Response to Anonymous Referee #1 on "Identification of linear response functions from arbitrary perturbation experiments in the presence of noise

Part II. Application to the land carbon cycle in the MPI Earth System Model"

Guilherme L. Torres Mendonça[1,2], Julia Pongratz[2,3], and Christian H. Reick[2]

[1]International Max Planck Research School on Earth System Modelling, Hamburg, Germany
[2]Max Planck Institute for Meteorology, Hamburg, Germany
[3]Ludwig-Maxmillians-Universität München, Munich, Germany

Correspondence: Guilherme L. Torres Mendonça (guilherme.mendonca@mpimet.mpg.de)

We thank Anonymous Referee #1 for the positive review of our paper. Below we respond to the comments point by point.

***AR#1*: Line 193 - Is it too strong a statement to say that the prediction error comes solely from the deterioration of the recovery of the response function and not from nonlinearities? The optimal (or even appropriate) form and coefficients in subgrid parameterisations of any one of the many unresolved processes within Earth system models would in general be dependent on the level of forcing.**

Authors: As mentioned in the introduction of Part I, the linear response equation (1) can be seen as the linear term in a Volterra series, which is an expansion of the response of the system into the perturbation that under certain assumptions completely describes this response for any time-dependent perturbation. In this expansion, all nonlinearities of the system, *regardless of their origin*, are represented by the terms nonlinear in the forcing. Therefore, as long as the forcing strength is sufficiently small, such nonlinearities do not influence the response, which can be completely described by Eq. (1) for any time-dependent forcing once the linear response function is known.

***AR#1*: Could this type of nonlinearity influence the deterioration in the recovery of the response functions? Note, in general parameterisations developed in GCMs are designed / tuned to reproduce the historically observed climate, and not necessarily future ones with different forcing.**

Authors: Yes, for large enough forcing strength such nonlinearities from parametrizations do deteriorate the recovery of the response function. In fact, an example where this happens is shown in Fig. 6(a): There, one sees that when the response function $\chi_\beta(t)$ is derived from data taken for forcing strengths larger than about 100 ppm, the prediction error starts to increase. As explained in section 2.2, this increase in the prediction error can be unambiguously traced back to the deterioration in the recovery of the response function caused by nonlinearities in the 1%-experiment data from which the response function was derived. As we found out in the study, the origin of this deterioration is the nonlinear relationship between NPP and atmospheric CO_2.

***AR#1*: To what extent are the responses sensitive to the historical trajectory of the emissions? For example could the sensitivities determine in the the 1% runs be used to determine the responses in a more temporally complex trajectory as specified in the ScenarioMIP project?**

Authors: As explained above – and also in the introduction of Part I –, in principle the derived response functions can be employed to predict the response to any time-dependent perturbation, as long as the perturbation strength is sufficiently small. Therefore, the temporal complexity of the perturbation trajectory would not be an issue. Nevertheless, the response functions that we derive in the present study describe ultimately the response of the land carbon cycle to perturbations in atmospheric CO_2. In historical simulations one is not in the ideal situation where the only perturbation to the system is the increase in atmospheric CO_2: There is also land-use change, other greenhouse gases, etc. Therefore, studying historical simulations by means of linear response functions is in principle possible, but one would have to take into account the response to these additional perturbations. This is indeed an interesting research direction, but it sidetracks from the core of our study. Therefore we would prefer not to address this comment in the revised manuscript.

***AR#1*: To what extent are the responses sensitive to the spatial distribution of the emissions? Clearly there are many spatial distributions that could produce the same global average (or even tropical / extra-tropical averages). Presumably not all of these distributions would produce the same response.**

Authors: Indeed the global response could be different if the different regions would have a different CO_2 concentration. In such a case the reviewer is right: If the CO_2 was very different in different regions, then the tropical/extra-tropical response functions we derived would not show what is really happening in these regions. In this case, we would have to derive the functions taking into account the different CO_2 concentrations for the different regions – as we did when deriving $\chi_{NPP}(t)$ for different NPP perturbations over tropics and extra-tropics (Eqs. (19) and (20)). But since in reality CO_2 is so well mixed, this is a hypothetical consideration. We will clarify in the manuscript that the tropical/extra-tropical response functions $\chi_\beta^{tr}(t)$ and $\chi_\beta^{et}(t)$ can be interpreted as the locally correct response functions because of CO_2 being well mixed.

***AR#1*: Following this line of thinking, could one consider the response functions between the global average quantities as the first scale in a spatial spectrum? Could one calculate response functions per say the principal components (PCs) of land carbon and PCs of surface temperature, or some other modal decomposition of these fields?**

Authors: Yes, in principle these functions can also be employed to study the dynamics of the system spatially. We have shown a simple example of this by looking at the responses for tropics and extra-tropics, but in the literature one finds also applications to study latitudinal distributions and even entire global maps (Thompson and Randerson, 1999; Lucarini et al., 2017). It would therefore indeed be an interesting idea to employ these functions to investigate the spatial response of the carbon cycle as suggested by the referee. Nevertheless, this idea is also beyond the scope of the present study, and therefore we would prefer not to address it in the revisions.

With best regards,

Guilherme L. Torres Mendonça, Julia Pongratz and Christian H. Reick

References

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Thompson, M. V. and Randerson, J. T.: Impulse response functions of terrestrial carbon cycle models: method and application, Global Change Biology, 5, 371–394, 1999.