

Replies to Reviewer #2:

Reviewer #4 said, "I have serious concerns about the differences between their findings and prior work and the suitability of the experimental setup" and "I would imagine that differencing "flatAndes" and "real" simulations would provide much more connection to the real world" and "one might ask are these simulations too detached from the real world to be scientifically meaningful?" I agree with these comments and note that the manuscript still describes differences between the "flat" and "only Andes" cases, rather than between the "noAndes" and "real" simulations. I note that Fig 3 and line 211 show that there is very little difference in the Pacific meridional overturning circulation between the "noAndes" and "real" simulations.

Response: We thank the reviewer for this insightful comment. We agree that the comparison between the NoAndes and Real experiments is more directly relevant to the present-day climate system and therefore provides a clearer assessment of the climatic impact of the Andes under realistic boundary conditions. However, the primary objective of this study is to isolate the dynamical role of the Andes Mountains. A direct comparison between NoAndes and Real includes the influence of all remaining global topographic features and therefore does not uniquely identify the contribution of the Andes. For this reason, we employ the Flat and OnlyAndes experiments, which provide a cleaner framework for quantifying the circulation changes induced solely by the uplift of the Andes.

Importantly, the relatively small differences in AMOC and PMOC between the NoAndes and Real simulations indicate that the Andes alone are not the primary control on the modern overturning circulation. This result is consistent with our Andes2TP and TP2Andes experiments, which indicate that the Tibetan Plateau exerts a comparatively stronger influence on large-scale atmospheric circulation and therefore may play a more important role in shaping the modern strong-AMOC/weak-PMOC state. We have clarified this point in the revised manuscript (Lines 227-232).

Reviewer #1 said, "The "flat" configuration is unrealistic and therefore examining the influence of Andean uplift against such an artificial baseline has little meaning" and "Therefore, the extensive descriptions in the manuscript of the model's initial wave adjustments and atmospheric setups are largely model-specific artifacts." I agree with these comments and note that these wave adjustments and setups remain a substantial part of the revised manuscript in Sections 4b and 4c and involving

Figs 5 through 8. My conclusion is that this revised manuscript has not really addressed the major issues brought up in the first round of reviews. I think that the results presented are not of sufficient interest to justify publication in the Journal of Climate.

Response: We thank the reviewer for this comment. We acknowledge that the Flat configuration is an idealized framework and does not represent a realistic climate state. Our objective is therefore not to reconstruct the actual uplift history of the Andes, but to isolate the dynamical effects of Andean topography in a controlled coupled-model experiment.

We agree that the rapid atmospheric and oceanic adjustments following the imposed topographic perturbation should not be interpreted as a realistic evolution of the climate system. However, the analyses presented in Sections 4b and 4c are included primarily to identify the physical pathway through which the Andes-induced signal propagates from the tropical Pacific to the subpolar North Pacific and subsequently influences the Pacific overturning circulation. In this sense, the adjustment process is used as a diagnostic tool to reveal the mechanism linking the local topographic forcing to the remote circulation response, rather than as a result of interest in itself. To avoid possible misunderstanding, we have revised the manuscript to clarify this motivation (Lines 312-323).

Replies to Reviewer #3:

General Comments:

The manuscript investigates the physical mechanisms by which the uplift of the Andes Mountains influences the Pacific Meridional Overturning Circulation (PMOC) using a suite of topography-sensitive simulations in CESM 1.0. Overall, the study is well-structured and provides a physically coherent narrative linking South American topography to subpolar North Pacific ocean dynamics. The authors have been proactive in addressing the concerns raised by the previous reviewers. In particular, the addition of the Andes2TP and TP2Andes experiments significantly strengthens the paper by explaining why a vigorous PMOC is absent in the modern climate despite the presence of the Andes. Furthermore, the clarification of the research motivation—shifting from a paleoclimate reconstruction to a mechanistic sensitivity study—provides much-needed focus. However, while the authors have generally responded well, several concerns regarding the interpretation of the "Flat" baseline and the robustness of the equatorial warming signal remain. I recommend that the manuscript be accepted for publication once the following several (mostly minor) concerns are addressed.

Response: We thank the reviewer for the positive and constructive comments. The remaining concerns have been carefully considered, and our detailed responses are provided below.

Specific comments:

- 1. In the "Flat" experiment, a PMOC of approximately 10 Sv is already present, which the introduction of the Andes increases to ~15 Sv. While the authors have correctly changed their terminology from "triggered" to "intensified," the manuscript still frames the Andes as a primary driver. It should be stated more explicitly that in this model framework, the "mountain-free" state is the primary enabler of the PMOC, while the Andes act as a secondary enhancer.*

Response: Thank you for this helpful suggestion. We agree that a substantial PMOC (~10 Sv) already exists in the Flat experiment, indicating that the PMOC is not solely generated by the Andes uplift in our model framework. The primary objective of this study is to investigate how the Andes strengthen the PMOC relative to the Flat reference state. Following your suggestion, we have revised the relevant text throughout the manuscript to more clearly distinguish between the existence of the PMOC in the Flat configuration and the enhancing effect of the Andes uplift (Lines 210-213).

2. The authors find a weak equatorial warming in response to Andean uplift, which contradicts previous studies (e.g., Feng and Poulsen 2014; Xu and Lee 2021) that found cooling. The authors attribute this to the "Andes-from-flat" setup versus the "flat-from-realistic" setup of prior work. This suggests a significant "topographic path dependency" where the result changes based on the baseline; the authors should include a cautionary note on whether this specific warming/salinification pathway would hold under more realistic intermediate topographic configurations.

Response: We thank the reviewer for this thoughtful comment. To address this issue, we directly compared the SST response patterns reported by Feng and Poulsen (2014), Xu and Lee (2021), and our study by placing the corresponding figures side by side (Fig. R1). This comparison shows that the apparent discrepancy mainly arises from emphasizing different regions of the tropical Pacific rather than from opposite basin-wide responses.

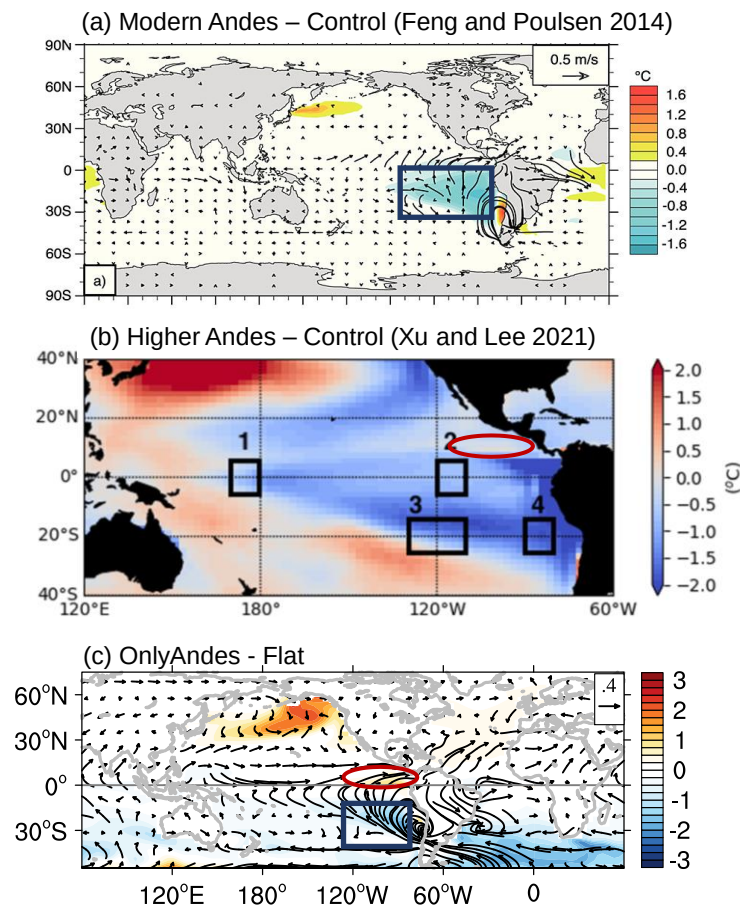


Fig R1. Comparison of SST anomaly patterns in Feng and Poulsen (2014), Xu and Lee (2021), and out study, with emphasis on the southeastern Pacific cooling and the warming north of the equator.

As shown in Fig. R1, all three studies exhibit pronounced cooling over the southeastern Pacific. At the same time, warming anomalies are also present in the tropical eastern Pacific, although their locations and amplitudes differ among studies. For example, Xu and Lee (2021) shows warming immediately north of the equator, whereas our simulations produce a stronger warming signal extending into the equatorial eastern Pacific. A careful comparison therefore indicates that the terms “tropical cooling” and “tropical warming” refer to different parts of the tropical Pacific rather than representing mutually exclusive responses.

Based on this comparison, we do not consider the available evidence to support the interpretation of topographic path dependency. Rather than indicating fundamentally different responses caused by the “Andes-from-flat” versus “flat-from-realistic” experimental designs, the published results consistently reveal a spatially heterogeneous SST pattern characterized by southeastern Pacific cooling together with localized warming in the tropical eastern Pacific. The key differences among studies therefore lie in the detailed spatial distribution and relative magnitude of the SST anomalies, rather than in a reversal of the sign of tropical temperature change.

Nevertheless, we acknowledge that the sensitivity of the tropical Pacific response to the prescribed topographic configuration remains an important source of uncertainty. We have therefore added a discussion noting that whether the warming–salinification pathway identified in our simulations persists under more realistic intermediate stages of Andean uplift warrants further investigation (Lines 522–532).

3. *Despite previous feedback, the manuscript still devotes considerable space to the first 100 years of "fast" atmospheric and wave adjustments. Given that Andean uplift occurs over millions of years, these model-specific transient features are geologically instantaneous. The authors should consider further streamlining the transient analysis in Section 4 to keep the focus on the quasi-equilibrium state.*

Response: We thank the reviewer for this suggestion. We agree that the atmospheric and oceanic adjustments during the first century are geologically rapid compared with the timescale of Andean uplift and should not be interpreted as a realistic reconstruction of the uplift process. The purpose of Section 4 is therefore not to simulate the temporal evolution associated with Andean uplift, but rather to diagnose the physical pathway through which the Andes-induced signal is

transmitted from the tropical Pacific to the subpolar North Pacific and ultimately influences the PMOC. In this sense, the transient response is used as a diagnostic tool to reveal the underlying mechanism linking local topographic forcing to the remote circulation response.

We therefore retain the analysis of the fast adjustment processes because they provide essential mechanistic insight into how the Andes-induced signal propagates through the coupled atmosphere–ocean system. Without this analysis, it would be difficult to establish the connection between the local topographic forcing and the remote North Pacific response identified in the equilibrium state. To avoid possible misunderstanding, we have revised the manuscript to clarify that these transient adjustments are used as a diagnostic tool for identifying the mechanism, rather than as a realistic representation of climate evolution during Andean uplift (Lines 312–323).

4. The authors acknowledge that surface buoyancy forcing alone (from evaporation and salinity) may not be sufficient to trigger intensified North Pacific Deep Water (NPDW) formation, as concurrent warming exerts a compensating effect. They suggest that large-scale dynamical adjustments are the primary driver. This distinction is critical and should be reflected more clearly in the Abstract to ensure the mechanism is not misinterpreted as being solely thermal or saline.

Response: We thank the reviewer for this suggestion. We have revised the Abstract carefully following your suggestion (Lines 30–36). It is important to emphasize the role of large-scale ocean dynamical adjustments in the development of NPDW formation. Our interpretation is that the intensification of NPDW is not driven solely by salinity forcing; rather, large-scale dynamical adjustments also provide the necessary mechanism.

Reference:

- Feng, R., and C. J. Poulsen, 2014: Andean elevation control on tropical Pacific climate and ENSO. *Paleoceanography*, **29**(9), 795–809, <https://doi.org/10.1002/2014PA002640>.
- Xu, W., and J.-E. Lee, 2021: The Andes and the southeast Pacific cold tongue simulation. *J. Climate*, **34**(1), 415–425, <https://doi.org/10.1175/JCLI-D-19-0901.1>.