Climate of the Past Discussions

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Reply on RC1

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Author comment on "Sea surface temperature evolution of the North Atlantic Ocean across the Eocene–Oligocene transition" by Kasia K. Śliwińska et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2021-184-AC1, 2022

We would like to thank Dr. Michiel Baatsen for his time and effort reviewing our manuscript. Our replies to the comments are marked as bold text.

The authors present a new high quality dataset of proxy SSTs in the Northwest Atlantic Ocean spanning the late Eocene into the Oligocene. The obtained SSTs are compared to other available sites nearby, as well as adequate recent model results which spark an interesting discussion. I believe that these results can greatly contribute to our understanding of the events surrounding the EOT, covering a region where the available data is scarce.

Thank you for such a positive overall evaluation of our manuscript

General remarks:

The manuscript is structurally sound, provides a balanced amount of proxy-/model-derived data as well as an extensive methodology and discussion sections. Overall, an extensive language/grammar check is needed as many small errors and typos remain in the text. **We will go through the manuscript and corrected the language and grammar errors and typos.**

While the comparison to model data is quite useful and important, the use of a single model makes it hard to judge which part of the results are the most model-sensitive. It is probably quite hard to find other adequate model data for this specific case, but the limitations could be highlighted more, especially considering the different deep water formation regimes. Compared to e.g. results in DeepMIP, despite representing Early Eocene conditions, it is clear that different models present a whole suite of possible overturning regimes under comparable boundary conditions. **This is true. We will now cite Zhang et al. (2022) and we will discuss how the GFDL model overturning circulation in the Eocene compare to other models and what the implication of that could be for the results.**

Although relevant, much of the discussion is rather superficial and qualitative in nature. Many of the claims/ideas would be hard to check in the available model data, but it could be helpful to have a more detailed look into some of the mechanisms that drive the changes in circulation and SST shown. This could include e.g. the radiative balance, surface/gateway fluxes, meridional temperature gradients and/or transports, and wind

stresses. **The reason why we have not presented extensive model analysis is because we do not want to take the focus away from the core contribution of the paper, which is the new high temporal resolution SST data in a region near modern deep-water formation zones. We do not mean to make claims; but on the contrary, present how difficult it can be to use paleoclimate proxies and modelling to make any strong claims about what happened at the EOT. However, we can see that at some points we used words like "probably because of" without justifying that. We will be more careful with that and add analysis such, as further analysis of the AMOC stream function, where appropriate. Please also see below how we address the specific points relevant to this general point.**

Minor comments:

The introduction cites many earlier, i.e. pre-2010 papers, so it could be useful to check for some more recent work on some of the subjects discussed here (e.g. potential Greenland glaciation or sensitivity to model boundary conditions around the EOT). **We will check it.**

In equation 1, the terms [37:2] and [37:3] are not explained **We will add an explanation of these terms in Equation 1**

L184: rephrasing this sentence would make it more readable **it will be corrected**

L194: this statement may be a bit outdated, as several studies presented model simulations of comparable resolution in more recent years; e.g. Li et al. 2018, Tardif et al. 2020, Baatsen et al. 2020. Also several studies within DeepMIP, albeit for Early Eocene. **We will now state that our model resolution is in line with state-of-the-art models for the EOT and add these citations.**

L209: I would rephrain from using the term 'observations' for proxy data; these are proxies that give us an indication of SSTs in the deep past, but are not actual observations. **It will be corrected, we will refer to them as "proxy reconstructions"**

Section 4.2: same remark as L209, also acronym NA used for North Atlantic which seems inconsistent with the previous sections, in which no acronym is used or introduced. **The acronym is introduced in line 27. We will now however, spell North Atlantic in full**

L266: increased CO2 would indeed likely lead to higher temperatures and a reduced meridional gradient, but will still increase lower latitude temperatures as well. It does seem like increasing CO2 would not be very helpful if only higher latitude SSTs are underestimated by the model. **We agree that the model already overestimates the low latitude temperatures by a few degrees when the CO2 is 800 and this will get worse if the CO2 is increased. We have in the previous version pointed to the fact that this higher CO2 explanation has a problem in that there is little evidence for a much higher CO2 and now we will add the issue about increasing the lower latitude temperature as well.**

L286: As the AMOC has not collapsed in the modern climate, this comparison is a bit odd. Some future projections show an AMOC slowdown, but this needs to be stated more carefully. **The reference is to an idealised study in which the AMOC is artificially shut down by a salinity perturbation. We do not mean to suggest that an AMOC collapse is a modern observation, only that in a modern framework, an induced AMOC collapse also cause NA cooling. We will clarify this in the new revision.**

L289: it would be helpful to have some more specifics on the actual related AMOC strengths and associated meridional heat transport to support this claim. **We will add**

further analyses of AMOC streamfunctions, and the SST in the formation regions in each case, in order to clarify this statement about changing AMOC strength.

L327: This may even be more important than changes in AMOC strength, as they do not induce the expected SST changes seen in the proxy record (as argued). On the other hand, the idea of this site sitting on the edge of 2 gyres shifting over time does not match well with the relatively small SST variability, as such SST changes are often strongly related to the background gradients. **Indeed, the zonal temperature gradients are in general weak in the model, so a simple shift in the gyre boundaries would not make a big SST difference at the boundary of the gyres when all else is the same. The SST gradient can be larger between the western boundary current and the eastern side of the same gyre than between two gyres. We will now clarify this aspect in more detail. Specifically, the barotropic streamfunction in Figure 7 shows that the circulation in this region changes completely when the Arctic closes and the AMOC starts up, and Figure 6a and 6b show that the associated NA warming broadly outlines the subpolar gyre boundary of the open cases and it has a strong gradient at site 647 so that if the site was just a few degrees to the south (or arguably the gyre to the north) it would experience much less warming and might even have a degree or two cooling when taking into account the CO2 cooling. Given that the gyres are most likely quite model dependent, we do not want to put too much weight on the exact position of the site in relation to the gyres but rather point to the fact that the NA warming is quite regional and the circulation at the core site here is quite dynamic and on the boundary of where warming occurs. We will be clearer about that in the revised version of our manuscript.**

Figures:

Fig4: Not very intuitive and tough to read; many overlapping points and lines. Consider separating the pre/post-34.5Ma into 2 panels? **It is not obvious how to separate the model simulations in pre/port-34.5 Ma bins, especially the Arctic-close high CO2 case and the Arctic-open low CO2 case. We have instead significantly increased the resolution of the figure which will be much sharper in the revision.**

Fig5: It is hard to distinguish between the different panels and see the differences, especially for the proxy SSTs. Differences are also shown in Fig6, but as of now Fig5 does not seem to be adding much information apart from an overall idea of absolute SSTs. **The idea is to spatially compare the different model simulations to the proxy reconstructions for absolute SST for both pre 34.5 Ma and post 34.5 Ma, something which is not possible to see in our other figures.**

Fig7: What is the added value of showing the barotropic stream function? This is rather hard to interpret, as it represents the depth-integrated flow, while the rest of the manuscript mostly discusses (near-)surface conditions. With the presence of a meridional overturning circulation, such as the AMOC in this case, it becomes quite hard to distinguish the wind-driven gyres within these fields. **The barotropic streamfunction is a quite common way to show the boundaries of the gyres in the North Atlantic. It gives a good indication of the upper layer circulation, including the AMOC, except arguably over strong deep boundary currents. The main point here about the upper layer circulation in the region of the site being quite dynamic and the currents changing drastically with the changing paleogeography, is unlikely to break down if the deep circulation was subtracted from the streamfunction. But it is necessary to include the full depth circulation to construct a streamfunction, because it must be non-divergent.**

Technical comments/typos:

As noted above, a thorough language check is needed. **It is checked and will be corrected**

Some examples: L95 conclude with summary, L128 as follow, L151 fiveteen, L282 studies has, L304 gateway changes?, L307 require L338 provides **we will address these issues.**

Typos:

L90: circulation **will be corrected**

L206: the the **will be corrected**

L245: equivalent **will be corrected**

L251: ensemble **will be corrected**

Section 5.1: title SST (2x) -> EOT? **will be corrected**

L293: Arctic **will be corrected**

L294: it may **will be corrected**

Fig2: therein **will be corrected**

Other small Errors:

L276: the model has too low polar temperatures? **will be corrected**

L306: Southern Ocean Gateways? **will be corrected**

L357: missing word **The sentence should state: "It is possible that the AMOC did not start up in the late Eocene, but alternative explanations are then required for the deep ocean circulation proxies that suggest this (Coxall et al., 2018)"**