The authors wish to thank the reviewers for their constructive and insightful comments which have greatly improved the manuscript. We address the comments as detailed in the following text and in the revised manuscript. The reviewers' comments are in bold underline and the normal text is our responses.

The model does have some limitations related to its parameterizations, including using a single cloud cover fraction from pre-industrial simulations. One test of the importance of this feature could be testing a range of possible cloud cover fractions (from 2xCO2 experiments, for instance) in ZEMBA. Brief mention of which parameters in Table 1 have (1) high uncertainty and (2) significant impact on the modeled climate would be helpful, as would references for the chosen parameter values. How are the parameters tuned, and are their values within the accepted range of uncertainty? For example, the chosen diffusion coefficient Da is slightly higher than estimates from GCMs (~1.05 x 10^6, e.g., Ge et al., 2023; "The sensitivity of climate and climate change to the efficiency of atmospheric heat transport").

Following the suggestions by both reviewers, we have assessed the limitations of prescribing a single cloud cover fraction from a pre-industrial simulation of the Norwegian Earth System Model Version 2 (NorESM2). In the revised manuscript, we have included a section of the appendix (A1) where we perform the same pre-industrial simulation of ZEMBA but with cloud cover taken from the Community Earth System Model 2 (CESM2), the Meteorological Research Institute Earth System Model Version 2.0 (MRI-ESM2.0), ERA5 atmospheric reanalysis averaged from 1940 to 1970 and from the Clouds and Earth's Radiant Energy Systems Energy Balanced and Filled (CERES) product averaged from 2005 to 2015. Figure 1 (presented in the appendix of the revised manuscript) shows the different cloud cover fractions used (Fig. 1a,c) and their influence on surface air temperature in ZEMBA (Fig. 1b,d). To summarise, when ZEMBA is forced by MRI-ESM2 and ERA5 cloud cover, which correspond closely to NorESM2 over most of the tropics and mid-latitudes, the differences in zonal mean temperature are quite small (less than 0.25°C). The CESM2 and CERES products, however, contain much higher percentages of cloud cover (relative to NorESM2) over the tropics and mid-latitudes, which generates a strong cooling effect in ZEMBA. Using CESM2 and CERES produces a global mean cooling- relative to standard PI simulation of ZEMBA- of 1.67°C and 2.4°, respectively. Overall, the choice of cloud cover fractions can have a strong impact on surface air temperature for the pre-industrial. A different choice of cloud cover fraction in ZEMBA would require a retuning of other model parameters to ensure the model simulates surface air temperatures with reasonable accuracy for the pre-industrial. For more details see Appendix A1 of the revised manuscript.

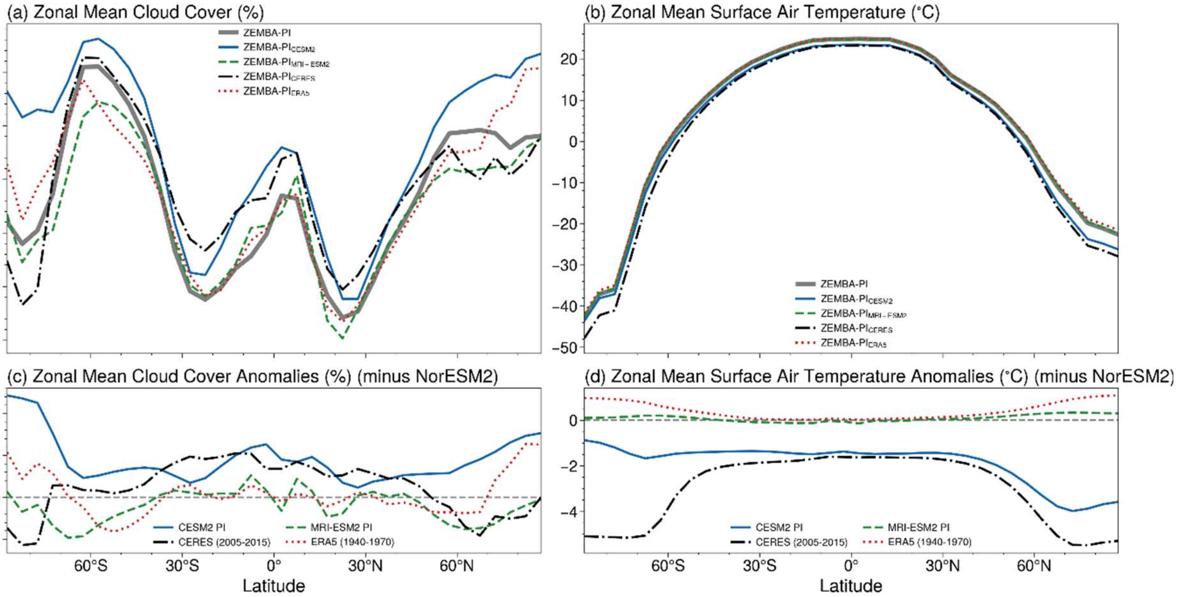

Figure 1: (a) Different values of zonal mean cloud cover including NorESM2 (ZEMBA-PI in grey), CESM2 (ZEMBA-PI$_{CESM2}$ in blue), MRI-ESM2 (ZEMBA-PI$_{MRI-ESM2}$ in green), CERES 2005-2015 (ZEMBA-PI$_{CERES}$ in black), ERA5 1940-1970 (ZEMBA-PI$_{ERA5}$ in red); (b) the zonal mean surface air temperature simulated by ZEMBA in response to these different cloud covers; (c) the differences in zonal mean cloud cover relative to NorESM2 PI cloud cover; and (d) the differences in zonal mean surface air temperature (caused by using different cloud cover fractions) relative to the standard ZEMBA-PI simulation. Pre-industrial cloud cover from CERES and MRI-ESM2 is taken from the Earth System Grid Federation at https://esgf-node.llnl.gov/search/cmip6/ (last accessed: 25/10/2024). ERA5 cloud cover is taken from \cite{ERA5} (last accessed on 25/10/2024) and CERES is taken from https://ceres.larc.nasa.gov/data/ (last accessed: 25/10/2024).

Regarding the tuning procedure, it involves applying the model parameters chosen in Bintanja (1997), or those modified in the subsequent study by Stap et al. (2014), before adjusting the parameters to ensure a good match for simulations of PI surface air temperature. In a previous iteration of the model, we performed a large ensemble simulation to optimise the values for the key model parameters. However, we did not repeat this procedure for the latest version of the model, although we note the main findings regarding a strong sensitivity to cloud cover parameters are the same as those shown below. As for the chosen diffusion coefficient Da, we acknowledge it has been adjusted in both hemispheres to ensure a better PI simulation. Therefore, any deficiencies in the simplified radiation parameterization, ocean heat transport model or surface albedo, etc., have likely been compensated for by changing Da. In the Numeric subsection of the Methods, we have added this text providing additional details on the tuning procedure [**line 346**]:

"Values for key model parameters are summarized in Table 1. These are based on values used in previous studies using an EBM which formed the basis of ZEMBA (Bintanja, 1997; Stap et al., 2014), but with small adjustments to improve the simulated pre-industrial zonal mean temperature. The coefficient for atmospheric heat transport (Da) has been modified in both hemispheres to improve the simulated polar temperature. A parameter sensitivity study is included in Appendix A, demonstrating that the cloud cover parameters significantly impact the simulated climate. In particular, ZEMBA is very sensitive to the globally-averaged cloud optical depth parameter (τ), which has been used as a tuning parameter to adjust the radiation budget to match the present-day (Bintanja, 1997; Stap et al., 2014). The full list of all model variables, parameters and constants is included in Appendix B."

In the revised manuscript we have included additional sensitivity experiments (in the appendix) to assess the relative impact of internal model parameters on the simulated climate. As noted in Bintanja (1997), it is challenging to define a realistic range or uncertainty of certain model parameters which are representative of processes averaged across an entire latitudinal band (e.g. ocean heat transport) or even globally (e.g. turbulent heat flux coefficient, cloud optical depth). Therefore, we decided to replicate the large perturbations to model parameters made by Bintanja (1997) to study the sensitivity of the model to key parameters and contrast this to the earlier study by Bintanja (1997). In Appendix A1 we include a section detailing the sensitivity of the model to internal model parameters with the following figure, showing a heightened sensitivity to cloud parameters, and especially the globally averaged cloud optical depth parameter. For more details see Appendix A2 of the revised manuscript.

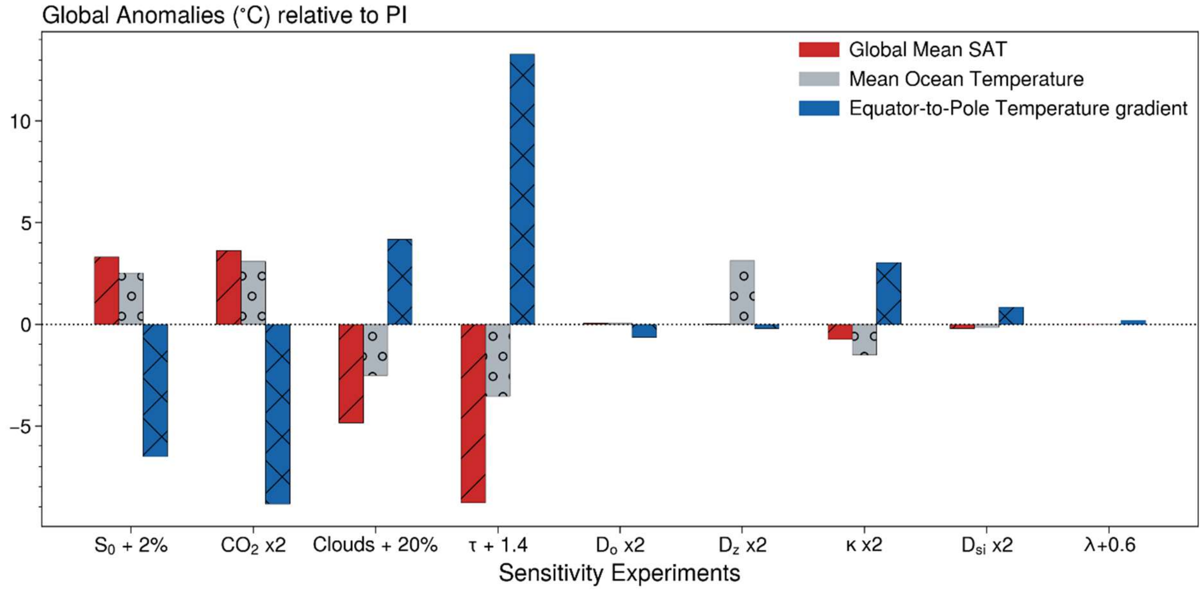

Figure 2: Anomalies in global mean surface air temperature, global mean ocean temperature and the air temperature difference between the equatorial (0◦-10◦) and polar regions (80◦-90◦) for changes in the solar constant (SO), atmospheric CO2 level (CO2), cloud amount, cloud optical depth (τ), ocean diffusion coefficient for horizontal eddy/gyre heat transport (Do), ocean diffusion coefficient for vertical heat transport (Dz), coefficient for turbulent heat fluxes (κ), sea ice thickness (dsi) and a Hadley cell parameter (λ).

Additionally, some clarification on the impact and inclusion of the seasonal cycle would be useful. Is the seasonal cycle being solely driven by insolation changes, or do other parameters change as well? Are simulated climate significantly different if annual-mean insolation values are used? In Siler et al. (2018), only annual-mean precipitation and evaporation patterns were modeled (not seasonal variations); given ZEMBA's underestimation of snow coverage over land (Fig. 5), is the inclusion of seasonal hydrology reasonable?

The seasonal cycle is driven exclusively by changes in insolation. No other input parameter in the model contains a seasonal cycle. In the radiative fluxes subsection of the Methods, we have clarified this with the sentence [**line 129**]: *"The seasonal cycle is driven exclusively by changes in insolation."*

To respond to the question as to whether the simulated climate is significantly different if ZEMBA is instead forced by annual-mean insolation, we have repeated the PI, LGM and 2xCO_2 experiments but with annual-mean insolation at every latitude. Figure 3 below shows the differences in insolation (Fig. 1a-d), surface air temperature (Fig. 3e-h) and sea ice (Fig. 3i-l) between ZEMBA forced with a seasonal cycle and ZEMBA forced with annual-mean insolation.

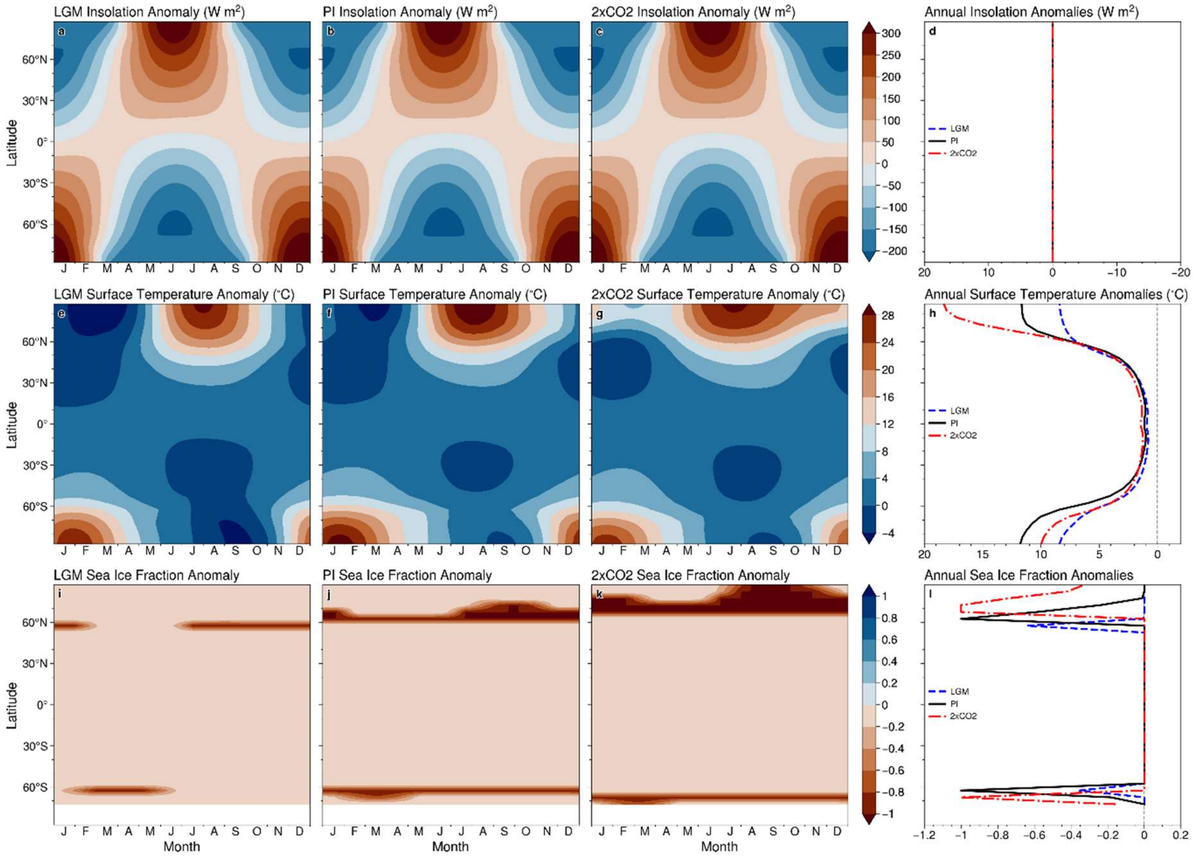

Figure3: Anomalies in insolation (top row), surface air temperature (middle row) and sea ice (bottom row) for ZEMBA forced with the full seasonal cycle in insolation, relative to the ZEMBA forced with annual mean insolation. Anomalies in the seasonal cycle of each variable are shown for the LGM (a,e,i), PI (b,f,j) and 2xCO2 (c,g,k) simulation of ZEMBA. Additionally, changes in the annual-mean of each variable, for each experiment, is shown on the right-hand-side (d,h,l).

For each experiment, the absence of the seasonal cycle leads to significant global cooling, ranging from 2.45 and 3.34°C. The higher temperatures induced when the model is forced by seasonal insolation has also been noted by Bintanja (1997), which they explain by the concentration of solar radiation at the high latitudes in the summer months, when both zenith angles and snow-cover is low, thereby reducing the surface albedo and promoting further absorption of shortwave radiation. To account for this, Bintanja (1997) retuned the annual mean version of their EBM with a lower cloud optical depth, to ensure it produces a somewhat similar climate to the seasonal version of the mode. Overall, the inclusion of the seasonal cycle significantly affects the simulated climate and ZEMBA appears particularly sensitive to summer insolation.

To address this finding in the revised manuscript, we have added the following text in the radiative fluxes subsection of the Methods [**line 129**]:

"The absence of a seasonal insolation cycle results in a markedly colder climate. As noted by Bintanja (1997), employing an annual-mean version of their EBM results in insolation no longer being concentrated in the summer months, when lower zenith angles and reduced snow cover enhances the absorption of shortwave radiation."

Line 95 – "its" not "it's"

Amended in the new manuscript.

Line 555 – there is a model available that couples a carbon cycle to an EBM with a hydrologic cycle, and simulates ice sheet growth and decay (Kukla et al; "All aboard! Earth system investigations with the CH2O-CHOO TRAIN v1.0"). A reference should be included, and

would recommend rephrasing "There are comparatively few EBMs which incorporate a hydrological cycle (Jentsch, 1991) and none – to our knowledge – used for studies of glacial-interglacial cycles."

We have rephrased this sentence in the revised manuscript as follows [**line 585**]: *"There are comparatively few EBMs which incorporate a hydrological cycle (Jentsch, 1991; Kukla et al., 2023)."*

In the same paragraph, we later reference the Kukla et al., 2023 paper [**line 590**]: *"Kukla et al. (2023) introduced a moist static energy balance model with a hydrological cycle coupled to a carbon cycle model, suited for studying the long-term relationship between the carbon cycle, hydrological cycle and climate. However, the modelled precipitation does not impact the surface albedo, which is instead simplified as a function of surface temperature, and, like Jentsch (1991), it lacks the seasonal insolation cycle necessary to study the climate response to Milankovitch cycles"*