

1 (Reviewer comments in *italics*; Responses in **bold**)

2  
3 Response to Anonymous Referee #1 Received and published: 11 July 2017

4  
5 *General Comments:*

6 *Reviewer summary:*

7 *The manuscript presents results from the DGVM INLAND evaluating the effect of climate variability,*  
8 *fire and phosphorus limitation on vegetation structure and dynamics in the transitional zone between*  
9 *the forested Amazon and grassland savanna of the Cerrado. Changes in net primary production,*  
10 *aboveground biomass, and leaf area index are assessed between simulations, and simulated*  
11 *aboveground biomass is compared to observations. Transects along the Amazon-Cerrado transition*  
12 *zone are analyzed in subsets, as well as the region as a whole. Inclusion of climate variability, fire and*  
13 *maps phosphorus limitation improves simulation of vegetation structure across the region and for four*  
14 *of five transects. The cerrado transect has the lowest correlation to observations. Fire has the strongest*  
15 *impact on vegetation characteristics, followed by phosphorous limitation. Overall, INLAND with these*  
16 *included factors appears effective at simulating vegetation across the region, but regional deficiencies*  
17 *show that more improvements can be made.*

18 *Article contribution and overall impact:*

19 *This study highlights the need for improved simulation of vegetation in a key forest-savanna transition*  
20 *zone. A shift in vegetation in this region has the capacity to impact the cycling of water and nutrients as*  
21 *well as energy fluxes beyond the area of forest-savanna transition. Uncertainty in future climate and*  
22 *fire behavior as well as the feedback between these factors make the vegetation state of this region*  
23 *difficult to predict. The manuscript does a good job of presenting the challenges of simulating*  
24 *vegetation in this transitional zone where climate, nutrients and fire are essential contributors to*  
25 *vegetation state. The inclusion of phosphorous limitation in the simulations for the region is an*  
26 *important addition to the evaluation of vegetation state. The discussion would benefit from a more*  
27 *detailed description of the fire model and fire activity during simulation. The concluding*  
28 *recommendations for future work also need to be clarified. Discussion of the importance of vegetation*  
29 *size structure and how this is or is not represented in INLAND should also be added. A key component*  
30 *of the mortality of woody vegetation to fire is its size at the time of fire and the ability to accumulate size*  
31 *between fires. This is central to the work of many of W. Hoffman's papers in the region (Hoffman et al*  
32 *2003, Hoffman et al 2009, Hoffman et al 2012). Please add discussion of size structure to the*  
33 *manuscript.*

34  
35 **Response: We are grateful to the reviewers for their insightful comments and helpful suggestions.**  
36 **We have included a better fire model description and have described how it works throughout the**  
37 **discussion of its impact on the vegetation structure. We have included a more complete discussion**  
38 **about the influence of fire on size structure along the transition. Details about recommendations**  
39 **for future work were also included.**

40 *Detailed comments:*

41 1. Page 6 line 101-107: Add the 1x1 degree grid size to this section.

42  
43 **Response:** This information was added. See below:

44 “The present study focuses on the Amazon-Cerrado transition (Figure 1). We use the official  
45 delimitation of the Brazilian biomes proposed by IBGE (2004), and define five transects along the  
46 transition border with  $1^\circ \times 1^\circ$  grid size (the terms “transition”, “Amazon-Cerrado transition” and  
47 “Forest-Savanna transition” are used interchangeably with the same meaning throughout this  
48 manuscript).”

49  
50 2. Page 9 line 159-164: Provide more detail concerning fire model. Is the fire ignition probability the  
51 same in every pixel, or is there spatial variability? If there is spatial variability what drives this  
52 parameterization? Does flammability vary by PFT?

53  
54 **Response:** The fire ignition probability is spatially varied in INLAND. INLAND incorporates all  
55 fire components of the CTEM (Canadian Terrestrial Ecosystem Model) model (Arora and Boer,  
56 2005). These components simulate fire at the daily timescale (instead of the yearly timescale of  
57 earlier models) by computing the probability of fire occurrence, which is based on biomass  
58 availability, flammability and ignition source for each pixel (using observed lightning frequency).  
59 Burned area is modeled as an ellipse of dimensions determined by wind and fuel conditions. The  
60 fire model of CTEM uses an arbitrary anthropogenic fire probability which is summed to the  
61 natural ignition probability. In summary, the natural ignition probability is represented by a  
62 lightning scalar, which varies from 0 to 1 as cloud-to-ground lightning frequency varies from a  
63 specified lower value of essentially no lightning to an upper value close to the maximum observed.  
64 The probability of fire ignition due to human causes may be selected depending on location and  
65 human activity and determines the lower limit of ignition constraint. In INLAND, we use 0.50 for  
66 the probability of fire ignition due to human cause. Additionally, we suggest the reviewer to verify  
67 the arbitrary ignition scheme in Figure 3c in Arora and Boer (2005), which we do not have  
68 permission to reproduce. Moreover, in INLAND the vegetation structure is represented by two  
69 layers. The fire occurrence reduces the upper canopy decreasing the trees LAI (LAI upper), and  
70 opening the canopy. The opening canopy implicates in more luminosity penetration and  
71 consequently increase of photosynthesis rates by grasses (increasing of LAI lower) initializing a  
72 competition between PFTs for light resource. We have included these details concerning fire  
73 model in the Methods section.

74  
75 3. Page 16 line 316: define “transition” here and throughout manuscript. The reference is not always  
76 clear. Most often it appears to be Amazon-Cerrado transition or forest-savanna transition, if that is  
77 correct please add the extra detail here and throughout manuscript (Pg 20 line 403, pg 21 line 419, pg  
78 22 line 426,428,443, pg 23 line 451)

79  
80 **Response:** We agree with the reviewer that this term was not always clear and may generate  
81 doubts. To clarify, we included in Page 6 line 105-106 a brief reference: “The terms Amazon-

82 **Cerrado transition, forest savanna transition or transition are used interchangeably with the**  
83 **same meaning throughout this manuscript”.**

84 4. Page 17 line 323-325: Update sentence to “responsible for altering the simulated AGB to approach  
85 the observed AGB” or some variant. Current sentence structure is unclear.

86  
87 **Response: The sentence has been changed. See below:**

88 **“In T2, T3 and T4, however, fire is responsible for altering the simulated AGB to the observed**  
89 **AGB in the eastern pixels of the Cerrado domain (Figure 5)”.**

90  
91 5. Page 18 line 345-349: What observational data set is this being compared to for current vegetation  
92 state? Is this a by pixel comparison of the same grid size?

93  
94 **Response: We use the official delimitation of the Brazilian biomes proposed by IBGE (2004),**  
95 **which reconstructs in more detail the probable location of the vegetation before the**  
96 **anthropogenic interference. This database is a vector database and is available in**  
97 **[http://downloads.ibge.gov.br/downloads\\_geociencias.htm](http://downloads.ibge.gov.br/downloads_geociencias.htm).**

98  
99 6. Page 18 line 359-364: Do the climate datasets used in simulation include reduced rainfall and ENSO  
100 effects? Explain this further.

101  
102 **Response: The CRU climate database, which is used in our study, included reduced rainfall and**  
103 **ENSO effects. The CRU gridded climate dataset is a database developed from monthly**  
104 **observations at meteorological stations across the world's land areas (Harris et al., 2014). These**  
105 **dataset includes six mostly independent climate variables (mean temperature, diurnal**  
106 **temperature range, precipitation, wet-day frequency, vapor pressure, and cloud cover).**  
107 **Maximum and minimum temperatures have been arithmetically derived from these. This gridded**  
108 **product will be publicly available, including the input station series (<http://www.cru.uea.ac.uk/>**  
109 **and <http://badc.nerc.ac.uk/data/cru/>).**

110  
111 7. Page 21 line 409: Update to “for the most part Dynamic Vegetation Models”  
112

113 **Response: That has been changed.**  
114

115 8. Page 22 line 435-437: Add more detail clarifying how the INLAND model differs from reality. Is it  
116 able to simulate rapid restoration following fire? If not, what would need to be added to the model's fire  
117 or vegetation characteristics?  
118

119 **Response: In our model, the restoration of vegetation after fire occurrence is exclusively due to**  
120 **the canopy opening and consequently more luminosity penetration into lower canopy. Two layers**  
121 **in the INLAND represent the vegetation structure. The fire occurrence reduces de upper canopy**  
122 **decreasing the trees LAI (LAI upper), and opening the canopy. Thus, we have more luminosity**  
123 **penetration and consequently increase of photosynthesis rates by grasses (increase of LAI lower)**

124 initializing a competition for light resource. The dynamic vegetation module computes for each  
125 PFT: gross and net primary productivity, changes in biomass pools, simple mortality disturbance  
126 processes and resultant LAI, with the same manner before the fire occurrence, thus allowing  
127 vegetation type and cover to change with time. We have included more details about fire model  
128 (in section 2.2) describing the INLAND Surface Model and added more details about restoration  
129 after fire occurrence in the discussion.

130  
131 9. Page 22 line 444: Update to “but the inclusion of these effects”  
132

133 **Response: That has been changed.**

134  
135 10. Page 22 line 442-445: This needs more explanation. Is the vegetation simulation insufficient  
136 because of the presence of transitional and robust pixels in the cerrado in fig 5? Or is this because of  
137 comparisons to observed data of vegetation in the cerrado?  
138

139 **Response: The sentence was re-written. See below:**

140 “From Figure 5, it is clear that CV, F and P limitation in the transition zone reduce the AGB,  
141 approaching the simulated to the observed data. However, the inclusion of these effects is still  
142 insufficient to represent the actual vegetation structure in the Amazon-Cerrado border (Figure  
143 6L).”  
144

145 11. Page 23 line 449: what is meant by residence time?  
146

147 **Response: Residence time is the average time a particle resides (passes) in a pool or system. In**  
148 **INLAND, the residence time is a parameter of the vegetation used by the PFTs to allocate carbon**  
149 **in the different compartments of biomass (leaves, roots and stems). The residence time of carbon**  
150 **in a biomass compartment is intended to represent the loss of biomass through mortality and**  
151 **tissue turnover.**

152  
153 12. Page 24 line 477-479: Explain this in more detail: “It does not dynamically change the allocation”  
154

155 **Response: Parameters can be fixed or dynamically allocated, which means that they can change**  
156 **over time. Fixed parameters for a given PFT are assumed during the carbon allocation in**  
157 **INLAND. For tropical evergreens trees, for example, we have 50% of carbon allocation in stems,**  
158 **25% in leaves and 25% in roots. Even though there is evidence that in the Amazonia-Cerrado**  
159 **transition the carbon allocation rates may vary in some situations of water stress, the INLAND**  
160 **model do not represent this strategy.**

161  
162 13. Page 25 line 495-496: Reword this sentence. The meaning is not clear.  
163

164 **Response: We agree to the reviewer. This sentence was changed. See below:**

165 **“Obtaining ecophysiological parameters is a challenge to the scientific community once the field**  
166 **measurements depend on fieldwork conducted throughout all the transition area.”**  
167

168  
169

170 *14. Page 26 line 522-525: Inclusion of spatially explicit parameters may or may not improve DGVM*  
171 *simulation. This assumes that the existing processes are accurate, and that it is merely parameters.*  
172 *Provide more discussion of this possibility, or re-word this section.*  
173

174 **Response: There are evidences that the inclusion of spatially explicit parameters may improve**  
175 **DGVM simulation. Castanho et al. (2013) showed that the simulated aboveground biomass in**  
176 **Amazonia improved with spatially biophysical parameters such as woody biomass residence**  
177 **clearer time, maximum, carboxylation capacity ( $V_{max}$ ), and NPP allocation to wood. They found**  
178 **that using single values for key ecological parameters in the tropical forest biome severely limits**  
179 **simulation accuracy. We believe that the same limitation occurs along the transition. The use of**  
180 **spatial parameters allows represent the spatial heterogeneity along the Amazon-Cerrado border**  
181 **and may lead to simulated spatial variability of biomass. However, the lack of data observed in**  
182 **this region limits the representation and understanding of how biophysical parameters vary**  
183 **throughout the transition. Thus, it is necessary obtain physiological and structural parameters to**  
184 **establish numerical relationships between the environment and the vegetation dynamic models.**  
185

186 *Page 26 line 525-527: What is meant by temporal variability? Size structure?*  
187

188 **Response: Currently the physiological parameters of vegetation are fixed, each PFT uses a fixed**  
189 **carbon allocation parameter, mortality, carboxylation capacity and others from start to finish of**  
190 **the simulation. We suggest that these parameters should be dynamically allocated, i.e. temporal**  
191 **variability in physiological parameters of vegetation, as a function of other simulated variables**  
192 **should be included, to improve the simulation results.**

193

194 (Reviewer comments in italics; Responses in bold)

195 Response to Anonymous Referee #2 Received and published: 23 July 2017

196 *This work uses the vegetation model INLAND to evaluate the individual and combined effects of the*  
197 *climate variability, the fire and the Phosphorus (P) limitation on the Brazilian ecosystem. The changes*  
198 *on the NPP, J and AGB were evaluated in relation to 12 climate simulations. The AGB was also*  
199 *evaluated in function of observed data. In addition to climate variability, this work shows the*  
200 *importance of considering the soil nutrient limitation as well as the disturbances caused by the biomass*  
201 *burning in the study of vegetation dynamics. It is also presented some deficiencies of the DGVMs and*  
202 *the databases used to feed the INLAND model. Understanding the mechanisms that affect the vegetation*  
203 *and the efforts to improve numerical models in order to simulate such effects is of paramount important*  
204 *to the scientific progress. Therefore, this study is of great relevance and, in my opinion, it is suitable for*  
205 *publication in theBG. However, I have some recommendations and doubts that I would like to see being*  
206 *clarified before publication.*

207 *Specific comments*

208 *1. L55-L60: observing the Figure 6d (CV+PC), all the Amazon region became “very robust”, so we can*  
209 *assume that the simulation that considers only the climatic effect didn't indicate the “savannization of*  
210 *the Amazon”, in other words, the results obtained in this study don't agree with the mentioned works.*  
211 *Can you comment on this?*

212 **Response: The “savannization of the Amazon” have been appointed by studies that use future**  
213 **climate scenarios (Oyama and Nobre, 2003; Betts et al., 2004; Cox et al., 2000; Cox et al., 2004;**  
214 **Salazar et al., 2007 Pereira et al., 2012) or climate scenarios associated to changes on vegetation in**  
215 **the deforestation case (Shukla et al., 1990; Malhi et al., 2009; Pires and Costa, 2013). Our results**  
216 **do not indicate the “savannization of the Amazon” because they are based on past climate.**

217 *2. L140: “values smaller than  $0.8 \text{ m}^2\text{m}^{-2}$  characterize a grassland vegetation type” – Grassland can*  
218 *have LAI values much higher than  $0.8 \text{ m}^2\text{m}^{-2}$ . Darvishzadeh et al., 2008 found out grassland's average*  
219 *values of  $2.76 \text{ m}^2\text{m}^{-2}$  and maximum value of  $7.34 \text{ m}^2\text{m}^{-2}$ . Please check if the INLAND really utilizes this*  
220 *threshold of LAI to define grassland.*

221 **Response: We agree with the reviewer, although we think the reviewer misunderstood the text.**  
222 **The total LAI for grasslands can definitely be much higher than  $0.8 \text{ m}^2\text{m}^{-2}$ . In this sentence, we**  
223 **refer to the LAI upper (tree LAI). That means that grassland vegetation type cannot have trees**  
224 **with LAI greater than  $0.8 \text{ m}^2\text{m}^{-2}$  while the LAI lower (grasses) is not limited.**

225 3. 3. L85-L87: According to Oliveira et al. (in press), the weather also has influence in the nutrients.  
226 Then, the climate change's effect cannot be higher due to the indirect effects in the nutrients? Can you  
227 comment on this?

228 **Response:** Certainly, there is influence between weather and nutrients. For example, a very  
229 intense rain can leach nutrients, such as nitrogen, as well as strong winds can carry clay particles  
230 where numerous nutrients are adsorbed. However, in this work the nutritional conditions are  
231 prescribed and fixed. In this way, we cannot assert that the climate change's effect is higher due to  
232 the indirect effects in the nutrients. Oliveira et al (in press) has also been updated to Oliveira et al.  
233 (2017).

234 4. L157-L158: How are the other PFTs affected by the availability of P?

235 **Response:** Tropical evergreen and deciduous trees are affected by availability of P in INLAND  
236 while other PFTs are unaffected. The lack of scientific reports about the influence of phosphorus  
237 on shrub and grass vegetation along the Amazon basin justify why only these two PFTs are  
238 affected. The phosphorus limitation in INLAND is based on regression equation developed by  
239 Castanho et al. (2013), which use results of Fyllas et al. (2009) and Mercado et al. (2009). Fyllas et  
240 al. (2009) show that soil fertility is one of the most important predictors for observed higher  
241 nutrient concentration in Amazon tree leaves, while Mercado et al. (2009) report that the  
242 correlation between observed Vmax and P concentration in Amazon tree leaves. Thus, Castanho  
243 et al. (2013) developed a similar regression equation to that of Mercado et al. (2009, 2011) between  
244 Vmax and total P concentration in soil, instead of P concentration in leaves, allowing estimate  
245 Vmax for the whole Amazon.

246 5. L262: I didn't understand where the 8.7% came from. Could you make it clearer?

247 **Response:** We calculated the average biomass values for each biome area (Amazon and Cerrado)  
248 using the biomes delimitation from IBGE showed in Figure 1. This average biomass value was  
249 calculated for all simulations (Table 1), to compare the difference in the average value of each  
250 simulation. In Cerrado, average biomass is 8.7% lower in the simulation with inter-annual  
251 climate variability (CV) than with average climate (CA).

252 6. L339-L344: It can be seen in Figure 6 large differences between CA + F (Line3) and CV + F (Line  
253 4). However, the differences between CA (Line 1) and CA + F (Line 3) and the ones between PC  
254 (Column 1), PR (Column 2) and PG (Column 3) are not very significant. Thus, the climatic variability  
255 is dominant when considering the three effects. Probably, if a fifth map showing CA + PG + F -  
256 CA+PG is constructed in Figure 4, it will be quite distinct from Figure 4d. Therefore, it should be  
257 exposed more clearly how it came up to the conclusion described in L513-515.

258 **Response:** In Figure 6, we evaluate only the robustness of the simulations. Although there is little  
259 difference between the vegetation types along the central Cerrado domain in CA (Line 1) and CA  
260 + F (Line 3), the most part of these changes is very robust when fire is considered. We do not use  
261 the vegetation types to infer which are the main determinant drivers on the transition, we use the  
262 Figure 6 only to show how these drives affect the distribution of vegetation. It is clear, however,  
263 that the CV+F combinations yield the best vegetation patterns, with minor differences associated  
264 with soil P.

265 The difference between CA + PG +F – CA+PG shows similar behavior that on CV simulations,  
266 but we did not plot this difference because in our statistical analyses only the interannual climate  
267 variability showed significant influence on AGB and LAI. Finally, to write the sentence in L513-  
268 515 (“fire is in the main determinant factor of the vegetation changes along the transition. The  
269 nutrient limitation is second in magnitude, stronger than the effect of inter-annual climate  
270 variability”), we use F-statistics in Tables 3, 4 and 5, which permits infer the magnitude of fire,  
271 phosphorus limitation, and climate on AGB and LAI. To clarify this, we rewrote this sentence to  
272 “Based on the F-statistic in Tables 3, 4 and 5, this work shows that fire is in the main determinant  
273 factor of the changes in vegetation structure (LAI, AGB) changes along the transition. The  
274 nutrient limitation is second in magnitude, stronger than the effect of inter-annual climate  
275 variability.”

276

277 7. L342: *I think it is unlikely that an area with “deciduous forest” will turn into “evergreen forest”*  
278 *after being consumed by fire. Please comment if this is possible or if it is a model deficiency.*

279 **Response:** In INLAND simulation, the “deciduous forest” is turning into “evergreen forest” after  
280 being consumed by fire happens in only 5 pixels and in average climate condition only, in a clay  
281 soil with large water retention capacity (Figure 6G-I) In this situation, where there is little water  
282 stress in the CA simulation, both evergreen and drought deciduous PFTS have each one very high  
283 LAI, and the PFT that dominates can be defined by minor effects. Fire, although active, is  
284 probably too small to be relevant in a non-stressed ecosystem. However, when the interannual  
285 climate variability is considered, INLAND replaces the “evergreen forest” in Figures 6G-I to  
286 “Savanna and Grasslands” (Figure 6J-L). These results show the limitations of CA and the  
287 importance to consider the interannual climate variability on simulations to improve the  
288 vegetation simulated.

289 *Technical corrections*

290 1. L22: “1960 – 1990” → “1961 – 1990”, as described in L204.

291 **Response:** This has been changed in the revised manuscript.



292

293 2. L23: “two regional datasets” → “two datasets”.

294 **Response: This has been changed in the revised manuscript.**

295 3. L62: “particularly the P limitation.” → “particularly the Phosphorus (P) limitation.”

296 **Response: This has been changed in the revised manuscript.**

297 4. L72: “Phosphorus (P) is a” → “P is a” or “Phosphorus is a”.

298 **Response: This has been changed in the revised manuscript.**

299 5. L103: Transects 1 and 2 are more related to “Cerrado” than “Amazon”, as shown in Figures 1, 2  
300 and 5. Please rewrite this sentence.

301 **Response: We do not agree with this technical correction. The transects were located 50% in**  
302 **Amazon domain and 50% in Cerrado domain, as we described.**

303 6. L105: “Transect 1 (T1, 43 °-49 °W; 5 °-7 °S)” → “Transect 1 (T1, 44 °-50 °W; 5°-7°S)”.

304 **Response: This has been changed in the revised manuscript.**

305 7. L107: “Transect 5 (T5, 53 °-61 ° W; 13 °-15 ° S)” → “Transect 5 (T5, 52 °-60°W;13°-15 ° S)”.

306 **Response: This has been changed in the revised manuscript.**

307 8. L138: “annual mean LAI<sub>upper</sub> above” → “annual mean LAI<sub>upper</sub> below”.

308 **Response: We do not agree with this technical correction. The annual average of “LAI upper” in**  
309 **INLAND needs to be above 0.8 m<sup>2</sup> m<sup>-2</sup>. This value is prescribed by the model.**

310 9. L173: “We used the P-mehlich-1” → “We used the Pmehlich-1”.

311 **Response: This has been changed in the revised manuscript.**

312 10. L176: “resulting in 12 additional pixels” – Wouldn’t it be 6?

313 **Response: There are 12 pixels, as described in Supplementary Materials.**

314 11. L176: “pixels with observed total P content” → “pixels without observed total P content”

315 **Response: These additional pixels with the observed total P content are described in**  
316 **Supplementary Materials.**

317 12. L186: “Above-Ground AGB (AGB) database” → “Above-Ground Biomass (AGB database)”

318 **Response: This has been changed in the revised manuscript.**

319 13. L194-L196: *There are two pixels for each longitude in each transects. Do the Figures 3 and 5 show*  
320 *the mean of the two pixels, or only the upper or the lower one?*

321 **Response: The Figures 3 and 5 show the average of two pixels. This information was added to the**  
322 **caption of both figures.**

323 14. L212: *Remove the phrase: “The model simulations were run for the time period 1582-2008, a total*  
324 *of 427 years.” – The boundary condition begins in 1948, so it can’t be said that the model began in*  
325 *1582. This was only an artifice used to simulate the same period for seven times.*

326 **Response: This has been changed in the revised manuscript.**

327 15. L224: “the simulations  $(CV + PC) - (CA + PC) = (CV - CA)|PC$ ” → “the simulations  $(CV + PC)$   
328 *and  $(CA + PC)$ ” - The notation “ $(CV - CA)|PC$ ” is interesting, but it wasn’t used. Then it can be  
329 removed.*

330 **Response: This has been changed in the revised manuscript.**

331 16. L228: “and  $CA + PC$ , so that  $(CA + PC + F) - (CA + PC) = F|CA, PC$ . Similarly,” → “and  $CA + PC$ .  
332 Similarly,”.

333 **Response: This has been changed in the revised manuscript.**

334 17. L230: “between  $CV + PC + F$  and  $CV + PC$ , so that  $(CV + PC + F) - (CV + PC) = F|CV, PC$ . The  
335 different” → “between  $CV + PC + F$  and  $CV + PC$ . The different”.

336 **Response: This has been changed in the revised manuscript.**

337 18. L273: “TB declined by 2% for PR”, - In Figure 4b it looks positive, so it would be an increase  
338 instead of a decrease. Please check it.

339 **Response: This 2% refers to the area average of Cerrado domain.**

340 19. L393: “compared to  $CV + PC$ ” → “compared to  $CV + PC - CA + PC$ ”.

341 **Response:** In this sentence, we are comparing CV+PG – CV+PC.

342 20. Figure 4d: “ $CV + PG + F - CV + PC$ ” → “ $CV + PG + F - CV + PG$ ”.

343 **Response:** This has been changed in the revised manuscript. Although this is not a regionally  
344 relevant event, we modified the text to include this discussion.

345

346 **References:**

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350 Gonzalez, G., Malhi, Y., Phillips, O. L., and Lloyd, J.: Basin-wide variations in foliar properties of  
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356 2009.

357 Mercado, L. M., Patiño, S., Domingues, T. F., Fyllas, N. M., Weedon, G. P., Sitch, S., Quesada, C.  
358 A., Phillips, O. L., Aragão, L. E. O. C., Malhi, Y., Dolman, A. J., Restrepo-Coupe, N., Saleska, S.  
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361 *Roy. Soc. B*, 366, 3316–3329, doi:10.1098/rstb.2011.0045, 2011.

362

363

364 *Reviewer comments in italics; Responses in bold)*

365 *Response to Anonymous Referee #3 Received and published: 25 July 2017*

366 *General Comment: This manuscript mainly focuses on Amazon-Cerrado transitional vegetation. For*  
367 *this region, a mechanistic model is used to determine the effects of various processes on aboveground*  
368 *biomass (AGB). In particular, the effects of fire phosphorus (P) limitation, and interannual climate*  
369 *variability are evaluated. It is concluded that all of these effects are important, but that fire is the main*  
370 *driver of vegetation change along the transition. The manuscript also reports that the model simulates*  
371 *>80% of the spatial variability in AGB in the transition zone.*

372 *Understanding the spatial distribution of tree biomass in the tropics is a very active area of research.*  
373 *The questions asked by the authors, especially in regard to P limitation, are open ones and quite worthy*  
374 *of investigation. It is very reasonable to approach questions about mechanisms, such as those asked by*  
375 *the authors, using a mechanistic model. Nevertheless, I was unconvinced by the analysis that was*  
376 *presented. I have major concerns about the implementation of P limitation and the statistical analysis.*  
377 *The phenology scheme was not described in much detail, but could strongly influence the results.*  
378 *Several claims in the discussion were weakly, if at all, supported by the results.*

379

380 *Specific Comments*

381 *I do not think that the authors really implemented P-limitation in their model. As I understood the*  
382 *manuscript, simulated P dynamics do not affect vegetation biomass. Instead, the authors prescribe a*  
383 *map of Vmax based on a statistical regression between Vmax and soil P. As such, there is no*  
384 *mechanistic representation of P limitation in this model. Without a mechanistic link, I do not think it is*  
385 *correct to ascribe variation in AGB to variations in P. This manuscript can be improved by*  
386 *investigating the effects of different mechanistic implementations of P cycling and P limitation on the*  
387 *simulated vegetation.*

388 **Response: Indeed, we did not implement a full P cycle model, but rather we parametrized what**  
389 **we believe is the most important relationship between soil P and photosynthesis. In this study, we**  
390 **only use the P-limitation through the linear relation developed by Castanho et al. (2013) to**  
391 **evaluate the biomass along the Amazon-Cerrado transition. The P cycle is slow, and a full**  
392 **representation of the soil P may be advantageous only over a time scale of several decades to**  
393 **centuries. In the shorter term (a few decades), starting from a known point in soil fertility as we**  
394 **did, seems to be a more appropriate approach. The values of P in the map influence Vmax, which**

395 **mechanistically influences NPP and biomass. This has been demonstrated before by Castanho et**  
396 **al. (2013).**

397 **The implementation of a full P cycling and is out of the scope of this manuscript. The main**  
398 **objective of this manuscript is investigate the influence of P-limitation, climate and fire**  
399 **occurrence on AGB, and not implement P cycling.**

400 *1. Ptotal may indeed have some positive relation with Vmax, but Equation (1) still seems problematic to*  
401 *me. What happens when Ptotal is very large, and vegetation is presumably no longer limited by P? This*  
402 *equation would say that Vmax would still increase, but surely there must be some maximum value when*  
403 *other factors become limiting.*

404 **Response: Equation (1), being an empirical equation, represents the relationship between P and**  
405 **Vcmax in the range where there are observed values. In the hypothetical case of a very high**  
406 **Ptotal, and a consequent very high Vmax, other bottlenecks in the model code (limitation by light**  
407 **or by water or by temperature) would limit gross photosynthesis. However, this is unlikely, given**  
408 **that the Amazon and Amazon-Cerrado transition soils are known for being nutrient poor.**

409 *More generally, I was not convinced that the most important way P affects plants is through Vmax. For*  
410 *example, what about maintenance of some approximate C:N:P stoichiometry, carbon costs of P*  
411 *acquisition, etc.?*

412 **Response: Castanho et al. (2013) provided empirical evidence that Vmax is influenced by P-total.**  
413 **The other processes described by the reviewer, along with other process not described, may also**  
414 **be important, but they have yet to be implemented and tested. Our study, however, falls in line**  
415 **with the common use of parameterizations in the modeling literature, to quickly test some effects**  
416 **before a full and more complex model is implemented.**

417 *2. The statistical analyses are inappropriate and do not support the conclusions. The statistical tests*  
418 *used by the authors are only appropriate when there is some random variable. I did not identify*  
419 *anything in the simulation design that could lead to a random effect (for example, some stochastic*  
420 *process). I recommend cutting the whole statistical analysis.*

421 **Response: With all due respect to the reviewer, we believe that this point is not correct. There are**  
422 **several sources of random variability in the data, such as (from lower to higher): spatial**  
423 **variability in the soils texture (in both CA and CV simulations), spatial variability in soil fertility**  
424 **(in PR and PG simulations), the interannual climate variability (in the CV case), and the random**  
425 **ignition in the fire module.**

426 3. *The model description incomplete. Is the source code available somewhere? Exactly how does this*  
427 *version of the model differ from previous versions? Any new equations or new parameter values need to*  
428 *be documented here.*

429 **Response:** The source code can be downloaded from <http://biosfera.dea.ufv.br/en-US>, clicking on  
430 models and, then, on INLAND. The INLAND project was mainly a revision of the IBIS code,  
431 through assembly and standardization of different IBIS versions, and improvements in software  
432 engineering. We used the version described by Senna et al. (2009) as starting point for INLAND.  
433 No changes in tuning were done since that paper, except the addition of the P parameterization,  
434 which was described in detail. Some of the key equations and parameterizations, however, were  
435 described by Foley et al. (1996) and Kucharik et al. (2000).

436 4. *The manuscript indicates (lines 120-121) that a temperature-based phenology scheme was used. But*  
437 *a drought phenology scheme is more appropriate for the tropics. I can imagine that the results would*  
438 *change dramatically if a drought phenology scheme were used. The original IBIS model had a drought*  
439 *phenology scheme, right? I guess that was not implemented here?*

440 **Response:** We agree and thanks the reviewer for this commentary. That was our mistake. This  
441 sentence has been modified. The INLAND, such as IBIS, has phenology scheme based on winter-  
442 deciduous and drought-deciduous behavior of particular PFTs. For winter-deciduous plants  
443 (outside the area of study), the temperature based is used, while for tropical drought-deciduous  
444 plants, the PFTs drop their leaves during the least productive months of the year, defined in  
445 terms of the previous year's carbon balance. This phenology scheme is extensively described in  
446 Foley et al. (1996) and Kucharik et al. (2000). Lines 120-121 were changed to "The vegetation  
447 phenology module simulates the processes such as budding and senescence based on drought  
448 phenology scheme for tropical deciduous trees."

449 5. *I was surprised that the manuscript did not discuss alternative stable states in terms of either the*  
450 *AGB database or the simulations. How was the AGB database constructed, given that there may be*  
451 *alternative stable states? I found it remarkable that the model was able to capture 80% of the*  
452 *variability. Would this result indicate that the idea of alternative stable states is not really appropriate*  
453 *in the Amazon-Cerrado transition?*

454 **Response:** We are not sure we understand this comment. Alternatives states in this region would  
455 arise as a consequence of climate change and antropogenic disturbance. This is clearly outside the  
456 scope of this study, which aims at representing the actual non-disturbed status of the vegetation,  
457 and attribute the processes responsible for its present status, in terms of climate variability, fire  
458 and P limitation.

459 *Additional comments*

460 *Lines 88-89: This is too vague. A discussion of the failures would be welcome.*

461 **Response: In accordance with the referees's wishes, we included references and have now**  
462 **changed this paragraph to "Currently, no model has demonstrated to be able to accurately**  
463 **simulate the vegetation transition between Amazon and Cerrado. In general the DGVMs simulate**  
464 **evergreen forest along the Amazon-Cerrado border neglect savanna occurrence (Botta and Foley,**  
465 **2002; Bond et al., 2005; Salazar et al., 2007; Smith et al., 2014). This difficulty may be due to**  
466 **absence or not well represented disturbances such as fire, nutritional limitation or soil proprieties.**  
467 **Thus, we need a better understanding of the drivers on transitional vegetation to determine the**  
468 **parameters and establish relations between the environmental and transitional vegetation**  
469 **physiognomies."**

470 *Line 155: This equation needs more description. Is the same Vmax assigned to all PFTs? Is it meters*  
471 *square of leaf area or meters squared of ground?*

472 **Response: There is reference to equation and specified the PFTs limited by phosphorus on the**  
473 **manuscript. Please check Line 157: "This equation has been developed by Castanho et al. (2013)**  
474 **based on data for tropical evergreen and deciduous trees, and is applied only to these two PFTs in**  
475 **the model."**

476 *Lines 269-276: It is arbitrary as to whether there are increases or decreases. Whether there is an*  
477 *increase or a decrease depends on the chosen baseline. Also on this paragraph, I am wondering*  
478 *whether tree biomass simply follows soil P?*

479 **Response: The increase or decrease biomass in PG and PR was evaluated from PC using the**  
480 **subtraction between the simulations: (CV+PR)-(CV+PC) and (CV+PG)-(CV+PC). These**  
481 **differences represents the isolated effect of P limitations on tree biomass along the simulated area.**

482 *Line 280: Note that the word "inflammable" actually means easily ignited.*

483 **Response: We agree with the reviewer. This sentence was changed to "The small or null fire effect**  
484 **in the Central Amazon rainforest is related the greater water availability on the Amazonia, which**  
485 **makes the forest naturally not flammable as well as a gradient towards seasonally dryer climate**  
486 **increases the intensity and magnitude of fire effects towards the Cerrado (Figure 4d)."**

487 *Lines 278-281: Not justified. Where is water availability shown, and how is it defined?*

488 **Response:** We agree with the reviewer. This sentence was changed to “The small or null fire effect  
489 in the Central Amazon rainforest is related the greater water availability on the Amazonia, which  
490 makes the forest naturally not flammable as well as a gradient towards seasonally dryer climate  
491 increases the intensity and magnitude of fire effects towards the Cerrado (Figure 4d).”

492 *Lines 300-302: Why does fire cause LAI to increase?*

493 **Response:** In INLAND the vegetation structure is represented by two layers: upper and lower  
494 canopy. The fire occurrence reduces the upper canopy decreasing the trees LAI (LAI upper),  
495 opening the canopy, and leading to more luminosity available to the lower layer, and consequently  
496 increasing the photosynthesis rates by grasses (increase of LAI lower). In general, the LAI lower  
497 increases quickly after the fire occurrence contributing with the increases of the LAI total that  
498 represents the sum of the two layers.

499 *Line 409-411: There are exceptions (Goll et al, Yang et al).*

500 **Response:** We agree to the reviewer. This sentence was changed.

501 *Lines 416-424: This paragraph seems too speculative given the model results.*

502 **Response:** We excluded this paragraph.

503 *Lines 425-428: This is also not strongly supported.*

504 **Response:** This is supported by Tables 3, 4 and 5.

505 *Lines 460-462: But does it help explain the spatial variability?*

506 **Response:** Yes. Patterns along the eastern part of the transects are determined by fire, which is  
507 less important in the western part of the transects.

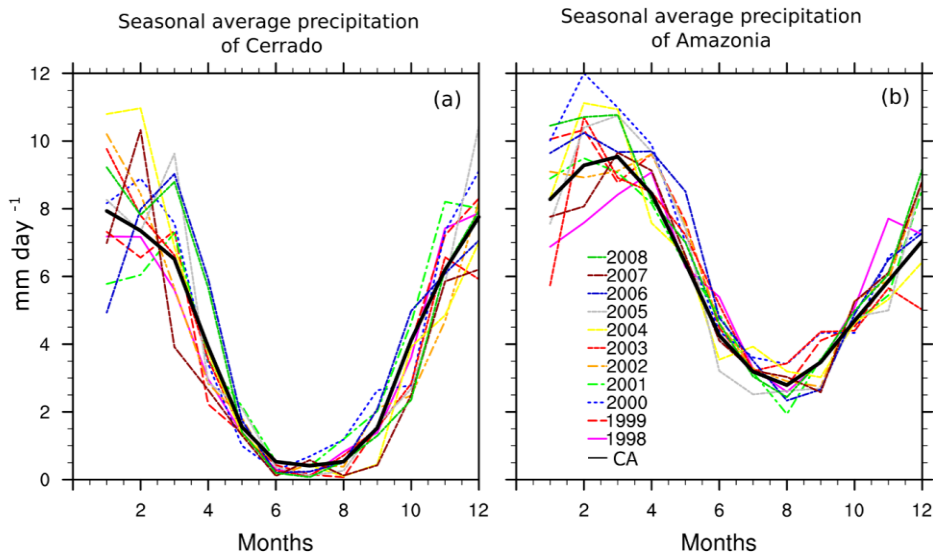
508 *Line 502: Showing the climate data would make this point more convincing.*

509 **Response:** This is well known in the literature, but anyway. We provide three figures in this  
510 response to clarify this point to the reviewer. The seasonality of precipitation for Amazon and  
511 Cerrado biomes used in this study is shown in Figure R1. The dry season duration is larger in the  
512 Cerrado domain (Figure R1a) than in the Amazonia domain (Figure R1b). In the Cerrado, dry  
513 season comprise a period of about 6 months with little or no rain.

514 Spatial variability of precipitation and temperature are shown in Figures R2 and R3, respectively.  
515 These figures plot the difference between the average of 1999-2008 (a subset of CV) and CA  
516 (average of 1961-1990) highlighting the spatial variability of these climate variable throughout the

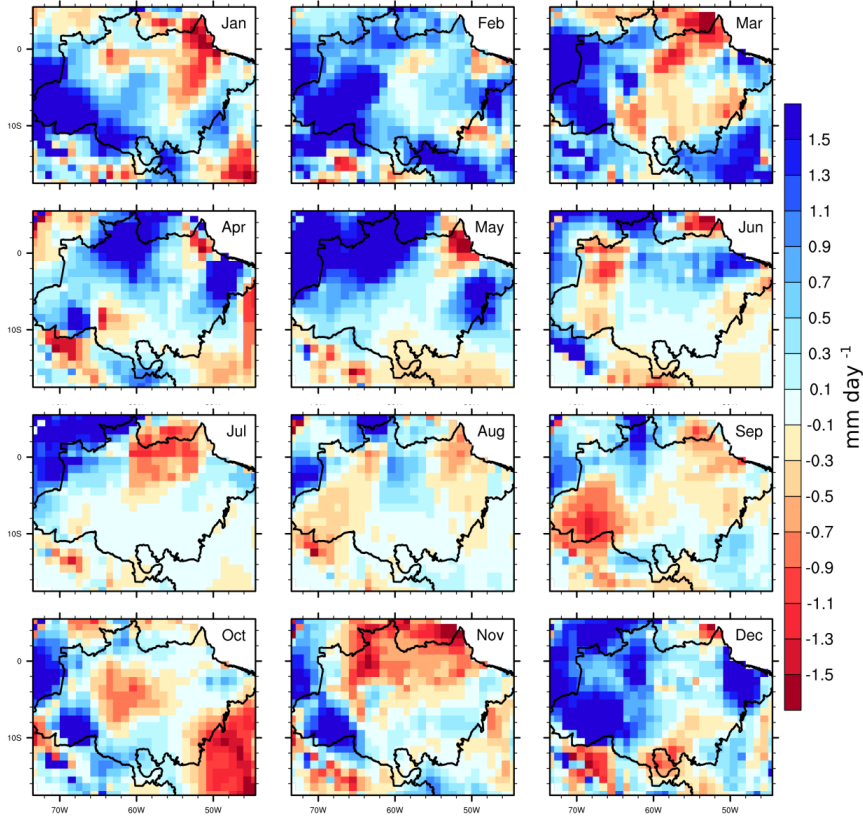


517 study area. Comparing the interannual climate variability with the average climate, precipitation  
518 decreases (Figure R2) and temperature increases up 1.5°C (Figure R3) in central Cerrado in  
519 October, November, December and January. The lower precipitation associated with higher  
520 temperatures in central Cerrado can explain a low biomass, low LAI vegetation and savanna  
521 existence without fire disturbance. Note that this is a 10-year subset of the CV database. The  
522 actual year-to-year variations present much more intense amplitudes.  
523



524 Figure R1. Seasonal of precipitation for Amazon and Cerrado domains for average climate (CA) -  
525 black line - and the last ten years of interannual- climate variability (CV) – color lines.  
526

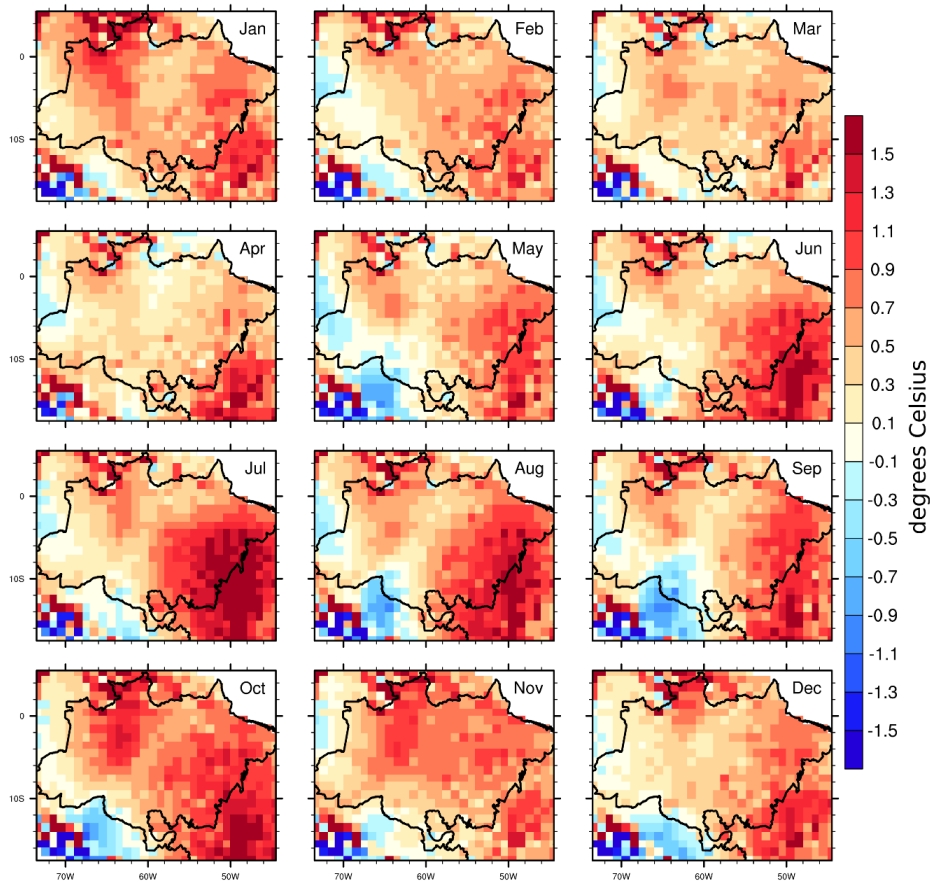
Spatial variability of precipitation (CV - CA)



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528  
529  
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**Figure R2. Spatial variability of precipitation for study area considering the average of the last 10 years of CV (1999-2008) and average climate CA (1961-1990).**

Spatial variability of temperature (CV - CA)



532  
533  
534  
535

Figure R3. Spatial variability of temperatures for the study area considering the average of the last 10 years of CV (1999-2008) and average climate CA (1961-1990).

536

References:

537  
538

Bond, W. J., Woodward, F. I. and Midgley, G. F.: The global distribution of ecosystems in a world without fire, *New Phytol.*, 165(2), 525–538, doi:10.1111/j.1469- 8137.2004.01252.x, 2005

539 **Smith, B., Waarlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J. and Zaehle, S.:**  
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541 **based dynamic vegetation model, *Biogeosciences*, 11(7), 2027–2054, doi:10.5194/bg-11-2027-2014,**  
542 **2014**

543

544 **Influence of climate variability, fire and phosphorus limitation on**  
545 **the vegetation structure and dynamics in the Amazon-Cerrado**  
546 **border**

547

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562 **Abstract**

563 Climate, fire and soil nutritional limitation are important elements that affect the vegetation  
564 dynamics in areas of forest-savanna transition. In this paper, we use the dynamic vegetation model  
565 INLAND to evaluate the influence of inter-annual climate variability, fire and phosphorus (P) limitation  
566 on the Amazon-Cerrado transitional vegetation structure and dynamics. We assess how each  
567 environmental factor affects the net primary production, leaf area index and aboveground biomass  
568 (AGB), and compare the AGB simulations to observed AGB map. We used two regional datasets – the  
569 1961-1990 average seasonal climate and the 1948 to 2008 inter-annual climate variability, two datasets  
570 of total soil P content in soil, based on regional (field measurements) and global data and the INLAND  
571 fire module. Our results show that inter-annual climate variability, P limitation and fire occurrence  
572 gradually improve simulated vegetation types and these effects are not homogeneous along the  
573 latitudinal/longitudinal gradient, showing a synergistic effect among them. In terms of magnitude, the  
574 effect of fire is stronger, and is the main driver of vegetation changes along the transition. The  
575 nutritional limitation, in turn, is stronger than the effect of inter-annual climate variability acting on the  
576 transitional ecosystems dynamics. Overall, INLAND typically simulates more than 80% of the AGB  
577 variability in the transition zone. However, the AGB in many places is clearly not well simulated,  
578 indicating that important soil and physiological factors in the Amazon-Cerrado border, such as lithology  
579 and water table depth, carbon allocation strategies and mortality rates, still need to be included in the  
580 model.

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585 **1 Introduction**

586 The Amazon and Cerrado are the two largest and most important phytogeographical domains in  
587 South America. The Amazon forest has been globally recognized and distinguished not only for its  
588 exuberance in diversity and species richness, but also for playing an important role in the global climate  
589 by regulating water (Bonan, 2008; Pires and Costa, 2013) and heat fluxes (Shukla et al., 1990; Rocha et  
590 al., 2004; Roy et al., 2002). The Cerrado is recognized worldwide for being the richest savanna in the  
591 world (Myers et al., 2000; Klink and Machado, 2005). It is characterized by different physiognomies,  
592 ranging from sparse physiognomies to dense woodland formations, and the latter are commonly mixed  
593 with Amazon rainforest forming transitional areas. The Amazon-Cerrado transition extends for 6270 km  
594 from northeast to southwest in Brazil, and the ecotonal vegetation around this transition is a mix of the  
595 characteristics of the tropical forest and the savanna (Torello-Raventos et al., 2013).

596 Gradients of seasonal rainfall and water deficit, fire occurrence, herbivory and low fertility of  
597 the soil have been reported as the main factors that characterize the transition between forest and  
598 savanna globally (Lehmann et al., 2011; Hoffman et al., 2012; Murphy and Bowman, 2012). However,  
599 few studies have evaluated the individual and combined effects of these factors on Brazilian ecosystems  
600 ecotones (Marimon-Junior and Haridasan, 2005; Elias et al., 2013; Vourtilis et al., 2013).

601 It is challenging to assess the degree of interaction among these various environmental factors in  
602 the transitional region and to infer how each one influences the distribution of the regional vegetation.  
603 In this case, Dynamic Global Vegetation Models (DGVMs) can be powerful tools to isolate the  
604 influences of climate, fire and nutrients, therefore helping to understand their large-scale effects on  
605 vegetation (House et al., 2003; Favier et al., 2004; Hirota et al., 2010; Hoffman et al., 2012).

606 Previous modelling studies using DGVMs that investigate climate effects in the Amazon  
607 indicate that the rainforest could experience changes in rainfall patterns which would either transform  
608 the forest into an ecosystem with more sparse vegetation – similar to a savanna, what has been called as  
609 the "savannization of the Amazon" (Shukla et al., 1990; Cox et al., 2000; Oyama and Nobre, 2003;  
610 Betts et al., 2004; Cox et al., 2004; Salazar et al., 2007) - or to a seasonal forest (Malhi et al., 2009;  
611 Pereira et al., 2012; Pires and Costa, 2013). These studies had great importance to the improvement of  
612 terrestrial biosphere modeling, but they neglect two important processes in tropical ecosystem  
613 dynamics: fire occurrence and nutrient limitation, particularly the Phosphorus (P) limitation.

614 In tropical ecosystems, fire plays an important ecological role and influences the productivity,  
615 the biogeochemical cycles and the dynamics in the transitional biomes, not only by changing the  
616 phenology and physiology of plants, but also by modifying the competition among trees and lower  
617 canopy plants such as grasses, shrubs and lianas. Fire occurrence, depending on its frequency and  
618 intensity, may increase the mortality of trees and transform an undisturbed forest into a disturbed and  
619 flammable one (House et al., 2003; Hirota et al., 2010; Hoffmann et al., 2012). Fires also affect the  
620 dynamics of nutrients in the savanna ecosystem, changing mainly the N:P relationship and P availability  
621 in the soil (Nardoto et al. 2006).

622 Studies suggest that P is the main limiting nutrient within tropical forests (Malhi et al., 2009;  
623 Mercado et al., 2011; Quesada et al., 2012) unlike the temperate forests. Phosphorus is a nutrient that is  
624 easily adsorbed by soil minerals due to the large amount of iron and aluminum oxides in the Amazon  
625 and Cerrado acidic and strongly weathered soils (Dajoz, 2005; Goedert, 1986). In the tropics, the warm  
626 and wet climate favors the high biological activity in the soil and the litter decomposition, not limiting

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628 the nitrogen for plant fixation. In Cerrado, higher soil fertility is related to regions with greater woody  
629 plants abundance and less grass cover, similarly to the features found in the Amazon rainforest (Moreno  
630 et al., 2008; Vourtilis et al., 2013; Veenendaal et al., 2015). However, the phosphorus limitation is often  
631 neglected by DGVMs. which usually assume unlimited P availability and consider nitrogen as the main  
632 limiting nutrient. However, N is not a limiting nutrient for trees in the tropics (Davidson et al. 2004),  
633 while P availability affects the trees dynamics.

634 In principle, in transitional forests, where the climate is intermediate between wet and seasonally  
635 dry, the heterogeneous structure and phenology make it difficult to represent these forests in models.  
636 The Amazon-Cerrado border is the result of the expansion and contraction of the Cerrado into the forest  
637 (see Marimon et al., 2006; Morandi et al., 2016), especially in the Mato Grosso state, where extreme  
638 events, such as intense droughts, influence the vegetation dynamics (Marimon et al., 2014) and the  
639 nutrient (Oliveira et al., 2017) and carbon cycling (Valadão et al., 2016).

640 Currently, no model has demonstrated to be able to accurately simulate the vegetation transition  
641 between Amazonia and Cerrado. In general the DGVMs simulate evergreen forest along the Amazon-  
642 Cerrado border and neglect savanna occurrence (Botta and Foley, 2002; Bond et al., 2005; Salazar et al.,  
643 2007; Smith et al., 2014). This difficulty may be due to absence or not well represented disturbances  
644 such as fire, nutritional limitation or soil proprieties. Thus, we need a better understanding of the drivers  
645 on transitional vegetation to determine the parameters and establish relations between the environmental  
646 and transitional vegetation physiognomies.

647 In this paper we use the dynamic vegetation model INLAND (Integrated Model of Land Surface  
648 Processes) to evaluate the influence of inter-annual climate variability, fire occurrence and P limitation

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**Excluído:** Currently, no model has demonstrated to be able to accurately simulate the vegetation transition between Amazon and Cerrado. A better understanding of the main drivers that determine the distribution of different vegetation physiognomies in the region is crucial for more reliable simulations of the transitional tropical ecosystems in future climate scenarios.

661 in the Amazon-Cerrado transitional vegetation dynamics and structure. We assess how each element  
662 affects the net primary production (NPP), leaf area index (LAI) and aboveground biomass (AGB) and  
663 compare the model simulated AGB to observed AGB data. The results presented here are important to  
664 build models that accurately represent the transition vegetation, and show the need to include the spatial  
665 variability of eco-physiological parameters in these areas.

## 666 2 Materials and methods

### 667 2.1 Study Area

668 The present study focuses on the Amazon-Cerrado transition (Figure 1). We use the official  
669 delimitation of the Brazilian biomes proposed by IBGE (2004), and define five transects along the  
670 transition border with 1° × 1° grid size (the terms “transition”, “Amazon-Cerrado transition” and  
671 “Forest-Savanna transition” are used interchangeably with the same meaning throughout this  
672 manuscript). Transects 1 to 4 are established considering approximately 330 km into the Amazon and  
673 330 km into the Cerrado domain, while Transect 5 is 880 km long on the southern Amazon-Cerrado  
674 border. The transects are located as follows: Transect 1 (T1, 44°- 50°W; 5°- 7°S), Transect 2 (T2, 46°-  
675 51° W; 7°-9S), Transect 3 (T3, 48°-54° W; 9°-11° S), Transect 4 (T4, 49° - 55° W; 11°-13° S), and  
676 Transect 5 (T5, 52° - 60° W; 13°-15° S) (Figure 1).

### 677 2.2 Description of the INLAND Surface Model

678 The Integrated Model of Land Surface Processes (INLAND) is the land-surface component of  
679 the Brazilian Earth System Model (BESM). INLAND is basically a revision of the IBIS model  
680 (Integrated Biosphere Simulator, described by Foley et al., 1996; Kucharik et al., 2000), through

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689 [assembly and standardization of different IBIS versions, and improvements in software engineering. We](#)  
690 [used the version described by Senna et al. \(2009\) as starting point for INLAND. No changes in tuning](#)  
691 [were done since that paper, except the addition of the P parameterization, described below.](#)

692 [The model](#), considers changes in the composition and structure of vegetation in response to the  
693 environment and incorporates important aspects of biosphere-atmosphere interactions. The model  
694 simulates the exchanges of energy, water, carbon and momentum between soil-vegetation-atmosphere.  
695 These processes are organized in a hierarchical framework and operate at different time steps, ranging  
696 from 60 minutes to 1 year, coupling ecological, biophysical and physiological processes. The vegetation  
697 structure is represented by two layers: upper (arboreal PFTs) and lower (no arboreal PFTs, shrubs and  
698 grasses) canopies, and the composition is represented by 12 plant functional types (PFTs) (e.g., tropical  
699 broadleaf evergreen trees or C4 grasses, among several others).The photosynthesis and respiration  
700 processes are simulated in a mechanistic manner using the Ball-Berry-Farquhar model (details in Foley  
701 et al., 1996). [The vegetation phenology module simulates the processes such as budding and senescence](#)  
702 [based on drought phenology scheme for tropical deciduous trees](#). The dynamic vegetation module  
703 computes the following variables yearly for each PFT: gross and net primary productivity (GPP and  
704 NPP), changes in AGB pools, simple mortality disturbance processes and resultant LAI, thus allowing  
705 vegetation type and cover to change with time. The partitioning of the NPP for each PFT resolves  
706 carbon in three AGB pools: leaves, stems and fine roots. The LAI of each PFT is obtained by simply  
707 dividing leaf carbon by specific leaf area, which in INLAND is considered fixed (one value) for each  
708 PFT.

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**Excluído:** The vegetation phenology module simulates the processes such as budding and senescence based on empirically-based temperature thresholds for each PFT

715 INLAND has eight soil layers to simulate the diurnal and seasonal variations of heat and  
716 moisture. Each layer is described in terms of soil temperature, volumetric water content and ice content  
717 (Foley et al., 1996; Thompson and Pollard, 1995). Furthermore, all of these processes are influenced by  
718 soil texture and amount of organic matter within the soil profile.

719 Considering these aspects of vegetation dynamics and soil physical properties the model can  
720 simulate plant competition for light and water between trees, shrubs and grasses through shading and  
721 differences in water uptake (Foley et al., 1996). These PFTs can coexist within a grid cell and their  
722 annual LAI values indicate the dominant vegetation type within a grid cell. For example, the dominant  
723 vegetation type is a Tropical Evergreen Forest if the PFT tropical broadleaf evergreen tree has an annual  
724 mean upper canopy LAI ( $LAI_{upper}$ ) above  $2.5 \text{ m}^2 \text{ m}^{-2}$ . On the other hand, the dominant vegetation type is  
725 a Tropical Deciduous Forest if the tropical broadleaf drought-deciduous tree has an annual mean  
726  $LAI_{upper}$  above  $2.5 \text{ m}^2 \text{ m}^{-2}$ . Where total tree LAI ( $LAI_{upper}$ ) is between  $0.8$  and  $2.5 \text{ m}^2 \text{ m}^{-2}$ , dominant  
727 vegetation type is savanna, and  $LAI_{upper}$  values smaller than  $0.8 \text{ m}^2 \text{ m}^{-2}$  characterize a grassland  
728 vegetation type.

729 We assume that the vegetation types Tropical Evergreen Forest and the Tropical Deciduous  
730 Forest in INLAND represents the Amazon rainforest, while Savanna and Grasslands represent the  
731 Cerrado. Savanna would be equivalent to the Cerrado physiognomies *Cerradão* and *Cerrado sensu*  
732 *strictu*, while Grasslands would be equivalent to the physiognomies *Campo sujo* and *Campo Limpo*  
733 (*sensu* Ribeiro and Walter, 2008).

734 The soil chemical properties are represented by the carbon, nitrogen and phosphorus. The carbon  
735 cycle is simulated through vegetation, litter and soil organic matter, where the biogeochemical module

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737 is similar to the CENTURY model (Parton et al., 1993; Verberne et al., 1990). The amount of C existing  
 738 in the first meter of soil is divided into different compartments characterized by their residence time,  
 739 which can vary in an interval of hours for microbial AGB and organic matter to several years for lignin.  
 740 The model considers only the soil N transformations and carbon decomposition, but the N cycle is not  
 741 fully simulated and N does not influence the vegetation productivity, i.e., there is a fixed C:N ratio. The  
 742 P cycle also is not fully implemented, instead the P-limitation is spatially parameterized through the  
 743 linear relation developed by Castanho et al. (2013) to limit the gross primary productivity. A map of  
 744 total P available in the soil ( $P_{total}$ ) is used by the model to estimate the maximum capacity of  
 745 carboxylation by the Rubisco enzyme ( $V_{max}$ ) for each grid using Equation (1).

$$V_{max} = 0.1013 P_{total} + 30.037 \quad (1)$$

747 where  $V_{max}$  and  $P_{total}$  are given in  $\mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$  and  $\text{mg kg}^{-1}$ , respectively. This equation has been  
 748 based on data for tropical evergreen and deciduous trees, and is applied only to these two PFTs, while  
 749 the other PFTs are unaffected.

750 INLAND also contains a spatial fire module, from the Canadian Terrestrial Ecosystem Model  
 751 CTEM (Arora and Boer, 2005). In this module, three aspects of the fire triangle are considered – the  
 752 availability of fuel to burn, the flammability of vegetation, and the presence of an ignition source. Each  
 753 is represented daily by an independently calculated probability, and the product of the three is the,  
 754 probability of fire occurrence. Availability of fuel to burn depends on biomass, flammability depends on  
 755 soil moisture and ignition depends on a random lightning occurrence and a constant anthropogenic  
 756 ignition probability (in these runs prescribed to 0.50). The burned area fraction is calculated daily and  
 757 depends on the probability of ignition, spread rate (as function of wind speed, soil moisture), simulated

**Formatado:** Fonte: Não Negrito, Inglês (Estados Unidos)

**Excluído:** P is used only to limit the gross primary productivity

**Excluído:** The

**Excluído:** through a linear relationship

**Excluído:** developed by Castanho et al. (2013)

**Excluído:** in the model.

**Excluído:** ly

**Excluído:** depending on environmental conditions

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**Excluído:** of an ignition source.

**Excluído:** The

**Excluído:** is the product of the three

**Excluído:** The individual probabilities are calculated at the daily timescale based on soil, climate and vegetation conditions to generate a daily burned gridcell area fraction for each PFT. Following Arora and Boer (2005), a

**Excluído:** fire

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781 length to breadth ratio of fire, and extinguishing rate. The daily area burned is accumulated through the  
782 year, and its ratio to the grid cell area is applied at the end of each year as a “penalization fraction” to  
783 leaf, wood and root biomass pools. For more details, see Arora and Boer (2005).

**Excluído:** summed

**Excluído:** ly

**Excluído:** total

**Excluído:** Therefore, at the end of each year both upper and lower LAI are decreased, according to the amount burned, triggering competition.

**Excluído:** Th natural ignition probability, is summed to arbitrary anthropogenic fire probability, (in these runs prescribed to )and the burned area is modeled as an ellipse of dimensions determined by wind and fuel conditions (Arora and Boer, 2005).¶

## 784 2.3 Observed data

### 785 2.3.1 Phosphorus databases

786 We used two P databases to estimate  $V_{\max}$  (Equation 1): one regional (referred to as PR) and one  
787 global database (referred to as PG). In addition, a control P map (PC) represents the unlimited nutrient  
788 availability case, equivalent to a  $V_{\max}$  of  $65 \mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , or  $350 \text{ mg P kg}^{-1}$  soil, according to  
789 Equation 1.

**Excluído:** Equation

790 The PR database was developed from total P in the soil for the Amazon basin published by  
791 Quesada et al. (2011) plus 54 additional available P samples (P extracted via Mehlich-1 extractor,  
792  $P_{\text{mehlich-1}}$ ) (Figure 2a). We used the  $P_{\text{mehlich-1}}$  and clay contents measured in a forest-savanna transition  
793 region in Brazil (Mato Grosso state) to estimate  $P_{\text{total}}$  and expand the coverage area of the P data  
794 (Section S1). These 54 samples were gridded to a  $1^\circ \times 1^\circ$  grid to be compatible with the spatial  
795 resolution used by INLAND, resulting in 12 additional pixels with observed total P content (Figure 2a).  
796 For pixels without observed  $P_{\text{total}}$ , the  $P_{\text{total}}$  was assumed to be  $350 \text{ mg P kg}^{-1}$  soil, similarly to the PC  
797 conditions.

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798 A global dataset of  $P_{\text{total}}$  (Figure 2b) was also used to estimate  $V_{\max}$ . This global data set is part  
799 of a database containing six global maps of the different forms of P in the soil (Yang et al., 2013). The  
800  $P_{\text{total}}$  was estimated from lithologic maps, distribution of soil development stages, fraction of the

816 remaining source material for different stages of weathering using chronosequence studies (29 studies),  
817 and P distribution in different forms for each soil type based on the analysis of Hedley fractionation  
818 (Yang and Post, 2011), which are part of a worldwide collection of soil profile data. The uncertainties  
819 and limitations associated with this database are restricted to the Hedley fractionation data used, which  
820 are 17% for low weathered soils, 65% for intermediate soils and 68% for highly weathered soils (Yang  
821 et al., 2013).

### 822 2.3.2 Above-Ground **Biomass** (AGB) database

823 The AGB database used was created by Nogueira et al. (2015) and considered undisturbed (pre-  
824 deforestation) vegetation existing in the Brazilian Amazonia. This database was compiled from a  
825 vegetation map at a scale of 1:250000 (IBGE, 1992) and AGB averages from 41 published studies that  
826 had conducted direct sampling in either forest (2317 plots) or non-forest or contact zones (1830 plots).  
827 We bi-linearly interpolated the AGB (dry weight) for each transect considering  $1^\circ \times 1^\circ$  to ensure  
828 compatibility of the observed and simulated data.

829 Five longitudinal transects (Figure 1) were used separately to characterize AGB in the Amazon-  
830 Cerrado border (Figures 3a and 3b). In T1, T2, T3 and T4, the higher AGB values in the west and lower  
831 values in the east are consistent with the transition from a dense and woody vegetation (the Amazon  
832 forest) towards a sparse vegetation with lower AGB (the Cerrado). However, T1 shows a more gradual  
833 reduction of AGB along the west to east gradient, while in T2, T3 and T4, the transition is more abrupt.  
834 In T5 no west-east gradient is present with high AGB heterogeneity and predominant low AGB across  
835 the transect (Figure 3b).

836

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## 839 2.4 Simulations

840 The model was forced with the prescribed climate data based on the Climate Research Unit  
841 (CRU) database (Harris et al., 2014). Two climate boundary conditions were used: the first is referred to  
842 as the monthly climatological average (CA) that represents the average climate for the period 1961-  
843 1990. The second climate boundary condition is the historical dataset, for the continuous period  
844 between 1948 and 2008 (CV). For both boundary conditions, the variables used are rainfall, solar  
845 radiation, wind velocity and maximum and minimum temperatures. The CRU database has been widely  
846 used by the scientific community in case studies, because these data preserve the spatial mean of the  
847 rainfall data, although, they do not provide adequate representation of their variance precipitation  
848 (Beguería et al., 2016). The dataset has a 1-degree spatial resolution and a monthly time resolution.

849 Soil texture data is based on the IGBP-DIS global soil (Global Soil Data Task 2000) (Hansen  
850 and Reed, 2000). In the CV group of runs, the model was spin-up by cycling the 1948-2008 climate data  
851 (61-year) seven times, totaling 427 years. In the CA group of runs, the annual mean climate data was  
852 cycled 427 times. In both cases, CO<sub>2</sub> varied from 278 to 380 ppmv, according to observations in the  
853 period, updated annually. In both cases, only the model results of the last 10 years were used to analyze  
854 the results.

855 The experiment design is a factorial combination of the climate scenarios (CA, monthly  
856 climatological average, 1961-1990; CV, monthly climate time series, 1948-2008), the nutrient limitation  
857 on V<sub>max</sub> (PC, no P limitation (V<sub>max</sub> = 65 μmolCO<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup>); PR, regional P limitation; PG, global P  
858 limitation) and the occurrence of fire (F) or not (Table 1). The 12 combinations in Table 1 allow the  
859 evaluation of individual and combined effects of climate, soil chemistry, and the incidence of fire on the

**Excluido:** The model simulations were run for the time period 1582-2008, a total of 427 years.



863 variables: Net Primary Production (NPP), tree AGB, and LAI of the upper and lower canopies ( $LAI_{upper}$ ,  
864  $LAI_{lower}$ ).

865 We consider that the subtraction between the simulations  $(CV+PC)$  and  $(CA+PC)$  represents  
866 the isolated effect of inter-annual climate variability without P limitations. The same logic is applied to  
867 isolate other factors such as fire and P in different climate scenarios. For example, the fire effect under  
868 average climate without P limitation case is calculated by the difference between  $CA+PC+F$  and  
869  $CA+PC$ . Similarly, the isolated effect of fire under a climate with inter-annual variability scenario  
870 without influence of P limitation is calculated by the difference between  $CV+PC+F$  and  $CV+PC$ . The  
871 different combinations of climate scenarios with and without fire effects and with and without P  
872 limitations are described in Table 2.

## 873 2.5 Statistical analysis and determination of the best model configuration

874 The statistical analysis is divided in four parts. First, we present maps of the isolated effects for  
875 all simulated area calculated as the average of [the](#) last ten years of simulated spatial patterns. The  
876 statistical significance of the isolated effects on NPP, LAI and AGB are determined using the t-test with  
877  $p < 0.05$ . The results are tested in each pixel, for all the simulated domain ( $n = 10$ ).

878 Second, we present an analysis of variance using the one-way ANOVA and the Tukey-Kramer  
879 test in the transition zone. We consider all 31 pixels which fall in transects T1 to T5 ( $n_{pixels}$ ). The results  
880 presented are based on the set of last 10 years of simulation (1999-2008,  $n_{years}$ ) for the 12 combinations  
881 ( $n_{simulation}$ ) in Table 1. Moreover, we grouped treatments according to climate regardless of P limitation,  
882 presence or absence of fire, where all sets with CV vs CA are tested (Group 1,  $n=1860$ , ( $n_{pixel} \times n_{year} \times$   
883 ( $n_{simulation}/2$ )). Similarly, in Group 2 we tested if PC, PR or PG were significantly different from each

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891 other regardless the F or climate used (Group 2,  $n=1240$ ,  $(n_{\text{pixel}} \times n_{\text{year}} \times (n_{\text{simulation}}/3))$ ). In Group 3 we  
892 tested if fire introduced a significant effect regardless of climate and P limitation (Group 3,  $n=1860$ ,  
893  $(n_{\text{pixel}} \times n_{\text{year}} \times (n_{\text{simulation}}/2))$ ). Finally, all treatments were tested to each simulation assessing their  
894 individual effects on NPP, LAI and AGB ( $n_{\text{pixel}} \times n_{\text{year}} = 310$ ).

895 Third, a correlation coefficient between the simulated and observed values for AGB was  
896 calculated for each transect. The simulated variables are averaged for the last 10 years of simulations  
897 (1999 - 2008) and compared to AGB from Nogueira et al. (2015) within a grid cell.

898 Finally, we evaluate INLAND's ability to assign the dominant vegetation type by analyzing 10  
899 years of probability of occurrence. If the dominant vegetation type (evergreen tropical forest, or  
900 deciduous forest for the Amazon rainforest, and savanna or grasslands for Cerrado) in a pixel is the  
901 same in more than 90% of the simulated years (9 out of 10), then the simulated vegetation type is  
902 defined as "very robust" for that pixel; if it occurs in 70 - 90% of the simulated years, the simulated  
903 result is considered to be "robust". If the dominant vegetation occurred in less than 70% of simulated  
904 years, the pixel is considered "transitional" vegetation.

### 905 **3 Results**

#### 906 **3.1 Influence of climate, fire and phosphorus in the Amazon-Cerrado transition region**

##### 907 **3.1.1 Spatial patterns**

908 Overall, the inclusion of inter-annual climate variability (CV) resulted in a decrease in the  
909 simulated average tree biomass (TB) by 3.8% in [the entire Brazilian](#) Amazonia, and by 8.7% in [the](#)  
910 [entire](#) Cerrado in comparison to average climate (CA), [with values obtained by the difference CV+PC -](#)

911 CA+PC (Figure 4a). The spatial differences between CV and CA for TB simulations are statistically  
912 significant and range from  $-3 \text{ kg-C m}^{-2}$  to  $+2 \text{ kg-C m}^{-2}$ . The state of Pará, with higher influence of the El  
913 Niño phenomenon, experienced the highest decrease in TB in the CV simulation. In the state of  
914 Roraima, on the other hand, there was an increase of about  $2 \text{ kg-C m}^{-2}$  in TB when CV was considered.  
915 Bolivia and southwest of Mato Grosso state also presented, in some grids points, a significant increase  
916 in AGB higher than  $2 \text{ kg-C m}^{-2}$ .

917 On average, P acts as a limiting factor in the simulated TB, decreasing by 13% in regional P  
918 (PR) simulation and 15% in global P (PG) simulation. In PR, TB decreased mainly in the southeastern  
919 Amazonia (between Pará and northeastern Mato Grosso states) and northwestern Amazonas state  
920 (Figure 4b). In PG, the largest TB decline occurred in central Amazonia, northeastern Pará and  
921 northeastern Mato Grosso (Figure 4c). In Cerrado, on the other hand, TB declined by 2% for PR and 9%  
922 for PG with respect to the control simulation. In PR, the few pixels in the Cerrado that have P limitation  
923 showed a significant decrease in TB (Figure 4b), while in PG the TB reduction was statistically  
924 significant for most of the Cerrado domain, except in southern Tocantins state (Figure 4c).

925 The tree biomass reduction due to fire events is much higher in magnitude than due to P  
926 limitation or inter-annual climate variability (Figure 4d). The small or null fire effect in the Central  
927 Amazon rainforest is related to the greater water availability in Amazonia, which makes the forest  
928 naturally not flammable as well as a gradient towards seasonally dryer climate increases the intensity  
929 and magnitude of fire effects towards the Cerrado (Figure 4d). The fire effect on TB over the Amazon  
930 domain was 21-24% of the P limitation effect (range for PR and PG cases), while the fire effect on TB

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Excluído: The greater water availability is related to small or null fire effect in the Central Amazon rainforest agrees with the fact that Amazonia is naturally inflammable as well as a gradient towards seasonally dryer climate that increases the intensity and magnitude of fire effects towards the Cerrado (Figure 4d)

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944 over the Cerrado was more than 250% of the P limitation effects in CV simulations, which is due to  
945 quick growth of grasses after fire occurrence in the latter.

### 946 3.1.2 Influence of climate, fire and phosphorus in the transects

947 Results of the ANOVAs and Tukey-Kramer test indicate that the inclusion of CV, limitation by  
948 P (PR and PG) and fire in INLAND led to significantly different averages of NPP, LAI and AGB in the  
949 transition zones. This influence of climate, P and fire are shown separately in Tables 3 to Table 5 and  
950 combined in Table 6.

951 The effects of climate and P on productivity show that CV reduces the NPP from  
952  $0.68 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  to  $0.64 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  (Table 3) and the P effect results in NPP decline from  
953  $0.71 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  to  $0.64 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  (both PR and PG) (Table 4). The fire effect, moreover, has a  
954 positive effect on NPP from  $0.66 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  when fire is off to  $0.67 \text{ kg-C m}^{-2} \text{ yr}^{-1}$  when fire is on.  
955 This difference, albeit low, is statistically significant (Table 5).

956 In addition CV and P limitation reduce the  $\text{LAI}_{\text{total}}$  in the canopy (Table 3 and Table 4),  
957 increasing three times  $\text{LAI}_{\text{lower}}$  and decreasing  $\text{LAI}_{\text{upper}}$  (Table 5). The magnitude of fire effect on AGB  
958 (46.7%, Table 5) is greater in relation to the CV (5%, Table 3) and P (14%, Table 4) limitation effects.

959 Even though CV effects on NPP and AGB for each simulation is not statistically significant, the  
960 effects of fire and P limitation (regardless of phosphorus map) are. Fire effects are significant only for  
961 structural variables as AGB,  $\text{LAI}_{\text{total}}$ ,  $\text{LAI}_{\text{upper}}$  and  $\text{LAI}_{\text{lower}}$ . It presents an increase of LAI total of  
962  $1.52 \text{ m}^2 \text{ m}^{-2}$  in CV+PG+F in relation to CV+PG, and of  $1.32 \text{ m}^2 \text{ m}^{-2}$  in CV+PR+F in relation to CV+PR  
963 (Table 6).

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965 **3.1.3 West-East patterns of AGB in the Amazon-Cerrado transition**

966 The model used in this study simulates > 80% of the observed AGB variability in all treatments  
967 along the transition area except in T5 (Table 7). It shows that the model is able to capture AGB  
968 variability along the transition area, which is relevant when compared to studies that simulate 50% of  
969 the observed AGB variability (Senna et al., 2009; Castanho et al., 2013).

970 It is not possible to identify a treatment that best represents AGB in all transects (Table 7). A  
971 combined analysis of Table 7 and Figure 5 indicates a general agreement that observed AGB decreases  
972 from W to E in T1 to T4, and this is well captured by several configurations of the model, with specific  
973 differences among them. Overall, CA and PC configurations, being the least disturbed treatments, yield  
974 higher AGB, while the introduction of CV, PG and F reduce the AGB. However, the simulated results  
975 may be above or below the observed ones, which suggests that additional local factors are not included  
976 in the model.

977 The curves of AGB (Figure 5) show the impact of CV, PG and F along the W-E transition. PG  
978 has a high influence on the transition, decreasing the ABG especially in the western part of the  
979 transects, where the Amazon vegetation is predominant. This feature is particularly simulated in T3 and  
980 T4, where PG decrease the AGB by  $2 \text{ kg-C m}^{-2}$  in the west pixels of these transects (Figure 5). In T1,  
981 T2 and T5, AGB decline is also higher with P limitation when compared to the curves limited only by  
982 CV. However, in T1 model simulations tend to underestimate the highest and the lowest AGB extremes,  
983 and the absolute values were always underestimated, despite the improvement in correlation with the  
984 inclusion of the fire component (Table 7).

985 In T2, T3 and T4, however, fire is responsible for altering the simulated AGB to the observed  
986 AGB in the eastern pixels of the Cerrado domain (Figure 5). In T5 these relations are similar, with  
987 climate presenting less influence on AGB decrease than P, and fire appears mainly as an AGB reduction,  
988 factor.

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### 989 3.2 Simulated composition of vegetation

990 Most of the pixels in CA show very robust simulations, with more than 90% of the same  
991 vegetation cover in the simulated last 10 years (Figure 6a-c and 6g-i). A larger number of pixels with  
992 transitional vegetation were simulated in CV (Figure 6d-f and and 6j-l). An even higher variability in  
993 CV compared to CA simulations was observed when we added the effects of P limitation and fire  
994 (Figure 6a and 6j-l).

995 The vegetation composition in all P limitation scenarios for CA simulations resulted in robust  
996 simulations for nearly all pixels, except for the north of Cerrado domain (Figures 6a, 6b and 6c). The  
997 CA+PC and CA+PR simulations had the same vegetation composition, while CA+PG replaced the  
998 deciduous forest by evergreen forest in the central Cerrado region, around 8°S 46°W (Figures 6A, 6B  
999 and 6C). This behavior might be related to the higher  $P_{total}$  values in PG than PR and PC for the Cerrado  
1000 region (Figure S1). Cerrado was better represented in CV+PC, CV+PR and CV+PG than in the same  
1001 CA combinations (Figure 6). The occurrence of forested areas in central Cerrado decreased in CV  
1002 combinations, these being replaced by the savanna or grassland vegetation class.

1003 When the effect of fire was added to CA simulations, the model simulated an increase in the  
1004 uncertainty on the vegetation cover classification in the Cerrado region. The effect of fire reduced the  
1005 presence of deciduous forest in central Cerrado biome as well as in CA+PC, and the vegetation was

1013 replaced by evergreen forest in about 5 pixels with clay soils with large water retention capacity in  
1014 CA+PC+F (Figures 6G, 6H, 6I). In this situation, where there is little water stress in the CA simulation,  
1015 both evergreen and drought deciduous PFTs have each one very high LAI, and the PFT that dominates  
1016 can be defined by minor effects. Fire, although active, is probably too small to be relevant in a non-  
1017 stressed ecosystem. In CV simulations, however, fire effect results in the replacement of the deciduous  
1018 and perennial forest by savanna and grasses in all central Cerrado region (Figures 6J, 6K and 6L). These  
1019 results show the limitations of CA and the importance to consider the interannual climate variability on  
1020 simulations to improve the vegetation simulated.

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1021 For all combinations used, transitional forest areas in the northern and southwestern Cerrado  
1022 biome are not adequately represented. With >90% of concordance, INLAND assigns the existence of  
1023 tropical evergreen forest rather than deciduous forest in some pixels in the north of the transition, and  
1024 the existence of tropical evergreen forest rather than savanna in the southwest, indicating difficulty to  
1025 simulate transitional vegetation in these regions.

#### 1026 4 Discussion

1027 The inclusion of CV, PR and PG and fire in INLAND showed significant influences on the  
1028 simulated vegetation structure and dynamics in the Amazon-Cerrado border (Figure 4 and Table 6),  
1029 suggesting that these factors play key role on vegetation structure in the forest-savanna border and can  
1030 improve the simulated representation of the current contact zone between these biomes. This is broadly  
1031 consistent with the literature that investigated causes of savanna existence in the real world (Hoffmann  
1032 et al., 2012; Dantas et al., 2013; Lehmann et al., 2014). In this study, the spatial analysis and the Tukey-  
1033 Kramer test (TK) show a difference in magnitude among these factors in vegetation, with fire

1035 occurrence and P limitation being stronger than inter-annual climate variability along the transects  
1036 (Figure 4).

1037 The spatial analysis showed that CV declines AGB predominantly in eastern Amazonia (Figure  
1038 4a). Climate of this region is intensely affected by El Niño–Southern Oscillation (ENSO), which could  
1039 reduce precipitation by 50%, placing the vegetation under intense water stress (Botta and Foley, 2002;  
1040 Foley et al. 2002; Marengo et al., 2004; Andreoli et al., [2012](#); Hilker et al., 2014). This reduction in  
1041 rainfall in dry years brings in direct changes in carbon flux (NPP) and stocks in leaves and wood,  
1042 leading to changes in vegetation structure. In addition to inter-annual changes in the rainfall, inter-  
1043 annual variability in other climate variables in CV also affect AGB, as average, maximum and  
1044 minimum temperature, as well as wind speed and specific humidity, and influence photosynthesis on  
1045 the model both directly (through Collatz and Farquhar equations) and indirectly (e.g. through  
1046 evapotranspiration). Our results showed significant differences for most part of the biomes, except  
1047 central Amazonia (Figure 4a), where CV and precipitation seasonality have been pointed as secondary  
1048 effects on vegetation (Restrepo-Coupe et al., 2013), since there is no shortage of water availability  
1049 during the dry season.

1050 Along the Cerrado, lower water availability in some years in CV affects tree biomass, although  
1051 that vegetation is predominantly grassy-herbaceous. The AGB decline is significant for most part of the  
1052 simulated Cerrado domain (Figure 4a) and average values could represent half the amount of typical  
1053 tree biomass in this biome. This reduction in AGB reflects INLAND's ability to simulate similar  
1054 Cerrado conditions and expose the few trees to high water stress.

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1056 Throughout the transects, however, no significant difference was found for average AGB  
1057 between CV+PC and CA+PC by TK at  $p < 0.05$  (Table 6). On the other hand, when we analyzed the  
1058 influence of CV for the same pixels, but using all simulations (Table 3), regardless of P limitation and  
1059 fire occurrences, the results showed that the decrease in AGB by  $0.38 \text{ kg-C m}^{-2}$  (5.7%) is statistically  
1060 significant along the transition.

1061 P limitation effect was statistically significant for PR and PG along all the Amazon domain and  
1062 the main differences between these simulations were the spatial patterns of tree AGB decrease (Figure  
1063 4b and Figure 4c). We cannot affirm which of these databases is better because they are the results of  
1064 different methodologies and observations (Quesada et al., 2009; Yang et al., 2014). However, PG  
1065 showed a higher AGB decrease in central Amazonia, northeastern Pará and northeastern Mato Grosso  
1066 state, indicating that in these areas the P limitation is higher. This result does not corroborate the  
1067 northwest-southeast AGB gradient found in the Amazon basin, which showed a higher productivity in  
1068 the west where soils are more fertile than those found in the southeast (Aragão et al., 2009; Saatchi et  
1069 al., 2007; Nunes et al., 2012; Lee et al., 2013). On the other hand, PR AGB agrees with the northwest-  
1070 southeast gradient, presenting less limitation in the soils of central Amazonia with declines in AGB  
1071 mainly in the southeastern part of the rainforest (between Pará and northeastern Mato Grosso states)  
1072 (Figure 4b).

1073 In Cerrado, P limitation also influenced vegetation (Figure 4c) and presented statistically  
1074 significant differences when compared CV+PG – CV+PC. In this biome, as well as in the Amazon, tree  
1075 abundance richness and diversity have been generally associated with increases of soil fertility (Long et

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1078 al., 2012; Vourtilis et al., 2013), highlighting the importance of P in the composition and maintenance  
1079 of vegetation, especially in transition areas.

1080 Compared to the Amazon domain, the magnitude of effects of P limitation is lower in the  
1081 Cerrado. However, few pixels in PR that have P limitation showed a significant decrease in arboreal  
1082 AGB (Figure 4b), while in PG, we found reduction of AGB for most of the Cerrado domain, except  
1083 only for the southern Tocantins state (Figure 4c). Despite the differences in spatial patterns, there was  
1084 no statistically significant differences between PR and PG within the transects (Table 4 and Table 6).

1085 The spatial difference between PG and PR showed that PG is lower than PR in the western  
1086 Amazonia, and higher in northern Amazonia. Moreover, PG have low P values in south of the  
1087 transition compared to PR, while in Cerrado domain P values ranged between 120 to 200 mg kg<sup>-1</sup>  
1088 (Figure S1). Although the PR dataset includes every known P data collected in the region, these  
1089 differences reinforce the need to improve the data of P<sub>total</sub> in the soils of the Amazon and  
1090 Cerrado/Amazon transition domains. Currently, P<sub>total</sub> data in Cerrado is scarce, and make unfeasible to  
1091 establish a proxy similar to Castanho et al. (2013), which was specific for the Amazon.

1092 In INLAND, the simple P-limitation parameterized through the linear relation Vmax and P<sub>total</sub>,  
1093 showed significant spatially differences in AGB simulated and an improvement in simulations,  
1094 highlighting the importance of P-limitation in modeling studies. For the most part, Dynamic Global  
1095 Vegetation Models (DGVMs) do not consider the complete phosphorus cycle (see exceptions in Goll et  
1096 al., 2012 and Yang et al., 2014), despite the importance of nutrient cycling for AGB maintenance and  
1097 tropical vegetation dynamics in dystrophic soils. For example, nutrient cycling in the Amazon/Cerrado  
1098 transition is closely related to the hyper-dynamic turnover of the AGB (Valadão et al. 2016), in which

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1101 some key species might also be crucial to the hyper-cycling of nutrients through which vegetation  
1102 sustain the constant input of nutrients, including large annual amounts of available P (Oliveira et al.  
1103 2017).

1104 The fire occurrence is an important factor controlling the AGB dynamics in the Cerrado or in the  
1105 transition vegetation (Hoffman et al., 2003; Hoffman et al., 2012; Silvério et al., 2013; Couto-Santos et  
1106 al., 2014; Balch et al., 2015), which this study clearly replicates, showing statistically significant  
1107 influences when compared to control simulations (Figure 4d and Table 5). In the transition, the fire  
1108 effect may reduce average AGB by 50% (Table 5), which under climate change or deforestation  
1109 conditions may lead to an even stronger change in the vegetation structure and dynamic. According to  
1110 Hoffmann et al., (2009) the undisturbed forests in the Amazon-Cerrado border appear to be more  
1111 resilient to fire in relation to the other tropical forests and the vegetation-fire dynamics is mainly  
1112 controlled by tree “topkill” (defined by the authors as complete death of the aerial biomass). In  
1113 INLAND, the effect of fire on AGB is similar to the “topkill” presented by Hoffmann et al., (2009),  
1114 being represented by the penalization fraction described earlier, and applied annually to the leaf, wood  
1115 and root biomass pools of the pixel. Therefore, at the end of every year both upper and lower LAI are  
1116 decreased, according to the amount burned, triggering competition between both canopies for light, and  
1117 increasing the photosynthesis rates and stocks of carbon in leaves, stems and roots pools in the lower  
1118 canopy. The carbon allocation in INLAND is fixed and is not modified after fire occurrence, as  
1119 observed in some species of the savanna-forest transition (Hoffman et al., 2009; 2012). Thus, during  
1120 recovery from a fire, the vegetation dynamics follows the model standard procedure.

**Excluído:** The decrease in tree AGB occasioned by P limitation can contribute to a decrease in litter production and consequently could affect nutrient cycling in tropical ecosystems. According to Oliveira et al. (2017), the litter produced by vegetation corresponds to the main return route to the available fraction of P for plants, especially in the transition areas, where  $P_{available}$  in the soil is very low. In our model, however, P acts directly in the photosynthesis limitation through  $V_{max}$  and cannot be reabsorbed by the roots. Thus, the litter produced in vegetation contribute only to dry matter and fire occurrence increase. In nature, the litter affected by fire occurrence volatilizes the small amount of P available to plants, increasing the nutrient losses of the ecosystem. Despite this simplified representation in INLAND, it can represent the P influence on woody AGB in the Amazon and Cerrado. ¶

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1179 In the Cerrado domain, the simulated fire effect implies in significant increases in shrubs and  
 1180 herbaceous vegetation and decreases in the arboreal component, resulting in increment of LAI<sub>lower</sub> and  
 1181 decrease of LAI<sub>upper</sub> (Table 5). These changes in canopy structure after fire occurrence are exclusively  
 1182 due to the canopy opening and consequently more penetration of photosynthetic radiation into the lower  
 1183 canopy.

1184 The model does not include neither characteristics related to resilience such as velocity, intensity  
 1185 and duration of the burning (Hoffman et al., 2003; Rezende et al., 2005; Elias et al., 2013; Reis et al.,  
 1186 2015) nor the representation of some tree morphological adaptation that confers to Cerrado species  
 1187 resilience to fire occurrence, such as bark thickness. Thus, trees and grasses throughout the Amazon-  
 1188 Cerrado border are equally exposed to the same fire intensity inside the grid cell, without fire resistance  
 1189 differences. However, despite the limitations in the representation of resilience characteristics and  
 1190 morphological attributes of fire resistance, our results show that simulated biomass is more close to  
 1191 observed biomass in Cerrado areas when the fire module is activated (Figure 5). An improvement in  
 1192 distribution of biomes along the simulated transition area is also observed (Figure 6g-i), highlighting  
 1193 fire as an essential factor to represent the Amazonia-Cerrado border.

1194 This study shows an improvement in the correlations between simulated and observed AGB  
 1195 when compared to previous modeling studies, regardless of treatment, with correlation coefficients  
 1196 usually above 0.80 for the transects, except for T5, for which the correlation coefficient value is usually  
 1197 below 0.5 (Table 7). Senna et al. (2009) found 0.20 as maximum correlation coefficient between  
 1198 simulated and observed ABG while Castanho et al. (2013) showed 0.80 for Amazonia domain. From  
 1199 Figure 5, it is clear that CV, F and P limitation in the transition zone reduce the AGB, causing the

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- Excluído:** In nature the Cerrado is relatively resilient to fire depending on the
- Excluído:** are not included in the model .
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- Excluído:** In our model,
- Excluído:** adaptation
- Excluído:** , different rates of regrowth after fire in relation to forest trees, representation of height stems different stem diameter that confers to some Cerrado species are not also considered is limited by due to the PFT representation
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1237 simulated data to approach the observed data. However, the inclusion of these effects is still insufficient  
1238 to represent the correct distribution of the vegetation types throughout the Amazon-Cerrado border  
1239 (Figure 6L). In our interpretation, this means that other important factors are still missing from the  
1240 simulation, especially in T5, where soils are rocky and shallow. A better spatial representation of soil  
1241 physical properties, including shallow rocky soils, as well as spatially varying physiological  
1242 parameterizations of the vegetation such as carbon allocation, deciduousness of vegetation, residence  
1243 time and tree structure that may discern thick from thin trees, are probably needed to improve the  
1244 simulations, in particular in the northern and southern extremes of the border (T1 and T5).

1245 In addition, literature shows that in the transition area, soils are very different than Amazon  
1246 soils, and that essential proprieties for modeling are peculiar (Silva et al., 2006; Vourlitis et al., 2013;  
1247 Dias et al. 2015). For example, Dias et al. (2015) recently showed that the pedological functions  
1248 normally used by DGVMs may underestimate the saturated hydraulic conductivity ( $K_s$ ) by >99%,  
1249 transforming a well-drained soil with  $K_s = 1.5 \cdot 10^{-4} \text{ m.s}^{-1}$  (540 mm.h<sup>-1</sup>) in reality into an impervious  
1250 brick with  $K_s = 3.3 \cdot 10^{-7} \text{ m.s}^{-1}$  (1.2 mm.h<sup>-1</sup>) in the model.

1251 For all transects, the AGB curves have similar patterns (Figure 5); the smaller difference is  
1252 observed between CA+PC and CV+PG curves, while the larger difference is when fire is present. The  
1253 effect of P limitation appears as an effect of intermediate magnitude, reducing the AGB by more than  
1254 the effect of inter-annual climate variability. In the east, it is observed that there is little or no difference  
1255 among AGB simulated by CA+PC, CV+PC and CV+PG, revealing that inter-annual climate variability  
1256 and P have smaller influence in the AGB. However, in the east of T2, T3 and T4, fire is the factor that

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**Excluído:** From Figure 5, it is clear that CV, F and P limitation in the transition zone reduce the AGB, approaching the simulated to the observed data, and play important roles in the simulations, but the only inclusion of these effects is still insufficient to represent the actual vegetation structure in the Amazon-Cerrado border (Figure 6L)

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1271 adjusts the simulated to the observed data (Figure 5), differently than the grid points in the West, where  
1272 CV+PG is a better proxy between observed and simulated data.

1273 Such conditions are interesting because they reflect the different mechanisms that regulate the  
1274 structure of these ecosystems and probably the phytophysiognomies distribution. For example, P  
1275 limitation seems to be the factor that improves simulated AGB in regions where the predominant  
1276 vegetation type is the tropical rainforest. Fire, on the other hand, improves the AGB in grid points  
1277 where the Cerrado occurs. Moreover, important factors such as productivity partitioning into leaves,  
1278 roots and wood carbon pools are assumed to be fixed in space and time within a given PFT, neglecting  
1279 the natural capacity of transitional forests to adapt itself and to adjust their metabolism to local

1280 environmental conditions (Senna et al., 2009). In years of severe drought, or under frequent fire  
1281 occurrence, transitional forests could prioritize the stock of carbon in fine roots instead of the basal or  
1282 leaf increment to maximize access to available water, make hydraulic redistribution of soil moisture to  
1283 maintain the greenness and photosynthesis rates, or increase the capacity to resprout after fire  
1284 occurrence (Hoffman et al., 2003; Brando et al., 2008). Brando et al. (2008) found high sensitivity in  
1285 carbon allocation for eastern Amazon basin trees, which reduced wood production by 13-60% in  
1286 response to an artificial drought. Although in INLAND soil moisture can reduce the photosynthetic  
1287 rates during the months of lower rainfall, it does not dynamically change the allocation rates, exposing  
1288 the PFTs in these areas to severe water stress and underestimating the AGB, such as in the west of T1  
1289 (Figure 5a).

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1294 T2, T3 and T4, located in the central part of the Amazon-Cerrado transition, showed the highest  
1295 average correlations between observed and simulated data (Table 7). For these transects, INLAND  
1296 seems to be able to capture the high variability of AGB gradient.

1297 At T5, located at the south of the transition, the average correlations were low for all treatments,  
1298 indicating that INLAND has difficulty to represent the AGB gradient there (Table 7). However, it  
1299 captures the lower AGB as compared to the northern ones. In this region, the vegetation is characterized  
1300 by a wide diversity of physiognomies, which varies with other preponderant factors, such as lithology,  
1301 soil depth, topography and fertility. The observed data also showed high AGB variability, indicating  
1302 that there are changes in the vegetation structure, featuring medium-sized and small vegetation types on  
1303 different soil types. In INLAND, however, features such as lithology and water-table depth are not  
1304 considered due to the complexity of its representation on the large scale, limiting the representation of a  
1305 heterogeneous environment throughout the transition.

1306 Patterns of vegetation distribution along the Amazon-Cerrado border exist are influenced not  
1307 only by inter-annual climate variability, P limitation, and fire, but also by the ecophysiological  
1308 parameters. Additional field experiments are needed to understand the relationship between currently  
1309 fixed parameters (such as carbon allocation, residence time, and deciduousness, among others) to the  
1310 environmental conditions and soil proprieties.

1311 Another point to discuss is that the model simulates, in a few pixels in southeastern Cerrado,  
1312 very robust simulations of the presence of savanna and grassland even in the absence of fire (Figure  
1313 6A-F and 6a-f). This is, in our view, a result of the intense water and heat stress in this region. In the  
1314 Brazilian Cerrado, the high temperatures (> 35 °C) combined to the dry season duration (as long as 6

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1343 months with little or no rain) exposes the vegetation to a severely stressed situation, so that a low  
1344 biomass, low LAI vegetation may exist without the need of a frequent disturbance.

1345

## 1346 5 Conclusions

1347 This is the first study that uses modeling to assess the influence of inter-annual climate  
1348 variability, fire occurrence and phosphorus limitation to represent the Amazon-Cerrado border. This  
1349 study shows that, although the model forced by a climatological database is able to simulate basic  
1350 characteristics of the Amazon-Cerrado transition, the addition of factors such as inter-annual climate  
1351 variability, phosphorus limitation and fire gradually improves simulated vegetation types. These effects  
1352 are not homogeneous along the latitudinal/longitudinal gradient, which makes the adequate simulation  
1353 of biomass challenging in some places along the transition. Based on the F-statistic in Tables 3, 4 and 5,  
1354 this work shows that fire is in the main determinant factor of the changes in vegetation structure (LAI,  
1355 AGB), along the transition. The nutrient limitation is second in magnitude, stronger than the effect of  
1356 inter-annual climate variability.

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1357 Overall, although INLAND typically simulates more than 80% of the variability of biomass in  
1358 the transition zone, in many places the biomass is clearly not well simulated. Situations for clearly wet  
1359 or markedly dry climate conditions were well simulated, but the simulations are generally poor for  
1360 transitional areas where the environment selected physiognomies that have an intermediate behavior, as  
1361 is the case of the transitional forests in northern Tocantins and Mato Grosso.

1362 There are evidences that the inclusion of spatially explicit parameters such as woody biomass  
1363 residence time, maximum carboxylation capacity ( $V_{max}$ ), and NPP allocation to wood may improve

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1366 Amazon rainforest AGB simulation by DGVMs (Castanho et al., 2013). However, in the transition, the  
 1367 lack of field parameters measured limits the inclusion of the variability of these biophysical parameters  
 1368 in DGVMs. Additional field work and compilation of existing ones are necessary to obtain  
 1369 physiological and structural parameters through the Amazon-Cerrado border to establish numerical  
 1370 relationships between soil, climate and vegetation. With the help of these data, the vegetation dynamic  
 1371 models will be able to correctly simulate current patterns and future changes in vegetation considering  
 1372 climate change scenarios. In addition, it is also needed to include not only the spatial variability, but  
 1373 also temporal variability in physiological parameters of vegetation, allowing a more realistic simulation  
 1374 of the soil-climate-vegetation relationship. Finally, our results reinforce the importance and need of the  
 1375 DGVMs to incorporate the nutrient limitation and fire occurrence to simulate the Amazon-Cerrado  
 1376 border position.

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- Excluído:** The lack of field parameters measured in the transition zone is still a major limitation to improve the DGVMs. Spatially explicit carbon allocation strategies, mortality rates, physiological and structural parameters are necessary to establish numerical relationships between the environment and the
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 1380 Atul K Jain is funded by the U.S. National Science Foundation (NSF-AGS- 12-43071).

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**Movido para baixo [1]:** Hoffmann, W. A., Da Silva, E. R., Machado, G. C., Bucci, S. J., Scholz, F. G., Goldstein, G. and Meinzer, F. C.: Seasonal leaf dynamics across a tree density gradient in a Brazilian savanna, *Oecologia*, 145, 307–316, doi:10.1007/s00442-005-0129-x, 2005.

**Movido (inserção) [1]**

**Excluído:** Hoffmann, W. A., Da Silva, E. R., Machado, G. C., Bucci, S. J., Scholz, F. G., Goldstein, G. and Meinzer, F. C.: Seasonal leaf dynamics across a tree density gradient in a Brazilian savanna, *Oecologia*, 145, 307–316, doi:10.1007/s00442-005-0129-x, 2005.¶

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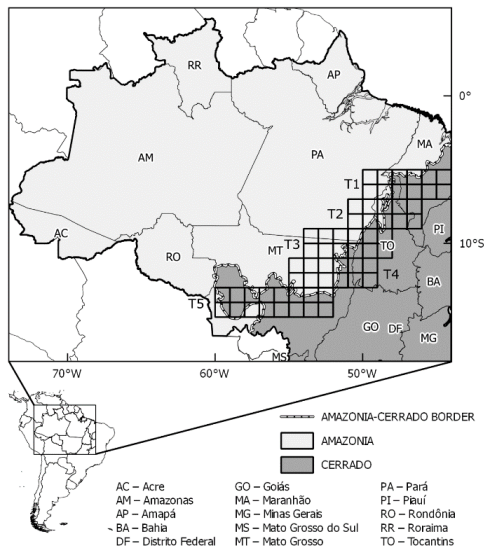
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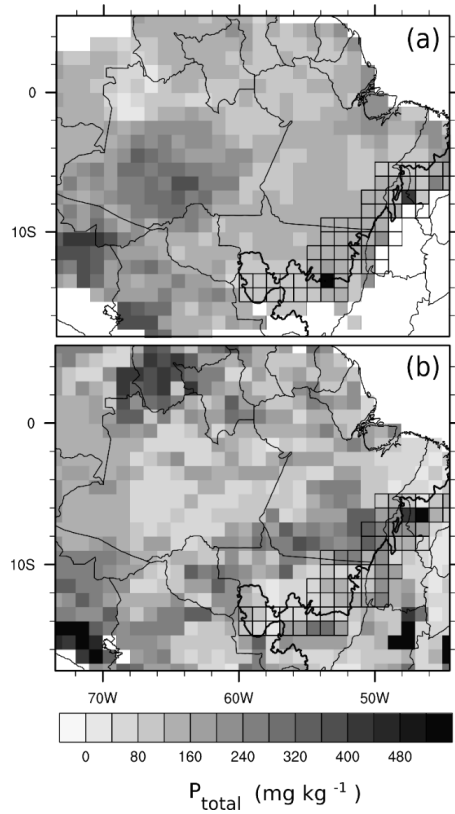
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1715 **Figure 1.** Delimitation of the study area Amazonia (in light gray) and Cerrado (in dark gray) (IBGE,  
 1716 2004), and the location of five transects used in this work (from T1 to T5). The dashed line represents  
 1717 the border between biomes.



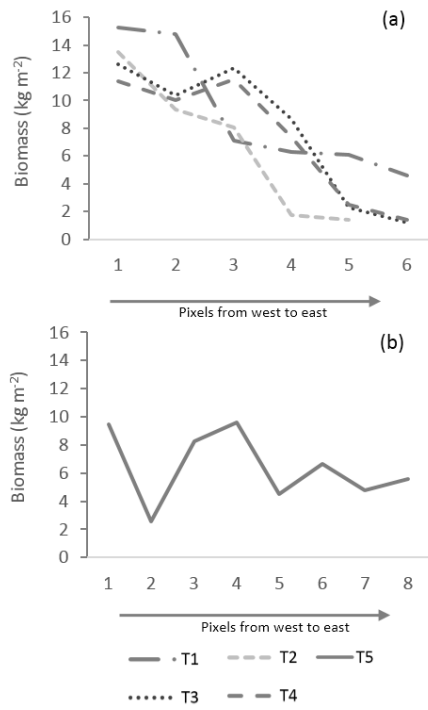
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1719 **Figure 2.** (a) Map of regional total P in the soil (PR), (b) Map of global total P in the soil (Yang et al.,

1720 2013) (PG).

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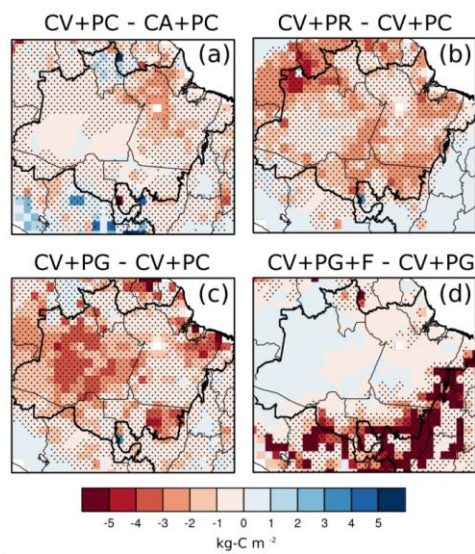


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1723 | **Figure 3.** Average variations of AGB in pixels from West to East in the Amazonia-Cerrado transition

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1724 | for transects T1, T2, T3 and T4 (a), and T5 (b).



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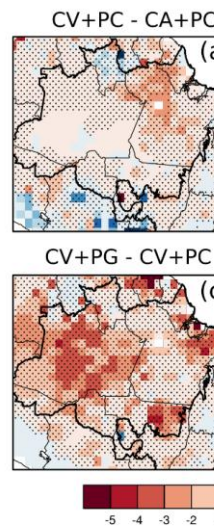
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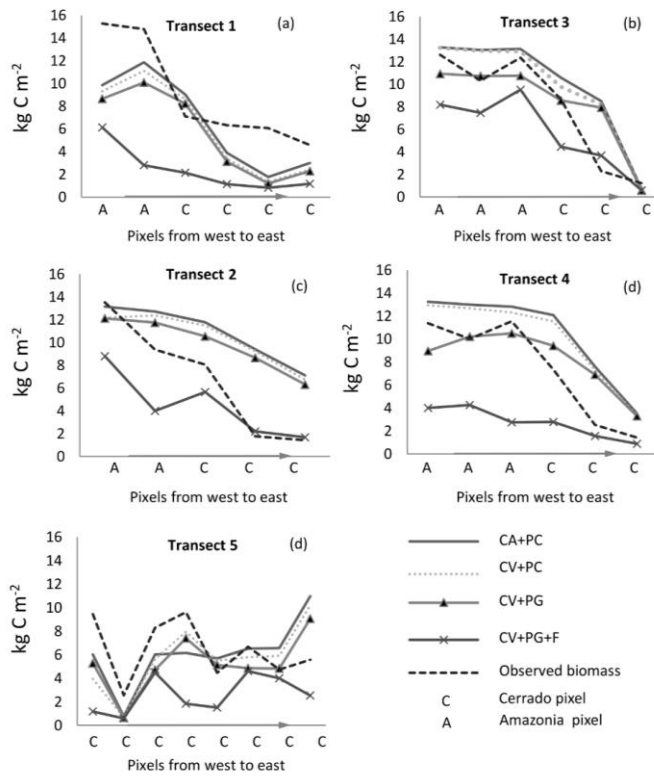
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**Figure 4.** Effects of inter-annual climate variability (a), Regional P limitation (b), Global P limitation (c), and fire (d) on AGB. The hatched areas indicate that the variables are significantly different compared to the control simulation at the level of 95% according to the t-test. The thick black line is the geographical limits of the biomes.

**Formatado:** Fonte: (Padrão) Times  
New Roman, 12 pt



**Excluído:**

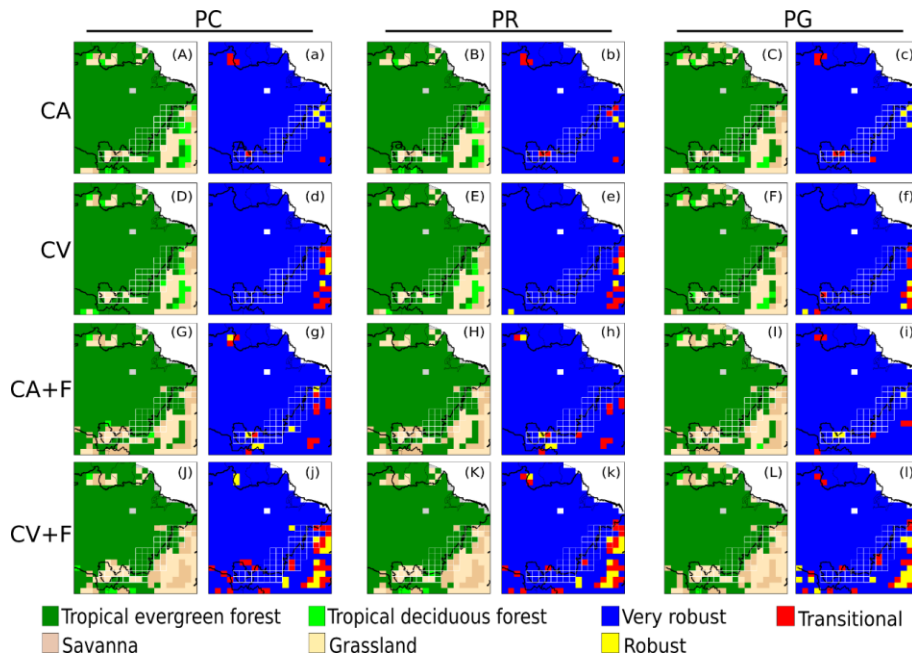


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1733 **Figure 5.** Average longitudinal AGB gradient in Amazonia-Cerrado transition simulated for T1 to T5  
 1734 considering different combinations: observed data; seasonal climate control simulation (CA+PC); inter-  
 1735 annual climate variability (CV+PC); inter-annual climate variability + global P limitation (CV+PG);  
 1736 and inter-annual climate variability + P + fire occurrence (CV+PG+F).

Excluído: Longitudinal

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**Figure 6.** Results for the dominant vegetation cover simulated by INLAND for the different treatments (A-L) and a metric of variability of results (a-l). Simulations are considered very robust if the dominant vegetation agrees on 9-10 of the last 10 years of simulation, robust if it agrees on 7-8 years, and transitional if on 6 or fewer years.

1746 **Table 1.** Simulations with different scenarios evaluated by INLAND model in Amazonia-Cerrado  
 1747 transition. CA, climatological average, 1961-1990; CV, monthly climate data, 1948-2008; the nutrient  
 1748 limitation on  $V_{\max}$  - PC, no P limitation ( $V_{\max} = 65 \mu\text{mol-CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ); PR, regional P limitation; PG,  
 1749 global P limitation).

Climate	CO <sub>2</sub>	Fire (F)	$V_{\max}$		
			PC	PR	PG
CA	Variable	Off	CA+PC	CA+PR	CA+PG
CA	Variable	On	CA+PC+F	CA+PR+F	CA+PG+F
CV	Variable	Off	CV+PC	CV+PR	CV+PG
CV	Variable	On	CV+PC+F	CV+PR+F	CV+PG+F

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1751

1752 **Table 2.** Individual and combined effects for each simulation in Amazonia-Cerrado transition. CA,  
 1753 climatological seasonal average, 1961-1990; CV, monthly climate data, 1948-2008; the nutrient  
 1754 limitation on  $V_{\max}$  - PC, no P limitation ( $V_{\max} = 65 \mu\text{molCO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ); PR, regional P limitation; PG,  
 1755 global P limitation)

Climate (C)	Phosphorus (P)	Fire (F)
(CV+PC)-(CA+PC)	(CA+PR)-(CA+PC)	(CA+PC+F)-(CA+PC)
(CV+PR)-(CA+PR)	(CV+PR)-(CV+PC)	(CV+PC+F)-(CV+PC)
(CV+PG)-(CA+PG)	(CA+PG)-(CA+PC)	(CA+PR+F)-(CA+PR)
	(CV+PG)-(CV+PC)	(CV+PR+F)-(CV+PR)
		(CA+PG+F)-(CA+PG)
		(CV+PG+F)-(CV+PG)

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1758 **Table 3.** Summary of average NPP, LAI and AGB for the Amazonia-Cerrado transition at the transects  
 1759 domains, considering all simulations with CA and CV regardless of fire presence or P limitation. The  
 1760 results of a one-way ANOVA are also shown, including the *F* statistic, and p value. Values within each  
 1761 column followed by a different letter are significantly different ( $p < 0.05$ ) according to the Tukey–  
 1762 Kramer test ( $n=1860$ : 31 pixels x 10 years x  $n_{\text{simulation}/2}$ ).

<b>Group 1</b>	<b>NPP</b>		<b>LAI<sub>total</sub></b>		<b>LAI<sub>lower</sub></b>		<b>LAI<sub>upper</sub></b>		<b>AGB</b>	
	kg-C m <sup>-2</sup> yr <sup>-1</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		kg-C m <sup>-2</sup>	
CA	0.68	a	7.47	a	1.98	a	5.49	a	6.68	a
CV	0.64	b	7.15	b	2.11	a	5.04	b	6.30	b
<i>F</i>	40.2		57.2		2.96		36.0		11.3	
<i>p</i>	<0.001		<0.001		ns		<0.01		<0.001	

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1765 **Table 4.** Summary of average NPP, LAI and AGB for the transition at the transects domains,  
 1766 considering different P limitation, regardless of climate and fire presence. The results of a one-way  
 1767 ANOVA are also shown, including the *F* statistic, and p value. Values within each column followed by  
 1768 a different letter are significantly different ( $p < 0.05$ ) according to the Tukey–Kramer test (n=1240: 31  
 1769 pixels x 10 years x  $n_{\text{simulation}/3}$ ).

<b>Group 2</b>	<b>NPP</b>		<b>LAI<sub>total</sub></b>		<b>LAI<sub>lower</sub></b>		<b>LAI<sub>upper</sub></b>		<b>AGB</b>	
	kg-C m <sup>-2</sup> yr <sup>-1</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		kg-C m <sup>-2</sup>	
PC	0.71	a	7.64	a	1.84	b	5.80	a	7.15	a
PR	0.64	b	7.15	b	2.19	a	4.95	b	6.20	b
PG	0.64	b	7.14	b	2.10	a	5.04	b	6.12	b
<i>F<sub>2,99</sub></i>	62.8		61.0		8.75		53.5		33.6	
<i>p</i>	<0.001		<0.001		<0.01		<0.01		<0.001	

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1772 **Table 5.** Summary of average NPP, LAI and AGB for the transition at the transects domains,  
 1773 considering presence or absence of fire. The results of a one-way ANOVA are also shown, including  
 1774 the *F* statistic, and *p* value. Values within each column followed by a different letter are significantly  
 1775 different ( $p < 0.05$ ) according to the Tukey–Kramer test ( $n=1860$ : 31 pixels x 10 years x  $n_{\text{simulation}/2}$ ).

<b>Group 3</b>	<b>NPP</b>		<b>LAI<sub>total</sub></b>		<b>LAI<sub>lower</sub></b>		<b>LAI<sub>upper</sub></b>		<b>AGB</b>	
	kg-C m <sup>-2</sup> yr <sup>-1</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		kg-C m <sup>-2</sup>	
Fire OFF	0.66	a	6.72	b	0.88	b	5.84	a	8.47	b
Fire ON	0.67	b	7.90	a	3.21	a	4.69	b	4.51	a
<i>F</i> <sub>3,84</sub>	8.28		937		1459		249		1719	
<i>p</i>	<0.005		<0.001		<0.01		<0.01		<0.001	

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1778 **Table 6.** Summary of average NPP, LAI and AGB for the transition at the transects domains,  
 1779 considering all factor combinations. The results of a one-way ANOVA are also shown, including the *F*  
 1780 statistic, and *p* value. Values within each column followed by a different letter are significantly different  
 1781 (*p* < 0.05) according to the Tukey–Kramer test (n=310: 31 pixels x 10 years).

	<b>NPP</b>		<b>LAI<sub>total</sub></b>		<b>LAI<sub>lower</sub></b>		<b>LAI<sub>upper</sub></b>		<b>AGB</b>	
	kg-C m <sup>-2</sup> yr <sup>-1</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		m <sup>2</sup> m <sup>-2</sup>		kg-C m <sup>-2</sup>	
CV+PC	0.69	bcd	6.96	d	0.84	e	6.48	a	9.01	ab
CV+PG	0.61	f	6.24	f	0.85	e	5.60	bc	7.91	c
CV+PR	0.62	f	6.33	f	0.85	e	5.74	bc	8.04	c
CV+PC+F	0.69	abc	7.92	b	2.91	cd	4.61	ef	4.89	de
CV+PG+F	0.63	ef	7.76	b	3.73	a	5.81	bc	3.91	f
CV+PR+F	0.63	ef	7.65	bc	3.47	ab	4.69	ef	4.02	f
CA+PC	0.72	ab	7.39	c	0.91	e	6.12	ab	9.31	a
CA+PG	0.64	def	6.64	e	0.91	e	5.40	cd	8.22	c
CA+PR	0.65	cdef	6.72	de	0.91	e	5.49	cd	8.31	bc
CA+PC+F	0.74	a	8.29	a	2.69	d	5.02	de	5.40	d
CA+PG+F	0.67	cde	7.90	b	3.29	abc	4.04	g	4.45	ef
CA+PR+F	0.67	cde	7.88	b	3.19	bc	4.18	fg	4.42	ef
<i>F</i>	<i>16.2</i>		<i>115</i>		<i>140</i>		<i>38.1</i>		<i>172</i>	
<i>p</i>	<i>&lt;0.001</i>		<i>&lt;0.001</i>		<i>&lt;0.01</i>		<i>&lt;0.01</i>		<i>&lt;0.001</i>	

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1783 **Table 7.** Correlation coefficients of AGB simulated by INLAND and field estimates (n= 310: 31 pixels  
 1784 x 10 years).

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>All transects</b>
CA+PC	0.843	0.928	0.886	0.937	0.337	0.786
CV+PC	0.838	0.884	0.890	0.939	0.355	0.781
CA+PR	0.793	0.848	0.830	0.911	0.399	0.756
CV+PR	0.795	0.793	0.832	0.907	0.527	0.771
CA+PG	0.814	0.951	0.838	0.889	0.388	0.776
CV+PG	0.825	0.922	0.840	0.879	0.496	0.792
CA+PC+F	0.988	0.987	0.977	0.892	0.133	0.795
CV+PC+F	0.976	0.947	0.933	0.908	0.187	0.790
CA+PR+F	0.842	0.805	0.981	0.808	0.561	0.799
CV+PR+F	0.925	0.804	0.927	0.808	0.319	0.757
CA+PG+F	0.844	0.961	0.980	0.830	0.430	0.809
CV+PG+F	0.845	0.932	0.931	0.881	0.177	0.753
CA avg	0.854	0.913	0.915	0.878	0.375	0.787
CV avg	0.867	0.880	0.892	0.887	0.344	0.774

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