Author response to referee comments for manuscript ESD-2018-84

TITLE: *Climate feedbacks in the Earth system and prospects for their evaluation*

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RESPONSE TO REVIEWER #3

!! ALL PAGE/LINE NUMBERS REFER TO THE DISCUSSION PAPER AS PUBLISHED ON THE ESD DISCUSSIONS WEBSITE !!

REVIEWER: General comments:
This paper is a comprehensive review of the state of knowledge of climate feedbacks in the Earth System. I read the document from the perspective of someone who wasn't necessarily familiar with all the details of climate feedbacks, which is the intended audience. Frankly, since there are so many feedbacks, each with their own nuances and levels of understanding, this is the appropriate perspective to have since no individual scientist can fully understand them all. So, from that perspective, I felt that the level of presentation and discussion was appropriate. I have a few minor suggestions included below. Overall, I thought that the feedback discussion section was better than the feedback evaluation section, though this likely mainly reflects the big challenges that our community faces with respect to evaluating feedbacks with limited and short record observational data.
The paper is well-written and is structured appropriately. I don't really have too many criticisms or suggestions as the paper was clearly put together in a thoughtful and careful way.

OUR RESPONSE:
We would like to thank the reviewer #3 for the constructive comments.

REVIEWER Minor point 1.:
P. 3, line 27: replace "climatological timescales" with "climate timescales"

OUR RESPONSE:
We will make this replacement.

REVIEWER Minor point 2.:
P. 5, line 18: I would add 'surface energy budget' into the list of things that LULCC affects. The changes in surface roughness between forests and grasslands/croplands is often one of the most important factors affecting the LULCC impact on climate through the impact on surface energy budget partitioning.

OUR RESPONSE:
We will include "surface energy budget" in this list.

REVIEWER Minor point 3.:
P.5, line 24: The comment about "Anthropogenic driving factors such as albedo changes from deforestation, agriculture . . ." seems to be mainly repetitive to the discussion of land use change higher up in the paragraph, but it is introduced as an additional 'factor'

OUR RESPONSE:
We will delete the "Further" at the beginning of this sentence.

REVIEWER Minor point 4.:
P. 13: I found the beginning of Section 3 to be a little bit confusing. Section 3 is meant to be about fast feedbacks, but then there is some discussion in the introductory material of fast versus slow feedbacks and

which overall feedbacks are considered. There is also a listing of the four basic feedback types, which are a mixture of fast and slow feedbacks. Maybe there needs to be a separate introductory section about what feedbacks will be considered and not considered. I would advise the authors to consider ways to clarify the text.

OUR RESPONSE:
We will restructure the text on page 13 lines 9-27, see the following point, and make clear which part is a general comment and which part refers to fast physical climate feedbacks only.

REVIEWER Minor point 5.:
P. 13: Similarly, the list of the four basic types of feedbacks doesn't transition cleanly/clearly into the detailed descriptions in the following sections. For example, the detailed descriptions don't start with the first basic feedback type (thermodynamic shortwave radiation feedbacks). And, the detailed feedback descriptions tend to bounce around across basic feedback types as well, with even a transition to another section to describe some of the basic feedback types. I'm not sure if it would be straightforward to rework ordering or text to guide the reader along a little better (and also not clear how important it is), but thought I would highlight the possible issue to the authors.

OUR RESPONSE:
We will restructure the text on page 13 lines 9-27. The four basic types of feedbacks refer to the columns of the right hand side of Table 1. We will make this clearer.
The text on page 13, lines 9-27 will be changed to:
"We will now describe the major feedback processes and the options that currently exist to evaluate them. The following general note may serve as a guide through this section. We first briefly summarise the fast physical feedbacks that are already part of conventional physical AOGCMs and then discuss the fast and slow Earth system feedbacks (Section 4) which have been included in climate simulations through the increasing model complexity of ESMs. The following feedbacks will not be considered in detail: (a) ice sheet feedbacks, due to their long timescale (though we will mention the freshwater release from melting glaciers and its impact on ocean circulation) and (b) socio-economic feedbacks (see van Vuuren et al. (2012)), as rigorous mechanisms to interpret these are still under development. Table 1 provides a general overview of the most important feedbacks (both short and long term). The feedbacks considered can be grouped into four basic types (see Table 1, right hand side): (1) thermodynamic shortwave radiation feedbacks (to a large degree these are the albedo feedbacks), (2) thermodynamic longwave (LW) radiation feedbacks (including dynamics of water vapour and heat redistribution through circulation, though these can also affect shortwave radiation), (3) atmospheric composition altering feedbacks due to GHGs (in addition to water vapour which is already mentioned in (2), such as CO_2, CH_4, N_2O, and O_3), and (4) atmospheric-composition-altering feedbacks involving non-GHGs and particles/droplets (such as NO_x and aerosols). For each family of feedbacks described in the following sections, we provide more details on the respective observational constraints in Appendix 1.

Fast feedbacks cover a timescale of months to a few years, where the upper end of the timescale spectrum (few years) would be defined by the mixing timescale of the upper ocean down to the thermocline (of course, equilibration times with the entire deep ocean also would be longer, up to several thousand years). Fast feedbacks are key to decadal climate prediction efforts, while slow feedbacks mainly come into play after a few decades."

REVIEWER Minor point 6.:
P. 17: Line 17 (should be line 18): "Clouds belong to the prime sources for uncertainty in". This is strange wording and could likely be improved.

OUR RESPONSE:
We will change the text to:
"Limited understanding of cloud processes and difficulties in simulating cloud feedbacks belong …".

REVIEWER Minor point 7.:
P. 24 (should be page 21), line 24: I believe that an increase in LAI can lead to an increase or a decrease in albedo. The direction of change depends on the underlying soil albedo. Note that the amplitude of these feedbacks described in this paragraph are highly uncertain, which could be stated, though maybe that is true of many of the feedbacks and therefore would be repetitive to state that there is high uncertainty for many feedbacks.

OUR RESPONSE:
We will add the following sentence: "One uncertainty source associated with this feedback is the original underlying surface albedo (if the underlying albedo was is high, then the feedback would even be reversed)."

REVIEWER Minor point 8.:
P. 20, Section 4.3.1: From my perspective, there is too much emphasis in this paragraph on the impact of permafrost thaw in increasing methane emissions. Schuur et al. (2015) emphasize that the biggest feedback from permafrost thaw is expected to be from carbon dioxide release as organic material currently frozen or nearly frozen in permafrost soils thaws and decomposes. Increased methane emissions associated with warmer and potentially wetter soils is also a permafrost carbon feedback, but it is not expected to be as large as that associated with CO_2 emissions. Note also that all current estimates of the permafrost climate-carbon feedback have neglected the potentially significant emissions from abrupt permafrost thaw processes. The literature on this is essentially negligible, though, so hard to cite.

OUR RESPONSE:
We will insert the following sentence on page 29, line 27:" The overall quantitative partitioning of permafrost carbon release into CO_2 and CH_4 is uncertain (Ciais et al., 2013)." (The reference is already included in the discussion paper.)
We will further change the subsequent sentence to: "See the discussion in Section 4.6 for implications of increased CH_4 emissions to the tropospheric gas-phase chemistry."

REVIEWER Minor point 9.:
P. 30 (should be page 29), line 32 (should be line 33): CO_2 fertilization is not due only to improved water use efficiency of plants. Increased CO_2 uptake by plants under high CO_2 conditions is due to the impacts of CO_2 concentration on plant photosynthetic processes.

OUR RESPONSE:
We will add "photosynthetic processes" to Figure 5 (combine it with the text string "water use efficiency").
We will add to the sentence on page 29, line 34, the text passage: "and enhanced photosynthetic processes (Liberloo et al., 2009; Norby et al., 2005)." The reference Liberloo et al. (2009) is already included in the discussion paper. We will add the following reference:
Norby, R. J., DeLucia, E. H., Gielen, B., Calfapietra, C., Giardina, C. P., King, J. S., Ledford, J., McCarthy, H. R., Moore, D. J. P., Ceulemans, R., De Angelis, P., Finzi, A. C., Karnosky, D. F., Kubiske, M. E., Lukac, M., Pregitzer, K. S., Scarascia-Mugnozza, G. E., Schlesinger, W. H., and Oren, R.: Forest response to elevated CO_2 is conserved across a broad range of productivity, P Natl Acad Sci USA, 102, 18052-18056, 10.1073/pnas.0509478102, 2005.

REVIEWER Minor point 10.:
P. 31, line 5: True, but the models with CN representation in CMIP5 have been shown to have unrealistic behavior with respect to N-limitation impacts on the carbon concentration feedback (e.g., Bonan and Levis, 2010).
Reference:
Bonan, Gordon B., and Samuel Levis. "Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4)." Geophysical Research Letters 37.7 (2010).

OUR RESPONSE:
We will add the following sentence: “The approach for C-N-coupling as applied in these models may need improvements (Bonan and Levis, 2010).” The following reference will be added:
Bonan, G. B., and Levis, S.: Quantifying carbon-nitrogen feedbacks in the Community Land Model (CLM4), Geophys Res Lett, 37, Artn L07401, 10.1029/2010gl042430, 2010.

REVIEWER Minor point 11.:
P. 47, Line 3: “Suggest an even larger RANGE of equilibrium”

OUR RESPONSE:
We will correct this.

REVIEWER Minor point 12.:
P. 45 (should be page 47), Section 5.1.3: It would be worth citing this recent paper (McDougall et al., 2019) that discusses the limitations of 1% experiments to assess feedbacks in ESMs.
Reference:
MacDougall, Andrew Hugh. "Limitations of the 1% experiment as the benchmark idealized experiment for carbon cycle intercomparison in C 4 MIP." Geoscientific Model Development 12.2 (2019): 597-611.

OUR RESPONSE:
We will change the sentence:
“For estimating feedbacks, ESM experiments are carried out under future scenario forcing (often the idealised scenario with 1% CO_2 yr^{-1} increase in atmospheric CO_2 is used as model runs are short, i.e. only 70 years until atmospheric CO_2 concentration doubles with respect to the pre-industrial start value).”
To:
“For estimating feedbacks, ESM experiments are carried out under future scenario forcing (often the idealised scenario with 1% CO_2 yr^{-1} increase in atmospheric CO_2 is used as model runs are short, i.e. only 70 years until atmospheric CO_2 concentration doubles with respect to the pre-industrial start value; a critical appraisal of the 1% CO_2 yr^{-1} increase scenario is given in MacDougall, 2019).
We will add the reference:
MacDougall, A. H.: Limitations of the 1 % experiment as the benchmark idealized experiment for carbon cycle intercomparison in (CMIP)-M-4, Geosci Model Dev, 12, 597-611, 10.5194/gmd-12-597-2019, 2019.

REVIEWER Minor point 13.:
P. 48, line 10: I would suggest citing the recently published ILAMB paper (Collier et al., 2018) in addition to Eyring et al. (2016c) to indicate the breadth of efforts in this arena of model assessment.
Reference:
Collier, Nathan, et al. "The International Land Model Benchmarking (ILAMB) system: design, theory, and implementation." Journal of Advances in Modeling Earth Systems 10.11 (2018): 2731-2754.

OUR RESPONSE:
We will add this citation and add the reference: Collier, N., Hoffman, F. M., Lawrence, D. M., Keppel-Aleks, G., Koven, C. D., Riley, W. J., Mu, M. Q., and Randerson, J. T.: The International Land Model Benchmarking (ILAMB) System: Design, Theory, and Implementation, J Adv Model Earth Sy, 10, 2731-2754, 10.1029/2018ms001354, 2018.

REVIEWER Minor point 14.:
P. 49, line 10: The text as written implies at the beginning that the ToE has a 30-60 year timescale. Clearly, as the authors note further down in the text, the ToE depends strongly on which variable and on what spatial scale is being considered. And, another paper on ToE related to carbon is Lombardozzi et al. (2014).
Reference:
Lombardozzi, Danica, Gordon B. Bonan, and Douglas W. Nychka. "The emerging anthropogenic signal in land–atmosphere carbon-cycle coupling." Nature Climate Change 4.9 (2014): 796.

OUR RESPONSE:
We will add that the ToE of 30-60 years refers to surface temperature (see also the respective comment of reviewer #2 and our respective response). We will add the following text on page 49, line 16: “ToEs for climate induced changes in land ecosystems are in the same range as for surface temperature, with some shorter ToEs in regional hot spots (Lombardozzi et al., 2014).” We will add the following reference:
Lombardozzi, D., Bonan, G. B., and Nychka, D. W.: The emerging anthropogenic signal in land-atmosphere carbon-cycle coupling, Nat Clim Change, 4, 796-800, 10.1038/Nclimate2323, 2014.

REVIEWER Minor point 15.: P. 51, Section 5.2.5: Seems like this paper that highlights some of the potential limitations associated with emergent constraints should be cited (Caldwell et al., 2018).
Reference:
Caldwell, Peter M., Mark D. Zelinka, and Stephen A. Klein. "Evaluating emergent constraints on equilibrium climate sensitivity." Journal of Climate 31.10 (2018): 3921-3942.

OUR RESPONSE:
We will add the following sentence on page 51, line 32: “This also applies to the ensemble size of models, where caution is needed especially when using small ensembles (Caldwell et al., 2018).”
We will add the reference:
Caldwell, P. M., Zelinka, M. D., and Klein, S. A.: Evaluating Emergent Constraints on Equilibrium Climate Sensitivity, Journal of Climate, 31, 3921-3942, 10.1175/Jcli-D-17-0631.1, 2018.

16. P. 54, line 1: Perhaps should replace the term “individual modeler” with “modelling groups”. Obviously, ESMs are not developed by individuals and decisions are not made about the quality of simulations by individual modelers either.

OUR RESPONSE:
We will carry out this change.