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Regional representativeness assessment and improvement of eddy flux observations in China

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HIGHLIGHTS

- The network of flux towers performed well in representing the environment of more than half of China.
- The towers in wetlands and barelands were poorly represented.
- Representativeness increased with towers added in forests, grasslands, wetlands and barelands.
- Substantial gains in representation were achieved by adding new towers on the Tibet Plateau.

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ABSTRACT

Both the amounts of data describing the site-scale carbon flux at a high temporal and spatial resolution collected in China and the number of eddy covariance flux towers have been increasing during the last decade. To correctly upscale these fluxes to the regional and global level, the representativeness of the current network of flux towers must be known. The present study quantifies the representativeness of the flux network for the regional carbon exchange. This analysis combined the total solar radiation, air temperature, vapor pressure and the enhanced vegetation index to indicate the environmental characteristics of each 1-km pixel cell and flux tower. Next, the Euclidean distance from each pixel to the tower was calculated to determine the representativeness of the existing flux towers. To improve the regional representativeness, additional tower locations were pinpointed by identifying and clustering the underrepresented areas. The existing network of flux towers performed well in representing the environmental conditions of the middle and the northeastern portions of China. The well-represented areas covered 60.9% of the total areas. The towers in croplands and grasslands represented the vegetation types well, but the wetlands and barelands were poorly represented. The representativeness of the flux network increased with the addition of nine towers located in forests, grasslands, wetlands and barelands. The representativeness of 27.5% of the land areas improved. In addition, the well-represented areas were enlarged by 15.2%. Substantial gains in representation were achieved by adding new towers on the Tibet Plateau. The representativeness of the northwest and southwest was improved less significantly, suggesting that more towers are required to capture certain ecosystem behaviors.

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1. Introduction

Terrestrial ecosystems play an important role in the global carbon cycle, especially in the context of global change and climate policy-making (Yu et al., 2013). Terrestrial ecosystems exchange approximately 120 Gt of carbon per year with the atmosphere through the processes of photosynthesis and respiration (Gonzalez-Meler et al., 2004; Schlesinger, 1997). A small change in terrestrial carbon exchange could have a significant impact on the CO_2 increment in the atmosphere (Amthor, 1997). Previous studies have indicated that a large number of climatic (temperature, radiation, precipitation), geochemical (nutrients, soil composition) and ecological (species, age) factors affect the terrestrial carbon cycle (Chapin et al., 2002; Chen et al., 2013; Granier et al., 2007; Thornton et al., 2002). Therefore, accurate quantification of the capability of carbon exchange in various terrestrial ecosystems is essential for understanding the global carbon cycle (Canadell et al., 2004).

By observing atmospheric turbulence, the eddy covariance technique is one of the most direct and defensible methods to estimate the exchanges of carbon dioxide, water vapor and heat between the atmosphere and the land surface. The technique is closely related to physiological and ecological processes and can reflect the seasonal and interannual variability of carbon fluxes (Baldocchi et al., 2001; Chen

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et al., 2013). Since being established in the early 1990s, eddy covariance flux towers have provided continuous measurements of the ecosystem-level net exchange of carbon (Wofsy et al., 1993). The FLUXNET is the global network of flux towers (Baldocchi et al., 2001). There are currently approximately 541 towers registered on the FLUXNET (http://www-eosdis.ornl.gov/FLUXNET/), which are distributed in different ecosystems and climate zones all over of the globe (Baldocchi, 2008).

The Chinese Terrestrial Ecosystem Flux Observation and Research Network (ChinaFLUX), launched in 2002, fills an important regional gap in FLUXNET and increases the number of ecosystem types being monitored by long-term observations (Yu et al., 2006). Since its establishment, ChinaFLUX has developed rapidly and expanded from the initial eight sites into a national scale network, with observation sites covering most of the terrestrial ecosystem types in China (Fu et al., 2010). The network of flux towers in China provides extensive and reliable measurements of the CO_2, H_2O and energy fluxes with high temporal and spatial resolution, which enables the estimation and prediction of the respective spatiotemporal variability of the carbon and water cycles under the global climate change scenario (He et al., 2010; Fu et al., 2010; Yu et al., 2013; Wang et al., 2013). To correctly upscale these fluxes to regional and global level, the representativeness of the current network is an important aspect to consider (Sulkava et al., 2011).

The representativeness of a network refers to the ability to reproduce the main characteristics of the quantities or processes of the population under study (Sulkava et al., 2011). Several studies have attempted to quantify the representativeness of the flux network for the carbon exchange of the various ecosystems (Nappo et al., 1982; Valentini, 2003). The methods used in these research studies could be summarized into two approaches: cluster-based and pixel-based. Although both approaches eventually use the Euclidean distance in the representativeness quantification, the first approach additionally delineates ecoregions using a k-means cluster analysis. The cluster-based method has been used intensively, see, e.g., Hargrove and Hoffman (2003), Hargrove and Hoffman (2004a,b), Hoffman et al. (2008, 2013) and Sulkava et al. (2011). The second approach directly calculates the Euclidean distances between the pixels and the tower sites. Recently, this approach has been used in many previous investigations to determine the network representativeness at a range of spatial and temporal scales (Carvalhais et al., 2010; Xiao et al., 2011; Yang et al., 2008).

Despite the relatively large number of flux towers in operation across China, the representativeness of the current flux network is still insufficient. Currently, the previous studies are primarily performed at individual geographic points. The tower measurements only represent fluxes at the scale of the tower footprint (i.e., the ecosystem level) ranging from a few hundred meters to several kilometers (Gong et al., 2009; Mi et al., 2006; Shuang et al., 2009; Xiao et al., 2012). Wang et al. (2014) recently studied the spatial distribution of flux towers in relation to the newly generated flux ecoregions and compared the land areas of ecoregions with the existing geographical regionalization. China is characterized by a complex topography, heterogeneous regional climates and various types of ecosystems (Yu et al., 2006). Although individual towers provide important information about the carbon flux in the immediate area surrounding each tower, the regional representativeness of the flux networks will influence the accuracy of the gridded flux estimates derived from tower fluxes (Xiao et al., 2012). Therefore, it is necessary to determine the degree of the flux environment across China represented by the existing network of eddy flux towers.

Quantifying the representativeness of the network is important for optimal network design, thus avoiding unnecessary duplication and maximizing the coverage of the monitoring network. This study utilizes data collected from flux towers at 91 different locations to reflect the existing flux network in China. To maximally improve the representativeness capacity of the current network, new towers were also proposed. Thus, the specific objectives of this study are to (1) estimate the representativeness of the flux towers on the regional scale and (2) determine the optimal additional tower locations.

2. Data and methods

2.1. Data

2.1.1. Tower locations

There are 91 flux towers in mainland China that were used in this study, which cover the major ecosystem types in China (Fig. 1). These 91 towers were grouped into the following vegetation types: coniferous forests (CF, 9 towers), broadleaf forests (BF, 14 towers), mixed forests (MF, 8 towers), grasslands (GL, 19 towers), wetlands (WL, 8 towers), croplands (CL, 26 towers), and barelands (BL, 7 towers) (Table A.1). Fig. 1 shows the distribution of the collected flux towers.

2.1.2. Selection of the environmental variables

Both the water and CO_2 flux exchanges were associated with the patterns of the meteorological variables, such as wind, temperature, precipitation and sunlight (Qin et al., 2008; Gao et al., 2013). Three meteorological variables, i.e., total solar radiation (RAD), air temperature (TEM), and vapor pressure (VAP), were chosen to represent the land–atmosphere energy and water exchanges, which have a direct impact on vegetation photosynthesis and respiration (Dan et al., 2005). For example, Wang et al. (2008) found that air temperature was one of the most important factors that controlled the patterns and variations of CO_2 exchange between the atmosphere and the steppe. Gao et al. (2013) also reported that the temperature increase had a greater influence than the precipitation changes on productivity in the Tibetan Plateau region. Thomas et al. (2011) found that the solar radiation had the largest influence on the daily values of the CO_2 fluxes, while temperature appeared to be the driver of the ecosystem respiration variation.

The vegetation indices derived from the satellite images are very useful to model and predict the vegetation carbon exchange (Gurung et al., 2009). The enhanced vegetation index (EVI) was selected because the vegetation physiological properties have an important effect on carbon exchange (Yang et al., 2008). The EVI is less sensitive to soil and atmospheric effects than the normalized difference vegetation index (NDVI) because it incorporates the blue spectral band. The EVI is directly related to the photosynthetic production of plants and indirectly related to the green biomass (Huete et al., 2002). As a result, the EVI remains sensitive to increases in canopy density beyond the level where the NDVI becomes saturated (Huete et al., 2002). Xiao et al. (2004) also found that the EVI had a stronger linear relationship with the gross primary production than did the NDVI.

2.1.3. Data sources

To analyze the representativeness within and among the years of operation of the existing network, we chose a spatial resolution of 1 km and a temporal resolution of 1 month in the period of 2005–2010. The climate data, i.e., RAD, TEM, and VAP, of 728 weather stations (China Meteorological Data Sharing Service System, http://cdc.cma.gov.cn/home.do) were interpolated using the ANUSPLIN package (Hutchinson, 1991, 1995, 1998, 2002). The monthly meteorological data were interpolated using thin plate smoothing splines based on the topography. Data from Taiwan were not included in this study. Before the 1-km resolution dataset was developed, a rigorous quality control process was used to ensure the accuracy of data from the weather stations. This process involves careful outlier identification and errors correction, based on the method of Feng et al. (2004). A total of 1.46%, 1.09% and 1.25% of the monthly values of RAD, TEM, and VAP were eliminated respectively. The remaining quality control passed meteorological data was spatially interpolated to 1-km resolution. Lots of data cleaning and quality control were performed also when the interpolations were proceeding.

To calculate the EVI of each pixel and tower, we formed a mosaic of the MODIS tiles and resampled this mosaic with the MODIS Reprojection Tool MOD13A3 (https://lpdaac.usgs.gov/products/modis_products_table/mod13a3). The 1:1,000,000 scale vegetation map of 2005 in China (Editorial Board of Vegetation Map of China, 2007) was

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