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Interactive Comment

Interactive comment on "On the state-dependency of the equilibrium climate sensitivity during the last 5 million years" *by* P. Köhler et al.

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Response to comments of reviewer #2

related to Köhler, P., de Boer, B., von der Heydt, A. S., Stap, L. B., and van de Wal, R. S. W.: On the state-dependency of the equilibrium climate sensitivity during the last 5 million years, Clim. Past Discuss., 11, 3019-3069, doi:10.5194/cpd-11-3019-2015, 2015.

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We will in the following respond in detail to all comments of reviewer #2 (Jonah Bloch-Johnson). Thus, the text of the review is also partly contained in this response letter, with our reply written in blue in-between. However, the general comment and the first specific comments are rather long and not repeated here in full length. Please refer to the original reviewer comment for further details.

Our reply to the first specific comment: In the first specific comment (which is rather long and therefore not repeated here) the reviewer argues for switching the independent/dependent variables in our scatter plots by plotting $\Delta T_{\rm g}$ on the x-axis and ΔR on the y-axis. A lengthly chain of argument is given for motivation (including some notations on how and why radiative forcing might change), which turns out to be (partly) taken from a recent article of the reviewer (Bloch-Johnson et al., 2015). There and elsewhere a fit is calculated through $\Delta T_{\rm g}$-ΔR-data, which then represents the climate feedback parameter λ, which is defined as the negative of the inverse of the climate sensitivity $S = -1/\lambda$, while S is the variable we like to investigate in our study here.
We are aware of the literature in which the climate feedback parameter is calculated as a fit through ΔR (y)-$\Delta T_{\rm g}$(x) scatter plots (e.g. Gregory et al., 2004). Of course, also the relationship between the climate sensitivity and climate feedback parameter is well known to us (see methods in Köhler et al., 2010). However, the case here is slightly different than in the example given in the comment and in the literature cited. Here, our ΔR contains the radiative forcing (without feedbacks), whose impact on climate we like to investigate, in detail the radiative forcing of CO_2 and land ice albedo. All responses of the climate system are (fast or slow) feedbacks, that should be covered by the climate sensitivity S we calculate here. These feedbacks influence ΔR in the notation given by reviewer, but do not influence the radiative forcing ΔR in our setup here. Therefore, in our approach the independent variable is ΔR and should be plotted on the x-axis.
Furthermore, there exist an important difference in our approach (paleo data-based) and the model-based analysis of present day results. The data we analyse are corre-

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sponding to equilibrium climate change, while in the analysis of Gregory et al. (2004) or others (e.g. Bloch-Johnson et al., 2015) all simulation results of all time steps in the process of the simulation results reaching equilibrium are used for analysis. This certainly leads to different results which also need to be discussed and interpreted differently.

Based on the reasoning above it is in our approach much more natural to understand ΔT_{g} as dependent variable (y-axis), and ΔR as independent (x-axis). Furthermore, in the applied method used in data-based approaches it is typically to calculate climate sensitivity $S = \Delta T_{\mathrm{g}}/\Delta R$ as the slope of any fitting function to the data with ΔT_{g} being on the y-axis and ΔR on the x-axis. It therefore is only naturally to continue in this direction (based on the same setting) even if non-linearity is now contained in the underlying relationship of both variables.

All said above is in our view already a valid argument to continue in our analysis based on the setting as so far given (with ΔR being on the x-axis). However, since the reviewer argues, that by changing x and y in the scatter plot we would improve the fit of the (non)-linear functions to the data we nevertheless briefly tested this prediction. When changing x and y (for our standard case with ΔT_{g}=$\Delta T_{\mathrm{g}1}$ for the scatter plots through $\Delta R_{[\mathrm{CO_2},LI]}$-$\Delta T_{\mathrm{g}}$) we can hardly improve the fits to the data. The r^2 for the fits through the ice core-based CO_2 values is even reduced by 10%, for the Hönisch data r^2 is reduced by 5%, for the Foster data r^2 is increased by 6%, for the Pagani data r^2 is increased by 4%. We also checked for the ice core data that binning of data prior to Monte-Carlo statistics does not influence these results. For the fits through $\Delta R_{[\mathrm{CO_2}]}$-$\Delta T_{\mathrm{g}}$ the r^2 for the ice core data become smaller by 7% if x and y are changed, for the three other data sets there are hardly any changes, especially no major improvements. Much more important, however, is the fact that the non-linearities are completely different now. We now find only a linear relationship between ΔT_{g} and ΔR for ice core and Hönisch data, but a non-linearity for Foster and Pagani in the ΔT_{g}-$\Delta R_{[\mathrm{CO_2},LI]}$ scatter plot, where we previously found only a linear relationship. However, when plotting the data with changed x and y it becomes apparent that a polynomial of higher order is

probably not the best choice for a function to be fit to the data, maybe some other non-linear function might help (e.g. log-function). Therefore, the statistical results we obtain here whether a linear or non linear fit better describes the data once x and y have been switched should be treated with care and they are probably of limited relevance.
Actually, when starting on this work we also investigated in the direction of using different fitting function. However, the routines we now use based on Numerical Recipes are not very good in finding the parameters of exotic functions to fit to the scattered data. Therefore, we restricted our approach to higher order polynomials.
For all those reasons given above we refrain from any further investigations in the direction of switching x and y.

The second specific comment concerns the non-linear relationship of sea level rise and land ice radiative forcing. Given the central importance of this non-linearity to the paper, it would be useful to have a more direct explanation of the workings of the ANICE model rather than only relying on a citation to previous work. The de Boer et al. 2014 paper can still be referenced, but some of its most relevant points could be brought over, and specifically which elements of the three-dimensional picture are most important for creating the non-linearity. This would help readers judge the robustness of this result. It would also be good to have a brief explanation of what ICE-5G is.

Our reply: We will improve the description of the ice sheet model ANICE and also of ICE-5G in order to clarify the text for the reader.

The third specific comment concerns arguments about the difference in sensitivity between the Pliocene and Pleistocene using the sensitivities gleaned from the Hönisch and Foster datasets. Figures 9 and 10 strike me as suggesting that both the present paper and Martinez-Boti et al. are right that the cold Pleistocene and the Pliocene have similar sensitivities, while the sensitivity in the warm Pleistocene was significantly higher than either (compare the peaks of the Hönisch ^{11}B cold Pleistocene, warm

Pleistocene, and the Martinez-Boti ^{11}B Pliocene sensitivity distributions in Figure 9; the first and third are close together, while the second is much higher.) Note that this sort of "third-order" sensitivity (two changes in strength) is not uncommon seen in models ("Climate feedbacks under a very broad range of forcing", Colman and McAvaney, 2009; "Fast atmosphere-ocean model runs with large changes in CO2", Russell et al., 2013), though typically the other way around (the present is relatively insensitive, e.g., Russell et al., 2013, surrounded on either side by a growing ice albedo feedback and a growing water vapour feedback). Some discussion on this point might be warranted.

Our reply: The important point on the compilation of S from our and other studies is, that Martinez-Boti never searched for any non-linearity in their data set. Also, they lumped all data of the last 800 kyr (the ice core data) together, so mixing cold climate states with climate state comparable to present day. However, we agree that extending the discussion of this issue might improve our draft and bring more clarity to our conclusions.

A few other smaller comments:

- Part of the above discussion of the ice sheet model should also note how deep ocean temperatures are used to estimate ΔT_{NH}, and if this relationship contributes to the non-linearity derived in this paper in any way.
- **Our reply:** A similar comment was brought up by reviewer #1 and in answering it (#1.2) we made additional analysis in which we tested which data-set improvement is most important for the found non-linearity. It turned out that in the revised global temperature change and the revised land ice albedo change are similarly important for finding a non-linearity in the ΔT-ΔR scattered data.
- As someone relatively unfamiliar with the proxy literature, I found Section 2.3

particularly useful in understanding the various CO_2 proxies available.

- **Our reply:** Thank you. We also believe that this discussion of the CO_2 data is especially valuable for people not very familiar with the field.

- I was a bit confused as to the units of the colorbar in Figure 1c. Are the colors representative of the globally-normalized forcing of the entire global ice sheet (in which case color would be independent of the y-axis) or are they supposed to represent the impact of the 5° latitudinal bins, in which case the units should be something like "W/m^2 per 5°"?

- **Our reply:** The plotted change in Fig 1c are the globally-normalised forcing of the ice sheets in the respective 5° latitudinal bins. Since we have been asked in #1.4 from reviewer 1 to be more specific how ΔR from land ice sheets is calculated we bring more details on how the data to Fig 1c have been calculated.

3 Technical Corrections

This paper has some grammar mistakes:

Our reply: Thanks for spotting and reporting all these mistakes which we will all correct accordingly.

References

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