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Contents

Report on the AsiaFlux Workshop 2007

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The AsiaFlux Workshop 2007: International Workshop on Advanced Flux Network and Flux Evaluation was held at Aspire Park, Taoyuan, Taiwan from 19 – 22 October. This workshop was organized by AsiaFlux and National Donghwa University (NDHU), Taiwan with funding supports from Ministry of Education, Culture, Sports, Science and Technology, Japan. Supports also were given from the National Environmental Studies (NIES) and Forestry and Forest Products Research Institute (FFPRI), Japan. Within Taiwan, Society of Subtropical Ecology and three instrument companies provided support and vital funding for the workshop. With a well prepared logistics, the spirit at the workshop was very warm. There were more than 130 participants from 10 countries including: China (34), France (1), France-Thailand (1), India (1), Italy (2), Japan (33), Korea (10), Malaysia (2), Taiwan (47), and US (2). Six oral sessions and 49 posters were presented. Two separate post conference field trips were arranged: 1) NDHU's Chilan Mountain (CLM) site at northern-eastern Taiwan (39 attendants) and 2) Mt. Peitungyen forest (guided by Ben-Jen Tsuang) and Lienhuachi flux stations (guided by Ming-Hsu Li) at middle part of Taiwan (27 attendants). All flux sites are located at the mountain area and the steep grade and winding mountain road gave all participants a good memory of the rough terrain of mountain area in Taiwan**.**

The workshop started with a warm welcome address given by Hen-Biau King (director of Taiwan Forestry Research Institute, chairperson of the Subtropical Ecology Society and ex-chair of the International Long Term Ecology Research Network, ILTER). During the opening session Yoshikazu Ohtani, chair of AsiaFlux, gave a summary of AsiaFlux activities as well as presented the next new project, CarboEastAsia. The next 3 speakers (Ben-Jei Tsuang, Tripathi Sandeep, and Elizabeth Philip presented development of flux projects or related activities in Taiwan, India, and Malaysia, together they presented the awareness of the importance of flux measurement in relation to the climate change impact in Asia countries. Riccardo Valentini, CarboEurope PI, presented a brief introduction of some synthesis results from CarboEurope and FLUXNET demonstrated the importance of an integrated approach of flux monitoring programs.

The next session with a subtitle of “measurement, methodology, technical development” started with Chun-Ta Lai represented the AmeriFlux gave a presentation of using carbon isotope ratio measurements to identify CO_2 sources such that biotic and anthropogenic sources can be distinguished and short-term changes in photosynthetic gas exchange activity can also be verified. Cheng-I Hsieh reported result from flux measurement of a paddy rice field in Taiwan and pointed out that more energy is used for evapotranspiration for rice crop and difference between the two crop seasons is significant. Tanvir Demetriades-Shah presented measurement of soil respiration and indicated that soil respiration measurement with chamber is sensitive to ambient CO_2 concentration such that continuous monitoring of soil respiration is necessary. The second session was closed with presentation of Yves Brunet from France. He offered a numerical model to deal with problems of complex terrain for flux estimation. The modeling result can be used to aid result interpretation and error quantification.

A special session entitle of “fluxes and biogeochemical cycles under the humid climate in Asia” was leading with a keynote presentation by Dongho Lee. The three strategic phases for the development of KoFlux was described and followed with the establishment of the Gwangneung supersite where cross-scale and multi-disciplinary studies have been taken. The development of a supersite offers an example for other Asian countries and regions where funding of many flux towers are difficult to secure. In term of the mountain forest site in most Asian countries, topographic heterogeneity always posts problems for carbon flux modeling, Makoto Tani suggested the rich findings of Japanese forest hydrological studies which heterogeneous terrain were always considered are very valuable. Yue-Joe Hsia gave a presentation of flux measurement of a cloud forest in Taiwan where the open path eddy covariance system was hampered by heavy fog all year round. With a steep slope site, diurnal up slope and down slope wind pattern also rise the uncertainty of flux estimation with significant advection at the site. The session closed with the presentation of Yuji Kominami. The Yamashiro experimental forest site is a temperate secondary broad-leaved forest is marked with spatial heterogeneity in addition to the steep slope terrain. Different approaches of estimation of NEE using two eddy covariance towers, chamber and long term biometric measurements were compared to give an estimation of u* threshold values was suggested. The study indicated the importance of concurrent measurements of carbon budget in a complex site condition.

There were three sessions for the morning of second day. Topics included flux estimation from remote sensing, measurement of soil CO_2 efflux, photosynthesis, methane flux, to modeling. Cheng-Chien Liu (Cheng-Kung Univ., Taiwan) presented his study using the newly launched Formasat-2 satellite imagery to estimate of crop yield. Automatic rotating radiometer was deployed to calibrate the ground reflectance of those imageries. Sinkyu Kang (Kangwon National Univ., Korea) used a GIS based ecohydrological model to scale up small watershed fluxes to regional scale based on high-resolution satellite images from Landsat. In terms of other green house gases, Ken Hamotani from Japan presented the measurement of methane flux over a larch forest using the relaxed eddy accumulation method to overcome the slower response of CH_4 gas analyzer. A well designed automated soil respiration chamber system was presented by Liang Naishen from NIES, Japan. The system has been tested and deployed at 14 flux sites from Pasoh, Malaysia to Laoshan, China. He also called to form an East Asia Chamber network under AsiaFlux. A total of four oral presentations were given from young colleagues from the ChinaFLUX. Fenghua Zhao uses water use efficiency (WUE) to show the coupled relationship between carbon and water at the winter wheat crop field in North China Plain. Qing-Hai Song presented their study of the tropical seasonal rain forest at Xishuangbanna where photosynthesis activities were related with fog presence. Hui Huang gave her result in using model based on Jarvis-type model with two functions (supply and demand) to simulate half-hour CO_2 and H_2O fluxes. The model was tested successfully with flux measurement during growth season from the Changbai Mt. flux tower site. Zhou Yanlian explored the variations of surface roughness length (z_o) over three distinct vegetation cover types, (Changbai Mt., flat terrain and temperate mixed forest, Qianyanzhou, rolling hills coniferous plantation, and Yucheng, flat crop field). She demonstrated the Zo varied with wind, LAI, and stability. Assumption of a constant surface roughness length would lead to significant errors in Surface Energy Balance System model (SEBS) especially over heterogeneous forest sites. For other flux measurement sites in China, Guangsheng Zhao introduced flux sites including steppe at Inner Mongolia, maze field at NE China, wetland at the Liaohe river delta, and boreal forest. Processes based model (TEDM, Terrestrial Ecosystem Dynamic Model) to estimate the NEE of several different ecosystems.

The last oral presentation session was arranged to extend the flux studies to larger scale focus on data sharing and synthesis. From the global perspective, Dario Papale presented an effort of assembling a dataset (932 site years from 246 sites, which include 19 Asian sites), these dataset will use centralized data processing steps, quality control, gap-filling, etc. and examples of possible results coming out from such a standardized dataset were also briefly discussed. At the end Papale also called upon our Asian colleagues to submit dataset and proposals to join the synthesis efforts. Ryuichi Hirata also from NIES, Japan, indicated the ecosystem gross primary production and respiration are regulated by annual mean air temperature from 13 forest flux sites in East Asia region since there are no sever stress to limit the GPP and RE. The effects of land use changes were presented by Xiaosong Zhao from the Institute of Atmospheric Physics, Chinese Academy of Sciences. Analysis of three different land uses (marshland, rice, and soybean crop) in NE China was presented. In general, irrigated rice crop had highest LE whereas LE of upland soybean crop was lowest. The results indicated water supply was the main controlling factor for the heat budget of these three different land cover types. Takashi Hirano from the Hokkaido Univ., Japan gave a presentation on CO_2 flux at three disturbed peatlands in Indonesia including swamp forest at undrained and drained peatland and a cutover area. All of them had positive CO_2 flues and functioned as source of the CO_2 and disturbances, such as drainage, deforestation and fires, increased NEE from tropical peatland. The session was closed with a presentation gave by Chau-Chin Lin from the Taiwan Forestry Research Institute. Lin suggested using an EML (Ecological Metadata Language) structured metadata database to facilitated data sharing among diverse ecological data. The system provided a platform such that data sharing and synthesis could be achieved using a Kepler workflow system. A preliminary case study demonstrated an alternative way to data sharing for flux measurement.

The workshop closed with a general discussion focused on “data sharing, integration analysis, and standardization of flux measurements” chaired by Joon Kim. The launching of “CarboEastAsia: A3 Foresight Program” was announced in Kim’s remark. During the session, Hirano Takashi gave a brief presentation on the works of the data base sub-working group. The web site of AsiaFlux DataBase have been established on 8th of Feb, 2007 The dataset included site information PDF files and half-hour flux data files in text (CSV) format. Submission of additional data sets was also called for the next research phase. AsiaFlux’s effort on standardization of EC measurements was also presented. A portable closed path system was proposed to check measurements among all Japanese flux sites. Attentions also called for difference of measurement among the open and closed EC systems. Papale again suggested the scheme of a standard data format and processing adopted by the European networks for AsiaFlux. The succession had many comments on data sharing which showed the awareness of data sharing among Asian colleagues. It is expected that the data sharing policy among Asian region will be discussed in depth with the forth coming A3 project.

During the last night of the workshop, in addition to the tightly arranged business meetings (MEXT project Expert Meeting, AsiaFlux Steering Meeting, and A3 Project Meeting), a Young Scientists Meeting was held concurrently, and the atmosphere of the young scientists was so hot such that several of the young scientists missed the field trip next morning.

In order to have enough time to be displayed for the large amount of poster presentations, the posters were displayed from the noon of first day through the second day. The long displaying time prompted many in depth discussions especially among many young scientists. Through personal discussion, not only scientific idea exchanged but also friendships were flying high.

Acknowledgement

The local organizer of AsiaFlux Workshop 2007 would to express to their thanks to all person involved in preparing and arranging the workshop. Because of their hard and enthusiastic working made the success of this workshop possible. Field trip arrangement of Ben-Jei Tsuang, National Chung-Hsing Univ. and Ming-Hsu Li, National Central University are also deeply appreciated. Special thanks also give to the sponsorship of Jauntering International Corporation, Environmental Science & Eng'n Corp, Taiwan, and Vaisala Oyj, Finland.

Message from the former chair of AsiaFlux

Yoshikazu OHTANI

Forestry and Forest Products Research Institute, Japan

Three years have already passed since I took over the role of chair of AsiaFlux Steering Committee from Prof. Yamamoto in October 2004. During this three-year period, we have been working to enrich our activities with supports from two individual projects. This is not the first time that I introduce the two projects, but I shall herewith mention those again and emphasize that Prof. Yamamoto and AsiaFlux Executive Committee members had prepared really well to obtain the supports.

1) "Initiation of the next generation AsiaFlux" by Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT)

2) "Standardization and Systematization of Carbon-Budget Observation in Asian Terrestrial Ecosystems Based on AsiaFlux Framework" by the Asia-Pacific Network for Global Change Research (APN)

After our project proposals have been adopted, we have restructured AsiaFlux framework and started the new activities, as shown in Table 1, led by newly situated workgroups which were corresponding to MEXT assignments. We have held workshop and training course regularly, launched AsiaFlux database, and renewed overall contents of our website. We have also increased efforts to collect site information from participants and those valuable metadata have been published on the AsiaFlux website as well as the quarterly newsletter which we release continuously. We have also contributed global FLUXNET community by providing data for the synthesis activities. Asian original synthetic activities has also begun and their first outcome will be published in the special issue of Agricultural and Forest Meteorology which will contain papers presented in the AsiaFlux workshop 2006 held in Thailand.

On another front, it was wonderful to see our capacity building activities such as training course and to gain a visible fruit as establishment of ThaiFlux, which is followed by several more new local networks. We witnessed that the new research structure was introduced to Bangladesh paddy field and a number of observation sites in China and Taiwan were increased rapidly. New observation is planed to start soon in India. We are also expecting some new movements among young researchers who are forming Youth AsiaFlux. This fresh international association will surely bring many active discussions on solving problems and

Table 1. Summary of the AsiaFlux Activities

August 24-26, 2005	AsiaFlux Workshop 2005, Fujiyoshida, Japan (4th Workshop)
November 29-December 1, 2006	AsiaFlux Workshop 2006, Chiang Mai, Thailand (5th Workshop)
October 19-22, 2007	AsiaFlux Workshop 2007, Taoyuan, Taiwan (6th Workshop)
August 21-30, 2006	1st AsiaFlux Training Course on Micrometeorology, Tsukuba, Japan
July 17-26, 2007	2nd AsiaFlux Training Course on Micrometeorology, Seoul, Korea
February 1, 2007	Renewal of AsiaFlux website
February 8, 2007	Establishment of the AsiaFluxDB
January 2008	Establishment of Youth AsiaFlux

collaborating study.

I am confident to announce that our recent activities have strengthened the tie of AsiaFlux organization and individual local community and we have now a solid grounding for a good fellowship of individual researchers. On the other hand, continuous information exchange and data sharing are still essential to our understanding of energy balance and carbon budget of Asian terrestrial ecosystem. We still have a lot of unsolved issues such as flux evaluation in nighttime or in complex topography, accuracy improvement of the flux calculation and scale-up issue which cannot be solved without collaborating with researchers in other fields such as ecological study, modeling, and remote sensing. As Prof. Yamamoto has also pointed out, we have to keep up with the competition in the international networks such as FLUXNET, iLEAPS and LTER. It's my sincere wish that Asian community is going to produce as many fruits as possible to contribute to the formation of international consensus of this science.

In 2007, our new project “CarboEastAsia” was started. It is officially know as “CarboEastAsia: Capacity building among ChinaFLUX, JapanFlux and KoFlux to cope with climate change protocols by synthesizing measurement, theory and modeling in quantifying and understanding of carbon fluxes and storages in East Asia” and the period is from FY2007 to from FY2011. It is often called as A3 foresight program since it is among China, Korea and Japan, and supported by National Natural Science Foundation of China (NSFC), Korea Science and Engineering Foundation (KOSEF) and Japan Society for the Promotion of Science (JSPS). There is no doubt that this new project is going lend more promotion in AsiaFlux’s scientific program. I hope every participant in AsiaFlux will combine their wisdom for further achievement under the leadership of new AsiaFlux chairman, Prof. Kim Joon.

Lastly, I would like to sincerely thank everyone who have spent vast amount of efforts to make AsiaFlux activities possible during my tenure, especially to Workgroup members, AsiaFlux Steering Committee members, Executive Committee members and secretariat members.

Observation and simulation on water, heat and carbon fluxes over grassland ecosystems in China

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1 Introduction

Terrestrial ecosystems affect climate through exchanges of energy, water, momentum, CO_2, trace gases, and mineral aerosols. Changes in community composition and ecosystem structure alter the fluxes and in doing so alter climate. Grasslands are one of the most widespread ecosystem types worldwide; they cover ca. 25% of the natural land surface, account for ca. 16% (18.9 Gt yr^{-1}) of the global annual net primary productivity (NPP) (Tieszen & Detling, 1983), store at least 10% of global carbon stocks (FAO, 1995; Eswaran *et al.*, 1993) and constitute an important component of the global carbon cycle (Parton *et al.*, 1995; Prentice *et al.*, 2001). Temperate grasslands, mostly distributed in America, Europe, and Asia, are sensitive to global climate change (Knapp *et al.*, 2002) and make a large contribution to global biogeochemical cycles (Sala, 2001). It is predicted that global climate changes would significantly affect temperate grassland ecosystems, including their productivity, composition, and carbon exchange. This is because rainfall and seasonality would be altered and evapotranspiration would increase as a consequence of possible changes in temperature and water availability under doubled atmospheric CO_2 equilibrium conditions (Watson *et al.*, 1998). These changes in grassland ecosystems would affect surface temperatures through boundary changes in vegetation cover and its biogeochemical cycling, especially carbon cycling, by affecting NPP and soil organic carbon (SOC). These changes may have a feedback effect on climate change.

China has a large area of grasslands, covering about 40% of China's territory. Grasslands include mainly temperate grasslands (steppes) in northern China and subalpine and alpine grasslands on the Tibetan Plateau and in the high mountains of western China (Chen and Fischer, 1998; Zhou *et al.*, 2002; Wang *et al.*, 2007). Primary vegetation types in these areas are extensions of the central Asian steppes. Given their vast area, China's grasslands are likely to play an important role in Asian and global carbon cycling and associated climate effects. Therefore, it is necessary and important to understand and improve estimates of water, heat and carbon fluxes over grassland ecosystems in China.

Over the past decades, many research studies used eddy covariance techniques to quantify the flux dynamics of grasslands (Barcza *et al.*, 2003; Flanagan *et al.*, 2002; Hunt *et al.*, 2004; Kato *et al.*, 2004; Kim *et al.*, 1992; Suyker and Verma, 2001; Suyker *et al.*, 2003; Verhoef *et al.*, 1996; Verma *et al.*, 1989; Zhao *et al.*, 2006). Some results indicated that grassland ecosystems in temperate regions play an important role in terrestrial carbon cycles (Novick *et al.*, 2004). Flanagan *et al.* (2002) reported that northern temperate grasslands accumulated 111.9 g C m^{-2} in wet years and lost 18 g C m^{-2} in dry years. A similar relationship between annual net ecosystem carbon exchange (NEE) and annual precipitation was also observed on water-driven grasslands, such as managed rangelands in Hungary (Barcza *et al.*, 2003), annual grassland in California (Xu and Baldocchi, 2004), tall grass prairie in Oklahoma (Suyker *et al.*, 2003) and tussock grassland in New Zealand (Hunt *et al.*, 2004). Research on grassland NEE has mainly focused on humid or semi-humid areas with annual precipitation higher than 300 mm, while semi-arid grasslands such as steppe grasslands in northern Asia, especially in China have received much less attention. One study has shown that grazed *S. krylovii* steppe in Mongolia is a small carbon sink in wet years (Li *et al.*, 2005), but the broader response of steppe ecosystems to varying conditions over time is still unknown. Consequently, a long term study is required to determine the adaptation and vulnerability of steppe grasslands to future climate change.

In this paper, we present diurnal and seasonal variations of NEE as well as their interannual variation of NEE in *S. krylovii* steppe during three years of extreme drought based on eddy covariance techniques for three consecutive years in a semi-arid *S. krylovii* steppe ecosystem in northern China, and propose a modified IBIS model from the effects of soil nutrients on photosynthesis and the carbon allocation, in order to understand and improve estimates of water, heat and carbon fluxes over grassland ecosystems in China.

2 Data and method

2.1 Eddy covariance observation

Fluxes and environmental factors were measured at Inner Mongolia Typical Grassland Ecosystem Field Observation Station since August 2003. The research site is approximately 24 km northeast of Xilinhot city (N 44°08′03″, E 116°19′43″, 1030 m), Inner Mongolia Autonomous Region, P. R. China. It is under the administration of the Institute of Atmospheric Environment, China Meteorological Administration (CMA), Shenyang.

This site is typical of short-grass steppe in northern China. The plant community is dominated by the cool-season C3 grasses *Stipa krylovii* and *Leymus chinensis*, which produce 80% above ground biomass. Other species include *Koeleria cristata, Carex duriuscula, Artmisia frigada, Aluum mongolicum, Cleistogenes squarrosa,* and *salsola collina*. Average canopy height is 35 ± 5 cm (mean ± SD). The grassland has not been grazed since 1996 and there is a substantial amount of dead plant material (litter) on the ground surface.

The region is described as a semi-arid, continent climate with low temperature and limited precipitation. The mean annual temperature and precipitation from 1970 to 2000 were about 2°C and 290mm, respectively. Monthly mean temperature ranged from -17.8°C in January to 21.3°C in July. The winter is extremely cold and dry, while weather from May to September is known to have clear days, high temperatures and at least 80% of the annual precipitation. Precipitation had quite high interannual variability. Only 8 years in the past 35 years had an annual precipitation higher than the long-term average. Drought events were recorded in 11years of the past 35 years, with annual precipitation less than 200mm, usually accompanied by higher-than-average annual temperatures. These hot and dry periods affected the ecological functions of *S. krylovii* steppe, reducing the carbon flux rate and threatening ecosystem health.

The soil type in the region is classified as chestnut soil. The surface horizon (top 10cm) has an average bulk density of 1.20g cm^{-3} and total organic matter content of the soil over a depth of 30cm without roots was 2.5%-4% (Li and Chen, 1999). About 80% of belowground biomass distributes at the depth of 30cm. Lime accumulated below the depth of 40cm.

Carbon dioxide, water and sensible heat fluxes have been measured at the site since August 2003 using eddy covariance techniques. The open-path flux instruments were mounted on top of a mast with the sensor head 2m above the ground and oriented in the prevalent wind direction (southwest). A three-dimensional ultrasonic anemometer (CSAT3, Campbell Scientific, Logan, UT) was used to measure wind speed, wind direction and air temperature. The CO_2 and H_2O concentrations were measured by an open-path fast response infrared gas analyzer (LI-7500, LI-COR, Inc., Lincoln, Nebraska, USA). The LI-7500 head was tilted 15ºS and situated 20cm horizontally from the CSAT3 head to prevent contamination from heat flux and to be convenient for maintenance. The IRGA was calibrated at regular intervals (every three months) for CO_2 and water vapor using a dew point generator (LI-COR 610, LI-COR, Inc., Lincoln, Nebraska, USA). Raw data were logged at 10Hz with a CR5000 data logger (CR5000, Campbell Scientific, Logan, UT, USA). Fluxes were calculated as the product of the mean covariance of vertical wind speed fluctuation and the scalar fluctuation of interest with an average time on a 30min constant. The coordinate rotation and WPL correction (Webb *et al.*, 1980) were applied to mean half-hourly fluxes of NEE. The fetch of the sensor located at the height of 2m was more than 200m in all directions.

A weather station was also established at the site, 30m from the eddy covariance tower. Photosynthetic active radiation (PAR) and net radiation (Rn) were observed at the height of 3m above the ground using a quantum sensor (LI190SB, LI-COR Inc., Lincoln, Nebraska, USA) and a four-component net radiometer (CNR-1, Kipp & Zonen, Netherlands). Air temperature (Ta) and relative humidity (RH) were measured at two height levels (2m and 4m; HMP45C, Vaisala Inc., Helsinki, Finland), and horizontal wind speeds were measured at the same height (Model A100R, Vector Instrument, North Wales, UK). Soil temperatures (Ts, 107-L, Campbell Scientific, Ltd, USA) and soil water content (SWC, CS615, Campbell Scientific Ltd, USA) were monitored adjacent to the meteorological tower. Soil temperature (Ts) was measured at six depths (0.05, 0.1, 0.15, 0.2, 0.4 and 0.8 m). Soil water content (SWC) was measured at four depths (0.1, 0.2, 0.3, 0.4m). Two soil heat flux transducers (HFT-3, Radiation and Energy Balance Systems, Seattle, Washington, USA) were placed about 5cm below soil surface in two separate locations, 3m away from the meteorological tower. Soil bulk density of $1.2 gcm^{-3}$ and a dry-soil heat capacity of 840 $Jkg^{-1}K^{-1}$ were used with half- hourly measurements of Ts and SWC to calculate soil heat storage (S). Soil heat flux (G) was estimated as the sum of soil heat flux measured at sensor depth (6cm) and the energy stored (S) in the soil above the sensor. Total precipitation was measured with a tipping bucket rain gauge (52203, RM Young Inc., Traverse City, MI, USA). All the meteorological data were recorded using a CR23X data logger (CR23XTD, Campbell Scientific Ltd, Edmonton, Alberta, Canada), and this data was combined by half-hour intervals for analysis. Precipitation data in the form of snow during the winter (from October 1 to April 30) came from the Xilinhot weather station.

Half hour flux data were rejected for any of the following conditions: (1) the half-hour measurement was incomplete, (2) precipitation occurred during that half-hour, (3) turbulence was low and air was poorly mixed, (4) anomalous values were recorded for either three dimensional wind velocities or scalars. In total, approximately 30%-40% of ecosystem fluxes were eliminated by these screening criteria. The quality of the data was evaluated by the degree of energy closure (Rn - G versus LE + H), which was > 85% each year.

Several strategies were introduced to compensate for the missing data. Interpolated values were used to fill gaps that were not longer than 2h. For larger gaps, NEE data was divided into daytime ($NEE_{day,}$ PAR > $10 \mu molm^{-2}s^{-1}$) and nighttime (NEE_{night}) periods to develop non-linear regressions for evaluating environmental effects on NEE and filling missing half-hour gaps. Light response curves were established by further dividing daytime data into half-month bins and then fitting the relationship between NEE_{day} and PAR to a Michaelis-Menten function (Falge *et al.*, 2001). To eliminate this possible uncertainty under stable nighttime conditions, the exponential function between soil temperature (5cm) and nighttime data at high turbulence ($u^* > 0.15 ms^{-1}$) was established by further dividing nighttime data into five soil moisture classes.

2.2 Modified IBIS model

A wide variety of numerical models have emerged in the last decade in an attempt to elucidate global biogeophysical processes related to energy and water. The integrated biopshere simulator (IBIS) of Foley *et al.* (1996) is designed to simulate such processes. It is designed to integrate a variety of terrestrial ecosystem phenomena within a single, physically consistent model that can be directly incorporated within atmospheric general circulation models (AGCMs). To facilitate this integration, the model is designed around a hierarchical, modular structure and uses a common state description throughout. IBIS consists of four modules operating at different time steps: (1) land surface module simulating the surface energy, water, carbon dioxide, and momentum balance at a relatively short time step (between 10 and 60 min), (2) vegetation phenology module describing the winter-deciduous and drought-deciduous behavior of specific plant types in relation to seasonal climatic conditions at a daily time step, (3) carbon balance module summing gross photosynthesis, maintenance respiration, and growth respiration to yield the annual carbon balance for each plant functional type, (4) vegetation dynamics module simulating time-dependent changes in vegetation cover resulting from changes in net primary productivity, carbon allocation, biomass growth, mortality, and biomass turnover for each plant functional type at an yearly time step. However, the accuracy of flux estimations from IBIS is restricted due to the constants of maximum capacity of Ribisco to perform the carboxylase function and carbon allocation. In order to describe the effects of soil carbon and nitrogen on leaf photosynthesis, the maximum rate of carboxylation V_{cmax} can be calculated from eqn. (1) based on a biochemical processes developed by woodward *et al.*(1995):

$$V_{cmax} = \frac{(A+R_d)[P_c + K_c \bullet (1+P_o/K_o)]}{P_c - 0.5P_o/\tau} \quad (1)$$

where internal CO_2 partial pressure Pc is equal to 70% of its atmospheric partial pressure Pa=35Pa, and A=Amax, i.e., the maximum light-saturated rate of photosynthesis in any leaf layer to nitrogen uptake.

$$A_{max} = \frac{190 \bullet N}{360 + N} \quad (2)$$

where N is the rate of leaf nitrogen uptake in any leaf layer of the canopy in proportion to the mean irradiance of the leaves:

$$N = N_T \bullet \frac{I}{I_0} \quad (3)$$

where N_T is the rate of total nitrogen uptake, I_0 is the incident irradiance on the canopy, I is the mean irradiance beneath a leaf area index (LAI), and be calculated by Beer's law:

$$I = I_0 e^{-kLAI} \quad (4)$$

where k is an extinction coefficient, a typical value is 0.5.

The dependence of nitrogen uptake on soil carbon and nitrogen is modified to include temperature-dependence based on uptake kinetics, derived from experimental systems operated at a range of temperatures. The response is based around the concept of the activation energy required for a process. Temperature-dependent nitrogen uptake is:

$$N_T = \frac{e^{u_1 - \frac{u_3}{0.00831T_k}}}{1 + e^{\frac{u_2 T_k - 205.9}{0.00831T_k}}} \bullet k_T(T) \quad (5)$$

$$u_1 = 40.8 + 0.01 \bullet (T_r - 273.16) - 0.002(T_r - 273.16)^2 \quad (6)$$

$$u_2 = 0.738 - 0.002(T_r - 273.16) \quad (7)$$

$$u_3 = 97.412 - 2.504\ln(N_p) \quad (8)$$

A response function $K_T(T)$ accounts for soil carbon that does not influence nitrogen uptake because of freezing. When soil carbon Sc is greater than 13000g/m^2 and temperature is less than 15^{o}C, $K_T(T)$ could be estimated by following equations:

$$K_T(T) = \{1 + (15 - T)/30\} \bullet (1 + S_C - \frac{13000}{10000}),$$
$$S_c > 13000g/m^2 \text{ and } T < 15^oC$$
$$K_T(T) = 1,$$
$$S_c \leq 13000g/m^2 \text{ or } T \geq 15^oC \quad (9)$$

Thus, Vcmax for a temperature of 25^{o}C can be estimated by equations from (1) to (9). A response function Kv(T) describes the effects of temperature on maximum carboxylation rate:

$$V_{cmax}(T) = V_{cmax} \bullet K_V(T) \quad (10)$$

$$K_V(T) = 1 + 0.051(T-25) - 2.48\times10^{-4}(T-25)^2 - 8.09\times10^{-5}(T-25)^3 \quad (11)$$

where T is air temperature. Again, a response function describes the effect of leaf temperature on light-saturated electron transport:

$$J_{max}(T) = (29.1 + 1.64V_{cmax}) \bullet K_J(T) \quad (12)$$

where $J_{max}(T)$ is the light-saturated rate of electron transport, and $K_J(T)$ can be expressed as:

$$K_J(T) = 1 + 0.041(T-25) - 1.54\times10^{-3}(T-25)^2 - 9.42\times10^{-5}(T-25)^3 \quad (13)$$

For a given availability of light (L), water (W), and nitrogen (N), the allocation of carbon to roots (r), stem (s), and leaves (l) is modified from the allocation scheme for global terrestrial carbon models given by Friedlingstein (1999):

$$\rho = 3r_0 \frac{L}{L + 2\min(W,N)} \quad (14)$$

$$\sigma = 3s_0 \frac{\min(W,N)}{2L + \min(W,N)} \quad (15)$$

$$\lambda = 1 - (\sigma + \rho) \quad (16)$$

where r_0 and s_0 are the fractional carbon allocation to root and stem for non-limiting conditions, respectively. Both r_0 and s_0 are set to 0.3, giving a leaf allocation of 0.4 under conditions where resources are totally non-limiting. Resource availabilities (L, W, N) are scalars ranging from 0.1 (severely limited) to 1 (readily available). Min (W, N) is the minimum value of the two scalars W and N. We use the canopy leaf area index (LAI) to estimate L:

$$L = e^{-k \times LAI} \tag{17}$$

where k is an extinction coefficient, a typical value is 0.5. The water availability, W, is determined from a soil water budget:

$$W = \frac{SW_m - WP}{FC - WP} \tag{18}$$

where SW_m is the calculated soil moisture, WP and FC are wilting point and field capacity, respectively. The latter two are functions of soil type. Nitrogen availability, N, can be expressed as the rate of leaf nitrogen uptake in any leaf layer of the canopy.

In order to validate the performance of modified IBIS, long term observation data of aboveground biomass in meadow steppe from Grassland Research Station of Northeast Normal University (1981-1990), typical steppe from Inner Mongolia Grassland Ecosystem Research Station, the Chinese Academy of Sciences (CAS) (1981-1994), and alpine meadow steppe from Haibei Research Station of Alpine Meadow Ecosystem, CAS (1981-1994), as well as flux observation from Inner Mongolia Typical Grassland Ecosystem Field Observation Station from August 2004 to December 2005.

3 Results

3.1 Dynamic patterns in net ecosystem carbon dioxide exchange

Net ecosystem carbon exchange (NEE) is defined as the sum of ecosystem respiration (TER) and gross ecosystem productivity (GEP) and is a key component of the global terrestrial ecosystem carbon cycle. Fig. 1 illustrated daily NEE pattern and its environmental control, all data from three consecutive sunny days were binned to reduce the sampling error. One was from DOY 251-253 in 2004 when LAI was $0.96 m^2m^{-2}$, one from DOY 155-157 in 2005 with LAI of $0.74m^2m^{-2}$, and the last from DOY 194-196 in 2006 with LAI of $1.0\ m^2m^{-2}$. The asymmetrical pattern of NEE was observed in the peak growing periods of 2005 and 2006, while a symmetrical pattern was found in the peak growing period of 2004. The magnitude of NEE varied substantially between years, $NEE_{\text{daytime max}}$ for three peak growing periods, -5.7, -2.3 and -5.5μmol$m^{-2}s^{-1}$, respectively, was mostly determined by the difference of LAI, but the other characteristics of the daily NEE pattern was a result of combined interactions of photosynthetic active radiation (PAR), volumetric soil water content (SWC), temperature (Ta) and vapor pressure deficit (VPD). On days when SWC was higher, carbon uptake by the canopy was stronger and more sustained around noon; whereas days with lower SWC showed an asymmetrical NEE, with most carbon uptake occurring in the morning, and less in the afternoon. Night-time NEE was much smaller in magnitude and was driven mainly by temperature and soil water content.

To determine the seasonal change of carbon flux, we integrated daily measurements of NEE and separation of GEP and TER. The maximum values of daily NEE, GEP and TER were near -2.1g C m^{-2} d^{-1}, -4g C m^{-2} d^{-1} and 3g C m^{-2} d^{-1} in summer time (Fig. 2a,b). Fluxes in winter were consistently smaller than those in summer, with losses typically between 0.1 and 0.3 g C m^{-2} d^{-1}.

In all three years, warm temperatures stimulated growth of the grasses, but the availability of soil water in summer time controlled the development of LAI. NEE and GEP peaked shortly after LAI peaked, and then carbon flux levels fell as soil moisture decreased. The increase in daily GEP during the autumn of 2004 was greater than TER after the heavy rainfall on August, so peaked daily NEE was higher and occurred later in 2004 than in both 2005 and 2006(Fig. 2). Due to the high SWC, and monthly precipitation in May of 2005, the ecosystem started assimilating carbon around the middle of May, and the peak value of daily NEE and GEP occurred in middle of June. Daily NEE crossed the line into positive in early July and the ecosystem became a carbon source from July to September of 2005. During this period, GEP and TER decreased at about the same rate; with these two components of NEE following similar trends, NEE kept a relatively constant magnitude of about 0.5 g C m^{-2} day^{-1} from July to September 2005. While each in the years of 2004 and 2005 had only one single carbon capturing period, two periods were observed in 2006. The first one happened in July with higher daily carbon flux patterns

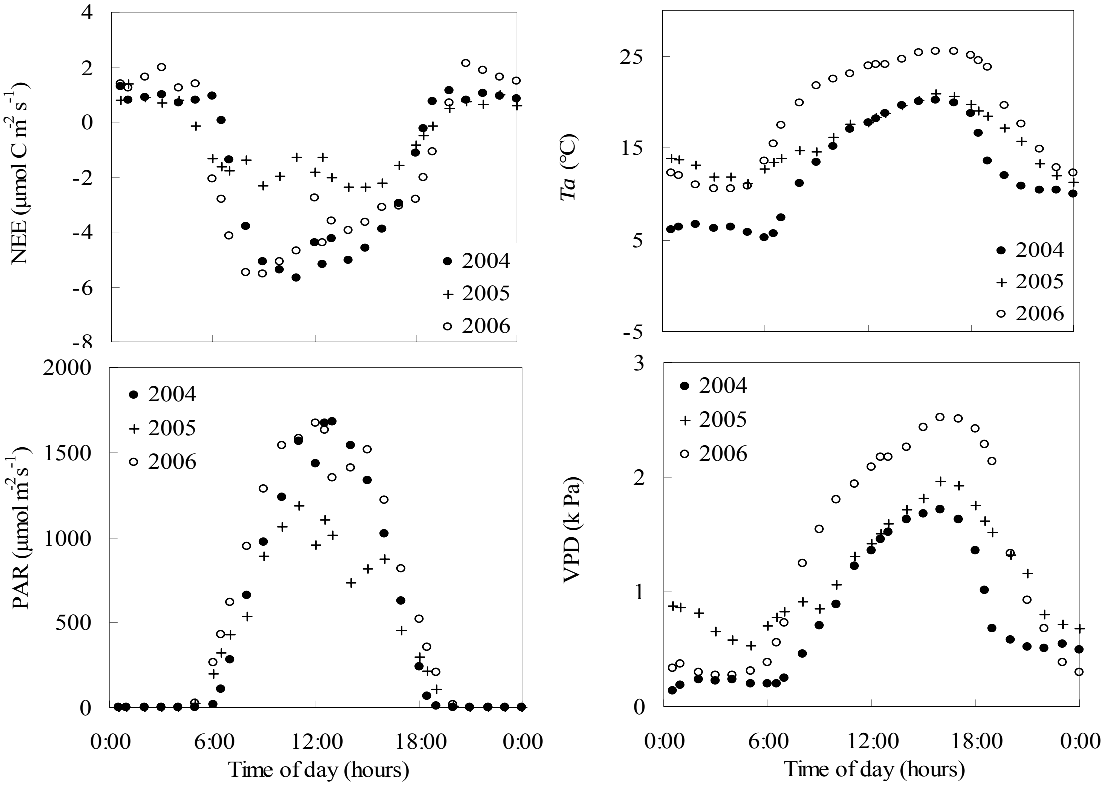

Fig. 1 Mean NEE diurnal patterns during the peak active periods over a northern temperate steppe in 2004, 2005 and 2006. The environmental conditions apparent at the same time are also shown. Values represent the mean±SD, n=7

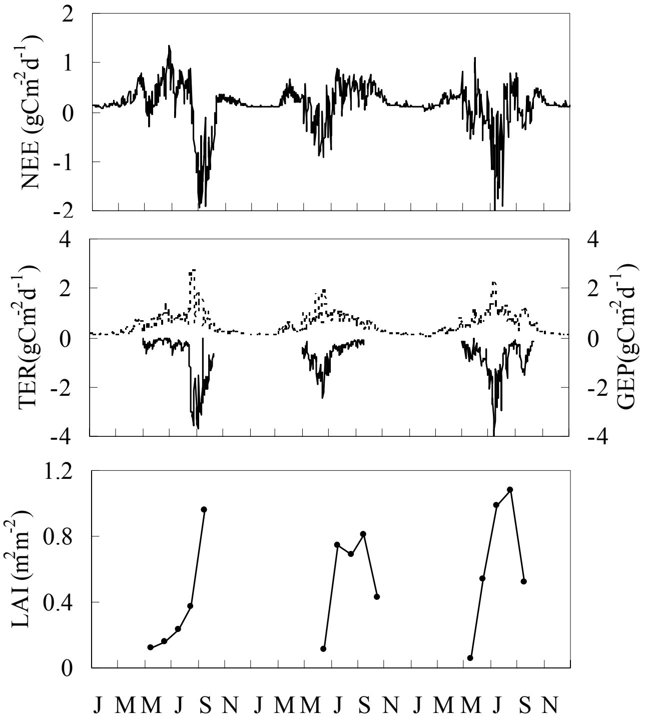

Fig.2 Seasonal and interannual patterns of daily NEE (a), TER and GEP (b) and monthly LAI (c) in 2004, 2005 and 2006

lasting about three months. The second one followed a heavy sleet in early September, when more than 40mm of precipitation fell during a single event. This caused a change in SWC from 0.11 to 0.20 m^3 m^{-3}, followed by fifteen days of carbon uptake during which 2.4 g C m^{-2} was captured from the atmosphere. This period of carbon uptake ended with lower autumn temperatures.

3.2 Annual Carbon Accumulation

Carbon releases over *S. krylovii* steppe were observed in all 3 years. The slopes of the accumulated NEE during the winter time were similar (0.1 – 0.15 g C m^{-2} d^{-1}) across the three study years. Total carbon losses from November to March were similar, 25.1-26.7 g C m^{-2}. Each year showed about 50 days of decrease in accumulated NEE, but the start and end dates of the growing season were different. Accumulated NEE increased from May to early August in 2004, and reached a peak emission value of 81.9 g C m^{-2} on 15 August and then showed a linear decrease by a rate of -1 g C m^{-2} d^{-1} until 30 September (35 g C m^{-2}). The corresponding values in 2005 were 27.7 g C m^{-2} on 15 May and -0.26 g C m^{-2} d^{-1} to 14.7 g C m^{-2} on 2 July. Carbon release was the lowest in 2006, with an accumulated NEE value of only 1.7 g C m^{-2} on 1 August.

3.3 Simulating flux dynamics over grassland ecosystems in China

The accuracy of flux estimations from modified IBIS was validated, in terms of long term aboveground biomass (AGB) observation data in typical steppe from Inner Mongolia Grassland Ecosystem Research Station, the Chinese Academy of Sciences (CAS) (1981-1994)(Fig. 3), meadow steppe from Grassland Research Station of Northeast Normal University (1981-1990)(Fig.4), and alpine meadow steppe from Haibei Research Station of Alpine Meadow Ecosystem, CAS (1981-1994) (Fig.5), as well as flux observation from Inner Mongolia Typical Grassland Ecosystem Field Observation Station from August 2004 to December 2005 (Fig.6). Modified IBIS could greatly improve the estimate of aboveground grassland biomass in China, and also simulated the dynamic fluxes of water, heat and carbon fluxes over grassland ecosystems very well.

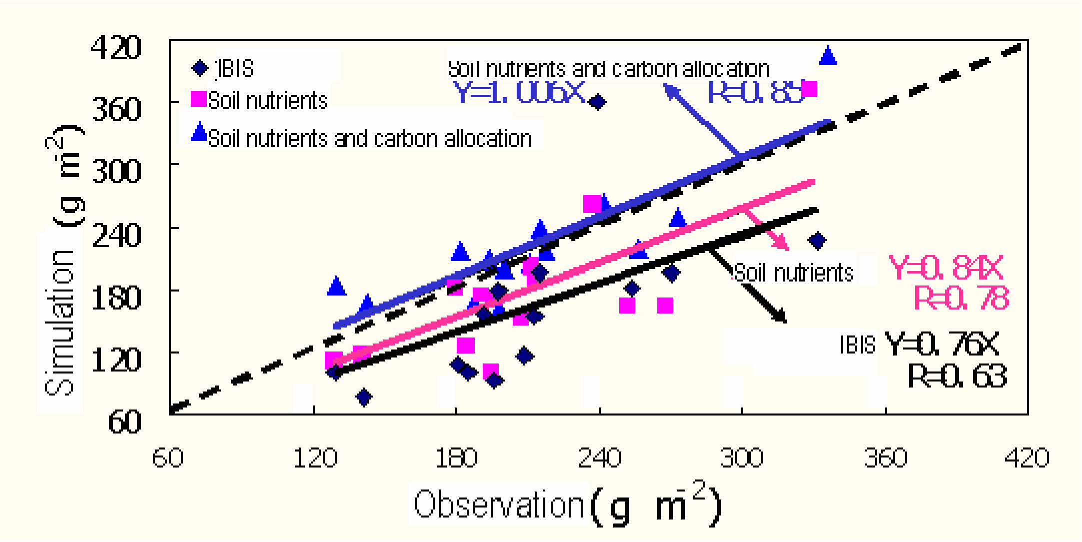

Fig. 3 Comparison of simulated and observed ABG in typical steppe from Inner Mongolia Grassland Ecosystem Research Station, CAS (1981-1994)

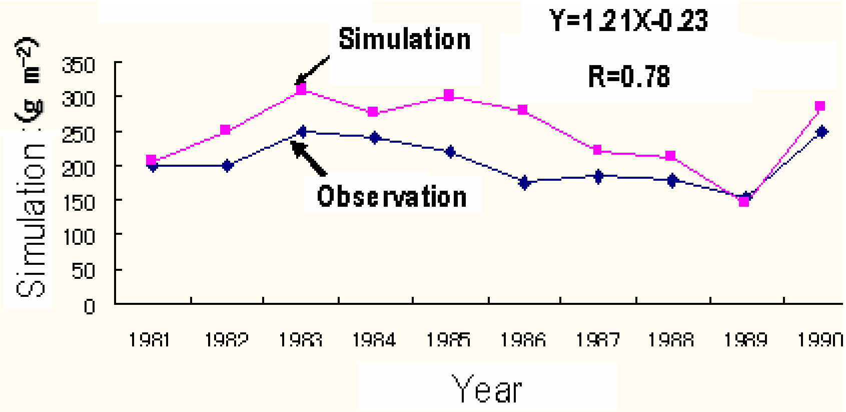

Fig. 4 Comparison of simulated and observed ABG in meadow steppe from Grassland Research Station of Northeast Normal University (1981-1990)

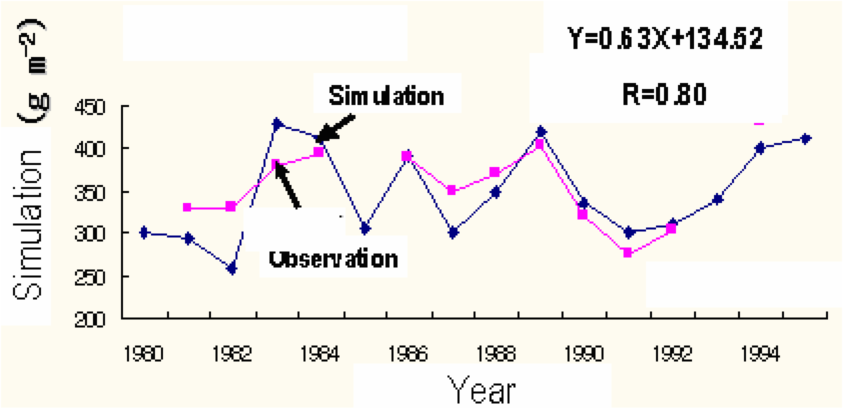

Fig. 5 Comparison of simulated and observed ABG in alpine meadow steppe from Haibei Research Station of Alpine Meadow Ecosystem, CAS (1981-1994)

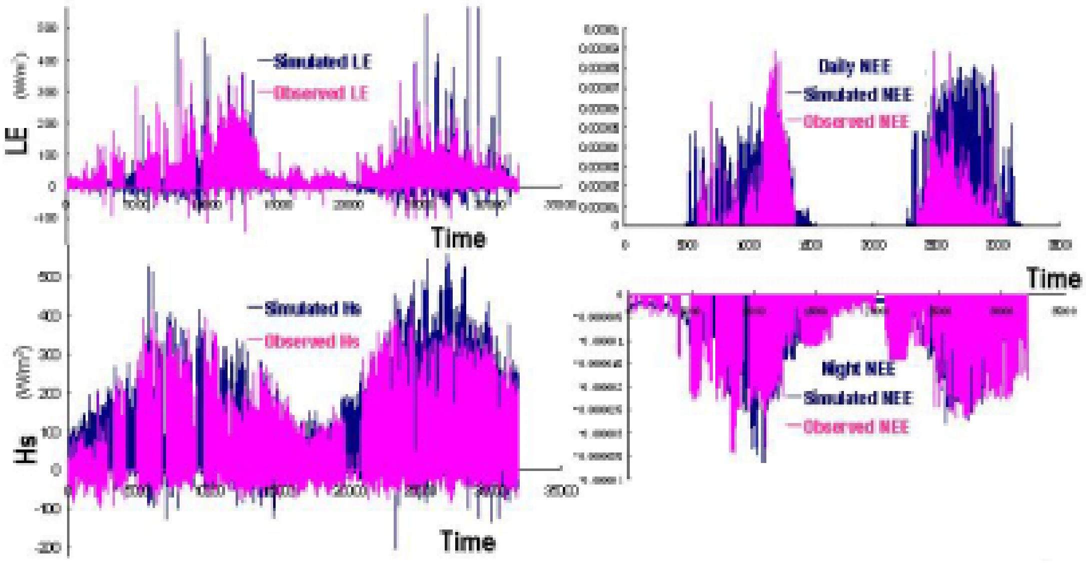

Fig. 6 Comparison of simulated and observed fluxes of water (LE), heat (Hs) and carbon (NEE) fluxes over grassland ecosystems in Inner Mongolia Typical Grassland Ecosystem Field Observation Station from August 2004 to December 2005

4 Conclusions

Carbon flux was measured continuously for three years over a semi-arid *S. krylovii* steppe in northern China. Results indicated that seasonal variations of carbon flux patterns followed the increase of LAI before it peaked, then it was controlled by SWC. Annual values of NEE were 48.9, 67.5 and 34.9 g C m^{-2} for 2004, 2005 and 2006, respectively. Carbon assimilation mostly occurred right after major rainfall events. Maximum daily NEE (1 g C m^{-2} d^{-1}) in 2006 was half of that (2.1 g C m^{-2} d^{-1}) in 2004 and 2006. Due to the differences in LAI, temperature, and SWC for the three peak growth periods, the maximum carbon uptake rate ranged from -5 to -8μmolC$m^{-2}s^{-1}$. This study also found that diurnal and annual amplitudes of carbon exchange were controlled by the pattern and the amount of precipitation. Our study confirmed the theory that the timing and amount of the rainfall events were the determining factors of carbon exchange in semi-arid grassland. Early and regular rainfall events had a positive effect on carbon uptake.

The study also indicated that the accuracy of ABG and flux estimations from IBIS is serious affected due to the constants of maximum capacity of Rubisco to perform the carboxylase function and carbon allocation. The modified IBIS could greatly improve the estimate of aboveground grassland biomass and fluxes of water, heat and carbon fluxes over grassland ecosystems in China, which includes the effects of soil carbon and nitrogen on leaf photosynthesis and the effects of light, water and soil nutrients on carbon allocation. It provides a key tool for carbon cycle studies and evaluations of terrestrial ecosystems as it represents processes and provides detailed information as to the workings of the terrestrial carbon system.

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Reference

Barcza1, Z., Haszpra, L., Kondo, H., Saigusa, N., Yamamoto, S., Bartholy, J. 2003. Carbon exchange of grass in Hungary. Tellus Series B-Chemical and Physical Meteorology, 55(2): 187-196.

Chen, Y.F., Fischer, G. 1998. A new digital georeferenced database of grassland in China. Interim Report IR-98-062. Laxenburg: International Institute for Applied Systems Analysis (IIASA), p. 24.

Eswaran, H., van den Berg E, Reich, P. 1993. Organic carbon in soils of the world. Soil Sci. Soc. Am. J., 57:192-194.

Falge, E., Baldocchi, D., Olson, R., Anthoni, P., Aubinet, M., Bernhofer, C., Burba, G., Ceulemans, R., Clement, R., Dolman, H. 2001. Gap filling strategies for defensible annual sums of net ecosystem exchange. Agricultural and Forest Meteorology, 107 (1): 43-69.

FAO. 1995. FAO Year book-Production (1994). Food and Agriculture Organization of the United Nations, Rome, Italy.

Flanagan, L.B., Wever, L.A. and Carlson, P.J. 2002. Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. Global Change Biology, 8(7): 599-615.

Foley, J. A., Prentice, I. C., Ramunkutty, N., Levis, S., Pollard, D., Sitch, S., and Haxeltine, A. 1996. An Integrated Biosphere Model of Land Surface Processes, Terrestrial Carbon Balance and Vegetation Dynamics. Global Biogeochem. Cycles, 10: 603-628.

Friedlingstein, P., Joel, G., Field, C.B., and Fung, I.Y. 1999. Toward an allocation scheme for global terrestrial carbon models. Global Change Biology, 5:755-770.

Hunt, J.E., Kelliher, F.M., McSeveny, T.M., Ross, D.J. and Whitehead, D. 2004. Long-term carbon exchange in a sparse, seasonally dry tussock grassland. Global Change Biology, 10(10): 1785-1800.

Kato, T., Tang, Y., Gu, S., Cui, X., Hirota, M., Du, M., Li, Y., Zhao, X., Oikawa, T. 2004. Carbon dioxide exchange between the atmosphere and an alpine meadow ecosystem on the Qinghai-Tibetan Plateau, China. Agricultural and Forest Meteorology, 124 (1-2):121-134.

Kim, J., Verma, S.B. and Clement, R.J. 1992. Carbon-dioxide budget in a temperate grassland ecosystem. Journal of Geophysical Research-Atmospheres, 97(D5): 6057-6063.

Knapp, A.K., Fay, P.A., Blair, J.M., Collons, S.L., Smith, M.D., Carlisle, J.D., Harper, C.W., Danner, B.T., Lett, M.S., McCarron, K.M. 2002. Rainfall variability, carbon cycling, and plant species diversity in a mesic grassland. Science, 298:2002-2205.

Li S.G., Asanuma J., Eugster, W., Kotani, A., Liu, J.J., Urano, T., Oikawa, T., Davaa, G., Oyunbaatar D. and Sugita M. 2005. Net ecosystem carbon dioxide exchange over grazed steppe in central Mongolia. Global Change Biology, 11: 1941-1955.

Li, S.L. and Chen, Y.J. 1999. Study on the Soil Water Dynamic and Physical Characteristic of Chestnut Soil in Xilin River Basin. Grassland of China, 3: 71-76.

Novick, K.A., Stoy, P.C., Katul, G.G., Ellsworth, D.S., Siqueira, M.B.S., Juang, J., Oren, R. 2004. Carbon dioxide and water vapor exchange in a warm temperate grassland. Oecologia, 138(2): 259-274.

Parton, W.J., Scurlock, J.M.O., Ojima, D.S., Schieml, D.S., Hall, D. O. 1995. Impact of climate - change on grassland production and soil carbon worldwide. Global Change Biol., 1:13-22.

Prentice, I.C., Farquhar, G.D., Fasham, M.J.R., Goulden, M.L., Heimann, M., Jaramillo, V.J., Kheshgi, H.S., Le Quere, C., Scholes, R.J., Wallace, D.W.R. 2001. The carbon cycle and atmospheric carbon dioxide. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van der Linden, J.P., Dai X., Maskell, K., Johnson, C.A. (eds) Climate change 2001: the scientific basis. Cambridge University Press, Cambridge, UK

Sala, O.E. 2001. Productivity of temperate grasslands. In: Roy, J., Sangier, B., Mooney, H.A. (eds) Terrestrial global productivity. Academic Press, San Diego, pp 285-300

Suyker, A.E. and Verma, S.B., 2001. Year-round observations of the net ecosystem exchange of carbon dioxide in a native tallgrass prairie. Global Change Biology, 7(3): 279-289.

Suyker, A.E., Verma, S.B. and Burba, G.G., 2003. Interannual variability in net CO2 exchange of a native tallgrass prairie. Global Change Biology, 9(2): 255-265.

Tieszen, L.L. & Detling, J. 1983. Productivity of grassland and tundra. In: Lange, O.L., Nobel, P. S., Osmond, C. B. & Ziegler, H. (eds.) *Encyclopedia of plant physiology. Vol.13D. Physiological plant Ecology IV. Ecosystem processes:mineral cycling, productivity and man's influence*, pp. 173-202. Springer-Verlag, Berlin, DE.

Verhoef, A., Allen, S.J., DeBruin, H.A.R., Jacobs, C.M.J. and Heusinkveld, B.G., 1996. Fluxes of carbon dioxide and water vapour from a Sahelian savanna. Agricultural and Forest Meteorology, 80(2-4): 231-248.

Verma, S.B., Kim, J. and Clement, R.J., 1989. Carbon dioxide, water vapor and sensible heat fluxes over a tallgrass prairie. Boundary-Layer Meteorology, 46(1): 53-67.

Wang, Y., Zhou, G., Wang, Y. 2007. Modeling responses of the meadow steppe dominated by *Leymus* chinensis to climate change. Climatic Change, 82:437-452.

Watson, R.T., Zinyowera, M.C., Moss, R.H. & Dokken, D.J. 1998. The regional impacts of climate change: An assessment of vulnerability. Cambridge University Press, New York, NY.

Webb, E.K., Pearman, G.I. and Leuning, R. 1980. Corrections of flux measurements for density effects due to heat and water vapor transfer. Quart. J. R. Meteorol. Soc., 106: 85-100.

Woodward, F.I., 1995. A global land primary productivity and phytogeography model. Global biogeochemical cycles, 9(4):471-490

Xu, L.K. and Baldocchi, D.D., 2004. Seasonal variation in carbon dioxide exchange over a Mediterranean annual grassland in California. Agricultural and Forest Meteorology, 123(1-2): 79-96.

Zhao, L.A., Li, Y.N., Xu, S.X., Zhou, H.K., Gu, S., Yu, G.R., Zhao, X.Q. 2006. Diurnal, seasonal and annual variation in net ecosystem CO_2 exchange of an alpine shrubland on Qinghai-Tibetan plateau. Global Change Biology, 12(10): 1940-1953.

Zhou, G., Wang, Y. & Wang, S. 2002. Responses of grassland ecosystems to precipitation and land use along the Northeast China Transect. Journal of Vegetation Science, 13: 361-368.

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Editor's Note

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