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Spatial variability of water use efficiency in China's terrestrial ecosystems

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ABSTRACT

Water use efficiency (WUE) reflects the coupling of carbon and water cycles. Analyzing the spatial variability of WUE can improve our understanding on the interaction between carbon and water cycles at a large scale, which also provides a basis for improving the regional carbon budget assessment. Based on China's eddy covariance measurements, we examined the spatial variation of China's WUE and its affecting factors. WUE showed a decreasing trend with the increasing altitude, which was the result of ecosystem type distribution resulting from the climatic gradient. After fully considering the vertical variation of WUE, we found that not only mean annual air temperature (MAT), mean annual precipitation (MAP), and mean leaf area index (MLAI) but also mean annual total photosynthesis active radiation (MAR) affected the spatial variation of WUE. With the increasing MAT, MAP, and MLAI, WUE increased significantly but the increasing MAR decreased WUE. The spatial variation of WUE could be directly depicted by MLAI and altitude, the equation including which explained 65% of the spatial variation of WUE. The effects of MAT and MAP on the spatial variation of WUE may be achieved through altering MLAI, while the mechanism underlying the effect of MAR on the spatial variation of WUE was still unclear, which should be the subject of future investigations. This study reveals the vertical variation of WUE and provides a new approach to generate the spatial variation in WUE, which will benefit the regional carbon budget assessment.

1. Introduction

Considerable attention in ecological studies is being given (Finzi et al., 2011; Schlesinger et al., 2011; Wang et al., 2012) to the close coupling of carbon and water cycles, which reflects the interaction between carbon and water cycles. The coupling between carbon and water cycles can be represented by the term “water use efficiency (WUE)”, which is often defined as the ratio of productivity to water loss (Reichstein et al., 2002; Beer et al., 2007; Steduto et al., 2007; Zhao et al., 2007). Analyzing the spatial variability of WUE is helpful for understanding the interaction between carbon and water cycles at a large scale (Ito and Inatomi, 2012), which may provide an alternative approach for regional carbon budget assessment (Beer et al., 2007, 2009, 2010).

Based on network eddy covariance measurements, which can simultaneously measure CO_2 and H_2O fluxes, scientists have analyzed the spatial variability of WUE in China and other regions. For example, using measurements from three forests in the North–south Transect of East-China (NSTEC), Yu et al. (2008) analyzed the difference in WUE among forests and found that WUE increased with increasing latitude, which resulted from the decreasing mean annual air temperature (MAT) and precipitation (MAP). Using observations from Northern China and Southeast China, Xiao et al. (2013) found that the spatial variability of WUE was primarily associated with MAP. Using measurements in three grasslands in the China Grassland Transect (CGT), Hu et al. (2008) found that WUE increased with the increasing leaf area index (LAI) but was not related to the increasing MAT and MAP. Integrating global measurements covering 43 sites, Beer et al. (2009) investigated the spatial variation of inherent water use efficiency (IWUE), the product of WUE multiplying vapor pressure deficit, and

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found that LAI dominated the spatial variation in IWUE. However, most of previous studies were conducted within the same ecosystem type (Hu et al., 2008) and covering limited range in altitude among ecosystems (Xiao et al., 2013), which made little attention paid to the vertical variation of WUE, while there was a substantial difference in global altitude. Therefore, it was still unclear whether WUE exhibited a vertical variation. In addition, if there was a vertical variation in WUE, we were still unknown about whether factors affecting the spatial variation of WUE varied after fully considering its vertical variation, which made our current understanding on the spatial variation of WUE imprecise.

Because of the uplift of the Qinghai-Tibetan Plateau (Wu et al., 2007), China experiences a distinct climate and ecosystem gradient that exhibits not only a horizontal distribution but also a notable vertical distribution (Yu et al., 2006). The unique distribution of climate and ecosystems in China provides a valuable platform for analyzing the spatial variation of WUE especially its vertical variation and its affecting factors, which may be helpful for fully understanding the spatial variability of WUE in China and globally. Scientists in China has conducted eddy covariance measurements for many years (Yu et al., 2013), which made it possible to investigate the spatial variation of WUE in China.

Integrating ChinaFLUX measurements and published data in literatures, we constructed a dataset containing concurrent CO_2 and H_2O flux measurements from 37 sites in China (Fig. 1), investigated the spatial variation of WUE and revealed its affecting factors. The main objectives were to fully reveal the spatial variation of WUE especially its vertical variation and to clarify factors that directly affected the spatial variation of WUE in China. Our results may improve our understanding on the interaction between carbon and water cycles at a large scale and may provide an alternative approach for assessing the spatial distribution of WUE thus carbon fluxes.

2. Material and methods

2.1. Sites used in this study

In this study, we collected data from two sources: ChinaFLUX measurements and published data from the literature.

Since 2002, ChinaFLUX has conducted continuous CO_2 and H_2O flux measurements at 9 sites using the open path eddy covariance system (Yu et al., 2006), which covered 4 forests, 3 grasslands, 1 cropland, and 1 wetland (Fig. 1 red sites).

In addition to ChinaFLUX measurements, we also collected published data in China from the literature, which comprised a dataset covering 9 forests, 9 grasslands, 4 croplands, and 6 wetlands (Fig. 1 black sites). Sites were selected following the follow criteria. First, measurements must have been made using the eddy covariance technique. Second, measurements must have been conducted for at least 1 year and the annual total GPP and ET had to be available. Third, the annual total GPP and ET must have been collected in the same year.

After integrating ChinaFLUX measurements and data from the literature, we constructed a dataset that contained simultaneous annual total GPP and ET measurements at 37 sites. Our dataset included 13 forest sites, 12 grassland sites, 7 wetland sites, and 5 cropland sites, which together represented most of major ecosystem types (Fig. 1) in China.

2.2. ChinaFLUX measurements and flux data processing

ChinaFLUX measurements were conducted using the open path eddy covariance system (Yu et al., 2006), which collected the raw data at a frequency of 10 Hz. The CO_2 and H_2O fluxes were calculated and stored at 30 min interval. Standard meteorological variables, including net radiation (R_n), photosynthesis active radiation (PAR), air temperature (Ta), soil temperature (Ts), precipitation, and soil water content, were also collected simultaneously at each site (Yu et al., 2006). Energy closure exceeded 0.7 at all sites (Li et al., 2005), which indicates the reliability of ChinaFLUX measurements.

ChinaFLUX measurements were processed using traditional data quality controlling routes (Yu et al., 2006), including the three-dimensional rotation (Aubinet et al., 2000), the WPL correction (Webb et al., 1980), the canopy storage calculation, and the spurious data removal. Spurious data that were caused by rainfall, water condensation or system failure, and that were lower than the friction velocity (u*) threshold, which was calculated following Reichstein et al. (2005), were removed.

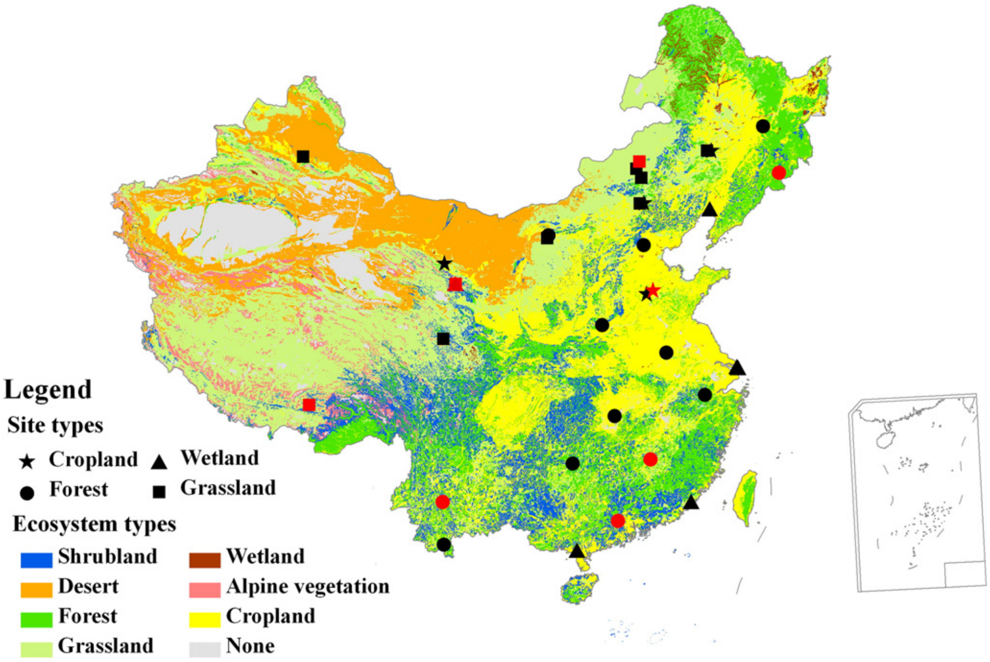

Fig. 1. Distribution of the 37 sites according to ecosystem types. The background is a vegetation map that is based on the Editorial Committee of Vegetation Map of China (2007). The red sites are ChinaFLUX sites while the black sites are other sites collected from literatures. The map was generated using ArcGIS 10.0 software.