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Title: Persistent Climate Model Biases in the Atlantic Ocean's Freshwater Transport

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Point-by-point reply to reviewer #2

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We thank the reviewer for their careful reading and for the useful comments on the manuscript.

In this manuscript van Westen and Dijkstra take a detailed look into what is causing the model biases in Fov in the Atlantic at 34S. They investigate the bias by looking at the different water masses at 34S and how they change immediately after the model spins up. These responses are compared in both a high (0.1 degree) and low (1 degree) CESM model and later compared to CMIP6 models and changes in future projections. In the CESM models the surface fresh bias can be related to the impact the Indian Ocean has on the Atlantic Surface waters, while slightly deeper the North Atlantic Deep Water biases are related to issues with surface fluxes in the North Atlantic Subpolar gyre. The manuscript furthermore investigates Fov in CMIP6 models and how it changes in future climate projections.

Having begun the review of this manuscript after reviewer 1 posted their response I agree with them on the manuscript. The authors have approached the Fov bias issue from a from the perspective of different water masses, which is a very nice and informative way of investigating the model bias. Therefore, I believe this work is of interest to the community. They have also completed and presented a large amount of analysis. However, there is a large amount of information packed densely into one manuscript and it would benefit from streamlining it and/or splitting the manuscript. Similarly with the figures, some panels could be combined instead of having separate panels for the two models allowing a few of the insets to become their own panels, as opposed to small postage stamps.

A few smaller points:

1. *The introduction seems short and could benefit from being expanded, discussion of the usefulness of Fov as an indicator would nice. See Yin and Stouffer 2007 and Mecking et al. 2016 for a discussion on using the divergence around the subtropical gyre. Also, the role of bias correction using flux adjustment (i.e. Liu et al. 2014, Liu et al. 2017, Jackson 2013). The paper Mignac et al. 2019 also worth mentioning.*

   Author's reply:

   Yes we agree, those studies are indeed relevant for the manuscript. The relevance of the F_{ovS} was already discussed in the manuscript (lines 292 – 305), but this can be mentioned in the introduction.

   Changes in manuscript:

   We will rewrite and extend the introduction of the manuscript. We will mention the relevant papers and discuss the usefulness of F_{ovS} as an indicator.

2. *line 80 – see Menary et al. 2020 figure S1 for a comparison between computing own AMOC and AMOC provided by CMIP6 models.*

   Author's reply:

   There are small deviations when using the AMOC streamfunction or the meridional velocities to determine the AMOC strength (in their paper at 35°N). The correlation coefficient between the two methods is very high ($r = 0.96$, Menary et al., 2020) and this provides (strong) confidence to use meridional velocities instead of the AMOC streamfunction. Ideally one would like to use the AMOC streamfunction, but not all CMIP6 model provide the AMOC streamfunction as standard output. To include as many CMIP6 models as possible (39 in total), we use meridional velocities to determine AMOC strength.

Changes in manuscript:

We will mention and discuss the study of Menary et al. (2020) here.

3. *What are the initial S&T conditions used in this study?*

Author's reply:

The ocean component was initialised with the January-mean climatological (from the World Ocean Atlas) for potential temperature and salinity and from rest (Chang et al., 2020).

Changes in manuscript:

We will clarify the initialisation of the ocean component (line 53).

4. *How are the freshwater transports computed in Fig.2 for the different water masses?*

Author's reply:

For each water mass we determine the vertical integral of the freshwater transport with depth between its vertical extent (e.g., see lower row in Figure 5). For example, the contribution of the Atlantic Surface Water (ASW, upper 500 m) is defined as:

$$F_{\mathrm{ovS}}(\mathrm{ASW}) = -\frac{1}{S_0}\int_{-500}^{0}\left[\int_{x_W}^{x_E} v^* \mathrm{d}x\right]\left[\langle S\rangle - S_0\right]\mathrm{d}z \qquad (1)$$

where $S_0 = 35$ g kg^{-1} is a reference salinity. The v^* is defined as $v^* = v - \hat{v}$, where v is the meridional velocity and $\hat{v}$ the section spatially-averaged (i.e., full depth) meridional velocity. The quantity $\langle S\rangle$ indicates the zonally-averaged salinity.

Changes in manuscript:

We will clarify the water mass contributions in the section 2 (Methods).

5. *There isn't very much mention about Faz in the manuscript despite being defined. Interestingly, looking at the inset in Figure 1b it is clear that Faz also makes a quick adjustment. One thing that is very noticeable in Figure 5 d,e and f is that there is an azonal structure in ASW.*

Author's reply:

There is indeed room to elaborate on F_{azS} in the manuscript and compare its magnitude against reanalysis.

Changes in manuscript:

We will add two new panels to Figure 1 to display the F_{azS} time series (now shown as insets in Figures 1a,b) and add the reanalysis time series for comparison. We will change the text accordingly and discuss the F_{azS} results when applicable.

6. *In figure 5 and A6 it would be nice to see the plots as biases as opposed to absolute values.*

Author's reply:

This is a nice suggestion but we prefer absolute values over anomalies (w.r.t. reanalysis). The AAIW water mass is now clearly depicted in Figure 5 and its origin (Figure 6) is much harder to interpret when showing the figures as anomalies. In Figure A6 only CMIP6 models are shown and without the reference (i.e., reanalysis) it is somewhat difficult to interpret. Moreover, the reanalysis fields need to be interpolated onto each CESM/CMIP6 model grid and this procedure may

give rise to small errors, in particular near the boundaries of the section.

Changes in manuscript:

No changes in the manuscript.

7. *There is no mention in the abstract about the future projection results.*

Author's reply:

It is indeed good to mention these results in the abstract.

Changes in manuscript:

We will change the text in the abstract accordingly.

I believe there are several nice results in this manuscript, and I would be happy to provide a more detailed review of this after the above mentioned comments have been considered.

References

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