Dear Author,
Thank you for your revised manuscript submission to ESD. The revised manuscript has been assessed by two reviewers. They note the potential value of the analysis, but have also requested major revisions; these include further clarification on aspects of the analysis, and changes in the presentation of your results and conclusions. Please address all their comments in your response, especially the reviewer comments on (i) the suitability of a simple 0-D model to provide quantitative analysis of the carbon budget, (ii) the request for further uncertainty analyses to strengthen your conclusions.

Reviewer 3

The study addresses a question of differing model-structures and their implications on forecasts of the global carbon cycle. The challenge of quantifying and resolving structural uncertainty has been largely ignored, with the implicit assumption of adding more detail makes a model better, which often not true. So on that basis I welcome this study and its results as they could provide an easy way of directing attention onto an important issue as a 'call to arms'.

I like to thank the reviewer for a carefully reading the manuscript and for a detailed review. This discussion is very useful and led to a further improvement of the manuscript. I will answer in detail below and track changes in a separate document.

However, the manuscript as written leaves many appropriate caveats which sets the context of the study to the final paragraph of the discussion. That leaves the introduction with the narrative of the Michaelis-Menten approach being more realistic (e.g. L57), but no empirical evidence of this at the scale of the model is given. This is also implied by the title of the article.

Thank you very much for this comment. Indeed, we usually discuss from the point of view of the process level, that MMK should be the more valid approach because the underlying biochemical reactions are enzymatic. However, both FOK and MMK come with assumptions at the landscape scale and hence it remains unclear, which approach is more valid at this large scale. I have addressed this very clearly in the discussion section, but I see that I used unbalanced sentences in the introduction section. Therefore, I rewrote the introduction section accordingly. See LThe idea of the paper is not to demonstrate that one of the approaches is more suited but to show the related structural uncertainty.

Similarly, the result and discussion are written from the perspective of differences between approaches as themselves of value rather than the size of difference in context of the GCB.

This is a very valid point. The idea of this paper is not to per se quantify carbon budgets or feedbacks. For this, an ESM is the valid tool. I only want to address the structural uncertainty that we face in the current models, when using either of the two approaches. Still, to demonstrate this uncertainty we need to see quantitative differences between the approaches and discuss them (see also discussion round 1 with reviewer #2). Please, see changes in abstract, discussion, and conclusion sections in which I focus more on the qualitative difference now.

Think the study would be best used to quantification of how large structural uncertainty can be and should be presented more in that light, e.g. that the structural uncertainty of this 1 component is potentially equal to a nearly years GPP, or greater than 1 years heterotrophic respiration.

I agree and compared the difference in the remaining C budgets for example with projected C release from permafrost ecosystems or other underrepresented feedbacks. I advance this discussion by also comparing the ca 100 PgC difference in the remaining C budget under SSP2-45 with a one year GPP or respiration flux (130 PgC), see L296.

Some minor comments on the text:
1) The calibration of both models to the same contemporary observations should be clearer. Some quantification of their ability to fit the contemporary period would also be interesting. In Figure 3 the results of the MMK appear to be diverging, to what extent these are still consistent with independent estimates would be useful.

This topic has been also discussed in the first round of reviews and led to a revised calibration of the MMK model parameters. As written in section 2.1, the FOK parameters are usually taken from Lade et al. (2018) but adjusted accordingly because I improved the terrestrial C equation. The tuning parameters lambda and alpha have been adjusted in order to represent pre-industrial C budgets and temperature trends. However, the focus of the paper is a comparison of FOK and MMK model results, there is no need to exactly match historical observation-based estimates (interannual variability is anyhow not possible). What is important here, is to find MMK parameters for which both models show similar pre-industrial results because we want to analyse feedback differences. For this, I explained in section 2.1 that I used a gradient decent method to optimize MMK parameters accordingly, because these parameters are most unclear and could not taken from literature. After 1950 we see the climate change signal and hence already FOK and MMK deviations.

2) That the study is mixing autotrophic and heterotrophic respiration, even though their dependences and links to total C are different. This again links back to the need to make clear that the results are illustrative not to be interpreted.

I agree, the model is simplified such that both respiration components are lumped together into one ecosystem respiration process. Related limitations are clearly discussed in L301 and following. I add here this point of only looking at one total respiration in L302.

3) The implicit assumptions of the two models could be clearer. FOK assumes that microbial pool will continue to grow thus maintaining a decomposition, where MMK assumes that the microbial pool remains unchanged. Both of these extremes are probably unrealistic.

Thank you very much for this hint, which improves the introduction section. See new L57-58 and L63.

4) Consider introducing more of the information from L292-311 earlier in the manuscript to support the narrative of structural uncertainty is important but that this is illustrative.

I would like to avoid repeating discussion section content in the introduction section, but I agree with the reviewer that we should have a hint on the model limitations upfront, see new lines L84-87 in the introduction section.

Reviewer 4

Beer presents an analysis of the carbon-climate feedback using two different formulations (first order kinetics, FOK, vs Michaelis-Menten kinetics, MMK) for calculating the terrestrial ecosystem respiration in a simple simple analytical global carbon cycle - climate model.

The value in this study lies in the qualitative understanding of the resulting differences in the feedback factor when using the different mathematical formulations. However, Beer presents a quantitative analysis suggesting that the terrestrial carbon-climate feedback doubles when assuming Michaelis-Menten kinetics. He concludes that the remaining carbon budget to keep global warming below 2°C is 66-113 Pg C higher when using MMK compared to FOK.

I would like to thank this reviewer for reading the manuscript in detail and for all the valuable comments which helped to further improve the paper. Thanks for seeing the value of the study. The idea is indeed to show qualitative effects and do not interpret exact numbers, hence orders of magnitudes are discussed in the paper. We also need to calculate some numbers in order to give such qualitative conclusions – that is for what the simple model is about. I went through abstract, discussion and conclusions again to make this more clear.

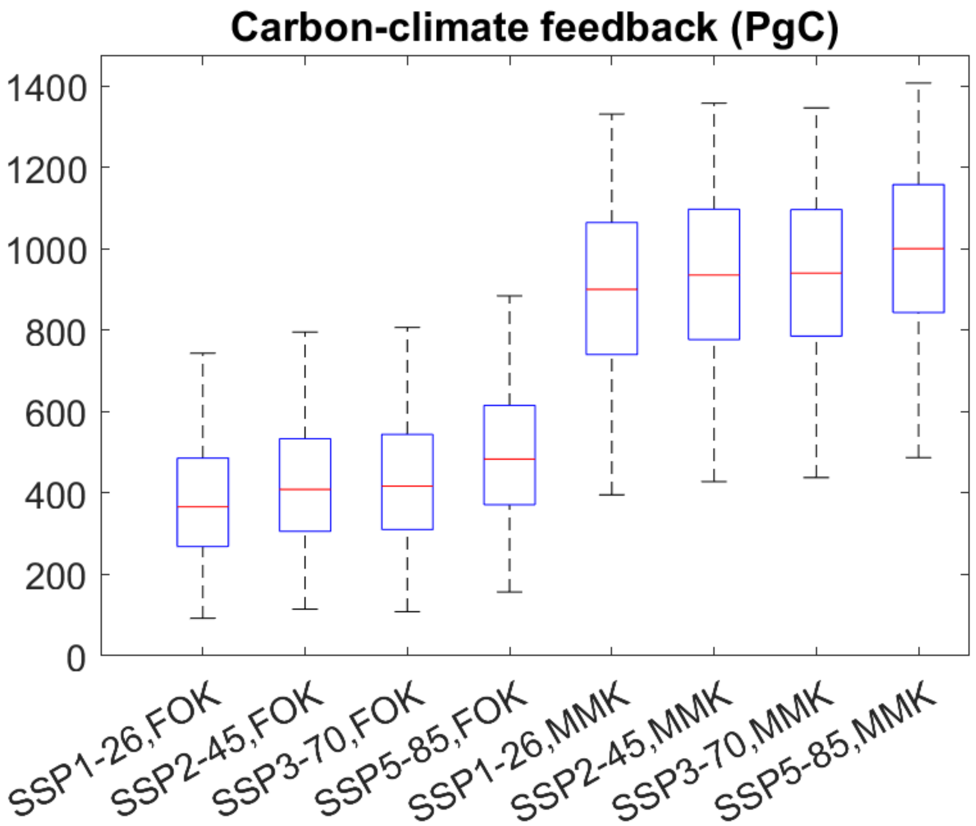
These figures are derived from a simple, 0-dimensional model and are presented without any uncertainty analysis. My first concern is whether such a simple model is suitable to perform a quantitive analysis of the remaining carbon budget when using a different respiration formulation.

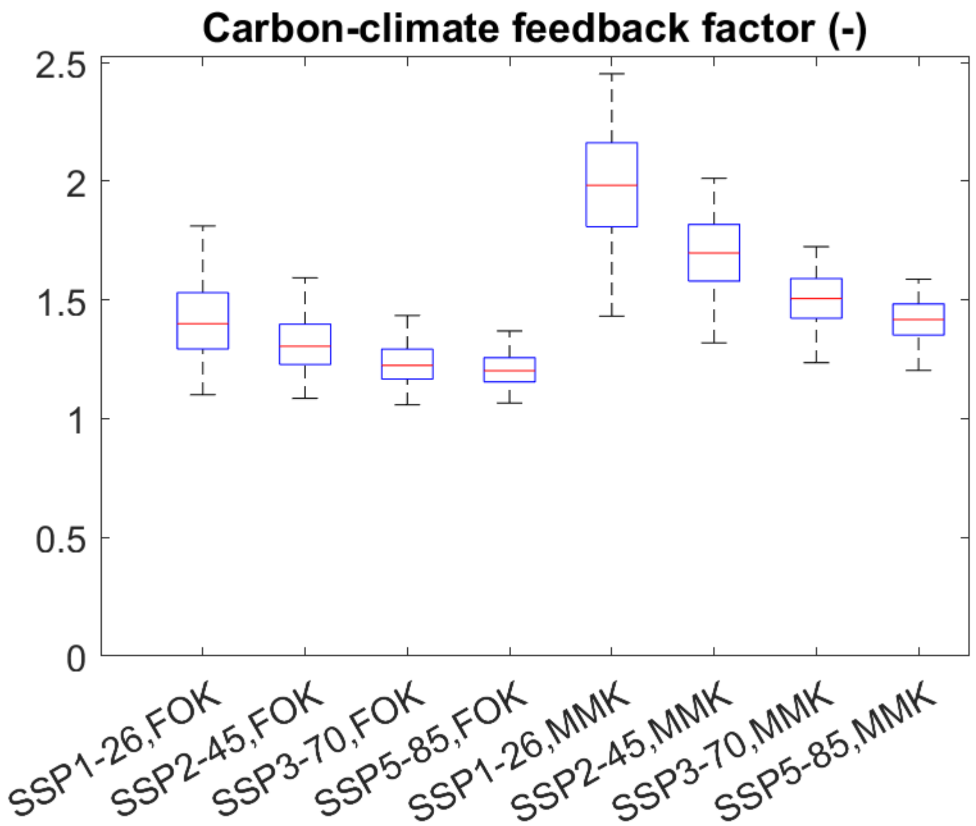
Of course, the model is most simplified and we should not interpret concrete single numbers. The idea is indeed to see the order of magnitude differences when assuming FOK vs MMK. However, in general, and despite its simplicity, the model is able to capture global trends in historical atmosphere, land and ocean C dynamics, and the global temperature trend. In addition, projections are similar to published IPCC model results with some deviation, e.g. an overestimation of the future ocean C sink. Compare L158-183. The model has been designed to study feedbacks (Lade et al., 2018).

And the second concern is that, since the analysis is based on a simplistic model, no uncertainty analysis of the estimated feedback and carbon budgets is performed.

Model projections and related feedback or remaining C budget estimations come with different kinds of uncertainty. This paper concentrates on the structural model uncertainty, that is the uncertainty related to different formulations of the equation for one process (here, respiration). I can show that this uncertainty is huge, feedback estimates can even double.

In addition, we can express uncertainty related to the parameters used in the model. This was not the focus of the paper, but indeed it can be interesting to compare such different kinds of uncertainty. Therefore, I selected two most sensitive parameters for the carbon-climate feedback (lambda and Q, Tab. 1), resampled 100 pairs of both using Latin Hypercube Sampling and assuming a standard deviation of 0.4 for lambda and 0.2 for Q in order to derive a reasonable parameter range (lamda=[1.5,3.5] and Q=[1.6,2.6]), and repeated the feedback and feedback factor calculation and the respective model runs using these 100 samples of parameters. The results are shown in the two new boxplots below. We can see a clear parameter uncertainty, but the structural uncertainty of the formulation of the respiration equation is even higher. Mean values between FOK and MMK result distributions are significantly different. That means that despite the parameter uncertainty, the conclusions about the structural uncertainty hold.


Carbon-climate feedback (PgC)
1400
1200
1000
800
600
400
200
0
SSP1-26,FOK
SSP2-45,FOK
SSP3-70,FOK
SSP5-85,FOK
SSP1-26,MMK
SSP2-45,MMK
SSP3-70,MMK
SSP5-85,MMK


Carbon-climate feedback factor (-)
2.5
2
1.5
1
0.5
0
SSP1-26,FOK
SSP2-45,FOK
SSP3-70,FOK
SSP5-85,FOK
SSP1-26,MMK
SSP2-45,MMK
SSP3-70,MMK
SSP5-85,MMK