Reviewer #1:

The TREED model is a vegetation model designed to simulate global vegetation dynamics and biodiversity potential outputting GPP, NPP, evapotranspiration, average plant height, below, and above ground biomass storage. These variables are simulated on an average grid point bases by applying eco-evolutionary optimality principles. The plants in the model adapt to maximize fitness under a steady state or transient climates. Evolving the plants to maximize their fitness lets TREED simulate average plant traits in the grid point without making assumptions with regards to the climate niche. This framework offers a method for understanding how biological systems reorganize during different climates.

The paper is well written and explains the technical parts of the paper in detail. The authors have taken the time to go over all the equations used in the model and describe how and why they are implemented. The paper can benefit from more Thurow evaluation to show where the limitations are, please see comments below. In addition, the authors have carefully provided a limited sensitivity study appropriate for this paper. I hope to see a follow up sensitivity study further exploring the trait evolutions of the plants in different paleo climates, but this would be too much for this paper. I have some minor comments and recommend this paper for publication:

We thank the reviewer for taking the time to evaluate our manuscript, the positive feedback and the constructive comments, which have helped to clarify the manuscript and the purpose of the TREED vegetation model.

Line 178: I think “ration” should be “ratio”

Corrected.

Table 1: would it be possible to add citations for the values (where applicable) or an indicator, something like “this study” for where you have made your own estimates. In addition, an indicator for the sensitivity level? I understand that this might be subjective at the moment and needs to be further investigated but as a potential user of this model that would help assess if I can/should/want/need to change this value or not.

We have extended Table 1 in line with the reviewer’s comments. We now include a column including references for all used parameters. Most of the values were adopted from other dynamic vegetation models (particularly from the LPJ model family; Schaphoff et al. 2018, Sitch et al. 2003). The parameters describing allometric relationships were calibrated in this study as now explained on L223-226. Regarding sensitivity levels, we now indicate parameters in bold for which we expect the model reaction to be particularly sensitive, following the sensitivity studies from Oberpriller et al. 2022 and Pappas et al. 2013 conducted for the LPJ vegetation model family from which the photosynthesis and respiration physiology, as well as the allometric equations were adopted.

Schaphoff et al., LPJmL4 – a dynamic global vegetation model with managed land – Part 1: Model description, Geosci. Model Dev., 11, 1343–1375, https://doi.org/10.5194/gmd-11-1343-2018, 2018

Sitch et al. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Global Change Biology, 25, 2003.

Oberpriller et al. Climate and parameter sensitivity and induced uncertainties in carbon stock projections for European forests (using LPJ-GUESS 4.0), Geosci. Model Dev., 15, 6495–6519, https://doi.org/10.5194/gmd-15-6495-2022, 2022.

Pappas et al. Sensitivity analysis of a process-based ecosystem model: Pinpointing parameterization and structural issues, JGR Biogeosciences, 118, 505–528, https://doi.org/10.1002/jgrg.20035, 2013.

I think “fumeroot” should be “fine root” and “Rubisco specifity” should be “Rubisco specificity”

Thank you - corrected accordingly.

Section 5.3: Please expand this analysis to include a more regional evaluation of where the model does well vs. where the model is lacking. In addition, the reasons given for the mismatched between the model and data are too brought and should be more mechanism specific where possible. For example, “Reduced height growth under high NPP levels indicates carbon turnover processes that are not currently represented in TREED and its height optimization.” Which processes are not represented and how does this effect the model? Is this region specific or a global problem? Do this for all three variables, NPP, GPP, and AET. This will help understand when the model is appropriate to use and the model limitations.

We have extended the regional analysis of the model biases. Particularly, we have now included a spatial bias plot for GPP, NPP, AET, H, AGB, and BGB in figures 3 and 5, clarifying regional differences in model performance. We have also extended the regional bias discussion in the text for carbon and water fluxes (L572-593) and carbon storage (L606-630). We clarify main limitations, including that the limited temporal resolution of the model (monthly) likely does not capture non-linear productivity dynamics in regions with pronounced changes in temperature and water availability, for example in the subtropics or savannah climates. For height and biomass carbon storage, we clarify which carbon turnover processes may play a role that are currently not represented, for example environmental disturbances due to fires, heat or cold spells that could increase mortality and increase annual carbon turnover or carbon investments into biotic interactions.

Figure 7: A contour plot will work better here showing the density of the points

Changed accordingly (now Figure 6).

Figure 8c: Please use a density plot here

Changed accordingly (now Figure 7c).

Figure 8d: Try to see if a density plot works, it might not because of the

Here, we did not apply a density plot due to the low density of observations.

Figure 11: What alphas and dispersal rates are used? (Add numbers to slow, fast, and intermediate)

We have added the respective information in the plot (now Figure 10a).

Section 7: It would be nice to add a section on model limitations. Several limitations are already stated in the appropriate sections however, I think the paper can benefit to list them again and address them in a more systematic way.

We have revised the discussion section following the reviewer’s suggestion. From the previous version we have kept three sections focusing on the main functionalities of the model, including the modelling of carbon fluxes and vegetation traits (7.1), the application of the model using eco-evolutionary adaptation dynamics (7.2), and the modelling of biodiversity dynamics

(7.3), including a discussion of important limitations for each functionality separately. We have now introduced and extended an additional section (7.4) summarising the main limitations of the model and combined it with an outlook of future developments that may address some of these limitations (L901-935).

Section 9: Please add the GitHub tag (or release name) also in the text, this makes it easier to check out the specific version

We have included a github release tag (Release TREED v1.0) in the code availability section (L953).

Reviewer #2:

The manuscript '*TREED (v1.0): a trait- and optimality-based eco-evolutionary vegetation model for the deep past and the present*' by Rogger et al. presents a description of a numerical, grid-based model to simulate trait-based vegetation dynamics and associated carbon-water fluxes, either in steady-state or transiently in response to environmental perturbation. The majority of the manuscript outlines the model development hence is suitable for publication in GMD. The model performance is evaluated by comparing the modelled carbon fluxes and vegetation traits in a modern climate to observations. Finally, the authors provide examples to demonstrate how the model can be used for paleo applications.

A major advantage of this trait-based model compared to models that simulate many different plant functional types is that it computationally cheap and circumvents the need to make assumptions about vegetation types in paleo-settings that are a large source of uncertainty. This makes the TREED model very suitable for paleoclimate studies. The new implementation of adaptation timescales and rate of evolution makes it especially interesting to study transient global-scale climate events of the past, both in terms of carbon cycle disruption and feedbacks at the onset of an event and also the expected timescales of recovery. Overall, the manuscript is well structured and describes all stages of the model clearly. Readers can easily identify the applied relationships in a transparent way and implemented equations are backed up with sufficient references for traceability. The model output compares well to present-day observations, demonstrating accurate simulation of carbon and water fluxes as well as key traits. Based on the above and added paleoclimate application, I strongly recommend publication in GMD. I only have a few comments or suggestions that could improve clarity in some areas.

We thank the reviewer for the positive evaluation and the constructive comments. We have implemented all of the reviewer's suggestions as detailed below.

General comments/suggestions

Caption Figure 1. A model schematic in my eyes is very important to show model mechanics. Please expand description, e.g. describe difference between square boxes and circles, and which components are model inputs versus outputs. Perhaps in the figure or caption also note time stepping of each component, e.g. is a calculation or action done once, or iteratively as the model runs through time/months and how does this differ between steady state and transient simulations? Also, the 'adaptation' step is optional if I'm correct and is only needed in transient runs. You could clarify the alternative pathway for steady-state simulations by connecting the 'optimisation' and 'key traits' boxes. (I only noticed Figure 3 further down the text. Might be worth combining Figure 1 and 3 into one that describes the whole model structure, inputs versus output, order of actions, and time stepping. Also clarify that -presumably- the '1 year of monthly climate inputs' is updated to new fields in step 2).

As suggested by the reviewer, we have combined the schematic figures on the model structure and time stepping into one (now Figure 1a and b; L139). In the figure and caption we have clarified what are model processes, inputs, and what variables are being tracked in the model. Additionally, we also clarify the two pathways of using the model in steady state mode (continuous arrows) or considering eco-evolutionary adaptation dynamics (dashed arrows).

The evaluation against present-day observations in Section 5 demonstrates the model performance. However, from sections above it is not entirely clear if or how model tuning has been performed beyond "*All allometric constants were calibrated using present-day canopy height and above ground biomass data*". I'd like to know e.g. which parameter values are inherited from previous studies, and which parameters have been tested to find the best match to present-day fields. If tuning was performed, please indicate what evaluation metric(s) have been used to find the best fit and what model vs data fields are compared. Might be resolved by adding an extra column to Table 1 that shows 'source' or parameter value and/or whether it's tuned in this model development and how.

We have extended Table 1, now including a reference to all parameters indicating from where they were adopted and which were defined in this study, including references giving a plausible range for these values. Most of the parameters were adopted from other vegetation models, particularly the LPJ vegetation model family. Regarding the allometric constants that were calibrated in this study, we now clarify on L222-226 that they were calibrated by using observed vegetation height data and allometric equations 5, 6, and 12 and by minimizing the RMSE to observed above-ground biomass density data. The resulting height to above-ground biomass density relationship is illustrated in Figure 6b.

The PETM application is a nice demonstration of how the model can be used for paleo simulations. Considering this is a model development paper, I'd be very interested to see a more extended evaluation of model mechanics that drive the patterns in Figs 10 and 11. It would be a good opportunity to show the effects of e.g. the biotic stress components in the context of climatic niches (Eq.52-55). Any geographical regions that are particularly water- or heat-stressed given certain evolutionary adaptation potentials and rates of dispersal?

We thank the reviewer for this suggestion, which will help to clarify the underlying dynamics to the general reader. We have included an additional figure 11 and section L781-796 describing the spatial dynamics of what limits vegetation productivity following the perturbation. We outline the effects of spatially varying temperature and precipitation changes and how they affect the photosynthetic efficiency by surpassing critical thermal limits and resulting in geographic regions where the vegetation recovery is expected to occur particularly slowly.

For review, I also attempted to run the TREED model but climate input fields are currently not uploaded so I could not verify if the model runs okay or whether results as reported in the manuscript are reproduced. I can, however, confirm that the uploaded code is accessible and includes a readme with sufficient information to run the model.

We thank the reviewer for going through the repository. The climate inputs fields are available on the Zenodo repository under: https://doi.org/10.5281/zenodo.17777279.

Line-by-line comments:

- Line 69-70. "…are fundamentally different from the present, as is the case for most of Earth's past (Judd et al., 2024), or as we expect …"

  Implemented.

- Figure 2. Instead of 'Model' in black, use TREED for clarity.

  Implemented.

- Line 231-232. Needs reference to support 50% of downward SW radiation is photosynthetically active radiation.

  We now include the following citations for this assumption on L245:

  Schaphoff et al., LPJmL4 – a dynamic global vegetation model with managed land – Part 1: Model description, Geosci. Model Dev., 11, 1343–1375, https://doi.org/10.5194/gmd-11-1343-2018, 2018

  Haxeltine, A. and Prentice, I. C.: A General Model for the Light-Use Efficiency of Primary Production, Functional Ecology, 10, 551, https://doi.org/10.2307/2390165, 1996a.

- Line 286-288. Add reference for equation 30.

  We now cite the following citations for equation 30:

  Schaphoff et al., LPJmL4 – a dynamic global vegetation model with managed land – Part 1: Model description, Geosci. Model Dev., 11, 1343–1375, https://doi.org/10.5194/gmd-11-1343-2018, 2018

  Sitch et al., Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Global Change Biology, 9, 161–185, https://doi.org/10.1046/j.1365-2486.2003.00569.x, 2003.

- Line 329 "…using a modified Arrhenius equation that accounts for *declining* respiration rates with temperatures". Should it be '*increasing* respiration rates with temperature'? Equation 39 shows a positive relation between temperature and g.

  Thank you – we corrected the description on L342.

- Figure 4 and 6. Can you add column titles saying 'TREED' and 'Observation' for clarity?

  We added the titles accordingly (now figures 3 and 5).

- Figure 8 caption. (c) Modelled latitudinal distribution…

  Added accordingly (now figure 7).

- Figure 11 caption. Define the 'alpha' again as you did for 'k'

  Added accordingly (now figure 10).

- Line 746. Add a few sentences to clarify how the different scenarios are simulated? Have you used new climate field inputs that correspond to 2, 4, 6, 8°C?

  We have clarified on L766-768 that the climate inputs for modelling the different warming scenarios were derived by simple linear interpolation using the available climate fields at 680 and 1590 ppm CO_2 to an atmospheric CO_2 that approximately correspond to 2, 4, 6, and 8 degrees of land surface warming.