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Geographical statistical assessments of carbon fluxes in terrestrial ecosystems of China: Results from upscaling network observations

Xian-Jin Zhu [a,b], Gui-Rui Yu [a,*], Hong-Lin He [a], Qiu-Feng Wang [a], Zhi Chen [a,b], Yan-Ni Gao [a,b], Yi-Ping Zhang [c], Jun-Hui Zhang [d], Jun-Hua Yan [e], Hui-Min Wang [a], Guang-Sheng Zhou [f], Bing-Rui Jia [f], Wen-Hua Xiang [g], Ying-Nian Li [h], Liang Zhao [h], Yan-Fen Wang [b], Pei-Li Shi [a], Shi-Ping Chen [f], Xiao-Ping Xin [i], Feng-Hua Zhao [a], Yu-Ying Wang [j], Cheng-Li Tong [k], Yu-Ling Fu [a], Xue-Fa Wen [a], Ying-Chun Liu [a,b], Lei-Ming Zhang [a], Li Zhang [a], Wen Su [a], Sheng-Gong Li [a], Xiao-Min Sun [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] *Key Lab of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun 666303, China*
[d] *Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China*
[e] *South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China*
[f] *State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China*
[g] *Faculty of Life Science and Technology, Central South University of Forestry and Technology, Changsha 410004, China*
[h] *Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining 810001, China*
[i] *Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China*
[j] *Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050021, China*
[k] *Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, China*

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ABSTRACT

Accurate quantifying the magnitudes and distributions of carbon budgets is helpful for strategies in mitigating global climate change. Based on spatial patterns of carbon fluxes (gross ecosystem productivity (GEP), ecosystem respiration (ER) and net ecosystem productivity (NEP)) and their drivers, we constructed geographical statistical assessment schemes and quantified the magnitudes of carbon fluxes in China. The optimal assessment scheme was then validated with observed eddy covariance data to analyze the spatial distributions of carbon fluxes. Using climate-based geographical statistical assessment schemes, our estimates of GEP, ER and NEP in China during 2000s were 7.51 ± 0.51, 5.82 ± 0.16 and 1.91 ± 0.15 PgC yr^{-1}, corresponding to 4.29%–6.80%, 5.65%–6.06% and 9.10%–12.73% of global annual carbon fluxes, respectively. The spatial distributions of GEP, ER and NEP, generated from the optimal scheme, were similar, following a southeast–northwest decreasing gradient. The maximum values for GEP, ER and NEP were 1790, 1300 and 490 gC m^{-2} yr^{-1}, respectively, which occurred in Central subtropics and Southern subtropics. Climate-based geographical statistical assessment schemes provided an independent dataset for the regional carbon budget assessment, which can be deemed as the potential carbon fluxes. Meanwhile, most areas in China were potential carbon sink especially Eastern China and the largest potential carbon sink appeared in Central subtropics and Southern subtropics.

1. Introduction

Increased atmosphere CO_2 concentration, partly resulting from human activities, has been regarded as one of the main forces causing the global climate change (Solomon et al., 2007). Terrestrial ecosystems were deemed as a major sink of atmosphere CO_2 (Tans et al., 1990; Ballantyne et al., 2012), therefore, enhancing the strength of carbon sink in terrestrial ecosystem has been regarded as a feasible way to mitigate the climate change (Liu et al., 2008). Accurate quantification of the terrestrial ecosystem carbon sink and its increasing potential will provide a scientific basis for carbon management in climate change mitigation.

Located in the mid-high latitude in the Northern Hemisphere, terrestrial ecosystems in China serve as a sink of atmosphere CO_2 and play an important role in maintaining the global carbon balance (Fang et al., 2007; Piao et al., 2009a; Piao et al., 2011). Furthermore, to meet the need of its economic growth, China has consumed huge energy

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

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resources with high carbon emission rates, which will likely keep increasing (Boden et al., 2010). Therefore, accurate quantifying the magnitude, the spatial distribution and the increasing potential of carbon sink for terrestrial ecosystems in China is also important for strategies in carbon management aiming at the global climate change mitigation.

The magnitude and distribution of carbon sink in China have been intensively investigated through the inventory approach and various models (Fang et al., 2007; Piao et al., 2009a; Piao et al., 2011; Tian et al., 2011a; Tian et al., 2011b), while there were some uncertainties among investigations. Meanwhile, the magnitude and distribution of carbon sink are affected by those of various carbon fluxes, including gross ecosystem productivity (GEP), net primary productivity (NPP), and ecosystem respiration (ER) and so on. Many studies have quantified carbon fluxes in China, such as GEP (Feng et al., 2007; Li et al., 2013), NPP (Fang et al., 2003; Tao et al., 2003; He et al., 2005; Feng et al., 2007; He et al., 2007; Gao and Liu, 2008; Gao et al., 2012), and net ecosystem productivity (NEP) (Cao et al., 2003; Tao et al., 2007; Ji et al., 2008; Sun, 2009) using various models, while there were substantial disagreements, e.g. NPP in China ranged from 1.43 to 4.73 PgC yr^{-1} (Gao et al., 2012), and NEP floated from 0.0625 to 0.12 PgC yr^{-1} (Cao et al., 2003; Tao et al., 2007; Ji et al., 2008; Sun, 2009). Moreover, the potential level of carbon fluxes, which was the base for calculating the potential increment of carbon sink, was still unsolved.

The eddy covariance technique, measuring the net exchange of CO_2 between the biosphere and the atmosphere at the ecosystem scale, is widely used all over the world (Baldocchi, 2008). In conjunction with remote sensing (RS) and climate data, eddy covariance measurements were upscaled to continental (Papale and Valentini, 2003; Xiao et al., 2008, 2010, 2011, 2012) or global scales (Jung et al., 2011) using the machine learning technique, which was regarded as an important forward step in assessing carbon fluxes (Jung et al., 2011). China has conducted eddy covariance observations since 2002 and establishes a national network of eddy covariance towers covering 17 sites (Yu et al., 2013), which experiences little disturbance especially fire and thinning and provides a valuable platform for calculating the potential level of carbon fluxes. However, there was no attempt in upscaling observations to the national scale.

By integrating ChinaFLUX observations and published carbon flux data (GEP, ER and NEP) from other sites in China, we constructed geographical statistical assessment schemes of carbon fluxes and selected the optimal scheme to examine the spatial distributions of GEP, ER and NEP. The specific objectives were: 1) to develop carbon flux assessment schemes; 2) to quantify the total annual carbon fluxes in China, and 3) to characterize the spatial distributions of mean annual biosphere–atmosphere carbon fluxes. As our assessment schemes were based on sites experiencing little disturbance and mainly dependent on climate, to some extent, our estimated carbon fluxes may be regarded as the potential carbon fluxes in China.

2. Data and methods

2.1. Integration of carbon flux data

Through integrating ChinaFLUX observations and published data in literatures, we built a dataset containing 52 site data (Yu et al., 2013), which covered most kinds of ecosystem types in China (Fig. 1a) and were fairly representative of typical Chinese climate types (Fig. 1b). Some sites from literature included NEP, GEP or ER incompletely, which made the site number used to develop assessment schemes unequal. In addition, the positive GEP and NEP indicate a carbon uptake from the atmosphere, while the positive ER represents a carbon release to the atmosphere.

2.2. Carbon flux assessment schemes

Yu et al. (2013) found that mean annual temperature (MAT) and mean annual precipitation (MAP) affected the spatial patterns of carbon fluxes (GEP, ER and NEP) among terrestrial ecosystems in China. GEP, ER and NEP also exhibited strict positive coupling correlations in their spatial patterns. Based on results from Yu et al. (2013), we developed three kinds of assessment schemes to assess carbon fluxes of terrestrial ecosystems in China.

2.2.1. Schemes based on the effects of MAT and MAP

Yu et al. (2013) found that GEP and NEP increased linearly while ER increased exponentially with the increasing MAT, and the R^2 was 0.57, 0.49 and 0.48 for GEP, ER and NEP, respectively. Furthermore, with the increasing MAP, GEP, ER and NEP grew significantly in a linear way, the R^2 was 0.61, 0.51 and 0.32, respectively. In addition, carbon fluxes were only limited by the most limited factor (Chapin et al., 2012). Therefore, a carbon flux assessment scheme was recommended as follows:

$$Cflux = \min\{f(MAT), f(MAP)\} \quad (1)$$

where *Cflux* is GEP, ER or NEP, respectively, *f*(*MAT*) and *f*(*MAP*) are regression equations between *Cflux* and MAT and MAP, and "min" indicates the smaller value referring to the *f*(*MAT*) and *f*(*MAP*). The

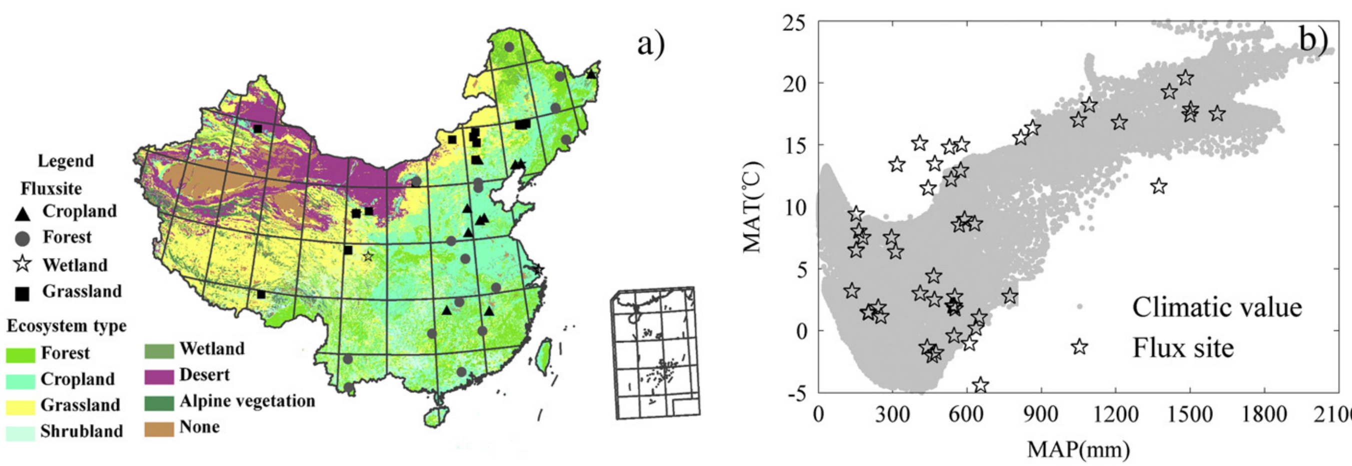

Fig. 1. The distribution of eddy covariance observations in China used in this study among ecosystem types (a) and mean annual climate space (b) in China. In panel (a), the background is the vegetation map according to the Editorial Committee of Vegetation Map of China (2007). In panel (b), climate parameters are the mean annual precipitation (MAP, *x*-axis) and temperature (MAT, *y*-axis) over a 50-year period of record (1961–2010), obtained from the China Meteorological Bureau database. Gray points represent the spatial distribution of the climatic data in China at a 20 km resolution.