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Estimating the spatial pattern of soil respiration in Tibetan alpine grasslands using Landsat TM images and MODIS data

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ABSTRACT

Monitoring soil respiration (R_s) at regional scales using images from operational satellites remains a challenge because of the problem in scaling local R_s to the regional scales. In this study, we estimated the spatial distribution of R_s in the Tibetan alpine grasslands as a product of vegetation index (VI). Three kinds of vegetation indices (VIs), that is, normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and modified soil adjusted vegetation index (MSAVI), derived from Landsat Thematic Mapper (TM) and Moderate-resolution Imaging Spectroradiometer (MODIS) surface reflectance product were selected to test our method. Different statistical models were used to analyze the relationships among the three VIs and R_s. The results showed that, based on the remote sensing data from either MODIS or Landsat TM, exponential function was the optimal fit function for describing the relationships among VIs and R_s during the peak growing season of alpine grasslands. Additionally, NDVI consistently showed higher explanation capacity for the spatial variation in R_s than EVI and MSAVI. Thus, we used the exponential function of TM-based NDVI as the R_s predictor model. Since it is difficult to achieve full spatial coverage of the entire study area with Landsat TM images only, we used the MODIS 8-day composite images to obtain the spatial extrapolation of plot-level R_s after converting the NDVI_MODIS into its corresponding NDVI_TM. The performance of the R_s predictor model was validated by comparing it with the field measured R_s using an independent dataset. The TM-calibrated MODIS-estimated R_s was within an accuracy of field measured R_s with R^2 of 0.78 and root mean square error of 1.45 gC m^{-2} d^{-1}. At the peak growing season of alpine grasslands, R_s was generally much higher in the southeastern part of the Tibetan Plateau and gradually decreased toward the northwestern part. Satellite remote sensing demonstrated the potential for the large scale mapping of R_s in this study.

1. Introduction

Soil respiration (R_s) is an important process in the carbon cycle of terrestrial ecosystems (Raich and Schlesinger, 1992). At an annual scale, R_s is estimated to contribute around 75×10^{15} gC year^{-1} to the global carbon budget and is second only to oceans in the magnitude of the gross CO_2 flux to the atmosphere (Schlesinger and Andrews, 2000). Thus, small changes in the rate of R_s may alter the annual C sink of terrestrial ecosystems (Cox et al., 2000; Trumbore, 2006). Accurately estimating R_s, as well as determining the effect of ecological factors on R_s, is the key to evaluating the role of soil biological processes in ecosystem carbon cycling (Fang et al., 1998; Craine et al., 1999; Chen et al., 2011).

R_s is not entirely produced by the decomposition of soil organic matter (SOM) (Kuzyakov and Larionova, 2005). As most soils are covered with vegetation, root-derived CO_2 contributes to CO_2 efflux from the soil as well. Photosynthesis stimulates R_s after the translocation of the recent photosynthate to roots and root-associated soil microbes (Moyano et al., 2007). Although large amounts of fresh carbon supply from photosynthesis serve as substrate for respiration, they may inhibit the decomposition of plant residues (de Graaff et al., 2010) and determine the SOM decomposition (Balogh et al., 2011). Bader and Cheng (2007) also found that the temperature response of R_s is mediated by fresh carbon supply or by current photosynthesis capacity. Therefore, R_s is closely correlated with current photosynthesis, which has been demonstrated clearly by previous studies (Högberg et al., 2001; Pendall et al., 2001; Tang et al., 2005; Moyano et al., 2007). Because large surveys of plant photosynthesis are virtually impossible to conduct at the regional scale, a proxy for plant photosynthesis, which can

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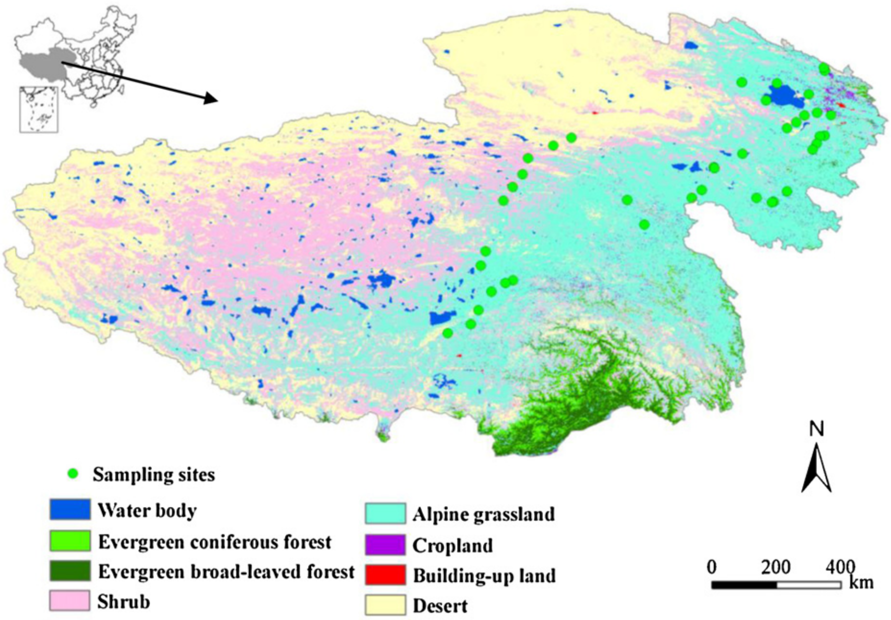

Fig. 1. Field sampling sites of soil respiration during the peak growing season of alpine grasslands, and land cover data from MODIS in the Tibetan Plateau in 2006.

explain the spatial variations in R_s, is required. The plant biomass is a good candidate, because it can strongly influence the rate of R_s (Fang et al., 1998; Han et al., 2007; Geng et al., 2012).

An understanding of grassland C dynamics is essential to clarify the contribution of grassland ecosystems to the global C budget (Scurlock and Hall, 1998). When greenness is near peak value in annual grassland communities, biomass and photosynthesis both reach the maximum and are closely related (Reeves et al., 2006). At the peak growing season of alpine grasslands in the Tibetan Plateau, belowground biomass is found to be the most important driving factor for large-scale variations in R_s (Geng et al., 2012).

Through measuring the reflected radiation from plant canopies, remote sensing techniques can be used to evaluate the biophysical parameters of plants within the sensor's field of view (Guo et al., 2011). The application of remote sensing in grasslands worldwide has been especially successful because of the relative structural simplicity of these ecosystems (versus, for example, that of woodlands or forests), as well as the tendency of the grasslands, especially those dominated by annual grasses, to be green for a significant fraction of the year (Wylie et al., 2002; Butterfield and Malmstrom, 2009). Numerous studies have shown that vegetation indices such as the normalized difference vegetation index (NDVI) can be strongly correlated with grassland biomass (Brinkmann et al., 2011) and are often used as tools for detecting and quantifying large-scale changes in grassland processes associated with global change (Cleland et al., 2006; Brinkmann et al., 2011; Ouyang et al., 2012). To date, limited studies have incorporated satellite-level remote-sensing data and R_s measured in the field. Thus, examining whether satellite-level remote-sensing data can be used to estimate R_s is necessary.

Landsat data with high spatial resolution have proven extremely useful in monitoring changes in land surfaces (Vogelman et al., 2001), but the 16-day revisit cycle and frequent cloud contamination have limited the application of Landsat over a large spatial scale, especially in regions with very unstable atmospheric conditions (e.g. Tibetan Plateau). The Terra or Aqua Moderate-resolution Imaging Spectroradiometer (MODIS) provides frequent coarse-resolution observations and is crucial for the timely monitoring of larger region. Thus, combining the Landsat and the MODIS data may be useful in monitoring the spatial distribution of R_s across a large area. This research explores the feasibility of using the multispectral Landsat TM images and MODIS data in predicting spatial patterns of R_s in the mid-growing season of alpine grasslands in the Tibetan Plateau. The primary objective of this study is to determine the application of broadband VIs, which can be estimators of plant biomass, to explain the spatial variation in R_s of the alpine grasslands in the Tibetan Plateau.

2. Methods

2.1. Study area

This study area is located in Qinghai-Xizang (Tibetan) Plateau in Southwest China (78.3°–103.1°E, 26.5°–39.5°N). The Tibetan Plateau is the highest and largest plateau on earth, with a mean elevation of about 4 km above sea level (asl). The mean annual temperature on the plateau is only 1.6 °C and its annual precipitation is around 413 mm (Yang et al., 2009). Greater than 60% of the plateau is covered by natural alpine grasslands (alpine steppe and meadow) (Li and Zhou, 1998). Moreover, a large part of the plateau has not been disturbed by human activities. Within the distribution area of alpine grasslands, 42 sites were selected for R_s measurements along a transect which stretches from 30.31 to 37.69°N and 90.80–101.48°E, and elevations from 2.925 to 5.105 km asl during late July and mid-August of 2006 (Fig. 1), when high convective activity and monsoon precipitation were concentrated (Yang et al., 2007). A detailed description of the sample sites can be found in Geng et al. (2012).

2.2. Field measurements

At each field measurement site, the sample data included diurnal soil respiration rate (R_s), soil temperature at 0–10 cm depth (T_s), soil moisture at 0–5 cm depth (SM), aboveground biomass (AGB) and belowground biomass (BGB). The detailed description of the field sampling design and the field data collection protocol can be found in Geng et al. (2012).

2.3. Remote sensing data

The Landsat Level 1 terrain corrected images (L1T, resolution = 30 m) were recorded by Landsat-5 TM instrument, and were