

Second Review of: Mid-Pliocene not analogous to high CO<sub>2</sub> climate when considering Northern Hemisphere winter variability (Oldeman et al., 2023)

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This is my second review of this study. I congratulate the authors on strengthening their manuscript. I found the overall study had a much more coherent storyline, the figures were easier to read, and I thought the added tropical Pacific discussion was interesting. I have only a few minor comments remaining before this study is accepted for publication.

Energy budget: In your response to the Editor you mentioned you would be completing an energy budget analysis to respond to his concern about why SAT changes in response to changing BCs. I either missed this, in which case it needs to be made more obvious, or it wasn't included. Either way, I think this concern needs to be addressed more clearly.

- We will include a brief energy budget analysis, using a simple energy balance model following Baatsen et al (2022), Hill et al (2014) and Heinemann et al (2009). We will include methods and results in the Supplementary material and mention the conclusions briefly in the main manuscript.
- Using this method, we can separate the surface warming between two simulations in contributions related to planetary albedo (i.e. shortwave fluxes), effective emissivity (i.e. longwave fluxes) and meridional heat transport. We can split the emissivity contribution in warming related to longwave cloud forcing, and warming related to clearsky emissivity, e.g. from greenhouse gases or lapse rate feedbacks.
- In section 4.1.2 'The role of mean surface temperature response', we will replace the first paragraph with conclusions from the energy balance model, with reference to the Supplement. We propose the following: **“Qualitatively, the SAT response to increased CO<sub>2</sub> and to the mid-Pliocene BCs is similar. However, an energy budget analysis reveals that the radiative forcings leading to the warming are not the same (shown in Supplementary material Figure S10). The surface warming in the E560 is explained by changes in effective emissivity from the increased greenhouse gas concentrations. The surface temperature response in the Eoi280 is a combination of changes in planetary albedo, as well as effective emissivity. The changes in emissivity here are related to lapse rate feedbacks and changes in water vapour. The warming due to changes in planetary albedo is mostly related to changes in vegetation and lakes. Albedo changes from the reduced Greenland ice sheet do not contribute to warming in January because the incoming solar radiation is at a minimum. This is different in the annual mean, as seen in Baatsen et al (2022). In both simulations, warming in areas with sea-ice loss is related to reduced emissivity from increased evaporation leading to increased cloud cover.”**

Hill et al (2014): <https://cp.copernicus.org/articles/10/79/2014/>

Heinemann et al (2009): <https://doi.org/10.5194/cp-5-785-2009>

L321 & L333: I didn't follow why you think the changes in precipitation around Greenland are related to sea ice.

- A decrease in sea-ice leads to increased precipitation through increased local evaporation and convection, see e.g. <https://www.pnas.org/doi/abs/10.1073/pnas.1504633113>

- We will make the following change in the manuscript: "...and a concentrated precipitation increase is seen South of Greenland. **The precipitation increase in the Arctic is related to a retreat of sea-ice in that area (not shown) through increased local evaporation (Kocec et al 2015), agreeing with the local SAT increase and MSLP decrease.**"

Figure 3: This isn't major, but I suggest flipping the color axis on the contours so that blue is wetter and red is dryer for panels b and c. I think it's then a bit more logical to quickly read the plots.

- Agreed, we will make that change accordingly

Figure 6: I had a hard time differentiating between bold and not bold font in these squares. I suggest using underlines or asterisks to show the  $p < 0.005$  values instead.

- We will use asterisks instead

Typos:

L203: Should be a colon rather than a semicolon. **Will change**

L349-350: "a lot more" and "a bit less" are both qualitative phrasings. You have statistical significance here, I suggest sticking to the quantitative descriptors. **We will remove 'a lot' and 'a bit' altogether since the sentence already includes information that these differences are statistically significant**

L370: "differences are that" is awkward grammar. **We will change: "The spatial pattern is very similar, with notable difference being that ..."**

L378: "the northern node is retreated polewards" is awkward. Maybe it should be "has retreated" instead. **We will change to: "while the northern node is weakened and shifted polewards."**

L394-396: I got confused with your use of parentheses here and missed the message you were trying to make. This isn't a case of "the mode is positively (negatively) correlated with..." sort of use you use slightly later in the manuscript. Please revisit this sentence. **We will change to: "... the correlation between the AO and EA is stronger than the correlation between the AO and NAO, which is not very obvious based on the similarities of the spatial patterns of these modes."**

L400-401: Similar strange parenthetical structure as comment above. **We will change as follows: "The AO shows the strongest correlation with the EA (PNA) in the NA (NP), and simultaneously the EA and PNA show a stronger correlation compared to the E<sup>280</sup>."**

L476: "a jet stream weak in strength" should be "a weak jet"? **We will change into 'a weak jet' as suggested**

L478: Similarly, "a jet less variable in strength" and "a jet more variable in latitude" is strange phrasing. **In L474, we propose to include "... jet stream that is less variable in strength (in terms of zonal wind speeds, Figure 7c)..." so that it is clarified what is meant by strength. In L478 we will add "... more variable in latitudinal location ..." as in L475 before.**

L483: "indexc" **Thanks, we will change to 'index'**

L485: "WEP is established before" should be "WEP has been established" **Agreed, we will change accordingly**

L498: "summarizing 2. - 4b." -- what are you referring to? Figures? **We are referring to the steps of the mechanism as elucidated before in the section. We will add "summarizing steps 2. - 4b. of the mechanism"**

Figure 9 Caption: "correlation coefficient in the caption" -- I think you mean in the legend. **Indeed, we will change accordingly**

L510: "that shows" rather than "that show" since the subject of that sentence is the "study."  
Thanks, we will change this

L577 & L281: You've referred to it as "Supplementary" material more throughout, so I suggest changing "Supplement" here. We will consistently use "Supplementary material" throughout

L654: I feel like there should be a "can" or "should" between "climate" and "be" in this sentence. We will add 'can', as in the research question posed in the Introduction

L679: "might not be" is rather weak language compared to the rest of your conclusion which says the Mid-Pliocene should not be used as an analogue. Agreed, we will change to "is not", which is more consistent also with the title and abstract

L683: "we think that it might" can just be "it may" We will change accordingly

Supplementary Material S6: I believe the second Figure S10 at the end of the section should be Figure S11. Indeed, we will change this accordingly.

Reviewer #2: comments on the revised manuscript

This study is much improved from the initial submission, and the authors have done an excellent job at addressing my concerns, including substantial new analysis, a section dedicated to the likely role of tropical SSTs, and substantial restructuring of the paper. The new title now accurately represents the findings. I am happy to recommend publication, subject to the following minor suggestions:

Line 17. How is the response of the climate to increased CO<sub>2</sub> determined by natural variations? **We meant to say that natural variability is a part of the response of the climate to increased CO<sub>2</sub>, not the other way around. We will change it: "... the response of the climate system itself, including feedbacks and natural variability, to increased CO<sub>2</sub>."**

Line 59. 'lowering of the Rocky mountains' implies to me that the mountains reduced in height over time, rather than, as I think you mean, that the mountains were lowered in the model simulations of the Pliocene. **Indeed, we mean that the mountains had been lowered in the simulations. We will change this to: "... primarily attributed to the reduced height of the Rocky Mountains in the model simulations."**

Line 130. I know you are focussed on the atmosphere, but given your results on the impacts of the tropical convection, which is almost certainly related to tropical SSTs, I think it is useful to also given information on the ocean model and resolution. **Agreed. We will include "... The model version used here employs the ocean model POP2 and the atmosphere module CAM4, ..." and in L135: "The atmospheric grid ... levels, while the ocean grid has a nominal 1° (1.25° x 0.9°) horizontal resolution."**

Line 261: "The weak but distinct eastern node with opposite sign in the CR20 disappears in the E280" – from my interpretation of figure 1g, the eastern opposite sign node is present in the shading, but not the black/white contours, which from the caption means it is present in E280 but not the CR20, the opposite to the text. **We acknowledge that this is confusing. We will change this sentence: "The center of gravity of the strong negative node shifts eastward in the E<sup>280</sup>, with regards to the CR20, likely because the variance shifts more eastward in the E<sup>280</sup>." This is slightly different information, but we think this is actually more relevant for the total context.**

I recommend being slightly more clear that Eoi280 is mid-pliocene boundary conditions, not mid-pliocene conditions, as stated in, for example, line 293. **Agreed, we will make sure to consistently refer to the Eoi280 simulation as 'mid-Pliocene boundary conditions'.**

Fig. 6. I understand that you don't need the AO column in panels b and c, but then you also don't need the top row – it's a little less clear to me why you would make the different panels a slightly different shape rather than just retain the triangles for the auto-correlations. **The motivation to remove one column was to reduce figure width (apart from the column not adding any extra information). To resolve this, we can add the extra column so that the shape is more consistent, and we will slightly increase the fontsize.**

Line 455. Suggest to add ('blue line') to help readers. **We will add this.**

### Section 3.3.3

Point 1a. Suggest '...Walker circulation, and lead to a northward shift...' for clarity that the northward shift isn't being reduced. **We propose to change the order of this sentence to the following, for clarity: "Shifts in the tropical mean state, specifically the ... of the ITCZ, reduce mean precipitation in the west-equatorial Pacific (WEP)."**

Point 3. It isn't clear to me why reduced Rossby wave forcing from the tropics would lead to a North Pacific jet that is more variable in latitude – is this from the literature or from your

results? This conclusion is from both our results and in support of literature. However, in the current phrasing it is indeed unclear and suggestive. We propose to change to the following, where we include an extra reference in support of the mechanism:

**“3a. Since the jet stream acts a wave guide for Rossby waves (e.g. Branstator, 2002), reduced upper-tropospheric Rossby wave activity over East Asia leads to a North Pacific jet stream that is weaker (Figure 2c) and less variable in strength (Figure 7c).**

**3b. A weaker jet stream is associated with Rossby wave breaking downstream (e.g. Woollings 2010, de Vries et al. 2013) which leads to a jet more variable in latitudinal location (e.g. Rivière 2010) over the central and eastern North Pacific (Figure 7d).”**

where Woollings (2010) and Rivière (2010) have already been cited in the manuscript, and de Vries et al. (2013) would be added: <https://link.springer.com/article/10.1007/s00382-013-1699-7>

Careful with correlations vs causality here – I’m not sure you can conclusively say that the change in Rossby wave tropical forcing causes changes to the jets, which cause the changes in the NPO/PNA patterns instead of changes in the Rossby wave tropical forcing causing changes in the NPO/PNA patterns which lead to change in the jet, can you? The zonal wind changes in Fig 9b and c look like they are likely approximately geostrophic if the pressure changes are equivalent barotropic. **This is a good point. However, we do not think any changes in the text are needed.** Based on our results, one can indeed not discern whether changes in the jet lead to changes to modes of variability, or the other way around, since we only show correlation coefficients. In the present manuscript, we already tried to avoid causality between jet and PNA/NPO by using words like ‘correlates with’ and ‘implies’, instead of ‘causes’.

Line 503. ‘thus lead to’ **Thanks, will change**

Line 505. I like that you have included the RWS analysis, but I think it is worth mentioning in the main manuscript that you include RWS analysis in the supplementary material, rather than just “more extensive analysis” **We will change this into: “More analysis on the connection between tropical convection and Rossby wave activity, including a computation of the Rossby wave source, can be found in ...”.** In addition, we will include a sentence in the Methods section (section 2.2): **“Additionally, we performed a calculation of the Rossby wave source, which is included in the Supplementary material.”**

Line 513: dates for citations shouldn’t be in parentheses within parentheses. **Thank, we will make this change**

Line 533: in E560 the warming is ‘mostly’ due to greenhouse gases? Is there any other forcing in this simulation? **This is a mistake, we will remove the word ‘mostly’**

Line 621. Can you clarify that those 3 changes seen by ‘most’ PlioMIP2 models (and thus, I assume, in the multi-model mean), are also seen in the CCSM4-Utr model? **Yes, we will add: “Most PlioMIP2 models, including CCSM4-Utr, show ...”**

Line 631. How does orography adjust as a feedback in response to climate change? **Here we mean that adjustment to orography changes is a feedback, but since this is unclear we will change it: “... such as adjustment to changes in ice sheets and to changes in orography, ...”**

Line 654. Grammar: ... we address the question of whether the mid-Pliocene climate can be... **We will change this.**

Supplementary: S5.3. I’m unsure how the RWS can be a wave guide for the jet stream. We typically think of the jet stream as waveguides for waves from a RWS. **This is a mistake and should be the other way around (as is correctly stated in the manuscript L473).** We will change this accordingly.