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Original Articles

Uncertainty in simulating regional gross primary productivity from satellite-based models over northern China grassland

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ABSTRACT

Large-scale estimation of regional terrestrial gross primacy production (GPP) can improve our understanding of carbon cycle. However, model based estimates are subject to uncertainty. In this study, eight satellite-based models (i.e. VPM, TG, GR, VI, CFIX, ECLUE, VPRM and MODIS-GPP) were compared for GPP simulation in northern China grassland based on 17 site-year eddy covariance measurements, meteorological data and satellite data. Also, the regional spatial–temporal GPP patterns during 2001–2013 in northern China grassland were simulated and their uncertainties were quantified. The results showed that the model simulations exhibited significant correlations with observed GPP across these eight models and R^2 or pseudo R^2 ranged between 0.64 and 0.89 ($p < .001$), ECLUE model performed best. The annual grassland GPP had been growing in fluctuations from 2001 to 2013, with the averaged value of 241.8 $g\,C\,m^{-2}\,a^{-1}$. Substantial spatial heterogeneity existed in grassland GPP, increasing from the west to the east. The disparities of satellite-based model structures resulted in the overall 49% relative uncertainty in regional simulation of GPP, which was high in area with arid dry climate. Our study highlighted the uncertainty traced back to model approaches under different environmental stresses (photosynthetically active radiation, soil water content and air temperature). For the accurate simulation of grassland GPP, uncertainty in alpine grassland and arid cold area on regional grassland GPP should be focused.

1. Introduction

Gross primary production (GPP) defined as the overall rate of fixation of carbon through the process of vegetation photosynthesis is the largest global CO_2 flux driving several ecosystem functions, such as respiration and growth (Beer et al., 2010). Large-scale estimation of terrestrial GPP for regions, continents, or the globe can improve our understanding of the feedbacks between the terrestrial biosphere and the atmosphere in the context of global change and facilitate climate policy-making (Hilton et al., 2015; Running et al., 2000; Schaefer et al., 2012; Xiao et al., 2008; Yuan et al., 2015). Accounting for 25% of the earth land surface and 10% of global carbon stocks, grassland plays an important role in global carbon cycling (Scurlock et al., 2002). And grassland in northern China (2.38 million km^2) accounts for 9.92% of the world's total grasslands (Fan et al., 2007; Scurlock and Hall, 1998). Simulations of GPP in northern China grassland are fundamental for the understanding of carbon storage and biogeochemical dynamics of terrestrial ecosystems (Luo et al., 2002).

GPP models can be classified into process-based models (Aber et al., 1996; Farquhar et al., 1980), satellite-based models (Xiao et al., 2004; Yuan et al., 2007) and empirical models (Wylie et al., 2007). These GPP models vary greatly in complexity, intended application, and their representation of physical and biological processes (Schaefer et al., 2012). In particular, satellite-based models provide opportunities for monitoring the spatial and temporal dynamics of GPP due to extensive satellite observations (Wang et al., 2010). As a part of integrated ecosystem models, the satellite-based models (including Vegetation Photosynthesis Model (VPM), Temperature and Greenness (TG), Vegetation Index model (VI), Greenness and Radiation model (GR), Carbon Fix model (CFIX), Eddy Covariance-Light Use Efficiency model (ECLUE), Vegetation Production and Respiration model (VPRM), Moderate Resolution Imaging Spectroradiometer GPP algorithm

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(MODIS-GPP) etc.) have been used to estimate GPP at various spatial and temporal scales because they rely on simple algorithms to estimate GPP (Beer et al., 2007; Gitelson et al., 2006; Jung et al., 2008; Sims et al., 2008; Wang et al., 2010; Wu et al., 2010; Xiao et al., 2004; Cai et al., 2014a,b; Yuan et al., 2014a,b). However, it is further recognized that uncertainties of satellite-based models themselves are still rather large, both in terms of parameter-based, and model structure related uncertainty (He et al., 2014; Jia et al., 2016; Wu et al., 2010; Yuan et al., 2015). To develop robust simulation of terrestrial GPP, a thorough understanding of model uncertainties should lead to a critical review of current modeling performance and avenues to improve known limitations (Jung et al., 2007). At present, relatively few studies have comprehensively described the uncertainties of GPP model results at large-region scale.

In this paper, we chose eight satellite-based models to capture the spatial-temporal patterns of grassland GPP in northern China and analyze their uncertainty propagated from different model structures. The specific objectives were (1) to determine the accuracy of satellite-based models in simulating GPP and provide a relatively objective large-scale GPP simulation in northern China grassland; (2) to quantify the relative uncertainty of regional GPP simulation caused by various model approaches.

2. Methods and data

2.1. Study area

The northern China grassland covers 2.38 million km^2 (Fig. 1). The mean annual temperature (MAT) and the mean annual precipitation (MAP) range from −3.1 to 8.9 °C and 62.7 to 694 mm, respectively and altitudes from 669 to 1435 m (Yang et al., 2010). The grassland zones in the study area includes nine grassland types: alpine meadow (AM), alpine steppe (AS), alpine desert-steppe (AD), temperate meadow-steppe (TM), temperate steppe (TS), montane meadow (MM), warm-temperate tussock & shrub-tussock (WT), tropical tussock & shrub-tussock (TT), and temperate desert-steppe (TD) (Chinese Academy of Sciences, 2001). According to Köppen–Geiger climate classification (Kottek et al., 2006), 35% area is covered by cold desert climate(BWk), followed by 31% tundra climate (ET), 13% cold semi-arid climate (BSk), 9% cool summer continental climate (Dwc), and 7% warm summer continental climate (Dwb). The remaining parts sum up 5% with hot summer continental climates (Dwa), hot summer humid continental climate (Dfa), warm summer humid continental climate (Dfb), winter dry boreal climate (Dfc), hot summer subtropical climate (Cwa), and warm summer subtropical climate (Cwb).

2.2. Description of satellite-based models

This study applied eight satellite-based models to simulate the regional GPP (Table 1), including TG, GR, VPM, VI, CFIX, ECLUE, MODIS-GPP and VPRM. Two of them are linear models (TG and GR) based on satellite data (Sims et al., 2008; Gitelson et al., 2006), while the others are Light Use Efficiency (LUE) model, which hypothesizes that plants harvest light to productivity according to the availability of resources. LUE model is built on two assumptions (Running et al., 2004): (1) GPP is directly related to the absorbed photosynthetic active radiation (APAR) through LUE, and (2) LUE may be reduced below its potential value by environmental stresses (Landsberg, 1986). Thus, the general form of LUE model is:

$$GPP = PAR \times fPAR \times LUE_{\max} \times f\,(T_S, W_S, \ldots) \tag{1}$$

where *PAR* is the incident photosynthetically active radiation (MJ m^{-2}) per time period, *fPAR* is the fraction of *PAR* absorbed by the vegetation canopy (APAR), LUE_{max} is the maximum LUE (g C m^{-2} MJ^{-1} APAR) without environment stress, *f* is a scalar varying from 0–1 representing the function from limiting environment stress, T_s *and* W_s are temperature and water regulation scalars. More information for the models was described in Supporting information.

2.3. Data sets

2.3.1. Eddy covariance flux measurements

We utilized 17 site-year eddy covariance (EC) measurements from eight grassland sites, with elevation ranging from 3000 to 4800 m, in 2003–2013 on the northern China grassland. These sites represented the dominant grasslands in the region: Qinghai-Tibet shrub meadow

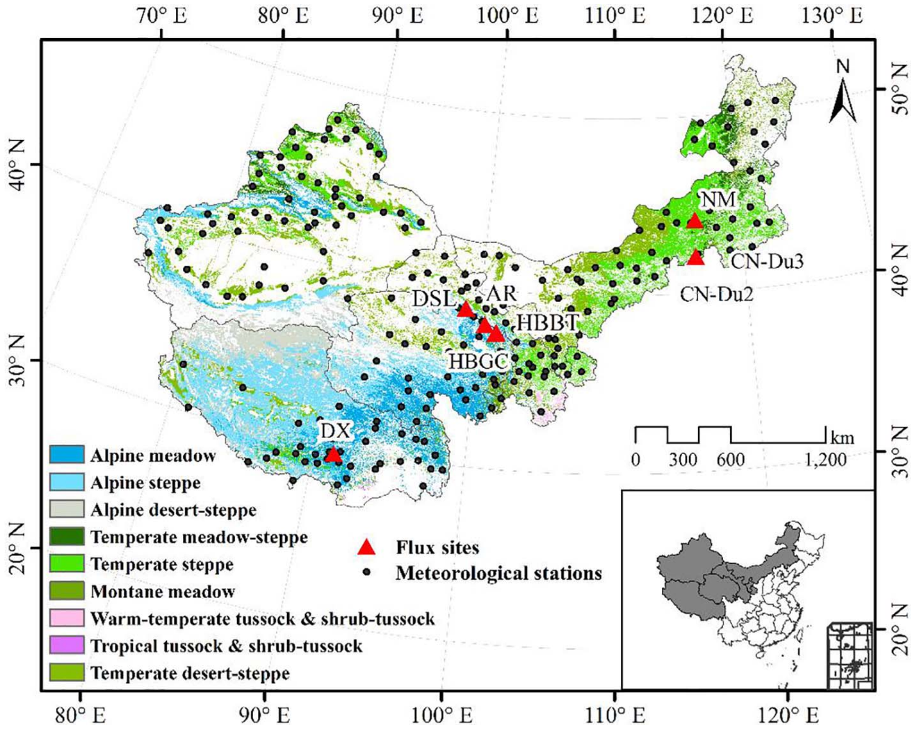

Fig. 1. The spatial distribution of 8 eddy covariance flux sites and 225 meteorological stations over northern China grassland.

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