



Research paper

Responses of the terrestrial carbon cycle to drought over China: Modeling sensitivities of the interactive nitrogen and dynamic vegetation



Binghao Jia^{a,b,*}, Yuanyuan Wang^c, Zhenghui Xie^a

^a State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

^b Plateau Atmosphere and Environment Key Laboratory of Sichuan Province, Chengdu, China

^c Beijing Meteorological Observatory, Beijing, China

ARTICLE INFO

Article history:

Received 30 April 2017

Received in revised form 9 November 2017

Accepted 11 November 2017

Keywords:

Drought

Terrestrial carbon cycle

CLM4.5

Interactive nitrogen cycle

Dynamic vegetation

Standardized precipitation index

ABSTRACT

Drought can trigger both immediate and time-lagged responses of terrestrial ecosystems and even cause sizeable positive feedbacks to climate warming. In this study, the influences of interactive nitrogen (N) and dynamic vegetation (DV) on the response of the carbon cycle in terrestrial ecosystems of China to drought were investigated using the Community Land Model version 4.5 (CLM4.5). Model simulations from three configurations of CLM4.5 (C, carbon cycle only; CN, dynamic carbon and nitrogen cycle; CNDV, dynamic carbon and nitrogen cycle as well as dynamic vegetation) between 1961 and 2010 showed that the incorporation of a prognostic N cycle and DV into CLM4.5 reduce the predicted annual means and inter-annual variability of predicted gross primary production (GPP) and net ecosystem production (NEP), except for a slight increase in NEP for CNDV compared to CN. They also resulted in better agreement with the gridded flux data upscaled from eddy covariance observations (7.0 PgC yr^{-1}) of annual GPP over the terrestrial ecosystems in China for CLM4.5-CN (7.5 PgC yr^{-1}) and CLM4.5-CNDV (7.3 PgC yr^{-1}) than for CLM4.5-C (10.9 PgC yr^{-1}). Compared to the CLM4.5-C, the carbon-nitrogen coupling strengthened the predicted response of GPP to drought, resulting in a higher correlation with the standardized precipitation index (SPI; $r_C = 0.62$, $r_{CN} = 0.67$), but led to a weaker sensitivity of NEP to SPI ($r_C = 0.51$, $r_{CN} = 0.45$). The CLM4.5-CNDV had the longest lagged responses of GPP to drought among the three configurations.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

As a major sink in the global carbon cycle, terrestrial ecosystems have sequestered 25%–30% of anthropogenic carbon dioxide (CO_2) emissions for the past five decades (Le Quéré et al., 2009). Terrestrial ecosystems slow increases in atmospheric CO_2 concentration by sequestering carbon in the vegetation biomass and soils, providing a negative feedback mechanism in the climate–carbon system (Chen et al., 2011; Pan et al., 2011; Reichstein et al., 2013; Zhao and Running, 2010). The occurrence of extreme climatic events (e.g., drought) can affect the functioning of the carbon cycle in terrestrial ecosystems by reducing photosynthetic capacity or altering respiratory processes (Zeng et al., 2005; Zscheischler et al., 2014). Severe regional drought has become more frequent under a chang-

ing climate and is likely to increase in frequency for the foreseeable future (Dai, 2013; Qian et al., 2011; Stocker et al., 2013). China experienced frequent severe droughts during the second half of the 20th century (Zou et al., 2005) and faces a projected increase in drought risk in the future (Wang and Chen, 2014). Therefore, it is necessary to explore the impact of drought on the carbon fluxes of terrestrial ecosystems; this will advance our understanding of the mechanism of carbon and water coupling under drought conditions and provide information needed for policy-making.

Site-level measurements from a global observation network (Schwalm et al., 2010; Sun et al., 2006) and satellite-based observations (Zhang et al., 2012; Zhao and Running, 2010; Zscheischler et al., 2014) usually have been used to quantify the impacts of drought on the carbon fluxes of terrestrial ecosystems. Compared to in situ and satellite-based observations, process-based terrestrial carbon cycle models can better capture the coupling mechanism between increasing climate extremes and decreasing carbon uptake (Reichstein et al., 2013; Zeng et al., 2005) and have been used to examine the response of the terrestrial carbon cycle to droughts over China (Liu et al., 2014; Pei et al., 2013; Xiao et al., 2009; Yuan

* Corresponding author at: State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China.

E-mail address: bhjia@mail.iap.ac.cn (B. Jia).

et al., 2014). For example, Xiao et al. (2009) used a process-based biogeochemistry model, the Terrestrial Ecosystem Model, to investigate the impact of twentieth-century droughts on the terrestrial carbon cycle in China and found that severe and extended drought substantially reduced the countryside annual net primary production (NPP) and net ecosystem production (NEP). Moreover, results showed that strong decreases in NPP were mainly responsible for the anomalies in annual NEP during the drought periods; heterotrophic respiration also experienced a strong decrease, but with smaller magnitude (Xiao et al., 2009). Yuan et al. (2014) pointed that the multiyear precipitation reduction changed the regional carbon uptake of $0.011 \text{ PgC yr}^{-1}$ in Northern China from 1982 to 1998 to a net source of $0.018 \text{ PgC yr}^{-1}$ from 1999 to 2011, and the average maize yield from 1999 to 2011 was reduced by $440 \text{ kg ha}^{-1} \text{ yr}^{-1}$ compared with linear trend yields. During the summer of 2013, southern China experienced the strongest drought on record for the past 113 years, which significantly reduced the satellite-based vegetation index, GPP, and evapotranspiration (Xie et al., 2016) and altered the regional carbon cycle (Yuan et al., 2016).

As one of the most important factors in terrestrial carbon cycle, nitrogen (N) plays an important role in the coupling between carbon and water by affecting photosynthetic rates and stomatal conductance (Bonan and Levis, 2010; Gotangco Castillo et al., 2012; Thornton et al., 2009). The process of carbon–nitrogen–water coupling leads to a change in canopy transpiration; the changing transpiration then affects photosynthesis through water stress (Lee et al., 2013). Furthermore, N limitation can decrease the positive effect of CO_2 fertilization on the vegetation productivity in unmanaged ecosystems (Langley and Magonigal, 2010); leaf photosynthesis may be more sensitive to reduced stomatal conductance at elevated CO_2 levels when N is limited (McMurtrie et al., 2008). In addition, dynamic vegetation (DV) models have been designed to be coupled with some land surface models for the study of global ecosystem–climate interactions (Zeng et al., 2008). The incorporation of DV in land models has been found to reduce the seasonal variability in predicted leaf area and moisture fluxes (Gotangco Castillo et al., 2012) and enhance climate persistence in earth system models by introducing long-term memory to the earth system (Delire et al., 2004). However, few studies have examined the influences of including the N cycle and DV on simulating the responses of terrestrial carbon cycle to drought.

The process-based model, Community Land Model version 4.5 (CLM4.5) (Oleson et al., 2013) has an option for running a prognostic carbon–nitrogen model (Thornton et al., 2007) or a dynamic global vegetation model (Gotangco Castillo et al., 2012; Levis et al., 2004; Zeng et al., 2008) or both. In this study, it was used to present an analysis on the relationships between drought (indicated by the standardized precipitation index, SPI) and vegetation production in China. The model simulations were compared with gridded observational carbon flux data (Jung et al., 2009, 2011). The objectives of this study were to (1) explore the diverse impacts of the interactive N and DV on the simulated changes in the response of terrestrial ecosystem carbon cycle to drought, (2) investigate such responses across plant functional types and climatic regions, and (3) discuss why the carbon–nitrogen coupling and dynamical vegetation would predict different responses to drought compared to the carbon-only configuration.

2. Model and methods

2.1. Model descriptions

The CLM4.5 model is the latest version of the CLM family and contains detailed biophysics, hydrology, and biogeochemistry representations (Oleson et al., 2013). Compared to previous versions,

CLM4.5 has many new modifications in the physical and biogeochemical parameterizations (Bonan et al., 2011; Koven et al., 2013; Li et al., 2013; Oleson et al., 2013).

The CLM4.5 model can be operated with a dynamic carbon cycle only (CLM45-C) or with an interactive carbon–nitrogen cycle (CLM45-CN). In addition, the CLM45-CN model configuration includes an option to include vegetation dynamics (CLM45-CNDV). A general description of the carbon–nitrogen cycle and dynamic vegetation processes in CLM4.5 is provided in Section 2.1.1 and 2.1.2, respectively. Further detailed descriptions can be found in Oleson et al. (2013).

2.1.1. Carbon–nitrogen cycle

In the CLM45-CN model the biophysical framework of CLM (Oleson et al., 2013) is merged with the prognostic carbon and nitrogen dynamics of the terrestrial biogeochemistry model Biome-BGC (Biome BioGeochemical Cycles) (Thornton and Rosenbloom, 2005). The integrated model is fully prognostic with respect to all carbon and nitrogen state variables in the vegetation, litter, and soil organic matter, and retains all prognostic quantities for water and energy in the vegetation snow–soil column from CLM4.5. These state variables are tracked for leaf, live stem, dead stem, live coarse root, dead coarse root, and fine root pools.

In CLM45-CN, the maximum rate of carboxylation (V_{cmax}) for leaf-level photosynthesis is calculated as following (Thornton and Zimmermann, 2007):

$$V_{cmax} = V_{cmax25} \cdot f(T_v) \cdot f(DYL) \cdot \beta_t, \quad (1)$$

$$V_{cmax25} = N_a \cdot F_{LNR} \cdot F_{NR} \cdot a_{R25}, \quad (2)$$

where V_{cmax25} is the maximum rate of carboxylation at 25°C ; T_v and DYL are leaf temperature and day-length, respectively; N_a is the area-based N concentration, F_{LNR} , F_{NR} , and a_{R25} are three constant parameters, which represent the fraction of leaf N in Rubisco, the mass ratio of total Rubisco molecular mass to N in Rubisco, and the specific activity of Rubisco, respectively. β_t is a soil water stress function, representing the influences of soil moisture on leaf-level photosynthesis. In addition, soil water has a direct effect on the leaf stomatal conductance g_s (i.e., the inverse of stomatal resistance r_s) through the Ball–Berry conductance model expressed as Eq. (3) (Collatz et al., 1991):

$$\frac{1}{r_s} = g_s = m \frac{A_n}{c_s/P_{atm}} h_s + b\beta_t, \quad (3)$$

where m is a plant functional type (PFT) dependent parameter, A_n is leaf net photosynthesis, c_s is the CO_2 partial pressure at the leaf surface, P_{atm} is the atmospheric pressure, h_s is the leaf surface humidity, b is the minimum stomatal conductance, and β_t is a soil water stress function. The function β_t ranges from one when the soil is wet to near zero when the soil is dry and is given:

$$\beta_t = \sum_i w_i r_i, \quad (4)$$

where w_i is a plant wilting factor and depends on the soil water potential of each soil layer; r_i is the distribution of roots in layer i and depends on the plant functional type (Oleson et al., 2013). Eq. (4) suggests that soil moisture estimations affect the accuracy of terrestrial carbon fluxes through the soil water stress function β_t ; in turn, β_t has a large impact on soil water content simulation through the transpiration in each layer, called the “soil moisture sink term” (evapotranspiration loss) in the soil water equation (Jia et al., 2013a).

The canopy-level photosynthesis (or gross primary production, GPP) is derived by summing the sunlit and shaded leaf-level photosynthesis rates multiplied by the sunlit and shaded leaf area indices, including potential reductions due to limited availability of mineral

Download English Version:

<https://daneshyari.com/en/article/8846130>

Download Persian Version:

<https://daneshyari.com/article/8846130>

[Daneshyari.com](https://daneshyari.com)