Authors' response to Referee #2

Interactive comment on "Early Eocene vigorous ocean overturning and its contribution to a warm Southern Ocean" by Yurui Zhang et al.

Anonymous Referee #2

I also reviewed the paper for another journal and the line numbers below refer to that version.

We are grateful to the reviewer for these insightful comments. As explained to the other reviewer the submitted version of the paper to Climate of the Past was modified from the version the reviewer has previously reviewed, and most comments and suggestions were already taken into account. Below we provide one-by-one replies to answer the questions raised by the reviewer (we denoted the replies by blue color) and to explain how and where these have been incorporated in the manuscript, and we done and/or to clarify some points. The line numbers (in brackets) correspond to the resubmitted version of the paper.

The study by Zhang et al. presents new model simulations of the early Eocene based on paleo-geographic reconstructions from the DeepMIP initiative, using the AOGCM IPSL-CM5A2. A comparison to simulations with modern conditions is used to investigate to role of ocean circulation changes and meridional heat transport for high latitude warmth in the Southern Hemisphere. The authors find a strong abyssal overturning circulation in the Southern Hemisphere (SOMOC) that leads to enhanced poleward heat transport that maintains warm Southern Hemisphere high latitudes. Additionally, in contrast to earlier studies no deep water is formed in the Northern Hemisphere in the early Eocene simulations. These are novel points worth to publish and the authors provide an elaborate analysis of factors (e.g. tidal mixing scheme and CO2 changes) controlling the vigorous SOMOC in their early Eocene simulations. Nevertheless, the current manuscript could be improved by testing their findings in the context of North Pacific deep-water formation as this might be the most important modulator of the presented results. In that sense, the absence of North Pacific deep-water formation might be inherently linked to the basic question 'What does explain such a strong SOMOC?' (line 275).

We have tried to elaborate a bit more in the revised version on why deep water formation occurs in the Southern Ocean but not in the Pacific, as explained in the following. [line 257-285]

Comments & Suggestions:

- To address this point, it might be helpful to include an additional experiment with a preindustrial CO2 concentration in the atmosphere. If this scenario is unlikely to give North Pacific deep-water formation, an artificial modification of the continental run-off distribution in the Pacific might help.
This is a good suggestion and indeed such an additional simulation (Eocene bathymetry and PI CO_2) would be useful. Yet, given the computational cost of running any of these simulations, it was not possible to run a new one for now (but we might in the future). However, the analysis of the Eocene 1.5-x simulation (which is not that different from what the reviewer is suggesting), and the comparison with the Eocene 1.5-x simulation suggests that the circulation is largely insensitive to the level of CO_2 during the Eocene (at least within this range), which makes us confident in the results presented in the manuscript.

- Line 234: In the Weddell Sea surface density is much larger than in the North Pacific (+0.51 kg/m3). Is it trivial from this value that North Pacific deep-water formation is absent? Do you expect a critical value?

What actually matters is the local change in stratification, of which the surface density is a good proxy in our case because the deep water density is much more similar in the two regions and between the different

simulations (we have clarified this point in the revised version, see Lines 261-266). So, although it would be nice, we do not think there is such a thing as a threshold that allows (or not) for deep water formation in the Pacific. That said, such a statement should be checked more carefully, and could be a basis of a model intercomparison study based on the DeepMIP archive.

- It is recommended to include the CO2 sensitivity into the section '3.3 Factors contributing to the vigorous SOMOC'

We respectfully disagree with the reviewer on that point. We feel that the storyline of the paper would get messy if we were to include the CO_2 sensitivity results earlier on, and we would lose the coherency that we believe section 6 has as it is.

- Please revise Table 2: the mean values and the relation to the uncertainty ranges is unclear, use units within the table for clarity, is the uncertainty range one or two sigma?

Uncertainty range had been added in Table 2. It read as "The uncertainty range is defined as the 2σ deviations (2.2% and 97.8%) for $\delta^{18}O$, and as the range between 5% and 95% percentile SST estimates for TEX^{86}, Mg/Ca and clumped isotope data."

The units are now indicated in the table.

Summary: Although the study is already at a reasonable level, the authors are encouraged to address the potential influence of North Pacific deep water on the presented findings. I would be happy to have a look at a revised manuscript version.