January 2007
Special Issue

AsiaFlux Newsletter

National report from TC2006 participants

Contents

Preface

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Asian terrestrial ecosystems - the richest in the world – are distributed continuously from tundra and boreal forests through temperate to subtropical and tropical forests latitudinally and from monsoonal rainforests through semi-arid grassland to desert longitudinally (Fig. 1). The magnitude of carbon sequestration in Asian terrestrial ecosystems has been predicted to play a key role in global carbon cycle and therefore has been known as an indispensable part to understand global climate changes caused by the greenhouse gas emission. Moreover, the temporal and spatial variations of carbon sequestration caused by the distinctive climate conditions in the region such as Monsoon impose an additional scientific challenge.

AsiaFlux was established in September 1999, as a regional research network that brings together scientists from the Asian countries working on the exchanges of carbon, water, and energy between terrestrial ecosystems and the atmosphere at daily to inter-annual time scales. Over the past eight years, AsiaFlux has grown from about 20 affiliated sites to over 100 sites

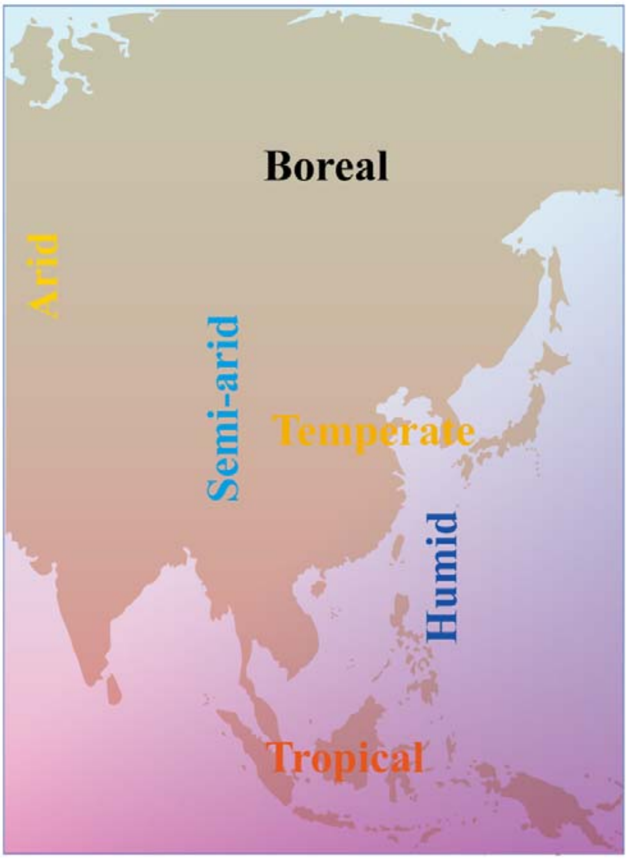

Fig 1 Distribution of the Asian terrestrial biomes.

that are distributed in various terrestrial ecosystems throughout the East Asian region. The first AsiaFlux workshop was held in September 2000 (WS2000) in Sapporo, Japan and the WS2002, WS2003, WS2005, and WS2006 were held in Jeju (Korea), Beijing (China), Fujiyoshida (Japan), and Chiang Mai (Thailand), respectively.

To date, most AsiaFlux sites have been operated by JapanFlux, KoFlux and Chinese flux communities. Exchanges of information and experiences with other Asian countries have been the urgent issue to build up a strong collaboration among researchers in Asian region. Therefore, to share the basic theory and observational and data processing techniques, AsiaFlux Short Training Course Sub-workgroup organized the first AsiaFlux summer school (TC2006) on 21-30 August 2006 in Tsukuba, Japan. Twenty participants from nine nations and regions, including Bangladesh, Mainland China, India, Indonesia, Malaysia, Philippines, Taiwan, Thailand and Viet Nam attended the short course. One of the remarkable outcomes is that many participants voluntarily submitted reviews regarding the carbon cycle researches in their own countries and the primary flux data obtained from their sites to the AsiaFlux Newsletter. After a review by the AsiaFlux Editorial Sub-Workgroup, the selected twelve articles are published on the AsiaFlux Newsletter as a Special Issue. The first part of the issue – Emerging Flux Studies in Asian Countries – focuses on the initial and potential flux researches in many Asian nations. The second part –Flux Studies in China – introduces the preliminary results and the scientific plan of the Chinese flux research communities which are becoming one of the largest flux research groups in the world. This special issue will provide a valuable opportunity to understand the current status and the future of the flux studies in Asian region.

Establishment of a Flux Study Site in Bangladesh with its Preliminary Observation Result

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1. Geographical and climatological profiles of Bangladesh

Bangladesh is situated in the Bengal Basin, one of the largest geosynclinals in the world. Physiographically, the country can be divided into hills, uplifted land blocks, and alluvial plains with the majority having very mean elevation above sea level. Climatologically, the country experiences subtropical monsoon climate, which is characterized by abundant rainfall during the monsoon (from July to October) followed by a cool winter period (from November to February), and then a hot dry summer (from March to June).

2. Vegetation distribution

Climate of Bangladesh is highly suitable for crop production. The total land area of Bangladesh is approximately 14.4 million hectares. About 9.4 million hectares, or 65% of the total land area are categorized into arable lands, and most of them (9.1 million hectares) are regularly cultivated (Fig. 1). This is one of the highest percentages in Asia. Seventy per cent of the population depends on agriculture, which contributes 34% to the Gross Domestic Product (GDP). Agriculture is the life nerve of Bangladesh. Most of the arable lands are covered with rice, but different types of cereal crops, pulse crops, vegetables, fiber crops, oil crops are also cultivated. Biomass fuels from wood, crop per capita residues and dung constitute 70% of total energy consumption (Rahman *et al.*, 2001a) and the supply of the biomass fuels per capita is declining gradually. Use of biomass fuels is the principal source of air pollution in this country.

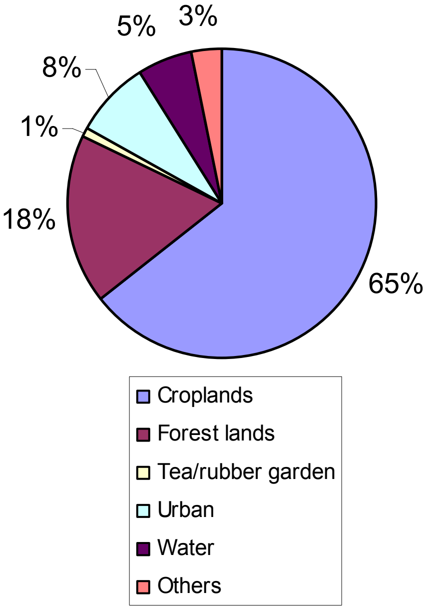

Fig. 1. Land use distribution in Bangladesh by area (Rahman *et al.*, 2001b)

Forests in Bangladesh cover about 2.56 million hectares (18% of the total land area). Ecologically, there are four main types of forests: tropical broadleaf evergreen forest (dominant species: *Dipterocarps spp.*), tropical semi-evergreen forest (savanna, bamboo and swamp forests), tropical moist deciduous forest or sal forest (*Shorea spp.*) and mangrove forest (*Heritiera spp.*). The first and the second are called hill forest and occupy 27% of the total forest area, while the sal forest and the mangrove forest occupy 5% and 28%, respectively, of the total forest area. In addition to these main types of forests, village forest, which includes fruit, date, areca and many varieties of bamboo, occupies 12% in the total forest area, and the remaining 28% is unclassified (GOB, 1993).

3. Establishment of flux site

Quantification of greenhouse gas exchanges between ecosystem (terrestrial/aquatic/agriculture) and the atmosphere is one of the key issues to assess the global budget of those gases. Although there are many different types of ecosystems in Bangladesh, observation of greenhouse gas exchanges in those ecosystems was not made

Fig. 2. The study site in Agriculture Farm of Bangladesh Agricultural University (February 2006)

Fig. 3. Sensors for eddy covariance flux measurement (left) and those for meteorological components (right).

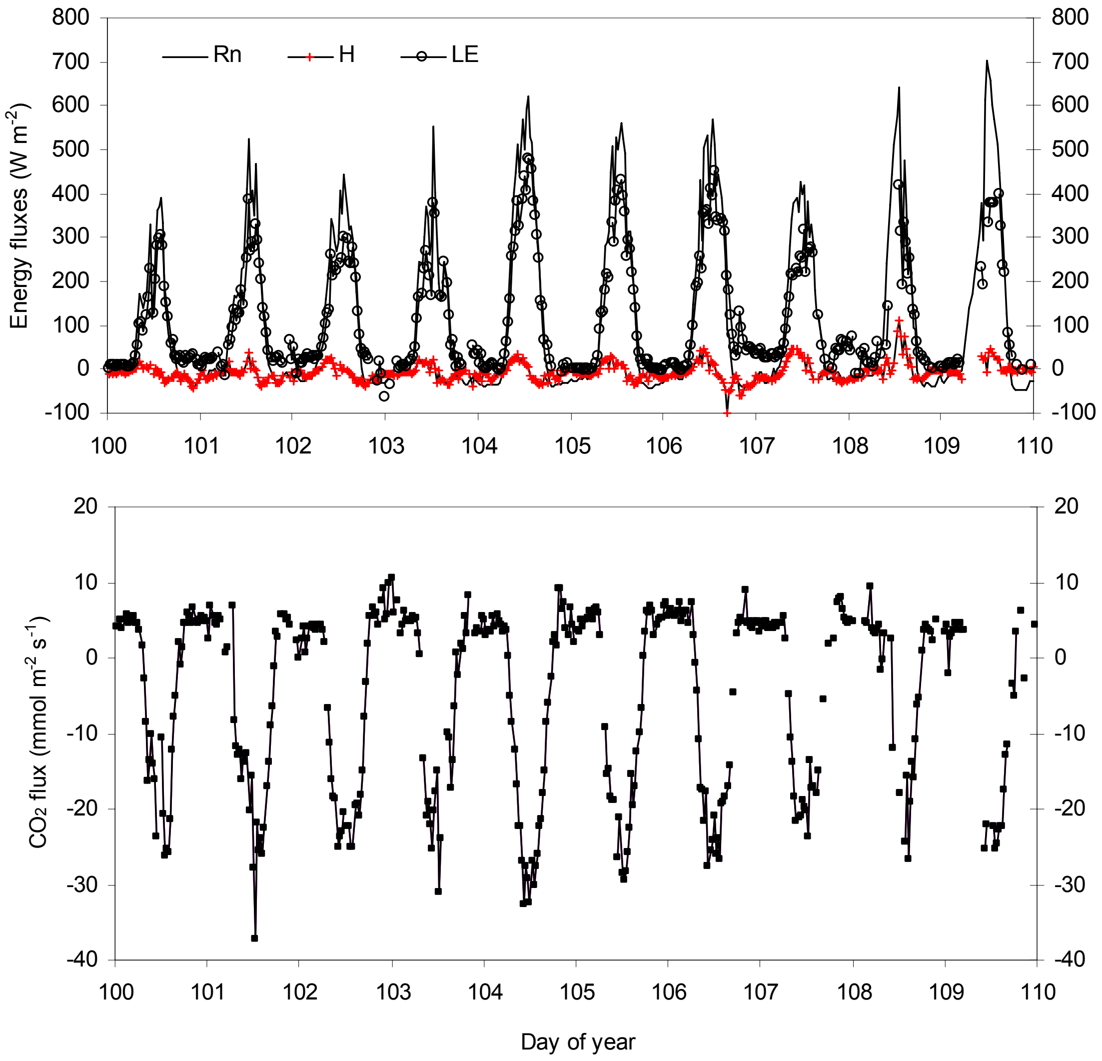

Fig. 4. Daily courses of half-hourly flux densities of net radiation (R_n), sensible heat (*H*), latent heat (*LE*) and CO_2 in the middle of the *Boro* rice growing season of 2006. Quality control tests by Vickers and Mahrt (1997) were applied and any hard-flagged fluxes were eliminated from the figure.

till January 2006. In February 2006, flux study in Bangladesh started first as a UGC (University Grant Commission, Bangladesh) -JSPS (Japan Society for the Promotion of Science) Joint Research Project entitled "Rice paddy flux observation in Bengali lowland", which is being supervised by Prof. Dr. Md. Abdul Baten, Bangladesh Agricultural University and Dr. Akira Miyata, National Institute for Agro-Environmental Sciences, Tsukuba Japan. AsiaFlux also supports this study partly through MEXT fund.

The study site is located at the paddy field of Agriculture Farm of Bangladesh Agricultural University (24.75°N, 90.5°E, 18 m above sea level). This farm is located 6 km to the south of Mymensingh town and 115 km to the north of Dhaka (the capital of Bangladesh). The site is flat and has enough fetch for micrometeorological flux measurement (Fig. 2). The mean annual rainfall for the area is 2,175 mm, with 70% falling from May to August. The soils are dark-gray non-calcareous floodplain with sandy loam texture. Wind blows mainly from northeast to southeast. Cropping pattern follows rice-fallow-rice: *Boro* rice is cultivated in dry season, from late January to mid-May, while *Aman* rice is cultivated mostly in rainy season, from August to November. Cultivation of *Aus* rice between *Boro* and *Aman* has become less popular because of its low yield. The field is irrigated during *Boro* rice growing season, while it is mostly rain-fed during *Aman* rice growing season. At harvest, rice straw is taken away from the field keeping the hill (culm) bases at the field.

We installed a set of the open-path eddy covariance measurement system on a 3-m mast to measure fluxes of carbon dioxide (CO_2), water vapor and sensible heat (Fig. 3). The measurement system consists of a three-dimensional sonic anemometer, a commonly-used open-path infrared gas analyzer and a fast-sampling data logger. On another mast, we set sensors to measure meteorological components, *viz.* air temperature, relative humidity, incident and reflected solar radiation, net radiation, incident, reflected and transmitted photosynthetically active radiation, barometric pressure, soil heat flux, soil and water temperature. An electric power subline was drawn to the mast by setting steel poles. A small steel house (hut) was positioned between the last pole and the masts. Electric supply points, switches etc are put inside the hut. The masts are watched by our guards 24 hours a day. A solid brick house has been made far away from the mast for the guards. During the growing season, rice plants were sampled every two weeks to determine leaf area and dry matter.

Preliminary results

We started the measurement soon after the beginning of *Boro* rice growing season of 2006. Fig. 4 shows the diurnal pattern of fluxes of surface energy budget components and CO_2 in full heading stage of rice (70 to 79 days after transplanting). Around this period, rice plants attained maximum plant height of 87 cm and the maximum leaf area index of 5 m^2 m^{-2}. As shown in Fig. 4, latent heat flux is the dominant component in surface energy budget. On daily basis, more than 80% of net radiation was partitioned into latent heat flux, while sensible heat flux accounted for 5 to 7% of net radiation.

CO_2 flux exhibited a clear diurnal pattern ranging from –38 to 10 μmol CO_2 m^{-2} s^{-1}. It showed daytime uptake by the canopy and nighttime release from the canopy. The preliminary results indicate that our observation is going well, and we expect that next January we will be able to estimate the annual CO_2 budget for the first year of observation including fluxes during fallow periods. Further, by continuing the observation, we will be able to accumulate the data for discussing inter-annual variabilities in CO_2 exchange of our study site. This will enable us to characterize CO_2 exchange in double cropping rice paddy fields, which is commonly found in south and southeast Asian counties. In this way, we believe that we would be able to contribute to AsiaFlux.

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CO_2 Flux Initiatives for Tropical Forests in Malaysia

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Considerable studies have been conducted in Malaysia to quantify and estimate carbon stocks and flux in various forest ecosystems, land use and soil properties over many years. The knowledge on carbon cycle in the biogeochemical system is imperative in an effort to understand the role and services of tropical rainforests in the global and regional environment. Here, we briefly introduce the current research and present the status of long-term continuous monitoring of carbon fluxes over tropical forest in Malaysia. We identify primarily the carbon flux or exchange studies to share our experiences and to build strong collaboration with other research activities.

Pasoh Forest Reserve

The first CO_2 flux estimation, in Pasoh Forest Reserve located in Negeri Sembilan, was carried out by measuring the vertical CO_2 profiles above the forest to assess micrometeorological conditions and the primary production of lowland tropical rain forest. Intermittent measurements in the study estimated net CO_2 uptake rate between 1.0 to 1.2 mg CO_2 $m^{-2}s^{-1}$ under 907 W m^{-2} incoming solar radiation (Aoki *et al*., 1975). Hence, such study has generated significant interest in the assessment of carbon flux and micrometeorological factors within tropical rain forest.

The eddy covariance method was later introduced and conducted on a short-term measurement basis by means of a closed-path CO_2 analyzer to observe CO_2 flux within and above the canopy in Pasoh forest. The findings suggested a significant net CO_2 uptake during the measurement period of 6 days in 1998. The CO_2 flux was estimated between -1.0 to 0.5 mg CO_2 $m^{-2}s^{-1}$ and the daily net ecosystem CO_2 exchange (NEE) ranged from -2.08 to -2.74 g C $m^{-2}day^{-1}$ (Yasuda *et al*., 2003).

The most recent study investigated long-term CO_2 flux by an open-path CO_2 analyzer to evaluate the accuracy of annual NEE and effects of environmental factors on the flux (Fig. 1). Average diurnal change of CO_2 flux within Pasoh forest in 2003 was estimated to be from -18.0 to 10.0 µmol $m^{-2}s^{-1}$ and illustrated insignificant seasonal changes but affected by the atmospheric vapor pressure deficit (Takanashi *et al*., 2005). The annual NEE was estimated as -2.1 g C $m^{-2}day^{-1}$ in 2003.

The figures slightly contradict earlier findings of net CO_2 uptake possibly due to the duration of measurements. In addition, the study also highlighted possible errors in the evaluation of mass flow and neglecting the effects of vertical and horizontal advection, which could affect the NEE estimation. Yet, measurement of night-time fluxes still remains uncertain (Malhi *et al*., 1999) in the effort to obtain accurate estimation of net carbon balance.

Abundance of data on gas exchanges within the rain forest, nonetheless requires precise assessment on plant physiology in relation to other environmental and soil respiration processes. The uncertainty lies within the complication of physical and physiological processes and factors associated with CO_2 flux.

Accurate estimation of the whole biomass is imperative to evaluate NEE and the function of the forest ecosystem as a sink for carbon dioxide. However, belowground production in forests remains poorly understood due to the difficulties and the paucity of direct measurements (Kato *et al*., 1978; Clark *et al*., 2001). Considerable studies have been done to account for the soil carbon fluxes in Pasoh forest. One noteworthy study currently being conducted is the measurement of soil efflux using the automated chamber system (Fig. 2). The measurement estimated soil efflux of 31.0 t C ha^{-1} yr^{-1} (Liang *et al*, 2005; Liang, 2006). However, this figure was still inconclusive due to uncertainties associated with heterogeneity of big wood litterfall; productivity and turnover of fine roots; and long-term biometric data.

With immense data generated from studies conducted in Pasoh forest, thorough understanding on the carbon dynamics of tropical forest is progressively improving. Long-term measurements and observations are currently being conducted to fill in current knowledge gaps. This will eventually provide more reliable and accurate estimation of CO_2 flux and calculation of net primary productivity (NPP) or NEE for further enhancement of the understanding of carbon balance in tropical rain forests.

Lambir Hills National Park

Lambir, located in Sarawak, is another long-term ecological research site with extensive CO_2 monitoring and measurement efforts. Intensive observations were carried out during 1998 – 2000 to measure vertical profiles of environmental factors within the rainforest using tree towers. CO_2 analyzer was used to measure CO_2 concentration profiles. Other parameters, such as air temperature, humidity, wind speeds, leaf area density, and soil respirations were manually measured. The results suggested strong vertical gradients of environmental factors relative to the values above the canopy (Kumagai *et al*., 2001). Over the years, similar to Pasoh Forest Reserve, new technology and techniques including eddy covariance were adopted to improve the CO_2 flux measurement and observations (Fig. 3). Such initiative shows the importance of environmental factors and hydro-meteorological conditions in forest ecosystems to better understand their ecological functions.

Measurement of CO_2 flux via eddy covariance technique showed NEE of 0.75 t C ha^{-1} y^{-1} (being a net CO_2 source) by using the corrected measurement method (Saitoh *et al*., 2005a). The method was based on estimated correction factor for night-time CO_2 flux of NEE when weak stable conditions prevail during measurement of nocturnal ecosystem respiration (Saitoh *et al*., 2005b). However, the estimated annual NEE was incomparable with that reported in Amazonian tropical rainforests (Fan *et al*., 1990; Grace *et al*., 1995) due to interannual variability effects (Saitoh *et al*., 2005a).

Several studies have examined the implications of atmospheric CO_2 increment and climate variations on potential response of current carbon and water cycling in tropical rainforest. The possible response was investigated based on a combination of field measurements, climate modeling and simulation of simplified hydrologic model. Insignificant changes were observed on canopy photosynthesis despite projected considerable shifts in environmental factors and elevated CO_2 concentrations (Kumagai *et al*., 2004). Further investigations are needed to verify the effects of elevated CO_2 on the rain forest by adopting long-term extensive experiments.

The most recent study investigated interactions between environmental factors and leaf-level physiological parameters on canopy-level CO_2 exchange. The study adopted the one-dimensional multilayer biosphere-atmosphere models such as the soil-vegetation-atmosphere transfer (SVAT) model, with the eddy covariance measurements. The results suggested potential application of SVAT model on tropical rainforests which comprise considerable heterogeneities in canopy structure and leaf-level physiological properties, and implied a greater ease and potential for further integration in global climate and carbon sequestration model (Kumagai *et al*., 2006).

On the other hand, determination of carbon storage in or release from forest soil due to the influence of environmental factors is equally important in understanding the belowground CO_2 exchange process. Soil temperature and heat flux were estimated to evaluate the relationship between CO_2 released from the forest soil and the environmental conditions (Sato *et al*., 2004).

The study on annual water cycling and carbon budget has been extensively estimated via the eddy covariance method. Hence, current flux monitoring research initiative deliberates on the effect of severe drought with simultaneous monitoring of ecological study (Suzuki *et al*., 2005).

Canopy CO_2 Fluxes in Oil Palm Plantation

Eddy covariance technique was first established in oil palm plantation in 1993. The flux monitoring system was set up on a coastal plantation site in Banting, Selangor, which was planted in 1983 with planting density of 138 palms/ha. A 20 m tower was erected in the middle of the plantation with 500 – 1000m fetch. The observation system was used to determine CO_2 fluxes, water vapor and sensible heat (Henson, 1993).

The current eddy covariance system (Fig. 4) was installed in 2004 and established on an inland plantation site in Sintok, Kedah. The study intensively examined changes in carbon fluxes above the canopy and evaluated the influence of climatic conditions on gas and energy exchanges. The estimation illustrated substantially lower levels of CO_2 flux and evapotranspiration in the middle of the annual dry season in February, as compared with the succeeding wetter months (Henson & Haniff, 2005). However, it was still inconclusive due to several limitations. The uncertainty in night-time measurement, as highlighted in tropical forest ecosystems, was the main obstacle in obtaining comprehensive and reliable carbon budget. In view of such problem, Henson & Haniff (2005) adopted modeling approach with assumptions to construct carbon budget based on the best available data. Thus, further studies and data collection are needed to quantify accurate respiration rates from other components such as ground cover, litter accumulation and soil respiration.

Prospective Strategy

There are currently three flux observation systems being established in Malaysia. The Pasoh forest reserve has been the main research area since the 70's under the International Biological Programme (IBP) (e.g. Soepadmo, 1978). The observations are concentrated on the core area (600 ha) of primary lowland mixed dipterocarp forest. Similarly, the flux measurements in Lambir Hills National Park are conducted on mixed dipterocarp and tropical heath forests. Flux measurement sites are also established in oil palm plantation and have been consistently in operation. The micrometeorological technique of eddy covariance has already been demonstrated to provide reliable estimates of carbon exchange and NPP or NEE. Thus, such initiative should be expanded to other ecosystems in the tropical regions.

Tropical peatlands are recognized as one of the largest global carbon storages and therefore the CO_2 exchange is of potential significance in the carbon cycle (Maltby & Immirzi, 1993; Siegert *et al*., 2002). Carbon and methane flux measurements were conducted from tropical peatlands in Sarawak under different land use (Melling *et al*., 2005) to quantify soil respiration in relation with the underlying environmental factors. As the ecosystem becomes increasingly vulnerable to development and reclamation, the understanding of soil CO_2 flux and the influence of environmental factors under various ecosystems and land-use changes are essential to account for the soil carbon budget. The current research initiative and focus is to establish long-term measurements for accurate interpretation of CO_2 flux variability and estimation of NEE under different land use on peatland ecosystems.

Acknowledgement

We would like to thank all the research members and collaborators in the flux observation research study.

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Fig. 1 Eddy covariance observation system at Pasoh forest reserve.

Fig. 2 Automated chamber system installed at Pasoh forest reserve.

Fig. 3 Flux observation system on the 80m crane established at Lambir Hills National Park, Sarawak.

Fig. 4 The eddy correlation instrument tower established in an oil palm plantation at Sintok, Kedah.

IRRI's Research on Rice and Global Climate Change

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Introduction

The International Rice Research Institute has studied the effects of climate parameters on the development and yield of rice plants even before the public debate on Global Warming and Climate Change. The initial experiments on temperature effects were conducted in the early 1960's and on CO_2 effects in the early 1970's. However, IRRI's work explicitly dealing with climate change research started in 1991. In the early 1990's, IRRI began a study of the interactive relationship between rice production and global climate change. The study was prompted by results from earlier studies suggesting rice production to be a major contributor to global warming due to large amounts of methane (CH_4) emission from rice fields. Methane is formed during the final steps of the anaerobic degradation chain caused by a group of bacteria called methanogens (Fig. 1). The perception that rice production was largely to be blamed for global warming caused an alarm and exerted political pressure on Asian nations to comply with an international convention to curtail gas emissions from rice production.

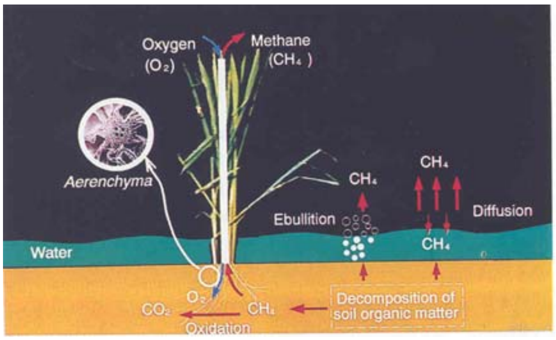


Fig 1 Methane production in a rice field.

IRRI's research results, however, allayed worries about such problems and established that the average emission level per unit of cultivated rice area is relatively low except for some rice ecosystems. Even in areas where gas emissions are high, it was found that it could be ameliorated without sacrificing yields.

The results of IRRI's research were crucial, as rice remains the most important crop in tropical and sub-tropical Asia, accounting for 90% of grain production and consumption. In fact, rice cultivation is a way of life in the region since it is closely intertwined with the economic, social, and cultural activities of the people. Nearly 150 million households in Asia depend on rice cultivation for their livelihood, with rice income accounting for 40-60% of total farm household income. The urban poor and the rural landless, the groups most vulnerable to food insecurity, spend 50-70% of their income on rice. Rice production has significantly increased over the past 30 years. This was driven by doubling the yields from the mid 1960's, especially in irrigated areas, which account for 75% of global rice production. This helps explain the strong reaction triggered in Asia by reports that rice growing was considered a potential threat to global warming. Efforts started immediately to closely understand the phenomena surrounding global climate change: its impact on the environment, especially on food production, and the factors that contribute to it.

IRRI's Previous Research Activities

IRRI's work on global climate change started in 1991. A five-year project funded by the US Environmental Protection Agency (EPA) was the first comprehensive approach to study the interaction between climate change and a major food crop, rice.

Research activities were:

- Methane emissions from flooded rice fields;
- UV-B effects on rice and rice blasts;
- Temperature/carbon dioxide effects on rice yield; and
- Assessing the potential impact of climate change on rice yields by combining crop and climate models.

From 1993 to 1999, IRRI coordinated the "Interregional Research Program on Methane Emissions from Rice Fields." The program was funded by United Nations Development Program / Global Environment Facility (UNDP/GEF) and work was done in collaboration with national research institutes, particularly in China, India, Indonesia, Thailand, and the Philippines (Fig. 2), and with the Fraunhofer Institute for Atmospheric Environmental Research (Germany).

Fig 2 Field stations of the Interregional Research Program on Methane emission from Rice fields.

The Fraunhofer Institute seconded scientific staff (Dr. R. Wassmann) to IRRI and established automated measurement stations (Fig. 3). These systems were operated by specially trained personnel of IRRI and national research institutes. The project had the twin goals of quantifying emissions from major rice growing systems and identifying possible strategies for mitigating emissions.

Fig 3 Methane emission field chambers under irrigated conditions (A: IRRI, Philippines) and under deepwater conditions (B: Prachinburi, Thailand)

Highlights of the Project

Some of the key results obtained in the CH_4 emissions project are shown in Table 1.

Open top chambers have been installed on the IRRI farm to study the effects of increasing CO_2 and temperatures. Higher CO_2 has a positive effect on crop biomass, but its net effect on rice yield depends on possible yield reductions associated with increasing temperature. CO_2 enrichment resulted in significant increases in rice biomass (25-40%) and yields (15-39%) at ambient temperature, but those increases tended to be offset when temperature increased along with rising CO_2. Increased CO_2 may also cause a direct inhibition of maintenance respiration at night temperatures higher than 21°C. Rice response to elevated CO_2 also depends on nitrogen supply. If additional CO_2 is given and N is not available, lack of sinks for excess carbon (e.g. tillers) may limit the photosynthetic and growth response. Derived from long-term records of temperature and yields, IRRI researchers showed a statistically significant correlation of (i) increasing night temperature and (ii) declining rice yields.

IRRI organized numerous workshops, meetings, and training courses dealing with aspects of global climate change. One international workshop on “Climate Change and Rice” was held at IRRI in March 1994. Similarly, several training courses on greenhouse gas emissions were conducted in cooperation with international organizations such as START (Global Systems for Analysis, Research, and Training). These links proved vital to ensuring feedback on the work with national agricultural research systems (NARS).

To disseminate the results of various global climate change studies, IRRI scientists have published more than 100 articles and book chapters dealing directly or indirectly with climate change and rice. IRRI has also co-published three books on rice production and climate change: *Climate Change and Rice* (Springer Verlag) edited by Peng et al. (1995), *Modeling the Impact of Climate Change on Rice Production in Asia* (CABI) edited by Matthews et al. (1995), and *Methane Emissions from Major Rice Ecosystems in Asia* (a special issue of *Nutrient Cycling in Agroecosystems,* Kluwer) edited by Wassmann et al. (2000).

Table 1 Key results obtained in the CH4 emissions project

Problems	Solutions
Rice-growing countries were being accused of contributing to global warming because of allegedly high CH_4 emissions.	The project has yielded an ample database documenting that: ▪ Rice production is not a major cause of the greenhouse effect on a global scale. ▪ Methane emission rates show pronounced variations in space and time that can be dealt with by a newly developed model and GIS database. ▪ High emission rates are associated with specific management practices. ▪ Management practices can be modified to reduce emissions without affecting yields.
Rice-growing countries must try to persuade farmers to adopt mitigation technologies while avoiding any unnecessary burdens for them.	The project has successfully explored trade-offs between mitigation technologies and socio-economic aspects and found that: ▪ Intermittent drainage in irrigated systems reduces emissions and can also save water. ▪ Improved crop residue management through composting, mulching, and early incorporation of organic manure can also reduce emissions. ▪ Direct seeding results in less labor and water input and at the same time reduces methane emissions.
Rice-growing countries faced problems in complying with the stipulations of the United Nations Framework Convention on Climate Change because of insufficient data, know-how, and infrastructure.	The project has: ▪ Generated baseline data for major rice ecosystems to include in national inventories and provided further mitigation options. ▪ Provided infrastructure by training a team of local researchers and ensured their findings to be published internationally.
There was high uncertainty in the estimate of CH_4 emission from rice.	Because of the project’s automatic sampling system, continuous measurement of CH_4 increased reliability of estimates under different management practices.

IRRI's Planned Research Activities

An international workshop on *Climate Change and Rice* was held at IRRI during 20-23 March 2006 to review the state of the art scientific infrastructure and identify priority areas for research on climate change in rice systems. It was agreed that IRRI in collaboration with research institutions worldwide will establish a **Rice and Climate Change Consortium (RCCC)** to address climate change and rice as a Frontier Project in its *Strategic Plan for 2007-2015.*

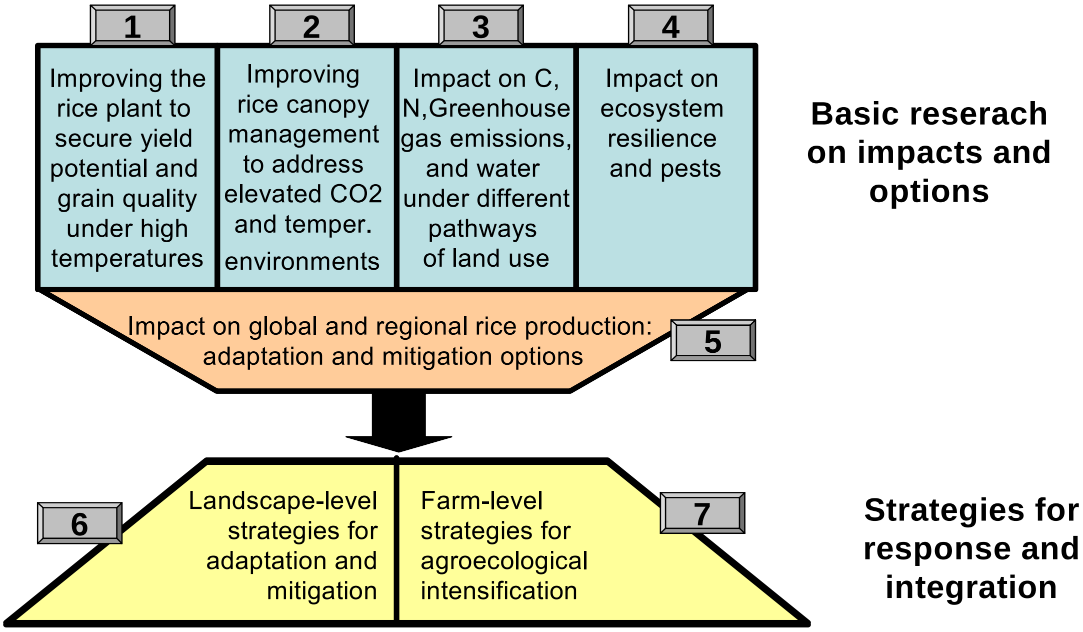
The RCCC will ensure synergistic interactions among the different research groups, including joint use of strategic research sites; exchange of data, models, and other information; and integrative regional case studies. The RCCC will also provide linkages with global and regional climate change networks and organizations, provide key data and new information to them, and advise local, national, regional, and global policymakers. Funding will be sought from a multitude of international and national donors and IRRI and its partners will provide significant start-up funds.

In its first phase, the RCCC will undertake seven major interlinking and interactive research projects over a time span of 8 years (2007-15) to examine the impact of climate change on rice and rice-based systems and to develop strategies for responding to climate change at the farm and landscape levels (Fig. 4)

These research projects aim to develop rice plants that can better cope with hotter climate and to design new management systems and policies that reduce global warming and increase ecosystem resilience to climate change.

Projects 1 and 2 will concentrate on improving our understanding of the impact of climate change on rice at the crop canopy, plant, plant organ, and molecular levels. New canopy management strategies and new rice varieties with greater tolerance of heat and other climatic stresses are expected to result from this work. Linkage of functional genomics with climate change issues provides a new avenue for crop improvement research, which will be of seminal value for many other cultivated crops.

Projects 3 and 4 focus on key biotic and abiotic components of rice ecosystems and how they change under new land uses that may result in response to climate and socioeconomic drivers. State-of-the-art measurement technologies employed will include eddy covariance flux towers, tunable diode lasers, open-path lasers, and chemiluminescense for micrometeorological characterization of the net ecosystem exchange of water, energy, CO_2, CH_4, N_2O, and NH_3. The new generation of high-quality measurements obtained from integrative "supersites" will allow us not only to develop much improved models but also



study key systems and intervention options at the production scale.

Projects 5, 6, and 7 will assess and implement response options at global, regional, landscape, and farm scales. The detailed information obtained from projects 1, 2, 3, and 4, particularly the new germplasm, much improved process-level understanding, and more accurate crop and agroecosystem models, will provide key inputs for these activities.

RCCC Activities with relevance to flux measurements (Project 3: Impact on carbon, nitrogen, and water under different land use scenarios)

Background and importance

Biophysical and socioeconomic drivers force farmers in Asia to seek out new management systems that provide higher income, consume less water and labor, and are resilient to pests and adverse climate events. In the past, rice yields could substantially be increased through intensified land management (comprising improved fertilization, higher fertilizer doses, etc.) and the introduction of multiple cropping systems. In addition to this intensification, the Asian rice production systems – which in most cases encompass flooded fields for long periods of time – are now increasingly converted to more and more non-flooded conditions in the field. At the same time, farmers in many Asian regions divert from double rice cropping to a single crop (in the wet season) followed by an upland crop (in the wet season), which causes longer aeration of soils.

These changes will significantly alter the flows of carbon and reactive nitrogen compounds, water and energy. Large uncertainties exist in predicting the outcomes of these changes with regard to productivity, sustainability, efficiency of resource use, and impact on global warming. Novel measuring techniques and comprehensive approaches to quantifying and modeling soil-plant-atmosphere processes are needed to do more accurate and precise up- and down-scaling of different scenarios of climate change, land use and crop management. Interdisciplinary research facilities endowed with state-of-the art scientific infrastructure are required to quantify the processes involved at production-scale in systems that represent current and future forms of land management. This will supply crucial information needed for regional and global assessments and it will establish the process-level understanding for developing pathways for a conversion of rice-based systems in Asia towards higher yield potentials under minimized environmental impacts.

Goal

To quantify, understand and model the pools and flows of carbon, nitrogen, and water in different rice-based agro-ecosystems as the basis for developing improved prediction models and more efficient cropping systems that enhance food production, income, system sustainability, and resource efficiency and reduce global warming potential.

Specific objectives

This project will provide answers to the following questions:

- What are the short- and long-term pool-changes in carbon and nitrogen under different intensification scenarios of lowland cropping systems of Asia?
- What are the net emissions of greenhouse gases (CH_4, N_2O, CO_2) deriving from flooding, fertilizer application, soil and residue management in different rice systems?
- How do different rice cropping systems compare in terms of resource use efficiencies, namely water, nitrogen and energy use? How much do the different pathways of lateral N flow, namely nitrification (N_2O and NO emissions), denitrification (N_2, N_2O and NO emissions), NH_3 volatilization and N leaching, contribute to the overall N losses at field and landscape scale?
- How do the changes in cropping systems affect functionality and composition of the microbial communities in rice soils? What are the quantitative and qualitative changes in the biological cycles of N and P within the ecosystem?
- What is the short- and medium-term impact of shifts in land use and aeration on the availability of nutrients for plants?
- What are the differences in the micro-climate of flooded/ non-flooded rice fields and how do they alter net exchange of water and energy during day and night time?

- How do the direct and indirect changes stemming from intensification/ diversification affect the source strength of GHG (emissions vs. sequestration) at the landscape level and how do these trends translate into the national level of GHG emissions from the agricultural sector?
- Are diversified cropping systems more sustainable than rice mono-cropping systems? What are the effects in terms of soil quality and pest vulnerability?
- What are attainable, production-scale levels of resource use efficiency and global warming potential in current and future lowland cropping systems?
- What management practices are required for low emissions of GHG at high yields?
- How can current soil-plant-atmosphere models be improved to allow more accurate predictions of the consequences of climate and land use changes?

Approach

The Rice and Climate Change Consortium (RCCC) has recently been initiated by the International Rice Research Institute (IRRI) as a strategic research program that links rice researchers in Asia with the world's leading research institutions on climate change. The RCCC comprises a wide range of research institutions investigating the interactive nature of rice and climate change, i.e. rice as a crop affected by climate change as well as a source of greenhouse gases.

As a key component of the RCCC, we propose to establish three 'supersites' on climate change research in key rice-growing regions of Asia: (1) irrigated lowland rice in tropical southeast Asia (Philippines), (2) lowland rice systems with new ecosystem functions in urbanizing eastern Asia (China), and (3) rice-wheat systems in the Indo-Gangetic Plain (India). Each site will be 15 to 20 ha in size and equipped for long-term, interdisciplinary research on climate change impact on rice and impact of diversifying rice-based cropping systems on climate change. At each site, four to five agroecosystems that represent major pathways of transformation of Asian rice landscapes, each 4-5 ha in size, will be established and equipped with automatic measurement systems for landscape-level measurement of fluxes and budgets of water, energy, carbon and nitrogen compounds. The systems studied will represent current and future gradients in cropping intensity, water and nitrogen use and soil aeration that we expect to evolve in response to socioeconomic and environmental drivers in Asia.

State-of-the-art measurements technologies employed will include eddy covariance flux towers, tunable diode lasers, open-path lasers and chemiluminescense for micrometeorological characterization of net ecosystem exchange of water, energy, CO_2, CH_4, N_2O, and NH_3. Ground level soil and plant measurements and automatic gas chamber systems will be used to quantify sources and sinks in more detail, monitor the different systems over time, and evaluate up- and down-scaling strategies. Whole-system budgets of carbon, nitrogen, water and energy will be quantified and verified with independent approaches.

The new generation of precise, production-scale measurements with high time resolution (less than hourly to daily) will provide the foundation for developing and validating novel agroecosystem simulation models for use in regional and global simulation analyses. The study design will also allow evaluating new strategies for ecosystem modeling across diverse landscapes and linking this to the modeling of atmospheric processes. As part of other research projects within the Rice Climate Change Consortium, the supersites will also be used for studies on climate change impacts on rice, crop adaptation and ecosystem resilience to climatic stress. Through other proposals, supersites in China and India will also be equipped with Free Air CO_2 Enrichment (FACE) and Free Air Temperature Enrichment (FATE) systems to study CO_2 × temperature interactions in crops and their feedback on soil, water and atmospheric processes.

Expected Outputs

- Complete budgets of C, N, water, and energy for agricultural systems that represent major directions for crop diversification and ecological intensification in Asia.
- Innovative management guidelines for achieving high resource-use efficiency and balancing the performance of crop production systems with regard to net

return, preservation of the resource base, and net global warming potential.

- New agroecosystem simulation models capable of predicting the consequences of climate and land use changes at different scales and with reduced uncertainty.
- A new scientific foundation for policy makers on consequences and recommended pathways for future transformations of irrigated rice systems in Asia.

Impact and uptake pathway

The three supersites will become the world's premier research facilities for atmospheric processes, climate change, and natural resources management in rice-based ecosystems and also serve as key educational facilities for policy makers, researchers and students from Asia and other parts of the world. The proposed project will closely collaborate with a wide range of international networks dealing with atmospheric processes, the global C, N, water and energy cycles, and long-term ecological research, e.g., FluxNet, AsiaFlux, ILTER, GTOS, GEWEX. Data obtained from the three supersites will be utilized by scientists worldwide to improve regional and global models and predictions of carbon, nitrogen, water and energy cycling.

Modelers will particularly benefit from the high-quality data generated, which will allow them to improve scalable, process-based ecosystem models, link them with atmospheric and climate change models, and thoroughly evaluate up- and down-scaling strategies. Social scientists and policymakers will benefit from the newly acquired information and improved agroecosystem models by being able to do more accurate regional and global predictions of climate and land use change impacts, including their up- and down-scaling. The improved process-level understanding will allow significant improvements of IPCC guidelines for assessing and mitigating climate change impacts. Students and young scientists from Asia and other parts of the world will be trained in state-of-the-art research approaches, enhancing scientific knowledge and capacity with emphasis on global change and rice. Farmers in Asia will benefit from innovative management practices developed for the various systems studied, which will be further evaluated across Asia through other research conducted at satellite sites.

Carbon Budget of Some Tropical and Temperate Forests

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Abstract

Using the non-rectangular hyperbola parameterization technique, the carbon budget of some tropical and temperate ecosystems was estimated and their sequestration ability was compared. Five (5) sites belong to tropical zone while seven (7) sites correspond to temperate biome. Carbon fluxes were evaluated based on the environmental factors affecting the ecosystem. Results showed that tropical sites have least seasonality in relation to CO_2 uptake and release. Production was continuous all throughout the year owing to their suitable climatic condition, faster rate of fixation, and longer growing season. Conversely, seasonality in CO_2 absorption and emission in temperate areas is evident. Carbon influx started to rise in spring, peaked on mid-summer and declined towards autumn, while in winter, a definite loss of carbon to the atmosphere occurred. With the result of parameterization made, it can be construed that tropical sites are relatively better net carbon absorber with an annual average net ecosystem production (NEP) of 5.63 tC/ha/yr compared to 3.30 tC/ha/yr in temperate regions.

Introduction

Forests play a crucial role in the global carbon cycle because they store large quantities of carbon in vegetation and soil. They can influence carbon sequestration in the atmosphere by assimilating CO_2 through biomass build-up and releasing it through decay. This potential role of forests to sequester atmospheric carbon is considered to be the most feasible and cost-effective way to curb increasing rate of CO_2 in the atmosphere.

With the advent of flux tower sites in measuring meteorological data, carbon fluxes of both tropical and temperate ecosystems can be best quantified using this modern-day technology. Unlike the conventional forest biometry method done at the expense of cutting down trees by way of destructive sampling, measuring carbon exchange using meteorological parameters is advantageous because it can readily explain ecosystem variations by way of parameterization; it is also environment-friendly and non-labor intensive; and it easily clarifies the intra-annual variability in a given biome.

In light of the pressing need to quantify CO_2 fluxes in tropical and temperate ecosystems and in order to describe and explain their seasonal patterns of gas exchange, this study aimed at evaluating and comparing the carbon exchange capacities of tropical and temperate biomes using available data from the AsiaFlux and AmeriFlux networks by employing parameterization techniques in estimating the carbon budget.

Methods

Sites Investigated

Table 1 shows the flux tower sites being considered in both tropical and temperate regions.

Data Collection, Processing and Analysis

Only data taken in year 2003 were considered for comparison. In most of the temperate forests, data were obtained in Ameriflux network except in the case of Takayama, Japan whose data were personally shared by one of its principal investigators, Dr. Nobuko Saigusa of the National Institute of Advanced Industrial Science and Technology (AIST). On the other hand, data in most of tropical ecosystems were given by the group leader of those sites, Dr. Minoru Gamo, also of AIST except in Tapajos, Brazil whose data were obtained in AmeriFlux network.

Data were analyzed employing the gap filling parameterization technique. Unlike parameterization using rectangular hyperbola (which often causes overestimation of Φ and GPP_{max}), this particular study used the non-rectangular hyperbola applied by Hirano et al., (2005); Takanashi et al., (2005); as mentioned by Gamo et al (2005) in their previous studies. This is governed by the equation:

$$P = \frac{(\phi I + P_{\max}) - \sqrt{(\phi I + P_{\max})^2 - 4\phi I \theta P_{\max}}}{2\theta} - R$$

But this equation only applies to individual leaf; hence, to attain the goal of upscaling it into canopy as a whole from the analogy of that single leaf, the expressions are replaced with Gross Primary Productivity (GPP), Absorbed Photosynthetic Active Radiation (APAR), and Ecosystem Respiration (R_{ec0}) for Photosynthesis Rate (P), Intensity of Light (I), and Dark Respiration (R), respectively. Therefore, the equation can now be rewritten as:

$$GPP = \frac{(\phi APAR + GPP_{\max}) - \sqrt{(\phi APAR + GPP_{\max})^2 - 4\phi APAR\,\theta GPP_{\max}}}{2\theta}$$

In this equation, R_{ec0} (initial slope of the line) was estimated with the assumption that production is zero at night. Hence, nighttime respiration is assumed to be the respiration at sunset considering that temperature difference between sunset and sunrise is only 2-3 degrees

Table 1. Climatic and vegetative types of tropical and temperate ecosystems under investigated

Flux Tower Site	Climate	Vegetative Type
Tropical Region		
Bukit Soeharto, Indonesia	Tropical Rain Forest	Secondary Forest
Mae Klong, Thailand	Tropical Seasonal	Mixed Decidous Forest
Pasoh, Malaysia	Tropical Seasonal	Dry Evergreen Forest
Sakaerat, Thailand	Tropical Rain Forest	Lowland Rainforest
Tapajos, Brazil	Tropical Rain Forest	Rainforest
Temperate Region		
Takayama, Japan	Cool Temperate	Cool Temperate Decidous Boradleaf Forest
Niwot Ridge Forest, Colorado	Temperate	Subalpine Coniferous Forest
Howland Forest, Maine	Temperate Continental	Decidous Evergreen Needle Forest, Boreal
Sylvania Wilderness Area, Michigan	Temperate-Northern	Old-growth eastern hemlock/basswood
Duke Forest, North Carolina	Temperate	Pine Forest
Metolius, Oregon	Temperate	Pine Forest
Walker Branch Watershed, Tenessee	Temperate	Mixed Broadleaved Forest, Decidous Forest

(Gamo, 2005). GPP_{max} denotes the saturation point of photosynthesis and APAR is the amount of active radiation absorbed by plants. Quantum yield expressed as parameter phi (Φ) indicates the initial slope of the curve and theta (Θ) is the degree of sharpness of the shoulder between GPP_{max} and Φ.

Net ecosystem production (NEP) was computed by deducting from gross photosynthesis the rate of respiration and is expressed as:

$$NEP = GPP - R_{ec}$$

Where, GPP is the estimated gross primary production while R_{ec} was computed using the equation:

$$R_{ec} = R_{ec0}\, 2^{\frac{T - T_o}{10}}$$

Where:

R_{ec}: Rec at arbitrary time with APAR > 0

R_{ec0}: R_{ec} 'before sunrise', when APAR=0.

T_o: ambient temperature 'before sunrise'

T: ambient temperature corresponding to R_{ec}

In this equation, it is assumed that the temperature dependence of daytime respiration was the same as that of the nighttime respiration, the same principle as what Saigusa et al (2005) used in their previous study. This is in order to avoid the flux underestimation during stable nights.

Results and Discussions

Underlying Uncertainty

For both tropical and temperate biomes, data points were seen to be randomly distributed within the range of about ± 50%. The reasons behind the uncertainties are still unclear, thus, further studies addressing these problems are necessary.

Parameterized Variables

Variations in Ecosystem Respiration at Sunrise (R_{ec0})

In almost all cases, R_{ec0} follows a more or less similar trend in all temperate sites (Figure 1). Very low R_{ec0} rates were observed during winter, however, they slowly rose at the beginning of leaf formation in April and peaked from June to August. A gradual decline occurred during the leaf defoliation period in autumn.

On the other hand, tropical regions (Figure 2) demonstrated higher respiratory tendencies than the temperate zones. There was no distinct trend of the line, yet, R_{ec0} was higher during the rainy season than the warmer periods.

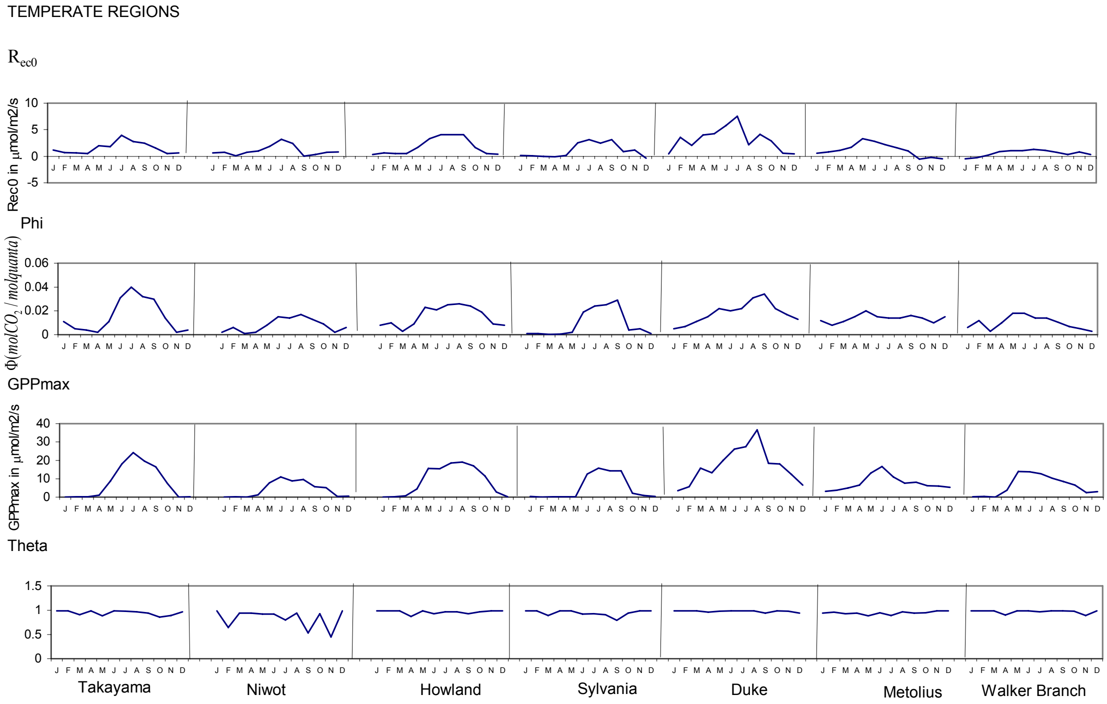

Fig 1 Results in parameterization made in temperate sites (data were taken in 2003).

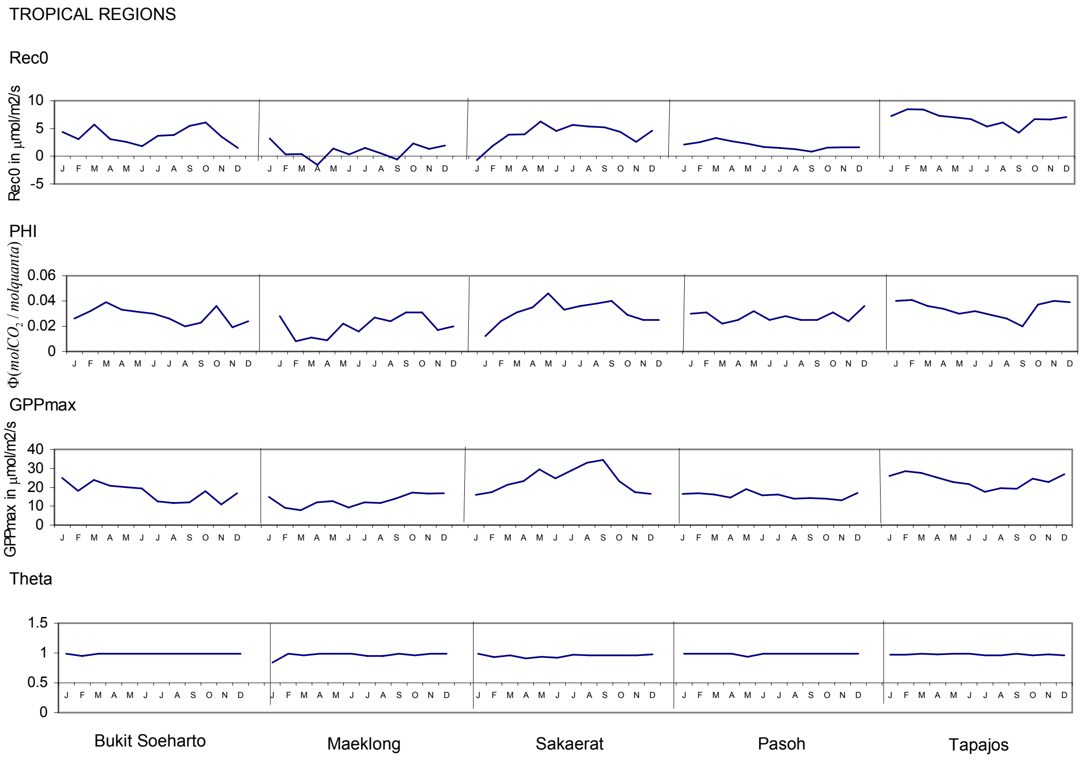

Fig 2 Results in parameterization made in tropical areas (data were taken in 2003).

Maximum Gross Primary Production (GPP_{max}) Rates

The monthly average observed GPP_{max} (in $\mu mol/m^2/s$) for temperate regions is 8.13. A very low production occurred in winter then started to increase in April or May, peaked during summertime in June to September and gradually decreased during autumn in October to December (Figure 1).

However, tropical site's annual average GPP_{max} is still significantly higher at 18.63 compared to temperate zone's 8.13. The line is irregular but the overall production in tropical forest still outweighs that of temperate zone (Figure 2).

The Phi (Φ) and Theta (Θ) Values

For both ecosystems, Θ values follows the trend of GPP_{max} but still tropical sites possessed higher values compared to temperate regions as production is constrained during the winter periods in these areas. (Figures 1 and 2).

As far as the theta (Θ) is concerned, data points in most of the regions of both biomes were laid more or less closer to the regression line (from 0.91-.99), except in the case of Niwot, Colorado in temperate zone where lower theta values were observed (Figures 1). This means that data on this site were much varied compared to the rest of the regions.

Seasonal Variability In Relation to Production

Figure 3 depicts the computed annual gross primary production (GPP) of both regions. Distinct seasonality in CO_2 uptake and release is very evident in temperate biomes wherein all sites followed a similar seasonal trend. Photosynthesis increased rapidly as canopy develops and peaked on mid-June. It remained constant until August to September and gradually declined towards autumn. In winter, a definite loss of carbon occurred.

Being an evergreen forest may become advantageous to Duke and Metolius (18.10 tC/ha/yr and 10.68 tC/ha/yr, respectively) because their production were seen to be permanently occurring all throughout the year although at a lesser extent compared to highest producing forest of Sakaerat in the tropics.

Tropical forests, on the other hand, have least seasonality in terms of carbon absorption and emission. But they show larger gross production compared to temperate sites. This can be due to the faster rate of fixation and a longer growing season in these areas (Aber and Melillo, 1991).

The highest annual GPP in tropical areas is Sakaerat (29.0 t C/ha/yr). While it belongs to a typically seasonal forest but they are densely-vegetated with mostly evergreen dipterocarps which are known to withstand adverse climatic conditions and therefore maintain continuous production despite the dryness. An exceptional case was shown in Bukit Soeharto (second highest GPP next to Sakaerat). It fixed relatively more carbon but its emission was higher than it can absorb. One reason can be due to the effect of disturbances that happened in 1982-1983 and 14 years later in 1997-1998, wherein Bukit Soeharto had experienced massive wildfires associated with El Nino Southern Oscillation event (Guhardja et al, 2000). Another is the rampant illegal cutting of trees by timber poachers in the vicinities of the Bukit Soeharto flux monitoring station (personal communication with Dr. Gamo). It is therefore suggested that a thorough investigation on this site shall be given to elucidate the present carbon fixing ability of this forest.

Seasonal Changes and its Effect to Respiration

While it is true that tropical regions produce relatively higher than the temperate sites, however, they also tend to respire more than the latter. Average annual respiration rates (R_{ec} in t C/ha/yr) in tropical areas were high at 11.06 but temperate areas only emitted carbon at an average rate of 6.01. Figure 3 shows the R_{ec} for both ecosystems.

Considering the warmer temperature in the tropics, tropical sites tend to respire more than the cooler temperate sites, especially during dry periods. During dry months, the amount of water in the soil is likely reduced. But it must be noted that precipitation in tropical areas occurred all throughout the year even during dry months. Thus, a better understanding of the seasonal and diurnal rainfall pattern in the tropics is highly recommended towards this end.

Meanwhile, seasonality in carbon release is much more evident in temperate forests. The lower respiration rate in winter can be explained by the limitation of active microbial activity due to lower temperature in deeper soil layers. Freezing temperature may also hamper root respiration. This coincides with the findings of Malhi et al. (1999) in which respiration driven by temperature at 10cm soil depth is nearly zero in winter.

The Overall Carbon Balance

In temperate zones, Metolius has the greatest net ecosystem production (in t C/ha/yr) of 5.42 while sub-alpine Niwot Forest has the lowest with only 1.60 (Figure 4). In the tropics, Sakaerat was the highest net absorber at 9.89 and Bukit Soeharto possessed the lowest NEP (-2.80). As mentioned earlier, Bukit Soeharto has great potential of absorbing carbon but its absorptive capacity cannot offset the huge amount of CO_2 that it has emitted in the atmosphere. Average annual NEP was 5.63 and 3.30 for tropical and temperate regions, respectively.

Conclusion

Disregarding much of the uncertainties behind the results, the net ecosystem production (NEP) showed that tropical ecosystem is a better net absorber than the temperate zones. But some researchers find it difficult to support this view considering that fluxes of carbon from the tropics are very poorly constrained due to lack of data and methodological limitations. Hence, long-term studies must be conducted to monitor the extent of gas exchange in these areas, as they are the most disturbed forest ecosystem. It is also worthwhile to compare the sites within each region (tropical and temperate) to further elucidate the differences of these sites within the same forest ecosystem.

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Measurement of Mass and Thermal Fluxes in Taiwan

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Land-atmosphere interactions involve complicated physical, chemical, and biological processes and play an important role in global hydrological cycles. The change of global climate and human activities may significantly affect the spatial and temporal characteristics of these processes. In order to understand the various processes influencing the land-atmosphere interactions, measurements of mass and thermal fluxes at different types of landcover are critical and require extensive field studies. These measurements in Taiwan are mainly established and maintained by research teams of universities in recent years. Table 1 lists sites having capability of measuring LH (Latent Heat) and SH (Sensible Heat) and associated information of these sites. Observations and results of three sites, including TWCLF, TWNCU, and TWLHL, are introduced in the followings.

The TWCLF site is the most sophisticated site in Taiwan. Carbon dioxide, water vapor, and sensible heat fluxes were measured by the eddy covariance method. A 3-D sonic anemometer and an open-path analyzer were mounted on top of a 24-meter instrument tower over a natural regenerated stand that consists mainly of the tree species of Taiwan cypress (*Chamaecyparis obtusa var. formosana*). Synchronized analog signals from the open-path analyzer and 3-D sonic anemometer (3 dimensional wind speeds and the sonic temperature) were digitalized with a sampling rate of 10 Hz. All digital data were recorded by computer and stored in hard disc for later analysis. Figure 1 shows the CO_2 fluxes measured by the eddy covariance method. The data quality is poor due to frequent fog and rainfall.

The TWNCU site is an integrated hydrometeorology site. The land cover is short grass at about 5~10 cm. Like a conventional meteorological station, net radiation, wind speed/direction, air pressure, air temperature, relative humidity, tipping bucket rain gauge, and pan evaporation were measured since 2004 at 10 minutes resolution. At the same location, vertical soil moisture by Sentek capacitance probe and temperature by thermocouples at -10 cm, -30 cm, -50 cm, -70 cm, -90 cm are being measured at the same frequency. Under the assumptions that horizontal water flow and infiltration are negligible, the loss of soil water is equivalent to the amount of evapotranspiration. Figure 2 shows the relationship between surface water content and the ratio of AET/PET at the TWNCU site. AET is estimated by the soil water loss of 0-40 cm and the PETs are estimated by PM (Penman-Monteith) and PT (Priestley-Taylor) methods. In addition to low frequency approach, the eddy covariance method was applied for comparisons. Figure 3 is the LH and SH measured by the eddy covariance method. The LH was equivalent to an ET depth of 1.80 mm and the soil water loss was 1.78 at the same day.

A 20 m measurement tower of the TWLHL site was established in the summer of 2006. Figure 5 is the schematic diagram of instruments installed at this site. This is the most comprehensive tower in forest ecosystems in Taiwan. The canopy height is about 17 m. Soil moistures measured by Sentek capacitance probe and soil temperatures by thermocouples are placed at -10 cm, -30 cm, -50 cm, -70 cm, and -90 cm. Soil heat flux plate is being measured at -5 cm. A drainage gauge is installed at -50 cm to collect infiltrated water. Temperature and relative humidity sensors are placed every 5 m from ground surface to 20 m. Net radiation and conventional wind speed/directions are measured over canopy top. The sampling frequency is 30 minutes. In addition to low frequency instruments as mentioned above, an eddy covariance system, including a 3-D sonic anemometer Young 8100 and a Krypton Hygrometer KH20, will be periodically practiced for LH and SH measurements.

This document is only a preliminary report of ongoing mass and thermal fluxes measurements in Taiwan. Due to data availability, not all sites are included and discussed herein.

Table 1 Mass and thermal observations in Taiwan

ID	Starting Year	Land cover	Latitude	Longitude	Elevation (m)	Annual Rainfall (mm)
TWCIM	2000	Urban	23.498N	120.424E	28	2900
TWCIR	2005	Rice paddy	23.491N	120.407E	22	2985
TWCLF	2005	Needle leaf forest	24.591N	121.499E	1650	4000
TWNCH	2006	Urban	24.121N	120.678E	84	2575
TWNCU	2004	Grassland	24.968N	121.185E	130	2270
TWLHL	2006	Broadleaf forest	23.931N	120.894E	700	2100
TWTAR	2005	Rice paddy	24.031N	120.688E	55	2066

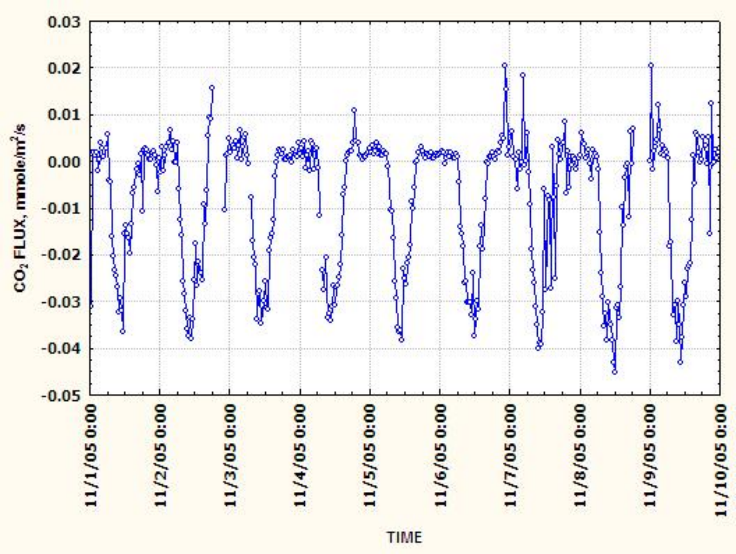

Fig 1 CO_2 flux measured by the eddy covariance method at TWCLF site

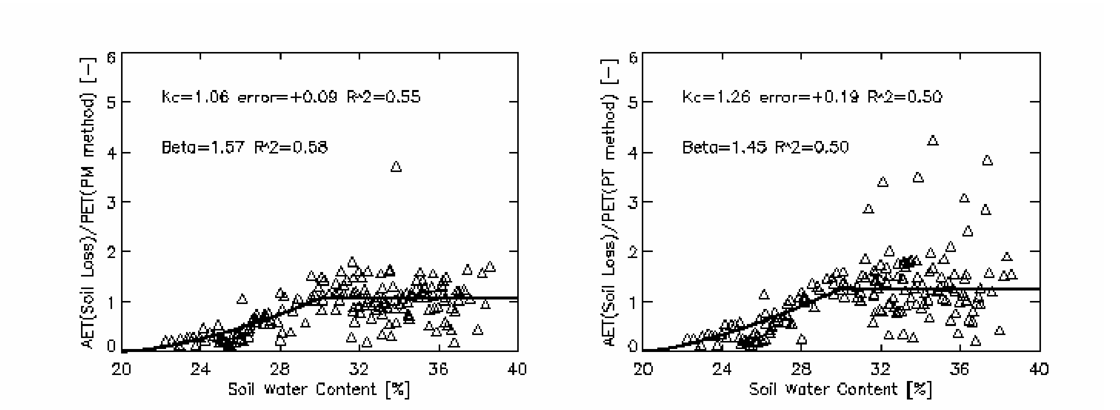

Fig 2 The relationship between surface water content and the ratio of AET/PET at the TWNCU site. AET is estimated by soil water loss of 0-40 cm and PETs are estimated by PM (Penman-Monteith method) and PT (Priestley-Taylor method).

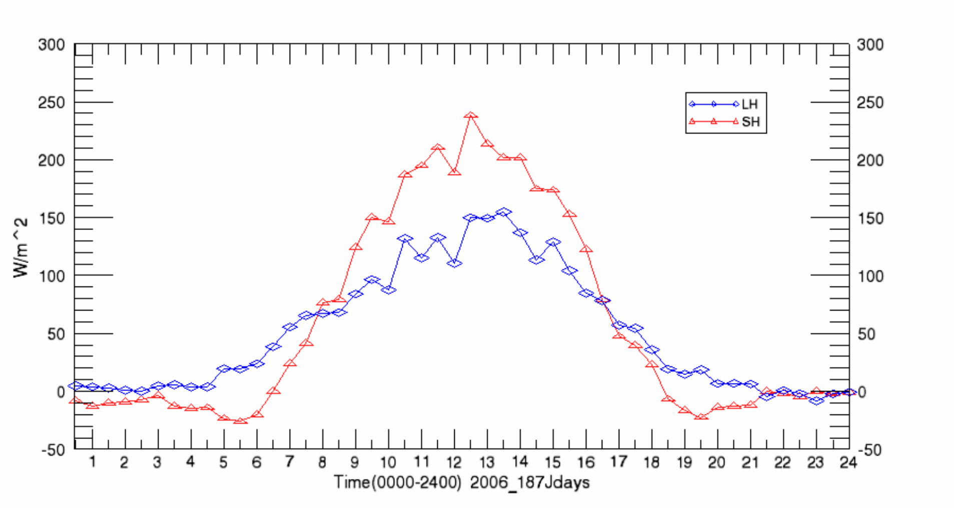

Fig 3 LH and SH measured by the eddy covariance method at the TWNCU site for J day of 187, 2006

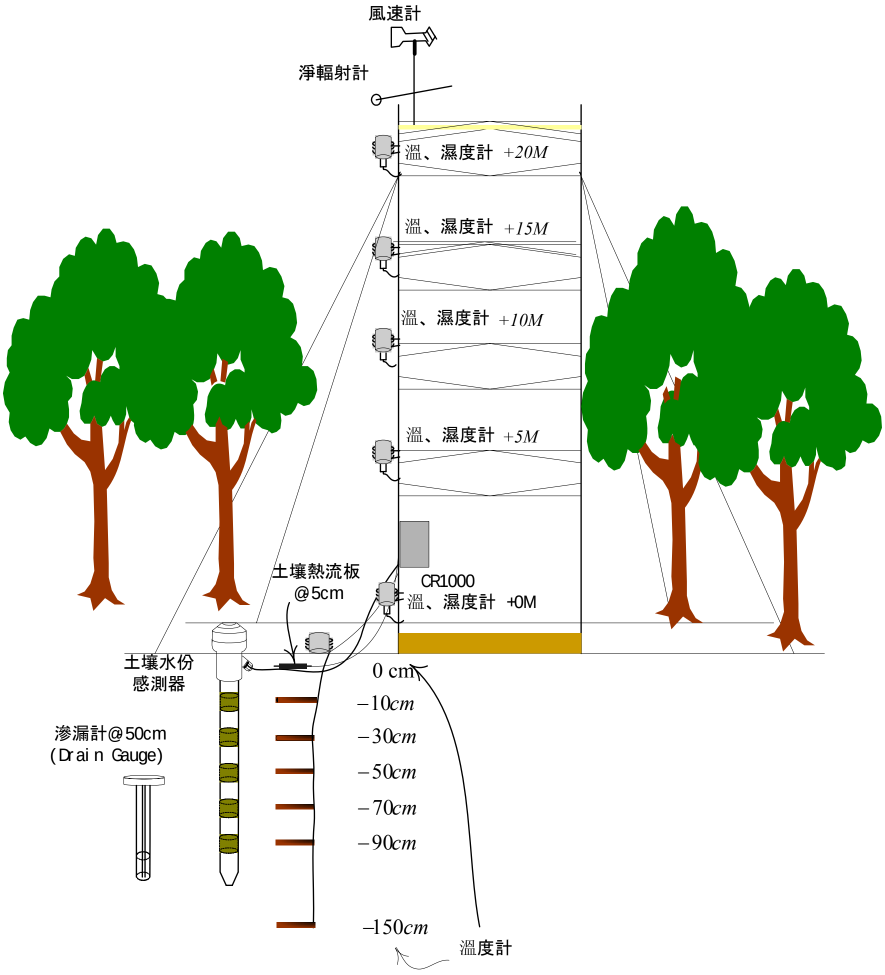

Fig 5 Schematic diagram of instruments at the TWLHL site

Vegetation Distribution and Current Status of CO_2 Flux Observation in Taiwan

Ching-Hwang LIU

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1. Vegetation distribution in Taiwan

Taiwan is located between the tropical and subtropical regions. The dimension of Taiwan is about 400km in north-south direction and 200km across with a high mountain ridge at the center of the island oriented in N-S direction. The climate is modulated by subtropical high in summer and by north-east monsoon in winter. Due to the complexity of terrain and climate, a variety of the vegetation distribution exists. With the elevation of terrain, the vegetation distribution is different. As shown in Figure 1, the vegetation distribution is strongly modulated by the terrain, slope, rainfall, temperature and human activities (please refer to http://ngis.zo.ntu.edu.tw/vegetaion_map/index.htm for more information). In general, 40% of the land is covered by the agricultural and fruit ranches and 60% of the land is covered by the forest. The ages of the trees are variable. The oldest trees may be up to several thousands years old. In general, the tree ages are between few hundreds years and few tens years.

2. CO_2 flux research in Taiwan

Taiwan is very young in the CO_2 flux measurement history. The only one existing 24m-height flux observation tower was built by Prof. Y.-J. Hsia in March on 2005 (reference web site: http://metacat.ndhu.edu.tw/Twflux/index.htm). This site is located at the north-east tip of Taiwan (figure 2) at the elevation about 1500 meters. The ground slope is about 15 degree and the surrounding average canopy height is about 10.3 m. It has a Li-Cor 7500 open path CO_2/H_2O analyzer and started collecting data since early April of that year. Other flux related instruments include ultrasonic anemometer, Li-8100 automated soil CO_2 flux system, Li-Cor Li-610 Dew Point generator, and Li-Cor 840 CO_2 and H_2O analyzer. Meteorological data are also being collected such as global radiation; reflect solar radiation, downward longwave radiation, terrestrial radiation, net radiation, wind speed, wind direction temperature, relative humidity, rainfall, soil temperature, soil heat flux, soil water content, and photosynthetic active quantum flux. This site conducted a pilot study of the CO_2 flux observation in Taiwan area. The data retrieval rate is 15% in April, 50% in May, 60% in June, but the retrieval rate is quite low between July and October due to typhoons. Using the data collected between April and September, the preliminary study has shown that the mean horizontal wind speed is 1.4m/s, mean vertical wind speed is 0.1 m/s, and the maximum wind speed is 4.5 m/s. The air temperature is between 15 and 20 °C and humidity is between 50 and 100%. The CO_2 concentration is between 300 and 400 ppm which does not change very much within the observed period. The average concentration is 325 ppm, but it may go up to 388 ppm during the night time. The average sensible heat flux is 45 W/m^2 and 550 W/m^2 for day-time. A sensible flux of -128 W/m^2 was measured for an inversion case. The average latent heat flux of evpotranspiration is $71W/m^2$, max is $784W/m^2$, and minimum is $-130W/m^2$. The CO_2 flux is quite similar during this period. The averaged daily flux is -3506 mol/ha/day which is about 154kg/ha/day (figure 3). These results are quite reasonable but more testing and data quality evaluation are still ongoing.

3. Status of Chinese Culture University site

In this coming fiscal year, the Chinese Culture University and the National Central University will be funded by the Environment Protection Administration of Taiwan for establishing two new towers. These two sites will be almost identical to the existing site discussed above. The Chinese Culture University site will be built in our experimental forest ranch (Hua-Lin ranch) which is located at the south bound suburb of the Taipei city with an area of 92ha (24 53 31.47N, 121 34 01.16E). It is virgin forest experimental ranch. The average canopy height is about 10m and the average tree ages are about 30 years. The slope of the terrain is about 30 degree. Our department has just established a brand new surface meteorological observation site at Hua-Lin ranch in June 2006. This site is equipped with all fundamental meteorological instruments (figure 4). In addition, a GPS receiver, vertical pointing rainfall measurement radar, and a rain drop size disdrometer are also installed. This site will be collecting data for our own research and will also benefit to the future projects. The CO_2 flux tower will be built about 100 meter to the east of this surface observation site.

4: Reference:

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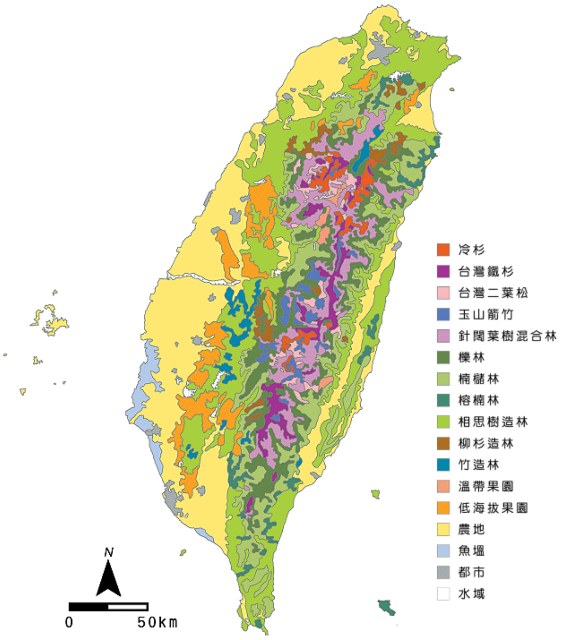

Figure 1: Vegetation distribution (adapted from:http://ngis.zo.ntu.edu.tw/vegetaion_map/index.htm)

Figure 2: Pilot CO_2 flux site of Taiwan

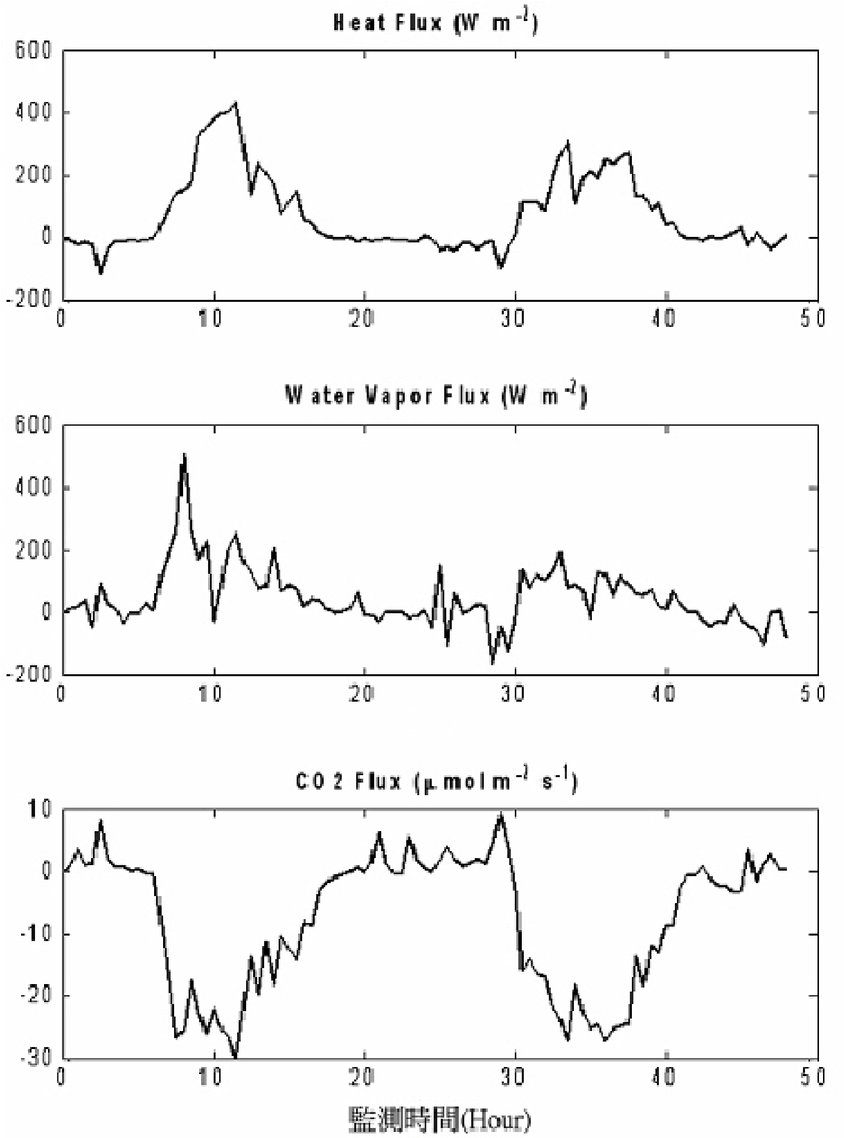

Figure 3: Sensible heat flux, water vapor flux, and CO$_2$ flux of Dong Hua site during 2005/06/04 00:00 LST and 06/05 23:00LST

Figure 4: Chinese Culture University Hua-Lin surface observation site

Can Gio Biosphere Reserve, Ho Chi Minh City, Vietnam

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Can Gio (formerly Duyen Hai) is located south of Ho Chi Minh City in its suburban district. During the Indochina War, the mangroves here were damaged by herbicides. After the war, the forest was destroyed by locals felling trees for such needs as fuel wood and house construction. A Mangrove rehabilitation programme was begun in 1978 with vast tracks of mangroves planted. Some 20,000 ha of *Rhizophora apiculata* were planted and accompanied by 10,000 ha of natural regeneration. Between 1978 and 1991, the mangroves were classified as economic forest, between 1991 and 2000, the forest became protected forest and since 2000, the forest has been deemed a mangrove natural reserve.

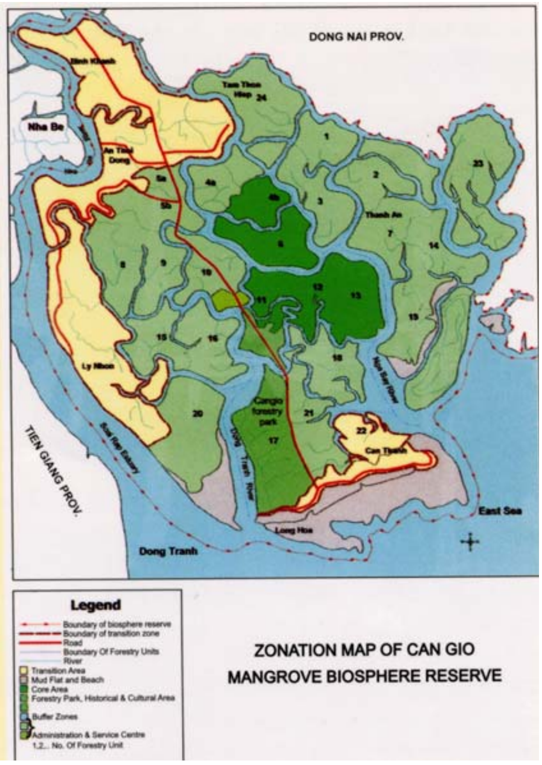
Designated as the Biosphere Reserve by UNESCO, it is the first for Vietnam. The management of the mangrove forest changed hands several times as its classification varied. The successes and failures in mangrove forest management during the course of this period are presented in this report.

1. Introduction of Can Gio Mangrove Biosphere Reserve

Ho Chi Minh City (formerly Saigon) is located about 1,300 km south of Hanoi and includes a mangrove in Can Gio, a suburban district and covers an area of 71,361 ha. It is the poorest district of the city with the population of 62,000. A network of rivers and channels traverses the delta and the main waterways leading to the port of Ho Chi Minh City.

From 1964 - 1970, Can Gio mangrove forest (formerly Rung Sat) was sprayed heavily with herbicides: 665,666 gallons of Agent Orange; 343,385 gallons of Agent White and 49,200 gallons of Agent Blue. As a result, 57% of mangrove forest in the district was destroyed (Ross, 1975). In some areas, large trees of *Rhizophora*, *Sonneratia*, and *Bruguiera* were killed by the herbicide spraying and in many areas the vegetation was completely destroyed. Only *Avicennia* and *Nypa* palm were able to survive and regenerated after the application of herbicide. Some species such as *Phoenix paludosa* and *Acrostichum aureum*, a fern that dominated on elevated land, have expanded. After many years of chemical spraying, the degraded land still has only scattered small trees.

Since 1978, a vast programme of reforestation has been undertaken by Ho Chi Minh Forestry Department. Up to now, the reforestation effort has brought vast ecological improvements to the environment such as biodiversity, i.e., wild animals such as monkeys, otters, pythons, wild boars, crocodiles and various kinds of birds have returned to the artificially regenerated mangrove forests. In 1991, Can Gio mangrove forest has been declared an "Environmental Protection Forest" by the Council of Minister and Can Gio has become one of the most beautiful and extensive



ZONATION MAP OF CAN GIO MANGROVE BIOSPHERE RESERVE site of rehabilitated mangrove in the world. It was also approved as Mangrove Biosphere Reserve by UNESCO in 2000.

After 28 years, more than 19,000 hectares of mangrove forest have been planted, mainly with *Rhizophora apiculata* species following massive wartime destruction. This process has served to meet the demand for wood fuels and construction materials in HCMC, as well as to re-establish suitable conditions for the development of various activities such as fishery, aquaculture, research, education, ecotourism and others. But in last few years, the mangrove has faced with the degraded forests by management policy, human impacts and natural disasters.

The area of Can Gio Mangrove Biosphere Reserve

The forest resource of Can Gio Biosphere Reserve covers an area of 31,111 ha or 43.06 % of the total area. About 10,982 ha of natural mangrove forests and 19,096 ha are artificial forest occupied 38.61% and 61.39% of the forest respectively.

Table 1: Extent of Can Gio Mangrove Biosphere

Category	Area (ha)	Percent (%)
1. Forested area	**31,111**	**43.60**
a. Forest plantation	19,096	26.76
b. Natural mangrove	10,982	15.39
c. Wasteland	1,033	1.45
2. Non forested area	**37,250**	**56.40**
a. Waterways	22,091	30.96
b. Utilized land	15,059	21.10
c. Others	3,100	4.34
Total	**71,361**	**100.00**

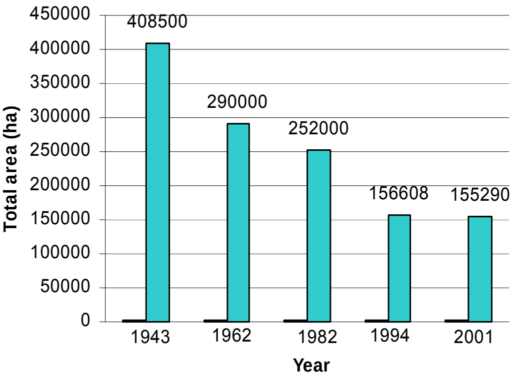
2. Introduction of Mangrove in Viet Nam

Geographical distribution

Phan Nguyen Hong (1991) divided Vietnam mangrove into 4 zones:

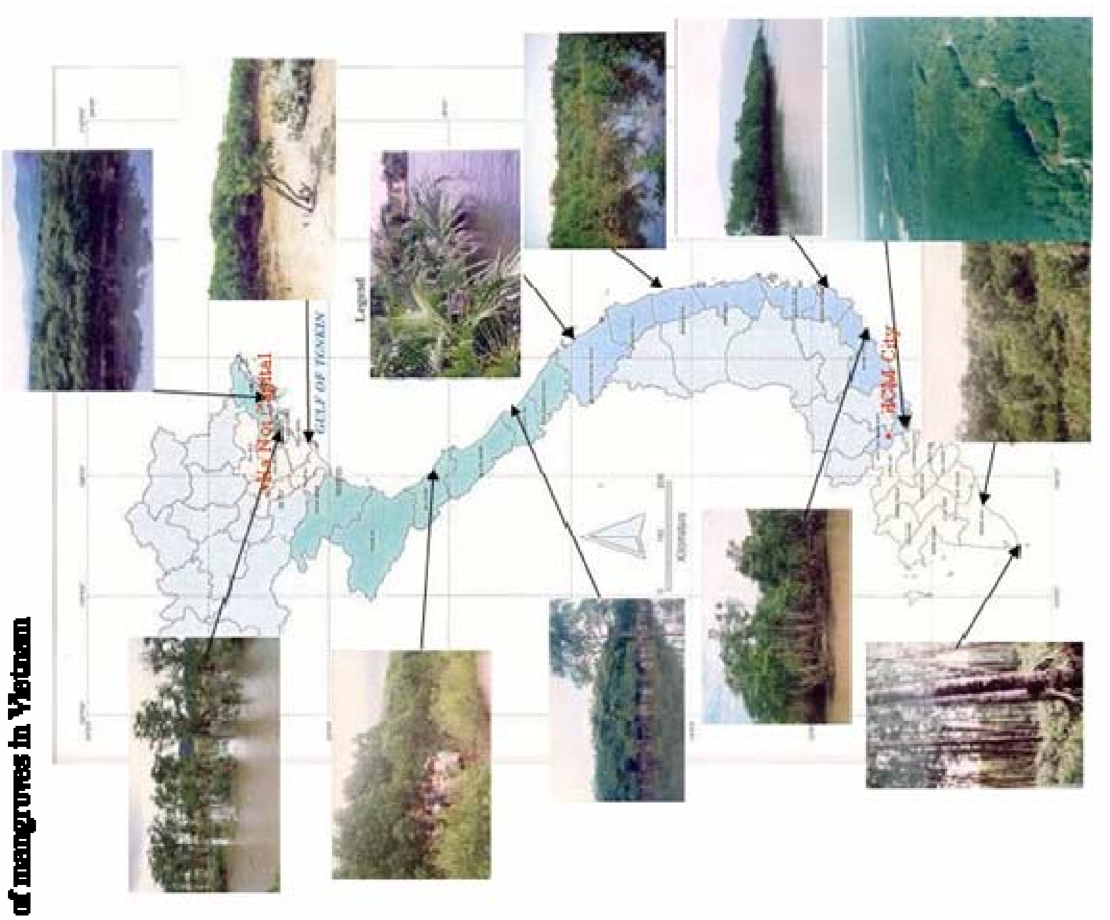
- Zone 1: Northeast coast
- Zone 2: Northern delta
- Zone 3: Central coast
- Zone 4: Southern delta

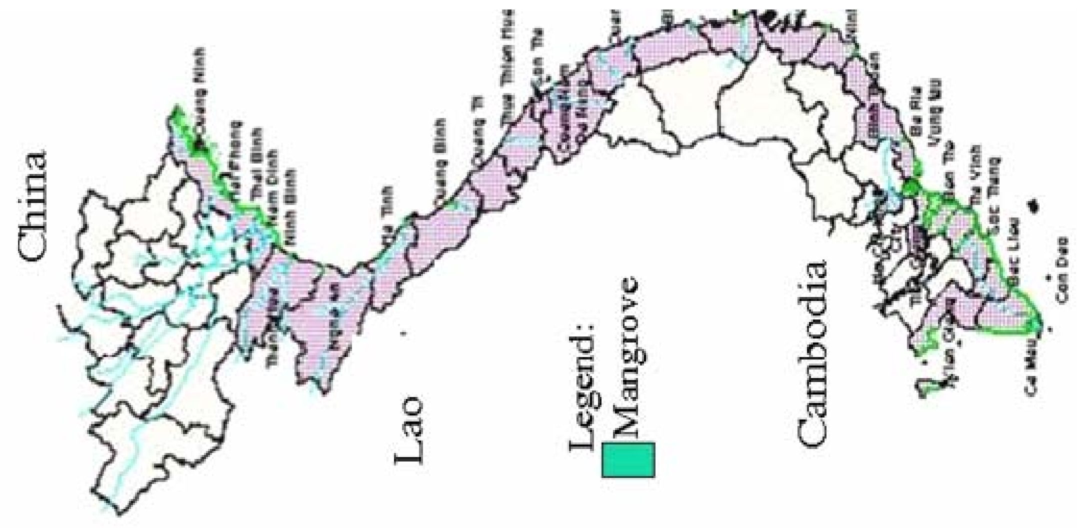
Mangrove area in Vietnam



No	Province/City	Mangrove area (ha)
	Total area	**155,290**
1	Quang Ninh	22,969
2	Hai Phong	11,000
3	Thai Binh	6,297
4	Nam Dinh	3,012
5	Ninh Binh	533
6	Thanh Hoa	1,000
7	Nghe An	800
8	Ha Tinh	500
9-19	10 provinces and cities of Northern	700
20	Ba Ria-Vung Tau	1,500
21	**Ho Chi Minh City**	**24,592**
22	Long An	400
23	Ben Tre	7,153
24	Tien Giang	560
25	Tra Vinh	8,582
26	Soc Trang	2,943
27	Bac Lieu	4,142
28	Ca Mau	5,285
29	Kien Giang	322

Distribution of mangroves in Vietnam





3. Introduction of Mangroves of the world

Mangroves are distributed circum-tropically, occurring in about 112 countries, with total area coverage of about 18 million hectares. Of the total, 41.4% exist in south and Southeast Asia. The Mangroves occupy about one quarter of the world's coastline, but they form just about 0.45% of the world forests (world Resource Institute, 1996 – 97).

Region	**Areas in sq km**	**% of total**
South and Southeast Asia	75,170	41.4
The Americas	49,096	27.1
West Africa	27,995	15.4
Australasia	18,788	10.4
East Africa and Middle	10,348	5.7
Total	**181,397**	**100**

Mangroves are largely restricted to latitudes between 300 N and 300 S. Northern extensions of this limit occur in Japan (31022’ N) and Bermuda (32020’ N); southern extension are in New Zealand (380 03’ S), Australia (380 45’ S) and on the east coast of the South Africa (320 59’ S) (Spalding, 1997)

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Progress in ChinaFLUX

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An accurate evaluation of carbon flux between vegetation and atmosphere is critical for quantifying the spatial pattern of carbon budget in terrestrial ecosystems (Baldocchi, 2003). As a member of FLUXNET, ChinaFLUX plays an important role in exploring the interaction of soil-plant-atmosphere, evaluating the role of terrestrial ecosystem in global carbon cycle, and investigating the response of terrestrial ecosystem carbon exchange to global environmental changes. The objectives of this paper are to: (1) briefly overview the development of ChinaFLUX; (2) summarize main achievements of ChinaFLUX in flux measurement techniques, in understanding of the controlling mechanism of environmental factors on terrestrial ecosystem carbon balance and in modeling of carbon and water fluxes in terrestrial ecosystem and (3) discuss the future directions of ChinaFLUX.

1. Introduction of ChinaFLUX

Chinese Terrestrial Ecosystem Flux Research Network (ChinaFLUX) relies on Chinese Ecosystem Research Network (CERN) and was established in 2002. It has four scientific objectives: (1) To develop the standard methodology for long-term measurement of terrestrial ecosystem CO_2, H_2O and heat fluxes in China; (2) To obtain data on the net ecosystem exchanges of CO_2, H_2O and heat in a variety of vegetation communities, and data on CO_2, CH_4 and N_2O emission from and/or uptake by the soil in these communities; (3) To obtain data on ecological patterns and processes that are relevant to carbon cycle in the terrestrial environment; (4) To develop process-based models of water and carbon cycles for typical Chinese ecosystems.

At present, ChinaFLUX has four forest sites (Changbaishan (CBS), Qianyanzhou (QYZ), Dinghushan (DHS) and Xishuangbanna

Table 1 Background of the 8 ChinaFLUX sites

Sites (abbreviation)	Location and altitude	Climate and soil	Vegetation	Canopy height
Changbaishan forest site (CBS)	42°24′ N 128°05′ E; 738 m	Temperate continental monsoon climate Upland dark brown forest soil	Temperate deciduous broad-leaved and coniferous mixed forest. *Pinus koraiensis, Tilia amurensis, Quercus mongolica, Fraxinus mandshurica, Acer mono* etc.	26 m
Qianyanzhou forest site (QYZ)	26°44′ N 115°03′ E; 102 m	Typical subtropical monsoon climate Typical red earth	Typical subtropical monsoon man-planted forest. *Pinus elliottii, Pinus massoniana, Cunninghamia lanceolata, Schima superba* etc.	12 m
Dinghushan forest site (DHS)	23°10′ N 112°34′ E; 300 m	Monsoon humid climate of torrid zone of south Asia Lateritic red-earth, yellow-earth, and mountain shrubby-meadow soil	Typical subtropical typical tropical evergreen broad-leaved forest. *Cleistocalyx operculatus, Syzygium jambos, Castanopsis chinensis, Pinus massoniania, Rhododendron moulmainense* etc.	20 m
Xishuangbanna forest site (XSBN)	21°57′ N 101°12′ E; 756 m	Typical monsoon humid climate of torrid zone of south Asia Lateritic and red lateratic soil	Tropical seasonal rain forest. *Pometia tomentosa, Terminalia myriocarpa, Barringtonia macrostachya, Gironniera subaequalis, Mitrephora maingayi, Garcinia cowal, Knema erratica, Ardisia tenera, Mezzettiopsis creaghii, Dichapetalum gelonioides*	40 m
Yucheng cropland site (YC)	36°57′ N 116°36′ E; 28 m	Temperate semi-humid and monsoon climate Soil type is aquox and salt aquox, and surface soil is rich in light-mid loam	Warmer temperate dry farming cropland Winter wheat and summer maize	0.8 m (wheat); 3 m (maize)
Haibei grassland site (HB)	37°36′ -37°39′ N 101°18′ -101°20′ E; 3215-360 m	Highland continental climate Soil type is alpine meadow soil, alpine scrubby meadow soil and swamp soil	Typical frigid vegetation of Northern Qinghai Tibetan Plateau. *Potentilla fruticisa shrub, Kobresia humilis meadow and Kobresia tibetica swamp meadow*	0.6 m (shrub); 0.2 m (meadow); 0.5 m (swamp)
Inner Mongolia grassland site (NMG)	44°30′ N 117°10′ E; 1189 m	Temperate semi-arid continental climate Chernozem soil	Typical steppe and meadow steppe. *Leymus chinense, Stipa grandis and S. krylovii. Stipa Baicalensis, Festuca Lenesis, Filifolium sibiricum*	0.4 m
Dangxiong grassland site (DX)	30°51′ N 91°05′ E; 4250 m	Plateau monsoon climate Meadow soil with sandy loam	Typical Kobresia meadows of the northern Tibetan plateau. *Kobresia littledalei, Blysmus sinocompressus, K. microglochin*	0.15 m

(XSBN)), three grassland sites (Haibei (HB), Inner Mongolia (NMG) and Dangxiong (DX)) and one cropland site (Yucheng (YC)) that are conducting long-term fluxes observation of carbon dioxide, water and heat (Table 1). In addition, chamber method was used at 16 sites to measure soil efflux of greenhouse gases such as CO_2, CH_4 and N_2O etc. In recent two years, more than 40 new flux sites have been established by some institutes and universities in China (such as the Institute of Chinese Academy Science, China Meteorological Administration, Chinese Forestry Academy), which greatly enhances the extension and intensity of flux research in China(Fig.1).

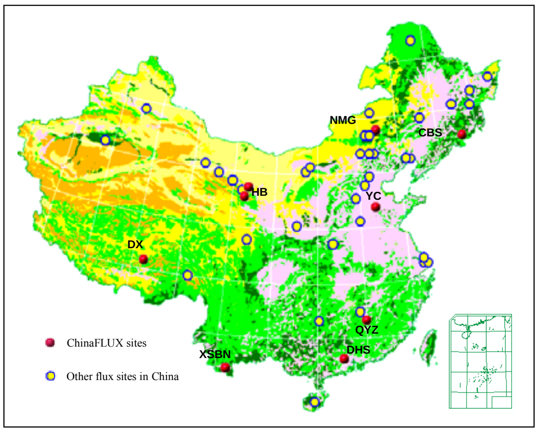

Fig.1 Distribution of flux observation sites in China

2. Major progresses of ChinaFLUX

A mass of first-hand flux data in major terrestrial ecosystems has been obtained since the establishment of ChinaFLUX in 2002. At present, ChinaFLUX has published three special issues (one in "Agricultural and forest meteorology", two in "Science in China, series D"), which was mainly on carbon/vapor balances in different ecosystem, environmental controls on carbon/vapor flux, development of the process-based models of carbon/water cycles and techniques of field observation.

2.1 Flux observation technique, data processing and evaluation

Same as many other techniques, eddy covariance method also has its own disadvantages. Errors appeared when the natural condition cannot meet the requirements of eddy covariance flux measurement (Baldocchi, 1988). Main causes of the errors are induced by: loss of high and low frequency signal due to the limitation of sensor's physical attribute (Moore, 1986); underestimation of long term carbon balance by choosing improper coordinate system and due to the turbulence that is not well-mixed during the nighttime (Lee, 1998; Massman and Lee, 2002). ChinaFLUX has developed a relatively sound flux data processing procedure through long-term exploring and practice, including data collection and storage, flux calculation and error correction.

2.2 Environmental controls on ecosystem carbon budget

2.2.1 Evaluation of carbon budget in major ecosystem

Most sites of ChinaFLUX have continuously measured CO_2 flux for 2~3 years. The three forest sites in eastern China (CBS, QYZ and DHS) are big carbon sinks. Observation data indicated that tropic seasonal rain forest ecosystem at XSBN site was a net carbon source. This site located in a valley with complex terrain and drainage flow as well as advection occurring frequently. Significant uncertainty and errors might exits in the eddy covariance measurement results in this region. The semi-arid *Leymus chinensis* steppe at NMG was evidently a carbon source in both 2004 and 2005. In contrast with the temperate steppe, the alpine meadow and alpine shrub at HB, located at north-eastern Tibet Plateau, were net carbon sinks during the observing years. The alpine meadow at DX, located at the southern edge of Tibet Plateau with the highest altitude, however, is a small carbon source too. The winter wheat-corn rotation farmland ecosystem at YC was sequestrating carbon during the 2 measurement years.

2.2.2 Response of ecosystem CO_2 exchange to environment

GEP is mostly determined by the coordination of temperature and moisture. Seasonal variation and annual total GEP at CBS site are mainly affected by temperature and leaf area index (Zhang et al., 2006a; Zhang et al., 2006b). The alpine meadow on Tibet Plateau (HB and DX) is also mainly controlled by temperature (Li et al., 2006). In growing season with enough radiation, moisture is the primary factor determining the production of forest ecosystem. Precipitation and its temporal variability is the key factors that affect the GPP at NMG (Flanagan et al., 2002).

Many studies have found that temperature is the primary factor that governs ecosystem respiration among various environmental factors (Lloyd and Taylor, 1994). Q_{10} and annual total respiration of the forest ecosystems in ChinaFLUX follow the order as XSBN > CBS > QYZ > DHS, indicating Q_{10} decreased with increasing temperature (Shi et al., 2006). Results show that Q_{10} in grassland was higher than that of forest (Tjoelker et al., 2001). In addition to temperature, soil moisture, soil organic matter and microbes are also found to be influencing soil respiration. Fu et al. found that the Q_{10} of semi-arid steppe decreases distinctly under moisture stress (Fu et al., 2006). They also suggested that moisture may become the key factor that controls ecosystem

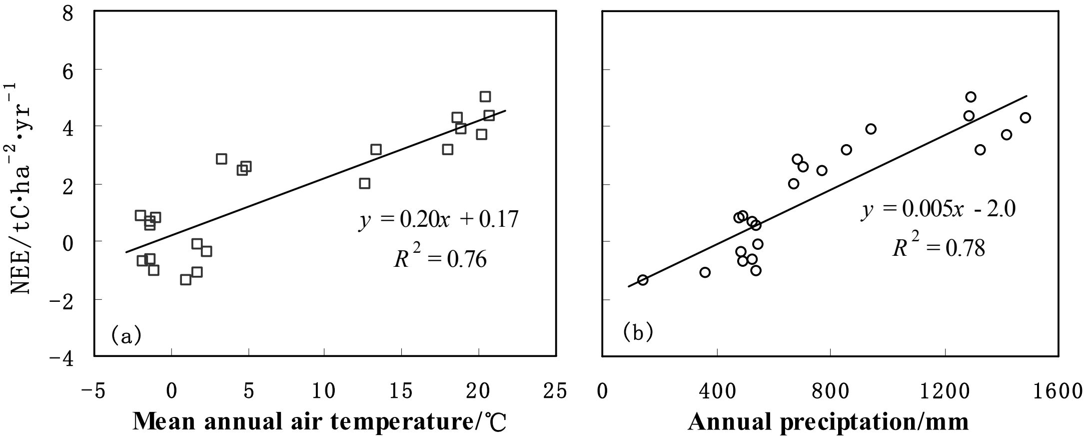

Fig.2 The relationship between the annual total NEE and annual mean temperature (a) and annual mean precipitation (b) in the typical ecosystems of ChinaFLUX. (Data source is the same as table 1 but not including Xishuangbanna site)

respiration under severe drought stress. With both eddy covariance and chamber method, results suggested that Q_{10} model is better than multiplicative model in describing the seasonal variation of R_{eco} in ecosystems which could easily suffer drought stress (Yu et al., 2005).

Most of ecosystems in the east of China (CBS, QYZ, YC, NMG) experienced a drier and warmer year in 2003. But these ecosystems showed different responses to the seasonal and interannual changes in temperature and precipitation. GEP and R_{eco} at QYZ and NMG were significantly restrained by water stress and NEE decreased evidently in the drought summer of 2003 (Liu et al., 2006; Suyker et al., 2001; Flanagan et al., 2002). YC also had lower production in the drier year. But CBS did not show distinct decrease of NEE in 2003. NEE of alpine grasslands (HB and DX) were usually restrained by the low temperature and short growing season, although there was abundant precipitation in warm season at the two sites. At the temperate steppe NMG, precipitation and soil moisture have greater effects than temperature. At regional scale, there were significantly positive relationship between net ecosystem carbon uptake and temperature or precipitation among various ecosystems such as forest, grassland and cropland (Fig. 2).

2.3 Modeling of carbon/vapor fluxes in ChinaFLUX

To better understand the mechanism of main ecosystem processes, many models were developed or applied in ChinaFLUX. Ren et al. (2005) and Zhang et al. (2005) established photosynthesis-transpiration coupling model on canopy scale by using the observed flux data from CBS and YC sites. Wang et al. simulated the variation of ecosystem carbon and water fluxes during the growing season at CBS in 2003 at hourly step based on the BEPS model. He et al. simulated the CO_2 flux of three different ecosystems (cropland, forest and grassland) of ChinaFLUX with BP artificial neural network (ANN), using energy flux, temperature and surface soil water data (He et al., 2006). Gu et al. parameterized and validated CEVSA model by using the ground investigation information of the flux data from QYZ site in 2003 (Gu et al., 2006).

3. Key issues and future direction of ChinaFLUX

ChinaFLUX has obtained some significant results during the first three years of its development, and has received worldwide attention from flux research community. Compared with other countries or regional networks, flux observation and research in China is still at the primary phase and much more efforts are needed for further research on following issues

3.1 Key issues in ChinaFLUX

Issues about the representativeness and reliability of observed flux data with EC technique under difficult topography, vegetation and climate conditions haven't been resolved yet. The three forest sites of QYZ, DHS and XSBN all locates in complex terrain. ChinaFLUX will make more efforts on, ①evaluation and correction of flux in complex terrain; ②techniques under complex meteorological condition and the correction methods for the underestimation during nighttime; ③comparisons among eddy covariance, biometric, chamber and aerodynamic method.

Further cognition on the mechanism and processes of ecosystem carbon/water flux is needed to explain the observation results, and apply the results to regional scale. Many other observation methods (such as isotope technique, soil respiration measurement, aviation observation in atmospheric boundary layer and remote sensing etc.) are needed in future for deeper understanding of biological and environmental controls on different components of ecosystem carbon and water flux.

The data-model fusion system can greatly accelerate the work on ecological processes research at different scales. ChinaFLUX has carried out some primary studies on flux data-model fusion (He et al., 2006). As one of the major research contents, ChinaFLUX will take much more efforts on developing a data-model fusion system, and use this system to inverse the historical variation of terrestrial ecosystem production and to predict the future trends of ecosystem carbon budget under possible climate scenario.

Primary results of ChinaFLUX showed great variation in the carbon sequestration capacity among different ecosystems and different years. Long-term (5-10 years) measurement is particularly needed to accurately evaluate the function of CO_2

sink/source in most ecosystems. In addition, for the diverse vegetation types in China, there is large uncertainty in evaluating the ecosystem carbon budget on national scale only with data from current ChinaFLUX sites. Therefore, the emergent task is to extend the diversity of biomes and climate by adding more flux sites.

3.2 Future directions of ChinaFLUX

Terrestrial transect is a bridge to link site observation with regional research and a media of scale conversion between different spatial and time scales. IGBP start-ups 15 transects in 4 critical regions, including North East Chinese Transect (NECT) and North South Transect East Chinese (NSTEC). Influenced by the monsoon and the high elevation of Tibet Plateau, the grassland in China formed a natural transect driven by the change of water and heat conditions spatially (Chinese Grassland Transect, CGT) (Yu and Sun, 2006). EACEEFT (Euro-Asian Continental Eastern Edge Forests Transect) and EACGT (Euro-Asian Continental Grassland Transect) are both basic platform for international cooperation research on global change and terrestrial ecosystem on continental sale. NECT、NSTEC and CGT are important parts of EACEEFT and EACGT, and are also the core research region of ChinaFLUX. Combining flux observation and transect research is one of the main future directions of ChinaFLUX to understand the response and adaption of water, carbon and nitrogen cycles to global change, and discover the formative mechanism of the spatial pattern of terrestrial ecosystem structure, function and process.

Carbon, water and nitrogen cycles are coupled ecosystem processes. Most present carbon-water coupled models simplified the coupling relationship of carbon and water cycles and are difficult to exactly simulate the processes of ecosystem carbon and water cycles (Yu et al., 2004). Global change has increased ecosystem primary production. It also results in more effective nitrogen absortion by vegetation and fixation by soil organic matter, and eventually limiting ecosystem porduction (Luo et al., 2001). Long-term ecological effect of nitrogen deposition is still unkown (Norby and Cotrufo, 1998). ChinaFLUX has not carried out the integrated research on water-carbon-nitrogen cycles yet. However, it is a key issue to observe ecosystem water-carbon-nitrogen couping, explore the relationships between water, carbon and nitrogen cycles and the response and adaptation of terristrial ecosystem to global changes in critical regions of NSTEC, NECT and GCT.

As a main part of FLUXNET, ChinaFLUX will play an important role in assessing the carbon budget on Euro-Asian Continent and global ecosystems, in exploring the response and adaptation of terristrial ecosystem to global changes. In order to study terrestrial ecosystem carbon cycle, carbon budget and the interaction between carbon cycle and global change, ChinaFLUX should cooperate with not only the domestic organization of flux research, but also other national/regional fluxnet (e.g. AsiaFlux、KoFlux、AmeriFlux、CarboEurope、OzFlux).

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Preliminary Review on CO_2 Flux Observation and Research by China Meteorological Administration (CMA)

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Background and Strategy

China Meteorological Administration (CMA)'s interest in observing the atmospheric chemical composition mainly began in the early 1980's when acid rain emerged as a serious problem in many areas of China, particularly in the southwestern provinces. A series of acid deposition observation sites were set up by CMA in order to monitor acid pollutants and assess their impact on local environment. Later on, with the global environmental focus turned to the ever increasing concentration of greenhouse gases (GHGs) in the atmosphere, CMA was also actively involved in a number of international programs such as Global Atmosphere Watch (GAW) for monitoring GHGs. This led to the establishment in 1980s of 3 regional atmosphere background stations and in 1994 the Mt. Waliguan Station which is one of the 24 GAW global background stations and the only one on the interior Eurasia continent. Ever since then, observation of GHGs flux and research in carbon cycle has become one important mission of CMA.

Recently, CMA has been reshaping a new operation system and more efficient monitoring network. Monitoring and research on atmospheric chemical compositions has been separated as one of the eight major operation fields (tracks) within CMA. It is planed that besides the four background stations (Mt. Waliguan Station in Qinghai Province and three regional stations in Beijing, Heilongjiang and Zhejiang Province), another 3 regional background stations will be established in Xinjiang, Yunnan and Hubei Province. CMA would also set up GHGs background observation sites in typical ecosystems as a supplement to the background stations, currently there are at least five already in operation. CMA mainly aims at measuring all atmospheric chemical components in these stations and GHGs observation is of course the most important part. CMA's ultimate objective is to establish a network composed of 30 stations, including observation sites in 14 key monitoring zones. From August, 2003, organized by Chinese Academy of Meteorological Sciences (CAMS), a number of eddy-covariance systems have been setting up across the country in key ecological locations and this is the first CMA program specifically aimed at establishing carbon flux network. However, all the above mentioned background stations or observing sites could also be encompassed as the CMA flux components although formal guidelines or regulations on how CMA Flux will be operated are still evolving.

CMA Flux Network

According to preliminary statistics, there are at least 15 to maximum 22 Carbon flux observation sites in routine operation using eddy covariance systems within CMA (Fig.1). They could be roughly divided into three categories:

- 4 background stations directly invested and managed by CMA
- A number of flux observation sites (roughly 9 to 12) belonged to CMA subordinate research bodies, usually financed by the Ministry of Science and Technology
- Around 4-6 eddy-covariance systems set up with support from international cooperation programs, e.g. JICA, NOAA etc.

It must be noted that CAMS has proposed and pushed the CAM Flux program (under the leadership of Professor Bian Lingen) to set up eddy-covariance (EC) systems in different ecosystems and landscapes in China for a better understanding of surface flux and its response/feedback to climate change. It is actually these widely distributed EC systems that have made up the majority and framework of CMA flux. Currently with support from CMA provincial institute, CAMS has already established a network consisted of 7 EC sites. In the near future, 5 more EC systems will be set up. Altogether there will be around 14 EC systems in operation which cover a variety of ecosystems, landscapes and environment in China. In most cases, the EC equipment would installed in existing stations, therefore, except surface flux (H, LE, G, F_{CO2}), it is quite convenient to measure related meteorological and ecological variables simultaneously. These variables include LAI, soil temperature and wetness, radiation components, precipitation, gradients of wind, humidity and air temperature,

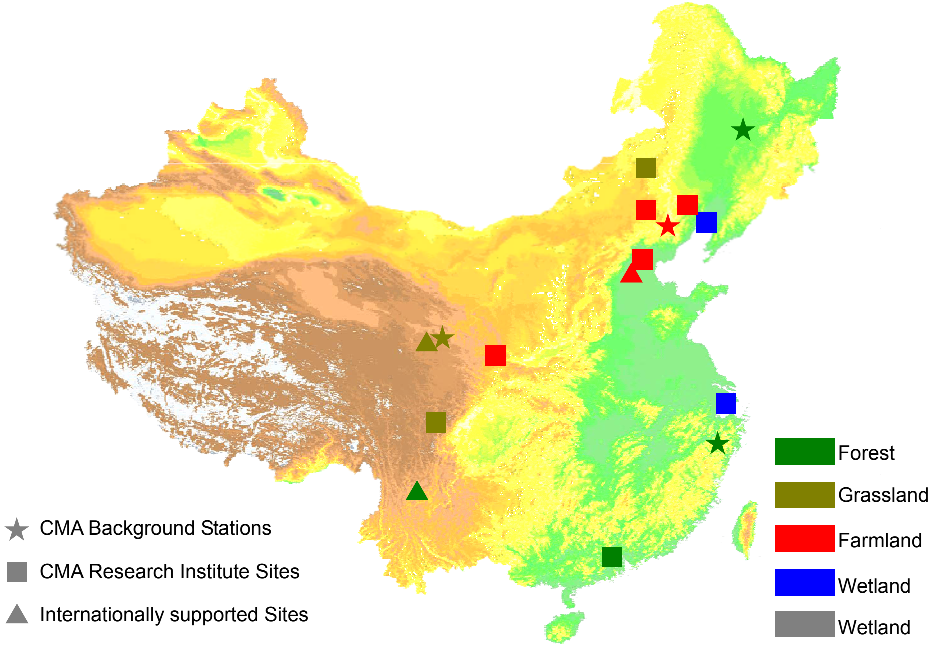

Fig. 1 CMA Flux Network (may not include all available sites)

etc. CAMS and its provincial partners are now developing flux data policies and guidelines so as to guarantee an efficient monitoring network and quality research within CMA. It is also intended to cooperate and integrate CMA flux with both domestic and international flux networks.

Many CMA provincial bureaus are also promoting their observation networks with particular focus on GHGs flux monitoring. All these CMA observation stations are located across the county and covered at least five typical ecosystems (Fig.1). Approximately, there are two sites in alpine grassland on the Tibetan Plateau, one in the Inner Mongolia grassland and one in tropic grassland. There are 2 sites in wetlands (the Liaohe River and the Yangtze River estuary), two or three sites located in forestry area (Longfengshan in Heilongjiang and Lin'an in Zhejiang Province), no less than three sites in the farmland (Shangdianzi in Beijing and Gucheng in Hebei Province).

Carbon cycle research by CMA

CMA has conducted research in carbon cycle promptly after its establishment of GAW stations with monitoring data available. However, since atmospheric chemistry is relatively a new area for CMA, it still needs time and effort to achieve significant research. CMA's subordinate research institutes, e.g. CAMS and other 8 research institutes at provincial level, are the major strength in carrying out research. Till now, they have been doing intensive job in the following areas:

- **Analysis on the background concentration of GHGs at the GAW background stations**

With the accumulation of sufficient observation data (1980s - now), the background concentration and temporal variation of CO_2, CO and CH_4 were studied. One significant finding is that the CO_2 concentration observed at Mt. Waliguan Station is on a steady rise over the last 10+ years, which corresponded quite well with the results observed elsewhere such as at Mauna Loa Station in Hawaii. But due to the inner continental environment of Waliguan, the seasonal variation is less than other sites. Research shows that data obtained at Waliguan is quite representative for the northern hemisphere, and hence the data has been widely used internationally.

- **CO_2 flux observation and modeling in farmland**

A number of observation and experiments were carried out in paddy field in southern provinces in order to explore the CO_2 flux and the sink/source characteristics in farmland ecosystems. One important finding is that Chinese paddy field served as a sink of CO_2 with a net deposition of about 41 $g\cdot m^{-2}\cdot d^{-2}$ in growing seasons (June to July).This is quite significant considering the vast paddy areas in China. Based on in situ observation, digital experiments were conducted to model the CO_2 flux of rice in different growing periods. The simulated results also confirmed the observed fact that Chinese paddy fields could be significant carbon sink although the deposition amount might be less than that observed in field.

- **Response of terrestrial ecosystems to concentration of CO_2 in atmosphere**

This is the area that CMA has done quite intensive studies on several special vegetation types in grassland, forest as well as individual plant species with regard to their response to the increasing concentration of atmospheric CO_2. Many research results have been published. For example, experiment has shown that the productivity of grassland composed of the *Aneurolepidium chinense* community could increase by 20% with enriched CO_2. Both in situ observation and modeling indicated that the *Dahurian Larch* forest in northeast China is a carbon sink but poor management may reduce its sink capabilities.

CMA research institutes also did a lot of other research on carbon cycling, such as on how to improve the observing techniques and data qualities to ensure more reliable measurement of flux.

Flux sites of the Institute of Plateau Meteorology (IPM)

From the early 2004, IPM has started to construct its first comprehensive station for atmospheric observation and experiment in Litang County, Sichuan Province on the eastern Tibetan Plateau. Till the October of 2005, the first phase of construction has completed and the station is in trial operation. An eddy covariance system (Campbell LI7500) is installed which measures CO_2 flux at a height of 2.2 m. The station is located on alpine grassland with quite flat topography (Fig.2).

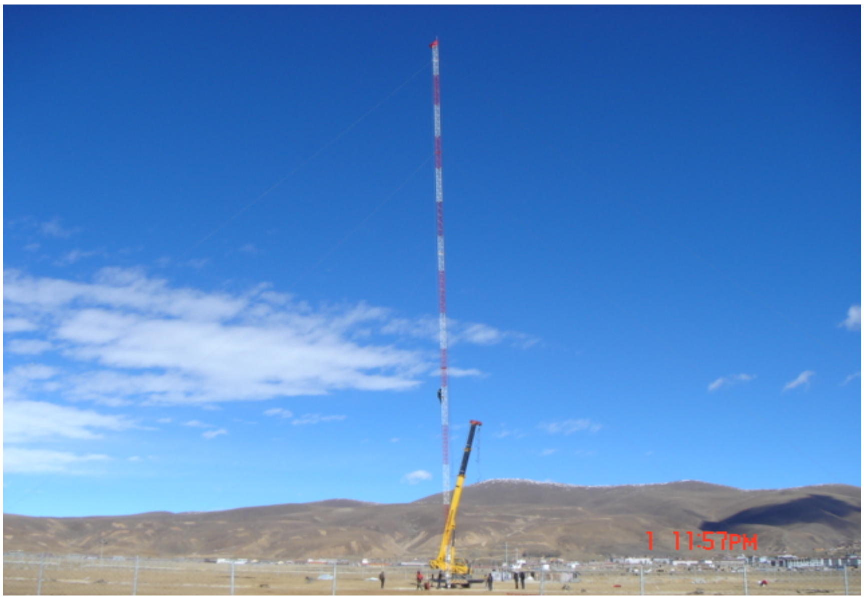

Fig. 2 Landscape of IPM Observation Station

Fig. 3 The wetland Landscape of the planed Flux Observation Station

Introduction to Study on CO_2 Flux in Laoshan Site, Northeast of China

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In China, forests are mostly distributed in northeast and southwest. The area of land covered by forests in China is 1.7491×10^9ha (statistic value in 2006). 18.21% of China mainland is covered by many kinds of forest. Plantation, 0.5365×10^9ha in area, is one of the most basilic components of China forest. Larch forest is considered to play a very important role on the global ecosystem carbon budget due to its huge distribution in the boreal forest of Eurasia. To evaluate the carbon sequestration ability of the large biome and the possible influence of environmental variables, we established a site in a Larch plantation of northeast China using closed-path eddy covariance technique, and conducted ecological and physiological research at the site. (Wang et al., 2005)

Introduction to the site:

Our flux site is in Laoshan Station, located in Maoershan Experimental Forest Farm of Northeast Forestry University, northwest of Zhangguancai Mountain which belongs to Changbaishan cordillera. Geographical coordinates of the research site is 45°20′N,127°34′E. Average elevation above sea level of the site is 340m (W.J. WANG et al., 2006). The typical temperate monsoon climate of China mainland dominates the whole area. The annual mean precipitation is about 700mm (but the statistic in this area from 2001 to 2004 shows less precipitation than before, about 650mm) and rainfall mainly occurs in growing season. The mean potential evapotranspiration is 1.094 mm, and the mean air relative humidity is 70%. The mean annual air temperature in the past years is about 2.8^{o}C (NEFU, 1984). From 2002 to 2004, the mean air temperature is 6.09℃, higher than before. Soil in the site is characterized by the typical dark brown forest soil, fertile and mesic. The depth of dark brown soil is about 40cm, while soil becomes less brown with increasing depth from 40 to 110cm where rock substrate is often observed. The amount of soil organic matter varied among

Fig1. Flux tower, larch (*Larix gmelinii*) plantation and soil profile in Laoshan site

forest types and generally is 4%-12.4% at 5-10cm depth. Soil pH is about 6.0. In winter, surface soil (0-15cm under the surface) stays frozen for about 5 months. Deep soil (deeper than 15cm) never freezes even in winter (Wang et al. 2005a).

Of all plantations in Maoershan experimental forest farm, *Larix gmelinii* is the most popular tree in afforestration, and its volume and area are 69.6% and 66.3%. Larch plantation is mainly distributed in the slope from 0-15degree, and over 70% of these plantations are in the slope less than 10 degree. The site is just located on a slope of about 5-6 degrees with south aspect, and about 200m from a mountain of about 500 m elevation on the northern edge. A low hill covered with broad-leaved deciduous forest lies on the western part of it. The larch plantation in our study site was 3300 ha^{-1} and afforested in 1969 (Shi, 2001).

About fifty-five species including arbor, shrub and herb belonging to 30 families, are observed in the station. In arbor layer, *Larix gmelinii*, *Franxinus mandshurica* and *Betula platyphylla* are the dominant canopy species. The mean canopy height is about 17 m, and the height of *Larix gmelinii* is approximately 18m and the DBH is 17.2±4.5cm. Some shrub tree species, such as *Acer mono, Pinus koraiensis, Quercus mongolica, Ulmus japonica, Euonymus pauciflorus, Aralia elata, Syringa reticulata* var. *mandshurica, Acanthopanax senticosus, Acer ginnala, Sorbus alnifolia, Franxinus rynchophlla, Rhamnus yoshinoi, Corylus heterophylla* and *Phellodendron amurense* are observed in the forest floor. Many grass species also grow well on the forest floor through vegetative period, especially in early spring. The grass species include *Adenocaulon adhaerescens*, *Agrimonia obtusifolia*, *Chelidonium majus*, *Polygonatum humile*, *Cacalia hastata*, *Filipendula palmata*, *Convalaria keiskei*, *Ploygonatum involucratum*, *Rubia chinensis*, *Brachybotrys paridiformis*, *Carex* spp. etc. (Shi *et al.*, 2001)

Study in the site

For clarifying the function of larch plantation in the global warming processes, a flux tower with eddy covariance method was built in our study site in 2002 (Wang *et al.*, 2002). The tower equipped with a closed-path eddy covariance system was used to measure the sensible heat, latent heat, H_2O and CO_2 fluxes over the larch plantation. It includes the equipments mentioned thereinafter. Wind velocity and virtual temperature were measured using a three-dimensional ultrasonic anemometer (SAT-550, KAIJO, Japan), which was installed at 29 m above ground (about 10 m above the canopy layer). Concentrations of CO_2 and H_2O were measured with a closed-path CO_2/H_2O infrared gas analyzer (IRGA, LI-7000, LICOR, USA) set in a temperature-controlled box at the top of the tower (20 m high). Air samples were automatically drawn using a diaphragm pump at the rate about 6.5 L min^{-1} from the air inlet, which was installed at the almost same height with but 40 cm apart from the anemometer; and the air was led to the IRGA via a Dekabon tube of about 11 m in length and 4 mm in inner diameter. To prevent condensation of air sample in cold and humid condition, a linear heater was fixed to the whole air sampling tube. The IRGA was operated in differential mode with a CO_2 and H_2O free N_2 gas flowing through the reference cell. The gain of CO_2 and H_2O of the analyzer was automatically checked once a day by flowing two standards CO_2 gases of 320 ppmv and 420 ppmv. The raw data of the three components of wind velocity and virtual temperature from the ultrasonic anemometer and vapor and CO_2 concentrations from IRGA were sampled in 10 Hz and temporally stored in a data logger (CR 23X, CSI, USA), and finally automatically transferred to an online computer every 3 hours.

The incident and reflected long- and short-wave radiations were measured using a net radiometer (MR-40, EKO, Japan) installed on the tower at 21 m above ground; the incident and reflected photosynthetic active radiations (PARs) were measured using PAR-02 sensors (PREDE, Japan) at the same height. The PAR transmitted through the canopy was measured in the forest floor at 1 m above the ground at 3 locations around the tower. Air temperature and relative humidity were measured at 14 m (within the canopy) and 21 m (above the canopy) with ventilated thermometers and hygrometers (HMP45D, VAISALA, Finland). Precipitation was measured using a rain gauge (YG-52202, YOUNG, USA) installed on the top of the tower at about 22 m above ground. Variation of air pressure was measured using a

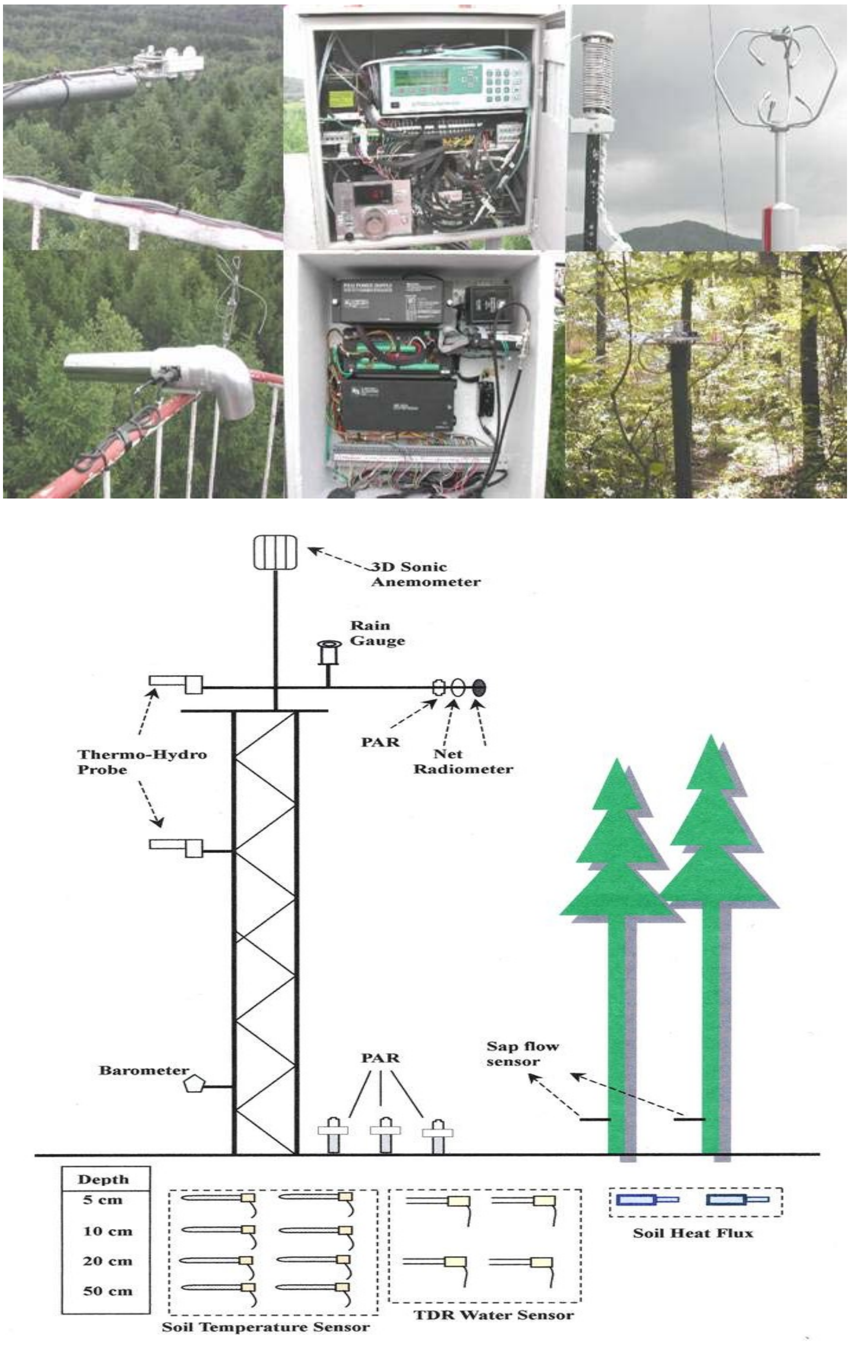

Fig 2 Meteorological and flux measurements at the site.

barometer (PTB101B, VAISALA, Finland) at 3 m above ground. Soil temperatures at depths of 5cm, 10cm, 20cm and 50 cm were measured using C-PTG-30 (Climatec, Japan). Soil water contents at depths of 5 and 20 cm were determined using time-domain reflectometry (TDR) sensors (CS-615, CSI, USA). Variations of Soil heat flux at a depth of 5 cm were detected using soil heat flux sensors (MF-81, EKO, Japan). The equipments mentioned above secure long-term data of environmental conditions and the flux of matter and energy.

Simultaneously, validation measurement by ecophysiological method and biomass assay method were also carried out (Wang, 2001b). As a part of the ecophysiological study in this site, works were carried out from 2001 to 2006 such as photosynthesis and respiration measurements (LI6400,LICOR, USA) of leaf and cone, respiratory consumption from stem, root, litter, and branch and soil microbe. (Wang et al., 2006; Wang, 2005)

To understand the effect of forest-clear-cut on soil respiration, a plot that was clear-cut ~ 10 years ago with vegetation similar to larch plantation (about 1.5 ha and 100m far from the larch plantation) was selected to compare with the larch plantation. Several species, such as larch, birch, ash, Korean pine and Scots pine which could be found in the canopy or near the larch plantation are also compared with the larch plantation. Their ages were quite similar (30-40 years old) with the larch in the site. Therefore, an inter-species comparison on stem respiration, soil respiration (LI6400, LICOR, USA & Portable Automatic Soil CO_2 Efflux System, Liang Naishen, Japan) and its components were also carried out in this study(Wang et al, 2003)

Results we have got

Larch forest is an important and typical component of representative natural ecosystems in northeast China, and is regarded as important carbon sink in moderating global carbon balance. In the Daxingan Mountains region, northeast China, the aboveground biomass and primary productivity of these forests decreased with increasing latitude, along with different climatic zones. Namely, in the same age group, aboveground biomass and primary productivity were generally higher than those in the southern climatic zone (85.37ton ha^{-1} for young forests), while they were generally lower in northern climatic zone (41.81 ton ha^{-1} for young forests and 55.6 ton ha^{-1} for middle age forests). Within the same vegetation type, higher density and primary productivity were observed in young and middle age forests (less than 50 to 100-year-old), while relatively lower values were observed in mature forests (Wang et al., 2005). In the Laoshan station, from intra-and inter-species comparison, considerable variation of allometric relations was found among different association of *L. gmelinii* forest and different larch species. This variation may be habitat dependent, but not species specific. Both at the level of stand and ecosystem, biomass accumulation and productivity were affected by tree age and management and habitat environment. Moreover, shrubs and grasses make a proportionally higher contribution to the productivity of ecosystem. In a regional scale, NPP of larch forests increases with latitude. In addition, carbon allocation to root increases as latitude increases. Productivity of *L. gmelinii* forest in northeast China was similar or even higher than other larch forests, other kinds of forests both in China and in boreal and temperate forest regions around world. By investigating the CO_2 flux of larch forest ecosystems, the carbon uptake rate was greatly influenced by the VPD and tends to decrease with increasing VPD when the VPD exceeded 15hpa. The light-use efficiency was considerably higher on cloudy days than on

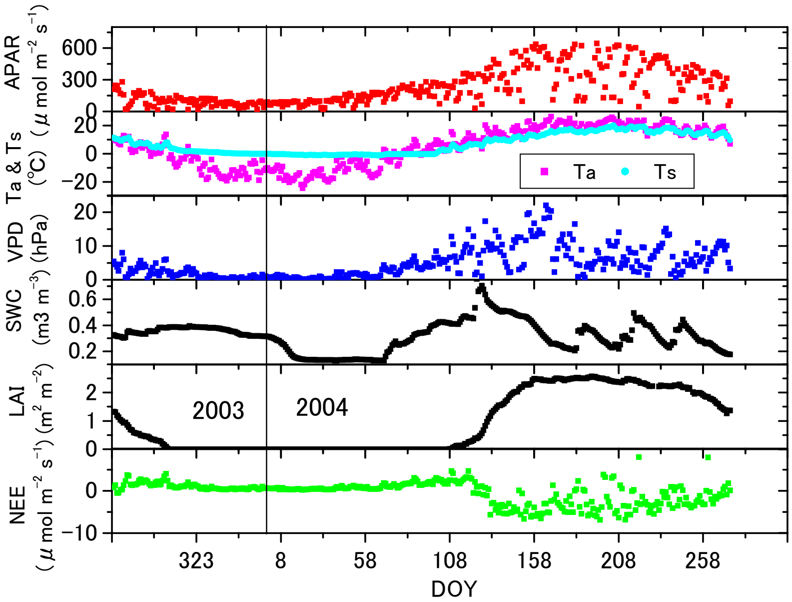

Fig 3.Seasonal variation of C flux

clear days. However, the temperature effect on photosynthesis was found to be minimal at this site.

NEE of the larch ecosystem varied seasonally, acting as a carbon source in dormant season and a carbon sink in growing season. The larch forest ecosystem at Laoshan was a carbon sink, which assimilated 120 to 190 gC/yr. The initial light use efficiency in June was the highest, but the potential maximum GEP was lower than in July and August. Respiration mainly determined by air temperature. GEP varied with APAR following a saturation model. High VPD (>10 hPa) reduced the GEP linearly. Higher temperature showed no influence to GEP but Lower temperature (<10hPa) decreased GEP. June was the most important month for carbon uptake (>90%). This might be ascribed to high light use efficiency and sufficient radiation, but the high VPD tended to lower the GEP (Wang, 2004).

On the other hand, we evaluated the carbon sequestration ability of the large biome and the possible influence of environmental variables using closed-path eddy covariance technique. The net ecosystem exchange of the larch ecosystem at the Laoshan station varied seasonally. The larch ecosystem acted as a carbon source in dormant season from October 2003 to April 2004, but converted to a carbon sink in growing season. Annually, it was a carbon sink during the year from October 2003 to September 2004, and assimilated 121 g C m^{-2} yr^{-1} ($u^*>0.20$ ms^{-1}) to 190 gC $m^{-2}yr^{-1}$ ($u^*>0$ ms^{-1}) (Wang et al., 2005). Of which, June was the most important month for carbon assimilation, i.e., carbon uptake during this period constituted 93% of the annual accumulated amount. The ecosystem respiration was mainly controlled by temperature, and the photosynthetic activity was determined by radiation in general. However, the photosynthetic process of the larch ecosystem was also largely influenced by vapor pressure deficit (VPD) and temperature. We found that 10 hPa was the threshold between humid and dry environment for the larch ecosystem. Under humid condition (VPD<10 hPa), the gross ecosystem production (GEP) increased with increasing temperature, but the net ecosystem production (NEP) showed almost no change with increasing temperature because the increment of GEP was counterbalanced by that of the ecosystem respiration. Under dry environment condition (VPD>10 hPa), GEP was strongly affected by VPD and decreased with the increasing VPD at a rate of 0.30 μmol m^{-2} s^{-1} hPa^{-1}, and the ecosystem respiration was also enhanced simultaneously due to the increase in air temperature, which was linearly correlated with VPD. As a result, the net ecosystem carbon sequestration was greatly reduced with the increasing VPD at a rate of 0.52 μmol m^{-2} s^{-1} hPa^{-1}. We also found that a moderate air temperature zone (from about 10 to 25 °C) was the optimum condition for net carbon sequestration of the larch ecosystem (Wang et al., 2003).

Soil respiration was measured in four forest stands (larch, Korean pine, Scotch pine and birch) by trenching - box in Laoshan Station. The result showed that the highest proportion of total soil respiration was microbial respiration (above 60%) , the second one was root respiration (20%～30%), and the lowest was litter respiration (10%). The variation of soil respiration under different treatments was exponentially correlated with soil temperature. There was no obvious correlation between respiration and soil moisture.

Larch cone scales are green, but little is known of their photosynthetic role in cone development or how they differ in gas exchange characteristics from needle leaves. Respiration and photosynthetic rates were maximal in young cones. During cone development, R_{cone} decreased progressively from a maximum value of about 21.9 μmol m^{-2} s^{-1} to around 0.3 $\mu molm^{-2}$ s^{-1} in late August. Correspondingly, P_{cone} decreased gradually from 7.8 μmol m^{-2} s^{-1} to zero. Normalized per unit fresh mass and per unit cone surface area, changes in R_{cone} and P_{cone} during maturation showed broadly similar trends. P_{cone} was positively correlated with the total chlorophyll concentration in cone scales ($r^2 > 0.82$, $P < 0.001$), whereas there was no correlation between foliar chlorophyll concentration and P_{leaf} ($r^2 = 0.02$, $P > 0.1$). A good correlation was observed between P_{cone} and soluble sugar concentration in cone scales ($r^2 = 0.85$, $P < 0.001$), but there was no significant correlation between starch concentration and P_{cone} ($r^2 = 0.07$, $P > 0.1$). However, both soluble sugar and starch concentrations in leaves were positively correlated with P_{leaf} ($r^2 > 0.22$, $P < 0.01$).

Nitrogen concentration in cone scales and in leaves was positively correlated with the corresponding photosynthetic rate. A positive correlation was observed between stomatal density and P_{cone} ($r^2 = 0.91$, $P < 0.001$), but no correlation was found between g_s and P_{cone}. The C_i–P_{cone} relationship was statistically significant, whereas no such relationship was found in leaves. The water status of cone scales significantly influenced P_{cone} ($r^2 = 0.51$, $P < 0.01$), whereas leaf water content did not affect leaf photosynthesis ($r^2 = 0.07$,$P > 0.1$). Chlorophyll concentration was higher in needles than in cone scales, both per unit surface area and per unit fresh mass. The Chl a/b ratio was 18% lower in cones than in leaves ($P < 0.05$). Soluble sugar concentration in cone scales was only 70% of that in leaves; there was a similar trend in starch concentration. Nitrogen concentration was significantly lower in cone scales than in needles. Dark respiration rates were higher in cones than in leaves, but only young cones had higher photosynthetic rates than leaves. Photosynthetic rate per unit chlorophyll was, on average, 1.60 times higher in leaves than in cones. Similarly, P_{leaf} /N was more than 30 times higher than P_{cone} /N. The ratios R_{cone}/N and R_{leaf}/N were broadly similar for cones and leaves. Stomatal density was about three times higher on leaves than on scales of young cones, and much higher than on scales of mature cones. The value of C_i (400–1000 μmol mol^{-1}) was about three times higher in cone scales than in leaves (about 220 μmol mol^{-1}), and was also higher than atmospheric [CO_2] (about 360 μmol mol^{-1}).(Wang et al., 2006)

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Eddy Covariance (EC) Flux Research in Institute of Botany, Chinese Academy of Sciences

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Introduction

The continuously increasing concentrations of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that are mainly resulted from human activities, have greatly influenced the inherent carbon and water cycling of terrestrial ecosystem and resulted in distinct global environmental changes. The long-term and continuous measurements of carbon and water exchange between biosphere and atmosphere are necessary for understanding environmental controlling mechanisms over carbon and water cycling of terrestrial ecosystem, evaluating the capability of carbon sequestration and illustrating spatio-temporal patterns of carbon sink/source of terrestrial ecosystems (IPCC, 2001; Yu et al., 2005). Eddy covariance sites measuring carbon and energy fluxes provide a unique contribution to the study on the environmental, biological and climatological controls of net surface exchange between vegetation and the atmosphere (Baldocchi et al., 2001; Wilson et al., 2002). At present, these equipments and technologies are being widely used to study carbon and water flux of terrestrial ecosystems in the world.

Eddy covariance (EC) sites:

Up to now, 9 EC flux towers had been set up by Institute of Botany, Chinese Academy of Sciences (CAS) since 2003. They are widely distributed in typical grasslands, cropland, desert steppe, sandland, boreal forest and Populus artificial forest in North China. These sites are important part of US-China Carbon Confederation (USCCC) launched in 2003. The detailed information is as follows:

Typical Grasslands

Four EC flux towers were set up in typical grasslands in Inner Mongolia to monitor effect of different human disturbance on carbon and water flux of typical grassland ecosystems.

(1) Degraded *Leymus chinensis* steppe site: Its location is 43°32′45″N, 116°40′40″E. Elevation is 1250m. Biome/Vegetation is typical steppes dominated by *Leymus chinensis*, *Stipa grandis* and *Artemisia frigida* etc. This site is a grazing steppe.

(2) *Stipa grandis* steppe site: Its location is 43°32′45″N, 116°40′40″E and its elevation is 1250m. Biome/Vegetation is typical steppes dominated by *Stipa grandis* and *Artemisia frigida* etc. This site has been fenced since 1980 from free grazing steppe.

(3) *Stipa krylovii* steppe site: One was set up in Xilinguole, Inner Mongolia. Its location is 44°08′03″N, 116°19′43″E and its elevation is 1100m. Biome/vegetation is typical steppes dominated by *Stipa krylovii* and *Leymus chinensis* etc. This site has been fenced since 1997 from free grazing steppe.

Another one was set up in Duolun, Inner Mongolia. There is an ecotone of cropland and pasture. Its location is 42°32′03″N, 116°13′36″E and its elevation is 1350m. Biome/Vegetation is dominated by *Stipa krylovii*, *Artemisia frigida*, etc. This site has been fenced since 2001 from free grazing steppe.

Cropland

One EC flux tower was set up to monitor the exchange of CO_2, H_2O flux between agricultural ecosystem and atmosphere. This site is located in 42°32′03″N, 116°13′36″E, its elevation is 1350m. It is very near to *Stipa krylovii* steppe site located in Duolun, and the distance between two towers is less than 1km. Biome/Vegetation is *Triticum aestivum* plantation. This site was reclaimed about 35 years ago.

Desert steppe and Sandland

Two EC flux towers were set up near the Ordus Sandland Ecological Station for examination of the difference in carbon and water flux between desert steppe and sandland. Its location is about 39°29'N, 118°11'E, its elevation is about 1200-1350m. Biome/Vegetation is *Artemisia ordosica, Caragana intermidia, Salix psymophild*,etc in desert steppe.

Boreal forest

One EC flux tower was set up in Huzhong,Heilongjiang province to monitor carbon and water exchange between soil, vegetation and atmosphere of boreal forest ecosystem. Its location is 51°35.50'N, 123°12.81'E. Its altitude is 698m. Biome/vegetation is *Larix gmelinii, Betula costata etc.* This site is a secondary coniferous forest.

Populus artificial forest

One EC flux tower was set up in Kubuqi desert, Inner Mogolia to understand the effect of sandland conversion to artificial forest on carbon and water exchange between soil, vegetation and atmosphere. It is located 40°32′18″N, 108°41′37″E. Biome/Vegetation is Populus and liquorice (*Glycyrhiza uralensis*). This site was sandy dune before planting Populus forest at 2001.

Research Objectives

The research objectives of flux research is to facilitate a better understanding of the environmental factors influencing the rate and magnitude of carbon sequestration and water cycling across a range of ecosystems and climatic gradients with the use of mutually agreed upon measurement protocols and equipment, and through a collaborated network of data sharing and analysis.

Advance in flux research

At present, a mass of valid data have been obtained and accumulated from these eddy covariance sites. The multi-disciplinary, multi-scale research approaches have been employed in these flux sites to monitor the basic elements in soil-vegetation-atmosphere continuum and the key processes of carbon and water cycles in different ecosystems, which provided valid datasets and experimental platform for integrated research on ecosystems carbon and water cycle.

A set of EC data disposal software for EC data rectification and interpolation have been developed by "Global Change and Terrestrial Ecosystems" Research Group, Institute of Botany, CAS. Based on flux data from *Stipa krylovii* steppe stations in Xilinguole, Inner mongolia since 2003, the flux traits of typical steppe ecosystems were analyzed. Two models were developed to estimate fluxes of terrestrial ecosystems: variational technique based on micrometeorological gradient observation and process-based dynamic Chinese terrestrial ecosystem model (DCTEM). Variational technique used full information provided by the boundary layer observation, the surface energy budget, and the Monin-Obukhov similarity theory. DCTEM includes four submodels: Land surface process model, vegetation phenology model, carbon allocation model, carbon balance model and soil biogeochemical model. Those two models could describe the flux dynamics of terrestrial ecosystems very well.

Up to now, 9 EC sites have been set up by Institute of Botany covering many terrestrial ecosystems in North China. They provided a good platform to understand the spatio-temporal patterns of carbon sink/source in terrestrial ecosystems, compare the contribution of different ecosystem to Chinese carbon and water cycle, and elucidate the responses of carbon and water flux to environmental change and human activities in different ecosystems.

Acknowledgements

This work is supported by National Natural Science Foundation of China (No. 30300049) and Chinese Academy of Sciences (KSCX2-SW-133). The authors thank Dr. Shiping Chen and Dr. Steve McNulty. Some information about EC sites came from their reports downloaded from http://usccc.ibcas.ac.cn/meetings/IBCAS050630/IBCAS050630.htm.

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Stipa krylovii **steppe in Xilinguole**

Stipa krylovii **steppe in Duolun**

Leymus chinensis **steppe in Xilinguole**

Cropland in Duolun

Boreal forest in Huzhong

Populus artificial forest in Kubuqi

Overview of Chinese Forest Ecosystem Research Network and Carbon Flux Measurements

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About CFERN

The Chinese Forest Ecosystem Research Network (CFERN), which is a long term ecological research network covering a broad spatial scale and is composed of forest, desert and wetland ecosystems distributed in different geographical regions, is directly managed by the State Forestry Administration (SFA), PR.China. There are 15 forest ecological research stations in CFERN which represent diverse ecosystems and research emphases (Fig.1).

The objectives of CFERN

The objectives of CFERN are as following:

- Promoting multi-disciplinary and integrated research and enhancing cooperation and communication among the network members;
- Carrying out long-term terrestrial ecosystem monitoring and research activities;
- Collaborating and sharing data and information between the network members in order to increase the efficiency of research and the understanding of forest ecosystems.

The mission of the CFERN

The overall mission of the CFERN is to study structure and function of forest ecosystems in China. It includes:

- Understanding ecological processes and forest ecosystem dynamic over extended temporal and spatial scales;
- Creating database of forest resource, ecological environment, water resource on a given area or state level;
- Establishing assessment and monitoring system of forest ecological effects in core sites;
- Identifying and providing solution for ecological problems;
- Setting up dynamic monitoring network and warning system of forest ecological environments;
- Monitoring the long-term response of forest ecosystems to the most relevant stress factors by analyzing data from a network of selected study sites,

The core research areas of CRERN

- Impacts of forest vegetation on water resource and eco-hydrological process;
- Forest carbon storage and carbon cycle;
- Climate change and forest ecosystem;

Site describtion of major stations in CFERN

Genhe Station

The research station is in the north-west hillside of The Great Xinganlin Mountains (N50°49'-50°51', E121°30'- 121°31'). Vegetation is dominantly boreal forest with *Larix gmelinii.*

Maoershan Station

Maoershan & Liangshui Station was founded in 1974 by Northeast Forestry University (NEFU) and located in Maoershan and Liangshui, respectively (127°30′-127°34′E, 45°20′-45°25′N).The typical vegetation in Liangshui is primitive Korean Pine forest . Maoershan has different types of secondary and artificial forests with different disturbances.

Taiyueshan Station

The Station was set up in 1991 and managed by Beijing forestry university (BJFU). It is located in Lingkong mountain forestry center of Taiyue forestry management bureau, Shanxi province (N36°33', E112°03'). Forests are dominantly *Pinus tabulaeformis, Larix principis-rupprechtii* ,*Quercus liaotungesis*, *Populus davidiana*, *Betula platyphylla* etc.

Qinling station

The Station was set up in 1980 and managed by Northwest Agriculture & Forestry University (NWAFU). It is located in the middle of Qinling mountains, Shanxi province (N33°18'-33°28' , E108°20'-108°39'). Forests are dominantly *Pinus armandii.*

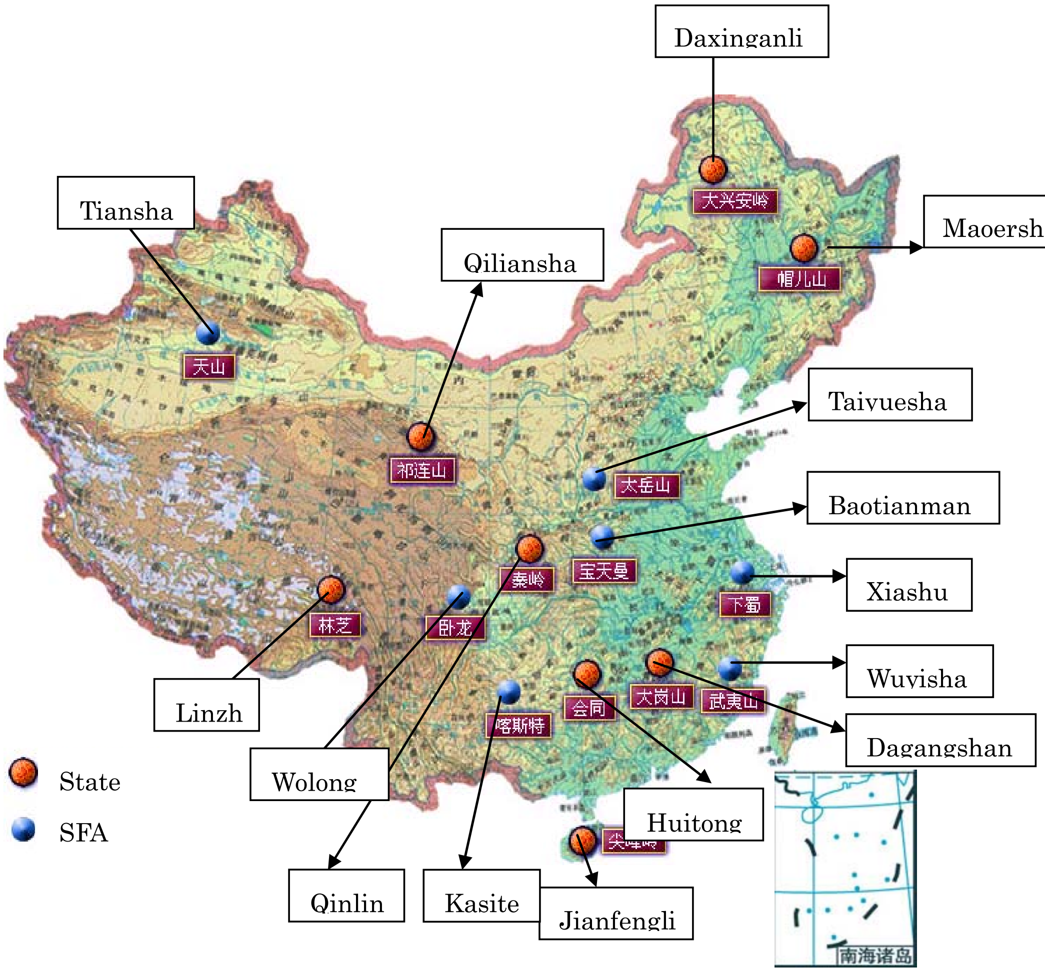

Fig.1 Distribution of 15 forest ecological research stations affiliated to CFERN in China

Baotianman station

The Station was set up in 2002 and managed by Chinese Academy of Forestry (CAF). It is located at Baotianman natural reserve, Henan province (N33°25'-33°33', E111°53'-112'). Forests are dominanted with broad-leaved species such as *Quercus aliena* var. *acute*, *Toxicodendron verniciflnum*, *Tilia tuan*, *Carpinus cordata*, etc.

Xiashu Station

The site was set up by Nanjing Forestry University in 1986 and is a unique long term ecological research site for urban forest in China (31°59’N, 119°14’E). The dominant community is mixed deciduous trees such as *Platycarya strobilacea*, *Liquidambar formosana*, *Pistacia chinensis*.

Dagangshan Station

It is located in Fenyi, Jiangxi province and managed by the Chinese Academy of Forestry (CAF) (114.30~114.45E, 27.30~27.50N). Main vegetations are evergreen coniferous forest, evergreen broad-leaved forest, deciduous broad-leaved forest, mingled forest, bamboo and so on.

Wuyishan Station

It is located at Wuyishan State Natural Reserve, Fujian (117°27'-117°51'E, 27°33'-27°44'). Vegetations are subtropical ever green broad-leaved forest that is typical and representative type in the same latitude of the globe.

Huitong Station

It was established in 1979 and located in Huitong, Hunan province (N26°50', E109°45'). The vegetation is dominantly artificial Chinese fir forest.

Jianfengling Station

It is located at southwest Hainan Island (18°36'~52'N in latitude and 108°50'~109°05'E) and managed by CAF. The various vegetation types are distributed in this region along altitudinal gradient, such as semi-deciduous monsoon forest, evergreen monsoon forest, gully rain forest, mountain rain forest and mossy forest.

Qilianshan Station
The station is located in Gansu province (E 100°17’, N38°24'). *Picea crassifolia* is distributed in the north and semi-north slopes, dry-grassland and some shrubs are in the south or semi-south slopes.

Wolong Station
It is located at Wolong State Natural Reserve, Sichuan (102°52′-103°24′E, 30°45′-31°25N). Forest is mainly sub-alpine dark coniferous forest, whose representative species are *Abies faxoniana*, *A. fabri*, *Picea brachytyla*, etc.

Linzhi Station
The station is located at Linzhi County, Tibet. (29°351-29°571N, 94°251-94°451E). Vegetation type is subalpine forest, whose representative species are *Picea likiangensis* Var. *linzhiensis* and *Abies georgei* Var *smithii.*

Kasite Station
It is located at Guiyang, Guizhou province(N26°53'-27°03', E106°51'-107°07'). The zonal forest vegetation is sub-tropical moist evergreen broad-leaved forest with non-zonal karst evergreen broad-leaved forest.

Research site with carbon flux measurement

Station with EC measurement equipment

Station Name	Open-path	Closed-path	Profile	Vegetation type	Orgnization
Dagangshan	√	√	√	Subtropical evergreen forest	CAF
Jianfengling	√	√	√	Monsoon forest	CAF
Maoershan	√	√	√	Secondary broad-leaved forest	NEFU

Other research site with EC measurement equipment

Research site	Open-path	Closed-path	Profile	Vegetation type	Orgnization
Laoshan, Heilongjiang	√	√	√	Larch plantation	NEFU
Daxing, Beijing	√	√	√	Popular plantation	BJFU
Anqing, Anhui	√	√	√	Wetland popular plantation	CAF
Yueyang Hunan	√	√	√	Wetland popular plantation	CAF

Carbon flux equipment in Dagangshan

Meteorological observation tower in Jianfengling

Meteorological equipment in Dagangshan

Carbon flux equipment in Jianfengling

Carbon flux measurements in Dagangshan and Jianfengling stations

Main publications

Because all carbon flux equipments mentioned above are just installed on sites, their measurements are mostly under calibration process. There are several other sites in preparation for carbon flux measurement. Thus, it will take 2 or 3 years to complete the whole carbon flux network under the designation of CFERN. A few of carbon flux results has been published while most available publications in relation to carbon cycle focused on forest soil carbon process.

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AsiaFlux Newsletter Special Issue
January 2007

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Editor's Note

I would like to express my gratitude for the participants and staffs of TC 2006. This special issue was made possible by their dedicated effort.

The editor of
AsiaFlux Newsletter Special Issue:
Dongho LEE
(Yonsei University, Korea)