We would like to thank the two referees and the editor for their time and effort. We appreciate the referees′ thorough reading of our article and their comments, questions and suggestions. In the following, we will first give a general answer addressing the main issues raised, then address the more specific comments by answering to them one by one (blue font), following the original referee′s statements (black font).

We understand that our explanation on our choice and construction of the forcing data sets was a bit confusing. We will add clarifications as well as a schematic figure to aid the understanding of the manipulations of the seasonal cycle. We will explain our choice of the featured experiments better and elaborate on our motivations.

We will also work on the clarity of the storyline and in general aim to improve our explanations to help the reader follow our line of argument and to improve readability of the article. Furthermore, we will provide more information on the forcings′ impact of surface fluxes. We will include an investigation of the Antarctic Slope Front in the 6 experiments presented in 3.2. While we will remove the Ross Sea from Results, and present the corresponding graphs as supplementary material, we will add the region of the Amery Ice Shelf in Discussion (graphs as supplementary material) to strengthen the evidence for universal validity of our found density balance as the determining factor for a regime shift on the Antarctic continental shelf.

EGUsphere, referee comment RC1
https://doi.org/10.5194/egusphere-2022-1044-RC1, 2022

Comment on egusphere-2022-1044
Anonymous Referee #1

Referee comment on "On the drivers of regime shifts in the Antarctic marginal seas" by Verena Haid et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-1044-RC1, 2022

Review of *"On the drivers of regime shifts in the Antarctic marginal seas"* by Verena Haid, Ralph Timmermann, Özgür Gürses, and Hartmut H. Hellmer

The manuscript presents a set of model experiments used to explore a potential regime shift in the Antarctic marginal seas, with a strong focus on the Weddell Sea. The authors use various modifications of atmospheric forcing data to study the development of the HSSW and WDW density and find that the density difference between these water masses is a deciding element for shifting into a warm regime. The results agree with other model studies using various forcing combinations, but in this study, the regime shift is reversible, provided that the forcing returns to present-day conditions.

The manuscript builds on a series of model experiments that contribute to understanding a possible regime shift in the Weddell Sea. However, it is quite hard to follow the story as a reader, and I would recommend the authors revise the manuscript, considering the following major issues.

Major issues:

- One of my major concerns about this manuscript is the storytelling. The authors write well in terms of language and grammar, but many important aspects of the story are hard to extract from the text. As a reader, I had to go back and forth several times to find details and understand the paper's main findings. Therefore, I will encourage the authors to help the reader by looking into how to tell the story more directly. For instance:

- There exist many studies on the possible regime shift in the Weddell Sea. Can you make a stronger introduction to this study to show more clearly how this study differs from the others and what we can learn from it?

  We will revise the introduction and put more effort into clarifying what sets our study apart from previous studies, as well as the advantages of our approach.

- Understanding the suite of experiments and what you expect to learn from them is not straightforward. Could you, perhaps, make hypotheses you hope to answer based on sub-sets of the experiments to more clearly show the purpose of each experiment?
  We will add explanations on our reasoning for choosing the forcings used in the different experiments.

- The forcing data needs more explanation. It is not clear how the ERA-Interim and the HadCM3 data differ. It would be helpful with text and figures to understand these differences. Figure 4 does show mean fields but not seasonal variability. It would also help if you described and perhaps showed a figure of the SA_G experiment compared to REF. It is unclear if the seasonality is exaggerated or suppressed by removing the difference between ERA-Interim and the HadCM3 21C-A1B. I would also like to challenge you to make a graphical presentation of the various experiments to help the reader visualize the various alterations. Such a graphic could be in an appendix or supporting material.
  We will clarify our explanations, both for the choice of forcings and the composition of the forcing data sets. A graphic will be added to help the reader's understanding of seasonality, short-term variability and interannual variability of the forcing used in the different experiments.

- It would be worthwhile to dig deeper into the coastal conditions before the regime shift. The author presents the temperature at sill depth, but it would be useful to also discuss and show how the Antarctic Slope Front (ASF) evolves.
  We further explored our results data set. We defined the location of the strongest vertical gradient at the ocean bottom along the continental slope as a proxy to the location of the ASF and found that analysis of this property in the different experiments does not explain the different tipping point behaviours, nor the timing of the warm water inflow. Specifically, SUMMER_S remains stable despite a quick shoaling of the ASF (within the first five years) to depths of 550-650 m (less than Filchner Trough sill depth).
  We thank the referee for this really helpful question and will include a paragraph on the ASF in the article.

- The title of the study concerns Antarctic marginal seas more generally, but the main part of the study targets the Weddell Sea. The discussion of the Ross Sea appears to be disjoint from the rest of the manuscript, and it is unclear if you looked into other regions along the Antarctic coast for further comparisons. I would recommend keeping the focus on the Weddell Sea (also in the title) and leaving the Ross Sea as part of the discussion. There is a limited value added by the figures from the Ross Sea, given that they are similar to the Weddell Sea and can easily be explained or compared by text description.
  We agree and will remove the Ross Sea from the Results chapter. It will be mentioned in Discussions and the Figures will be added as supplementary material. On the other hand, we will add the Amery region treated in the same way. The title of the manuscript will be changed to 'On the drivers of regime shifts in the Antarctic marginal seas exemplified by the Weddell Sea' so the focus is clear while maintaining that the finding is expected to be universal.

In addition, here are some minor recommendations to pay attention to:

Figure 1: Is there a reference you can add to the caption? Is this adapted from other work?

It is a very basic sketch of a hysteresis curve drawn by the first author of this study, with some added details to help the reader's understanding of the explanatory text in the article. There is no conscious copying of anyone's creative property.

Figure 3: It is very hard to decipher the different lines. It would be helpful with varying colors and line styles to make it possible for colorblind people to interpret the results and bigger panels or different vertical ranges to see the results better. Also, is there a reason you would analyze the Ross data in the SA_W scenarios? It would be good to explain why.

We will rework the figures in terms of color choice and/or style. The figure adhered to the maximum width given by the journal. We will consider a 2x3 arrangement of the panels instead of the 3x2 format to increase readability of the graphs. The analysis of Ross data for SA_W is mostly motivated for completeness. As suggested by Referee #2, we will remove the Ross Sea from the Results chapter into the supplements (with a short mention in the Discussion).

Figure 4: What is the purpose of this figure? The datasets are very similar. If you want to show these figures, it would be helpful with a third set of panels showing the difference between the datasets to enhance the understanding of the differences.

We will add panels showing the differences between the plots.

Figure 5: I suggest plotting REF as it is, and plotting the others as anomalies (subtracting REF). This would make it ieasier to compare differences. The divergent colormap also makes temperature variation near 1.5 degC appear stronger than they are. Is there a reason why you split the warm and cold colors at 1.5 deg C? If not, I would suggest to use a non-diverging color scheme.

While it would make it easier to see differences to REF, it would make it harder to understand the situation in any of the experiments on their own. Therefore, we prefer to keep the figure as is. We can, however, adapt the color map.

Figure 7: I do not think you need to include this figure.

As all other parts referring to the Ross Sea, we will remove this Figure (and related parts of the text) from the Results chapter and add this as supplement.

Paragraph 45: I am unsure if it is appropriate to flag specific projects and funding sources here. I would suggest putting this information in the acknowledgment and changing the sentence to target your contribution in general.

We do not see a problem with the mention of the project here, since it provides information about the scientific forum and framework around the study.
We will ask for the editor's opinion and follow their advice in this matter.
In any case, we will delete the words 'Within this project, …' at the start of the second sentence in the paragraph.

Paragraph 75: Is there a reference for the HadCM3 model data and the empirical relationships you are using?

Yes, there is a reference for the HadCM3 data: Johns et al. (2011). You can find it in the first sentence on the data set. We will also add Collins et al. (2011) as a reference.
The equations are based on equations from Stull (2017, Chapter 4, Eq. 4.1a, 4.1b, 4.7 and 4.14a) and Bolton (1980, Eq. 10). We'll add the references and adjust the presentation of

the equations in the manuscript to be closer to the source equations.

Paragraph 95: It would be helpful to present a graphic that shows the REF and the SA_G, and possibly the seasonal means for the datasets for at least one of the atmospheric variables.

We will add a graphic that will help explain the changes done to the forcing, as previously mentioned in the response to the major issues.

Paragraph 105: How does it affect the forcing data when July and August are eliminated? Are there discontinuities that affect the results? What happens in Feb-August in the transition zone at 50 deg S?

The elimination of July and August in the south leads to a short and mild winter. The gap between the months June and September is bridged only by linear interpolation of the data in the 6-/12-hour interval. Similarly, in the transition zone at 50° S the forcing data are linearly interpolated over a narrow band of 0.75°. These inconsistencies will of course have a local effect on the ocean, but this is hardly avoidable even with a more elaborate treatment of the transition zones. We did not encounter any obvious issues resulting from this choice.

Paragraph 125: Is the mean temperature an integral over the entire volume or only the deeper part (how deep)? The figure caption states that it is below 200 m, but you should mention this here too.

We will add the vertical limits to the text. Thanks for noticing the omission.

Paragraph 125: The sentence starting with "The coincidence of…" needs to be revised for clarity. It would also benefit from more elaboration as to the causality question.

We will clarify and elaborate on our reasoning in this paragraph.

Paragraph 125: All other references to figures use "Fig. X". I suggest you do this for Figure 5 here too.

We will do so. Thanks for noticing the mistake.

Paragraph 135: Please refer to a figure where you find the results.

A reference to Fig. 3 will be added.

Paragraph 145: Some of the points here would be good to mention in the introduction to help motivate your selection of experiments.

We will work on the Introduction with the specific aim to better explain our motivations and goals in this study and will follow your suggestion. This will also help with the first major issue in your list.

Paragraph 175: How is the ACC altered in the SUMMER_S? Is warm water available at the depths where it can access the shelf, and do you see a relaxation of the front?

In SUMMER_S, the ACC is weakened compared to REF. After 60 years REF has a volume transport of 152 Sv through Drake Passage, while SUMMER_S only has 130 Sv. The Weddell Gyre on the other hand is strengthened (in year 60: 23 Sv in REF vs. 35 Sv in SUMMER_S)
Defining the Antarctic Slope Front by the strongest vertical temperature gradient at/near the ocean floor, reveals a fast shoaling of the ASF to varying depths of 450-580 m within the first 5 years. Therefore, warm water is available above the Filchner Trough sill depth, however, it is not dense enough to fill the cavity under FRIS.

Paragraph 180: Could you provide some motivation for why you compare the density in front of Ronne, and not the density in the Filchner Trough, where the warm water enters the shelf?

Because in the southern Weddell Sea, the densest shelf water is produced by the polynyas in front of Ronne Ice Shelf (e.g. Haid and Timmermann, 2013). Thus, the water mass competing with the Warm Deep Water to fill the cavity is found at the Ronne Ice Shelf front. The spatial separation of the inflow paths of the two competing water masses in the FRIS case allows the two density curves to cross. At other ice shelves (if no fitting adaptation of the metric is possible) the curves will only meet each other (with allowance for some mixing and heat loss taking place between continental shelf break and ice shelf front), since the maximum at the ice shelf front will only be able to pick up the densest inflowing water independent of its source.

Paragraph 195: Please elaborate on what happens when the on-shelf density becomes lighter than the off-shelf waters. Is there any delay in response or any seasonal variation of interest?

For our featured experiments with a regime shift, we find lags of 2-3 years for the meltrate reaction to the crossing of the density curves (and later increases of the difference). There are seasonal variations in the on-shelf density which may allow for seasonal intrusions of (M)WDW even before the annual mean value of the on-shelf density drops below that of the density at the shelf break, but these are not reflected in the area-mean melt rate.

Paragraph 325: This paragraph appears to be more appropriate for the discussion section

We will follow the referee's suggestion and move it into the Discussion chapter.

Paragraph 330: The final paragraph is irrelevant to the conclusion. I am unsure if it ok to advertise other parts of a specific project in this manner.

With the mention of these studies, we are aiming to provide the interested reader with suggestings for further reading. We will ask for the editor's advice and follow it.

Response References:

Not including References already given in the manuscript.

Bolton, D. 1980. The Computation of Equivalent Potential Temperature, *Monthly Weather Review*, *108*(7), 1046-1053.

Collins, M., Booth, B.B.B., Bhaskaran, B., Harris, G.R., Murphy, J.M., Sexton, D.M.H., and Webb, M.J. 2011. Climate model errors, feedbacks and forcings: a comparison of perturbed physics and multi-model ensembles, Clim. Dyn., 36, 1737-1766, doi:10.1007/s00382-010-0808-0.

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