Saini et al. “The Influence of Glacial Northern Hemisphere Ice Sheets on Atmospheric Circulation”

General comments:

This manuscript presents a comprehensive modeling study of how atmospheric and oceanic systems responded to boundary conditions during Marine Isotope Stage 3 (MIS 3), with a focus on the 49 ka interval. It is appropriate for Climate of the Past because it examines a less-studied period relative to the Last Glacial Maximum (LGM) and uses the comprehensive Earth System Model (ACCESS-ESM1.5) to identify the primary factors influencing glacial circulation.

By pivoting away from a strictly North Atlantic-centric narrative, this study addresses a significant gap in the paleoclimate literature and establishes a more comprehensive global perspective. Its primary novelty is the examination of the high-obliquity state at 49 ka, characterized by an axial tilt of 24.43°, under the challenging constraints of glacial conditions, including reduced CO_2 levels and expansive ice sheets. This configuration offers a rare opportunity to analyze the complex interplay between orbital forcing and glacial topography. Furthermore, the research elucidates critical interhemispheric teleconnections, demonstrating how Northern Hemisphere ice sheets drive far-reaching climatic responses in the Southern Hemisphere, most notably through the reorganization of the Hadley Circulation (especially the Hadley cells) and the modulation of Australian monsoon patterns.

The stepwise experimental approach is a major strength of this paper. By isolating orbital/GHG effects (49ka-co), albedo (49ka-alb), and topography (49ka-full), the authors clearly identify which boundary conditions influence particular climatic responses.

The study finds that ice sheet topography is the primary driver of a roughly 6° southward shift and a zonal orientation of the North Atlantic jet during winter. While these patterns align with established LGM research, confirming them for smaller MIS 3 ice sheets is a key contribution. The simulated Atlantic Meridional Overturning Circulation (AMOC) also strengthens to 31 Sv, 47% above Pre-Industrial levels, due to topographic shifts that influence North Atlantic wind stress and the transport of warm, saline water into the Labrador Sea. In the Australian climate, the model captures monsoon strengthening and increased northern precipitation consistent with proxy data. However, it predicts drying in southern Australia, contradicting evidence of wetter conditions, highlighting the need for higher-resolution modeling or more detailed discussion to better understand moisture transport.

This manuscript provides a solid understanding of MIS 3 climate dynamics but needs further clarification on key points. 1) Address instances where the combined ice sheet effects differ from their sum to clarify nonlinear interactions, highlighting synergistic or antagonistic responses that elucidate feedback loops. 2) Discuss the Bering Strait closure's role in the 49ka-full experiment, distinguishing its effects on AMOC and salinity from broader topographic influences to identify the primary drivers of the AMOC response. 3) Address equilibrium concerns directly, explaining why the 49ka-alb model state, despite not reaching full equilibrium, captures atmospheric trends, and clarify that minor imbalances do not affect the 49ka-full results from a 760-year run, thereby strengthening the manuscript.

Specific comments:

[**Abstract**]

The abstract is scientifically sound and aligns with the scope of this journal, though it could be tightened in a few areas for clarity and impact. The main problem is insufficient quantitative detail: although it references “southward shifts" and "minor changes,” it fails to include specific magnitudes from the results, like the 6° shift in the westerlies. The shift from focusing on the

North Atlantic to findings in the Southern Hemisphere feels abrupt. Although “nonlinear interactions” are highlighted as an important discovery, the abstract does not clearly explain what they are, such as how topography and albedo could oppose or reinforce each other. Additionally, the phrase “all ice sheet-related boundary conditions” is somewhat vague in a summary; clarifying that it encompasses the crucial role of topography would better emphasize the study's mechanistic focus. Finally, clearly tying the “Australian rainfall” link to the ITCZ shift earlier in the text would improve the logical flow of the teleconnections described.

[**Introduction**]

The introduction has a clear structure and effectively highlights the research gap concerning the less-studied mechanistic effects of Northern Hemisphere ice sheets during MIS 3, compared with the well-studied Last Glacial Maximum. One potential improvement is to make the rationale for selecting the specific 49-ka time slice more explicit, especially by elaborating on how its high obliquity and low greenhouse gas levels are expected to influence global teleconnections. While North Atlantic dynamics are well explained, the transition to Southern Hemisphere impacts, such as Australian rainfall, in the final paragraph feels somewhat disconnected from the earlier regional focus. A more balanced thematic development earlier in the section could better set the stage for the study's broader planetary implications. Furthermore, although the text mentions that millennial-scale variability complicates isolating equilibrium climate responses, it could more clearly explain how the current modeling approach specifically addresses this challenge to provide the “detailed, mechanistic impacts” described.

[**Methods**]

Is the following my interpretation correct?

The 49ka-alb experiment's 272-year run was too short for the simulation to fully stabilize. This is especially important given the stepwise changes in boundary conditions, such as salinity shifts and the Bering Strait closure, which could cause model 'memory effects' or incomplete ocean adjustments. Nonetheless, doubts about the reliability of the results are reduced because the main emphasis was on atmospheric circulation responses. Additionally, extending the final experiment by 760 years allowed for better system stabilization.

[**Results**]

The Results section highlights several noteworthy findings, beginning with a simulated Atlantic Meridional Overturning Circulation (AMOC) strength of 31 Sv. This value exceeds the pre-industrial control by 47% and is a pronounced outlier among comparable MIS 3 interstadial simulations. The physical plausibility of such vigorous overturning under glacial boundary conditions, and the specific model sensitivities that drive it, require careful scrutiny. Furthermore, a clear model-data discrepancy emerges over southern Australia, where simulated drying conflicts with proxy evidence for wetter conditions. Addressing this common paleoclimate mismatch requires a deeper discussion of missing processes or resolution-related biases, consistent with the journal's emphasis on model-data integration. Two methodological aspects also merit clarification: first, the intermediate “albedo-only” experiment is not in equilibrium, complicating the quantitative isolation of albedo versus topography effects; and second, if possible, the combined forcings in the “full” ice sheet experiment (topography and Bering Strait closure) call for a clearer separation of the oceanic responses to wind stress from those to the altered land-sea mask, the latter being a known driver of Atlantic salinity and AMOC intensification.

[**Discussion**]

Significant issues include the regional mismatch in Southern Australian hydroclimate, where the model predicts drying while paleo-archives suggest increased wetness. The manuscript acknowledges this discrepancy and attributes it to a lack of a northward shift in the westerlies in the model, but (as a reviewer) I would like to require a more thorough investigation of why ACCESS-ESM1.5 specifically fails to capture this signal. Another major point of contention is the simulated AMOC strength, which at 31 Sv represents a 47% increase over pre-industrial levels and stands as an outlier compared to several other MIS 3 modeling studies that report significant AMOC weakening. While the authors connect this to ice-sheet topography and wind-stress changes, we expect a more detailed mechanistic comparison that explains why this specific model configuration deviates so significantly from previous results in the literature. Furthermore, the explicit mention that the 49ka-alb simulation did not reach complete equilibrium may limit quantitative comparisons of the separate influences of albedo and topography. Finally, although the manuscript's title highlights the role of Northern Hemisphere ice sheets, the Discussion confirms that the experiments did not isolate the individual roles of the Laurentide and Antarctic ice sheets, which may be seen as a missed opportunity to refine the understanding of hemispheric-scale climate forcing during this period.

[**Conclusions**]

The primary scientific limitation of this study lies in its inability to isolate the individual contributions of the Laurentide and Antarctic ice sheets within the 49ka-full experiment. Consequently, while the research aims to elucidate MIS 3 mechanisms, we cannot definitively attribute Southern Hemisphere climatic shifts to specific ice masses. The conclusions also adopt an overly optimistic tone regarding Australian rainfall, overlooking a key model-proxy discrepancy noted in the discussion: the simulated drying of southern Australia directly contradicts paleo-records suggesting wetter conditions. Explicitly highlighting such tensions in the final synthesis would strengthen the paper by pinpointing where glacial boundary conditions or model physics may require refinement, thereby offering greater value to the journal's audience.

Line-by-line comments:

L.229: “Tabel A1” to “Table A1”

L.240: “Figures 3, 9a,” to “Figures 3 and 9a,”

L.264: “on Australian climate” to “on the Australian climate”

L.277: “in 49ka-full experiment” to “in the 49ka-full experiment”

L.282: “different..” to “different.”

L.283: “for 38 ka time slice” to “over a 38 ka time slice”

L.283: “the Norwegian Earth System Model (NorESM) model” to “the Norwegian Earth System Model (NorESM)”

L.288-289: “The processes … is” to “The processes … are”

L.358: “occur” to “occurs”

L.365: “with Weij et al. (2024)” to “with those of Weij et al. (2024)”