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Climate of the Past
Discussions

Interactive comment on "Technical Note: Calculating state dependent equilibrium climate sensitivity from palaeodata" *by* Peter Köhler et al.

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Response to Reviewer #2 (Jonah Bloch-Johnson) May 19, 2016

Our reply: This rather long review only deals with the question if in the scatter plot of ΔR-ΔT from which climate sensitivity might be calculated, ΔR is the independent variable (plotted on the x-axis) and ΔT is the dependent variable (plotted in the y-axis) or vice versa. The reviewer was already a reviewer of our 2015 paper and this point was already brought up in the discussion phase in 2015. Accordingly, we tested the importance of this assumptions on our results and layed out some arguments why we think ΔR should stay on the x-axis. Please refer to the peer-review process of the 2015 paper for details. One of our arguments was and still is, that the calculation of S from palaeodata developed around the definition we put forward in Eq 1: $S = \Delta T/\Delta R$, from which the most natural choice of calculating S as the slope of the regression line in the linear case has developed. This is and was our starting point, from which we developed how the analysis might be performed, once the system is not linear anymore.
Reading this review and the own paper of the reviewer (*Bloch-Johnson et al.*, 2015) in detail, we think we see the reason why he insists on switching the axes. This might come from the term equilibrium non-linearity as defined in that paper. It is based on the generally used Taylor-expansion of $\Delta R = \lambda \Delta T + a(\Delta T)^2 + O((\Delta T)^3)$. Normally, and of course in the whole concept of S this expansion is simply taken as first order, so $S = -1/\lambda = \Delta T/\Delta R$. In that paper (*Bloch-Johnson et al.*, 2015), the authors show that there may be quadratic or even higher order corrections to this expansion that become particularly important in the long tails of climate sensitivity distributions. In that sense, writing $\Delta R = \lambda \Delta T + a(\Delta T^2)$, ΔR is a function of ΔT and should be plotted on the y-axis (with ΔT on the x-axis).
We argue differently: We say that $\Delta T = S\Delta R$ and S might not be constant, but a (unknown) function of T and R. It is, therefore, not even clear that there exists a functional relation $T(R)$ or $R(T)$, and we try different approaches to directly estimate S from the cloud of points. In this case it doesn't matter at all whether we use $T - R$ or $R - T$ relations.
Some comments on the details given in this review:

- In the introduction some fundamental motivation why temperature should be the independent variable are given. Nothing to be added there, apart from the fact, that for palaeostudies the forcings and feedbacks that change the climate system with respect to pre-industrial climate, are the interesting parts, and that models typically calculated temperature changes as response to those (making temperature the dependent variable again).
- In section 2.1 it is argued that temperature change as function of forcing change is not necessarily a well-defined function, bringing some arguments about bifurcation and a reanalysis of some simple model-based calculations some of us have published in *von der Heydt et al.* (2014). Note, that this model is unrealistically simple and was used only to verify the difference between fast and slow feedback processes. Furthermore, even in *von der Heydt et al.* (2014) we put forward an analysis in a scatter plot, similar to here, with ΔR being on the x-axis.
- In section 2.3 the non-linear regressions shown in 2015 are repeated, but with x and y changed in the analysis to determine a non-linear function. It is argued, that now even the fit through the data based on CO_2 from the Pagani and Foster lab (apart from one case) agree with our main finding, that climate sensitivity is lower in colder periods. So far, we did not find any significant non-linearity in the Foster and Pagani data sets. We think, that this support found for our earlier findings is encouraging, but the fits through both Foster and Pagani for both our approach (ΔR on x-axis) and the approach of the reviewer (ΔT on x-axis) is far away from going through the origin (ΔT=0 when ΔR = 0). While in our view meeting the origin is of fundamental importance in this overall approach, we think these new results are therefore only of limited usage and will not change the conclusions we put forward in 2015.
In principle we can follow the (physically motivated) arguments put forward why we should switch x and y, however, we can not see, that this should be uttermost important (see above our understand why we think the reviewer insists on switching the axis). Saying that, we agree that there might be benefits in following this switch in the axes, but we can not say that it will change the overall findings. The core of this review is on

the method of how to set up the scatter plot. Thus, it is more on how good (or bad) the previous papers we published have been setup. Interestingly, the reviewer was finally happy with our setup in 2015, and did not insist on change axes in the scatter plots, while he here seemed to rethink his former position.
How to continue? The issues we bring up (the quantification of S based on local slope versus pointwise, how they disagree and how they can be transformed into each other) would also show up when we switch axes, the equations how to transform one into the other might in detail be different. Therefore we think this technical note is well served if, for the time being, it is performed in the setup as is. However, we keep the suggested switches of axis in mind and might continue future investigations in that direction following the suggestions brought up here.

References

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