Reviewer #2

Willeit et al. present and investigate DO-type millennial-scale oscillations from CLIMBER-X simulations. By analyzing North Atlantic surface ocean buoyancy fluxes, the authors provide further insight into the processes controlling convective stability and DO oscillations. The model indicates that transitions between different AMOC states occur when the buoyancy flux in the northern North Atlantic shifts from negative to positive, affecting convection patterns. Factors such ice sheet size, and CO2-induced cooling play crucial roles in stabilizing or destabilizing convection, shedding light on the mechanisms behind abrupt climate changes like DO events. The investigation of AMOC stability properties presented here is very comprehensive. In addition to the role of ice sheet size and CO2, the effects of climatic noise and ocean diapycnal mixing were also studied. The manuscript is well written, the results are very interesting and I enjoyed reading it very much. In my opinion, the study should be published in CP after the following points have been addressed.

We thank the reviewer for the positive appraisal of our work and the valuable comments.

- Previous studies have focused on the role of orbital parameters in DO-oscillations (e.g. Zhang et al. 2021; Kuniyoshi et al. 2022). Willeit et al. used present-day orbital parameters. How does this influence the results? I suggest to add a short discussion.

For this study we have not performed a systematic analysis of the role of orbital forcing as we think that the combined effect of CO2 and ice sheets is sufficient to explain the concept of buoyancy control of DO events and adding a third dimension would result in unnecessary complications. However, for mid-glacial ice sheets we have run additional simulations showing that lower obliquity generally brings the system closer to the instability regime, resulting in DO-like oscillations being produced already for higher CO2 (Fig. 1 below). This is consistent with results presented by Zhang et al. (2021).
We plan to investigate the role of orbital forcing in more detail in future work using transient model simulations of the last glacial cycle.

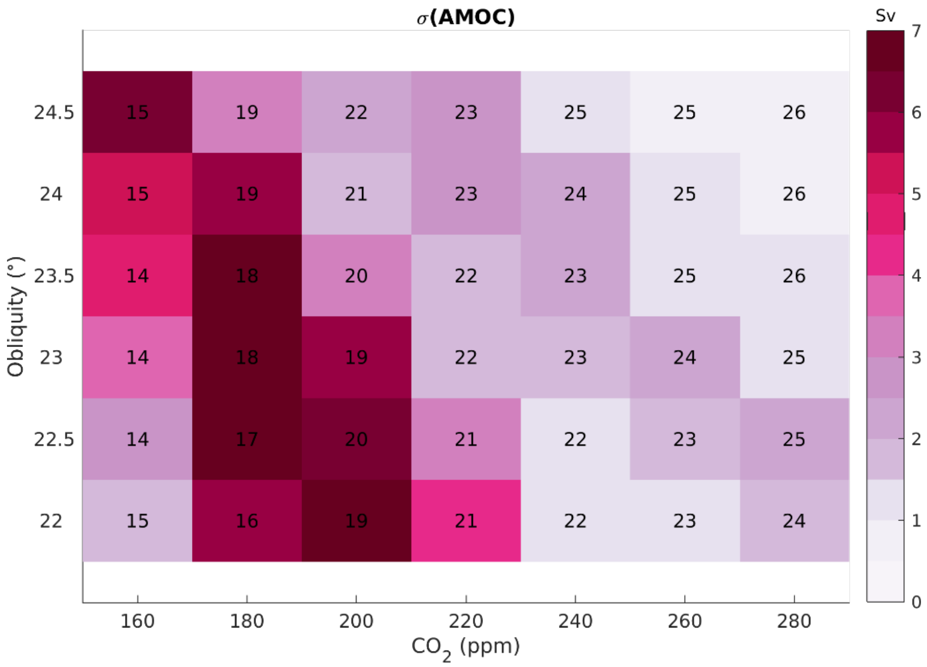

Figure 1. Standard deviation of simulated AMOC time series for mid-glacial ice sheets and CO2 concentration ranging between 160 and 280 ppm for different obliquities. Precession and eccentricity are equal to present-day values.

- CLIMBER-X underestimates the amplitude of Greenland temperature variations. Please discuss possible causes of this shortcoming.

The deficiency in the simulated temperature response in the model is somewhat expected as the atmosphere in CLIMBER-X works best over relatively flat terrain, while the Greenland ice sheet is characterized by large slopes and the circulation over steep slopes is not properly resolved by the model. DO events are expected to affect mainly winter temperature in the northern North Atlantic, primarily as a response to the retreat in sea ice. This temperature changes are going to be largest in a relatively thin layer close to the surface and since in the atmosphere model the transport of heat is mostly horizontal, the warming over the ocean is not very efficiently transported to the summit of the Greenland ice sheet.
Also other models, including many GCMs, tend to underestimate the DO warming over Greenland (e.g. Menviel et al., 2020; Li et al., 2010; Kuniyoshi et al., 2022).

- The surface buoyancy flux analysis is very interesting. However, the authors do not explicitly consider the role of sea ice in controlling surface heat and freshwater fluxes. More discussion on sea ice effects would be necessary.

The contribution of sea ice formation and sea ice melt to surface freshwater and heat fluxes is accounted for in the computation of the surface buoyancy flux. We will make this more explicit in the main text and the Appendix.

- The authors describe an important role of the Laurentide ice sheet in "blocking part of the Pacific-to-Atlantic atmospheric moisture transport" (line 183). However, there should be additional effects of the ice sheet on moisture transports, e.g. through weakening of the hydrologic cycle by cooling the atmosphere. Please add further discussion to this topic.

Following also the suggestions by the other Reviewers, we will ad further discussion of how the Laurentide ice sheet affects the surface freshwater balance in the model.

- The authors test the role of ocean diapycnal diffusivity and obtain interesting results. However, the discussion of the results comes up a little short here. Previous studies have explored effects of ocean mixing on AMOC stability. In particular, several studies showed that diapycnal mixing not only strengthens the AMOC but also enhances hysteresis width and the stability of the AMOC (e.g. Nof et al. 2007; Prange et al. 2003; Sijp and England 2006). I suggest to put the CLIMBER-X results into context considering previous work.

As suggested by this Reviewer and Reviewer #1, we will expand this section extending the discussion to include some previous work on the effect of diapycnal diffusion on AMOC strength and stability.

- Line 144: "...which cannot be done with GCMs resolving synoptic processes". Yes, but in principle one could also add noise to the surface fluxes in GCMs. I suggest to rephrase to be more precise.

We will rephrase this sentence to:
'*Our model has the advantage that it enables a separate investigation of the role of noise on DO dynamics, which can only be partly addressed with GCMs resolving synoptic processes, i.e. by adding additional noise on top of the internally generated variability.*'

- Figure 7: Add more information to the figure caption (i.e. which boundary conditions were used in this specific experiment?).

The figure shows results from the simulation with mid-glacial ice sheets and a CO2 of 180 ppm. We will add this information to the caption.

- Equation (D2) in line 266 describes the surface buoyancy flux. I am wondering whether the model uses a real freshwater flux formulation or virtual salt flux. Please clarify.

The ocean model in CLIMBER-X is a rigid-lid model and we therefore use a virtual salt flux formulation for the surface freshwater flux, as described in detail in Willeit et al. 2022. We will clarify this in the revised manuscript.