RC1

Dear reviewer 1, many thanks taking the time to review. We appreciate the positive feedback. In this document we aim to answer your specific comments. We think the manuscript will be improved after implementing these changes.

I enjoyed reading Oldeman et al manuscript on the relationship between North Pacific climate and ENSO variability during the mid-Pliocene. The manuscript is well-written, and the figures are very clear. I had some minor edits in the .pdf version of the manuscript. (we have copied the comments into this document including line numbers).

I'd encourage the authors to explore the residual part of the Aleutian low (AL) variability a little more in-depth. If the AL variability is not linked to Arctic variability, what about the variability of western Pacific moist convection, and the resulted upper-tropospherical heating? It was suggested at various places in the manuscript that the convective heating and the generated Rossby wave, i.e. the atmospheric bridge, is the mechanistic link between the tropical and AL variability, but was mainly discussed in the context of ENSO. Yet, the variability of western Pacific moist convection probably won't be entirely explained by ENSO, right? Can residual western Pacific variability explain the residual AL variability?
Thank you for this remark. We have explored the residual AL variability more in depth (including a look at the Arctic Oscillation), but there does not seem to be one feature that can explain the residual AL change for all or even most models. Also because the residual AL variability change is not the main focus of this paper, we decided to only include the mean state changes as described in Section 4.2.2 and Supplementary Figure S6. We are hesistant to include more results in the manuscript, as we will explain below.

Arctic variability

- To clarify, we are not ruling out that the changes to the residual AL variability are related to changes in Arctic *variability*. In section 4.2.2. and Supplementary figure S6, we correlate the change in residual AL variability to mean state changes (and not variability changes). Hence, it seems clear that changes in the residual AL are not related to *mean state changes in the Arctic*, but we have not assessed whether Arctic variability changes are related to the residual AL variability changes.
- In order to explore the residual AL variability more, we investigate the influence of the Arctic Oscillation (AO), which we define as the leading SLP EOF in DJFM between 20°N and 90°N (note: this analysis is not currently included in the manuscript or Supplement). We compute the principal component (PC) per model and simulation and correlate the PC with the total Aleutian low (AL) index ánd the residual AL index. The AO correlates quite strongly with the AL, with an MMM value of about 0.71 (not much difference between E280 and Eoi400) and a few models showing correlation coefficients of >0.90. The AO correlates a lot less with the residual AL (in comparison to the total AL), with a MMM correlation coefficient of 0.54 and no model showing values >0.90.

- The change in residual AL variability correlates significantly with the change in AO SD (~0.70), which could imply that the change in residual AL is related to a change in AO. However, the change in the total AL variability correlates a lot stronger with the change in AO (~0.90). So, removing the ENSO signal from the AL variability does not increase the ensemble change correlation, but rather decreases it.
- An important point here is that -by construct- the AO will contain a large part of the AL variability as the leading SLP EOF captures most of the SLP variability in the North Pacific. In fact, the AO can be considered a sum of the variability of the Aleutian low and the North Atlantic Oscillation. So, the change in (residual) AL variability and the change in AO are bound to correlate, simply because they represent a large part of the same SLP variability in the first place. It is for this reason that we do not think it is relevant to include this result in the manuscript.
- Lastly, the residual AL variability could still be related to other forms of Arctic variability, such as variability related to sea-ice, but we consider it outside of the scope of this paper to assess these changes.

West Pacific moist convection / precipitation variability

- Indeed, tropical West Pacific moist convection variability is not entirely explained by ENSO variability. The correlation between the Nino3.4 and WEP precipitation is 0.82 in E280 MMM and 0.69 in Eoi400 MMM, implying that around 20 - 30% of WEP precipitation variability is not (linearly) explained by ENSO variability (again – these are results not currently included in the manuscript).
- To explore whether the changes to residual AL variability are related to or explained by residual western tropical Pacific moist convection, we split the WEP precipitation in a part that regresses with Nino3.4 and a residual (using the LRM). We compute the SD of this residual precipitation and correlate the difference in residual precipitation variability with the difference in residual AL variability, and find a non-significant correlation coefficient of 0.21 (p-value of 0.47). This means that the change in the residual AL variability is **not** related to a change in the residual West Pacific moist convection variability (i.e. the residual WEP precipitation variability).
- We will include this result by a brief mention in the main text in L317: **"The change in residual AL variability is also not related to a change in residual WEP precipitation (Supplementary Material Figure Sxx)."** And accordingly include the figure in the Supplement.
- In addition, regressing the residual AL variability onto the tropical precipitation shows weak regression values and low correlation coefficients that are largely not significant (depending on the model and simulation). This is a further indication that West Pacific tropical precipitation is not the main driver of a change in residual AL variability for all models (i.e. not consistent among the ensemble).

Specific comments

L43. “drier conditions over the subtropics” - The drier conditions only apply to the subtropical ocean. On land, monsoon in the subtropics is generally enhanced (e.g. Berntell et al, 2021; Feng et al., 2022)
Berntell, E., Zhang, Q., Li, Q., Haywood, A.M., Tindall, J.C., Hunter, S.J., Zhang, Z., Li, X., Guo, C., Nisancioglu, K.H. and Stepanek, C., 2021. Mid-Pliocene West African Monsoon rainfall as simulated in the PlioMIP2 ensemble, Clim. Past, 17, 1777–1794.
Feng, R., Bhattacharya, T., Otto-Bliesner, B.L., Brady, E.C., Haywood, A.M., Tindall, J.C., Hunter, S.J., Abe-Ouchi, A., Chan, W.L., Kageyama, M. and Contoux, C., 2022. Past terrestrial hydroclimate sensitivity controlled by Earth system feedbacks. Nature Communications, 13(1), p.1306.
Thanks for the addition. We agree and will change accordingly: “... specifically wetter conditions over the deep tropics**, such as the Pacific Intertropical Convergence Zone (ITCZ, Han et al. 2021). The subtropics get drier over the ocean but precipitation over land is generally enhanced related to enhanced monsoonal activity (Berntell et al 2021, Feng et al 2022).**”

L48-49. Please also see the Zhang et al., (2014) and Tierney et al., (2019). Both suggest that the zonal gradient is not as reduced as previously thought and could be in line with model estimates.
Zhang, Y.G., Pagani, M. and Liu, Z., 2014. A 12-million-year temperature history of the tropical Pacific Ocean. Science, 344(6179), pp.84-87.
Tierney, J.E., Haywood, A.M., Feng, R., Bhattacharya, T. and Otto-Bliesner, B.L., 2019. Pliocene warmth consistent with greenhouse gas forcing. Geophysical Research Letters, 46(15), pp.9136-9144.
Thanks for the suggestion. We will add a sentence in between the sentences of L52: “**In addition, more recent reconstructions and modelling efforts suggest that the zonal SST gradient is not as reduced as previously thought and could be in line with model estimates (Zhang et al 2014, Tierney et al 2019).**”

L75. ‘interesting’ → ‘valuable’?
We will change “an interesting” to “**a valuable**”

L161. “The LRM is constructed” - Isn't this just the quality of the ordinary least square? I may be more clear, i.e., "Ordinary least square ensures that the ..."
Thanks for the suggestion. We agree and will change the sentence: “**Ordinary least square ensures that the** LRM is constructed such that ...”

L161. “Niño-regr. part” - variance of the regression as a function of Nino-3.4 index, and ...
We will change “Nino-regr. part” to “**part of the AL variability that regresses with the Niño3.4 index (Niño-regr. part)**”

L165. “Niño-regr. AL” – write this out?
We will change “Niño-regr. AL” to “**Niño-regr. part of the AL ..**” as we have just introduced the Niño-regr. ‘abbreviation’ before.

L170. "ECS is defined as ..." - Add "with pre-industrial boundary conditions. " ECS is likely dependent on background warmth and forcing.
Thanks for this remark, we agree and will add: "... to a doubling of CO_2 **with pre-industrial boundary conditions** once the ..."

L202. In the Eoi400: Eoi400 shows a logarithm relation between ENSO and AL amplitude.
We agree that the relation in Figure 2b looks like a logarithmic relationship. However, we do not think it necessary to *quantitatively* assess whether this might fit a logarithmic curve, also because there is no physical mechanism to suggest such a relationship. We are not convinced that it is relevant here to suggest that the relationship is logarithmic without including a quantitative assessment as well (as we do consistently with the linear correlation coefficients throughout the study).

Figure 4. what about the regression between AL index and the precipitation field?
Here, we aim to show the directional link or teleconnection between ENSO and the Aleutian low SLP variability, and highlight the link via Pacific tropical convection. Hence, we are are not showing the regression between the AL index and precipitation. The associated precipitation pattern of the AL variability shows a kind of dipole over the central and western North Pacific with drier conditions in the equatorward midlatitudes and wetter conditions in the poleward midlatitudes, in both E280 and Eoi400, which are expected precipitation patterns. Apart from the reason explained above, the impact of the Aleutian low variability is not a research aim of this study, and hence we do not think it necessary to include these results.

Section 4.2.1. You probably can already see the non-linear correlation between AL and ENSO, if exists, in the scatter plot of Fig. 2c? It does not look very non-linear to me.
That is a fair point. But the spread in the points is relatively large, and the linear correlation coefficient is not 1, which could suggest non-linear influences. We do not think that this point requires changes in the manuscript.

Figure 8. I'd strongly suggest remove the gray arrows in between most of the boxes and replace with question marks since there is no causal relationship being well established. Also the two black arrows between AL and PDO and Between ENSO and PDO should also be replaced with question marks.

- We appreciate your suggestion.
- Regarding the gray arrows. In the Figure legend and caption, and in the text (L374-377), we already mention that the gray arrows are based on correlation and that they do not suggest causality or directionality. However, we don't want to suggest that these arrows suggest a causal relationship, so in addition to the text in the legend and caption we will make the arrow lines dashed or replace them by connector lines instead of arrows. Questionmarks might suggest that we have no information on this relation, which is not true since we do compute significant correlation coefficients.
- Regarding the black arrows. We establish a lag-correlation between AL and the PDO in the Supplement (Figure S1), which is also explained in the text (L387), so

this directional link has been established. Therefore, we believe that we can show this relation via this directional black arrow.

- For the link between ENSO and PDO the same holds, i.e. through lead-lag correlation a directional link between ENSO and PDO has been established in Canal-Solis et al (in prep). So, we think that this black arrows is justified. We will ask, however, whether our colleagues working on the Pliocene PDO expect to submit soon, since then we can cite a preprint with doi showing the PlioMIP2 ENSO-PDO correlations. If that will not be soon, we will include a result on the ENSO-PDO lead-lag in the Supplement, or we will change this arrow to a gray arrow or connector line instead.