

Author's response to reviewer comments:

“Including vegetation dynamics in an atmospheric chemistry-enabled GCM: Linking LPJ-GUESS (v4.0) with EMAC modelling system (v2.53)”

by

Matthew Forrest et al.

(Third round of revisions)

Once again, we thank the reviewer taking the time to review the revised version of our manuscript. As before we reproduce the reviewers' comments in full and address them in turn, the reviewers' comments are in black, our responses are in [blue](#). We include proposed alterations to the manuscript to address the reviewers concerns in [green](#).

Apologies for the amount of time it has taken to do this review. I did warn the editors that it would take a while, but I'm not sure any of us realised quite how long.

The authors have made detailed and convincing responses to my initial review and have made extensive revisions to the m/s. I won't go over there responses unless it related to changes still required to the m/s, but I would like to point out that they really were very good. In the paper itself, the authors do a much better job of explaining the motivation of the work, the model setup and evaluation methods and how their results link to future development priorities. The introduction could still be slightly clearer on what is actual is being turned on and evaluated in the model (covered minor comments) , I am still not completely satisfied with the author response and changes with regard to scale dependency of the land surface, and I think there is a slight mismatch between some of the figures and text which might need a bit of clearing up. But these should only require slight changes to the manuscript, so I have marked this up as minor revisions.

There are also a few small corrections and specific comments.

Goodluck with future model development and (potential) CMIP7 involvement!

[We are pleased that the reviewer is generally content with the revisions and will address the outstanding points below.](#)

Small but not quite minor comments

Land surface resolution dependence

From the author's response:

There is no inter-gridcell communication in LPJ-GUESS (ie it can be considered as a 'site model' that simulates an arbitrary list of sites) so spatial resolution does not directly affect the processes.

You do not need inter-gridcell communication for resolution effects to be important. Many of the processes simulated by LPJ-GUESS are extremely non-linear, so simply aggregating inputs over larger scales could affect the quality of performance of LPJ-GUESS, even if using a fantastic coarse resolution model or perfect observational driving data. In fact the authors make this very point when considering likely changes in scores expected at different resolution due to homogenization of LPJ-GUESS output and observations on page 20, lines 14-16.

An example I think some of the authors might know about is fire - on fine scales you would need a model that includes fine scale processes (rate of spread etc), whereas on a coarse resolution, rate of spread becomes less important and a control based model (such as BLAZE suggested towards the end) is much easier to parameterize for broadscale controls (Burton, 2019). Soils are perhaps another example, and I think somewhere buried in soil is information on the impact of averaging soils on model hydrology.

Understood (finally!). Although it could be argued that spatial resolution affects the processes *indirectly* via its effects on the input data rather than processes themselves. But yes, the point is most definitely taken.

However, in the revised m/s, there are not only a couple of instances where this is a potential problem, but these should either be changed or removed. Specifically:
Page 3 line 31: The processes could also be resolution dependent.

Here we assume the reviewer is referring to the processes missing from LPJ-GUESS. This is potentially true, but as these processes are missing from the model, their potential resolution-dependence does not affect the analysis here, so we see no need to modify the text.

Page 6, line 26-29: two sentences starting with "As LPJ-GUESS..." The logic here is probably wrong. But the extra resolution in the revised m/s, and climate plots in the appendix, probably provide the tools you need to attribute between climate biases and climate aggregating. And I **think** it will read okay if you add "...(*i.e.* climate biases **or climate aggregating**)" at the end.

Here we propose to change the text highlighted by the reviewer to:

"As LPJ-GUESS has no inter-gridcell interactions and no processes are gridcell size/spacing dependent, it has no direct sensitivity to the spatial resolution at which it is run. However, in the coupled setup, LPJ-GUESS will be sensitive to spatial resolution via the climate data received from EMAC. Thus, the changes in the vegetation produced by the EMAC-coupled simulations at different resolution can only be due to changes in the EMAC produced climate (*i.e.* altered climate biases or climate aggregating). "

Page 13, line 15/16: "*indicating that this discrepancy is caused by biases in the EMAC climate at low resolution.*" If you can demonstrate this by examination of the climate plots in the appendix, then this is fine. If not, add the caveat about climate averaging again. I **think** you manage this a couple of sentences later so it might just involve some rearranging of these few sentences.

Yes indeed, the sentence later explains with is terms of climate biases. We have re-arranged the text so that it now reads:

“This is most apparent for the lowest resolution (T42) EMAC simulation but improves with increasing spatial resolution, with the T63 simulation being better substantially than T42. The EMAC simulation with the highest spatial resolution (T85) showed only a small tendency to underestimate high latitude vegetation, to a similar degree as the offline CRUNCEP simulation. Examination of the climate bias plots for temperature and radiation (Figs B2 and B3) reveals a high-latitude growing season low temperature bias and low plant available radiation bias at low resolution. This was somewhat mitigated at higher resolution as would be expected due to a better representation of the synoptic scale systems in T63 and T85 (Roeckner et al., 2006). Correspondingly, the GPP simulated in this area (Fig. 3) confirms this by revealing a broad tendency to underestimate GPP above 50° N in the T42 simulation. This tendency lessens at higher resolution and is not seen in the offline CRUNCEP simulation. The consequences of this high-latitude underestimation of productivity at lower resolutions are also visible when comparing to observed tree cover (Fig. 4), biomass (Fig. 5) and canopy height (Fig. 6), showing that this issue affected both forested and non-forested vegetation types.”

That's all I can spot. Other instances, Page 13, line 19/20 , for example, are fine as you have backed it up with previous assessment of climate simulation at different resolutions.

Biome and tree cover bias attribution

Specifically page 12, line 24-26.

Temperate tree cover in the EMAC simulations actually look more extensive than observations in Figure 4, though still less than the CRUNCEP simulations (Fig 4). This first sentence should be rewritten to make this clear. GPP does look slightly less than obs in some regions (Fig 3), but the difference between CRUNCEP and EMAC GPP is a lot more clear cut, so maybe use that again.

The point here was to discuss temperate forest vegetation zone (in terms of potential natural vegetation) rather than tree cover (where the observations include extensive deforestation), so our reference to Fig 4 in that first sentence was slightly misleading and wasn't meant to imply comparison to the tree cover observation. We have removed it. We have also added the following sentence to correctly discuss tree cover in this context:

“This underestimation led to reduced tree cover in the EMAC simulations compared to the CRUNCEP simulation (Fig. 4) and hence reduced temperate forest extent.”

Minor/specific comments

Page 1 line 7: The sentence starting “The LPJ-GUESS...” should provide a bit more detail about the processes that have been enabled and evaluated in this study. Something at the level of detail as the lines of the next sentence, which lists things not enabled.

Yes, this is helpful information to provide in the abstract. The text now reads:

“The LPJ-GUESS framework is based on ecophysiological processes, such as photosynthesis, plant and soil respiration, ecosystem carbon, nitrogen and water cycling and includes a comparatively detailed individual-based representation of resource competition, plant growth and vegetation dynamics as well as fire disturbance. Although not enabled here, the

model framework also includes crop and managed-land scheme, a representation of arctic methane and permafrost, and a choice of fire models; and hence represents...”

Page 1, line 17: replace the average NME score with all three scores. Averaging across benchmarks is a bit of a controversial issue (see (Blyth et al., 2010; Kelley et al., 2013; Randerson et al., 2009)), so is best avoided seeing. There’s only 3 numbers you’d need to quote so that should be fine in the abstract.

The given references don’t appear to argue against naively averaging *normalised* benchmarking metrics. However, there is no reason not to quote all the numbers as suggested so that is done in the revised manuscript. The new sentences in the abstract now read:

“The highest resolution simulation gave NME scores of 0.63, 0.66, 0.84 and 0.53 for tree cover, biomass, canopy height and GPP respectively (after correcting tree cover and biomass for human-caused deforestation which was not present in the simulations). These scores are just 4% worse on average than an offline LPJ-GUESS simulation using observed climate data and corrected for deforestation by the same method.”

Page 2, line 10: remove “simulations”

Done.

Page 2, line 20-21: mentioning fire and phosphorous here makes it sound like your going to include them in the model. Both are future developments though (I know GlobFIRMs in the model, but you later point out that this needs replacement). So I’d leave them out of the introduction and just provide a note about how important they are in the discussion (either future work or conclusions).

We have removed those mention sof fire and phosphorous. Fire is already discussed explicitly in the future work section and for phosphorous we have added the follow senrence to the future work section (end of third paragraph):

“A potential longer-term aim is to include a representation of the phosphorus cycle which strongly limits terrestrial productivity (Elser et al.,2007) and is currently in development for LPJ-GUESS.”

New reference:

Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., and Smith, J. E.: Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems, *Ecology Letters*, 10, 1135–1142, <https://doi.org/10.1111/j.1461-0248.2007.01113.x>, <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1461-0248.2007.01113.x>, 2007.

Page 3, line 1: It seems like there’s an “in” missing. I.e., “has already been used **in** both a global ESM”. Or maybe it’s “has already been used **both in** a global ESM”. (My grammar isn’t great).

Yes, we changed it to the first variant (although I think both are correct).

Page 3, line 15: replace “both” with “all” (there are more than two ESM components and each probably claims it’s own community ;)

Yes, in fact we changed it to “continuous development of all components.”, to avoid the discussion of ‘communities’ entirely.

Page 3, line 15: The sentence beginning “When development is complete....” you should mention before this sentence that you are just focussed on one-way coupling.

Yes, for additional clarity we have re-worked the text by bringing some later text to before this and modified the “When development is complete” sentence to read:

“By bringing together these two modelling systems, our intent is to produce a fully-featured ESM which benefits from the continuous development of all components. We plan to follow a step-wise model integration roadmap, whereby the coupling between LPJ-GUESS and EMAC is tightened in well-defined, consecutive steps and processes (such as land use) are included or enabled in a consecutive manner. This will allow us to assess the effects of one model on the other, and the effects of the inclusion of new processes, in a step-wise and logical fashion. For our first step, we have chosen to simulate and evaluate the vegetation produced when LPJ-GUESS is forced by EMAC-simulated climate, ie. a one-way coupling without the feedback from the land surface to the atmosphere.

Upon completion of the full model integration process (including bidirectional coupling which is not presented here), the trace gas emissions from LPJ-GUESS will form key inputs to the atmospheric chemistry representations in EMAC allowing...”

Page 3, line 17: “Then the full model will become a powerful tool”, slightly more cautionary language would be better. Maybe replace “will” with “should” or “We aim for the full model to become....”

Yes, we replaced “will” with “should”

Page 5 line 20: add something like “In this study...” at the start of the paragraph, just to make it clear that you are inputting on a daily timestep for this study, rather than the monthly timestep mentioned in the following sentence

Since LPJ-GUESS *always* works on a daily time step for these processes we prefer not to make this alteration as it is actually misleading. The following sentence refers to input data (not process time-step).

Page 5 line 22: Sentence starting “In these circumstances...” Does the disaggregator involve some stochastic implementation as well? If so, say so, and as you have an extra stochastic process, maybe move the two sentences starting “All stochastic processes ...” on line 12 to a new paragraph just before 2.1.3. If not, don’t worry.

Yes, it does have a stochastic component so we have moved the text as suggested.

Page 6 line 6/7: Sentence starting “However in both these cases...” where does the soil moisture come from in this study? Was it simulated in LPJ-GUESS?

Yes, it was simulated in LPJ-GUESS. We changed the text to read:

“However in both these cases, daily soil moisture from the land surface model was also used to drive LPJ-GUESS (in this implementation LPJ-GUESS's internally calculated soil moisture was used).”

Page 6, line 29: Should “T63” now be replaced with “T89”?

The definition of “finer” spatial resolution is admittedly somewhat arbitrary but since T63 does show improvements compared to T42 we believe that the sentence is still factually correct so prefer to keep it as is.

Page 7 line 5: Should “1990-1990” be “1990-1999”?

Yes, changed.

Page 8, line 25: Figure 1 in the author responses is a good way of showing that the parts of the model being accessed here is in equilibrium -potentially quiet important to demonstrate given the short spin up time. The authors may want to consider including it as a supplement or appendix figures?

Yes, this is a nice idea. These plots are now included as an additional appendix with the additional text:

“The net ecosystem change plots shown in Figure B1 display no systematic variation from zero in either space or time indicating that the vegetation from LPJ-GUESS is in equilibrium with the climate from EMAC. The small variations from zero that are visible are due to the stochastic processes in LPJ-GUESS and internal climate variability in EMAC.”

Page 8 line 16: should there be an “a” before “function”?

Yes, corrected.

Page 14, line 4: refer to figure 3 and 4. Also, I’m not sure I see the overestimation of either GPP or biomass. Maybe there is some work needed on the colour bar of figures 3 and 4?

References added. Regarding the colour bars, this is more obvious in the original plots, it would appear some clarity is lost when they are included in the .pdf. We will ensure they are correctly rendered in the final document at the proofing stage.

Page 14 line 22/23: “low competitiveness of grass PFTs vs tree PFTs” could also be due to other processes affecting competition, and not just fire frequency? E.g soil moisture, simplistic soil depth, drought response, PFT heretical setup, establishment rates etc. And I don’t think you’ve offered evidence to suggest that it is caused fire frequency or why fire frequency should be singled out?

Yes, as no evidence is offered this is entirely speculative so we will simply remove the text in the parentheses referring specifically to fire frequency.

Page 14 line 26-28: I’m not sure I follow this. It sounds like NME scores in this study are comparable to scores in Kelley et al. 2013, which the text implies included LPJ-GUESS? A pre-GUESS version of LPJ was used in Kelley et al. 2013, so if I read this correctly, then the sentence needs adapting. If I didn’t read this correctly, the sentence could do with some clarification.

In Kelley et al. 2013 a different model from the LPJ ‘family’ was used, and from the sentence structure we can see how confusion could arise. We propose to replace the text “including LPJ-GUESS (Table 1).” with the following sentence text:

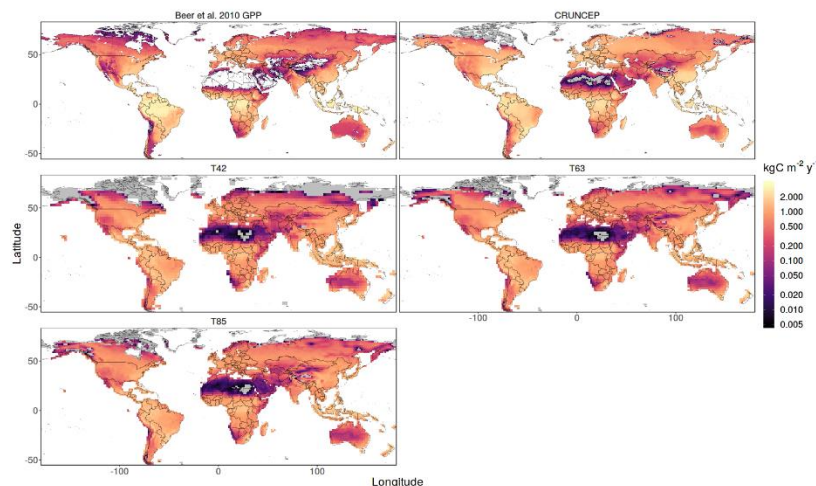
“and the offline *CRUNCEP* LPJ-GUESS simulations performed in this study (Table 1)”

Page 14, lines 30 - Page 19 line 3: It feels like this couple of sentences should be moved up to just after the first sentence of this section.

As this text is in the combined Results and Discussion section, we prefer to leave the ordering as is, i.e. first introducing the results and then discussing their context and caveats.

Page 15, Figure 3: The colour scale on the top 5 figures could be altered (i.e not linear) to make spatial patterns of GPP in EMAC maps clearer.

Yes, we have logged the scale and reversed the colour palette which improves definition a little bit and include this revised figure in the manuscript:



We have also added the following text to figure caption:

“In the upper panel the colour scale in has been log-transformed and grey areas denote GPP values less than 5 gC m^{-2} .”

Page 19, line 4: The sentence starting “In summary” feels better places at the end of the section after discussion of metric scores accounting for land use, or maybe even removed as this is covered in the discussion.

Yes, we have moved this to the end of the following section after the metric scores accounting for land use have been discussed.

Page 19, line 21: You’ll have to explain a bit better how the sentence before suggests that the disturbance rate in particular needs re-evaluating.

Yes, we have modified the sentence to read:

As LPJ-GUESS biomass has been shown to be sensitive to disturbance rates (Hickler et al. 2004, Pugh et al. 2019.), the average global patch-destroying disturbance rate of 0.01 yr^{-1} could be re-evaluated and the rather simplistic mortality could be further developed in LPJ-GUESS.

References:

Hickler, T., Smith, B., Sykes, M. T., Davis, M. B., Sugita, S., and Walker, K.: Using a Generalized Vegetation Model to Simulate Vegetation Dynamics in Northeastern Usa, *Ecology*, 85, 519–530, <https://doi.org/10.1890/02-0344>, <http://onlinelibrary.wiley.com/doi/10.1890/02-0344/abstract>, 2004.

Pugh, T. A. M., Arneth, A., Kautz, M., Poulter, B., and Smith, B.: Important role of forest disturbances in the global biomass turnover and carbon sinks, *Nature Geoscience*, 12, 730–735, <https://doi.org/10.1038/s41561-019-0427-2>, <https://www.nature.com/articles/s41561-019-0427-2>, 2019.

Page 20, line 31: I think there's an "and" missing in "... fluxes), **and** to form..."
Grammatically speaking there is no need for an "and" there as that would imply the three clauses are a list but they are not intended to be. In fact, a better modification to the sentence is to remove both the commas, which we have done.

Page 21 line 14: I think it is worth briefly explaining why BLAZE was selected, rather than another model such as SPITFIRE or a re-parameterised GLOBFIRM.
This decision was not ours to make, and (although we could speculate) we feel it would be more appropriate that the responsible people discuss their reasoning in a publication focussing on the implementation of BLAZE within LPJ-GUESS.

Page 22 line 26: replace "will" with "should"
Yes, see below.

Page 23 line 6: "A future publication will present..." should be replaced with something like "Future development should focus on...", so as not to pre-empt what journals might publish.
Yes. Sentence changed to,
"Future development should focus on completing the two-way model coupling and investigate the effects of the atmosphere."

Page 23 line 8 onwards: That's quite a nice way to finish.
Thank you.

Page 27, Figure B1: Swap the colours around so blue means more precip.
Whilst we can understand the logic here for precipitation, in all other difference plots in the paper red means more and blue means less, so we prefer to keep consistency within the manuscript.

Page 29, Figure B3 caption. I'm not sure I understand, particularly the sentence starting "Note that these plots compare shows the radiation available..". Are all plots adjusted by 0.17? And what is meant by "adjusted"
Yes, the wording here is not clear. Only the CRUNCEP offline radiation values were adjusted by 0.17. And adjusted simply mean "apply albedo value". We have rephrased to:
"The CRUNCEP gross shortwave flux has had the standard LPJ albedo value of 0.17 applied (temporally and spatially invariant), and the EMAC gross shortwave flux has had the spatially and temporally varying albedo values in the land surface scheme applied."

References

Blyth, E., Gash, J., Lloyd, A., Pryor, M., Weedon, G. P. and Shuttleworth, J.: Evaluating the JULES Land Surface Model Energy Fluxes Using FLUXNET Data, *J. Hydrometeorol.*, 11(2), 509–519, 2010.

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