 SD gC m^{-2} yr^{-1}), NPP (864 ± 96 SD gC m^{-2} yr^{-1}) and NEP (403 ± 102 SD gC m^{-2} yr^{-1}).

CO_2 balance assessments remain scarce for tropical humid tree-crops (*Cocos nucifera* or coconut palm, *Elais guineensis* or oil palm, *Coffea sp*. or coffee, *Theobroma cacao* or cocoa, *Hevea brasiliensis* or rubber tree, etc.), although their plantations occupy over 47 Mha in the humid tropics (FAO 2003). The coconut tree is the largest contributor (23% of that area), being a multi-purpose tree-crop, with important domestic and industrial uses and opportunities for the Clean Development Mechanism (Tan *et al*. 2004, Roupsard *et al*. 2004).

The aim of this newsletter is: *(i)* to sum up results from a three-year eddy-covariance experiment (COCOFLUX) on a mature coconut plantation with a grass under-storey in Vanuatu (Oceania, S-W Pacific); *(ii)* to compare the productivity of this plantation with results from tropical evergreen and humid forests.

Materials and Methods

Location, climate and stand (Photo 1)

The study was carried out during three years, 2002 to 2004, in a mature coconut plantation, 19-21 years after planting (YAP), which was part of the Vanuatu Agricultural Research and Technical Centre (VARTC), on Espiritu Santo, Vanuatu, South Pacific (15° 26.6′ S, 167° 11.5′ E; altitude 80 masl). The climate was tropical and humid. No hurricane or El-Niño event affected this experiment. The growing conditions (soil texture and fertility, absence of seasonal water shortage, climate) were considered to be close-to-optimum (Roupsard *et al*., 2006). The mean annual temperature was 25.1 °C and mean annual rainfall was 2763 mm.

Photo 1: Aerial view of the COCOFLUX eddy-covariance site (Vanuatu, S-W Pacific). Photo Eric Malézieux, CIRAD.

The stand had been row-planted in 1983 with the Vanuatu Red Dwarf x Vanuatu Tall (VRD x VTT) high-yielding hybrid coconut variety (Labouisse *et al*. 2005). The planting design was triangular and equilateral. Coconut tree canopies covered around 75% of the ground. The grass under-storey included mainly *Paspalum* sp. (21% of soil coverage), *Mimosa pudica* (11%) *Desmodium heterophyllum* (9%), *Mikania micrantha* (9%) and *Sida* sp. (8%). The true leaf area index (LAI), obtained by destructive sampling, was similar for both layers *i.e.* around 2.95 for the coconut layer and varying between 1.95 and 3.50 for the grass under-storey (Roupsard *et al*., 2006). LAI was constant for the coconut layer (Roupsard *et al*., 2007).

Micro-climate and eddy-covariance

The eddy-covariance experiment was set up in accordance with the Carboeuroflux recommendations (Aubinet *et al*., 2000). 3D wind components and temperature were measured at reference height (22 m, coconut canopy height being 16m) on top of the eddy-covariance tower, using a WindMaster Pro ultrasonic anemometer (Gill Instruments, Lymington, UK) at 10 Hz. CO_2 and H_2O fluctuations were measured at 5 Hz with a Li-7500 open path (LiCor, Lincoln, NE, USA). Raw data were collected and pre-processed by "Tourbillon" software (INRA-Ephyse, Bordeaux, France) for a time-integration period of 1800 s. Raw-data were post-processed using EdiRe software (University of Edinburgh, UK) into half-hourly values. All data were de-spiked according to statistic filters, the axes were rotated two times in order to fit the "natural wind coordinate system" (McMillen, 1998; Lee *et al*., 2004), scalars data were linearly de-trended, and vapour fluxes were corrected for the buoyancy (Webb *et al*., 1980) and the high frequency losses (Moore *et al*., 1986).

Micro-climate variables were logged at reference height on a CR10X associated with an AM416 Multiplexer (Campbell Scientific, Shepshed, UK). The measurement period was 30 s, integrated half-hourly. Instruments in use were: global radiation, silicon cell pyranometer SKS1110 (Skye Inst. Ltd); net radiation, NR-Lite (Kipp & Zonen, Delft, The Netherlands); incident photosynthetic photon flux density (Qp), home-made probe (Dauzat and Eroy, 1997) calibrated against commercial probes; temperature and humidity, MP103A (Rotronic, Bassersdorf, Germany); rainfall tipping-bucket, ARG100 (R.M. Young, MI, USA); wind-speed and direction, 03001 Wind Sentry (R.M. Young, MI, USA).

NPP of coconut tree (NPP_c) and grass (NPP_g)

Briefly, for every plant organ monitored, net primary productivity (NPP) was linked to dry mass (DM) variations over time (t, on a monthly basis) and to mortality or litter production (L), as follows:

$$NPP = \frac{\Delta DM}{dt} + L \qquad (1)$$

The sampling of 10 trees was stratified, based on a preliminary stand survey of tree height and nut load distributions. They were monitored non-destructively (January 2002 to December 2005, 19 to 22 YAP), climbed every month (2002-2003) and then every week (2004-2005), i.e. 1,200 climbs to measure nut growth, new leaf emission and stem height. Above ground NPP was derived, using specific allometric equations, based on destructive samplings (10 other representative trees felled for biomass; sub-samples dried in a ventilated oven at T = 70°C to constant weight). Belowground tree NPP was assessed by large rhizotrons and sequential trenching, in order to assess root lifespan and turnover.

Above-ground grass NPP was assessed by successive harvests (n = 8), during 18 months between 2002 and 2004, within in two subplots, covering a total of 101 m^2 and representative of the horizontal heterogeneity. Those results were extrapolated to the entire 2002-2004 period. Below-ground, NPP_g was estimated from allocation ratios of root to shoot available in the literature for tropical fertile and wet grasslands (Scholes and Hall 1996; House and Hall 2001).

NEP

Net Ecosystem Productivity (NEP or C balance of the ecosystem) was computed as the algebraic sum of CO_2 fluxes measured at reference height (F_c), after filtering for signal quality. Gap-filling was performed using Mean Diurnal Variation technique (MDV) proposed by Falge *et al*. (2001).

GPP

The gross primary productivity (GPP) was assumed to correspond to the net photosynthesis of the ecosystem (coconut palms + grass under-storey). F_c was split into diurnal ($F_{c,day}$) and nocturnal ($F_{c,night}$) values. $F_{c,night}$ data were discarded when the friction velocity (U*) was < 0.4 m s^{-1}. The remaining values of $F_{c,night}$ were assumed to represent the respiration of the ecosystem during the night ($R_{e,night}$) and were adjusted to night air temperature ($T_{a,night}$) using a Vant'Hoff model (Falge *et al*., 2001). $R_{e,day}$ was then derived from $R_{e,night}$ after Vant'Hoff correction for the current diurnal temperature.

GPP was then computed following:

$$GPP = F_{c,day} - R_{e,day} \qquad (2)$$

where GPP was the gross primary productivity; $F_{c,day}$ was the diurnal CO_2 flux measured by eddy covariance; $R_{e,day}$ was the diurnal respiration of the ecosystem.

Results and Discussion

GPP

Fig. 1 presents the GPP annual sum for the coconut plantation (red arrow for COCOFLUX site), together with results redrawn from the meta-analysis by Luyssaert *et al*. (2007) for global forest biomes and according to site mean annual temperature. The coconut plantation (mean annual temperature = 25.1 °C; mean annual rainfall = 2763 mm) participated to the most productive sites in terms of GPP (with a three-year annual average of 3900 gC m^{-2} yr^{-1}), close to general results from other tropical humid evergreen forests (average 3551 ± 160 SD gC m^{-2} yr^{-1}). In the case of tropical humid evergreen ecosystems, limitations for productivity can be considered amongst the lowest of the globe. However, in spite of rather high levels of annually cumulated radiation within the tropics, an important seasonal variation in radiation may remain (due to variations in sun elevation and cloudiness), and hence still somewhat restrict GPP.

NPP and Ra

Fig. 2 presents the NPP annual sum for the coconut plantation (red arrow for COCOFLUX site). According to Navarro *et al*. (unpublished results), the three-year average NPP was 1610 gC m^{-2} yr^{-1}. The NPP/GPP (carbon-use efficiency) was 0.41, which appeared quite consistent in comparison with temperate forests (NPP/GPP ranging from 0.44 to 0.54). NPP here was around twice as much as the average value of 864 ± 96 gC m^{-2} yr^{-1} reported by Luyssaert *et al*. (2007) for tropical humid evergreen forests, which was questionning. However, Luyssaert *et al*. (2007) discussed their rather low value of NPP/GPP = 0.24, which they attributed to higher rates of autotrophic respiration and/or non-C losses in tropical humid forests.

Autotrophic respiration (R_a) was estimated at 2400 gC m^{-2} yr^{-1} from the composition of plant organs, construction costs (Penning de Vries *et al*. 1989), and maintenance coefficients (de Wit *et al*. 1978). The sum of NPP and R_a (4010 gC m^{-2} yr^{-1}) closely matched eddy-covariance GPP (3900 gC m^{-2} yr^{-1}), which is considered here as a satisfactory cross-validation of independent methods (eddy-covariance *vs* classical).

NEP and Re

Fig. 3 presents the NEP annual sum for the coconut plantation (red arrow for COCOFLUX site). The three-year average apparent NEP was 813 gC m^{-2} yr^{-1}, to be compared with the 403 ± 102 SD gC m^{-2} yr^{-1} reported by Luyssaert *et al*. (2007) for tropical humid evergreen forests. Both results change by a factor of 2. We would interpret a higher C storage in the coconut plantation in two ways: first, part of the NPP of the coconut plantation was actually exported every 2 month out of the plantation (copra from the nuts) and thus did not contribute to R_e: this amounted to around 130 gC m^{-2} yr^{-1}, hence reducing the apparent NEP to a corrected NEP of 683 gC m^{-2} yr^{-1}. Second the coconut plantation was very young (19-21 year-old) in comparison with the natural forests, and was thus likely further from equilibrium between GPP and R_e than mature forests.

Finally, we found a R_e/GPP of 0.83 (corrected for copra export), close to the value reported by Luyssaert *et al*. (2007) for tropical humid evergreen forests of 0.87.

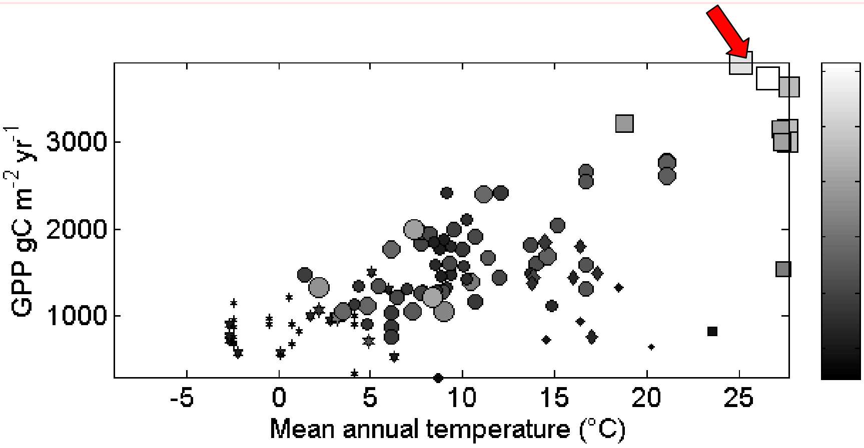

Fig. 1: GPP according to the mean annual temperature. The size and gray tone of the marker is a measure for the annual precipitation sum (mm). Stars mark boreal, circles temperate, diamonds Mediterranean and squares tropical forests.

The figure is re-drawn from the original one published by Luyssaert *et al*. (2007). The apex of the red arrow shows the COCOFLUX site (square symbol, measured mean annual site temperature =25.1 °C; measured mean annual rainfall = 2763 mm).

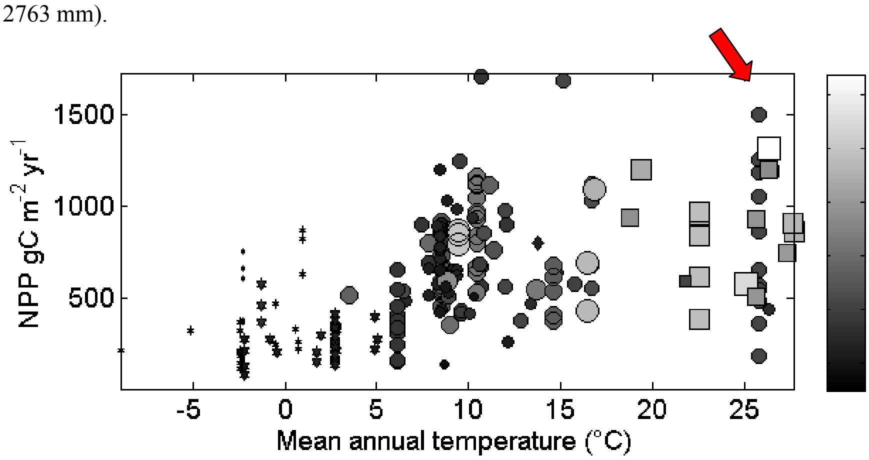

Fig. 2: NPP according to the mean annual temperature. The size and gray tone of the marker is a measure for the annual precipitation sum (mm). Stars mark boreal, circles temperate, diamonds Mediterranean and squares tropical forests.

The figure is re-drawn from the original one published by Luyssaert *et al*. (2007). The apex of the red arrow shows the COCOFLUX site (no symbol for this variable), including all compartments of coconut tree and under-storey, aboveground and belowground (measured mean annual site temperature =25.1 °C; measured mean annual rainfall = 2763 mm).

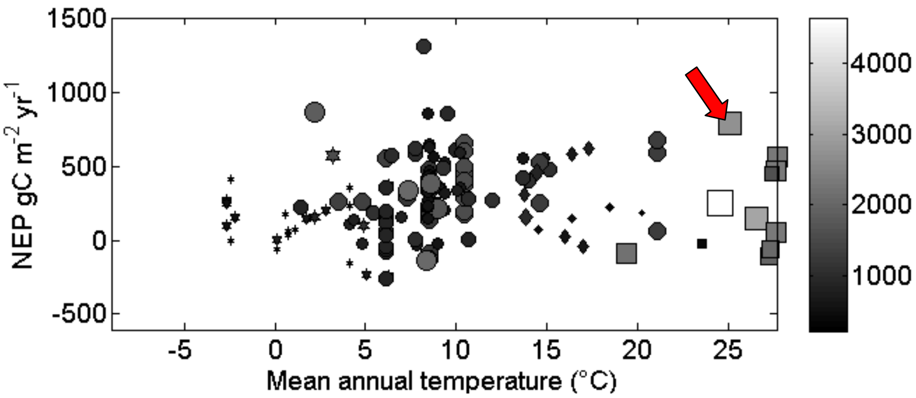

Fig. 3: NEP according to the mean annual temperature. The size and gray tone of the marker is a measure for the annual precipitation sum (mm). Stars mark boreal, circles temperate, diamonds Mediterranean and squares tropical forests.

The figure is re-drawn from the original one published by Luyssaert *et al.* (2007). The apex of the red red arrow shows the COCOFLUX site (square symbol, measured mean annual site temperature =25.1 °C; measured mean annual rainfall = 2763 mm).

Conclusions

A tropical plantation of coconut tree with a grass under-storey (total LAI of around 6 for the two layers) and placed in close-to-optimum growing conditions (high level of fertility, no seasonal drought, evergreen, continuous growth) displayed productivity characteristics close to tropical evergreen humid forests, *i.e.* amongst the highest levels encountered in global forest biomes. Climate, fertility, LAI and phenology appeared to be key elements for ranking productivity of ecosystems, irrespective of their status (from artificial to natural). This is an appealing result, notably for other tropical perennial crops grown in fertile conditions and in absence of drought, such as *e.g.* oil palm, coffee, rubber tree. It would deserve further investigations, together with other annual tropical crops.

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We are indebted to Global Change Biology-Blackwell Publishing where original figures from Luyssaert *et al*. (2007) can be referred to.

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Estimation of Evapotranspiration above Rice Crop Stand Using Flux Profile Method – A Case Study

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Flux profile method is a comparatively simple approach to determine flux transfer particularly for water vapour as it involves less instrumentation. This principle is used in most of the evaporation models accepted worldwide. Besides that the aerodynamic constants such as zero plane displacement, roughness length, friction velocity used in this model can be determined from canopy characteristics like plant height, leaf area index, leaf distribution etc. with reasonable accuracy (Shaw and Pereira, 1982 and Stanhill, 1969), which makes this approach compatible with advanced tools like Remote Sensing (RS) and Geographical Information System (GIS). For flux estimation in large spatial scale the RS-based observations of different vegetation indices are used in suitable empirical models to determine canopy characteristics (Tucker, 1979, Jackson and Huete, 1991) and aerodynamic constants those are subsequently used for simulating flux transfer at regional scale.

However, accuracy of flux profile relation approach largely depends upon uniformity of boundary layer development as in case of large plain land under field crops or pasture lands with short and uniform canopy structure. But in case of hilly terrains and natural forest areas it may show misleading trend due to highly complex nature of boundary layer.

The present study has been carried out to estimate the evapotranspiration (ET) flux from rice crop stand using flux profile relationship. This investigation is done under the network research programme on 'Energy Water Balance and Crop Growth Monitoring using Satellite Data' sponsored by Space Application Centre, Indian Space Research Organization (ISRO). The importance of this study lies in the fact that about 34–43% of the world's irrigation water is used to irrigate rice (Bouman *et al*. 2006). However, water resources are getting increasingly scarce and rice is a main target for water-saving initiatives (Rijsberman, 2006).

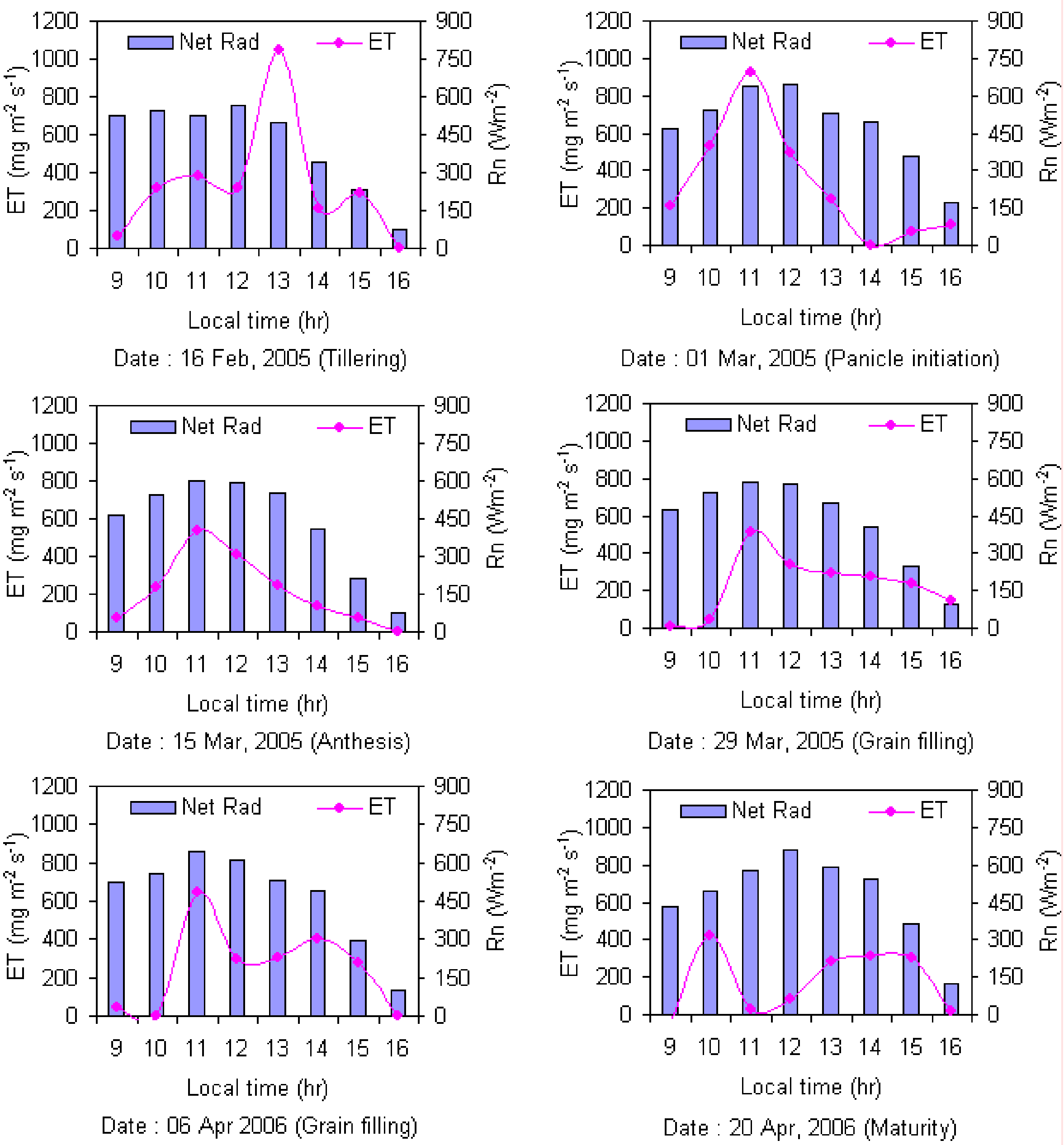
The study area is located in the eastern India at 23° 01' (N) latitude, 88° 35' (E) longitude and at an altitude of 9 m above MSL. The extensive rice cultivation in this region offers 3 km x 3 km of continuous rice crop stand, which is ideal for uniform boundary layer development.

Wind profile study above rice crop stand

Hourly mean data on air temperature, relative humidity and wind speed were recorded at three levels above the crop canopy (within 2 m above the crop height) along with net radiation at one level. The zero plane displacement, roughness length and friction velocity were determined from the empirically from the logarithmic wind profile equation. The Richardson's number was estimated from the wind speed and temperature profile to determine the stability factor. The momentum transfer coefficient was estimated from wind profile equation and the vapour transfer coefficient was derived from momentum transfer coefficient after appropriate stability correction. Finally the hourly ET rate was estimated from the flux profile relation using vapour transfer coefficients. (Montieth and Unsworth, 1990)

Table 1: Estimated zero plane displacement (d) from wind profile observations

Date (Crop stage)	Crop height (m)	Mean wind speed (m s^{-1})			Zero plane Displacement (m)
		u_1	u_2	u_3	
16 Feb (Peak Tillering)	0.36	Z_1= 0.5 m	Z_2= 0.75 m	Z_3 = 1.25 m	0.266
		1.325	1.8625	2.388	
01 Mar (Panicle initiation)	0.57	Z_1= 0.7 m	Z_2= 1.0 m	Z_3 = 1.6 m	0.524
		0.688	1.237	1.738	
15 Mar (Anthesis)	0.79	Z_1=1.0 m	Z_2= 1.3 m	Z_3 = 1.9 m	0.667
		0.425	0.750	1.088	
29 Mar (Pod filling)	0.93	0.371	0.657	0.900	0.807
06 Apr (Pod filling)	0.95	1.174	1.714	2.200	0.775
20 Apr (Maturity)	0.95	0.814	1.114	1.429	0.658



Figure–1 : Diurnal pattern of net radiation and evapotranspiration flux above rice crop stand at critical developmental stages

The evapotranspiration as estimated from the latent heat flux is given by:

$$\lambda ET = -\left(\frac{\rho C_P}{\gamma}\right) \times k^2 (z-d) \frac{\delta u}{\delta z} \times \frac{\delta e}{\delta z} \times F$$

where, λ : Latent heat of vaporization, ET : Evapotranspiration (Vapour flux), ρ : Density of moist air, C_P : Specific heat of air at constant pressure, γ : Thermodynamic value of psychrometric constant, k : Von-Karman's constant, d : Zero plane displacement, u: Wind speed, z : Height, F : Stability factor

Wind speed at the height z:

$$u(z) = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right)$$

where, u_*: Friction velocity and z_0: Roughness length

Momentum transfer coefficient:

$$K_M = u_* \times k \times (z-d)$$

Richardson number:

$$Ri = \frac{g}{T} \times \frac{(T_2 - T_1)(z_2 - z_1)}{(u_2 - u_1)}$$

where, g: Acceleration due to gravity, T: Temperature, and u : wind speed

Stability factor:

$F = (1 - 5Ri)^2$,when Ri is positive

$F = (1 - 16Ri)^{3/4}$, when Ri is negative

In the present study the zero plane displacement is estimated by measuring wind speed at three heights above the crop surface and fitting the wind speed at corresponding heights in logarithmic equation (Table-1). The heights of measurement were adjusted as per the crop height at different stages of growth. It was found that the zero plane displacement showed an increasing trend with increase in crop height till pod filling stage and decreased slightly thereafter.

The evapotranspiration (ET) in mg m^{-2} s^{-1} estimated by flux profile method as explained above is presented in Figure-1. The results of the study showed large diurnal fluctuation in ET flux at all stages of crop growth. This might be due to the fact that ET is a complex function of net energy received, wind speed, vapour pressure difference as well as stomatal activity. However, the ET recorded during morning (9 hr local time) and afternoon (16 hr local time) was, in general lower than that of mid day (11 to 13 local mean time) except at maturity stage where the trend was erratic. The peak ET flux was higher during tillering stage followed by that of panicle initiation stage when there was standing water in the crop field and the crop was in active growth.

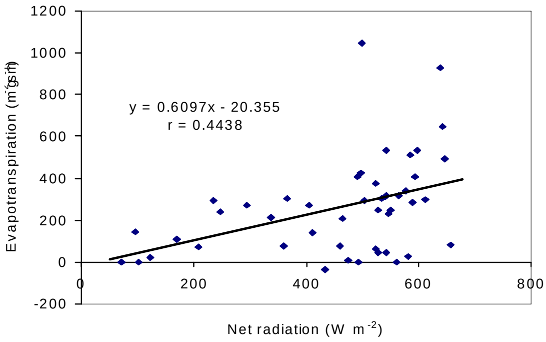


Figure - 2 : Relation between net radiation and evapotranspiration above rice crop stand

The net radiation absorbed on the crop surface is dissipated as sensible heat flux, latent heat flux and ground heat flux with a small portion being used as metabolic heat. The correlation between the net radiation and evapotranspiration (r = 0.4438, significant at P = 0.01) as recorded in the present study (Figure-2) emphasizes the role of net radiation in regulating ET flux during the crop season.

It can be concluded from the present study that evapotranspiration pattern has wide diurnal variability with its peak during mid day except at maturity stage. Higher evapotranspiration was observed during tillering stage followed by that of panicle initiation stage when field was more or less water stagnant. Furthermore, evapotranspiration is highly correlated with net radiation.

However, though flux profile approach is one of the most simple and adaptable techniques for large scale flux monitoring for its compatibility with remote sensing based empirical models it has to be standardized against lysimetric and eddy covariance measurements.

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Long-term Carbon Dioxide Flux Measurement at Bengal Lowland

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1. Background of establishment of a flux study site in Bangladesh Agricultural University

Concentration of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere is increasing, and climate modelers have already predicted a consequent global warming and changes in the prevailing climatic patterns. Climate is the primary factor for determining the adaptation of a crop to various regions, its cropping season and potential yield. It is necessary to assess the effects of global environmental changes on the production of major crops in each region, to form a basis for counter measures (cultivar improvements, alteration of crop species and cropping seasons, provisions for irrigation systems and production technologies, etc.). The increase of atmospheric CO_2 concentration itself and resultant potential disturbances to the global climate system will probably affect the growth of vegetation in the future and could also affect the security of world's food supply. This necessitates the development of a reliable observation of CO_2 exchange between the major crop fields and atmosphere for prediction of both the effects of global environment change and crop yield. In this respect Bangladesh Agricultural University (BAU) is concerned with long-term observation of CO_2 flux.

To assess the exchange of energy and other scalar quantities between various types of crop fields and the atmosphere, eddy covariance (EC) measurement is considered to be a precise and dependable tool by the scientific community devoted in agro-meteorological research. As we reported in a previous issue of AsiaFlux Newsletter (Hossen *et al.*, 2007), a flux study site (MYM site) was established at BAU campus in February 2006. We report here the present status of MYM site, our daily activities, problems we have faced or are facing and their solutions, to share our experience of one and a half year (three growing seasons) with AsiaFlux community members, especially with latecomers in developing countries, who are engaged in flux studies or are going to establish new flux sites in their countries.

Photo 1 MYM site in late growing season of Aman rice (dry season rice) in November 2006.

2. Measurement system and instruments at MYM site

To conduct a long-term flux measurement at MYM site, we installed two masts, one for EC measurement and the other for complementary micrometeorological measurement (Photo 1). We are improving the measurement system gradually and adding new sensors and data loggers. The present EC measurement system is shown in Table 1, and the meteorological measurements are listed in Table 2. Besides these automatic measurements, we also conduct biological measurements like plant height, leaf area index, dry matter content etc. to validate our consistency and reduce errors.

problem as soon as possible.

Table 1 Eddy covariance measurement at MYM site

System	Open-path system
Wind speed and acoustic temperature	Three-dimensional sonic anemometer (HS, Gill Instruments, UK)
CO_2 and water vapor densities	Open-path infrared gas analyzers (LI-7500, LI-COR, Lincoln, NE, USA)
Measurement height	2.95 m
Sampling frequency	10 Hz
Averaging time	30 min
Data logger	CR1000X (Campbell Scientific, Logan, UT, USA)
Data storage	Compact flash card (1 GB)
Original data (raw data or statistics)	Raw data

Table 2 Measurement of meteorology at MYM site

Observation items	Levels/depth/height	Instrument
Incoming and outgoing short-wave radiation	3.0 m	Four component net radiometer (MR-40, Eko, Tokyo, Japan)
Incoming and outgoing long-wave radiation	3.0 m	Four Component Radiometer (MR-40, Eko)
Net radiation	3.0 m	Four Component Radiometer (MR-40, Eko)
Incoming and outgoing PPFD	2.95 m	Quantum sensor (LI-190, LI-COR)
Transmitted PPFD	Below canopy	Quantum sensor (LI-191, LI-COR)
Incoming short-wave radiation	3.0 m	Pyranometer (MS-62, Eko) 1)
Air temperature	1.65, 2.95 m	Platinum resistance thermometer (HMP45A, Vaisala, Finland)
Relative humidity	1.65, 2.95 m	Humicap (HMP45A, Vaisala)
Soil temperature	0, 0.05, 0.1, 0.2, 0.4 m (five points)	Type-T thermocouple
Soil heat flux	0.05 m (three points)	Heat flux plate (MF-180M, Eko)
Soil water content	0.05 m (three points), 0.1, 0.2, 0.3 m	TDR (TDR100, Campbell Scientific, USA) 2)
Field water level	Two points	Capacitive water depth probe (model 6521, Unidata, Australia)
Water temperature	0.02, 0.05 m	Type-T thermocouple
Barometric pressure	-	Silicon capacitive pressure sensor (PTB210, Vaisala)
Precipitation	-	Observed at Meteorological Weather Station within BAU campus

Data are sampled and recorded using CR23X (Campbell) unless specified below.
1) A battery-driven data logger (KADEC-UP, Sapporo, Japan) is used for sampling and storage of pyranometer data.
2) CR10X (Campbell) is used for a sampling and storage of TDR data.

3. Activities at MYM site

As our study site is situated inside the campus of BAU, it is considerably easy for us to look after the instruments at a daily basis. Everyday, one of our team members visits the site and checks that all instruments are working fine. During the growing season we try to acquire data every alternate day or two days interval at most, but during the fallow period the interval is extended. While inspecting the site, it is mandatory to take a look at displays of the data loggers to identify instruments which are giving erroneous data and to rectify the

Besides these routine activities, we take plant height every alternate day starting after the 10th day of transplanting and collect plant samples with an interval of 7 to 10 days for other biological parameters like leaf area index, dry matter content, etc.

4. Problems we are facing and their solutions

Open-path eddy covariance (OPEC) is likely to face various problems, and we are no exception in this respect. Some problems and their solutions are stated below:

Electricity: In our country, we have power outage frequently and it is the likely condition for the sensors to malfunction and give erroneous data. Power requirement of the data loggers is very small and we can meet this by installing an uninterruptible power supply (UPS). However, the LI7500 requires a whooping 1 amp, and we were in severe difficulty due to its table file errors in the compact flash card after power failure. So we installed another instant power supply (IPS) unit that gives almost 4 hours backup to both the installed systems. As the EC and meteorological measurements depend on sensitive electrical instrument, power outage problem needs to be solved at any cost. In this regards, I would like to propose installation of a solar panel at the site for a better backup and to reduce discontinuity of sensor output.

Security: Strict security is maintained at the site 24 hours a day following three 8-hourly shifts, with 3 guards at each shift to look after the instruments. We have built a small room for the security guards and storage of other necessary logistics.

Rainy season: For OPEC users rainy season is the most crucial part of the year. All problems seem to accumulate and sensors tend to malfunction more frequently. All the non-ideal conditions for the flux measurement prevail. In the 2007 rainy season, we have had 400 mm of rainfall in 3-4 days, and some sensors were producing invalid data because the output was exceeding the voltage range specified in the datalogger program. We always keep contact with the NIAES members to fix these problems.

Data quality: Quality research needs quality measurement. If the measurement is not accurate, all the efforts go down the drain and our endeavors actually make no sense at all. At present monthly data files are prepared and sent to NIAES members for their comments and advices to rectify errors and to improve the data quality. However, assurance of data quality should be done by ourselves as soon as possible. Therefore, the people who are involved in our team need extensive training in different aspects of flux measurement, which is possible by the active cooperation of AsiaFlux through its training courses.

Methane: At rice paddy sites like ours, not only carbon dioxide but other greenhouse gases like methane needs to be accounted for and measured. We have not set about methane study yet due to limitations of analytical instruments and skills.

5. Invitation to BAU

Bangladesh Agricultural University was established in 18 August, 1961 on 486 hectares of land area. This esteemed institution is situated at the bank of river Brahmaputra 3 kilometers south from central Mymensingh. There are 6 faculties with 43 departments. The Department of Environmental Science, that we belong to is a part of the Faculty of Agriculture. Some international projects are in progress here including ours, and for the foreign scientists we have a separate deluxe guesthouse established by the funding of the United States Department of Agriculture (USDA). We welcome foreign scientists to visit BAU and collaborate with us at our flux study site.

6. Concluding remarks

Global warming is a universal problem, but it will commence as a regional issue. So, continuous measurements at different parts of the world hold a paramount importance in respect of a consistent and acceptable modeling of climate change and its aftermath. Since greenhouse gas emission is highly unlikely to be reduced within years or decades, we need to think, for the worst case, that concentrations of greenhouse gases will continue to rise. It is a big challenge how we can face this problem and go ahead. To achieve a sustainable green habitable planet for us and our future generations, we need to share our ideas and views and concentrate our efforts in quality research which will give trustworthy information and enable us to face this challenge.

Acknowledgements

MYM site was established and is operated under the project entitled “Rice Paddy Flux Observation in Bengal Lowland” supervised by Prof. Dr. Md. Abdul Baten, Department of Environmental Science, BAU, Bangladesh and Dr. Akira Miyata, NIAES, Japan. The project is funded by the University Grants Commission (UGC) and Japanese Society for the Promotion of Science (JSPS), and side-by-side AsiaFlux also supports our research activity with a partial funding from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). We acknowledge AsiaFlux for providing training courses on micrometeorology to young scientists in Asia.

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Measurement of CO_2 and Energy Fluxes over a Wetland on Chongming Island

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Introduction

Wetlands are transition areas between terrestrial and aquatic systems and are considered a resource for numerous economical and ecological values. They provide habitats for fish and wildlife, which are also areas for recreation, purifying water through sedimentation and storing carbon. In the last few decades, a continued rise in atmospheric CO_2 concentration has stimulated great interests in wetlands. As a large amount of terrestrial carbon is stored in wetlands (Canada, 1998), modification of temperature, precipitation and evapotranspiration can alter the carbon budget of wetland, and thus, in turn, may greatly influence an environmental change. Long-term measurement of CO_2 exchange can help us to determine whether certain wetlands act as carbon sinks or sources and to further evaluate the consequences of environmental change.

As the definition of wetlands is broad, it may be hard to reach a general principle for all types of wetlands, so we focus on the coastal wetland. Coastal wetlands have a great potential to accumulate carbon over long periods of time, for they continuously accrete organic-rich sediments into the soil (Bridges, 1978), which was supported by the meta-analysis by Chmura *et al*. (2003). Moreover, coastal wetlands release less methane when compared to freshwater wetlands, due to the suppression of sulfate brought on by tidal water (Magenheimer *et al*., 1996). As coastal wetlands have been degraded or lost quickly due to anthropogenic disturbance and plant invasion (Zedler and Kercher, 2005), it is important and urgent to understand their carbon potential.

Energy exchange not only affects radiative and temperature regimes, but water transport, plant growth and productivity as well, so a thorough understanding of energy exchange is useful and important (Dennison and Berry, 1989). The partitioning of energy within

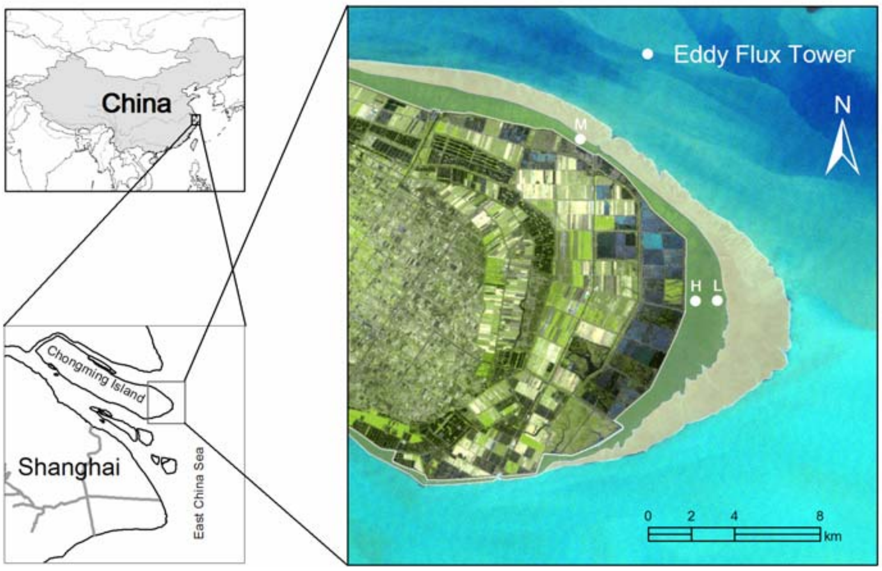

Fig.1 Location of study site and three Eddy flux towers.

wetland ecosystems has a direct impact on hydrologic conditions, which define wetlands. Previous studies showed that latent heat consumed large portions of available energy. In the diurnal scale, the heat stored in water also played an important role but when integrated over a long time, the heat storage term was negligible (Burba *et al*., 1999a; Burba *et al*., 1999b). This was different from the partitioning of energy flux in dry land ecosystems. While these studies were conducted on wetlands that hold comparably steady water levels, we still know little on how the available energy is consumed in coastal wetlands that suffer regular/irregular tides.

Study site

Our study site is located in the Dongtan of Chongming Island (31°25'~31°38'N, 121°50'~122°05'E), which has been growing at a rate of 150 m yr^{-1} toward the East China Sea as a consequence of quick sedimentation (Ma *et al*., 2003). The weather of this area is characterized by strong seasonal variation and abundant precipitation. From 1959 to 1986, the annual mean air temperature fluctuated around 15.3 °C and the coldest month was January with a mean temperature of 2.7 °C, while the highest monthly temperature was observed in August at about 27.6 °C (Huang *et al*., 1993). From 1987 to 1990, the annual precipitation varied around 1022 mm and 70% of the rainfall occurred between April and September (Huang *et al*., 1993). This area experiences irregular semi-diurnal tides and the maximum and average tidal ranges were 4.62~5.95 m and 1.96~3.08 m, respectively (Sun *et al*., 2001).

The soil salinity ranges from 2 to 6% (Huang *et al*., 1993). Typically, the soil contains a high fraction of sand, decreasing with the increasing distance from the sea, while the silt and clay fraction has the opposite trend (Wu *et al*., 2005). The inclination of the wetland is less than 1% (Yang *et al*., 2002). The three dominant plant species are *Scirpus mariqueter* (hereafter *Scirpus*), *Phragmites australis* (hereafter *Phragmites*) and *Spartina alterniflora* (hereafter *Spartina*). *Phragmites* and *Spartina* can grow up to 1.5~2.5 m high, while *Scirpus* is only 0.5~1 m tall. *Scirpus* often forms monospecific populations in the lower intertidal areas, while the other two plants can survive in the whole area. Due to strong adaptability to salt and hypoxia stress, *Spartina* is continually expanding and invading mudflats and other plant communities.

Instruments

Three eddy flux towers were established in August of 2004 as members of the US-China Carbon Consortium (USCCC).We followed the same protocol during the establishment of the towers, located on sites H, M and L respectively (Fig. 1), which represented three height levels of the wetland and hence different distances to the sea. Each tower was equipped with a CSAT-3 sonic anemometer (Campbell Scientific Inc., Logan, UT, USA) and a Li7500 infrared gas analyzer (Li-Cor Inc., Lincoln, NE, USA) at 4.8 m height.

A set of meteorological sensors were also installed in each triangular tower. Net radiation (Rn) was measured by installing a Kipp and Zonen (Delft, Holland) 4-way net radiometer, radiation by a Li-210X pyranometer (Li-Cor), photosynthetic active radiation (PAR) by a Li190SB (Li-Cor) and precipitation by a TE525 rain gage (Texas Electronics, Texas, USA) at 4~4.5 m above the ground. Air temperature (Ta) and relative humidity (RH) were measured by using a HMP-45C probe (Vaisala, Helsinki, Finland) at 2, 3 and 5 m above the ground. Soil temperature (Ts) was measured by a thermister (107 Probe, CSI) at 0.05 m into the soil and adjusted to 0.01, 0.05 and 0.10 m depths in April of 2006. Volumetric soil water content (VWC) was measured with a reflectometry sensor (CS616, CSI) at 0.05 m below the surface while was adjusted to 0~0.10 m in April of 2006 and soil heat flux was measured by three HFT3 soil heat flux transducer (CSI) at 0.05 m below the surface, which was modified to 0.01, 0.05 and 0.10 m, each with one plate in April of 2006. All micrometeorological measurements were recorded and averaged or summed every 30 minutes.

Preliminary results

To better elucidate the carbon exchange of wetlands, we only present the data in August, which is the peak period of growth. The diurnal variations of air temperature (Ta), vapor pressure deficit (VPD) and CO_2 flux (Fc) in August of 2006 are presented in Fig. 2. Clear diurnal variations of Ta, VPD and Fc were observed in each site. For each site, air temperature fluctuated within the range of 25~34°C, while lower values of VPD were observed in site M, suggesting a high evapotranspiration rate in this site.

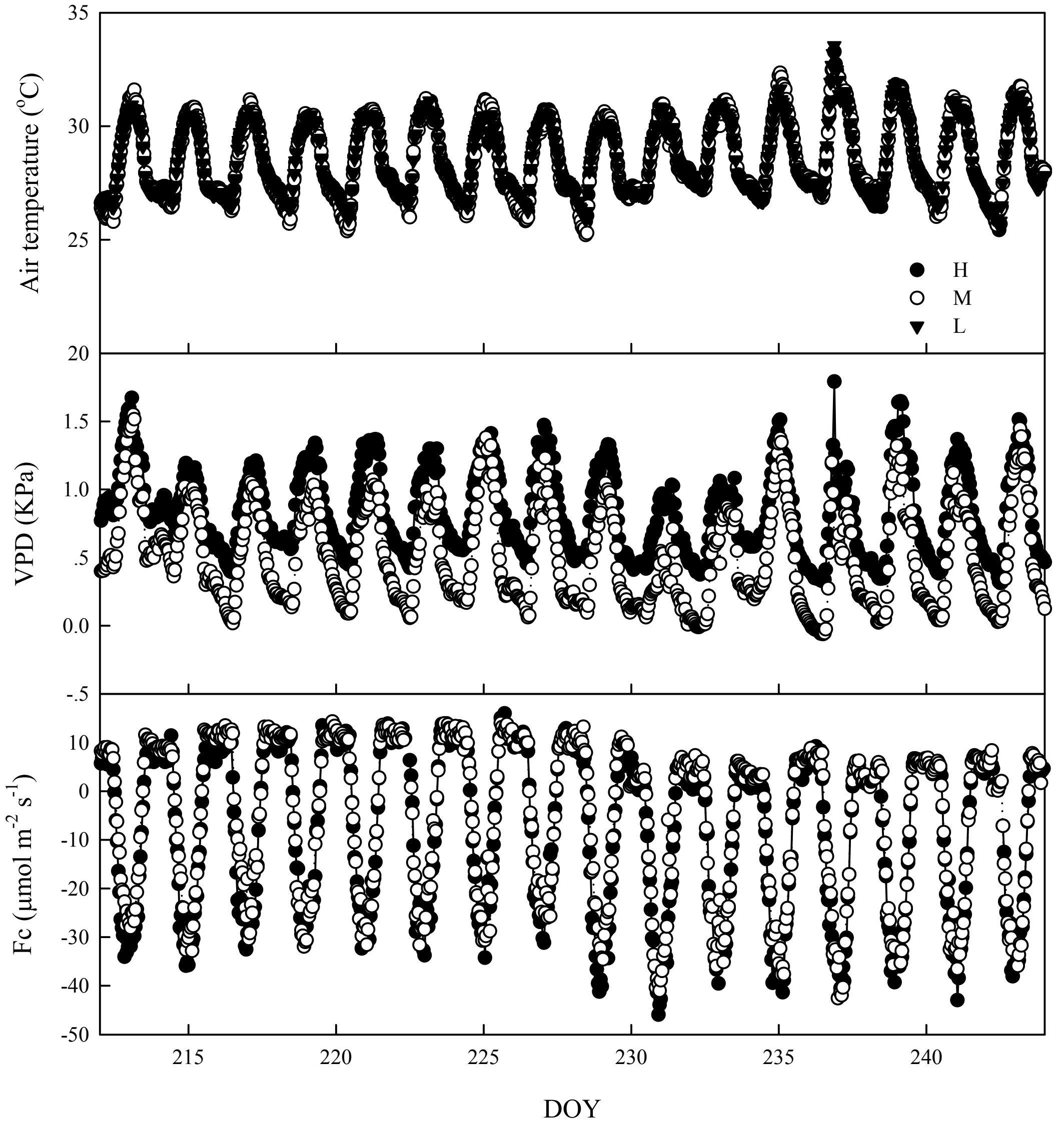

Fig. 2 Diurnal variations of air temperature (Ta), vapor pressure deficit (VPD) and CO_2 flux (Fc) in August, 2006 at the three sites. Site H stands for the site at the relatively higher elevation in the wetland, site L stands for the site at the lower elevation in the wetland and while site M is between sites H and L.

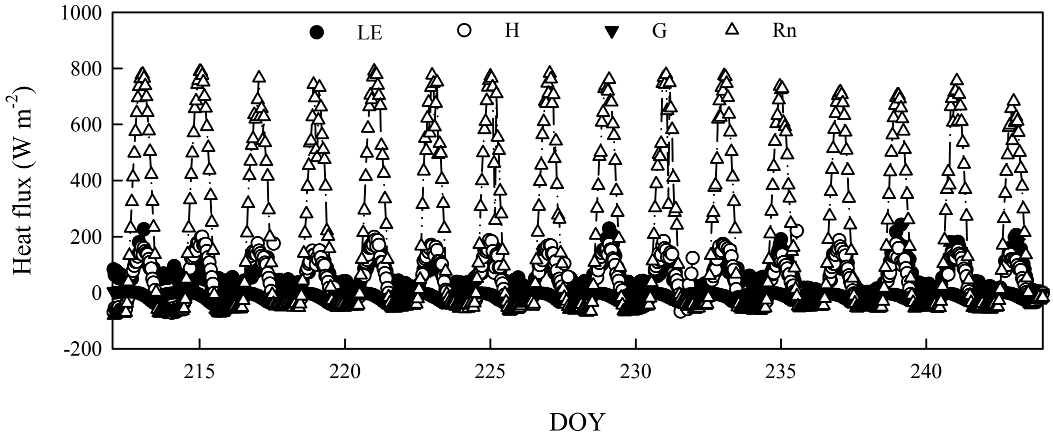

Fig. 3 Diurnal variations of latent heat (LE), sensible heat (H), soil heat flux (G) and net radiation (Rn) in August, 2006 at site L. Site L stands for the site at the lower elevation in the wetland.

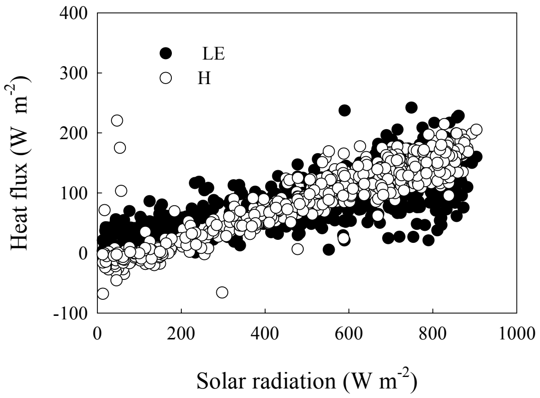

Fig. 4 Relationship between latent heat (LE)/sensible heat (H) and incoming solar radiation during daytime in August, 2006 at site L. Site L stands for the site at the lower elevation in the wetland.

Larger values of nighttime Fc were observed in site M, while larger values of daytime Fc were observed in site H. The magnitude of Fc typically ranged from -40 to 10 μmol m^{-2} s^{-1}, which suggested a strong carbon uptake. This range was larger than the values obtained in the Nueces River Delta (-8~4 μmol m^{-2} s^{-1} (Heilman *et al*., 1999)), possibly because in this study, 50% of the source area was open water.

The diurnal dynamics of the surface energy balance components (latent heat, sensible heat, soil heat flux and net radiation) in August at site L are presented in Fig. 3. Latent heat (LE) and sensible heat (H) followed net radiation (Rn), reaching a maximum at noon and declining throughout the afternoon; however, both of them only represented half of Rn. A similar pattern of LE was observed by Burba *et al*. (1999b). However, in the same study, with a lower magnitude of Rn (~600 W m^{-2}), H did not follow the fluctuation of Rn. The magnitude of the soil heat flux (G) was relatively low. Both LE and H showed a linear relationship with incoming solar radiation (Fig. 4). When the value of incoming solar radiation was lower than 300 W m^{-2}, LE showed a stronger dependency on Rn than H. Both LE and H seldom exceeded 300 W m^{-2}, even when the incoming solar radiation reached 900 W m^{-2}.

Conclusions

Our results gave good insight into the CO_2 and energy fluxes of a rarely-surveyed coastal wetland ecosystem. The measurements of Fc in August showed a strong carbon uptake capacity. Among the three sites, high nighttime respiration and high daytime assimilation in site M seem to cancel each other out and thus lead to relatively low carbon sequestration on a daily scale. As the plant community was under quick change due to the *Spartina* invasion, the carbon budget of the three sites may change as well. Quantifying the influence of the *Spartina* invasion on carbon flux will provide good experience for evaluating the effects of plant invasion.

Interestingly, the energy flux was similar to that in dry land and the degree of energy budget closure was surprisingly low. The heat exchange during rising and ebbing tides may account for the lost heat. Future research should integrate the hydrologic change into the calculation of the energy balance.

Acknowledgements

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Editor's Note

Thanks to all authors, committee members and to AsiaFlux secretary for their contribution to this Newsletter. Last AsiaFlux Workshop in Taiwan was a very interesting event. Many researchers stressed the importance of soil and roots to carbon balance. To bring some light into the soil blackbox we have to dig deep! No root, no fruit!

The editors of AsiaFlux Newsletter No.23:
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