Response to reviewer #3

We would like to thank the reviewer for the comments on our paper. In blue below is our response to the reviewer comments and suggestions (in black).

This paper serves as an introduction to the CLIMBER-X Earth system model. I found it to be extremely well written, and therefore pleasant to read. It describes in detail all of the key components of the model and how they interact, and then follows this with an evaluation of the model performance over the period 1850-present, which most readers will easily be able to relate to due to the authors' efforts to compare their simulation with both observations and the CMIP simulations and assessments.

CLIMBER-X itself performs well in almost every aspect shown, and the authors also make clear the model's deficiencies and limitations, which is crucial for potential users with applications in mind. As a paper intended to present a new model to the community, I think it serves that purpose well.

We would like to thank the reviewer for the positive appraisal of our paper.

Minor comment:

I think it would be of interest to the reader to know what degree of calibration has been done, and how. There are a couple of comments in the text, but I think the 'dark art' of how we tune our numerical models should be made more visible (see e.g. Mauritsen et al., 2012 for a good example). In this case, where it is clear that CLIMBER-X is well suited to methods of performing robust exploration of parameter space (see e.g. Williamson et al., 2013), it would be interesting to know the extent to which this has been done, or remains to be done. I suggest including a section (or possibly a subsection in 2), that describes the calibration (tuning) that has been done to the model. For example, were components, or schemes within the individual models tuned in isolation, or was the entirety of CLIMBER-X calibrated as one? To what observations or metrics was the model tuned to?

As mentioned already in the response to Reviewer #1, who raised a similar point, we will follow the suggestion and add a subsection where we give more details about the model tuning strategy.

Specific comments/corrections:

Line 77/78: Replace "16 CPUs" with "2 x 8 core CPUs". Also, if your computation is on a single node then the detail "Infiniband FDR14 Lenovo/IBM" is redundant and can be removed.

We will change this as suggested.

Line 96: I suggest "We made extensive use of…" instead of "We extensively made use of…"

We will change this as suggested.

Line 162: Seem to jump from Appendix 5 (line 153) to Appendix 7. I suggest carefully checking and renumbering/reordering as required.

We will shift the description of cloud parameterisations up, before the paragraphs dedicated to radiation. This will fix the order in which the different Appendix section are referenced to in the main text.

Line 233: question about rigid lid pressure?

The rigid-lid formulation does imply a surface pressure, the so-called rigid-lid pressure, which is directly related to the sea surface height. However, instead of solving the non-trivial equation for surface pressure, in the model we use an approximate approach in which surface pressure is simply diagnosed from integrating density above a reference depth. We will clarify this in the revised manuscript.

Line 269: Typo: “occupyied” > “occupied”

Done.

Line 295: Typo: “distiction” > “distinction”

Done.

Line 377: Could compare with Johns et al., (2011). Also worth noting that whilst the overturning transport itself is slightly higher than observation-based estimates suggest, the associated heat transport is lower than observation-based estimates suggest. This discrepancy suggests potential issues with the vertical structure of the transport and the ocean temperature and salinity, evidence of which can be seen in Figs. 12 and 14.

In the revised version of the manuscript we will add a comparison of the Atlantic meridional heat transport with estimates by Johns et al, 2011, together with a critical discussion of the relation of AMOC strength, heat transport and ocean temperature biases.

Line 433: Typo: “troposhere” > “troposphere”

Done.

Line 449: Suggest citing e.g. Held and Soden (2006) here as a reference for the relationship between the hydrological cycle and Clausius-Clapeyron. Do you see the same relationship between the amplification of the surface salinity pattern and the increasing hydrological cycle as Zika et al. (2018)?

We will follow the suggestion and add a reference to Held and Soden 2006. We will also analyze the pattern amplification of sea surface salinity in the model and compare it to Zika et al. 2018.

Line 466: Confusing sentence – reword.

We will rephrase the sentence.

Line 487: Not just EMICs, but also some low resolution AOGCMs (e.g. Hawkins et al. 2011). On this topic, have you calculated the F_{ov} for CLIMBER-X? In contrast to observation-based estimates, many low resolution models show positive values of F_{ov}.

We will add a reference to hysteresis experiments performed with AOGCMs.
F_{ov}, computed as the difference of the AMOC freshwater transports across the southern and northern boundaries of the Atlantic (e.g. Liu 2017), is negative (around -0.05 Sv) at present in CLIMBER-X, in agreement with observations. However, the AMOC seems to be in a monostable state in the model.

Line 491: Typo: "equilibrim" > "equilibrium"

Done.

Line 506: Typo: "models'" > "model's"

Corrected.

Line 673: "anyway" is not necessary – remove

Removed.

"*K*" is multiply defined:

- Line 604: "*K*" is the kinematic vertical viscosity coefficient
- Line 697: the eddy kinetic energy, "*K*".

We will change the symbol for the kinematic vertical viscosity coefficient.

Line 767: Typo "atmophere" > "atmosphere", and "computed" > "compute"

Fixed.

Lines 866, 868: "Mcdougall" > "McDougall"

Fixed.

Lines 932, 934, 956: Suggest changing "ocean water" to "seawater"

Changed.

Line 944: Suggest rewording "Melting of sea ice leads to…" to "Melting of sea ice results in…" to avoid potential confusion with sea ice leads.

Changed.

Figures 11 and 29: The white text on the contours is difficult to read.

We will change the font color in order to make it better visible.

Figures 3, 11, 13, 24, 29: add (a) and (b) for consistency with other figure style

Done.

Hawkins, E., Smith, R. S., Allison, L. C., Gregory, J. M., Woollings, T. J., Pohlmann, H., and de Cuevas, B. (2011), Bistability of the Atlantic overturning circulation in a global climate model and links to ocean freshwater transport, *Geophys. Res. Lett.*, 38, L10605, doi:10.1029/2011GL047208.

Held, I. M., & Soden, B. J. (2006). Robust Responses of the Hydrological Cycle to Global Warming, *Journal of Climate*, *19*(21), 5686-5699, https://doi.org/10.1175/JCLI3990.1

Johns, W. E., Baringer, M. O., Beal, L. M., Cunningham, S. A., Kanzow, T., Bryden, H. L., Hirschi, J. J. M., Marotzke, J., Meinen, C. S., Shaw, B., & Curry, R. (2011). Continuous, Array-Based Estimates of Atlantic Ocean Heat Transport at 26.5°N, *Journal of Climate*, *24*(10), 2429-2449, https://doi.org/10.1175/2010JCLI3997.1

Mauritsen, T., Stevens, B., Roeckner, E., Crueger, T., Esch, M., Giorgetta, M., Haak, H., Jungclaus, J., Klocke, D., Matei, D., Mikolajewicz, U., Notz, D., Pincus, R., Schmidt, H., and Tomassini, L.: Tuning the climate of a global model, J. Adv. Model. Earth Sys., 4, M00A01, doi:10.1029/2012MS000154, 2012.

Williamson, D., Goldstein, M., Allison, L. *et al.* History matching for exploring and reducing climate model parameter space using observations and a large perturbed physics ensemble. *Clim Dyn* **41,** 1703–1729 (2013). https://doi.org/10.1007/s00382-013-1896-4

Zika, J.D., Skliris, N., Blaker, A.T., Marsh, R., Nurser, A.J.G., & Josey, S.A. (2018). Improved estimates of water cycle change from ocean salinity: the key role of ocean warming, *Environmental Research Letters,* 13(7), 074036