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Impact of estimated solar radiation on gross primary productivity simulation in subtropical plantation in southeast China

Dengqiu Li [a,b,*], Weimin Ju [b,*], Dengsheng Lu [a,c], Yanlian Zhou [d], Huimin Wang [e]

[a] Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystem and Carbon Sequestration, School of Environmental & Resources Sciences, Zhejiang A & F University, Lin'an, Zhejiang Province 311300, China

[b] International Institute for Earth System Sciences, Nanjing University, Jiangsu Center for Collaborative Innovation in Geographic Information Resource Development and Application, Nanjing, Jiangsu Province 210023, China

[c] Center for Global Change and Earth Observations, Michigan State University, 1405 S. Harrison Road, East Lansing, MI 48864, USA

[d] School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, Jiangsu Province 210023, China

[e] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

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Abstract

Sunshine duration is widely used to estimate solar radiation, but this estimated inherently contains some uncertainties, limiting its applications. This study investigated the impacts of the estimated solar radiation on simulated gross primary productivity (GPP), which were obtained using ecosystem models – light use efficiency model (LUE) and process-based model – Boreal Ecosystem Productivity Simulator (BEPS) at an evergreen coniferous forest ecosystem in southeast China. The models for solar radiation and diffuse radiation estimation were calibrated through observation data from nearby meteorological stations. The results showed that the established model could be successfully used to estimate solar radiation with high coefficient of determination (0.92) and low root mean square error (2.18 MJ m^{-2} day^{-1}), but the solar radiation was overestimated when the clearness index was less than 0.15 and underestimated when it was within the range of 0.2–0.35 or greater than 0.6. The estimated solar radiation has significant influence on the diffuse radiation estimation and GPP simulation comparing with using observations. The two ecosystem models reacted differently to the errors of estimated solar radiation. For the LUE model, the estimated solar radiation led to the underestimated GPP in growing season (May–October), and overestimated GPP during non-growing season (November–April) with the bias ranged from −11% to 10% depending on the month of a year. For the BEPS model, estimated solar radiation resulted in overestimated GPP in most months with the bias ranged from −6% to 20%. The difference between the simulated GPP based on these two sources of solar radiation could be counteracted to some extent at the annual scale, especially for LUE model.

Keywords: Sunshine duration; Solar radiation; Diffuse radiation; Gross primary productivity

1. Introduction

Forest ecosystem plays a pivotal role in the global carbon cycle and partially mitigates the rising atmospheric carbon dioxide (CO_2) concentration due to its role as a carbon sink (Pan et al., 2011). Understanding the forest

* Corresponding authors at: Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystem and Carbon Sequestration, Zhejiang A & F University, Lin'an, Zhejiang Province 311300, China. Tel.: +86 0571 63746360 (D. Li), International Institute for Earth System Sciences, Nanjing University, Nanjing, Jiangsu Province 210023, China. Tel.:+86 025 89685670 (W. Ju).

E-mail addresses: lidengqiu001@163.com (D. Li), juweimin@nju.edu.cn (W. Ju).

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Nomenclature

a–e_i	coefficients in solar radiation and diffuse radiation estimation models
ε_{max}	maximum light use efficiency
Ω	clumping index
A_{canopy}	canopy-level photosynthesis
A_{sun}	photosynthesis rates of sunlit leaf groups
A_{sh}	photosynthesis rates of shaded leaf groups
APAR	absorbed photosynthetically active radiation
BEPS	Boreal Ecosystem Productivity Simulator
fPAR	fraction of photosynthetically active radiation
GPP	gross primary productivity
GPP_s	simulated GPP by LUE and BEPS models
GPP_e	estimated GPP from EC measurement
LUE	light use efficiency model
L_{sun}	sunlit leaf area
L_{sh}	shaded leaf area
L	total leaf area
LAI	leaf area index
MBE	mean bias error
N	number of observations
Q_{obs}	observed values
Q_{est}	estimated values
R_0	extraterrestrial radiation on horizontal surface
R^2	coefficient of determine
R_b	directed radiation
R_d	diffuse radiation
R_{de}	diffuse radiation calculated from estimated solar radiation
R_{do}	diffuse radiation calculated from observed solar radiation
RMSE	root mean square error
R_s	solar radiation
R_{se}	estimated solar radiation
S	sunshine duration
S_0	day length
T_a	minimum air temperature
VPD	vapor pressure deficit

carbon dynamics via ecosystem models is necessary for investigating the driving forces and mechanism of carbon sequestration (Pommerening et al., 2011; Richardson et al., 2012). Global solar radiation (R_s) is an essential input variable to ecosystem models. It provides the primary energy source driving the physical and biochemical processes (transpiration and photosynthesis) of plant and determining forest gross primary productivity (GPP) (Mercado et al., 2009). Unfortunately, the continuous R_s measurement is often not available at many forest regions (Adaramola, 2012; Liu et al., 2009a; Polo et al., 2015), and has to be estimated from other available meteorological observations (Angstrom, 1924; Besharat et al., 2013; Prescott, 1940; Yorukoglu and Celik, 2006). The impact of estimated R_s (R_{se}) on ecosystem models are mainly focused on the prediction of crop yields (cotton, maize, peanut, rice, etc.) around the world (Abraha and Savage, 2008; Garcia y Garcia et al., 2008; Phakamas et al., 2013; Trnka et al., 2007). However, fewer studies focused on the impact of R_{se} on the calculation of GPP in forest ecosystems, although these systems play an important role in global terrestrial carbon cycle.

The impacts of R_{se} on the outcome of ecosystem models are related to the model structure. The overall effects of bias in R_{se} might be canceled out because the biases are more or less normally distributed with a mean of zero and the relationships between R_s biases and yield estimates are more or less linear (Pohlert, 2004; Xie et al., 2003). It was also found that R_{se} produced deviations in excess of $\pm 25\%$ in site-specific yield forecast because of the complexity of the model response (Trnka et al., 2007, 2005). In recent decades, a variety of models have been developed for calculating forest GPP at site, regional and global scales, embracing light use efficiency (LUE) models and process-based ecological models (Cai et al., 2014; Chen et al., 2012; Cramer et al., 2001; Running and Coughlan, 1988; Xiao et al., 2004). The LUE models, such as CASA (Potter et al., 1993), Global Production Efficiency Model (GLOPEM) (Prince and Goward, 1995), MOD17 algorithm (Running et al., 2000), VPM (Xiao et al., 2004), EC-LUE (Yuan et al., 2007), assuming that GPP be directly related to absorbed photosynthetically active radiation (APAR), which is calculated as the product of R_s and fraction of photosynthetically active radiation (fPAR) (Yuan et al., 2014). They did not differentiate various responses of different leaves (sunlit and shaded leaves) to the environment and labeled as the "big-leaf" approach. The simulated GPP using these models is very sensitive to R_s due to the linear relationship between GPP and R_s (Yuan et al., 2014). For example, larger errors of these reanalysis radiation products (MERRA, ECMWF, and NCEP) resulted in larger uncertainty in GPP simulation comparing with these higher consistency satellite-derived radiation products (GLASS, ISCCP) in EC-LUE model (Cai et al., 2014). Another important GPP simulation strategy is to differ the sensitivity of carbon fixed by sunlit and shaded leaves to R_s, which named "two-leaf" model (Sprintsin et al., 2012). The sunlit leaves in the canopy are often light saturated as they both absorbed diffuse radiation (R_d) and directed radiation (R_b), whereas shaded leaves often suffer from a lower exposure to incoming radiation as only R_d reached (Mercado et al., 2009). GPP simulation using this kind of models is affected not only by R_s but also by the fractions of R_d (Sprintsin et al., 2012). This implies that the accuracy of R_{se} might have different impacts on "big-leaf" and "two-leaf" models. However,