Ecological Modelling 304 (2015) 34–43

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

A remote sensing model to estimate ecosystem respiration in Northern China and the Tibetan Plateau

Yanni Gao[a,b], Guirui Yu[a,*], Shenggong Li[a], Huimin Yan[a,*], Xianjin Zhu[a,c], Qiufeng Wang[a], Peili Shi[a], Liang Zhao[d], Yingnian Li[d], Fawei Zhang[d], Yanfen Wang[c], Junhui Zhang[e]

[a] *Synthesis Research Center of Chinese Ecosystem Research Network, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[b] *State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China*
[c] *University of Chinese Academy of Sciences, Beijing 100049, China*
[d] *Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining 810001, China*
[e] *Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China*

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 27 February 2015
Accepted 2 March 2015
Available online 22 March 2015

Keywords:
Ecosystem respiration
Gross primary production
Temperature
MODIS data
ChinaFLUX
PCM

ABSTRACT

Ecosystem respiration (R_e) is rarely quantified from remote sensing data because satellite technique is incapable of observing the key processes associated with soil respiration. In this study, we develop a Remote Sensing Model for R_e (ReRSM) by assuming that one part of R_e is derived from current photosynthate with the respiratory rate coupling closely with gross primary production (GPP), and the other part of R_e is derived from reserved ecosystem organic matter (including plant biomass, plant residues and soil organic matter) with the respiratory rate responding strongly to temperature change. The ReRSM is solely driven by the Enhanced Vegetation Index (EVI), the Land Surface Water Index (LSWI) and the Land Surface Temperature (LST) from MODIS data. Multi-year eddy CO_2 flux data of five vegetation types in Northern China and the Tibetan Plateau (including temperate mixed forest, temperate steppe, alpine shrubland, alpine marsh and alpine meadow-steppe) were used for model parameterization and validation. In most cases, the simulated R_e agreed well with the observed R_e in terms of seasonal and interannual variation irrespective of vegetation types. The ReRSM could explain approximately 93% of the variation in the observed R_e across five vegetation types, with the root mean square error (RMSE) of 0.04 mol C m^{-2} d^{-1} and the modeling efficiency (EF) of 0.93. Model comparison showed that the performance of the ReRSM was comparable with that of the RECO in the studied five vegetation types, while the former had much fewer parameters than the latter. The ReRSM parameters showed good linear relationships with the mean annual satellite indices. With these linear functions, the ReRSM could explain approximately 90% of the variation in the observed R_e across five vegetation types, with the RMSE of 0.05 mol C m^{-2} d^{-1} and the EF of 0.89. These analyses indicated that the ReRSM is a simple and alternative approach in R_e estimation and has the potential of estimating spatial R_e. However, the performance of ReRSM in other vegetation types or regions still needs a further study.

1. Introduction

Net ecosystem CO_2 exchange (NEE) is one of the main drivers for interannual variation in atmosphere CO_2 concentration (Trumbore, 2006). NEE is a small difference between two large fluxes of gross primary production (GPP) and ecosystem respiration (R_e). Accurate estimation of the spatio-temporal variation in NEE depends on the robust estimates of GPP and R_e.

Remote sensing (RS) technology has been used as a major tool in quantifying carbon balance of ecosystems at regional and global scales because it monitors ecosystem structure at high temporal and spatial resolution (Running et al., 2004; Rahman et al., 2005). There are various satellite-driven GPP models for estimating spatial GPP distribution from remote sensing data (e.g., Xiao et al., 2004; Running et al., 2004; Gitelson et al., 2006, 2012; Yuan et al., 2007; Sims et al., 2008; Wu et al., 2010). Yet, we lack similar methods for R_e estimation.

Ecosystem respiration is composed of different components that are determined by different mechanisms and factors. It is

* Corresponding authors at: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing 100101, China. Tel.: +86 10 64889432.
E-mail addresses: yugr@igsnrr.ac.cn (G. Yu), yanhm@igsnrr.ac.cn (H. Yan).

http://dx.doi.org/10.1016/j.ecolmodel.2015.03.001
0304-3800/

difficult for satellite technology to monitor various respiratory processes, especially those in the soil (Valentini et al., 2000; Running et al., 2004; Olofsson et al., 2008; Xiao et al., 2008; Tang et al., 2012), which limit the application of remote sensing data in R_e estimation. However, R_e showed close relationships with easily satellite-retrieved GPP (e.g., Knohl et al., 2005; Tang et al., 2005; Moyano et al., 2007, 2008; Larsen et al., 2007; Bahn et al., 2008; Gomez-Casanovas et al., 2012; Huang and Niu, 2013) and temperature (e.g., Lloyd and Taylor, 1994; Frank et al., 2002; Reichstein et al., 2003; Bond-Lamberty and Thomson, 2010) in most of ecosystems, and upon these relationships some empirical or semi-empirical satellite-driven R_e models were developed and validated at the plot or regional scale (Vourlitis et al., 2003; Gilmanov et al., 2005; Rahman et al., 2005; Schubert et al., 2010; Jägermeyr et al., 2014). However, extensive studies reported that the responses to GPP and temperature varied among the R_e components (e.g., Gaumont-Guay et al., 2008; Kuzyakov and Gavrichkova, 2010), and the current satellite-driven R_e models almost all neglected these differences. Therefore, we will develop a new Remote Sensing Model for R_e (ReRSM) based on the different responses of R_e components to the variations in GPP and temperature. Long-term eddy CO_2 flux data of five vegetation types (located in Northern China and the Tibetan Plateau) from the ChinaFLUX were used to assess the model performance. We also compared the estimated accuracy of the ReRSM with that of the RECO, which was a totally satellite-driven R_e model (Jägermeyr et al., 2014).

2. Materials and methods

2.1. Description of the ReRSM

Ecosystem respiration is mainly composed of five components (Fig. 1). They are plant growth respiration (R_g) and maintenance respiration (R_m) belonging to autotrophic respiration (R_a), and rhizomicrobial respiration (R_{rhi}, i.e., microbial respiration of rhizodeposits derived from living roots), microbial respiration of plant residues (R_{res}) and SOM decomposition (R_{SOM}) belonging to heterotrophic respiration (R_h).

$$R_e = R_g + R_m + R_{rhi} + R_{res} + R_{SOM} \quad (1)$$

It was reported that the substrates for plant growth respiration (R_g) (Amthor, 2000; Piao et al., 2010; Mahecha et al., 2010; Chapin et al., 2011) and rhizomicrobial respiration (R_{rhi}) (Kuzyakov and Cheng, 2001, 2004; Dilkes et al., 2004; Heinemeyer et al., 2006, 2007; Moyano et al., 2007, 2008; Gaumont-Guay et al., 2008; Kuzyakov and Gavrichkova, 2010; Mahecha et al., 2010) are both derived from current photosynthate, and their respiratory rates couple closely with GPP. During the process of plant photosynthesis, growth respiration (R_g) consumes some photosynthate to provide energy for satisfying growth demand. At the same time, part of photosynthate is transferred into rhizosphere soil at high rate in the form of root exudates, which can be rapidly utilized by rhizosphere microorganisms (R_{rhi}) (Kuzyakov and Cheng, 2001, 2004; Dilkes et al., 2004; Kuzyakov and Gavrichkova, 2010). Thus, we defined the components of R_g and R_{rhi} as GPP-derived respiration (R_{GPP}), and assumed that R_{GPP} can be represented by a fraction of GPP (a).

$$R_{GPP} = R_g + R_{rhi} = a \times \mathrm{GPP} \quad (2)$$

The substrates for plant maintenance respiration (R_m) (Amthor, 2000; Chapin et al., 2011; Kuzyakov and Gavrichkova, 2010), microbial respiration of plant residues (R_{res}) (Waksman and Gerretsen, 1931; Zhou et al., 2013) and soil organic matter (SOM) decomposition (R_{SOM}) (Bader and Cheng, 2007; Heinemeyer et al., 2007; Moyano et al., 2007, 2008; Gaumont-Guay et al., 2008) are separately derived from plant biomass, plant residues and SOM, and their respiratory rates respond strongly to variation in temperature under no water-limited conditions. Since plant biomass, plant residues and SOM are the organic matters that are stored in the ecosystems over a long term period, we defined them as reserved ecosystem organic matter (EOM) and their corresponding respiratory components as EOM-derived respiration (R_{EOM}). If we assumed that the differences among the responses of R_m, R_{res} and R_{SOM} to the variation in temperature are negligible and employed the widely used Lloyd and Taylor model (Lloyd and Taylor, 1994) to represent the temperature effect, R_{EOM} can be expressed as follows:

$$R_{EOM} = R_m + R_{res} + R_{SOM} = R_{ref} \times e^{E_0 * (1/(T_{ref}-T_0) - 1/(T+273.15-T_0))} \quad (3)$$

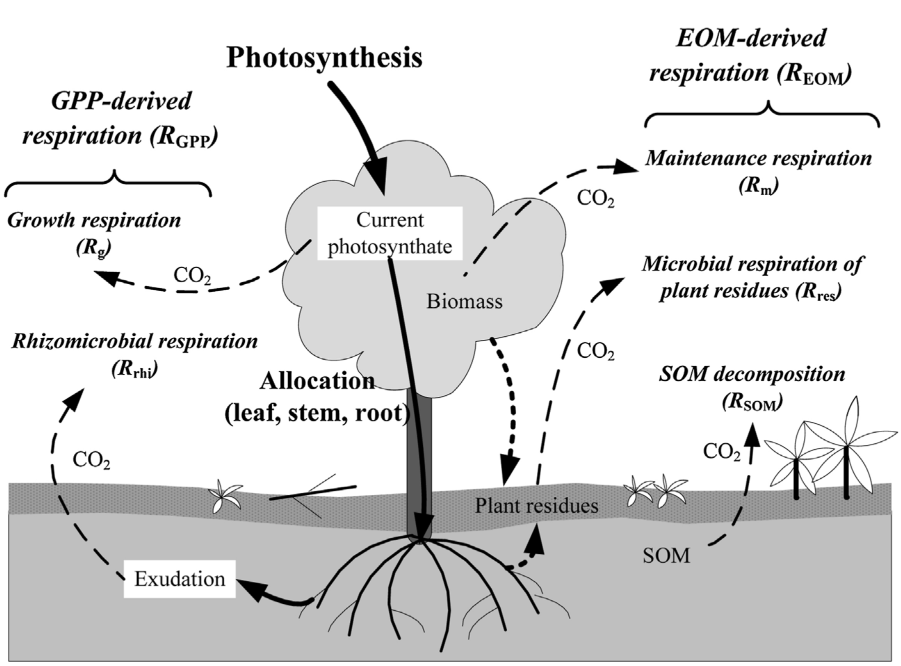

Fig. 1. Components of ecosystem respiration. SOM, soil organic matter; EOM, reserved ecosystem organic matter, including plant biomass, plant residues and SOM.