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Reply on RC1

Henrike Schmidt et al.

Author comment on "Causes of uncertainties in the representation of the Arabian Sea oxygen minimum zone in CMIP5 models" by Henrike Schmidt et al., Ocean Sci. Discuss., <https://doi.org/10.5194/os-2021-36-AC1>, 2021

This manuscript provides valuable insights into the misrepresentation of the Arabian Oxygen minimum zone (ASOMZ) in 10 historical CMIP5 model simulations, and relates these model deficiencies to the analysis of the different water masses that ventilate this OMZ. Overall, I have found the paper very useful in providing metrics to quantify the representation of the OMZ in these models. The approach of relating deficiencies at different depth of the water column to water masses of different origins provides a new and original understanding of the ventilation pathways of this OMZ, that complements nicely a previous study by the same first author in 2020. The main finding is that CMIP5 models tend to underestimate the lower part of the OMZ due to ventilation of highly oxygenated waters from the Southern Ocean.

I am confident that this work should eventually provide a very valuable contribution but I have a major concern, which is that I found that the writing was often clumsy, sometimes to a point where I was not sure I understood the meaning correctly. Although I did find the ideas and general approach of the paper very promising, reading it was not as pleasant as it could have been and I had to struggle my way through.

Reply to reviewer #1

We would like to thank the reviewer for taking the time and for providing feedback to improve the manuscript.

My major problem was that I could not really understand how water masses were determined based on my reading of 3.3. For example, I did not understand how the formation regions have been localized (lines 5-6-7). I also did not understand how the water mass properties (T-S) were derived from observations. Therefore, it was difficult to follow 4.3 (water representation in models).

We thank you for raising the point, that the determination and localization of the water masses in the models is hard to understand. We will rewrite that part for

better understanding. We have included here a preliminary revision of the chapter:

Red Sea Water and Persian Gulf Water (RSW and PGW) are geographically restricted in their formation regions. Figure 1a shows the formation region for RSW and PGW for which temperature and salinity ranges and mean values are determined (Table 2 and associated new figure).

In contrast to that Indian Central Water (ICW) is not geographically restricted in its formation regions. ICW is a mixed water mass and is characterised by a nearly linear temperature and salinity relation that is density-compensated (Tomczak, 1983) and can be identified in T-S diagrams. With this relation, we were able to define upper and lower temperature and salinity limits of ICW in observations and compared those values to respective values from literature values (see Tab. 2). ICW is formed on zonal oriented fronts in the tropical ocean sub-surface layers (Tomczak, 1983). Sprintall and Tomczak (1993) and Schott and McCreary (2001) described the geographical location of the formation region of ICW. Figure 1b shows the grid boxes where these T-S properties are found in the IO in WOA13 observations. These are in line with the description of the formation region as shown by Sprintall and Tomczak (1993) and Schott and McCreary (2001).

To investigate the formation region of ICW in the models, we followed the same procedure as previously described for the observations. The linear temperature/salinity relation as given by the T-S diagrams of the individual models (Fig. S4) sets the upper and lower temperature and salinity limits (see also Table 2).

Different to the observations and the literature, the resulting locations that determine the formation of the simulated ICW are not restricted to the subduction area of ICW. For consistency reasons, we therefore limit the formation region of ICW in the models to the subduction area of ICW as prescribed by Sprintall and Tomczak (1993) and Schott and McCreary (2001). We exclude grid boxes with similar T-S properties that are found outside the subduction region as well as those within the upper 200 m so that the oxygen content of subducted ICW is not affected by the well ventilated mixed layer. Figure S2 shows the respective area for each model and the deepest depth at each location, where the T-S properties are found.

Indian Ocean Deep Water (IODW) originates in the Southern Ocean, where it is often referred to as Circumpolar Deep Water and Antarctic Bottom Water, before it travels northward into the deep IO and mixes along its way with the surrounding water masses. IODW is thus defined as the densest water mass in the IO north of 60 °S that is found below 1500 m depth (Talley et al., 2011).

Fig 1c shows the formation region of IODW derived from observations for which temperature and salinity limits are determined. IODW in the models is defined in the similar way as in observations. In the models the derived formation regions of IODW in the Southern Ocean differ from those we find in observations (Fig. S3).

The oxygen content of the water masses as listed in Table 2 (and shown in the corresponding Figure) is calculated, for each model and the observations, by the arithmetic mean of all grid boxes of the corresponding source waters.

Major understanding issues also involved how Figure 1 was generated, how IODW, ICW, RSW/PGW were identified from Figure 2 (where do the ovals come from?).

The revision of section 3.3 also includes a more detailed description of the generation of Figure 1. The ovals in Figure 2 sketch the limits of the source water mass properties. We now include that in the caption: 'TS diagram of the Indian Ocean from observational data (WOA13) color coded by depth. The source water masses for the water mass mixing analysis are Indian Ocean Deep Water (IODW), Indian Central Water (ICW) and Red Sea and Persian Gulf Water (RSW/PGW). The ovals indicate the water masses providing an overview in the overall picture. Exact values of the water mass properties can be taken from Fig. 3 and Table 2.'

I really liked Figure 4, which is a very nice and synthetic way of representing the OMZ, but I add difficulties because of too many lines on the same plot. I would suggest to have more panels, for instance to group them by set of clusters instead of showing all models together, with WOA in all of them (which would make 4 clusters x 3 panels= 12 panels).

Thank you for raising this point. However, at this stage of the manuscript the clusters have not been introduced. The key message of that figure is to get a quick overview of all models and to show the overall wide range in the oxygen representation. Thus, we prefer to keep the figure as it is.

I have the same comment for Figure 5.

However, for Figure 5 we really like your suggestion. In the revised manuscript the panels are divided into the individual clusters. This makes it easier for the reader to capture the differences in the individual clusters.

Also I think it would be easier if the information contained in Table 2 was somehow shown in a set of figures, that would ease the presentation of results and the discussion.

Thank you for your suggestion. In addition to Table 2, we will include a Figure visualizing the information on the water mass properties given in the Table in the revised manuscript.

Information about the age tracer should also be shown in a synthetic figure.

We agree with the reviewer and will add a figure to the supplement visualizing the information about the age tracer that is given in the text.

In the end, because of my misunderstanding, my review is rather limited in terms of how I am able to evaluate the methodology and conclusions, and I believe that the presentation issues that I've raised must be fixed before a full assessment of the content can be provided.

