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Temperature and precipitation control of the spatial variation of terrestrial ecosystem carbon exchange in the Asian region

Zhi Chen[a,b], Guirui Yu[a,*], Jianping Ge[c], Xiaomin Sun[a], Takashi Hirano[d], Nobuko Saigusa[e], Qiufeng Wang[a], Xianjin Zhu[a,b], Yiping Zhang[f], Junhui Zhang[g], Junhua Yan[h], Huimin Wang[a], Liang Zhao[i], Yanfen Wang[b], Peili Shi[a], Fenghua Zhao[a]

[a] *Synthesis Research Center of Chinese Ecosystem Research Network, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *College of Life Sciences, Beijing Normal University, Beijing 100875, China*
[d] *Research Faculty of Agriculture, Hokkaido University, Kita 9, Nishi 9, Kita-ku, Sapporo, Japan*
[e] *National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Japan*
[f] *Key Lab of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun 666303, China*
[g] *Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China*
[h] *South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China*
[i] *Northwest Plateau Institute of Biology, Chinese Academy of Sciences, Xining 810001, China*

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ABSTRACT

Carbon exchange between terrestrial ecosystems and the atmosphere is one of the most important processes in the global carbon cycle. Understanding the spatial variation and controlling factors of carbon exchange fluxes is helpful for accurately predicting and evaluating the global carbon budget. In this study, we quantified the carbon exchange fluxes of different terrestrial ecosystems in the Asian region, and analyzed their spatial variation and controlling factors based on long-term observation data from ChinaFLUX (19 sites) and published data from AsiaFlux (37 sites) and 32 other sites in Asia. The results indicated that the majority of Asian terrestrial ecosystems are currently large carbon sinks. The average net ecosystem production (NEP) values were 325 ± 187, 274 ± 207, 236 ± 260, $89 \pm 134\,g\,C\,m^{-2}\,yr^{-1}$ in cropland, forest, wetland and grassland ecosystems, respectively. The spatial variation of gross primary production (GPP) and ecosystem respiration (Re) were mainly controlled by the mean annual temperature (MAT) and the mean annual precipitation (MAP) in the Asian region. There was a clear linear relationship between GPP and MAT, and a strong sigmoid relationship between GPP and MAP. Re was exponentially related to MAT and linearly related to MAP. Interestingly, those response modes were consistent across different ecosystem types. The different responses of GPP and Re to MAT and MAP determined the spatial variation of NEP. The combined effects of MAT and MAP contributed 85%, 81% and 36% to the spatial variations of GPP, Re and NEP, respectively. Our findings confirmed that the spatial variation of carbon exchange fluxes was mainly controlled by climatic factors, which further strongly supports the use of the climate-driven theory in the Asian region.

1. Introduction

The global land biosphere has been estimated to be a carbon sink with strong carbon uptake rate at mid-to-high latitudes in the northern hemisphere over the last two decades (Ciais et al., 1995; Tans et al., 1990). However, the sink magnitude and spatial distribution are still uncertain, due to the influence of natural and human factors such as climate, vegetation and land-use change (Crevoisier et al., 2010; Pan et al., 2011; Stephens et al., 2007). Therefore, understanding the spatial variation and controlling mechanisms of carbon exchange fluxes between different carbon pools at global and regional scales is helpful for accurately predicting future climate change (Yu et al., 2011).

Based on global net primary production (NPP) observation data, Lieth (1973) built the 'Miami' model to successfully describe the spatial pattern of global NPP using temperature and precipitation, which implied that the spatial pattern of ecosystem production was mainly controlled by climatic factors. Nemani et al. (2003) and

* Corresponding author at: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing 100101, China. Tel.: +86 10 64889432; fax: +86 10 64889432.
E-mail address: yugr@igsnrr.ac.cn (G. Yu).

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Yi et al. (2010) further proved ecosystem production was largely controlled by temperature at mid-to-high latitudes, and by precipitation at low latitudes. However, soil, vegetation and land use were also believed to influence the carbon pools (Chapin et al., 2002), and multiple factors were thought to control the carbon exchange fluxes at regional scales (Granier et al., 2007; Thornton et al., 2002). Considering more confounding factors will expect to more accurately assess the carbon balance, but it also may trade off by leading to more complicated and greater uncertainty to the global carbon budget assessment.

The spatial variation of net ecosystem production (NEP) and ecosystem respiration (Re) were weakly related to climatic factors in the European and North-American regions (Law et al., 2002; Luyssaert et al., 2007). Conversely, in the Asian region the spatial variations of gross primary production (GPP), Re and NEP were primarily related to climatic factors based on previous AsiaFlux sites (Hirata et al., 2008; Kato and Tang, 2008). In China, it was demonstrated that the spatial patterns of GPP, Re and NEP were determined by mean annual temperature and precipitation, and those response modes were consistent in different ecosystem types; this result further developed the climate-driven theory (Yu et al., 2013). With the development of the ChinaFLUX and AsiaFlux network of in situ and continuous measurements in recent decades, the regional analysis of spatial variation in carbon exchange fluxes and the controlling factors behind this are becoming available for the Asian region.

Therefore, this study integrated long-term continuous observation data from ChinaFLUX and published data from AsiaFlux and other affiliated sites, to (1) explore the spatial variation of terrestrial ecosystem carbon exchange fluxes in the Asian region, (2) explore the controlling factors of that spatial variation, and (3) test the applicability of a climate-driven theory in Asia. This study is expected to improve our understanding of the biogeographic mechanism of the spatial variation of ecosystem carbon exchange fluxes and to provide a theoretical basis for developing an assessment model of the carbon budget in terrestrial ecosystems on regional and global scales.

2. Materials and methods

2.1. Observation method

The eddy covariance technique provided a direct and continuous measure of the net carbon and water fluxes between the biosphere and atmosphere (Baldocchi et al., 1996), which consisted of a 3D ultrasonic anemometer to measure three-dimensional wind speed and temperature fluctuations, and an infrared gas analyzer to measure CO_2 and water vapor densities. The eddy covariance technique is closely related to physiological and ecological processes and can reflect seasonal and interannual variability of carbon fluxes (Baldocchi et al., 2001). Globally, there are currently more than 400 sites, spanning forest, grassland, cropland, wetland, tundra, and desert ecosystems (Baldocchi, 2008).

2.2. Data observation and process of ChinaFLUX

Since 2002, ChinaFLUX has grown into a regional observation and research network, covering four main ecosystem types: forest, grassland, cropland and wetland. The open-path eddy covariance (OPEC) system was used to measure carbon and water vapor fluxes at ChinaFLUX sites. All signals were sampled at 10 Hz frequency and the CO_2 and H_2O fluxes were calculated and recorded at 30 min intervals by a CR5000 datalogger (Model CR5000, Campbell Scientific, Logan, UT, USA). At each site, the meteorological variables were measured simultaneously, including solar radiation, air temperature, rainfall, soil temperature and soil moisture, which were sampled at a 2 s frequency and recorded at 30 min intervals (Yu et al., 2013).

To ensure the reliable processing of flux data, ChinaFLUX has developed a series of proven methodologies for assessing the performance of the observation system and flux data quality control (Yu et al., 2006), including the three-dimensional coordinate rotation (Zhu et al., 2004), WPL correction (Webb et al., 1980), storage flux calculation, outlier filter, nighttime CO_2 flux (Reichstein et al., 2005), gap filling (Falge et al., 2001) and net ecosystem exchange (NEE) flux partitioning (Reichstein et al., 2005). For details of data quality control and gap-filling refer to Yu et al. (2006).

2.3. Collection and integration of carbon flux observation data in Asia

Published carbon flux data from other sites in Asia during the past two decades (1995–2010) were collected. We adopted the following methods to screen these data:

Carbon flux data were uniformly measured by the eddy covariance technique, and subsequently passed a series of processes performed by the individual site researchers, including the three-dimensional coordinate rotation, WPL correction, storage flux calculation, outlier filter, nighttime CO_2 flux, gap filling and flux partitioning. In the dataset, the OPEC was applied in more than 80% of the sites. Although there remain several sites that applied the closed-path eddy covariance (CPEC), the error of these two system results was less than 5% (Baldocchi et al., 2001). The u^* threshold varied among different ecosystems because it was identified according to the local topography, vegetation and weather. High canopy vegetation (forests) tend to have larger u^* than low canopy vegetation (croplands and grasslands). The smallest u^* threshold is 0.1 m/s in forests, and is 0.01 m/s in low canopy ecosystems (Papale et al., 2006). In general, the u^* threshold is usually between 0.1 and 0.4 m/s (Reichstein et al., 2005) and the u^* threshold in our dataset fall into this range. For gap filling, Mean Diurnal Variation (MDV), Look-Up Tables (LookUp) and Nonlinear Regression (NLR) are used (Falge et al., 2001). More than 57% of sites applied the NLR approach in the dataset. Although these three approaches were adapted to different time scales and gap lengths, there was no significant difference between the interpolated results according to statistical analysis (Falge et al., 2001). For flux partitioning, two approaches were used in our dataset: (1) nighttime data-based (NB): respiration measurements made at night were extrapolated to the daytime based on the relationship between respiration and T_{air} or T_{soil} (Lloyd and Taylor, 1994; Reichstein et al., 2005); (2) daytime data-based (DB): light-response curves were fit to daytime NEE measurements and respiration was estimated from the intercept, then respiration was extrapolated into the nighttime using T_{air} or T_{soil} measured during the night (Falge et al., 2002; Lasslop et al., 2010). The NB approach was overwhelmingly applied in the dataset. Both methods were effective, and no obvious differences were reported between the partitioning results under the condition of no existing large soil carbon storage (Falge et al., 2002). Measurement systems and approaches applied for each site are explicitly shown in Table S2.

2.4. Additional selection criteria

Because the aim of this study was to analyze the spatial variation of carbon fluxes at an annual scale, all data were required to be continuous for longer than 1 year. Except for certain ecosystems in the boreal and subarctic zones, only continuous data collected during the growing season are available, including the Tura, Huzhong, Yichun and Zotino sites. At the Tura site, the annual NEP was estimated based on measurements during the growing seasons