

Answer to Anonymous Referee #2

We thank Referee #2 for pointing out the required clarification and constructive criticism for improvements. In the following text, we answer all the points discussed by Referee #2, where Referee comments are written as R: and authors comments are written as A:.

R: Generally the text reads well, but the flow and structure can be improved. The paper is quite long (the draft has 55 pages!), and the introduction does not place the sections well into context. The different datasets are dropped in without much context. After "1 introduction" comes "2 methodological consideration", "3 regional correlations", "4 Investigation of LGM climate physics", "5 Comparison of the sources of noise" "6 Statistical view on outlier models and generational issues", " 7 Prospects from single-model ensembles" and finally "8 Conclusions", the text meandering along and surprising with nice graphics and well thought-out sections. Please condense structurally and provide more overview in the beginning.

A: We modified the end of the Introduction to provide a better overview of the content of each section. The datasets are described in Methodological considerations, and each subsection of the results has a small introductory paragraph. We believe it is necessary to have this number of section and subsection as our paper covers wide and different topics.

"The paper is organized as the following:

- Section 2: We define the climate sensitivity, temperature variable and emergent constraint theory. We describe the PMIP models and the ensemble of analysis performed to investigate the spread of models.
- Section 3: We extend on methodological considerations by analysing global and regional correlations between temperatures and ECS in the LGM ensembles, as to provide a better view on potential tropical and extratropical biases.
- Section 4: We show the different aspects of the climate system which can be suspected as significant contributors of noise in the emergent constraints. This considers several climate components, i.e. atmosphere, ocean, land surface and cryosphere.
- Section 5: We discuss the results of Section 4, and in particular the contribution and amplitude of noise on the emergent constraint relationship arising from the LGM modelled climate. We categorize the sources of noise as state-dependent or structural.
- Section 6: We further discuss issues of the LGM ensemble which are not be directly connected to the physics of the LGM, such as the effect of outlier models and differences between PMIP generations.
- Section 7: We investigate the current potential of single-model ensembles in emergent constraint on ECS by analysing perturbed physics ensembles of the Max Planck Institute Earth System Model version 1.2 (MPI-ESM1.2-LR), the Community Earth System Model version 2.1 (CESM2.1) and the CESM model family. Section 8: We provide further recommendations on using paleoclimates to constrain ECS. We reflect on the biases affecting the LGM constraint, and evaluate which past climate is ideal for the emergent constraint approach. "

R: Enhance the discussion on limitations. Given that one aim is to "provide a framework for future development of palaeo-emergent constraints" a brief discussion (or at least acknowledgement) of the data/model setup based limitations should be included. One can wonder to what extent ECS is a useful metric in palaeoclimate, given that the system is rarely in equilibrium. The Earth system at beyond-millennial timescales is evolving and feedbacks act across timescales which cannot (yet) be considered with PMIP models. The distinction between "Earth System Sensitivity" and "Climate sensitivity" is not explicitly made, yet it is shown that ice sheet forcing contributes substantially to the radiative forcing and sensitivity.

A: This is an interesting aspect which indeed required further clarifications. In this paper, we apply the definition of ECS as used by the IPCC, which excludes some feedbacks such as the ice sheet feedback. Missing feedbacks are absent from both the abrupt4xCO2 simulation, from which ECS is diagnosed, and the LGM simulation; their inclusion should move models along the already existing

regression line, as it represents in some aspect the relationship between temperature / feedbacks between LGM and abrupt4xCO₂. Therefore, missing feedbacks which are considered in the definition of ESS are not expected to modify the regression properties. The issues analysed in this study mostly arise from differences between models that are not expected to improve when feedbacks are added. We have added a paragraph to the Discussion section to highlight this point. For the case where the 150-year long abrupt4xCO₂ simulation from which ECS is diagnosed is far from equilibrium compared to the LGM simulation, we referred to it in the extended paragraph on the ocean as a sources of noise, as suggested by Reviewer #1.

“It is important to highlight that the definition of ECS is similar to that of the Intergovernmental Panel on Climate Change (IPCC), which includes all feedbacks except the ice sheet feedback. The latter is therefore a missing feedback in both abrupt4xCO₂, from which ECS is diagnosed, and in the LGM state. Its inclusion should therefore affect both abrupt4xCO₂ and LGM temperatures proportionately, such that climate models would be displaced along the current relationship, and therefore the regression properties should remain similar. The issues analyzed in this study are, for most part, not missing feedbacks, but arise from the lack of consistency between models. These issues are not expected to be reduced with the addition of missing feedback, on the contrary, as models would have more freedom to differ from each other.”

R: Pliocene/LGM. Given that the LGM is in the title, once conclusion is that the Pliocene may be a better target to derive emergent constraints. So perhaps the title is not appropriate, and the framing should be adjusted.

A: We believe the title to be appropriate, as the focus of the paper is on the LGM and highlight issues with LGM physics; putting Pliocene in the title may misdirect readers. A paper focused on the Pliocene is planned for submission soon, which should address in details the issues of the Pliocene.

R: - p2 l32: last ice age --> correct to last Glacial period (we are still in an ice age) - correct citation Rohlin et al., 2012 should be PALAEOSENS Project Members. 2012. - Table 7 there are no parentheses (or rather, only two lonely ones)

A: Corrected. We also added a few clarifying words and corrected typos and a reference (Zhu et al., 2022b).