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Technical Note: A hydrological routing scheme for the Ecosystem Demography model (ED2+R)

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Abstract

Land surface models are excellent tools for studying how climate change and land use affect surface hydrology. However, in order to assess the impacts of earth processes on river flows, simulated changes in runoff need to be routed through the landscape using a hydrological transport scheme. In this Technical Note we describe the integration of the Ecosystem Demography (ED2) model with a hydrological routing scheme. ~~ED2 is a terrestrial biosphere model capable of incorporating sub-grid scale ecosystem heterogeneity arising from land use change, making it ideally suited for investigating combined impacts of changes in climate, atmospheric carbon dioxide concentrations, and land cover on the water cycle.~~ The resulting ED2+R model calculates the lateral propagation of surface and subsurface runoff resulting from the terrestrial biosphere models' vertical water balance in order to determine spatio-temporal patterns of river flows within the simulated region. We evaluated the ED2+R model in the

Summary of comments: hess-2016-114_review_final.pdf

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Number: 1 Author: Reviewer Subject: Note Date: 2016-06-17 22:33:13

Text and language notes:
-Avoid the repetition of the same idea in the different parts of the text and the excessive use of adjectives (i.e. substantial, serious, unique, substantially, etc.)
- Although, in general, the english is clear, consider final text edits by a native english..

Number: 2 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:00:16

This sentence is background...

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Tapajós, a large river basin in southeastern Amazonia, Brazil. The results showed that the integration of ED2 with the lateral routing scheme substantially improves the ability of the model to reproduce daily to decadal river flow dynamics in the Tapajós.

1 Introduction

Understanding the impacts of deforestation (e.g., Lejeune et al. 2015; Medvigy et al. 2011; Andréassian 2004) and climate change (e.g., Jiménez-Cisneros et al. 2014) on the earth's water cycle has been a topic of substantial interest in recent years because of potential serious implications to ecosystems and society (e.g., Wohl et al. 2012; Brown et al., 2005). Analyses of impacts of climate change on the earth's water cycle are increasingly using terrestrial biosphere models, which are capable of estimating changes in the vertical water balance ~~(i.e., evapotranspiration, soil moisture, deep percolation, surface and sub-surface runoff)~~ as a function of climate forcing and and/or land-use induced changes in canopy structure and composition (Zulkafli et al. 2013).

~~Terrestrial biosphere models can mechanistically represent the multiple interactions among land surface energy balance, the hydrological cycle, and the carbon cycle that occur in terrestrial ecosystems.~~ Examples of terrestrial biosphere models actively used for hydrological and earth systems sciences include: the Joint UK Land Environment Simulator (JULES) (Best et al. 2011; Clark et al. 2011); the Community Land Model (CLM) (Lawrence et al. 2011; Oleson et al. 2010); the Lund-Potsdam-Jena (LPJ) land model (Gerten et al. 2004; Sitch et al. 2003); the Max Plank Institute MPI-JSBACH model (Vamborg et al. 2011; Raddatz et al. 2007); and the Integrated Biosphere Simulator (IBIS) (Kucharik et al. 2000).

Initial formulations of the hydrological processes within terrestrial biosphere models were based on simple "bucket" model formulations (Cox et al. 1999 after Carson 1982). Moisture within each climatological grid cell of the domain was simulated in a single below-ground pool in which surface temperature and specific soil moisture factors determined evaporation, while runoff was equal to the bucket overflow (Cox et al. 1999; Carson 1982). Since that formulation, the hydrologic schemes within terrestrial biosphere models have become increasingly sophisticated. In the most recent generation of land surface models, water fluxes in and out of the soil column are vertically-resolved and take into account feedbacks among the different components, for instance, through an explicit formulation of the soil-plant-atmosphere continuum that allows a better representation of the interactions between evapotranspiration,

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Number: 1 Author: Reviewer Subject: Underline Date: 2016-06-18 00:18:23

Actually, the study showed that the river routing method improved the model river representation, when compared to a 'no river representation'...
isn't it obvious, or not? Also, river routing methods exists in a long time.. why is this result important, specially, when compared to other existing models, as you cited.

Number: 2 Author: Reviewer Subject: Highlight Date: 2016-06-17 19:48:04

Number: 3 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:48:14

Number: 4 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:48:20

Number: 5 Author: Reviewer Subject: Note Date: 2016-06-17 19:28:35

You can finish the first paragraph with the following... "Examples..

Number: 6 Author: Reviewer Subject: Note Date: 2016-06-18 00:16:29

This study focus on river routing... too much background information about the evolution of the vertical balance formulations, specially, when compared to literature of recent advances on large-scale river routing. Improve this aspect.
For instance, see Cama-Flood from Yamazaki et al. 2011 and other developments since then.

I suggest your introduction should convey the idea of "why river routing modeling is important and/or needed?"

Yazamaki et al. 2011 Water Resour. Res. 47, W04501, doi:10.1029/2010WR009726

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soil moisture and runoff (Clark et al. 2015). In this way, terrestrial biosphere models can estimate the temporal and spatial distribution of water resources across the simulated domain under changing climate and land cover conditions. The accurate computation of the vertical water balance, however, is only part of the process of estimation of river flows, which are vital data for water resource management (e.g. flood control, hydropower, irrigation). To calculate river flows from a land surface model that could be compared with actual river gauge observations, water runoff must be routed through the studied landscape, considering the topographic and geomorphological features that control water flow (Arora et al. 1999). Consequently, terrestrial biosphere models have been integrated with routing schemes. For example, JULES has been integrated with the Total Runoff Integrating Pathways (TRIP) (Oki et al. 2001; Oki et al. 1999); LPJ with the routing scheme described in Rost et al. (2008); CLM with the Variable Infiltration Capacity's river routing model (Liang et al. 1994); MPI-JSBACH with the Hydrological Discharge (MPI-HD) model (Hagemann & Gates 2001; Hagemann & Dumenil 1997); and IBIS with the river transport model THMB (Coe et al. 2008).

Similar to the models mentioned above, the Ecosystem Demography (ED2) is a terrestrial biosphere model that simulates the coupled water, carbon, and energy dynamics of terrestrial land surfaces (Longo 2014; Medvigy et al. 2009; Moorcroft et al. 2001). One of the key benefits of ED2's formal approach to scaling vegetation dynamics is its ability to describe, in a physically consistent manner, the coupled water, carbon and energy dynamics of heterogeneous landscapes (Hurtt et al. 2013; Medvigy et al. 2009; Moorcroft et al. 2001). ED2's ability to incorporate sub grid scale ecosystem heterogeneity arising from land use change means that the model is ideally suited for investigating of how the combined impacts of changes in climate, atmospheric carbon dioxide concentrations, and land cover are affecting terrestrial ecosystems. For example, ED2 was successfully used to simulate the carbon flux dynamics in the North American continent (Hurtt et al. 2002; Albani et al. 2006), and to assess the impacts on Amazonian ecosystems of changes in climate, atmospheric carbon dioxide and land use (Zhang et al. 2015). Moreover, ED2, coupled with a regional atmospheric circulation component, has been also successfully applied to assess the impacts of deforestation on the Amazonian climate (Knox et al. 2015; Swann et al. 2015). ED2 is a unique tool to evaluate impacts from global and regional changes on ecosystem function, and therefore, it could provide critical information for hydrological studies. In this technical note, we describe the integration of ED2 with a flow routing scheme. This exercise is aimed at calculating the lateral propagation and attenuation of the surface and subsurface runoff resulting from the vertical balance calculations, reproducing

Number: 1 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:04:34

You already talked about global issues in the first paragraph.. I suggest you go further with the global scale issues.. focus...

Number: 2 Author: Reviewer Subject: Underline Date: 2016-06-17 23:04:52

This sentence "that could be compared with actual river gauge observations.." is weak.

Despite "matching" modeled and observed data is needed during model development (i.e. calibration/validation) this is a weak motivation.

You are developing a process-based model... of course you want a good performance, but why? Describe your motivation in this perspective.

Number: 3 Author: Reviewer Subject: Note Date: 2016-06-17 19:35:30

There is a good opportunity to improve the description of the river routing models used in these studies. This is important to situate the ED2+R approach in the "state-of-art" here and further in discussion section
What was your motivation to use Muskingum-Cunge routing scheme in and not other?

Number: 4 Author: Reviewer Subject: Note Date: 2016-06-17 22:54:17

This paragraph has too many details and background on ED2.
Also, there is too much emphasizes on model capabilities, which are not specially relevant in this study.
For instance, I've found "ideally suited"and "unique tool" and "sucessfully" .. this is too much.

Number: 5 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:05:42

This second sentence repeats the overall idea of the first sentence...

Number: 6 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:06:15

excessive details and model 'capabilities'

Number: 7 Author: Reviewer Subject: Underline Date: 2016-06-17 23:05:57

This is interesting, but what was this studies findings? How could a river routing scheme in ED2 fill any scientific gaps concerning this past studies? Did any these studies indicate the need for a river routing method?

Number: 8 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:49:34

Number: 9 Author: Reviewer Subject: Underline Date: 2016-06-18 00:32:31

At the moment, the introduction indicates you implemented river routing mostly because ED2 didn't do it.. and that it could be useful.. ok...

Your scientific question is not clear.. based on background literature. Why are you doing this study? Again, why do you want to improve the river routing?

Why inland waters are important?
One reason..
Cole et al. 2007 Ecosystems (2007) 10: 171–184 DOI: 10.1007/s10021-006-9013-8

Why modeling and remote sensing are needed at large-scale?
Some examples..
Alsdorf, D. E., E. Rodríguez, and D. P. Lettenmaier (2007), Measuring surface water from space, Rev. Geophys., 45, RG2002, doi:10.1029/2006RG000197.
Prigent et al. (2007) Global inundation dynamics inferred from multiple satellite observations, 1993–2000, J. Geophys. Res., 112, D12107, doi:10.1029/2006JD007847.

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in this way river flows through a large basin. The advantage of the proposed model is the ability to better predict the sensitivity of river flows to global and regional environmental changes, combining the advantages of biosphere and hydrological models, bringing together global, regional, and local scale hydrological dynamics in a single modelling framework. The product obtained from this exercise was tested in the Tapajós basin, a large river system in southeastern Amazonia, Brazil.

2 Ecosystem Demography (ED2) model

ED2 is a biosphere simulation model capable of representing biological and physical processes driving the dynamics of ecosystems using climate and soil properties. It is unique amongst terrestrial biosphere models because, rather than using a conventional "ecosystem as big-leaf" assumption, ED2 is formulated at the scale of individual plants. The resulting ecosystem-scale dynamics and fluxes are then calculated through a formal scaling procedure that accurately captures the resulting macroscopic behavior of the ecosystem within each climatological grid-cell. It simulates ecosystem structure and dynamics as well as the corresponding carbon, energy, and water fluxes (Figure 1; Hurtt et al. 2013; Medvigy et al. 2009; Moorcroft et al. 2001). ED2 simulates the dynamics of different plant functional types subdivided into tiles with a homogeneous canopy (Swann et al. 2015; Medvigy et al. 2009). Generally, plant functional types are represented by: early successional trees (fast growing, low wood density, and water needy); mid successional trees; late successional trees (slow growing, shade tolerant, high wood density); and C4 grasses (comprising also pasture and agriculture) (Swann et al. 2015; Medvigy et al. 2009). Each grid cell is subdivided into a series of dynamic tiles that represent the sub-grid scale heterogeneity within each cell. The size of the grid cell is determined by the resolution of meteorological forcing and soil characteristics data, typical from 1 degree to 1 km. This characteristic of the ED2 model makes it suitable for a more realistic simulation of regions characterized by a mixture of natural and anthropogenically modified landscapes. ED2 simulates biosphere dynamics taking into consideration natural disturbances, such as forest fires and plant mortality due to changing environmental conditions, as well as human-caused disturbances, such as deforestation and forest harvesting (Medvigy et al. 2009; Albani et al. 2006). Disturbances are expressed in the model as annual transitions between primary vegetation, secondary vegetation, and agriculture (cropland and pasture) (Albani et al. 2006). Natural disturbance, such as wildfire, is represented in the model by the transition from primary

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Number: 1 Author: Reviewer Subject: Note Date: 2016-06-17 23:07:13

How do you know this? Can you show this?

Number: 2 Author: Reviewer Subject: Note Date: 2016-06-13 18:43:55

Why the interest in Tapajos? And why in Tapajós only.

Number: 3 Author: Reviewer Subject: Note Date: 2016-06-13 17:45:40

This paragraph is huge. Again, too much details on model structure and abilities.

Number: 4 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:04

Number: 5 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:09

Number: 6 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:16

Number: 7 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:12

Number: 8 Author: Reviewer Subject: Note Date: 2016-06-13 17:46:39

to reproduce...

Number: 9 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:19

Number: 10 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:22

Number: 11 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:25

Number: 12 Author: Reviewer Subject: Note Date: 2016-06-13 17:39:18

heterogeneity of what? specify.

Number: 13 Author: Reviewer Subject: Note Date: 2016-06-17 19:38:11

describe the range either in degree, or in km.

Number: 14 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:28

Number: 15 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:35

Number: 16 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:41

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~~vegetation (forest in the case of the Amazon) to grassland shrubland, and subsequently to secondary vegetation (forest re-growth); the abandonment of an agricultural area is represented with the conversion from grassland to secondary vegetation, while forest logging is represented by the transition from primary or secondary vegetation to grassland.~~ The model is composed of several modules operating at multiple temporal and spatial scales, including plant mortality, plant growth, phenology, biodiversity, soil biogeochemistry, disturbance, and hydrology (Longo 2014; Medvigy et al. 2009). For a more complete description of the model, we refer the reader to the literature available (Zhang et al. 2015; Longo 2014; Medvigy et al. 2009; Moorcroft et al. 2001). In this section, we describe in further detail the hydrological sub-component, most related to the topic of this specific study. The hydrological module of the ED2 model is derived from the Land Ecosystem-Atmospheric Feedback model (LEAF-2) (Walko et al. 2000). The model computes the water cycle through the vegetation, air-canopy space, and soils, which results in daily estimates of subsurface and surface runoff from each grid cell, isolated from the others in the domain. The number of soil layers and their thickness influence the accuracy with which the model is able to represent the gradients near the surface. Hydraulic conductivity of the soil layers is a function of soil texture and moisture (Longo 2014). Groundwater exchange is a function of hydraulic conductivity, soil temperature and terrain topography. Water percolation is limited to the bottom layer by the subsurface drainage, determining the bottom boundary conditions. A more detailed description of the hydrological sub-component of the ED2 model is available in Longo (2014).

ED2 runoff routing scheme (ED2+R)

Daily runoff estimates from ED2 were computed for specific grid cells independently; therefore a hydrological routing scheme was linked to this model in order to estimate flow attenuation and accumulation as water moves through the landscape ~~towards the basin outlet~~. The flow routing scheme chosen was adapted from the IPH-MGB, a rainfall-runoff model that has been extensively used in large river basins in South America (Collischonn et al. 2007). ~~The original IPH-MGB model is composed of four different sub-models: soil water balance, evapotranspiration, intra-cell flow propagation, and inter-cell routing through the river network.~~ Only the latter two sub-models were utilized as the processes accounted for by the first two are estimated with ED2. The resulting ED2+R model computes the daily total volume of water passing through any given grid cell in the resulting drainage network in two separate steps:

Number: 1 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:50:58

Number: 2 Author: Reviewer Subject: Underline Date: 2016-06-17 23:19:07

Break a section here...
call it 'ED2 hydrology module' or a name that suits you better.

Number: 3 Author: Reviewer Subject: Underline Date: 2016-06-17 23:08:58

How is the soil/vegetation parameterization? ED2 uses a global scale dataset of soil, vegetation or it depends on application?

Number: 4 Author: Reviewer Subject: Note Date: 2016-06-17 19:39:07

In this section you can say the ED2+R is based on MGB-IPH catchment and river routing scheme.

MGB-IPH should be mentioned in the introduction. Why did you pick this specific method?

Number: 5 Author: Reviewer Subject: Underline Date: 2016-06-17 23:10:24

This is an important feature of river routing and should also be stressed to improve this study introduction/motivation.

Number: 6 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:51:26

Number: 7 Author: Reviewer Subject: Note Date: 2016-06-17 23:09:53

MGB-IPH

Number: 8 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:22:41

Include additional and more recent MGB-IPH studies, you can check a list for reading at (www.ufrgs.br/hge/publicacoes/).

It important to stress that although the typical application uses a Muskingum-Cunge approach for river routing, the new MGB-IPH already allows the use of hydrodynamic solution and floodplain coupling (i.e. local-inertial, Pontes et al. 2015). In the Amazon River Basin application (Paiva et al. 2013) a full hydrodynamic solution was also required to solve low slopes and floodplain inundation characteristic of this basin.
This MGB-IPH model improvements must also be described and could be taken into the discussion as well.. along with the other models.

PONTES et al. (2015) Modelagem hidrológica e hidráulica de grande escala com propagação inercial de vazões. Revista Brasileira de Recursos Hídricos, vol. 20, n. 4. 2015.

Number: 9 Author: Reviewer Subject: Note Date: 2016-06-17 23:10:30

It is enough to say the 'catchment and river routing methods' were utilized.

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First, ED2 estimates of daily surface and subsurface runoff from each grid cell are divided into three linear reservoirs with different residence times to represent overland flow (surface reservoir), interflow (intermediate reservoir) and groundwater flow (base reservoir) (Figure 2). The reservoirs are used to determine the contribution and attenuation of river flow by different soil layers, characterized by different propagation times. The sum of overland flow, interflow, and groundwater flow is then moved from each grid cell into the drainage network computed from a digital elevation model (DEM) using the COTAT (Cell Outlet Tracing with an Area Threshold) algorithm (Reed 2003) and is enhanced with a parameter that accurately assigns flow directions to DEM grid cells over regions with meandering rivers (Annex A). Each DEM grid cell therefore becomes part of a flow path which then accumulates water to a final downstream drainage network outlet (Figure 3 - Panel b). A complete description of the technique for defining drainage networks from DEMs employed in this study can be found in Paz et al. (2006).

Once water reaches the drainage network, ED2+R solves the Muskingum-Cunge equation of flow routing using a finite-difference method as a function of river length, width, height and roughness as well as terrain elevation slope (Collischonn et al. 2007; Reed 2003). Statistical relationships for the river morphology were obtained as a function of the drainage area based on geomorphic data collected by Brazil's National Water Agency (ANA) and the Observation Service for the geodynamical, hydrological and biogeochemical control of erosion/alteration and material transport in the Amazon basin (HyBAM) at several gauging stations in the Amazon and Tocantins basins as presented by Coe et al. (2008). Later on, further studies successfully employed these statistical relationships to estimate river geometric parameters to carry out hydrodynamic simulations of the Amazon River system (Paiva et al., 2013; Paiva et al., 2011). Multiple groups of grid cells with common hydrological features, or hydrological response units, can be created in order to parameterize and calibrate ED2+R. In our approach, hydrological traits associated with soil and land cover are primarily computed in ED2, thus we calibrated ED2+R at the subbasin level as delineated considering the DEM. Details about the calibration procedure are provided in the next section.

4 Parameterization and evaluation for the Tapajós river basin application

We parameterized and evaluated the ED2+R formulation for the Tapajós River Basin, one of the largest tributaries of the Amazon. For calibration purposes the basin was divided into seven

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groundwater or base reservoir? pick one.
don't need any of the parenthesis.

Number: 2 Author: Reviewer Subject: Note Date: 2016-06-13 18:10:36

break the sentence at drainage network.

Number: 3 Author: Reviewer Subject: Underline Date: 2016-06-17 23:11:12

The DEM processing details are distracting and confusing at this point.

Is this pre-processing or COTAT runs during simulation?

Also, assuming you are not worried with floodplain terrain at the moment, the technique can be briefly explained with something like..
".. from a digital elevation model (Reed, 2003; Paz et al. 2006)"

Which DEM resolution are you using?

Number: 4 Author: Reviewer Subject: Underline Date: 2016-06-17 23:11:52

Muskingum-Cunge is a numerical scheme for the solution of the kinematic wave equation, which also accounts numerical diffusion to represent flow attenuation...

Number: 5 Author: Reviewer Subject: Underline Date: 2016-06-17 23:12:01

what do you mean by river height?

Number: 6 Author: Reviewer Subject: Underline Date: 2016-06-17 23:12:12

river flow routing

Number: 7 Author: Reviewer Subject: Underline Date: 2016-06-17 23:13:27

This sentence is ok, but as it is about the model application in Tapajos, it should be described in the section 4.

You should describe better how would you parameterize at continental or global scale?

Number: 8 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:12:37

This is not relevant for ED2+R method overview. Also, in Paiva et al. studies the authors derived their geomorphological relations, although the approach was similar to that of Coe et al. 2008...

Number: 9 Author: Reviewer Subject: Note Date: 2016-06-13 19:00:14

Change name for 'Study case: Tapajós river basin'

Number: 10 Author: Reviewer Subject: Note Date: 2016-06-13 18:59:36

Please, provide an overview of the Tapajós basin, such as hydrological features (i.e. precipitation, land-use, etc.)

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sub-basins, each of them with a corresponding gauge for which historical daily river flow observations were available (Panel a in Figure 3). Simulations were carried out for the period 1970-2008. The ED2 model was forced using reconstructed climate (Sheffield et al. 2006) and land use/land cover data (Hurtt et al. 2006; Soares-Filho et al. 2006) at 1-degree spatial resolution. The original meteorological dataset has a 3-hour temporal resolution, which was downscaled to an hourly resolution, as described in Zhang et al. (2015). Surface and subsurface runoff calculated for each cell with ED2 are connected with the three linear reservoirs of the routing scheme (Figure 2).

Model Calibration: The ED2+R model was manually calibrated through a two-step procedure using gauge observations (HYBAM and ANA) spanning a period of 17 years, from 1976 to 1992 (the period 1970-1975 was not considered in order to avoid simulation initiation effects). In the first step, the flow partitioning between the original ED2 surface and subsurface reservoirs and the ED2+R surface, intermediate, and base reservoirs (parameters α and β in Figure 2) were adjusted. Following the methodology described by Anderson (2002), the sensitivity of the α and β parameters was tested by running the model multiple times (>30). For each run, the goodness-of-fit was quantified comparing the results of the simulation to historical flow observations. The combination of the α and β parameters characterized by the highest goodness-of-fit was selected. Parameters α and β were assumed to be uniform for the whole basin. In the second step, the residence times (τ) of flow within the ED2+R reservoirs of each grid cell in the domain were calibrated (*CS*, *CI*, and *CB* in Figure 2). The calibration procedure characterizing the second step is similar to the previous one but in this case the calibration is repeated for each subbasin sequentially; the calibration process was conducted from the furthest upstream subbasins – headwaters – to the final outlet of the basin (Anderson 2002). The model was run multiple times (between 30 and 50 per subbasin) with different combinations of the three parameters (*CS*, *CI*, and *CB* in Figure 2); for each run, the goodness-of-fit was quantified. This allowed us to design a sensitivity curve of the model to different combinations of the three parameters for each of the seven subbasins, and to select the combination that best approaches the historical observations. Missing observations in the river flow records were filled via linear spatial and temporal interpolation between the series in neighboring gauge stations (Equation 1):

$$Obs_y(t) = K + \beta_1 \cdot Obs_z(t) + \beta_2 \cdot Obs_q(t) + \beta_3 \cdot Obs_y(t-365) + \beta_4 \cdot Obs_y(t+365) \quad (1)$$

Number: 1 Author: Reviewer Subject: Note Date: 2016-06-13 18:57:00

What is the grid/spatial discretization for hydrologic and river routing in this application? Which DEM was used?

Number: 2 Author: Reviewer Subject: Note Date: 2016-06-17 19:43:10

Please provide more details on landuse and land cover.

Number: 3 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:14:11

this was described earlier.

Number: 4 Author: Reviewer Subject: Note Date: 2016-06-13 19:07:23

put the "two-step procedure" in the end of the sentence.

Number: 5 Author: Reviewer Subject: Note Date: 2016-06-17 23:25:41

It means the ED2 was calibrated against discharges? after that alfa and beta are fixed?

Number: 6 Author: Reviewer Subject: Underline Date: 2016-06-17 23:15:12

this partitioning, alfa and beta parameters must be described earlier in sections 3 or 4.
In this way, this whole paragraph can be rewritten directly, as the calibration for alfa, beta and CB, CI, CS are much similar.
Also, tau, CB, CI and CS nomenclature is superposing, thus confusing. Use one or another and fix figures/text accordingly.

Number: 7 Author: Reviewer Subject: Underline Date: 2016-06-17 23:14:40

Explain, how did you set the alfa and beta intervals between 0 and 1?

Number: 8 Author: Reviewer Subject: Underline Date: 2016-06-17 23:15:37

*highest?

goodness-of-fit is often use to evaluate regression models or distribution models fitting..

while calibration is often based on minimization of objective functions..

Number: 9 Author: Reviewer Subject: Note Date: 2016-06-13 19:33:36

Show detailed information (i.e. parameters, gages used, period, number of days filled, etc.) on this regression model for each gage where the interpolation was used.

Calibration of the model using filled data with high correlation (r>0.85) can produce improved statistics. Isn't this affecting your results? Was the interpolation step really necessary and why?

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Where *z*, *y*, and *q* are three gauge stations with timeseries highly correlated (Pearson's r ≥ 0.85), and *t* expresses time in days. The estimated β coefficients were used for the estimation of the missing observations in the site *y*. For further details on the calibration procedure, see Appendix B.

The period 1993-2008 was used for model evaluation. Comparison between observations and simulated flows (goodness-of-fit) were carried out using Pearson's R correlation coefficient (Pearson 1895), volume ratio, and the Nash-Sutcliffe (NSE) coefficient (Nash & Sutcliffe 1970) (Figure 4).

5 Results

The integration of the routing scheme with ED2 substantially increases the ability of the model to accurately reproduce the observed temporal variations in river flows at the basin outlet (Figure 5). This statement applies to all of the sub-basins; the application of the routing scheme substantially improved the goodness-of-fit between simulated and observed values with respect to all three measures, Nash-Sutcliffe (NSE) (Figure 4, panel a), Pearson's R correlation coefficient (panel b in Figure 4), and volume ratio (panel c in Figure 4). Both routed (ED2+R) and non-routed (ED2) simulation results manage to reproduce reasonably well the observed water availability in the basin in terms of volume (panel c in Figure 4); however, the application of the routing scheme improves the ability of the model to reproduce the spatio-temporal propagation of water flows across the basin (panels a and b in Figure 4, and Figure 6). The model's performance in simulating river flows is generally higher in the downstream sub-basins and poorer in the headwaters; in the Upper Teles Pires and Upper Juruena, the model achieved the lowest NSE, and although water volumes are reproduced reasonably well, the seasonal variability is less accurate. The NSE and correlation values increased substantially in the central and lower part of the basin (Figure 4 and Figure 6). The Jamanxim basin results, especially during the validation period, are affected by the very short and fragmented observation time series.

Flow duration curves, representing the probability of the flow values to exceed a specific value, highlight the substantial improvement of the model results after applying the routing scheme (Figure 6). The simulated flow duration curves show an excellent match to the observations in

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Number: 1 Author: Reviewer Subject: Note Date: 2016-06-14 15:29:27

Explain volume ratio statistic.

The more recent Kling-Gupta efficiency metric (Gupta et al. 2009) overcomes some of the Nash-Sutcliffe's flaws, please calculate it.

Gupta et al, 2009, Journal of Hydrology, doi:10.1016/j.jhydrol.2009.08.003

Number: 2 Author: Reviewer Subject: Underline Date: 2016-06-17 19:52:59

Number: 3 Author: Reviewer Subject: Note Date: 2016-06-17 23:45:24

You also have the opportunity to compare the results for:
ED2
versus
ED2+ catchment routing
versus
ED2+catchment+river routing

Number: 4 Author: Reviewer Subject: Note Date: 2016-06-17 19:45:56

Focus on important numbers and features... some of interpretations could be better used in the discussion...

Number: 5 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:53:28

Number: 6 Author: Reviewer Subject: Note Date: 2016-06-14 15:37:37

show time series for the seven basins.

Number: 7 Author: Reviewer Subject: Note Date: 2016-06-14 15:31:14

Results shown in Figure 5 can be summarized in a Table, which will also facilitate the reading of metric values.

Number: 8 Author: Reviewer Subject: Note Date: 2016-06-14 15:39:50

Describe this improvement, in values, in the text.

Number: 9 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:53:24

Number: 10 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:29:16

model skill or model performance.

Number: 11 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:27:33

what do you mean by reasonable well?

Number: 12 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:47:17

Number: 13 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:28:34

what do you mean by water availability?

Number: 14 Author: Reviewer Subject: Underline Date: 2016-06-17 23:29:05

so.. the routing scheme, improved the routing when compared to the model with no routing... and?

Number: 15 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:29:34

*higher?

Number: 16 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:27:55

reasonably well... what is this?

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Where *z*, *y*, and *q* are three gauge stations with timeseries highly correlated (Pearson's r ≥ 0.85), and *t* expresses time in days. The estimated β coefficients were used for the estimation of the missing observations in the site *y*. For further details on the calibration procedure, see Appendix B.

The period 1993-2008 was used for model evaluation. Comparison between observations and simulated flows (goodness-of-fit) were carried out using Pearson's R correlation coefficient (Pearson 1895), volume ratio, and the Nash-Sutcliffe (NSE) coefficient (Nash & Sutcliffe 1970) (Figure 4).

5 Results

The integration of the routing scheme with ED2 substantially increases the ability of the model to accurately reproduce the observed temporal variations in river flows at the basin outlet (Figure 5). This statement applies to all of the sub-basins as the application of the routing scheme substantially improved the goodness-of-fit between simulated and observed values with respect to all three measures, Nash-Sutcliffe (NSE) (Figure 4, panel a), Pearson's R correlation coefficient (panel b in Figure 4), and volume ratio (panel c in Figure 4). Both routed (ED2+R) and non-routed (ED2) simulation results manage to reproduce reasonably well the observed water availability in the basin in terms of volume (panel c in Figure 4); however, the application of the routing scheme improves the ability of the model to reproduce the spatio-temporal propagation of water flows across the basin (panels a and b in Figure 4, and Figure 6). The model's performance in simulating river flows is generally higher in the downstream sub-basins and poorer in the headwaters; in the Upper Teles Pires and Upper Juruena, the model achieved the lowest NSE, and although water volumes are reproduced reasonably well, the seasonal variability is less accurate. The NSE and correlation values increased substantially in the central and lower part of the basin (Figure 4 and Figure 6). The Jamanxim basin results, especially during the validation period, are affected by the very short and fragmented observation time series.

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Number: 17 Author: Reviewer Subject: Underline Date: 2016-06-17 23:30:21

i can't see this result anywhere in figures or graphics..or anywhere..

Number: 18 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:54:19

Number: 19 Author: Reviewer Subject: Underline Date: 2016-06-17 23:30:54

I can't see this anywhere..

Number: 20 Author: Reviewer Subject: Note Date: 2016-06-14 15:50:00

Explain FDCs briefly in methods

Number: 21 Author: Reviewer Subject: Underline Date: 2016-06-17 23:31:16

at this point I know you are applying the routing scheme... use ED2 according ED2+R to avoid repetition

Number: 22 Author: Reviewer Subject: Strikeout Date: 2016-06-17 19:54:29

Number: 23 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:31:27

"Excelent.." I can see the significant improvement... Use metrics, please.

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the furthest upstream sub-basins, especially in the cases of the Upper Juruena and Upper Teles Pires (panels a and b in Figure 6). For downstream subbasins, Lower Juruena and Lower Teles Pires, flood duration curves show a general tendency of overestimating the lowest values of the distribution (panels c to g in Figure 6). This is also evident in the multiyear hydrograph (Figure 5), which shows that the ED2+R tend to overestimate the observations during the dry seasons of the period under consideration.

6 Discussion

As the results in Figures 4-6 show, the integration of ED2 with a simple one-way routing scheme ~~substantially~~ increases ~~the model's ability to reproduce daily water flows through a large river basin.~~ The results highlight the ability of the ED2+R model to more accurately capture the hydrological dynamics in the study domain in terms of both volumes (Figure 6) and seasonality of river flows (Figure 5). As seen in Figure 6, the performance of the model in simulating river flows in the basin is generally higher in the downstream sub-basins and poorer in the headwaters. This is due to both the relatively coarse spatial resolution of the model in combination with the limitations typical of most land surface models in capturing the interactions with the deep groundwater (Lobligeois et al. 2014; Zulkafli et al. 2013; Smith et al. 2004). The combined effect of groundwater interactions and spatial resolution is more evident in the upstream part of the basin because of the greater marginal contribution of baseflow in these areas. Further downstream, the effect of groundwater interactions and spatial resolution is masked by the larger rainfall-runoff contribution and the overall flow accumulation from the upstream subbasins. Other recent hydrological simulations of the Tapajós have obtained higher accuracy (e.g. Mohor et al. 2015; Collischonn et al. 2008; Coe et al. 2008); however, these simulations were set up discretizing the basin into a finer spatial resolution grid (9 to 20 km versus 55 km grid cells).

The principal advantage of the ED2+R model is the ability to better predict the sensitivity of the river flows to global environmental changes. As mentioned earlier, ED2+R combines the advantages of biosphere and hydrological models, bringing together global, regional, and local scale hydrological dynamics in a single modelling framework. This can be used to study how different hydrological systems are being affected by changes in climate forcing and changes in ecosystem composition and structure arising from the combination of: changes in climate, rising atmospheric carbon dioxide, and land-transformation.

Number: 1 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:32:42
(Figure 6a, Figure 6b)

Number: 2 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:31:45
What do you mean by general tendency?

Number: 3 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:33:00
(Figure 6c-6g)

Number: 4 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:33:45
tend??

Number: 5 Author: Reviewer Subject: Note Date: 2016-06-17 23:33:48
what happens in figure 6g, where ED2+R don't seem to improve lowflows when compared to ED2?

Number: 6 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:34:08
What is a simple one-way routing scheme? Where did this come from?

Number: 7 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:34:25
the performance of simulated daily discharges..

Number: 8 Author: Reviewer Subject: Strikeout Date: 2016-06-17 22:03:49

Number: 9 Author: Reviewer Subject: Underline Date: 2016-06-17 23:34:41
Don't repeat literal results...

Number: 10 Author: Reviewer Subject: Underline Date: 2016-06-17 23:36:18
I'm not sure, there are other things to consider like:
Can you explain why this would deep groundwater interactions are important in the Tapajos basin? What's the role of river hydraulics? What is the importance of evapotranspiration in this basin? How does this affect the model ability to simulate local to global scales?

Can't you calibrate or improve ED2 hydrology model parameterization to fix this? Isn't this asscoiated to the calibrated alfa and beta at the first step?

Number: 11 Author: Reviewer Subject: Underline Date: 2016-06-17 23:36:23
greater marginal contribution? Do you mean baseflow to total flow?
show this...

Number: 12 Author: Reviewer Subject: Note Date: 2016-06-17 23:36:33

Number: 13 Author: Reviewer Subject: Underline Date: 2016-06-17 23:37:45
"masked by?"

What do you mean by "larger rainfall-runoff contribution?"

Are you trying to say the river storage is more important than the groundwater?!

Number: 14 Author: Reviewer Subject: Note Date: 2016-06-17 22:08:45
So what do you mean by this?
Are these the only differences? What about the precipitation and climatological datasets, landuse vegetation?

Moreover, how is the river parameterization x river routing method x model performance affected at this basin scale?

Number: 15 Author: Reviewer Subject: Highlight Date: 2016-06-17 22:09:04

Number: 16 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:38:07
better than what?

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the furthest upstream sub-basins, especially in the cases of the Upper Juruena and Upper Teles Pires (panels a and b in Figure 6). For downstream subbasins, Lower Juruena and Lower Teles Pires, flood duration curves show a general tendency of overestimating the lowest values of the distribution (panels c to g in Figure 6). This is also evident in the multiyear hydrograph (Figure 5), which shows that the ED2+R tend to overestimate the observations during the dry seasons of the period under consideration.

6 Discussion

As the results in Figures 4-6 show, the integration of ED2 with a simple one-way routing scheme ~~substantially~~ increases ~~the model's ability to reproduce daily water flows through a large river basin.~~ The results highlight the ability of the ED2+R model to more accurately capture the hydrological dynamics in the study domain in terms of both volumes (Figure 6) and seasonality of river flows (Figure 5). As seen in Figure 6, the performance of the model in simulating river flows in the basin is generally higher in the downstream sub-basins and poorer in the headwaters. This is due to both the relatively coarse spatial resolution of the model in combination with the limitations typical of most land surface models in capturing the interactions with the deep groundwater (Lobligeois et al. 2014; Zulkafli et al. 2013; Smith et al. 2004). The combined effect of groundwater interactions and spatial resolution is more evident in the upstream part of the basin because of the greater marginal contribution of baseflow in these areas. Further downstream, the effect of groundwater interactions and spatial resolution masked by the larger rainfall-runoff contribution and the overall flow accumulation from the upstream subbasins. Other recent hydrological simulations of the Tapajós have obtained higher accuracy (e.g. Mohor et al. 2015; Collischonn et al. 2008; Coe et al. 2008); however, these simulations were set up discretizing the basin into a finer spatial resolution grid (9 to 20 km versus 55 km grid cells).

The principal advantage of the ED2+R model is the ability to better predict the sensitivity of the river flows to global environmental changes. As mentioned earlier, ED2+R combines the advantages of biosphere and hydrological models, bringing together global, regional, and local scale hydrological dynamics in a single modelling framework. This can be used to study how different hydrological systems are being affected by changes in climate forcing and changes in ecosystem composition and structure arising from the combination of: changes in climate, rising atmospheric carbon dioxide, and land-transformation.

Number: 17 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:38:45

why are you repeating this idea?

Number: 18 Author: Reviewer Subject: Note Date: 2016-06-17 23:38:17

Number: 19 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:39:05

what is: local and regional scale?
Also, it was said before that the ED2+R showed limitations to simulate some groundwater processes in headwaters...

Is ED2+R really prepared to run at global scale? What about the computational effort to run the ED2+R in comparison to ED2? What about its ability represent more complex river systems (i.e. floodplains, backwater effects)?

Number: 20 Author: Reviewer Subject: Note Date: 2016-06-14 16:21:32

What are the current limitations? Where is ED2+R when compared to other more sophisticated models?

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7 Conclusions

~~Biosphere models are excellent tools to study hydrological dynamics under climate and land use/land cover changing conditions. These models are usually set to simulate long periods in large regions, usually at global or continental scales. Their ability in reconstructing the water balance at relatively fine geographical and temporal resolution, taking into consideration global environmental changes makes them powerful instruments for hydrological simulations. In order to translate the results of the land surface simulation in terms of river flows, the simulated results need to be processed using a hydrological routing scheme.~~ In this Technical Note, we present the integration of the terrestrial biosphere model Ecosystem Demography 2 (ED2) with the Muskingum-Cunge routing scheme. We tested the integrated model (ED2+R) in the Tapajós river basin, a large tributary of the Amazon in Brazil, for the period 1970-2008. The results showed that the integration of a biosphere model with a routing scheme substantially improves the ability of the land surface simulation to reproduce the hydrological and river flow dynamics at the basin scale. The main limitations highlighted in this case study were linked to the relatively coarse spatial resolution of the model and the rough representation of groundwater flow typical of this kind of models. Moreover, the terrestrial biosphere model ED2 and the routing scheme are presented here in a one-way integration. The full coupling of the routing scheme and ED2 could further improve the ability to reproduce the water balance considering flooded ecosystems, a feature that could be extremely important especially in the simulation of environments like the tropical forest, where local evapotranspiration plays a primary role in the specific ecosystem's dynamics. Future efforts will be oriented towards the resolution of the highlighted limitations and current research is focusing on the application of ED2+R on understanding historical changes and future projections of the impacts of climate change and deforestation on the Amazon's water resources.

Annex A – COTAT algorithm

Cell outlet tracing with an area threshold (COTAT) algorithm (retrieved from Reed et al. 2003):

„The basic rules for the COTAT algorithm are defined here:

1. Identify an outlet pixel in each coarse-resolution cell. The outlet pixel drains the largest cumulative area of any pixel in that cell.

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Number: 1 Author: Reviewer Subject: Note Date: 2016-06-17 23:42:11

Describe your main findings and its relevance..

Number: 2 Author: Reviewer Subject: Strikeout Date: 2016-06-17 23:39:32

This is background...

Number: 3 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:41:24

see comment in discussion..

Number: 4 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:39:37

what so you mean by this? and why is this relevant?

Number: 5 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:40:10

not quite... muskingum-cunge is not really appropriate for floodplain dynamics, specially in large tropical floodplains.

also, what do you mean by flooded ecosystems?

Number: 6 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:39:54

could be? Isn't it?

Number: 7 Author: Reviewer Subject: Note Date: 2016-06-17 22:20:59

I don't think this section is needed.

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2. For each cell, trace downstream, from its outlet pixel, along the flow path defined by the high-resolution flow directions.

3. For each subsequent outlet pixel reached, determine its total drainage area and subtract the drainage area of the starting outlet pixel.

Case 1: If this difference is greater than a user specified area threshold, stop tracing.

Case 2: Otherwise, continue tracing to subsequent outlets until either the area threshold is exceeded or until the edge of the high-resolution grid is reached.

4. Assign the flow direction of the starting cell toward the neighboring cell with the farthest outlet along the trace defined in steps 2 and 3" (from Reed et al. 2003 – Section 3. Methodology, page 2)

Annex B – Calibration of the ED2+R model for the Tapajós River Basin

In this annex, we present the calibration of the ED2+R model for the Tapajós river basin. The calibration process has two steps, as highlighted in Figure 2. The first step is the partitioning of the flows from the two reservoirs of the ED2 biosphere model to the three reservoirs of the ED2+R routed biosphere model. The second step regards the adjustment of the residence times of the water flows in the three reservoirs for each of the grid cells in each of the subbasins (overland, intermediate, and groundwater flows – CS, CI, CB in Figure 2). Figure B.1 shows the different combinations of the α and β parameters introduced in Figure 2. The color bar indicates the Nash-Sutcliffe indicator (NSE) resulting from the comparison between the simulated and observed river flow values obtained using different combinations of the parameters α (x axis) and β (y axis). The chosen combination (indicated by an *x* in Figure B.1) lies in one of the optimal combination areas (NSE ~ 0.8).

The second step of calibration is represented by the adjustment of residence time of the overland, intermediate, and groundwater flows (CS, CI, and CB in Figure 2). Figure B.2 shows how the model is sensitive to marginal variation in initial conditions of baseflow, particularly in the upstream section (i.e. UTP - Upper Teles Pires, UJ – Upper Juruena, and LTP – Lower Teles Pires). Changes in initial groundwater contributions in the downstream part of the basin are almost completely uninfluential for the overall representation of the river flows (i.e. UT and LT - Upper and Lower Tapajós).

Number: 1 Author: Reviewer Subject: Note Date: 2016-06-17 23:40:48

The only criteria here was the ENS?

This is confusing:
1.Did you calibrate the ED2 (without +R)first?

2. Do you calibrate alfa, beta with ED2+R or ED2 only?

Explain clearly.

Number: 2 Author: Reviewer Subject: Highlight Date: 2016-06-17 23:40:30

"almost completely?"

"unifluential?"

Figure B.3 describes instead the calibration of the residence time for each of the subbasins. The different combinations of the values assigned to the parameters CS, CI, and CB significantly impact the overall goodness-of-fit of the river flow simulations (NSE indicator). The calibration process was conducted from the furthest upstream subbasins – headwaters – (UTP – Upper Teles Pires, UJ – Upper Juruena, and JA – Jamanxim) to the final outlet of the basin (LT – Lower Tapajós). The different combinations are marked with the corresponding NSE value; the optimal combination is marked in red (Figure B.3).

Author's contribution

F. Pereira, P. Moorcroft and J. Briscoe designed the study; F. Pereira developed the model code; F. Farinosi, M. Arias, and E. Lee carried out the analysis; F. Farinosi, M. Arias and P. Moorcroft wrote the paper.

Acknowledgements

This work was conducted while F. F. Pereira, F. Farinosi, E. Lee, and M. E. Arias were Giorgio Ruffolo Fellows in the Sustainability Science Program at Harvard University. F. Farinosi was also funded through a doctoral scholarship by Ca' Foscari University of Venice. Support from Italy's Ministry for Environment, Land and Sea is gratefully acknowledged. We would like to thank Marcos Longo for letting us use one of his figures, and Angela Livino for the useful comments. The authors would like to dedicate this study to the late Professor John Briscoe (1948 - 2014), who envisioned and co-led the Amazon Initiative of Harvard's Sustainability Science Program.

References

Albani, M., Medvigy, D., Hurtt, G. C. and Moorcroft, P. R.: The contributions of land-use change, CO 2 fertilization, and climate variability to the Eastern US carbon sink, Glob. Chang. Biol., 12(12), 2370–2390, doi:10.1111/j.1365-2486.2006.01254.x, 2006.

Anderson, E. A.: Calibration of Conceptual Models for Use in River Forecasting. [online] Available from: http://www.nws.noaa.gov/oh/hrl/calb/calibration1102/main.htm, 2002.

Number: 1 Author: Reviewer Subject: Note Date: 2016-06-14 16:53:49

How did you set the range of variation of each parameter?
Does the final parameters have a reasonable physical meaning?

Andréassian, V.: Waters and forests: from historical controversy to scientific debate, J. Hydrol., 291(1-2), 1–27, doi:10.1016/j.jhydrol.2003.12.015, 2004.

Arora, V. K., Chiew, F. H. S. and Grayson, R. B.: A river flow routing scheme for general circulation models, J. Geophys. Res., 104(D12), 14347, doi:10.1029/1999JD900200, 1999.

Best, M. J., Pryor, M., Clark, D. B., Rooney, G. G., Essery, R. . L. H., Ménard, C. B., Edwards, J. M., Hendry, M. A., Porson, A., Gedney, N., Mercado, L. M., Sitch, S., Blyth, E., Boucher, O., Cox, P. M., Grimmond, C. S. B. and Harding, R. J.: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, Geosci. Model Dev., 4(3), 677–699, doi:10.5194/gmd-4-677-2011, 2011.

Brown, A. E., Zhang, L., McMahon, T. A., Western, A. W. and Vertessy, R. A.: A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation, J. Hydrol., 310(1-4), 28–61, doi:10.1016/j.jhydrol.2004.12.010, 2005.

Carson, D.: Current parametrisations of land-surface processes in atmospheric general circulation models, in Land surface processes in atmospheric general circulation models, edited by P. Eagleson, Cambridge University Press, Cambridge, UK., 1982.

Clark, D. B., Mercado, L. M., Sitch, S., Jones, C. D., Gedney, N., Best, M. J., Pryor, M., Rooney, G. G., Essery, R. L. H., Blyth, E., Boucher, O., Harding, R. J., Huntingford, C. and Cox, P. M.: The Joint UK Land Environment Simulator (JULES), model description – Part 2: Carbon fluxes and vegetation dynamics, Geosci. Model Dev., 4(3), 701–722, doi:10.5194/gmd-4-701-2011, 2011.

Clark, M. P., Fan, Y., Lawrence, D. M., Adam, J. C., Bolster, D., Gochis, D. J., Hooper, R. P., Kumar, M., Leung, L. R., Mackay, D. S., Maxwell, R. M., Shen, C., Swenson, S. C. and Zeng, X.: Improving the representation of hydrologic processes in Earth System Models, Water Resour. Res., 51(8), 5929–5956, doi:10.1002/2015WR017096, 2015.

Coe, M. T., Costa, M. H. and Howard, E. A.: Simulating the surface waters of the Amazon River basin: impacts of new river geomorphic and flow parameterizations, Hydrol. Process., 22(14), 2542–2553, doi:10.1002/hyp.6850, 2008.

Collischonn, B., Collischonn, W. and Tucci, C. E. M.: Daily hydrological modeling in the Amazon basin using TRMM rainfall estimates, J. Hydrol., 360(1-4), 207–216, doi:10.1016/j.jhydrol.2008.07.032, 2008.

No Comments.

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Collischonn, W., Allasia, D., Da Silva, B. C. and Tucci, C. E. M.: The MGB-IPH model for large-scale rainfall—runoff modelling, Hydrol. Sci. J., 52(5), 878–895, doi:10.1623/hysj.52.5.878, 2007.

Cox, P. M., Betts, R. A., Bunton, C. B., Essery, R. L. H., Rowntree, P. R. and Smith, J.: The impact of new land surface physics on the GCM simulation of climate and climate sensitivity, Clim. Dyn., 15(3), 183–203, doi:10.1007/s003820050276, 1999.

Gerten, D., Schaphoff, S., Haberlandt, U., Lucht, W. and Sitch, S.: Terrestrial vegetation and water balance—hydrological evaluation of a dynamic global vegetation model, J. Hydrol., 286(1-4), 249–270, doi:10.1016/j.jhydrol.2003.09.029, 2004.

Hagemann, S. and Dumenil, L.: A parametrization of the lateral waterflow for the global scale, Clim. Dyn., 14(1), 17–31, doi:10.1007/s003820050205, 1997.

Hagemann, S. and Gates, L. D.: Validation of the hydrological cycle of ECMWF and NCEP reanalyses using the MPI hydrological discharge model, J. Geophys. Res., 106(D2), 1503, doi:10.1029/2000JD900568, 2001.

Hurtt, G. C., Pacala, S. W., Moorcroft, P. R., Caspersen, J., Shevliakova, E., Houghton, R. A. and Moore, B.: Projecting the future of the U.S. carbon sink, Proc. Natl. Acad. Sci., 99(3), 1389–1394, doi:10.1073/pnas.012249999, 2002.

Hurtt, G. C., Frolking, S., Fearon, M. G., Moore, B., Shevliakova, E., MALYSHEV, S., PACALA, S. W. and Houghton, R. A.: The underpinnings of land-use history: three centuries of global gridded land-use transitions, wood-harvest activity, and resulting secondary lands, Glob. Chang. Biol., 12(7), 1208–1229, doi:10.1111/j.1365-2486.2006.01150.x, 2006.

Hurtt, G. C., Chini, L. P., Frolking, S., Betts, R. A., Feddema, J., Fischer, G., Fisk, J. P., Hibbard, K., Houghton, R. A., Janetos, A., Jones, C. D., Kindermann, G., Kinoshita, T., Klein Goldewijk, K., Riahi, K., Shevliakova, E., Smith, S., Stehfest, E., Thomson, A., Thornton, P., van Vuuren, D. P. and Wang, Y. P.: Harmonization of land-use scenarios for the period 1500-2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands, Clim. Change, 109(1), 117–161, doi:10.1007/s10584-011-0153-2, 2011.

Hurtt, G. C., Moorcroft, P. R. and Pacala, S. W.: Ecosystem Demography Model: Scaling Vegetation Dynamics Across South America, Ecosyst. Demogr. Model Scaling Veg. Dyn. Across South Am. Model Prod. [online] Available from: http://daac.ornl.gov/MODELS/guides/EDM_SA_Vegetation.html, 2013.

No Comments.

Jiménez-Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., Jiang, T. and Mwakalila, S. S.: Freshwater resources., in Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, pp. 229–269., Cambridge University Press, ambridge, United Kingdom and New York, NY, USA. [online] Available from: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap3_FINAL.pdf, 2014.

Knox, R. G., Longo, M., Swann, A. L. S., Zhang, K., Levine, N. M., Moorcroft, P. R. and Bras, R. L.: Hydrometeorological effects of historical land-conversion in an ecosystem-atmosphere model of Northern South America, Hydrol. Earth Syst. Sci., 19(1), 241–273, doi:10.5194/hess-19-241-2015, 2015.

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. Cycles, 14(3), 795–825, doi:10.1029/1999GB001138, 2000.

Lawrence, D. M., Oleson, K. W., Flanner, M. G., Thornton, P. E., Swenson, S. C., Lawrence, P. J., Zeng, X., Yang, Z.-L., Levis, S., Sakaguchi, K., Bonan, G. B. and Slater, A. G.: Parameterization improvements and functional and structural advances in Version 4 of the Community Land Model, J. Adv. Model. Earth Syst., 3(3), M03001, doi:10.1029/2011MS000045, 2011.

Lejeune, Q., Davin, E. L., Guillod, B. P. and Seneviratne, S. I.: Influence of Amazonian deforestation on the future evolution of regional surface fluxes, circulation, surface temperature and precipitation, Clim. Dyn., 44(9-10), 2769–2786, doi:10.1007/s00382-014-2203-8, 2015.

Liang, X., Lettenmaier, D. P., Wood, E. F. and Burges, S. J.: A simple hydrologically based model of land surface water and energy fluxes for general circulation model, J. Geophys. Res., 99(D7), 14,415–14,428, 1994.

Lobligeois, F., Andréassian, V., Perrin, C., Tabary, P. and Loumagne, C.: When does higher spatial resolution rainfall information improve streamflow simulation? An evaluation using

No Comments.

3620 flood events, Hydrol. Earth Syst. Sci., 18(2), 575–594, doi:10.5194/hess-18-575-2014, 2014.

Longo, M.: Amazon Forest Response to Changes in Rainfall Regime: Results from an Individual-Based Dynamic Vegetation Model, Harvard University. [online] Available from: http://dash.harvard.edu/handle/1/11744438, 2014.

Medvigy, D., Wofsy, S. C., Munger, J. W., Hollinger, D. Y. and Moorcroft, P. R.: Mechanistic scaling of ecosystem function and dynamics in space and time: Ecosystem Demography model version 2, J. Geophys. Res. Biogeosciences, 114(G1), G01002, doi:10.1029/2008JG000812, 2009.

Medvigy, D., Walko, R. L. and Avissar, R.: Effects of Deforestation on Spatiotemporal Distributions of Precipitation in South America, J. Clim., 24(8), 2147–2163, doi:10.1175/2010JCLI3882.1, 2011.

Mohor, G. S., Rodriguez, D. A., Tomasella, J. and Siqueira Júnior, J. L.: Exploratory analyses for the assessment of climate change impacts on the energy production in an Amazon run-of-river hydropower plant, J. Hydrol. Reg. Stud., 4, 41–59, doi:10.1016/j.ejrh.2015.04.003, 2015.

Moorcroft, P. R., Hurtt, G. C. and Pacala, S. W.: A method for scaling vegetation dynamics: The ecosystem demography model (ED), Ecol. Monogr., 71(4), 557–586, doi:10.1890/0012-9615(2001)071[0557:AMFSVD]2.0.CO;2, 2001.

Nash, E. and Sutcliffe, V.: River flow forecasting Through conceptual models PART I- A Discussion of principles, J. Hydrol., 10, 282–290, 1970.

Oki, T., Nishimura, T. and Dirmeyer, P.: Assessment of Annual Runoff from Land Surface Models Using Total Runoff Integrating Pathways (TRIP), J. Meteorol. Soc. Japan, 77(1B), 235–255 [online] Available from: https://www.jstage.jst.go.jp/article/jmsj1965/77/1B/77_1B_235/_article, 1999.

Oki, T., Agata, Y., Kanae, S., Saruhashi, T., Yang, D. and Musiake, K.: Global assessment of current water resources using total runoff integrating pathways, Hydrol. Sci. J., 46(6), 983–995, doi:10.1080/02626660109492890, 2001.

Oleson, K. W., Lawrence, D. M., Bonan, G. B., Flanner, M. G., Kluzek, E., Lawrence, P. J., Levis, S., Swenson, S. C. and Thornton, P. E.: Technical Description of version 4.0 of the

No Comments.

Community Land Model (CLM), Boulder, CO - USA. [online] Available from: http://www.cesm.ucar.edu/models/cesm1.0/clm/CLM4_Tech_Note.pdf, 2010.

Paiva, R. C. D., Collischonn, W. and Tucci, C. E. M.: Large scale hydrologic and hydrodynamic modeling using limited data and a GIS based approach, J. Hydrol., 406(3-4), 170–181, doi:10.1016/j.jhydrol.2011.06.007, 2011.

Paiva, R. C. D., Collischonn, W. and Buarque, D. C.: Validation of a full hydrodynamic model for large-scale hydrologic modelling in the Amazon, Hydrol. Process., 27(3), 333–346, doi:10.1002/hyp.8425, 2013.

Paz, A. R., Collischonn, W. and Lopes da Silveira, A. L.: Improvements in large-scale drainage networks derived from digital elevation models, Water Resour. Res., 42(8), doi:10.1029/2005WR004544, 2006.

Pearson, K.: Note on regression and inheritance in the case of two parents, Proc. R. Soc. London, 58, 1895.

Raddatz, T. J., Reick, C. H., Knorr, W., Kattge, J., Roeckner, E., Schnur, R., Schnitzler, K.-G., Wetzel, P. and Jungclaus, J.: Will the tropical land biosphere dominate the climate–carbon cycle feedback during the twenty-first century?, Clim. Dyn., 29(6), 565–574, doi:10.1007/s00382-007-0247-8, 2007.

Reed, S. M.: Deriving flow directions for coarse-resolution (1-4 km) gridded hydrologic modeling, Water Resour. Res., 39(9), doi:10.1029/2003WR001989, 2003.

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J. and Schaphoff, S.: Agricultural green and blue water consumption and its influence on the global water system, Water Resour. Res., 44(9), doi:10.1029/2007WR006331, 2008.

Sheffield, J., Goteti, G. and Wood, E. F.: Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling, J. Clim., 19(13), 3088–3111, doi:10.1175/JCLI3790.1, 2006.

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., Sykes, M. T., Thonicke, K. and Venevsky, S.: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Glob. Chang. Biol., 9(2), 161–185, doi:10.1046/j.1365-2486.2003.00569.x, 2003.

No Comments.

Smith, M. B., Koren, V. I., Zhang, Z., Reed, S. M., Pan, J.-J. and Moreda, F.: Runoff response to spatial variability in precipitation: an analysis of observed data, J. Hydrol., 298(1-4), 267–286, doi:10.1016/j.jhydrol.2004.03.039, 2004.

Soares-Filho, B. S., Nepstad, D. C., Curran, L. M., Cerqueira, G. C., Garcia, R. A., Ramos, C. A., Voll, E., McDonald, A., Lefebvre, P. and Schlesinger, P.: Modelling conservation in the Amazon basin., Nature, 440(7083), 520–3, doi:10.1038/nature04389, 2006.

Swann, A. L. S., Longo, M., Knox, R. G., Lee, E. and Moorcroft, P. R.: Future deforestation in the Amazon and consequences for South American climate, Agric. For. Meteorol., 214-215, 12–24, doi:10.1016/j.agrformet.2015.07.006, 2015.

Vamborg, F. S. E., Brovkin, V. and Claussen, M.: The effect of a dynamic background albedo scheme on Sahel/Sahara precipitation during the mid-Holocene, Clim. Past, 7(1), 117–131, doi:10.5194/cp-7-117-2011, 2011.

Walko, R. L., Band, L. E., Baron, J., Kittel, T. G. F., Lammers, R., Lee, T. J., Ojima, D., Pielke, R. A., Taylor, C., Tague, C., Tremback, C. J. and Vidale, P. L.: Coupled Atmosphere–Biophysics–Hydrology Models for Environmental Modeling, J. Appl. Meteorol., 39(6), 931–944, doi:10.1175/1520-0450(2000)039<0931:CABHMF>2.0.CO;2, 2000.

Wohl, E., Barros, A., Brunsell, N., Chappell, N. A., Coe, M., Giambelluca, T., Goldsmith, S., Harmon, R., Hendrickx, J. M. H., Juvik, J., McDonnell, J. and Ogden, F.: The hydrology of the humid tropics, Nat. Clim. Chang., 2(9), 655–662, doi:10.1038/nclimate1556, 2012.

Zhang, K., de Almeida Castanho, A. D., Galbraith, D. R., Moghim, S., Levine, N. M., Bras, R. L., Coe, M. T., Costa, M. H., Malhi, Y., Longo, M., Knox, R. G., McKnight, S., Wang, J. and Moorcroft, P. R.: The fate of Amazonian ecosystems over the coming century arising from changes in climate, atmospheric CO2, and land use, Glob. Chang. Biol., 21(7), 2569–2587, doi:10.1111/gcb.12903, 2015.

Zulkafli, Z., Buytaert, W., Onof, C., Lavado, W. and Guyot, J. L.: A critical assessment of the JULES land surface model hydrology for humid tropical environments, Hydrol. Earth Syst. Sci., 17(3), 1113–1132, doi:10.5194/hess-17-1113-2013, 2013.

No Comments.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2016-114, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
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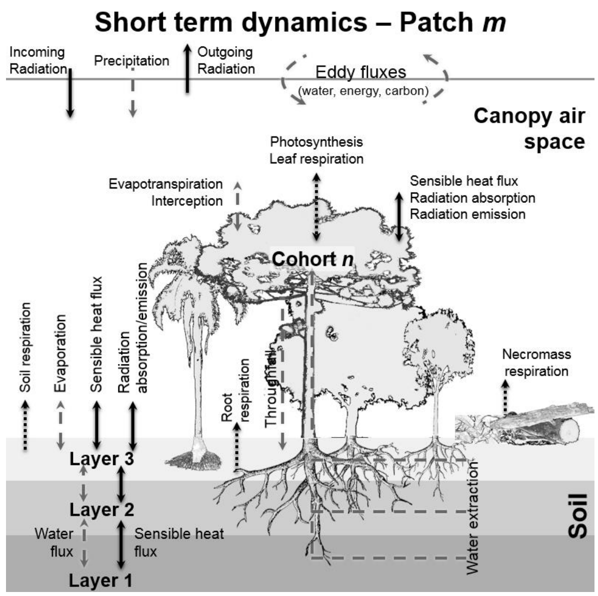

Figure 1. Schematic of the enthalpy fluxes (all arrows) and water fluxes (all but solid black arrows) that are solved in ED2. The schematic is based on Walko et al. (2000); and Medvigy et al. (2009). (Courtesy of Marcos Longo).

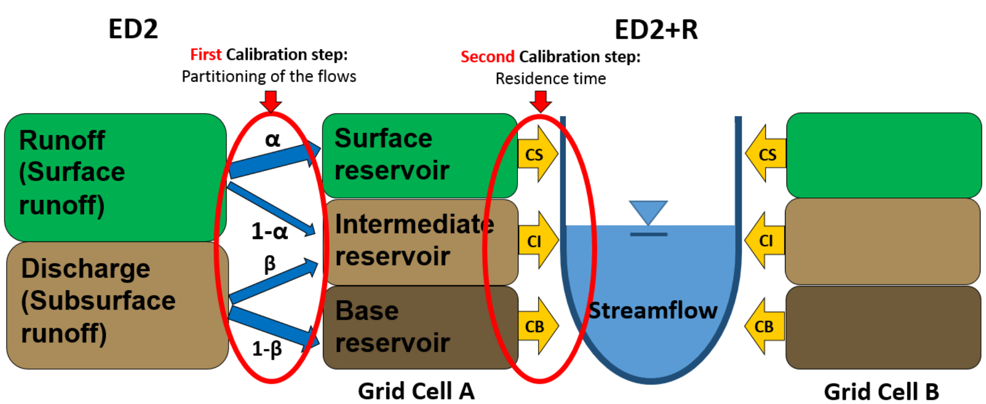

Figure 2. Schematic representation of the connection between the terrestrial biosphere model and the hydrological routing scheme. Calibrating parameters circled in red (Figure B.1 and Figure B.3). The reservoirs are used to determine the contribution of streamflow that comes from overland flow (surface reservoir), interflow (intermediate reservoir) and groundwater flow (base reservoir). The daily sum of these three reservoirs is then moved from each grid cell into the drainage network.

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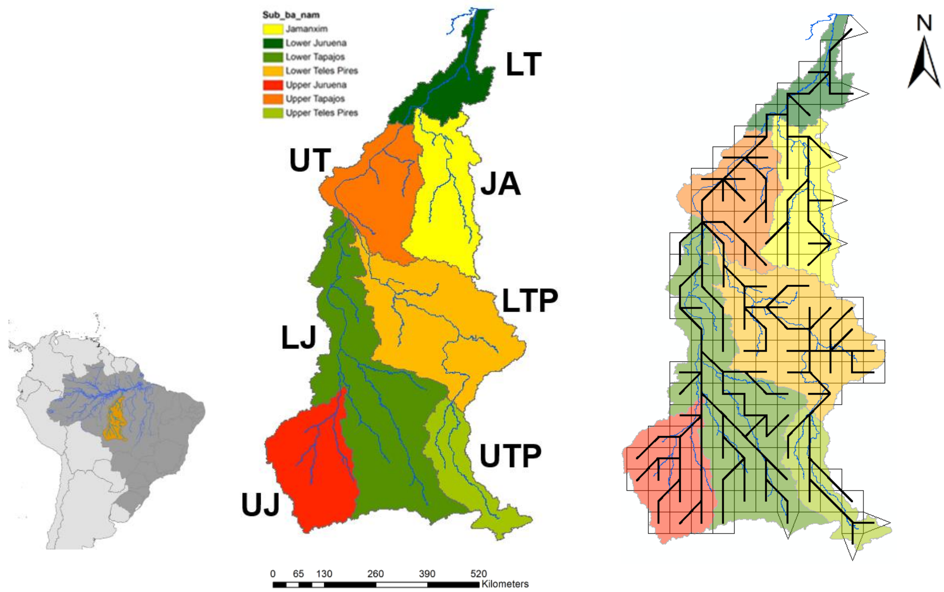

(a) (b)

Figure 3. (a) Organization of the Tapajós basin into seven sub-basins: Upper Juruena (UJ); Lower Juruena (LJ); Upper Teles Pires (UTP); Lower Teles Pires (LTP); Jamanxim (JA); Upper Tapajós (UT); and Lower Tapajós (LT). (b) ED2+R represents the domain in grid cells with 0.5° resolution (~ 55 km). The black segments indicate flow accumulation network.

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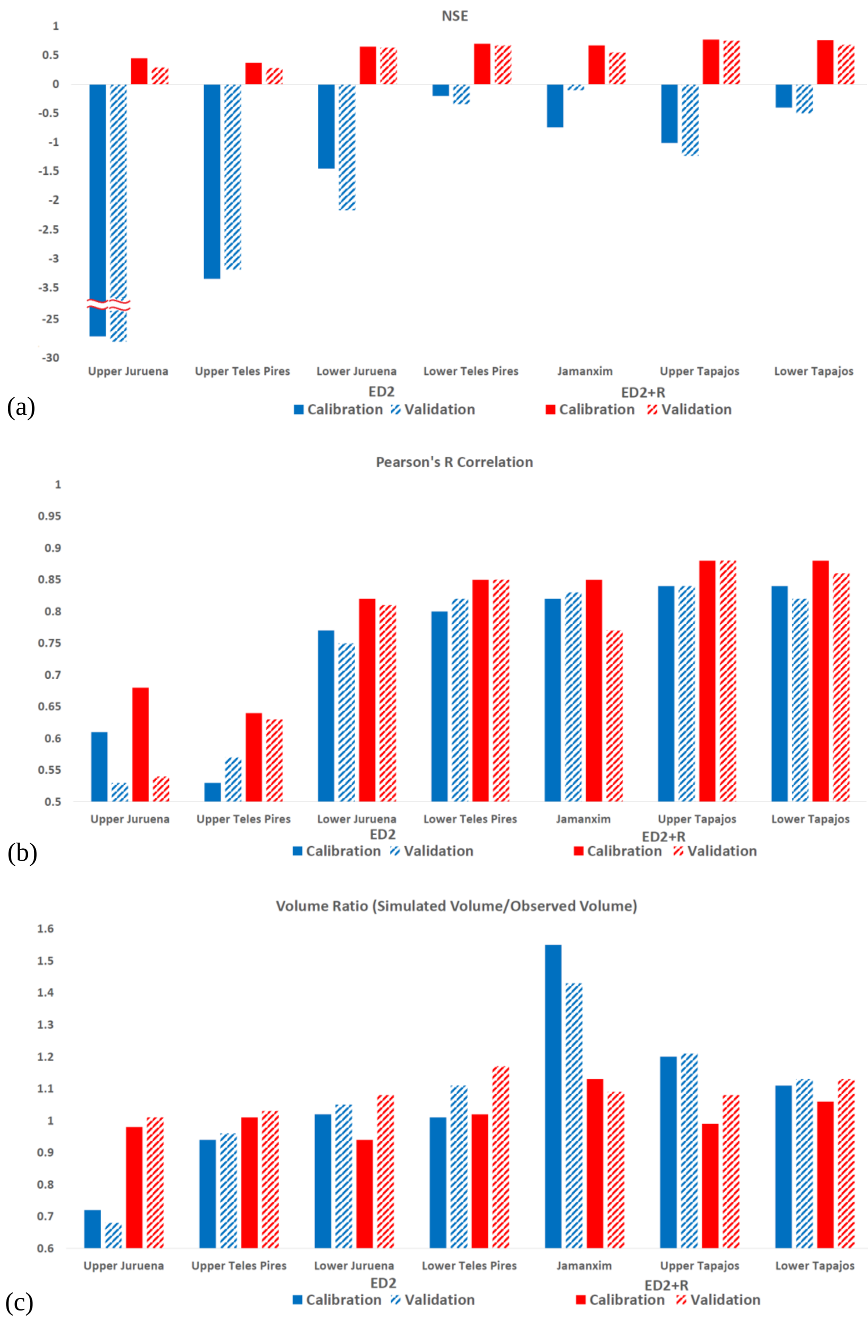

Figure 4. Calibration and validation results. (a) Nash-Sutcliffe, (b) Pearson's R, and (c) volume ratio, optimal values = 1; in red ED2+R results, in blue ED2. Filled bars corresponds to calibration period, shaded bars for validation period.

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a table would do it.. i think it is hard to read the values.

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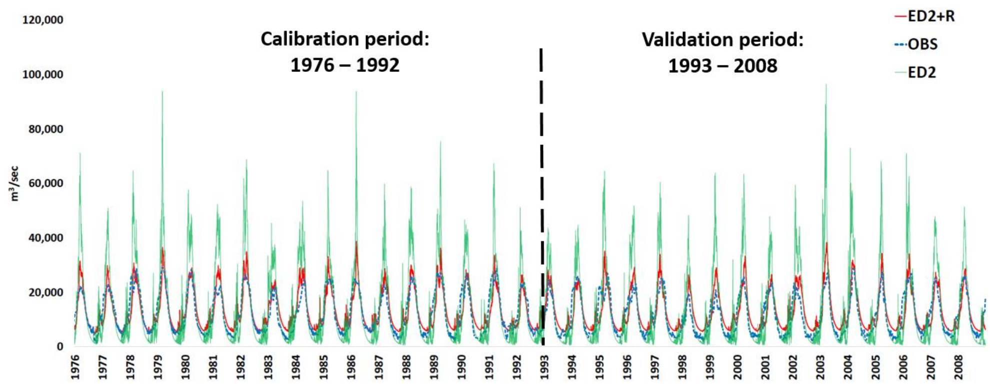

Figure 5. Calibration and validation of the river flow (m^3/sec) at Itaituba (farthest downstream river gauge – Lower Tapajós sub-basin). ED2 output (green line), ED2+R (red line), and Observations (blue dotted line). The dotted black line splits the calibration and validation periods.

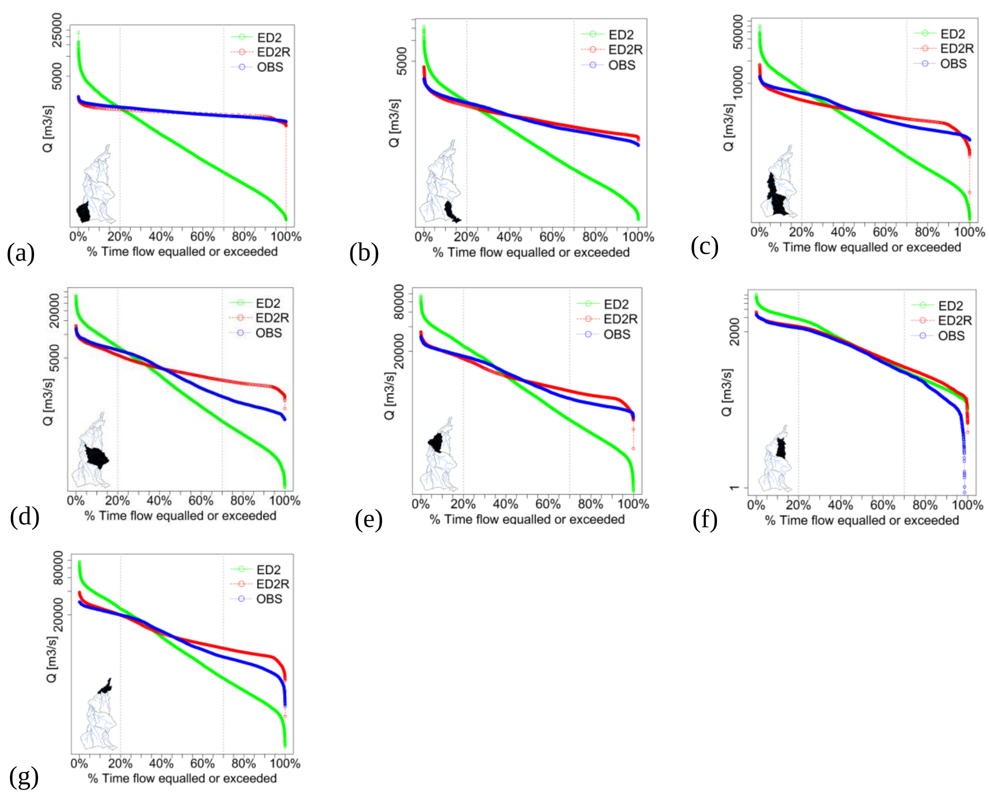

Figure 6. Flow duration curves (percentage of time that flow – m^3/s – is likely to equal or exceed determined thresholds) of observed values (blue), ED2 outputs (green), ED2+R (red) at the outlet of the seven sub-basins. (a) Upper Juruena (UJ); (b) Upper Teles Pires (UTP); (c) Lower

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Juruena (LJ); (d) Lower Teles Pires (LTP); (e) Upper Tapajós (UT); (f) Jamanxim (JA); and (g) Lower Tapajós (LT).

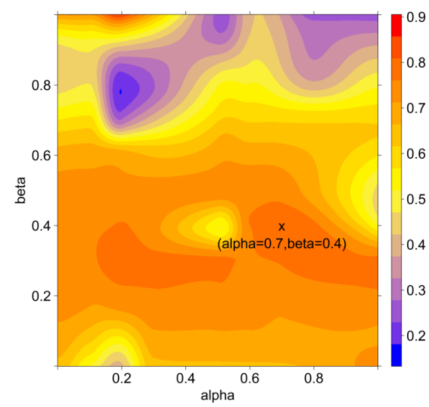

Figure B.1. Calibration of flow partitioning (parameters alpha and beta in Figure 2) between the ED2 and the ED2+R reservoirs. Color bar indicates the NSE values of the simulated versus the observed river flow values (0 very different, 1 very similar)

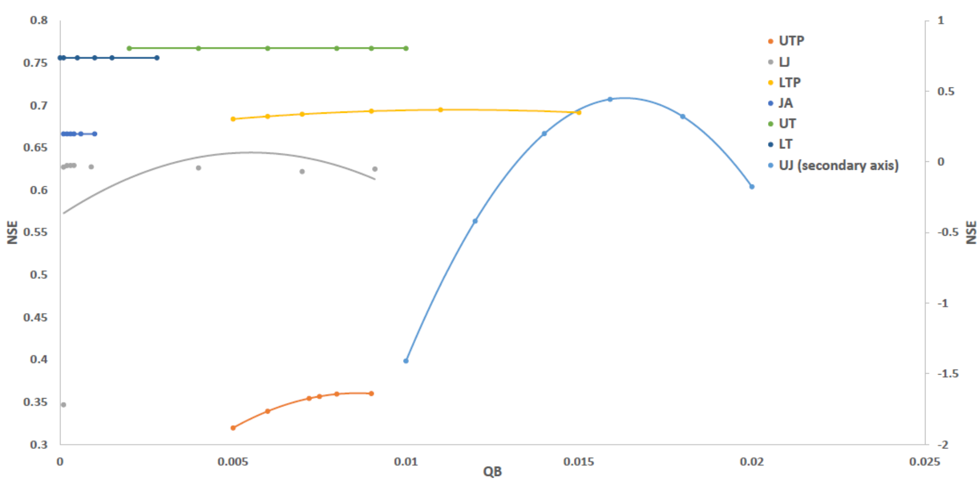

Figure B.2. Initial conditions of baseflow sensitivity for different ED2+R subbasins in the domain. Upper Juruena (UJ); Upper Teles Pires (UTP); Lower Juruena (LJ); Lower Teles Pires (LTP); Upper Tapajós (UT); Jamanxim (JA); and Lower Tapajós (LT).

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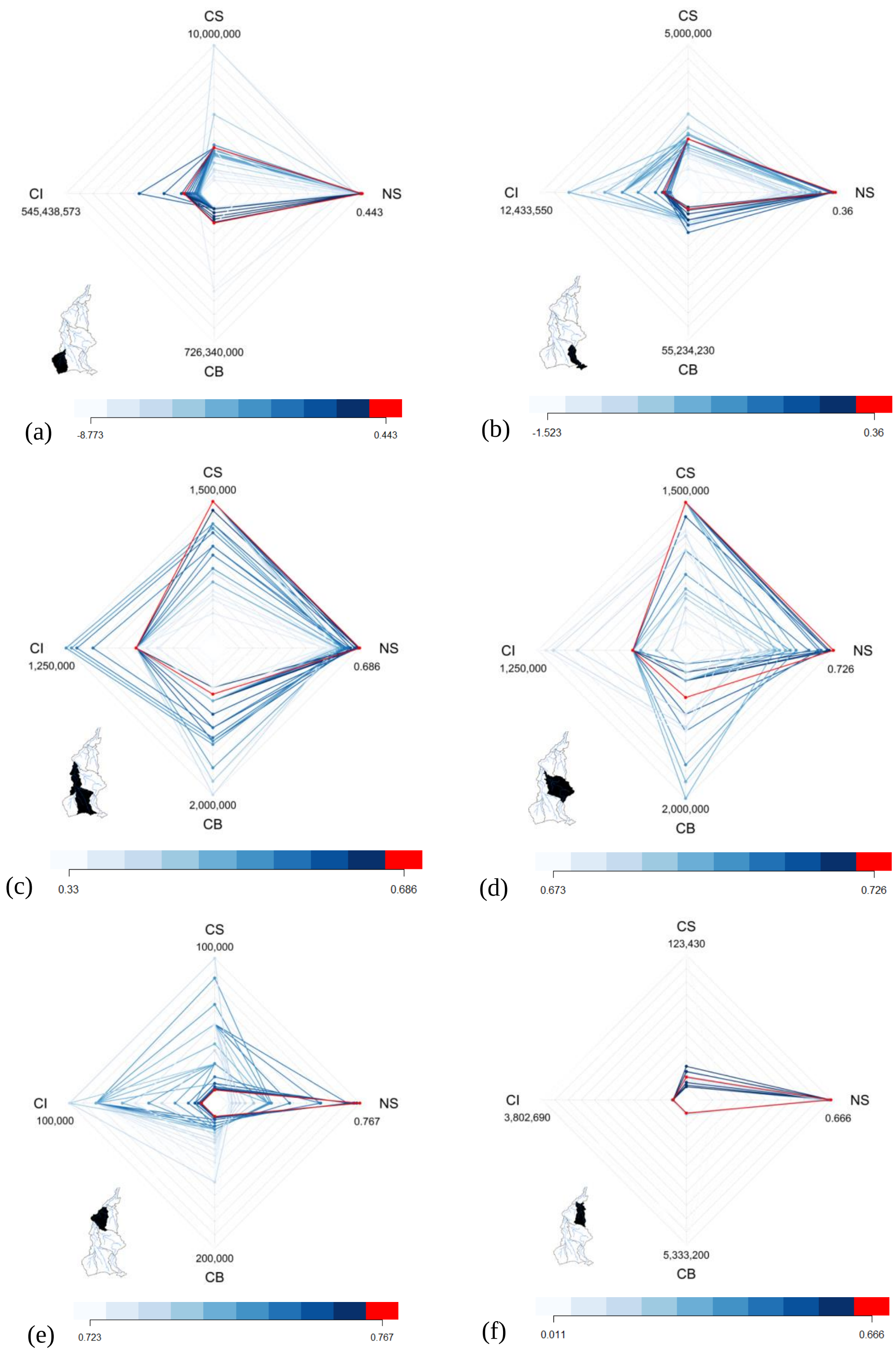

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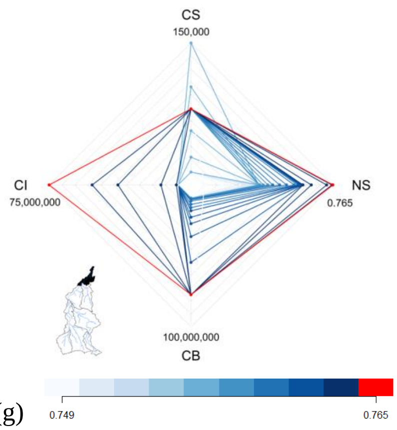

(g)

Figure B.3. Calibration of the residence times (τ) of the flow within the ED2+R reservoirs of different grid cells in the domain. Overland, intermediate and groundwater flows are indicated respectively by CS, CI, and CB (Figure 2). In red the chosen combination. (a) Upper Juruena (UJ); (b) Upper Teles Pires (UTP); (c) Lower Juruena (LJ); (d) Lower Teles Pires (LTP); (e) Upper Tapajós (UT); (f) Jamanxim (JA); and (g) Lower Tapajós (LT).

No Comments.