



This discussion paper is/has been under review for the journal Geoscientific Model Development (GMD). Please refer to the corresponding final paper in GMD if available.

Improving the ISBA_{CC} land surface model simulation of water and carbon fluxes and stocks over the Amazon forest

E. Joetzjer¹, C. Delire¹, H. Douville¹, P. Ciais², B. Decharme¹, D. Carrer¹,
H. Verbeeck³, M. De Weirdt³, and D. Bonal⁴

¹CNRM-GAME, Groupe d'étude de l'atmosphère météorologique, Joint Unit CNRS/Meteo-France (UMR3589), av. Coriolis, 31057 Toulouse, France

²Laboratory of Climate Sciences and the Environment (LSCE), Joint Unit of CEA-CNRS, L'Orme des Merisiers, 91191 Gif-sur-Yvette, France

³Laboratory of Plant Ecology, Department of Applied Ecology and Environmental Biology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

⁴INRA, UMR EEF, 54280 Champenoux, France

Received: 15 December 2014 – Accepted: 17 January 2015 – Published: 11 February 2015

Correspondence to: E. Joetzjer (emilie.joetzjer@gmail.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

GMDD

8, 1293–1336, 2015

**Modeling stocks and
fluxes of water and
carbon over the
Amazon**

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

We evaluate the ISBA_{CC} land surface model over the Amazon forest, and propose a revised parameterization of photosynthesis, including new soil water stress and autotrophic respiration functions. The revised version allows the model to better capture the energy, water and carbon fluxes when compared to five Amazonian fluxtowers. The performance of ISBA_{CC} is slightly site-dependent but similar to the widely evaluated land surface model ORCHIDEE, based on different assumptions. Changes made to the autotrophic respiration functions, including a vertical profile of leaf respiration, leads to simulate yearly carbon use efficiency and carbon stocks consistent with an ecophysiological meta analysis conducted on three Amazonian sites. Despite these major improvements, ISBA_{CC} struggles to capture the apparent seasonality of the carbon fluxes derived from the fluxtower estimations. However, there is still no consensus on the seasonality of carbon fluxes over the Amazon, stressing a need for more observations as well as a better understanding of the main drivers of autotrophic respiration.

1 Introduction

Despite intense deforestation and land use change, the Amazon rainforest has acted as a long-term carbon sink (Phillips et al., 2008; Gatti et al., 2010; Gloor et al., 2012; Gatti et al., 2014; Espírito-Santo et al., 2014), meaning that the carbon uptake by photosynthesis exceeded on average, the carbon released by autotrophic respiration and decomposition.

Recent observations showed that the Amazon sink has already been weakened by environmental perturbations such as deforestation (Lewis et al., 2009; Aragao et al., 2014; Pan et al., 2011) and extreme droughts (Marengo et al., 2011; Gatti et al., 2014). Any change from sink to source of carbon would have profound impacts, including enhancement of global warming through a positive carbon feedback loop (Foley et al., 2003; Cox et al., 2000; Huntingford et al., 2013). The response of the Amazon sink

GMDD

8, 1293–1336, 2015

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to the combined pressures of deforestation and climate change would be dramatic, especially as a majority of climate models project dryer and longer dry seasons at the end of the century (Fu et al., 2013; Joetzjer et al., 2013).

Given the strong coupling between climate and the carbon cycle and the emergence of holistic Earth System Models (ESM), modeling the Amazon rainforest is an important challenge. However, carbon balance projections are still highly uncertain, especially in the tropics (Friedlingstein et al., 2006; Jones et al., 2013; Anav et al., 2013; Huntingford et al., 2013). Beyond the scenario of anthropogenic CO₂ emissions, key uncertainties are related to the carbon cycle response to a given scenario which depends on both model-dependent regional climate sensitivity (Berthelot et al., 2005; Alström et al., 2012) and model-dependent representation of carbon fluxes and stocks themselves (Dalmonech et al., 2014; Huntingford et al., 2013).

Most land surface models (LSMs) still struggle to capture the seasonal pattern of the net ecosystem carbon exchange (NEE) over the Amazon basin (Saleska et al., 2003; Baker et al., 2008; Verbeeck et al., 2011), which is defined as the difference between the carbon released by both heterotrophic (R_H) and autotrophic respiration (R_A) and taken up through photosynthesis by Gross Primary Productivity (GPP). Recent model developments have focused on improving the seasonality of the simulated GPP, using an improved soil hydrology (Fisher et al., 2007; Baker et al., 2008; Grant et al., 2009), optimizing model's parameters (Verbeeck et al., 2011), or, and with more success, implementing new phenological processes (De Weirdt et al., 2012; Kim et al., 2012). Despite its major role in the carbon balance, less attention has been paid to ecosystem respiration (R_{ECO}) (Atkin et al., 2014; Rowland et al., 2014). Ecosystem respiration is the sum of R_H and R_A and is the result of multiple contributions (roots, wood, leaves for R_A and litter, soil carbon for R_H) that are all influenced by several environmental factors (temperature, soil water content, microbial dynamics). Ecosystem respiration plays a major role in explaining inter-annual variability of NEE at many forest ecosystems (Valentini et al., 2000; Saleska et al., 2003; Rowland et al., 2014).

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



In this paper, we evaluate the ISBA_{CC} (Gibelin et al., 2008) LSM over the Amazon forest using in situ measurements and propose an alternative parameterization of both photosynthesis and autotrophic respiration. Such a focus is justified not only because ISBA_{CC} has never been really evaluated on tropical rainforests, but also because ISBA_{CC} has been recently implemented in the CNRM Earth System Model to participate in the forthcoming phases of CMIP (Coupled Model Intercomparison Project) and C4MIP (Coupled Climate Carbon Cycle Model Intercomparison Project). In CMIP3, some early ESMs projected a possible Amazon dieback (represented as the depletion of ecosystem carbon pools) at the end of the 21st century (Cox et al., 2000, 2013; Huntingford et al., 2013). Such dramatic projections are however very uncertain, depending for instance on the projected change in precipitation and dry-season length (Good et al., 2013), on the response of forest water-use efficiency (Keenan et al., 2013), and therefore on the accuracy of the water and carbon stocks and fluxes simulated at the land surface.

Here we conduct a step by step evaluation of the ISBA_{CC} land surface model against in situ observations collected at five instrumental sites over the Amazon forest. To illustrate rather than really quantify model uncertainties, we also compare ISBA_{CC} to the ORCHIDEE LSM (Krinner et al., 2005), which is based on different assumptions for the representation of photosynthesis, carbon allocation and growth. In Sect. 2, we first briefly describe both models and the available observations. In Sect. 3, we propose alternative parameterizations of photosynthesis and photosynthesis sensitivity to soil water stress and of autotrophic respiration in ISBA_{CC}. In Sect. 4, we compare the skill of the various ISBA_{CC} parameterizations to capture the observed water and carbon fluxes and stocks. The main conclusions are summarized in Sect. 5.

2 Material

2.1 Observations

To evaluate carbon and water fluxes over the Amazon tropical forest, we use field measurements of five eddy flux towers in Amazonia. Four towers are located in Brazil and were established during the LBA (Large Scale Biosphere atmosphere) project (Da Rocha et al., 2009): Manaus km 34 (M34), Santarem km 67 (K67) and 83 (K83), Reserva Jaru (JRU). The fifth tower is the Guyaflux tower (GFG) located at Paracou in French Guiana (Bonal et al., 2008). At JRU the forest is a semi-deciduous forest, whereas the other sites are representing typical tropical rainforests. Site location is shown in Fig. 1 together with the corresponding monthly mean climatologies of temperature and precipitation. Large seasonal variations in precipitation are found at GFG and JRU, in contrast with the other sites. Most datasets can be downloaded from the LBA website. For a detailed description of each site, please refer to the literature indicated in Table 1.

For each site, meteorological forcings, such as incoming solar and infrared radiations, precipitation (P), temperature (T) and specific humidity, are recorded every 30 min above the canopy. Observations also include turbulent sensible (H) and latent heat (LE) fluxes and net ecosystem carbon exchange (NEE) measured using the eddy-covariance method (Shuttleworth et al., 1984; Aubinet et al., 2000; Baldocchi et al., 2001). Further information on data acquisition and pre-processing can be found in the references indicated in Table 1. Note that evaluation scores are here computed only against the more reliable daytime measurements (Aubinet et al., 2002). At K83, measurements of soil moisture were collected in two adjacent soil pits which are 10 m deep (Bruno et al., 2006) and 2 m deep (da Rocha et al., 2004) respectively.

Gross Primary Productivity (GPP) and carbon released by the whole ecosystem respiration (R_{ECO}) were retrieved from NEE data. However, it does not give any information either on the partitioning between autotrophic (R_{A}) and heterotrophic (R_{H}) respiration, or on carbon allocation to canopy, wood and roots. Yet, these are essential processes

GMDD

8, 1293–1336, 2015

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to correctly represent the functioning of the Amazon ecosystem (Malhi et al., 2011). Malhi et al. (2009) gathered ecological measurements from K67, M34 and Caxiuanã (1.72° S 51.46° W, Eastern amazon) to evaluate yearly average carbon cycling and allocation. We here use this dataset to evaluate the annual carbon fluxes (GPP, R_A , NEE), the carbon stocks and the carbon allocation between the different pools in ISBA_{CC} (Sect. 4.4).

Finally, flux data are noisy. Hollinger and Richardson (2005) evaluated the relative uncertainty of H , LE and CO₂ fluxes to be around 25 % on a temperate site. According to Desai et al. (2008), the flux partitioning method to retrieve GPP and R_{ECO} from NEE may add up to 10 % uncertainty. Despite these uncertainties, eddy flux measurements are for now the best way to investigate fluxes between the vegetation and the atmosphere especially when combined with ecological measurements like those gathered by Malhi et al. (2009).

2.2 Models and experimental design

ISBA_{CC} (Interaction Soil Biosphere Atmosphere Carbon Cycle, Noilhan et Planton, 1989; Noilhan et Mahfouf, 1996) and ORCHIDEE (Organizing Carbon and Hydrology In Dynamic Ecosystems – version 1187) LSMs compute the exchange of water, energy and carbon between the land surface and the atmosphere. Both models deal with photosynthesis and allocate photosynthetic assimilates in several living biomass carbon pools. In both models each carbon pool is associated with a respiration function and a specific turnover rate. None of these two models take into account demography.

Carbon assimilation and allocation in the biomass pools differ greatly between the two models. In ORCHIDEE, carbon assimilation is based on the leaf-scale equation of Farquhar et al. (1980) for C₃ plants and is assumed to scale from leaf to canopy with APAR decreasing exponentially with leaf area index (LAI), according to the “big leaf” approximation. Stomatal conductance is proportional to the product of net CO₂ assimilation by atmospheric relative humidity divided by atmospheric CO₂ concentration in the canopy (Ball et al., 1987). Standard equations are given in Krinner et al. (2005),

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



and Verbeeck et al. (2011) for tropical forest plant functional types. In contrast, ISBA_{CC} has a semi-empirical parameterization of net carbon assimilation and the mesophyll conductance (g_m) following the model of photosynthesis proposed by Jacobs (1994), based on Goudriaan et al. (1985) and implemented by Calvet et al. (1998). In its standard version, ISBA_{CC} uses Goudriaan's (1986) solution of radiative transfer to calculate net photosynthesis in 3 canopy layers. The standard ISBA_{CC} equations are given in Calvet et al. (1998, 2004) and Gibelin et al. (2008). In ORCHIDEE (v1187), the carbon allocation model accounts for 8 biomass compartments (leaves, roots, fruits/harvested organs, reserves, aboveground sapwood, belowground sapwood, aboveground heartwood, belowground heartwood) for tree plant functional types. The fractions of newly formed assimilates or reserves allocated to these pools are parameterized as a function of soil water content, temperature, light, and soil nitrogen availability.

ISBA_{CC} represents aboveground and belowground metabolic and structural pools, above and below ground woody biomass and below ground structural biomass adapted from Lemaire and Gastal (1997) and detailed below. The description of the litter and soil carbon content and the associated heterotrophic fluxes is similar between the two models and is based on the CENTURY model developed by Parton et al. (1988). We only use the first top meter of soil carbon from the dataset of Malhi et al. (2009) to evaluate ISBA_{CC} since CENTURY was designed to represent the carbon content in the first top meter. The litter is described by 4 pools defined by the lignin content and the location (metabolic and structural above and below ground). The soil organic cycling module differentiates 3 carbon pools (active, passive, slow and passive) according to their liability.

At each site, we ran ISBA_{CC} and ORCHIDEE offline forced by in situ hourly meteorological measurements (gap filled when necessary) made on top of each flux tower (available at "http://daac.ornl.gov/", except for GFG, available from the fluxnet website following the "LaThuile" data sharing policy). We imposed the same evergreen tropical broadleaf tree plant functional type at the 5 sites and used the in situ soil texture, root and soil depth information for each site found in the literature and summarized in

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 1. Soil texture is used to compute the wilting point and field capacity, and the hydrological and thermal exchange coefficients following Decharme et al. (2011). The organic content in the upper soil layers, which also affects the hydrological and thermal exchange coefficients, is given by HWSO (Harmonized World Soil Database, Nachtergaele et al., 2012). Both models were run until the slowest storage pools had reached equilibrium by cycling the atmospheric forcing over the available 3 years including the observed CO₂ concentration. To simulate soil moisture content in the deep Amazonian soils we used the soil multilayer diffusion scheme implemented in ISBA by Decharme et al. (2011, 2013) and in ORCHIDEE by de Rosnay et al. (2000, 2002). Both models impose a vertical distribution of roots following a decreasing exponential function of depth.

3 Towards a new parameterization of the tropical forest in ISBA_{CC}

ISBA_{CC} has never been evaluated over the tropical rainforest biome (Gibelin et al., 2008), and as shown below, in this control version (CTL), LE and R_A were seriously biased and needed to be corrected. This section describes the original ISBA_{CC} model (CTL) and the implemented modifications. First we describe the changes made on the photosynthesis parameterization and its sensitivity to soil moisture as summarized in Table 3. Second, we present the modified autotrophic respiration functions (version PS+R) and the original ones (CTL) as summarized in Table 4. The main parameters of ISBA_{CC} are given in Table 2.

3.1 ISBA_{CC}; selection of the reference version

As pointed out by Carrer et al. (2013), ISBA_{CC} overestimates Gross Primary Productivity (GPP) at global scale, and especially in the tropical forests where the original radiative transfer code (Calvet et al., 1998) resulted in too high available radiation. Carrer et al. (2013) proposed a new radiative transfer scheme, dividing the canopy in 10

layers and accounting for the effect of direct and diffuse light and for sunlit and shaded leaves. As illustrated in Fig. 2 for the K67 site, the original radiative transfer scheme greatly overestimates the GPP at hourly and seasonal time scales. The other sites have a similar behavior (not shown). The new version of the radiative transfer allows ISBA_{CC} to better capture the amount of GPP thanks to a more detailed and physical approach. To avoid unrealistic GPPs, we chose to test the version of ISBA_{CC} with Carrer et al. (2013) radiative transfer scheme and call it our control version (CTL).

3.2 Water and carbon coupling and drought sensitivity: description of the original and modified parameterization (PS version)

The original ISBA_{CC} photosynthesis model relies on a “mesophyll conductance” (g_m), defined by Jacobs (1994) as the initial slope of the CO₂ response curve at high light intensity and limiting CO₂ concentrations.

$$g_m = \frac{A_m}{C_i - \Gamma} \quad (1)$$

with C_i the leaf-internal CO₂ concentration, Γ the CO₂ compensation point and A_m the photosynthesis rate at saturating light and low C_i .

The model also supposes a constant ratio of C_i to atmospheric CO₂ concentration (C_a) when atmospheric humidity is constant.

$$f = \frac{C_i - \Gamma}{C_a - \Gamma} \quad (2)$$

In drier atmospheric conditions, the ratio decreases according to:

$$f = f_0 \left(1 - \frac{D_s}{D_{\max}} \right) + f_{\min} \left(\frac{D_s}{D_{\max}} \right) \quad (3)$$

where D is the atmospheric humidity deficit, D_{\max} the deficit resulting in complete stomatal closure, f_{\min} the value of f at D_{\max} , and f_0 the value of f at saturating humidity

($D_s = 0$). f_{\min} , f_0 and D_{\max} are model parameters depending on plant type and based on available observations. Following Eq. (2), C_i also decreases with drying air (increase in D_s):

$$C_i = f \cdot C_a + \Gamma(1 - f) \quad (4)$$

Assimilation is then calculated from light (Eqs. A7–A9 in Calvet et al., 1998), air humidity, C_a , the ratio of C_i/C_a and finally, the stomatal conductance (g_s) is deduced from the assimilation rate.

Jacobs (1994) photosynthesis model was designed to simulate the assimilation rate and the stomatal conductance of grapevines in semi arid conditions. While ISBA_{CC} is used for large scale studies using a PFT (Plant Functional Type) approach, there were few attempts to adapt the ecophysiological parameters to each functional group, especially for evergreen tropical broadleaf trees. We used published measurements from about 20 different tree species (Domingues et al., 2005, 2007) from Tapajos National forest to derive $A_{m,\max}$, the maximum photosynthesis rate at high light intensity and f_0 (see Eq. 3). The original values and the values of these two parameters are given in Table 3.

The soil water stress function (WSF) empirically describes the effect of soil moisture on transpiration and photosynthesis. In the case of ISBA_{CC}, soil water content (SWC) weighted by the roots profile, affects transpiration and photosynthesis through changes in g_m and, in the CTL version, f_0 . The WSF implemented in ISBA_{CC} by Calvet (2000) was first designed for herbaceous species and adapted for trees (Calvet et al., 2004). As described in Table 3 the parameterization for trees supposes a relationship between f_0 and soil wetness index (SWI) and was derived from measurements taken on saplings from *Pinus pinaster* and *Quercus petraea*. It had never been tested on mature trees and tropical species and does not perform well when tested in the Amazon as shown below. Therefore, we propose an alternative parameterization assuming a constant f_0 coherent with in situ observations (Domingues et al., 2007) and validated against the two artificial droughts experiments lead in the eastern Amazon (Joetzjer et al., 2014,

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



and references within). Further in this paper, we call version PS, ISBA_{CC} version with these different values of $A_{m,max}$, f_0 and the modified WSF.

3.3 Autotrophic respiration and specific leaf area: description of the original and modified parameterization (PS+R version)

An analysis of the yearly carbon use efficiency (CUE) defined by the fraction of GPP invested into the Net Primary productivity (NPP/GPP) (Rowland et al., 2014) shows that ISBA_{CC} overestimates R_A from leaves, roots and wood, leading to a loss of more than 90 % of the carbon assimilated on an annual basis (corresponding to a CUE < 0.1). This result is not realistic. Over the Amazon, the CUE is roughly estimated to be around 0.3 (Chambers et al., 2004; Malhi et al., 2009, 2011; Metcalfe et al., 2010). Therefore, a new parameterization of each respiration term is proposed and described below.

ISBA_{CC} simulates 6 biomass pools, originally described in Gibelin et al. (2008) as:

- leaf biomass (B_L)
- B_2 , an active structural biomass pool which represents the stem in the case of grass and crop, and can be assimilated to new twigs for trees.
- B_3 , a small biomass pool used for numerical stability purposes, and accounts for a negligible amount of the carbon actually stored.
- B_4 , a below ground structural biomass pool representing the roots sapwood and the fine roots.
- B_5 , an above ground woody biomass pool representing the above ground wood (trunk and branches).
- B_6 , a below ground woody biomass pool representing the roots heartwood.

The evolution of each biomass pool B (kg m^{-2}) is given by:

$$\frac{\Delta B}{\Delta t} = A_B - D_B - R_B \quad (5)$$

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



where $\Delta t = \text{one day}$, A_B ($\text{kg m}^{-2} \text{day}^{-1}$) is the increase in biomass coming from photosynthetic assimilation or allocation from another reservoir, D_B ($\text{kg m}^{-2} \text{day}^{-1}$) represents turnover or carbon reallocation to another pool, and R_B ($\text{kg m}^{-2} \text{day}^{-1}$) is a decrease term due to respiration.

3.3.1 Leaf respiration

Originally, leaf dark respiration integrated over the canopy was parameterized, following Van Heemst (1986) as:

$$R_{\text{leaf}} = \frac{A_m}{9} \cdot \text{LAI} \quad (6)$$

with LAI the Leaf Area Index and A_m , the photosynthetic rate at high light intensities (Table 1). A_m being constant throughout the canopy, respiration is identical from the top to the bottom leaves, while assimilation decreases from top to bottom according to the absorbed fraction of PAR calculated by the radiative transfer scheme (Carré et al., 2013). However, observations show that leaf respiration is positively correlated to area based leaf nitrogen content (N_{AREA}) (Meir et al., 2001, 2008; Reich et al., 2006), and N_{AREA} is driven by light availability according to the theory of optimal nutrient allocation availability (Field and Mooney, 1986). Indeed, N_{AREA} is highly correlated to photosynthesis capacity as most of the leaf nitrogen is dedicated to the synthesis of photosynthetic proteins. So, a constant value for dark respiration throughout the canopy as supposed in ISBA_{CC} is not reasonable, particularly for high canopies. Therefore we imposed a vertical profile of respiration based on an exponential profile of leaf nitrogen (Sect. 2.5; Bonan et al., 2011, 2012).

$$R_{\text{leaf}} = \frac{A_m}{9} \cdot \exp(-k_n) \cdot \text{LAI} \quad (7)$$

With k_n the within-canopy profile of photosynthetic capacity set to 0.2 according to Mercado et al. (2009) and Bonan et al. (2011). This parametrization greatly reduces the leaf dark respiration of the canopy compared to the original one.

3.3.2 Twigs, stem and trunc

5 In the original version of ISBA_{CC} (Gibelin et al., 2008) the woody biomass (B_5) does not respire. If heartwood does not respire, sapwood made of living cells (including phloema cells) does. We adopted the simple parameterization of sapwood respiration from IBIS (Kucharik et al., 2000). We first calculate an estimated sapwood fraction (λ_{sap}) from an assumed sap velocity, the maximum transpiration rate and the tree height following
 10 Kucharik et al. (2000). Then, the respiration of the 5th reservoir, R_5 is computed as:

$$R_5 = B_5 \cdot \lambda_{\text{sap}} \cdot \beta_{\text{wood}} \cdot f(T) \quad (8)$$

where β_{wood} is a maintenance respiration coefficient defined at 15 °C and $f(T)$ is given by the Arrhenius temperature function modified by Lloyd and Taylor (1994).

$$f(T) = \exp \left[E_0 \left(\frac{1}{15 - T_0} \right) - \frac{1}{T - T_0} \right] \quad (9)$$

15 with T the temperature of the given carbon pool in °C (here, the surface temperature because ISBA_{CC} does not simulate a vegetation temperature), E_0 a temperature sensitivity factor and T_0 a temperature reference set at 25 °C.

For the B_2 biomass reservoir, (twigs), the function proposed in ISBA_{CC} is:

$$R_2 = B_2 \cdot \eta \cdot Q_{10}^{\frac{T_s - 25}{10}} \quad (10)$$

20 where $Q_{10} = 2$ and $\eta = 0.01$ ($\text{g g}^{-1} \text{ day}^{-1}$) and T_s (°C) the temperature of the surface. We did not find any measurement for respiration of twigs and did not find any other model representing this reservoir. We assumed that respiration per unit biomass of

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



this reservoir had to be lower than respiration of leaves, and similar or slightly larger than sapwood. A comparison with respiration functions from other models showed that Eq. (10) is about the same magnitude as respiration functions for leaves from ORCHIDEE, LPJ (Sitch et al., 2003) and IBIS (Foley et al., 1996) for temperatures up to 30 °C but increases strongly at higher temperatures. It is also an order of magnitude larger than respiration of sapwood from these models, which does not seem realistic. To be coherent with B_5 , we adopted Kucharik et al. (2000) formulation. Therefore:

$$R_2 = B_2 \cdot \beta \cdot f(T) \quad \text{with } \beta = 1.25 y^{-1} \quad (11)$$

3.3.3 Root respiration

Originally, root respiration followed the linear respiration given in Ruimy et al. (1996):

$$R_4 = B_4 \cdot R_0 (1 + 0.16 T_p) \quad \text{with } R_0 = 1.9 \times 10^4 \text{ g g}^{-1} \text{ day}^{-1} \quad (12)$$

To be consistent with sapwood respiration, R_4 is now computed as:

$$R_4 = B_4 \cdot \beta \cdot f(T) \quad (13)$$

The original Specific Leaf Area (SLA) taken by Gibein et al. (2006) was changed by the observed value from Domingues et al. (2007). Further in this paper, we call version PS+R, ISBA_{CC} version including the Table 3 parameters and functions, and the changed autotrophic respiration and SLA summarized Table 4.

4 Results and discussion

We now evaluate and compare three versions of ISBA_{CC}: CTL, PS and PS+R described in Sects. 3.1–3.3 respectively. We illustrate model diversity by showing the fluxes simulations of the ORCHIDEE (v.1187) land surface model. Note that we mostly show results from K83 because deep soil moisture measurements are available.

4.1 Soil moisture

Looking at the top-10 m daily soil water content simulated in 2003 at K83 (Fig. 3, bottom panel), the slight wet bias found in the original ISBA_{CC} model (CTL) is reduced when using either the modified PS or PS+R versions. Note that the ISBA_{CC} soil moisture content was also successfully evaluated at K67 and at Caxiuanã (Joetzjer et al., 2014). Moving to the vertical profile of soil moisture (Fig. 3 mid panels), and whatever the model version, the vertical profile of organic matter prescribed in ISBA_{CC} (Decharme et al., 2006) allows the model to simulate a relatively wet top-1 m horizon as observed. However, it is not sufficient to capture accurately the observed soil moisture dynamics. From February to April the soil moisture increases slowly from the surface to 6 m while ISBA_{CC} simulates a much more rapid re-moisturization, and after a heavy rain (e.g. October) water infiltrates too quickly. This might be due to the vertically uniform soil texture prescribed in ISBA_{CC} due to the lack of in situ observations. In reality, the clay content is usually increasing with depth, which reduces the hydraulic conductivity at lower levels.

4.2 Energy budget

Focusing again on K83, while net radiation (R_n) is well captured by the three ISBA_{CC} simulations, the CTL experiment overestimates the sensible heat flux (H) and underestimates the latent heat flux (LE) (Fig. 4). As expected, the partitioning of the energy budget is better represented with the simulation using $A_{m,max}$ and f_0 parameters derived from the in situ observations (PS version, Table 3). The increase in LE simulated by PS compared to the CTL explains the reduction of the wet bias in SWC simulated by the CTL run (Fig. 3). Not surprisingly, the modification of the autotrophic respiration functions has little effect (run PS+R, Table 4) on the simulated energy budget and does not impact the temporal variability of R_n , H and LE which are reasonably well simulated at both diurnal and seasonal time scales.

GMDD

8, 1293–1336, 2015

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Figure 5 shows a summary of the annual mean scores of H and LE computed for the three versions of ISBA_{CC} and for ORCHIDEE at the five flux towers using Taylor diagrams and a comparison of biases relative to the model mean climatology. Correlations mainly reflect the diurnal cycle and are reasonable (above 0.6). The PS (and PS+R) parameterizations barely impact correlations and slightly improve the root mean square error (RMSE) compared to the CTL. However, the SD is improved for all sites compared to the CTL runs. The CTL runs show a systematic overestimation of H that is strongly reduced in both PS and PS+R versions. Conversely, LE is greatly underestimated (by about 30%) by CTL, whatever the season (not shown), at four among the five sites and this bias is reduced in the revised versions. At M34, although CTL overestimates H , it simulates reasonably well LE. The PS model version reduces the bias in H but overestimates LE. This result suggests that the measured energy budget is not perfectly closed and that the observed Bowen ratio should be considered with caution at M34.

The PS version improves the simulation of H and LE compared to the CTL experiment. Interestingly, changes in the parameterization of respiration (PS+R) barely alter the results compared to PS. The scores of ORCHIDEE are very close to those computed with the improved version of ISBA_{CC} with large positive biases for H at JRU and LE at M34. The fact that the results are more site-dependent than model-dependent suggests a problem in the prescribed atmospheric forcings or in the eddy-covariance measurements for these sites. The ISBA_{CC} and ORCHIDEE models being based on different parameterizations of photosynthesis, respiration and growth, the likelihood of the models being both wrong at the same location is rather small, except for processes unaccounted for by both models.

4.3 Carbon fluxes

Moving back to the K83 site, but looking at the carbon fluxes (Fig. 6), the ISBA_{CC} model reasonably captures the annual amount of carbon taken up by photosynthesis (GPP), released by respiration (R_{ECO}) and the net flux defined in the model as the difference

between R_{ECO} and GPP (NEE). GPP is correctly simulated by the CTL experiment thanks to the radiative transfer scheme proposed by Carrer et al. (2013) (Fig. 2). While the $A_{m,\text{max}}$ chosen in the PS simulation is around six times smaller than initially (Table 3), the increase in f_0 enhances the assimilation rate, leading to little change in GPP between CTL and PS. PS barely impacts simulated R_{ECO} and therefore NEE compared to CTL. While the revised SLA and respiration functions lead to slightly decreased GPP (PS+R), the decrease in R_{ECO} is even stronger and leads to an increased net rate of carbon uptake (more negative NEE).

The annual cycle of GPP, R_{ECO} and NEE, although relatively small in these tropical regions (Fig. 6, right column), is poorly simulated by the model. The model tends to increase GPP at the beginning of the dry season when radiation increases and soil moisture is not yet limiting. As such, the model behaves as expected and the observed annual cycle results probably from processes that are not accounted for by the model, such as leaf phenology. Not surprisingly given the model formulation, but in contrast to the observations, the modelled seasonal cycle of GPP coincides with the seasonal cycle of LE in all ISBA_{CC} simulations.

The scores computed for the five flux towers are again summarized in Taylor diagrams (Fig. 7, top). The GPP relative SD (RSD) computed with PS is improved at K67 but is slightly lowered at M34, while there are no substantial changes at K83 and JRU compared to CTL. This is also valid for the NEE. At GFG, the RSD of NEE is also improved. PS+R exhibits scores quite similar to the PS run. The systematic positive bias in GPP (about 10 to 25%) and in R_{ECO} (about 10 to 100%) found in the CTL run is reduced in PS, and even more in PS+R (Fig. 7, bottom). However, NEE results are site dependent as model modifications reduce the bias at JRU and M34 but increase it at K67, K83 and GFG. Looking at the absolute RMSE, errors are reasonable (between 5 and 10 $\mu\text{mol m}^{-2} \text{s}^{-1}$) compared to observation uncertainties and ORCHIDEE's results once again suggest that scores are more site-dependent than model-dependent.

It is important to note that flux towers measure directly only NEE. The R_{ECO} is reconstructed from nighttime (i.e. when there is no photosynthesis) measurements which are

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



however questionable (e.g. Reichstein et al., 2005). Daytime R_{ECO} is likely to differ from nighttime R_{ECO} because of the temperature diurnal cycle. Also, the lower wind speed at night and thus lower friction velocity (u^*) limits the efficiency of the eddy-covariance technique (Aubinet et al., 2002; Saleska et al., 2003). As GPP is reconstructed from NEE and R_{ECO} , more bias can be expected for this flux and conclusions on GPP should be also considered with caution.

4.4 Carbon Stocks and carbon use efficiency

The data compilation of Malhi et al. (2009) at Caxiuana, K67 and M34 provides valuable insights to evaluate the model ability to simulate the annual carbon storage per carbon pools (Fig. 8). While there are few differences between the CTL and PS+R simulations in terms of GPP and R_{ECO} , the carbon stocks greatly differ (Fig. 8). Over these three sites, observations indicate a total carbon stock around 330 tC ha^{-1} . The original model (CTL) greatly underestimates the stock by a factor of three. While modifications of the photosynthesis components (PS) slightly increases carbon stocks, the underestimation of the carbon storage persists. Changes in respiration functions (PS+R) lead to a more reasonable total amount of carbon stock.

Flux tower data provide high frequency information on the carbon flux between the ecosystem and the atmosphere, but do not allow us to distinguish between vegetation and soil fluxes. The meta analysis from Malhi et al. (2009) however allows us to evaluate the annual fluxes between the different carbon pools at Caxiuanã (Fig. 9). Compared to observations, the CTL run highly overestimates R_{A} and consequently underestimates the NPP. Therefore, the Carbon Use Efficiency (CUE), computed as the ratio NPP/GPP , is too low. 92 % of the carbon assimilated is directly respired, leaving only 8 % of the GPP to be allocated to the plant biomass pools. This result motivated the changes in autotrophic respiration functions presented in Table 4. These changes (simulation PS+R, Table 4) lead to a more realistic CUE (around 0.3 ; e.g. Malhi et al., 2009; Rowland et al., 2014.), therefore enhancing the carbon storage in the leaf, wood and root pools, but also in the litter and the soil organic matter. As a result, heterotrophic

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



respiration, largely underestimated by the original model (CTL), is now correctly simulated. Note that the CTL version has a reasonable estimation of R_{ECO} because the overestimation of R_{A} is partly counterbalanced by an underestimation of R_{H} through an underestimation of the heterotrophic carbon stock.

In spite of reasonable R_{A} at each site, the ISBA_{CC} model tends to overestimate the amount of carbon stored in the stems (Fig. 8). This pattern can very likely be explained by a too low mortality rate. At K67, the high amount of coarse and woody debris (Saleska et al., 2003) and the low amount of above ground biomass observed compared to the other sites suggest a recent higher than normal tree mortality. This could be triggered by drought associated with the strong El Niño events of the 1990s (Rice et al., 2004; Pyle et al., 2008) that these simulations forced by 3 years meteorological forcing cannot represent.

5 Conclusions

In this study, we proposed and evaluated revised parameterizations of the photosynthesis, its sensitivity to soil water stress and the autotrophic respiration function in the ISBA_{CC} land surface model implemented in the CNRM ESM, over the Amazon forest. As far as the energy and water budgets are concerned, net radiation and soil water dynamics that are driven by observed atmospheric forcing are reasonably well simulated by ISBA_{CC}. Our modifications of photosynthesis mainly allow the model to better capture the turbulent energy fluxes (H and LE). While the mean carbon fluxes are slightly better captured with the revised parameterization, ISBA_{CC} still struggles to capture the seasonality of the observed (NEE) or reconstructed (R_{ECO} and GPP) carbon fluxes. Interestingly, when ISBA_{CC} is compared to the ORCHIDEE model based on different parameterizations, scores are systematically more site-dependent than model-dependent. This either suggests problems in the prescribed atmospheric forcing, or in the eddy-covariance measurements, unless both models do not account for a crucial process. Further investigations are thus needed.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Changes made to the parameterization of R_A improve the simulation of the Carbon Use Efficiency, in good agreement with the observations from Malhi et al. (2009) and Rowland et al. (2014). By enhancing the carbon storage, biomass pools become larger and more consistent with observations. However, increasing the carbon stock in ISBA_{CC} by a factor of three between CTL and PS+R versions barely impacts the net carbon flux. This illustrates the weak link between carbon stocks and fluxes in the ISBA_{CC} model and the need for further improvements.

There is no silver bullet for the parameterization of autotrophic respiration, such as the Farquhar model for the carbon assimilation. Because R_A represents a large part of R_{ECO} , and R_{ECO} is crucial to determine the net carbon balance (NEE), both annual amount and seasonality of R_A need to be correctly represented. The ratio of respiration of a particular pool relative to its size is particularly instructive (Table 5) to evaluate the representation of the respiration process in the model. As can be seen at Caxiuana, K67 and M34, about 10 % of the carbon stored in the plants is respired annually and between 7 and 9 % of the litter and soil carbon content, depending on the site. As a whole, about 9 % of the total biomass (soil, litter and plant) is respired. These percentages are very well captured by the new (PS+R) version but totally misrepresented by the original scheme (CTL). Ecosystem respiration relative to the stock is three times too high although the absolute value was reasonable. Nevertheless, large uncertainties surrounds the seasonality of R_A (and consequently R_{ECO}). Considering the relevance of R_{ECO} in the seasonal changes of the ecosystem carbon budget (Meir et al., 2008; Rowland et al., 2014), and not only over the Amazon forest (Atkin and Macherel, 2009; Atkin et al., 2014), there is an urgent need to better understand the main drivers of autotrophic respiration in a wide range of environmental conditions.

Code availability

ISBA_{CC} is part of the larger sea and land surface scheme SURFEX. The control version (CTL) of ISBA_{CC} used here is part of SURFEX_v7.2 (<http://www.cnrm.meteo.fr/surfex/>)

and the modified version (PS+R) is part of SURFEX_v8 that will be released before summer 2015.

Acknowledgements. The authors thank Rogério D. Bruno and Humberto R. da Rocha for access to 10 m soil moisture observations. Thanks are due to the AMAZALERT FP7 project for supporting this study.

References

Ahlström, A., Schurgers, G., Arneft, A., and Smith, B.: Robustness and uncertainty in terrestrial ecosystem carbon response to CMIP5 climate change projections, *Environ. Res. Lett.*, 7, 044008, doi:10.1088/1748-9326/7/4/044008, 2012.

Anav, A., Friedlingstein, P., Kidston, M., Bopp, L., Ciais, P., Cox, P., Jones, C., Jung, M., Myrneni, R., and Zhu, Z.: Evaluating the land and ocean components of the global carbon cycle in the CMIP5 Earth System Models, *J. Climate*, 26, 6801–6843, 2013.

Aragao, L. E., Poulter, B., Barlow, J. B., Aragao, L. E., Poulter, B., Barlow, J. B., Anderson, L. O., Malhi, Y., Saatchi, S., Phillips, O. L., and Gloor, E.: Environmental change and the carbon balance of Amazonian forests, *Biol. Rev.*, 89, 913–931, 2014.

Araujo, A., Nobre, A., Kruijt, B., Elbers, J., Dallarosa, R., Stefani, P., von Randow, C., Manzi, A., Culf, A., Gash, J., Valentini, R., and Kabat, P.: Comparative measurements of carbon dioxide fluxes from two nearby towers in a central Amazonian rainforest: the Manaus LBA site, *J. Geophys. Res.*, 107, 58.1–58.20, 2002.

Atkin, O. K. and Macherel, D.: The crucial role of plant mitochondria in orchestrating drought tolerance, *Ann. Bot.-London*, 103, 581–597, 2009.

Atkin, O. K., Meir, P., and Turnbull, M. H.: Improving representation of leaf respiration in large-scale predictive climate–vegetation models, *New Phytol.*, 202, 743–748, 2014.

Aubinet, M., Grelle, A., Ibrom, A., Rannik, U., Moncrieff, J., Foken, T., Kowalski, A. S., Martin, P., Berbigier, P., Bernhofer, C., Clement, R., Elbers, J., Granier, A., Grunwald, T., Morgenstern, K., Pilegaard, K., Rebmann, C., Snijders, W., Valentini, R., and Vesala, T.: Estimates of the annual net carbon and water exchange of forests: the Euroflux methodology, *Adv. Ecol. Res.*, 30, 113–175, 2000.

GMDD

8, 1293–1336, 2015

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Aubinet, M., Heinesch, B., and Longdoz, B.: Estimation of the carbon sequestration by a heterogeneous forest: night flux corrections, heterogeneity of the site and inter-annual variability, *Glob. Change Biol.*, 8, 1053–1097, 2002.

Baldocchi, D., Falge, E., Gu, L., Olson, R., Hollinger, D., Running, S., Anthoni, P., Bernhofer, C., Davis, K., Evans, R., Fuentes, J., Goldstein, A., Katul, G., Law, B., Lee, X., Malhi, Y., Meyers, T., Munger, W., Oechel, W., Paw U, K. T., Pilegaard, K., Schmid, H. P., Valentini, R., Verma, S., Vesala, S., Wilson, K., and Wofsy, S.: FLUXNET: a new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities, *B. Am. Meteorol. Soc.*, 82, 2415–2434, 2001.

Baker, I. T., Prihodko, L., Denning, A. S., Goulden, M. L., Miller, S., and da Rocha, H. R.: Seasonal drought stress in the amazon: reconciling models and observations, *J. Geophys. Res.*, 113, 2005–2012, doi:10.1029/2007JG000644, 2008.

Ball, J. T., Woodrow, I. E., and Berry, J. A.: A model predicting stomatal conductance and its contribution to the control of photosynthesis under different environmental conditions, in: *Progress in Photosynthesis Research*, vol. 4, edited by: Biggins, J., Martinus Nijhoff, the Netherlands, 221–224, 1987.

Berthelot, M., Friedlingstein, P., Ciais, P., Dufresne, J.-L., and Monfray, P.: How uncertainties in future climate change predictions translate into future terrestrial carbon fluxes, *Glob. Change Biol.*, 11, 959–970, doi:10.1111/j.1365-2486.2005.00957.x, 2005.

Bonal, D., Bosc, A., Ponton, S., Goret, J. Y., Burban, B., Gross, P., Bonnefond, J. M., Elbers, J., Longdoz, B., Epron, D., Guehl, J. M., and Granier, A.: Impact of severe dry season on net ecosystem exchange in the neotropical rainforest of french guiana, *Glob. Change Biol.*, 14, 1917–1933, doi:10.1111/j.1365-2486.2008.01610.x, 2008.

Bonan, G. B., Lawrence, P. J., Oleson, K. W., Levis, S., Jung, M., Reichstein, M., Lawrence, D. M., and Swenson, S. C.: improving canopy processes in the Community Land Model version 4 (CLM4) using global flux fields empirically inferred from FLUXNET data, *J. Geophys. Res.*, 116, G02014, doi:10.1029/2010JG001593, 2011.

Bonan, G. B., Oleson, K. W., Fisher, R. A., Lasslop, G., and Reichstein, M.: Reconciling leaf physiological traits and canopy flux data: use of the TRY and FLUXNET databases in the Community Land Model version 4, *J. Geophys. Res.*, 117, G02026, doi:10.1029/2011JG001913, 2012.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Bruno, R. D., da Rocha, H. R., de Freitas, H. C., Goulden, M. L., and Miller, S. D.: Soil moisture dynamics in an eastern Amazonian tropical forest, *Hydrol. Process.*, 20, 2477–2489, doi:10.1002/hyp.6211, 2006.

Calvet, J. C., Noilhan, J., Roujean, J. L., Bessemoulin, P., Cabelguenne, M., Olioso, A., and Wigneron, J. P.: An interactive vegetation SVAT model tested against data from six contrasting sites, *Agr. Forest Meteorol.*, 92, 73–95, 1998.

Calvet, J. C., Rivalland, V., Picon-Cochard, C., and Guehl, J. M.: Modelling forest transpiration and CO₂ fluxes response to soil moisture stress, *Agr. Forest Meteorol.*, 124, 143–156, 2004.

Carrer, D., Roujean, J. L., Lafont, S., Calvet, J. C., Boone, A., Decharme, B., Delire, C., and Gastellu-Etchegorry, J. P.: A canopy radiative transfer scheme with explicit FAPAR for the interactive vegetation model ISBA-A-gs: impact on carbon fluxes, *J. Geophys. Res.-Biogeo.*, 118, 1–16, doi:10.1002/jgrg.20070, 2013.

Chambers, J. Q., Tribuzy, E. S., Toledo, L. C., Crispim, B. F., Higuchi, N., dos Santos, J., Araujo, A. C., Kruijt, B., Nobre, A. D., and Trumbore, S. E.: Respiration from a tropical forest ecosystem: partitioning of sources and low carbon use efficiency, *Ecol. Appl.*, 14, S72–S88, 2004.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., and Totterdell, I. J.: Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, *Nature*, 408, 184–187, 2000.

Cox, P. M., Pearson, D., Booth, B. B., Friedlingstein, P., Huntingford, C., Jones, C. D., and Luke, C. M.: Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability, *Nature*, 494, 341–344, 2013.

Dalmonech, D., Foley, A. M., Anav, A., Friedlingstein, P., Friend, A. D., Kidston, M., Willeit, M., and Zaehle, S.: Challenges and opportunities to reduce uncertainty in projections of future atmospheric CO₂: a combined marine and terrestrial biosphere perspective, *Biogeosciences Discuss.*, 11, 2083–2153, doi:10.5194/bgd-11-2083-2014, 2014.

da Rocha, H. R., Goulden, M. L., Miller, S. D., Menton, M. C., Pinto, L. D., de Freitas, H. C., and Silva Figueira, A. M.: Seasonality of water and heat fluxes over a tropical forest in eastern Amazonia, *Ecol. Appl.*, 14, S22–S32, 2004.

da Rocha, H. R., Manzi, A. O., Cabral, O. M., Miller, S. D., Goulden, M. L., Saleska, S. R., R-Coupe, N., Wofsy, S. C., Borma, L. S., Artaxo, P., Vourlitis, G., Nogueira, J. S., Cardoso, F. L., Nobre, A. D., Kruijt, B., Freitas, H. C., von Randow, C., Aguiar, R. G., and Maia, J. F.: Patterns

**Modeling stocks and
fluxes of water and
carbon over the
Amazon**

E. Joetzer et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

of water and heat flux across a biome gradient from tropical forest to savanna in Brazil, *J. Geophys. Res.-Biogeo.*, 114, G00B12, doi:10.1029/2007JG000640, 2009.

de Rosnay, P., Bruen, M., and Polcher, J.: Sensitivity of surface fluxes to the number of layers in the soil model used in GCMs, *Geophys. Res. Lett.*, 27, 3329–3332, doi:10.1029/2000GL011574, 2000.

de Rosnay, P., Polcher, J., Bruen, M., and Laval, K.: Impact of a physically based soil water flow and soil-plant interaction representation for modeling large-scale land surface processes, *J. Geophys. Res.-Atmos.*, 107, 4118, doi:10.1029/2001JD000634, 2002.

De Weirdt, M., Verbeeck, H., Maignan, F., Peylin, P., Poulter, B., Bonal, D., Ciais, P., and Steppe, K.: Seasonal leaf dynamics for tropical evergreen forests in a process-based global ecosystem model, *Geosci. Model Dev.*, 5, 1091–1108, doi:10.5194/gmd-5-1091-2012, 2012.

Decharme, B., Douville, H., Boone, A., Habets, F., and Noilhan, J.: Impact of an exponential profile of saturated hydraulic conductivity within the ISBA LSM: simulations over the Rhone basin, *J. Hydrometeorol.*, 7, 61–80, 2006.

Decharme, B., Boone, A., Delire, C., and Noilhan, J.: Local evaluation of the interaction between soil biosphere atmosphere soil multilayer diffusion scheme using four pedotransfer functions, *J. Geophys. Res.*, 116, 1984–2012, 2011.

Decharme, B., Martin, E., and Faroux, S.: Reconciling soil thermal and hydrological lower boundary conditions in land surface models, *J. Geophys. Res.-Atmos.*, 118, 1–16, 2013.

Desai, A. R., Richardson, A. D., Moffat, A. M., Kattge, J., Hollinger, D. Y., Barr, A., Falge, E., Noormets, A., Papale, D., Reichstein, M., and Stauch, V. J.: Cross site evaluation of eddy covariance GPP and RE decomposition techniques, *Agr. Forest Meteorol.*, 148, 821–838, doi:10.1016/j.agrformet.2007.11.012, 2008.

Domingues, T. F., Berry, J. A., Martinelli, L. A., Ometto, J., and Ehleringer, J. R.: Parameterization of canopy structure and leaf-level gas exchange for an eastern Amazonian tropical rain forest (Tapajós National Forest, Para, Brazil), *Earth Interact.*, 9, E1149, doi:10.1175/E1149.1, 2005.

Domingues, T. F., Martinelli, L. A., and Ehleringer, J. R.: Ecophysiological traits of plant functional groups in forest and pasture ecosystems from eastern Amazonia, Brazil, *Plant Ecol.*, 193, 101–112, 2007.

Espírito-Santo, F. D. B., Gloor, M., Keller, M., Malhi, Y., Saatchi, S., Nelson, B., Junior, R. C. O., Pereira, C., Lloyd, J., Froliking, S., Palace, M., Shimabukuro, Y. E., Duarte, V., Mendoza, A. M., López-González, G., Baker, T. R., Feldpausch, T. R., Brienen, J. W., Asner, P., Boyd, D. S.,

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

and Phillips, O. L.: Size and frequency of natural forest disturbances and the Amazon forest carbon balance, *Nature Communications*, 5, 3434, doi:10.1038/ncomms4434, 2014.

Farquhar, G. D., von Caemmerer, S., and Berry, J. A.: A biochemical model of photosynthetic CO₂ assimilation in leaves of C₃ species, *Planta*, 149, 78–90, 1980.

Field, C. B. and Mooney, H. A.: The photosynthesis–nitrogen relationship in wild plants, in: *The Economy of Plant Form and Function*, edited by: Givnish, T. J., Cambridge University Press, Cambridge, 25–55, 1986.

Fisher, R. A., Williams, M., da Costa, A. L., Malhi, Y., da Costa, R. F., Almeida, S., and Meir, P.: The response of an Eastern Amazonian rain forest to drought stress: results and modelling analyses from a throughfall exclusion experiment, *Glob. Change Biol.*, 13, 2361–2378, 2007.

Foley, J. A., Prentice, C., Ramankutty, N., Levis, S., Pollard, D., Sitch, S., and Haxeltine, A.: An integrated biosphere model of land surface processes, terrestrial carbon balance, and vegetation dynamics, *Glob. Biogeochem. Cy.*, 10, 603–628, doi:10.1029/96GB02692, 1996.

Foley, J. A., Costa, M. H., Delire, C., Ramankutty, N., and Snyder, P.: Green surprise? How terrestrial ecosystems could affect earth's climate, *Front. Ecol. Environ.*, 1, 38–44, 2003.

Friedlingstein, P., Cox, P., Betts, R., Bopp, L., von Bloh, W., Brovkin, V., Cadule, P., Doney, S., Eby, M., Fung, I., Bala, G., John, J., Jones, C., Joos, F., Kato, T., Kawamiya, M., Knorr, W., Lindsay, K., Matthews, H. D., Raddatz, T., Rayner, P., Reick, C., Roeckner, E., Schnitzler, K. G., Schnur, R., Strassmann, K., Weaver, A. J., Yoshikawa, C., and Zeng, N.: Climate-carbon cycle feedback analysis: results from the C4MIP model intercomparison, *J. Climate*, 19, 3337–3353, 2006.

Fu, R., Yin, L., Li, W., Arias, P. A., Dickinson, R. E., Huang, L., Chakraborty, S., Fernandes, K., Liebmann, B., Fisher, R. A., and Myneni, R. B.: Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection, *P. Natl. Acad. Sci. USA*, 110, 18110–18115, doi:10.1073/pnas.1302584110, 2013.

Gatti, L. V., Miller, J. B., D'Amelio, M. T. S., Martinewski, A., Basso, L. S., Gloor, M. E., Wofsy, S., and Tans, P.: Vertical profiler of CO₂ above eastern Amazonia suggest a net carbon flux to the atmosphere and balanced biosphere between 2000 and 2009, *Tellus B*, 20, 581–594, doi:10.1111/j.1600-0889.2010.00484.x, 2010.

Gatti, L. V., Gloor, M., Miller, J. B., Doughty, C. E., Malhi, Y., Domingues, L. G., Basso, L. S., Martinewski, A., Correia, C. S. C., and Borges, V. F.: Drought sensitivity of Amazonian carbon balance revealed by atmospheric measurements, *Nature*, 506, 76–80, 2014.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



- Gibelin, A. L., Calvet, J. C., and Viovy, N.: Modelling energy and CO₂ fluxes with an interactive vegetation, land surface model, Evaluation at high and middle latitudes, *Agr. Forest Meteorol.*, 148, 1611–1628, 2008.
- Gloor, M., Gatti, L., Brienen, R., Feldpausch, T. R., Phillips, O. L., Miller, J., Ometto, J. P., Rocha, H., Baker, T., de Jong, B., Houghton, R. A., Malhi, Y., Aragão, L. E. O. C., Guyot, J.-L., Zhao, K., Jackson, R., Peylin, P., Sitch, S., Poulter, B., Lomas, M., Zaehle, S., Huntingford, C., Levy, P., and Lloyd, J.: The carbon balance of South America: a review of the status, decadal trends and main determinants, *Biogeosciences*, 9, 5407–5430, doi:10.5194/bg-9-5407-2012, 2012.
- Good, P., Jones, C., Lowe, J., Betts, R., and Gedney, N.: Comparing tropical forest projections from two generations of Hadley Centre Earth System models, HadGEM2-ES and HadCM3LC, *J. Climate*, 26, 495–511, 2013.
- Goudriaan, J.: A simple and fast numerical method for the computation of daily totals of crop photosynthesis, *Agr. Forest Meteorol.*, 38, 249–254, 1986.
- Goudriaan, J., van Laar, H. H., van Keulen, H., and Louwarse, W.: Photosynthesis, CO₂ and plant production, in: *Wheat Growth and Modelling*, edited by: Day, W. and Atkin, R. K., NATO AS/Series, Series A, vol. 86, Plenum Press, New York, 107–122, 1985.
- Grant, R., Hutyra, L., and Oliveira, R.: Modeling the carbon balance of Amazonian rain forests: resolving ecological controls on net ecosystem productivity, *Ecol. Monogr.*, 79, 445–463, 2009.
- Hollinger, D. Y. and Richardson, A. D.: Uncertainty in eddy covariance measurements and its application to physiological models, *Tree Physiol.*, 25, 873–885, 2005.
- Huntingford, C., Zelazowski, P., Galbraith, D., Mercado, L. M., Sitch, S., Fisher, R. A., Lomas, M., Walker, A. P., Jones, C. D., Booth, B. B. B., Malhi, Y., Hemming, D., Kay, G., Good, P., Lewis, S. L., Phillips, O. L., Atkin, O. K., Lloyd, J., Gloor, E., Zaragoza-Castells, J., Meir, P., Betts, R., Harris, P. P., Nobre, C., Marengo, C., and Cox, P. M.: Simulated resilience of tropical rainforests to CO₂-induced climate change, *Nat. Geosci.*, 6, 268–273, 2013.
- Jacobs, C. M. J.: Direct impact of atmospheric CO₂ enrichment on regional transpiration, Ph.D. thesis, Agricultural University, Wageningen, 1994.
- Joetzjer, E., Douville, H., Delire, C., and Ciais, P.: Present-day and future Amazonian precipitation in global climate models: CMIP5 versus CMIP3, *Clim. Dynam.*, 41, 2921–2936, 2013.
- Joetzjer, E., Delire, C., Douville, H., Ciais, P., Decharme, B., Fisher, R., Christoffersen, B., Calvet, J. C., da Costa, A. C. L., Ferreira, L. V., and Meir, P.: Predicting the response of

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



the Amazon rainforest to persistent drought conditions under current and future climates: a major challenge for global land surface models, *Geosci. Model Dev.*, 7, 2933–2950, doi:10.5194/gmd-7-2933-2014, 2014.

Jones, C., Robertson, E., Arora, V., Friedlingstein, P., Shevliakova, E., Bopp, L., V. Brovkin, T. Hajima, E. Kato, Kawamiya, M., Liddicoat, S., Lindsay, K., Reick, C. H., Roelandt, C., Segschneider, J., and Tjiputra, J.: Twenty-first-century compatible CO₂ emissions and air-borne fraction simulated by CMIP5 Earth System Models under four representative concentration pathways, *J. Climate*, 26, 4398–4413, 2013.

Keenan, T. F., Hollinger, D. Y., Bohrer, G., Dragoni, D., Munger, J. W., Schmid, H. P., and Richardson, A. D.: Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise, *Nature*, 499, 324–327, doi:10.1038/nature12291, 2013.

Kim, Y., Knox, R. G., Longo, M., Medvigy, D., Hutyra, L. R., Pyle, E. H., Wofsky, S. C., Bras, R. L., and Moorcroft, P. R.: Seasonal carbon dynamics and water fluxes in an Amazon rainforest, *Glob. Change Biol.*, 18, 1322–1334, 2012.

Krinner, G., Viovy, N., de Noblet-Ducoudre, N., Ogee, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S., and Prentice, I.: A dynamic global vegetation model for studies of the coupled atmosphere–biosphere system, *Global Biogeochem. Cy.*, 19, 1–33, 2005.

Kruijt, B., Elbers, J. A., von Randow, C., Araújo, A. C., Oliveira, P. J., Culf, A., Manzi, A. O., Nobre, A. D., Kabat, P., Moors, E. J.: The robustness of eddy correlation fluxes for Amazon rain forest conditions, *Ecol. Appl.*, 14, 101–113, 2004.

Kucharik, C. J., Foley, J. A., Delire, C., Fisher, V. A., Coe, M. T., Lenters, J. D., Young-Molling, C., Ramankutty, N., Norman, J. M., and Gower, S. T.: Testing the performance of a dynamic global ecosystem model: water balance, carbon balance, and vegetation structure, *Global Biogeochem. Cy.*, 14, 795–825, 2000.

Lemaire, G. and Gastal, F.: N uptake and distribution in plant canopies, in: *Diagnosis of the Nitrogen Status in Crops*, edited by: Lemaire, G., Springer-Verlag, Heidelberg, 3–43, doi:10.1007/978-3-642-60684-7_1, 1997.

Lewis, S. L., Lloyd, J., Sitch, S., Mitchard, E. T., and Laurance, W. F.: Changing ecology of tropical forests: evidence and drivers, *Annu. Rev. Ecol. Evol. S.*, 40, 529–549, 2009.

Lloyd, J. and Taylor, J. A.: On the temperature dependence of soil respiration, *Funct. Ecol.*, 8, 315–323, 1994.

Malhi, Y., Aragao, L. E. O., Metcalfe, D. B., Paiva, R., Quesada, C. A., Almeida, S., Anderson, L., Brando, P., Chamber, J. Q., and da Costa, A. C. L.: Comprehensive assessment of

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



carbon productivity, allocation and storage in three Amazonian forests, *Glob. Change Biol.*, 15, 1255–1274, 2009.

Malhi, Y., Doughty, C., and Galbraith, D.: The allocation of ecosystem net primary productivity in tropical forests, *Philos. T. R. Soc. B*, 366, 3225–3245, 2011.

5 Marengo, J. A., Tomasella, J., Alves, L. M., Soares, W. R., and Rodriguez, D. A.: The drought of 2010 in the context of historical droughts in the Amazon region, *Geophys. Res. Lett.*, 38, 1–5, doi:10.1029/2011GL047436, 2011.

Meir, P., Grace, J., and Miranda, A. C.: Leaf respiration in two tropical rainforests: constraints on physiology by phosphorus, nitrogen and temperature, *Funct. Ecol.*, 15, 378–387, 2001.

10 Meir, P., Metcalfe, D. B., Costa, A. C. L., and Fisher, R. A.: The fate of assimilated carbon during drought: impacts on respiration in Amazon rainforests, *Philos. T. Roy. Soc. B*, 363, 1849–1855, doi:10.1098/rstb.2007.0021, 2008.

Mercado, L. M., Lloyd, J., Dolman, A. J., Sitch, S., and Patiño, S.: Modelling basin-wide variations in Amazon forest productivity – Part 1: Model calibration, evaluation and upscaling functions for canopy photosynthesis, *Biogeosciences*, 6, 1247–1272, doi:10.5194/bg-6-1247-2009, 2009.

15 Metcalfe, D. B., Meir, P., Aragao, L. E. O. C., Lobo-do-Vale, R., Galbraith, D., Fisher, R. A., Chaves, M. M., Maroco, J. P., da Costa, A. C. L., de Almeida, S. S., Braga, A. P., Gonçalves, P. H. L., de Athaydes, J., da Costa, M., Portela, T. T. B., de Oliveira, A. A. R., Malhi, Y., and Williams, M.: Shifts in plant respiration and carbon use efficiency at a large-scale drought experiment in the eastern Amazon, *New Phytol.*, 187, 608–621, 2010.

20 Nachtergaele, F., van Velthuisen, H., Verelst, L., and Wiberg, D.: Harmonized World Soil Database, Version 1.2, FAO, IIASA, ISRIC, ISSCAS, JRC, available at: <http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/> (last access: 15 November 2012), 2012.

25 Noilhan, J. and Mahfouf, J.-F.: The ISBA land surface parameterisation scheme, *Global Planet. Change*, 13, 145–159, 1996.

Noilhan, J. and Planton, S.: A simple parameterization of land surface processes for meteorological models, *Mon. Weather Rev.*, 117, 536–549, 1989.

30 Parton, W., Stewart, J., Cole, C.: Dynamics of C, N, P and S in grassland soils: a model, *Biogeochemistry*, 5, 109–131, 1988.

Phillips, O. L., Lewis, S. L., Baker, T. R., Chao, K. J., and Higuchi, N.: The changing Amazon forest, *Philos. T. R. Soc. B: Biological Sciences*, 363, 1819–1827, 2008.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Pyle, E. H., Santoni, G. W., Nascimento, H. E. M., Hutyra, L. R., Vieira, S., Curran, D. J., van Haren, J., Saleska, S. R., Chow, V. Y., Carmago, P. B., Laurance, W. F., and Wofsy, S. C.: Dynamics of carbon, biomass, and structure in two amazonian forests, *J. Geophys. Res. Biogeosci.*, 113, G00b08, doi:10.1029/2007jg000592, 2008.

5 Randerson, J. T., Hoffman, F. M., Thornton, P. E., Mahowald, N. M., Lindsay, K., Lee, Y.-H., Nevison, C. D., Doney, S. C., Bonan, G., Stoeckli, R., Covey, C., Running, S. W., and Fung, I. Y.: Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models, *Glob. Change Biol.*, 15, 2462–2484, 2009.

10 Reich, P. B., Tjoelker, M. G., Machado, J. L., and Oleksyn, J.: Universal scaling of respiratory metabolism, size and nitrogen in plants, *Nature*, 439, 457–461, 2006.

15 Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grunwald, T., Havrankova, K., Ilvesniemi, H., Janous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., Meyers, T., Miglietta, F., Ourcival, J.-M., Pumpanen, J., Rambal, S., Rotenberg, E., Sanz, M., Tenhunen, J., Seufert, G., Vaccari, F., Vesala, T., Yakir, D., and Valentini, R.: On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm, *Glob. Change Biol.*, 11, 1424–1439, doi:10.1111/j.1365-2486.2005.001002.x, 2005.

20 Rice, A. H., Pyle, E. H., Saleska, S. R., Hutyra, L., Palace, M., Keller, M., de Camargo, P. B., Portilho, K., Marques, D. F., and Wofsy, S. C.: Carbon balance and vegetation dynamics in an old-growth amazonian forest, *Ecol. Appl.*, 14, 55–71, doi:10.1890/02-6006, 2004.

Rowland, L., Hill, T. C., Stahl, C., Siebicke, L., Burban, B., Zaragoza-Castells, J., Ponton, S., Bonal, D., Meir, P., and Williams, M.: Evidence for strong seasonality in the carbon storage and carbon use efficiency of an Amazonian forest, *Glob. Change Biol.*, 20, 979–991, doi:10.1111/gcb.12375, 2014.

25 Ruimy, A., Dedieu, G., and Saugier, B.: Turc: a diagnostic model of continental gross primary productivity and net primary productivity, *Global Biogeochem. Cy.*, 10, 269–285, doi:10.1029/96gb00349, 1996.

30 Saleska, S. R., Miller, S. D., Matross, D. M., Goulden, M. L., Wofsy, S. C., da Rocha, H. R., de Camargo, P. B., Crill, P., Daube, B. C., de Freitas, H. C., Hutyra, L., Keller, M., Kirchhoff, V., Menton, M., Munger, J. W., Pyle, E. H., Rice, A. H., and Silva, H.: Carbon in amazon forests: Unexpected seasonal fluxes and disturbance-induced losses, *Science*, 302, 1554–1557, 2003.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Shuttleworth, J. W., Gash, J. H. C., Lloyd, C. R. Moore, C. J., Roberts, J., Marques, A. D., Fisch, G., Silva, V. D., Ribeiro, M. D. G., Molion, L. C. B., Sa, L. D. D., Nobre, J. C. A., Cabral, O. M. R., Patel, S. R., and Demoraes, J. C.: Eddy correlation measurements of energy partition for Amazonian forest, *Q. J. R. Meteor. Soc.*, 110, 1143–1162, 1984.

5 Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., and Sykes, M. T.: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, *Glob. Change Biol.*, 9, 161–185, 2003.

10 Valentini, R., Matteucci, G., Dolman, A. J., Schulze, E.-D., Rebmann, C., Moors, E. J., Granier, A., Gross, P., Jensen, N. O., and Pilegaard, K.: Respiration as the main determinant of carbon balance in European forests, *Nature*, 404, 861–865, 2000.

Van Heemst, H. D. J.: Potential crop production, in: *Modelling of Agricultural Production: Weather, Soil and Crops. Simulation Monographs*, edited by: Van Keulen, H. and Wolf, J., Pudoc, Wageningen, 13–26, 1986.

15 Verbeeck, H., Peylin, P., Bacour, C., Bonal, D., Steppe, K., and Ciais, P.: Seasonal patterns of CO₂ fluxes in Amazon forests: fusion of eddy covariance data and the ORCHIDEE model, *J. Geophys. Res.-Biogeo.*, 116, G02018, doi:10.1029/2010JG001544, 2011.

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

Table 1. Characteristics and references of fluxtowers used in this study.

Site	CODE	Cover period	Texture (fraction)	Root depth	Soil depth	References
Manaus km 34	M34	2003–2005	CLAY = 0.68; SAND = 0.20	8 m	12 m	Araujo et al. (2002)
Paracou	GFG	2007–2009	CLAY = 0.51; SAND = 0.33	8 m	12 m	Bonal et al. (2008)
Santarem km 83	K83	2001–2003	CLAY = 0.80; SAND = 0.18	8 m	12 m	Goulden et al. (2004)
Santarem km 67	K67	2002–2004	CLAY = 0.42; SAND = 0.52	8 m	12 m	Saleska et al. (2003)
Reserva Jarù	JRU	2000–2003	CLAY = 0.10; SAND = 0.80	4 m	4 m	Kruijt et al. (2004)

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 3. ISBA_{CC} modifications: photosynthesis and transpiration PS version.

Parameter	Description	CTL	PS	Units
$A_{m,max}$	maximum photosynthesis rate for C ₃ plants	2.2×10^{-6}	0.36×10^{-6}	kgCO ₂ m ⁻² s ⁻¹
f_0	coupling factor air saturated	dependent of the soil moisture content	0.74	unitless
Name	Soil Wetness Index	Water Stress functions applied to g_m	Water Stress functions applied to f_0	
CTL	SWI ≥ 1	$\ln(g_m^*) = 4.7 - 7 \cdot f_0^*$		
Tolerant	SWI _c < SWI < 1	$g_m = g_m^* - (g_m^* - g_m^N) \cdot \frac{(1-SWI)}{(1-SWI_c)}$	$f_0 = f_0^*$	
	SWI \leq SWI _c	$g_m = g_m^N \cdot \frac{SWI}{SWI_c}$	$f_0 = \frac{2.8 - \ln(g_m)}{7}$	
PS		$g_m = SWI \cdot g_m^*$	$f_0 = 0.74$	
Linear				
Symbol	Description			
SWI	Soil Wetness index		$SWI = \frac{\Theta - \Theta_{wilt}}{\Theta_{fc} - \Theta_{wilt}}$	
Θ	Soil water content (m ³ m ⁻³)			
Θ_{fc}	Field capacity (m ³ m ⁻³)			
Θ_{wilt}	Wilting point (m ³ m ⁻³)			
SWI _c	Critical extractable Soil Wetness Index		SWI _c = 0.3	
g_m^N	Value of g_m at SWI = SWI _c in mm s ⁻¹		$\ln(g_m^N) = 2.8 - 7 \cdot f_0^*$	

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Table 4. ISBA_{CC}: modifications autotrophic respiration functions PS + R version.

Respiration	CTL	PS + R
R_{leaves}	$\frac{A_m}{g}$	$\frac{A_m}{9} \cdot \exp(-k_n \cdot \text{LAI}) \cdot \frac{1}{\text{LAI}}; k_n = 0.2$
R_2	$B_2 \cdot \eta \cdot Q_{10}^{\frac{T_s-25}{10}}; \eta = 0.01 \text{ g (gj)}^{-1} \text{ and } Q_{10} = 2$	$B_2 \cdot \beta \cdot f(T); \beta = 1.25$
R_4	$B_4 \cdot R_0(1 + 0.16T_p); R_0 = 1.9 \times 10^{-4} \text{ g (gj)}^{-1}$	$B_4 \cdot \beta \cdot f(T); \beta = 1.25$
R_5	0	$B_5 \cdot \lambda_{\text{sap}} \beta_{\text{wood}} \cdot f(T); \beta_{\text{wood}} = 0.0125$
Parameters	CTL	PS + R
Temperature function	T_s surface temperature T_p soil temperature	$f(T) = \exp\left\{E_0 \left(\frac{1}{15-T_0} - \frac{1}{T-T_0}\right)\right\}; T_0 = 25^\circ\text{C}$
$\frac{1}{\text{SLA}}$	68.5 gDM m ⁻²	constant = 120 gDM m ⁻²
λ_{sap}	fraction of sap wood	

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

Table 5. Mean annual autotrophic and heterotrophic carbon stocks and respiration flux deduced from the synthesis of observations done by Malhi et al. (2009) and simulated by ISBACC (simulations CTL and PS+R) at Caxiuana, K67 and M34. The ratio defines the % of carbon respired per carbon pool.

		Caxiuana			Santarem K67			Manaus M34		
		Auto	Hetero	EcoS	Auto	Hetero	EcoS	Auto	Hetero	EcoS
Stocks	OBS	218.7	103.3	322	166.7	171.5	338.2	199.9	141.0	340.9
	PS+R	276.6	87.1	363.7	250.6	98.5	349.2	276.3	150.1	426.4
	CTL	89	27.7	116.7	74.3	29.9	104.2	93.5	51.6	145.1
Resp	OBS	21.4 ± 4.1	9.4 ± 0.8	30.1 ± 4.2	14.9 ± 4.2	14.9 ± 1.4	29.8 ± 4.4	19.8 ± 4.6	9.6 ± 1.2	29.3 ± 4.7
	PS+R	25.2	9.6	34.8	22.5	8.6	31.1	25.0	9.6	34.7
	CTL	33.9	3.2	37.2	30.3	2.8	33.1	32.2	3.5	35.7
Ratio %	OBS	9.8	9.1	9.4	8.9	8.7	8.8	9.9	6.8	8.6
	PS+R	9.1	11.0	9.6	9.0	8.7	8.9	9.0	6.4	8.1
	CTL	38.1	11.6	31.9	40.8	9.4	29.8	34.4	6.8	23.9

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

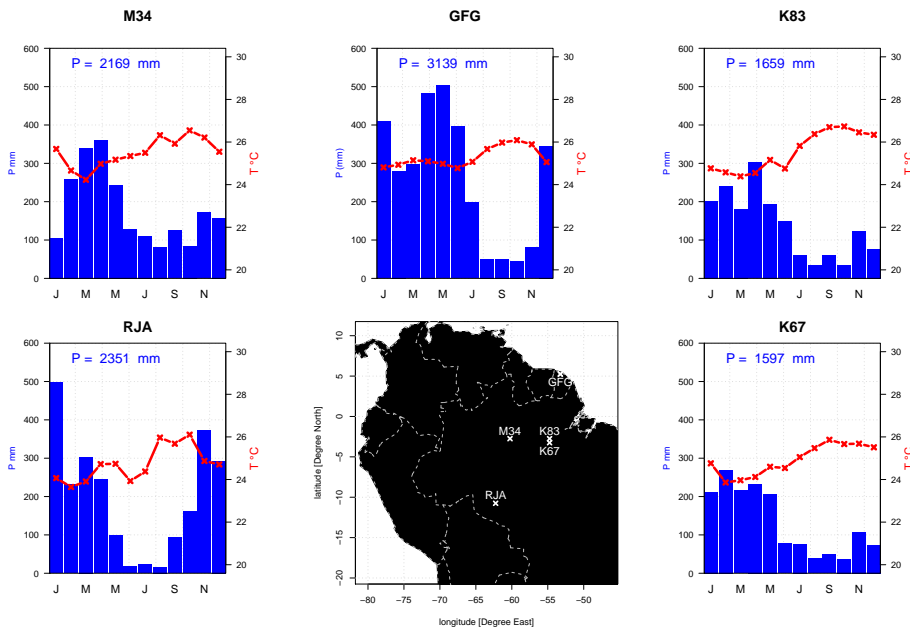


Figure 1. Mean annual cycle of precipitation (blue), temperature (red) calculated over 3 years (see Table 1) and location of the fluxtowers used in this study.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**Modeling stocks and
fluxes of water and
carbon over the
Amazon**

E. Joetzer et al.

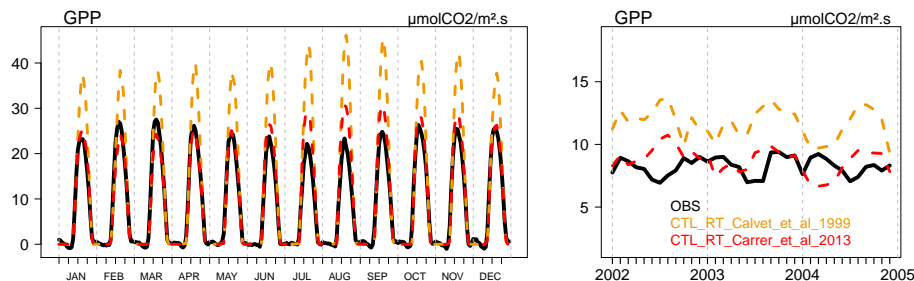


Figure 2. Observed and simulated GPP with the CTL version of ISBACC comparing the two radiative transfers at K67. Left panel shows the diurnal cycle for each month averaged over 3 years (2002–2004); right panel, monthly mean time series for 2002–2004.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

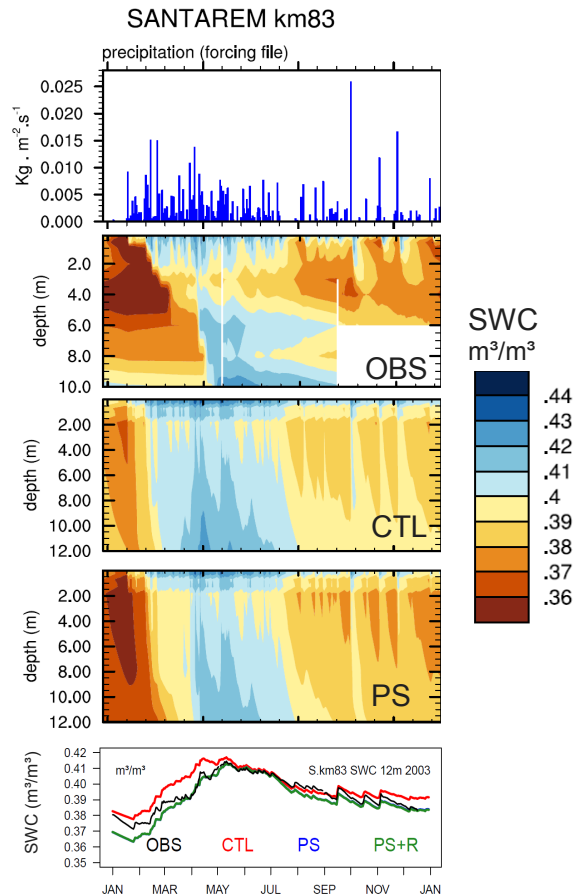


Figure 3. Daily precipitation, and observed and simulated soil moisture at K83 during 2003. We rescaled the soil moisture content of the 10 m pit (Bruno et al., 2006) to the values of the 2 m one (da Rocha et al., 2004).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

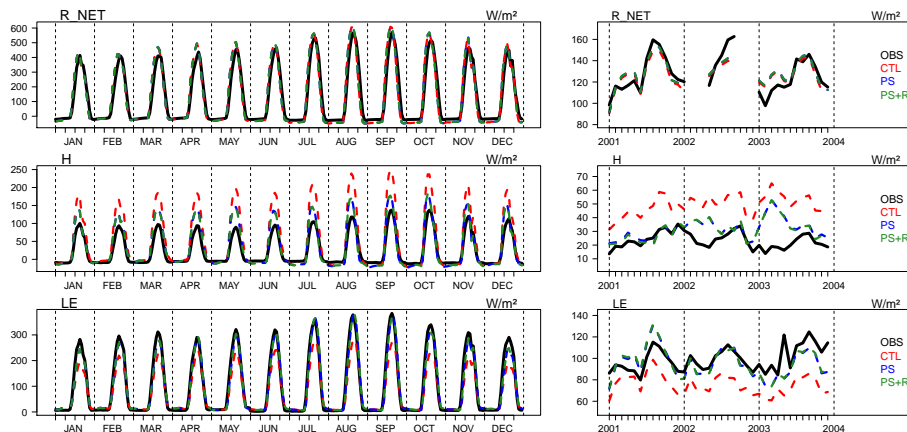


Figure 4. Observed and simulated RN, sensible heat (H) and latent heat (LE) at K83. Left panels show the diurnal cycle for each month averaged over 3 years (2001–2003); and right panels, monthly mean time series for 2001–2003.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

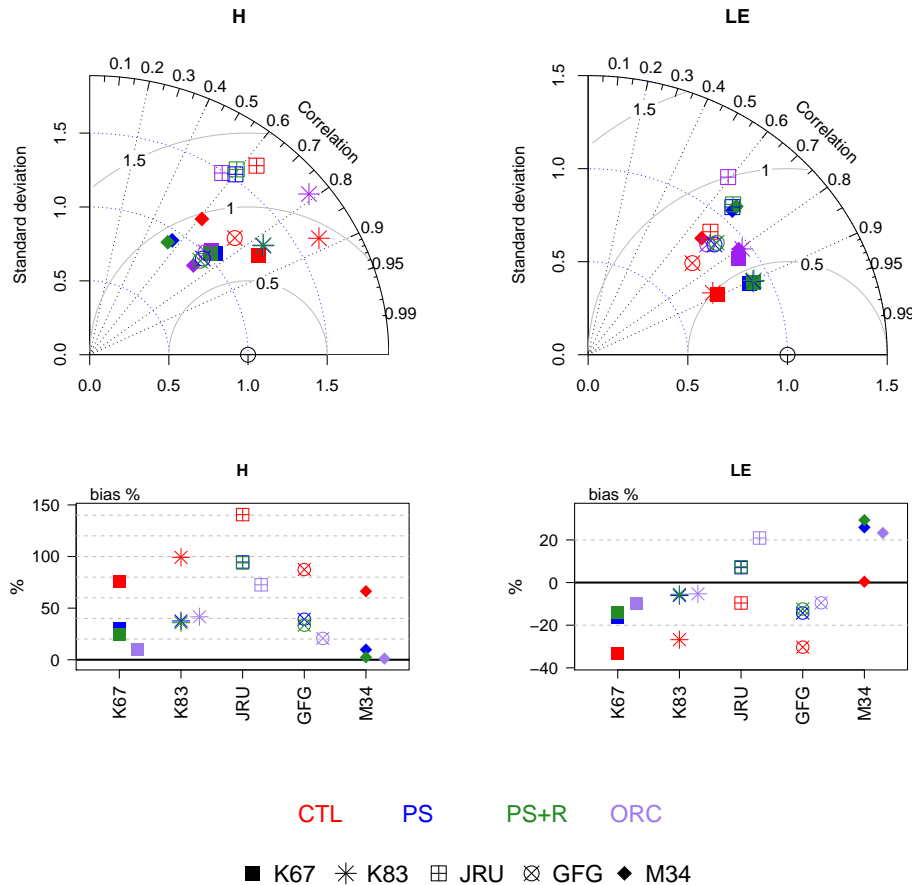


Figure 5. Taylor diagrams (top) and bias (%) (bottom) calculated among hourly values removing night values (Short Wave down $< 5 \text{ W m}^{-2}$) for H and LE at the five fluxtowers described in Table 1.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

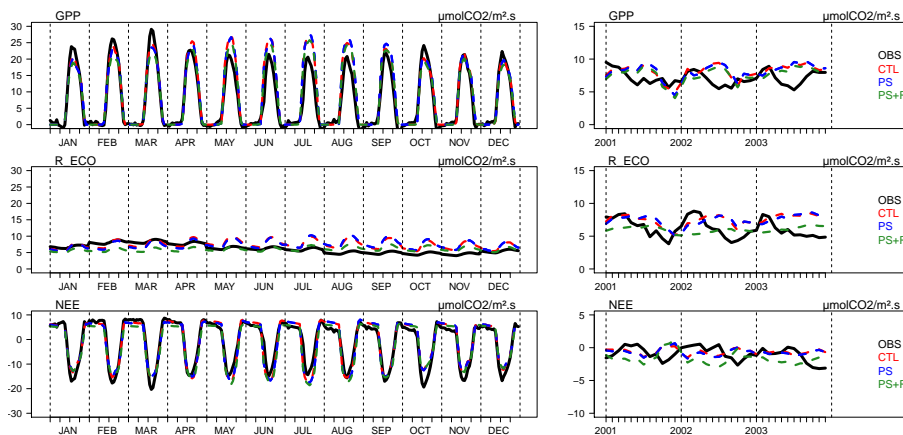


Figure 6. Same as Fig. 4 but for GPP, R_{ECO} and NEE.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

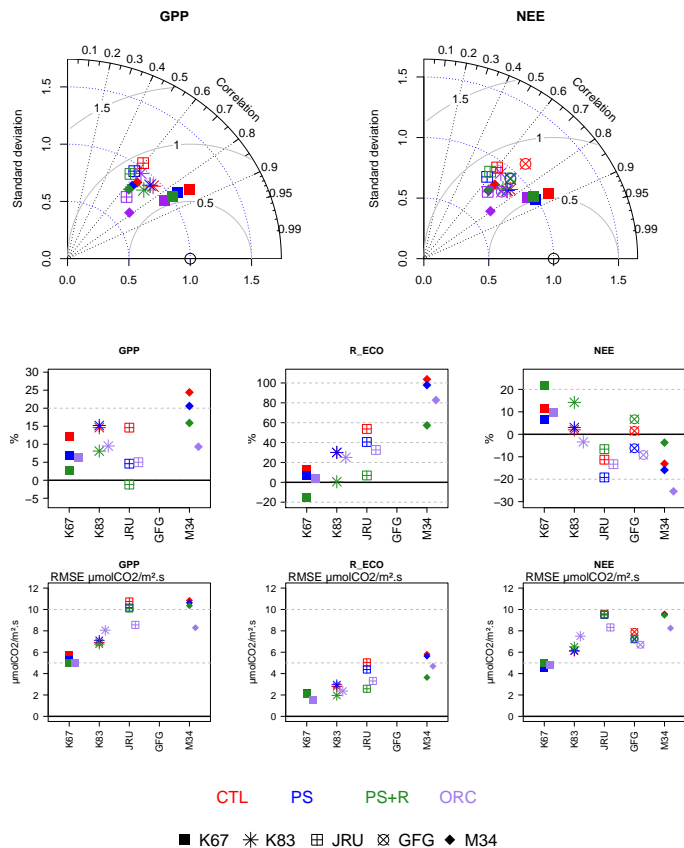


Figure 7. Taylor diagrams (top) for GPP and NEE and bias for GPP R_{ECO} and NEE (%) (bottom) calculated among hourly values removing night values (Short Wave down $< 5 \text{ W m}^{-2}$). Note that at GFG only NEE timeseries was available.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzer et al.

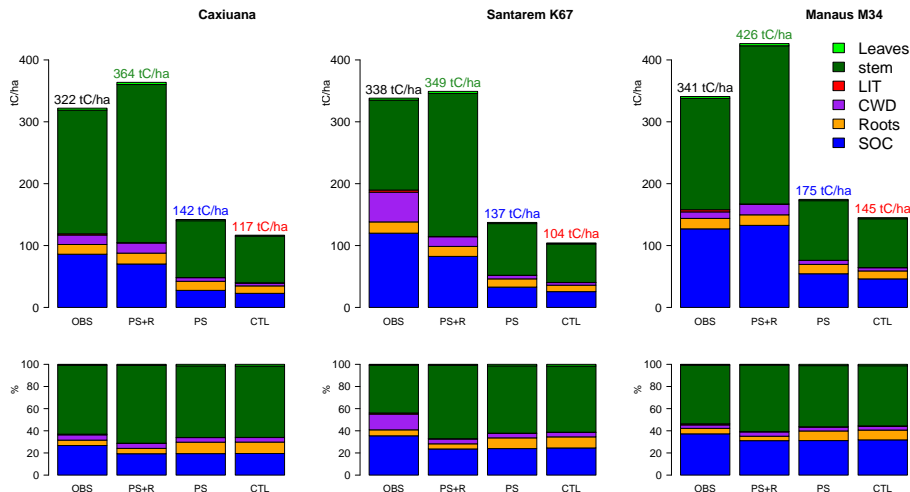


Figure 8. Observed (Mahli et al., 2009) and simulated (CTL, PS and PS+R) annual carbon pools (Leaves (B_L), Stem ($B_2 + B_5$), Litter (LIT), Coarse and Woody Debris (CWD), Roots ($B_4 + B_6$) and Soil Organic Content (SOC)) at Caxiuana, K67 and M34. Top panels show the absolute carbon stock in tC ha^{-1} and below panels the relative carbon stock (%).

Modeling stocks and fluxes of water and carbon over the Amazon

E. Joetzjer et al.

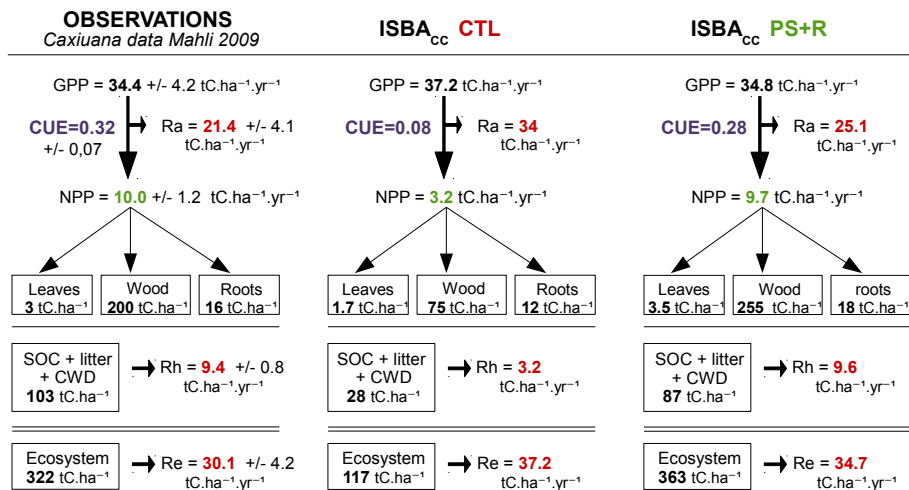


Figure 9. Annual carbon pools and fluxes from a synthesis of observations at Caxiuana (Mahli et al., 2009) compared to ISBA_{CC} (CTL and PS+R simulations). Adapted from Randerson et al. (2009).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

