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Climate of the Past
Discussions

Interactive comment on "A model-data assessment of the role of Southern Ocean processes in the last glacial termination" *by* Roland Eichinger et al.

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Reply to:
Interactive comment
on "A model-data assessment of the role of Southern Ocean processes in the last glacial termination" by R. Eichinger et al. (cp-2015-190)
from Anonymous Referee #1

Dear Anonymous Referee #1,

thank you very much for your valuable comments and suggestions. Please find our answers (in blue) to your comments (in black) below:

Eichinger et al. present results of simulations performed with DCESS model of intermediate complexity. The main goal of the study is to understand the changes in atmospheric D14C between 17.5 and 14.5 ka B.P. The impact of changes in permafrost, deep ocean ventilation, dust and a higher PO4 content are briefly looked into over the whole deglaciation. My main criticism is that in some ways the authors try to do too much without really looking at each of the processes. So, at the end little new informa- tion is coming out of the manuscript or some important information is missing to really understand the implications. Please find some specific comments below. The model used here is a simple Earth System Model of intermediate complexity, which comprises one high latitude zone and one low latitude zone, without "proper" water masses. This is thus a very idealized (simple) set up, which has significant implications when discussing the deglaciation, changes in permafrost, upwelling...

1. Southern Ocean upwelling:

   - The authors always refer to Southern Ocean upwelling, whereas there is no "proper" (NADW, AABW. . .) water masses. In addition, in the pre-industrial set up water downwells in the high latitude box and upwells in the low latitude box. There is therefore no Southern Ocean upwelling (as far as I can tell, because there is little information on the topic). In the LGM state, vertical diffusion is reduced in the high latitude box below 1km. Therefore in the LGM state sinking at high latitude is restricted to $\sim$2000m, correct? What are the water transports at the PI and LGM?

     The described ocean overturning is the same in LGM as in PI state, this is independent from the changes in vertical diffusion that we perform and not relevant for our study. It is the change in vertical diffusion that generates our LGM state by isolating the water masses in the high latitude ocean. However, this vertical exchange intensity change should not be understood as a change in real vertical diffusion, but rather as a conceptual way of separating the water masses or a model analogy to isolated deep water generation. We will add some additional explanations to clarify this apparent misunderstanding of the concept.

- The change in ventilation is simulated by a change in vertical diffusion, whereby diffusion linearly increases between 17.5 and 14.5 ka B.P. So is the upwelling during MI occurring in the low latitude box in the model? Is the whole deep ocean ventilated between 17 and 15 ka B.P.? What are the associated changes in water transport during MI?

  No, the "upwelling" takes place in the high latitude box, the overturning is not responsible for that, it is the recovery of the PI vertical diffusion profile. The deep water in the high latitude sector that had been isolated during glacial state can now (through restoration of vertical exchange intensity) mix with the upper ocean waters again, promoting outgassing. This is intended as an analogy to the (much more complex) changes in real ocean dynamics during the MI. We will revise the manuscript to make this point more clear.

- Shouldn't the authors show the vertical profiles of oceanic D14C, d13C and DIC, ALK and O2 at ∼15 ka B.P? The alkalinity profiles are not shown whereas it plays a strong control on atm. pCO2. All this information is crucial to understand the physical and biogeochemical response of the model to the forcing. The implications associated with the experimental design and model geometry should be clearly discussed and should be compared thoroughly with previous studies (see also references issues).

  After resumption of the ocean vertical diffusion, the ocean profiles go back toward the initial PI state shown in Shaffer et al. (2008). That state had been calibrated to reproduce observed low-mid latitude profiles, profiles that we

do show in our Fig. 2. Thanks for pointing this out. We will add the alkalinity profiles and will explain in more detail the changes taking place below and above the reduced vertical diffusion.

2. Heinrich 1-B/A:

   - Throughout the manuscript the authors refer to the "Mystery Interval", while totaling ignoring what we could call the "climatic intervals" of the last deglaciation,(Heinrich 1, the Bolling-Allerod) and the possible changes in oceanic circulation which occurred during that time period. While these changes in oceanic circulation cannot be simulated with the model used here, the implications should be discussed. H1 is not a simple case of "enhanced Southern Ocean upwelling" as NADW was probably very weak.

     Thank you for mentioning this, we will add some more discussion on this topic. Please note, however, that the goal of the present study is to investigate how much of the climate change during MI can be accounted for by Southern Ocean upwelling alone (+ other processes that can be represented by the model). In conclusion we also state that other (oceanic) mechanisms may be responsible for the rest of the climate change that could not be captured in our simulations, so we do not think there is a contradiction here.

3. Given these simplifications, the calculated C14 production rate is also associated with high uncertainties, even though it is quite informative to use several C14 production rate forcings. This is one of the most interesting part of the paper. As a summary, the experiments presented here serve as an estimate of the impact of high latitude diffusion change on atmospheric D14C. In general simple models give an upper estimate of possible changes, and if really the whole ocean below 2000m gets ventilated during MI, you would expect the value presented here to be an upper estimate. . .

As described above, please do not mistake the change in "vertical diffusion" performed here with literal oceanic vertical diffusion change, it is (just) a model analogy. Yes, this is representing an upper estimate of deep SOUTHERN Ocean ventilation during the MI, possible other water masses being ventilated are not captured of course. Thanks for pointing this out, we will add this point to the discussion.

4. Permafrost: The authors briefly study the impact of changes in permafrost across the deglaciation on pCO2, D14C and d13C, but some important information is missing. How much permafrost is stored at the LGM compared to PI? How does that compare with other studies? What is the time evolution of the permafrost changes? Changes in permafrost are associated with high uncertainties and given the very simple approach used here, a more accurate change in terrestrial carbon content associated with permafrost cannot be obtained here. The experiment can however give a bit of information on the associated change in pCO2 and D14C for a given terrestrial carbon release, but it is imperative to know the change in terrestrial carbon (in GtC) separated into vegetation and permafrost. There is no discussion on the reasons behind the possible changes in permafrost, their timing . . ... As such I don't really see the added value of the permafrost section. Also please see Kohler et al. 2014 (Nat. Comm.).

   Thanks for pointing this out, such information is indeed lacking in the paper. We will do this by adding another figure in section 3.2 (Impacts of permafrost and biosphere) showing time series of vegetation carbon, permafrost carbon and their sum (total terrestrial carbon) across the ALL_TF experiment. This will then serve to extend the discussion on this topic and to evaluate this effect in our simulations with respect to literature. Thanks for your suggestions on literature.
   An in-depth discussion on the reasons behind changes of permafrost and their timing, however, was not intended within this study and would go beyond the scope of the latter and the possibilities of the model. Despite the fact that it does

not add new value to permafrost research as such, the permafrost section is still well motivated due to its importance for the discussed processes and the model development work that had been conducted as part of the study.

5. References:

   - The introduction is imprecise and lacks a lot of important references for the work described. A lot of work on glacial/interglacial changes in pCO2 is not mentioned (see work by F. Joos team for example). A lot of references on C14 workis missing (Kohler et al. 2014, Huiskamp and Meissner 2012).

     Thanks for the suggestions, we will include some more literature if applicable. Your statement (first sentence) is very general. We will revise the text after taking into account your comments, however, please specify if there are particular issues in the introduction.

   - Some references are also used in the wrong context: For example p 18, the reference to Burke and Robinson (2012) is completely misused as they present D14C data from the Southern Ocean and not d13C data. As such the whole paragraph p18, L3-14 is wrong and please note that there is no d13CO2 dip during the B/A.

     Thank you for reading carefully, those are two slips of the pen. The reference should be Schmitt et al. (2012) here and as such, the paragraph makes sense again. And it is a short "rise" of $\delta^{13}C_{atm}$ during the B/A. We will correct that.

   - P3, L9-10 in the intro is wrong.

     Thanks, it will be changed to:
     Okazaki et al. (2010) argue that North Pacific water masses could help to explain the release of old carbon during the last glacial termination and Kwon et al. (2012) point out the possible influence of deep North Atlantic water masses for this process.

- P6, L9 is wrong

  Thanks for reading carefully, it will be corrected to:
  Hence, iron fertilization probably led to enhanced new production of organic matter in the high latitude ocean during the LGM

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