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Interactive comment on "African biomes are most sensitive to changes in CO_2 under recent and near-future CO_2 conditions" *by* Simon Scheiter et al.

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Schieter et al. provide a detailed assessment of the predictions of the aDGVM model in Africa focus on the question of timelags between transient and equilibrium climate states. They clearly illustrate the dependance of time lags and so-called carbon and tree cover 'debt' to the rates of change, the absolute values of CO2 and the presence or absence of fire. They link these findings back to applications in terms of assessing global carbon budgets, and implications for model benchmarking.

In general the paper is well written and the experimental design and results are both comprehensive and clearly depicted. I have few comments on these except for mostly

minor grammatical points. On the discussion points I think there is a little room for improvement. The notion of carbon debt needs a little more by way of explanation, specifically of why it is a debt and to whom the debt is owed, etc.

RESPONSE: We will clarify the notation of carbon debt, see our response below.

The specific recommendation that the authors make to the land surface modeling community regarding forcing data, initialization strategies etc. are also a little vaguely worded and could do with some expansion.

RESPONSE: We will clarify recommendations regarding model forcing and initialization. See also our response below.

Aside from that I think this manuscript provides a very solid illustration of the likely impact of lags on carbon cycle dynamics, and should provide a firm justification for further research into this topic.

RESPONSE: Thank you for the positive feedback.

Specific Comments Line 12: Lag effects imply. (as opposed to implicate)

RESPONSE: We will replace implicate by imply.

Line 18: During Earth's history. . .

RESPONSE: We will modify as suggested.

Line 25: Needs a reference for RCP8.5.

RESPONSE: We will add a reference (Meinshausen et al. 2011).

Line 49: Is 'mismatch' the right word? (given there's no real reason they should be matched in the first place. What about 'The substantial differences between the rate of change in environmental forcing and . . ." ?

RESPONSE: We agree and we will modify the text as suggested.

Line 52: Delete 'in' before 'constant'

RESPONSE: We will delete 'in'.

Line 63: Not sure I'd use 'oscillate' either. I'm not sure what I would use though, because isn't all vegetation to some extent in a transient successional state?

RESPONSE: We will reword and state 'vegetation is regularly forced into early successional states'.

Line 65: Influences 'whether', as opposed to 'if'.

RESPONSE: We will reword as suggested and use 'whether'.

Line 90: I don't really understand this sentence. . .

RESPONSE: We will reword the sentence: 'Yet, previous studies often focused on CO_2 levels predicted for 2100, assuming that both CO_2 and the climate system will have stabilized by then. Here, we study lag effects for a CO_2 gradient ranging from pre-industrial to future levels.'

Line 100: I'm not sure that I totally buy that temperature increases are too heterogeneous to be interesting here? Maybe say that CO_2 can be used as an illustration of the general principle which is likely extensible to shifts in other drivers?

RESPONSE: We agree that consideration of temperature and precipitation is also important and interesting. Therefore, a study considering these variables is in preparation. A further reason why we ignored these variables is that for most of the simulations, we study a CO_2 gradient from 100ppm to 1000pmm and it is challenging (or even impossible) to find time series for temperature and precipitation that cover and correspond to such a large range. Hence, studies considering several climatic variables and CO_2 are constrained to a much smaller range (gridded products providing continuous time series are often constrained to the period 1950 to 2099). We will include this justification as well as the suggestion of the referee (CO_2 can be used as illustration

of the general principles) in the revision. In the Discussion we already mention that simulations considering various climate variables are necessary.

Line 103: What does 'typically' mean in this context?

RESPONSE: We will reword this and state 'vegetation is, in all transient scenarios that we consider, not in equilibrium . . .'.

Line 112: Splitting hairs, but isn't it a contradiction to have a 'G' in aDGVM and then also say that it's outright only for savannas? 'Optimise for use in savannas' maybe?

RESPONSE: aDGVM was originally developed for savannas, but with the intention to extend it to the global scale. Therefore, the name contains the 'G'. As suggested we will reword to '. . . dynamic vegetation model optimized for tropical grass-tree systems'.

Line 121: In this era of 'trait-based' modeling, how is the shade tolerance implemented exactly? As an environmental limit on recruitment?

RESPONSE: We assume that forest trees are less affected by light competition than savanna trees, such that forest trees have higher growth rates in dense vegetation stands with intense light competition than savanna trees. In aDGVM we use parameters that describe the strength of light competition between different grass and tree types, and we used different parameters for savanna and forest trees. We will add a statement to clarify this: 'Shade tolerance is implemented by different effects of light availability, which is in turn influenced by competitor plants, on tree growth rates. Fire tolerance is implemented by different topkill functions and re-sprouting probabilities after fire.'

Line 126: Should that be kJ/m2/s?

RESPONSE: Fireline intensity usually given in kW per meter flaming front, which is equal to kJ/m/s. We therefore think that units in the manuscript are correct.

Line 173: I don't quite understand here why you used all these different CO_2 scenarios, or why you'd expect the vegetation to -not- be at equilibrium with constant forcing? Is it about cycling or oscillations in the intrinsic dynamics of the model?

RESPONSE: We expect that in transient runs, vegetation is not in equilibrium with the environment (i.e. CO2) because exposure to these CO2 levels is not long enough to allow vegetation to reach equilibrium. We therefore require all the equilibrium simulations for different CO2 levels that are transgressed during transient simulations, to determine the deviance between vegetation states at transient vs equilibrium runs. In equilibrium runs, we do expect that vegetation is in equilibrium with constant forcing. This also includes equilibrium states where state variables oscillate regularly, e.g., due to fire impacts. The different CO2 scenarios with constant CO2 forcing are required to identify equilibrium vegetation states for a variety of constant environmental (i.e. CO2) conditions. In addition, we simulated transient scenarios with increasing and decreasing CO2 and different rates of change. We will carefully check and reword the text to make clear why we require all these simulations.

L178: Why was a smoothing algorithm needed? To smooth over stochastic outputs?

RESPONSE: Simulations for equilibrium conditions were only conducted for a set of CO2 concentrations (100ppm, 150ppm, 200ppm, . . ., 1000ppm). In contrast, transient simulations provide model results for a much higher resolution of CO2 levels between 100ppm and 1000ppm (depending on the rate of change of CO2). To be able to calculate differences between transient and equilibrium vegetation states for the entire CO2 gradient, we not only need values at 100, 150, 200ppm, . . . in equilibrium simulations, but also values in between. Therefore, we applied the smoothing algorithm. In addition, as mentioned by the referee, smoothing also reduces stochasticity in model outputs. We will reword the text to clarify why we apply smoothing.

L218: Were there 200 replicates for all runs, or just for the study site in SA? (and if so, why?)

RESPONSE: The 200 replicates were only done for the study site, but not for

continental-scale simulations. We conducted replicate runs because processes such as fire occurrence or demographic processes are stochastic in aDGVM. Averaging across these replicates allows us to reduce stochasticity and to obtain more robust responses of various state variables. For continental-scale simulations, we typically consider responses for different biomes, i.e., we average over space. Replicate simulation runs were therefore not conducted. We will reword the methods to make clear that and why we only conducted one run for continental-scale simulations.

L250: I really like this figure. . ..Can you make it so that the text doesn't overlap the orange lines?

RESPONSE: We will modify Fig 4 to avoid overlap between text and lines, and we will also check other figures to avoid overlap.

L275: Why does fire slow down the transition? Is it because systems are stuck in stable equilibria one way or another?

RESPONSE: Yes, we argue in the discussion that fire prevents vegetation transitions and keeps vegetation in the fire-driven state. We will also include a short explanation in the results section: 'Increased lag size in the presence of fire can be attributed to hysteresis effects. High fire activity traps vegetation in a fire-driven state and prevents biome transitions into alternative vegetation states.'

L285: The terminology of 'debt' is slightly confusing to me, especially as the quantities of 'debt' are negative. Does that mean there is negative debt? And to whom is the debt owed? The atmosphere or the ecosystem? I guess a negative carbon debt is a promise that the system will take up more CO2 in the future?

RESPONSE: Debt refers to carbon storage potential of vegetation that has not been realized yet. It indicates that vegetation has the potential to sequester more carbon under given CO2 levels than transient simulation suggest. The potential carbon storage for given CO2 is defined by the equilibrium simulations. In figures, we plotted debt with negative values to clearly distinguish from surplus (Fig A2) and to make clear that vegetation is committed to substantial changes even if the climate system stabilizes. We will carefully revise the definition of carbon debt in the revision (in sec. 3.4) to make clear that 'we define debt is carbon storage potential that has not been realized yet, and that the atmosphere owes to vegetation'. We prefer to keep the negative sign to make clear that potential carbon and tree cover exceed carbon and tree cover in transient runs.

L315: I'm tripped up again by the use of 'typically'... Do you mean in the transient simulations? By implication in the real world? Also technically I guess this is a prediction, rather than an illustration, so many change 'show' to something less forceful.

RESPONSE: Yes, we mean that vegetation in transient simulations is not in equilibrium. We will reword to avoid 'typically' and state 'Using a dynamic vegetation model, we predict that vegetation exposed to transient environmental forcing is not in equilibrium with environmental conditions . . .'. In the discussion, we also provide references reporting lag effects in empirical experiments.

L320: Also change 'previous findings' to 'previous model results' or suchlike.

RESPONSE: We will reword as suggested.

L325: I feel like this section is missing a statement on what, if any, other studies have had to say on this topic, for Africa or elsewhere. Or indeed, is this type of analysis totally novel?

RESPONSE: The aim of this paragraph is to put the results presented in this study into the context of previous aDGVM studies and highlight the novelty within the 'aDGVM world'. Yet, we discuss the novel results in the context of previous studies in later sections of the discussion. We therefore prefer to keep this section focused on aDGVM. Yet we will carefully reword the section to make clear that it only refers to aDGVM results.

L328: This justification for why the fire runs have greater lags should perhaps come earlier in the manuscript.

RESPONSE: We will add an explanation why fire increases lags in the results. See also our response to comments regarding L275.

L358: This needs a little more clarification. I.e. "(the strong CO_2 effect) can compensate for other predicted changes in climate drivers, e.g. reduced rainfall"

RESPONSE: We will reword as suggested.

L357: Maybe expand on what a high CO_2 sensitiviy might mean for the results of this paper?

RESPONSE: We will check the manuscript carefully to ensure that implications are highlighted sufficiently. In particular, we will add 'If aDGVM overestimates CO_2 sensitivity of vegetation, the size of carbon debt due to lag effects may be overestimated, while the duration of lags may be underestimated if simulated response to changing CO_2 is more sensitive than in reality. We are however confident that even with reduced CO_2 sensitivity the overall response pattern would remain rubust, although the quantities might change.'

L385: change to :prevents both savanna and forest trees recruitment"

RESPONSE: We will reword this statement (in response to referee 3): "Fire rarely occurs in simulated forests, and therefore they reach equilibrium faster than other biome types. Fire activity in forests is sufficient to slightly increase times to reach equilibrium in comparison to simulations with fire suppressed."

L398: Need a reference for 'as is currently often the case'.

RESPONSE: We will delete 'as is currently often the case', because this statement is very bold.

L420: Would it make sense to frame the carbon debt here in terms of the overall carbon budgets of the different RCPs? For example, if emissions stabilises at the end of RCPxx, then the ecosystems would continue to keep absorbing carbon to get to their equilibrium ecosystem state and re-absorb xx PgC from the system?

RESPONSE: Good suggestion, we will reword and reframe the paragraph as suggested.

L439: I don't really understand this part. How can modifications to the initial climate conditions have an impact on the successional stage? Also, I think it's fairly standard to do pre-industrial spin-up and then transient simulations to the present day. Are you proposing an alternative approach to climate drivers here?

RESPONSE: We argue that initial vegetation states (rather than climate) in the model should agree with successional states of vegetation at the beginning of the transient simulation run. This can for example be achieved by considering land-use history, or by ensuring that vegetation height or age is in agreement with observation and not only variables such biomass, NPP, GPP. An approach using forest height for initialization has for example been adopted by Rödig et al. (2017) for initialization of the FORMIND model. We will carefully revise this paragraph to be more specific about the initialization procedures.

Rödig, E, Cuntz, M, Heinke, J, Rammig, A, Huth, A. (2017) Spatial heterogeneity of biomass and forest structure of the Amazon rain forest: Linking remote sensing, forest modelling and field inventory. Global Ecol Biogeogr. 26: 1292– 1302.

L444: Further, given that we need to run transient simulations with ramping CO2, that is slightly at odds with initializing with contemporary observations.

RESPONSE: We don't see a contradiction here, because initialization can also consider transient simulations. For example one could use simulated and observed time-series of LAI or NDVI for model benchmarking. Such benchmarking would require the use of transient climate and CO2 forcing.

L474: Maybe cite Julia Nabels work with TREEMIG as illustrative of the complexities of the implementation of seed dispersal?

RESPONSE: We will cite the Nabel et al. (2013) Ecological Modelling paper.

L500: Again, I'd argue that it 'predicts' or 'projects' or 'indicates', but perhaps not that it 'shows'.

RESPONSE: As suggested, we will replace 'shows' in the Conclusions.

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