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Accurate representation of leaf longevity is important for simulating ecosystem carbon cycle

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Abstract

Leaf longevity and leaf turnover rate are important plant traits relating to plant growth, leaf photosynthesis and respiration, plant canopy dynamic and many other factors, but dynamic global vegetation models only set inaccurate values for these factors. In this study, we firstly investigated the leaf longevities at major vegetation types based on 418 field measurements from around the world. By replacing the default leaf longevities in the Lund-Potsdam-Jena model (LPJ) with the revised values, we examined the changes in simulated carbon cycle caused by the revised parameters. The results suggested that the compiled observations of leaf longevity were significantly different from the default values in LPJ. Both the vegetation production and respiration of the simulated natural ecosystems showed significant changes based on the revised leaf longevity compared with the predictions developed using default model parameters. Of all of the variables, the aboveground and belowground litter pools showed the largest changes (about 10% globally). Globally, the default parameters induced a significant overestimation of terrestrial carbon sink by 3%, compared with a simulation using the revised parameters. Furthermore, the uncertainties in leaf longevity caused various uncertainties (5–30%) in the simulated carbon fluxes and carbon pools. The offset of biases in intermediate variables might result in rational final model outputs. Overall, more accurate leaf longevities are critical for simulating the vegetation distribution and ecosystem carbon cycle.

Zusammenfassung

Die Lebensdauer der Blätter und ihre Turnover-Rate sind wichtige Merkmale von Pflanzen. Sie stehen in Beziehung zum Pflanzenwachstum, zu Photosynthese und Respiration der Blätter, zur Kronendynamik und vielen anderen Faktoren, aber dynamische, globale Vegetationsmodelle verwenden nur ungenaue Werte für diese Faktoren. Wir ermittelten zunächst die Blattlebensdauer für wichtige Vegetationstypen (418 Erhebungen weltweit). Indem wir die Vorgabewerte aus dem Lund-Potsdam-Jena-Modell (LPJ) durch die revidierten Werte ersetzten, ermittelten wir die dadurch verursachten Änderungen im simulierten Kohlenstoffkreislauf. Die Ergebnisse zeigten, dass die zusammengetragenen Beobachtungen zur Blattlebensdauer sich signifikant von den Vorgaben des LPJ-Modells unterschieden. Sowohl Produktion als auch Respiration der Vegetation der simulierten Ökosysteme zeigten mit den überarbeiteten Werten signifikante Veränderungen gegenüber den mit Vorgabewerten errechneten Vorhersagen. Von allen Variablen zeigten die ober- und unterirdischen Streuvorräte die größten

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Veränderungen (durchgängig etwa 10%). Die Vorgabewerte verursachten eine signifikante Überschätzung der terrestrischen Kohlenstoffsenke um 3% im Vergleich zu einer Simulation mit den revidierten Werten. Darüber hinaus verursachten Unsicherheiten bei den Blattlebensdauern verschiedene Unsicherheiten (5-30%) bei den simulierten Kohlenstoffflüssen und –vorräten. Genauere Daten zur Blattlebensdauer sind entscheidend für die Simulation von Vegetationsverteilung und Kohlenstoffkreislauf im Ökosystem.

Keywords: Leaf longevity; Leaf turnover rate; Lund-Potsdam-Jena model; Ecosystem carbon cycle; Model uncertainty

Introduction

Dynamic global vegetation models (DGVMs) are indispensable tools for studying terrestrial ecosystem processes and their interactions with climate change (Prentice, Heimann, & Sitch, 2000; Wramneby, Smith, Zaehle & Sykes, 2008). Since the 1980s, the need to better understand and quantify the global behavior of terrestrial ecosystems as a major factor in earth system dynamics has driven the development of DGVMs (Sitch et al., 2003). Several of the fully integrated DGVMs, such as the Lund-Potsdam-Jena (LPJ) model and the Integrated BIosphere Simulator model (IBIS), which combine the biogeochemical and biogeographic modeling approaches have been developed (Foley et al., 1996; Sitch et al., 2003; Sato, Itoh, & Kohyama, 2007) and used widely to investigate and estimate the vegetation dynamics, biogeochemical processes, carbon balance and ecosystem responses to environmental changes on a regional or global scale (Kucharik et al., 2000; Dargaville et al., 2002; Yurova, Volodin, Agren, Chertov, & Komarov, 2010).

Nevertheless, DGVMs still contain many uncertainties in both model structures and parameters (Fisher et al., 2010; Wang et al., 2010; Yuan et al., 2012). It is well- known that DGVMs are globally parameterized models (Zaehle, Sitch, Smith, & Hatterman, 2005). However, imperfect knowledge of processes and limited observations restrict the model parameterization, and result in large model errors (Hallgren & Pitman, 2000; Snowling & Kramer, 2001). Wramneby et al. (2008) suggested that the parameter uncertainties in LPJ could lead to a shift in plant competitive balance. Zaehle et al. (2005) concluded that the uncertainty in parameters generated considerable uncertainty in global net primary production by controlling assimilation rate, plant respiration and water balance. Generally, different parameters represent the predominant influence on different processes. Jiang et al. (2012) suggested that the reFlative importance of parameters varied both temporally and spatially, and was shifted by climate inputs. Therefore, to assess the reliability of modeled scenarios and to identify parameters that require further development, it is necessary to examine the parameter uncertainties (White, Thornton, Running, & Nemani, 2000; Sykes, Prentice, Smith, Cramer, & Venevsky, 2001).

Leaf longevity and turnover rate are important plant traits and vary substantially among species (Chabot & Hicks, 1982; Kattge, Diaz, Lavorel, Prentice, & Leadley, 2011; Schleip, Lattanzi, & Schnyder, 2013); however, they are modeled roughly in current DGVMs. Previous studies regard leaf longevity and turnover rate as indicative of a plant's trade-off between productivity and persistence, as they determine the residence time of leaves and then constrain the circulation rate of carbon and nutrients to a certain extent (Reich, Walters, & Ellsworth, 1992; Schleip et al., 2013). Therefore, they are two critical parameters characterizing plant traits in vegetation models. Plant leaf longevities show large differences ranging from a few weeks to more than 10 years (Reich et al., 1992; Kikuzawa, 1995). DGVMs, however, generally assumed inaccurate values of leaf longevity and turnover rate for each plant type, and previous studies have indicated substantial differences between the default values and observations (Kikuzawa & Lechowicz, 2006). To our knowledge, few studies have calibrated the parameters of leaf longevity and turnover rate for major plant types worldwide. Therefore, it is necessary to investigate the uncertainties brought about by coarsely assigned leaf longevity and turnover rate, and the corresponding impacts on model outputs.

Several studies have approached the issue of parameterization uncertainty in DGVMs (White et al., 2000; Zaehle, Sitch, Smith & Hatterman, 2005; Wramneby et al. 2008), however, few of these are related to the parameters of leaf longevity and turnover rate. In this study, we adopted the LPJ model, which is typical of DGVMs as a family of models and has been used widely to estimate global or regional carbon cycle, both with respect to its representation of structural ecosystem components (plants and soil) and ecosystem processes (Sitch et al., 2003; Zaehle et al., 2005; Bondeau et al., 2007; Yurova et al., 2010). Then, the leaf longevity and turnover parameters for each plant functional type (PFT) were revised based on numerous observational datasets. Finally, the model was run with the default and revised parameter sets, respectively. By comparing the model outputs with default and revised parameter sets, we aimed to investigate the impacts of revised leaf longevity and turnover parameters on estimates of vegetation dynamics, ecosystem production and respiration, dynamic of carbon pools and carbon balance as modeled by LPJ.