Clim. Past Discuss.,
https://doi.org/10.5194/cp-2019-34-AC1, 2019

Climate of the Past
Discussions

Interactive comment on "Modelling ice sheet evolution and atmospheric CO_2 during the Late Pliocene" *by* Constantijn J. Berends et al.

Constantijn J. Berends et al.

c.j.berends@uu.nl

Received and published: 11 June 2019

Rebuttal to the review by Anonymous Referee 1

We thank the reviewer for their comments on the manuscript and would hereby like to address the concerns they raised. Comments in italics, below our rebuttal. Page and line numbers refer to the revised manuscript.

The introduction is too short to draw an overall background of this study. For example, concerning the late Pliocene warm period, the authors only list the related references without introducing the related results briefly. Much attention is paid on the MIS M2 and no introduction for the glacial interval after 3.0 Ma. However, the title of this paper indicates the objective of this study is to draw the ice sheet and pCO2 evolution over *the late Pliocene and their transient simulation is also carried out from 3.65Ma to2.75 Ma. Thus, the introduction needs to be modified or the title needs to be changed.*

We agree that the introduction does not pay enough attention to the Pliocene other than MIS M2. We will expand this section. Since the results section presents and discusses results for the entire late Pliocene, focussing both on the cold M2 and the warm KM5c, we believe that, after expanding the introduction section to more adequately cover the entire late Pliocene, the title of the manuscript need not be changed.

P2, L1-21: Briefly discussed the findings of referenced studies about the Pliocene climate, ice-sheets, sea-level and CO2.

The authors validate the inverse method by applying it to investigate the last glacial cycle. In their results, the inversed pCO2 and modelled Benthic delta O18 show good agreement with the data. The modelled benthic delta O18 are largely improved comparing to their previous study (Berends et al., 2018), this is reasonable since the extra matrix provides more suitable climate states for the last glacial cycle. However, this extra climate matrix is not suitable for the late Pliocene. Unlike the PI, the pCO2 records during these warm periods are mostly higher than 300ppmv. In this climate matrix, there is only one warm state (PlioMIP,405ppmv) and it is far from the relative cold climate states, this will add more uncertainties to the warm period simulation for sure. To better understand the late Pliocene warm interval, at least, a medium warm-pCO2(between 405 and 280 ppmv) and a strong-than-PI insolation climate matrix need to be included.

While it is true that our climate matrix contains only one snapshot with CO2 higher than 280 ppmv, both the PRISM_280 and PRISM_220 snapshots are warmer than pre-industrial, due to the smaller ice sheets. This means that, even for the warmer-than-present eras, our climate matrix actually contains more information than the climate matrix used by Berends2018, which still managed to reproduce the last glacial cycle properly. We therefore believe our climate matrix is suitable for simulating the Pliocene.

While we agree with the reviewer that additional GCM snapshots for intermediate CO2 and insolation values and different ice sheets would be of added value, few such GCM simulations exist that are suitable for our study. A study that was recently published in GPC (Prescott et al. 2018: Regional climate and vegetation response to orbital forcing within the mid-Pliocene Warm Period: A study using HadCM3) could have provided useful data for us, but was only published after we'd already started this project. We agree that any new work on the Pliocene using our method could benefit from including these, and possible other, GCM results.

We will add a few lines to the manuscript describing this line of reasoning.

P7, L10-14: Added a few lines justifying our use of the new, extended climate matrix for simulating the Pliocene.

P20, L18: Added a reference to Prescott2018 to the discussion.

Please explain more details about the equation (2). What is the theoretical relation between (1) and (2) ? Why can this relation be also established during the late Pliocene without glacial-interglacial cycle?

Equation (1) quantifies the d18O-based inverse modelling method used by de Boer et al. (2013). Essentially, their model determines how global mean temperature (the inversely modelled variable) should have evolved, such that its combined effects on deep ocean temperature and global ice volume reproduce the observed d18O signal. Our own study takes this process one step further, by describing global climate not in terms of one single globally uniform temperature offset, but by using spatially variable temperature and precipitation fields. That way, our model determines how atmospheric CO2 should have evolved in order to change global climate in such a way that the resulting changes in ice volume and deep ocean temperature reproduce the observed d18O signal. Equation (2) quantifies how this is done; for every model time-step, the difference between the observed and modelled d18O signal is calculated. If the modelled value is not negative enough, this means that either the deep ocean is too warm, or there is too little land ice. CO2 is then lowered for the next timestep, which leads to a cooling and therefore to more ice, bridging the gap between modelled and observed d18O. As long as there is a direct relation in the model between deep ocean temperature and pCO2, this method should produce accurate results even when there is little to no land ice present.

We agree that this conceptual description of the inverse modelling method should be included in the manuscript, and will add it to the Methodology section.

P8, L13-19: Added a conceptual explanation of the inverse modelling method to the Methodology section.

Line numbers are not continuous, it is not easy to comment.

We followed the Copernicus article template in restarting line numbers at 1 on every page.

Page 1 line 9: "such a climate state existed for a significant duration of time", please specify how this climate state is.

This means a warmer-than-present climate state.

P1, L9: changed this.

In Figure 1: There are a lot of pCO2 data across this period, here the authors only show one inverse data which may mislead readers.

We agree. We will add the available proxy records and the reconstruction by van de Wall 2011, which are used later on for model evaluation, to the figure.

Figure 1: added CO2 proxy data and model reconstructions.

Page 2 line 9: "Over a period of about 20,000 years". Why is 20 kyrs, please provide the specific date for MIS M2.

The warm peak in the d18O record directly prior to M2 occurs during MG1, at 3.315

My. The cold peak of M2 occurs about 20,000 years later, at 3.295 My. We will add this information to the manuscript.

P3, L8: Added this information to the manuscript.

Page 6 line 3: 200 ppmv, not 220 ppmv?

This is indeed a typo, we will fix it.

P8, L1: Fixed the typo.

Please describe the information for each labeled plot. Figure 9 is not labeled with the alphabet.

We agree that this should be fixed for all relevant figures in the manuscript. We will do so.

Figure 9: reordered the panels alphabetically.

Figure 10: added panel descriptions to the caption.

Figure 11: added panel descriptions to the caption.**Figure 6: added panel descriptions to the caption.**

Figure 9: reordered the panels alphabetically.

Figure 10: added panel descriptions to the caption.

Figure 11: added panel descriptions to the caption.

Interactive comment on Clim. Past Discuss., https://doi.org/10.5194/cp-2019-34, 2019.