REPLY LETTER FOR REFEREE #2

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In the following document, the original reviewer comments are in **Bold**. The author's responses are in plain font, and the alterations in the text are in *Italics*.

Following the discovery of spurious open ocean deep convection in the Weddell Sea in the ECCO reanalysis two-three years ago, this manuscript investigates whether this behavior is also found in other reanalysis products, and if so, which mechanism generates it. Reanalysis are often used instead of observations, in data-poor areas such as the Southern Ocean, yet are pretty much models. Such a study is hence vital both for the observational and modelling community.
The manuscript in its present form however does not really answer the questions announced in the abstract. The analysis concentrates on one reanalysis product only, and the explanations lack evidence to back them. The results that are shown are interesting and encouraging, but a substantial amount of rewriting is required. Please pay attention to the English language as well, and consider asking a native speaker to correct future versions of the manuscript.

We would like to thank the reviewer for the detailed and valuable comments on the manuscript. We have thanked both referees in the acknowledgments section.

"*We would finally like to thank C. Heuzé and the anonymous referee for the valuable suggestions that improved the manuscript.*"- Page 19, lines 24-25

Following the suggestion, the manuscript was reorganized, and several sections were rewritten to clarify the mechanisms involved in AABW formation. We agree that the analysis mainly focused on the UR025.4 reanalysis product. Therefore, we extended the explanations and discussions of the two other products (SoSE and ECCO2). New figures were added, and some of the old figures were edited to better support the explanations. A new results section was added to discuss the temperature and salinity changes and their links to brine release and surface cooling during AABW formation in the three models. We believe this section was a piece that was missing from the original manuscript and was necessary to back up the explanations of the AABW formation mechanisms. Finally, the authors also agree that the question proposed in the abstract was somewhat confusing, so this question was rewritten as follows:

"Despite those events are well described in non-assimilatory ocean simulations, the recent appearance of a massive open-ocean polynyas in the Estimating the Circulation and Climate of the Ocean Phase II reanalysis product (ECCO2) raises questions on which mechanisms are responsible for those spurious events and if they are also present in other state-of-the-art reanalysis products."- Page 1, lines 9-12.

Finally, the manuscript had the English carefully revised by the American Journal Experts (AJE), with the following certificate verification key: 2643-6C26-AB4A-DF99-D760

Major comment
Section 3 needs to be majorly rewritten so that you properly comment on all three reanalyses and actually demonstrate the mechanisms that you discuss. Try re-organizing your section (especially sections 3.2 and 3.3) following this structure:
1. Show a first figure;

2. Comment on it, for all three reanalyses. If they diverge (e.g. , SoSe and ECCO are different from UR), start demonstrating the mechanism by showing the next figure; then
2.1 Comment on that next figure for the reanalyses that agree with each other;
2.2 "In contrast, UR
...
" – Comment on the different reanalysis.
3. Reiterate as many times as necessary until the full process has been demonstrated for all three reanalyses.

We would like to thank the referee for the recommendation. Following the suggestion, the results section was rewritten to convey the ideas in a clearer manner. Specifically, section 3.2 was substantially reorganized to strictly discuss the water mass alterations. In section 3.4 (previously section 3.3), the previous results were combined to explain how AABW formed in the models. Now, the results section proceeds as follows:

Section 3.1 – First, we describe the SIC and SIT alterations for all reanalysis products including their similarities and differences.
Section 3.2- The water mass alterations are discussed by sector and then compared between the reanalysis products. We tried to follow this order of description whenever possible: first ECCO2, then UR025.4 and finally SoSE alterations.
Section 3.3- An analysis of the temperature and salinity anomalies in the three layers of the Southern Ocean was performed for each model. This analysis provides valuable clues on the mechanisms involved in AABW formation in each model and adds up to the discussion of the mechanisms of AABW formation. The analysis is performed for each model separately to avoid confusion.
Section 3.4 –The results of the previous 3 sections are joined in a detailed unifying explanation, which is explained as many times as needed to convey the main idea to the reader.

Also, make sure that your figures actually show what you are discussing. For example on page 6 from line 28, y, or use a figure showing year 2004 yet comment on the reanalyses in other years.

The appropriate figure addressing in this discussion was included. The previous sentence was "In UR025.4 a different process occurs. After 2005, SIT in eastern Antarctic Peninsula rise, reaching values higher than three meters in 2009, and only then starting to decrease (Figure 4a-c)" and referenced the maps of sea ice thickness. Now, the sentence is rewritten in a paragraph that references the annual mean sea ice thickness values as follows:

"*Conversely, UR025.4 exhibits annual SIT increases in the Weddell Sea, almost doubling that signaling 2009 (Figure 2b).*" – Page 7, Lines 11-12.

Additionally, we have checked all cited Figures regarding the companion sentences to ensure a clear understanding and fluency throughout the text.

Other comments
Throughout the text: Why are some water mass names in italics?

The water mass names were in italics in the first submitted version to highlight the first time that the water mass name appeared in the text. Since this generated confusion, the italics were removed.

The figures are not consistent. For example, Figs. 1 and 3 feature maps of sea ice concentration, but the third map (Fig. 4) is of sea ice thickness.

We agree that the use of different sea ice variables when analyzing polynya establishment is not adequate. According to the reviewer suggestions, the following changes were made to the figures:

- Sea ice thickness maps were added to the ECCO2 snapshots (previous Figure 1, current Figure 11)
- Sea ice concentration maps were added to the UR025.4 snapshots (previous Figure 4, current Figure 14).

Since we do not infer any additional information from the SIT maps of SoSE, the figure showing SoSE polynya was not changed.

Fig. 2 has black lines for "observations", but not Fig.5 and subsequent figures. Observational water mass distribution/volume should be provided, using the world ocean atlas for example.

We agree with the reviewer on the fact that accessing real water mass volumes is important to determine whether or not the modeled water mass volumes represented in the reanalysis are realistic. However, the current database of hydrographic variables (temperature and salinity) in the Southern Ocean is not detailed enough to accurately calculate the monthly variation of water mass volumes in each sector, as was done for the reanalysis products. A sentence explaining this issue was added to the text, as will be shown. Some studies, however, pinpoint mean percentages of water masses in parts of the Southern Ocean, and they were added to the discussion of the water mass percentages. In Section 3.2 was added:

"Tomczak and Liefrink (2005) analyzed the mean AABW contribution in the Western Pacific sector using ocean observations from the SR03 World Ocean Circulation Experiment transect (between 130°E and 150°E, and from 44°S to66°S). The study found that AABW fills approximately 30% of the sector, a percentage lower than the 43% found in ECCO2 in 2012." – Page 9, Lines 25-28.

Also in Section 3.4 was added:

"*Due to limited data sampling, real ocean monthly estimates of WSBW variability are not currently possible. However, some efforts have been made by previous studies to account for the average contribution of WSBW to the Weddell Sea sector. Pardo et al., (2012) used extended Optimum Multiparameter Analysis (eOMP) to quantify the volumes of the Southern Ocean water masses and found that the longitudinal limits of our Weddell Sea sector was filled with approximately 26±0.2% of WSBW, a percentage substantially lower than the 70% of WSBW estimated by ECCO2 in 2013. This previous article uses 45°S as the northern limit for the volume calculations, while our calculation uses 60°S, which accounts for some of the difference in the volume values.*" – Page 13, Lines 11-17.

P2, line 32: there are more than 15 models in CMIP5 – rephrase as "...found that most models of the Coupled..." or "...found that all 15 models they studied..."

This part was rewritten as follows:

"*Additionally, Heuzé et al. (2013) found that most models of the Coupled Model Intercomparison Project (CMIP) Phase 5 failed to represent the formations of dense waters accurately and instead created AABW by open ocean deep convection.".* – Page 1,Lines 33-34 and Page 2, Line 1.

P3, line 29: this sentence is confusing, what do you mean by "those distinct patterns"? Please rephrase.

The sentence was rephrased as *"The distinct simulation characteristics of the reanalysis products, such as the initialization methods and the assimilated variables, help track how the different features in the simulation frameworks affect AABW production.*" – Page 4, Lines 25-26.

P4, lines 17-24: you should summarize the water masses and their densities in a table, that would be clearer.

We agree with the referee in that matter, and hence an additional table (Table 1) was added to summarize the water mass densities for the Southern Ocean.

P5, line 2: are sea ice and ocean currents velocities directly provided, or are they calculated? if so, how?

The zonal and meridional components of the sea ice velocity are directly provided by the reanalysis, as well as the current velocities. This information was added to the main text:

"Finally, for a better description of the AABW formation process in UR025.4, we included analyses of the sea ice and ocean currents, all of which were provided by the reanalysis product." – Page 6, Lines 10-11.

P6, line 4: where do you show the neutral density layers?

That sentence was miswritten in the manuscript since we do not show neutral density layers, but neutral density contour maps. With the rewriting, that part was relocated to section 3.4 and was rewritten as follows:
"*The anomalous signals identified by the average SIC and SIT distribution in ECCO2 are mainly connected to the appearance of a large-scale sensible heat polynya the Weddell Sea sector (Figure 11a-c) and the neutral density alterations (Figure 11d-f), as previously pointed out by Azaneu et al. (2014).*" – Page12, Lines 24-26.

P6, line 20: give the value of the high heat content.

We agree that the value of the heat content is important for the discussion. This part of the manuscript now reads as follows:

"*The 100-m integrated oceanic heat content calculated is 5.724x1022 J under the polynya (August 2005), which is higher than the 5.708x1022 J heat content calculated for August 2008 when there are no ice-free areas. Although the difference is two orders of magnitude lower than the OHC value, the difference results in a one degree warmer surface temperature in August 2005 than in August 2008 and crosses the freezing point of seawater. Different from ECCO2, WDW in SoSE is present at the surface before the winter (Figure 10b). With the advancement of the sea ice in the winter of 2005, the WDW enduring high heat content at the surface delays sea ice formation until December, and as a result, an elongated polynya occurs in the Weddell Sea.*" – Page 14, Lines 12-18

P6, last sentence: that is not true, there is a small region with WSDW in 2004 on Figure 4d.

Thank you. The sentence was rewritten as follows: "*Before the thickening event, WSDW is present at approximately 700 m only in a small region east of the Antarctic Peninsula, while WDW takes up the majority of the Weddell Sea (Figure 14d).*" – Page 16, Lines 12-14.

P7, line 25: "unrealistic percentage" – that joins my previous comment, the reader does not know what would be a realistic value unless you show these in observations too. Throughout section 3.2: how do you define a significant change? How many percent?

Similar to the answer for the comment on Figure 2, monthly water mass volume variability estimates in the Southern Ocean are not possible today due to low data cover. Therefore, to understand whether or not a water mass volume is high, we compared the modeled water volumes with the mean volumes estimated by previous studies. We consider a "significant change" to be any percentage that is higher than the mean + one standard deviation of the real ocean water mass percentages. Some of the real ocean water mass estimates do not offer standard deviations, and hence we considered a change significant only based on the visual analysis of the oscillations in the water mass time series. Given those rules, the following text was added to clarify when the percentages are higher than expected:

"Due to limited data sampling, real ocean monthly estimates of WSBW variability are not currently possible. However, some efforts have been made by previous studies to account for the average contribution of WSBW to the Weddell Sea sector. Pardo et al., (2012) used extended Optimum Multiparameter Analysis (eOMP) to quantify the volumes of the Southern Ocean water masses and found that the longitudinal limits of our Weddell Sea sector was filled with approximately 26±0.2% of WSBW, a percentage substantially lower than the 70% of WSBW estimated by ECCO2 in 2013." Page 13, Lines 11-17

As described in the comment of Figure 2, in section 3.2, the following comparisons with real ocean data were added to the discussion of Weddell Sea sector water mass volumes:

"*Pardo et al. (2012) evaluated the mean volume of deep and bottom waters below 45°S and found that the Weddell Sea water column was comprised of approximately 25±8% of NADW. Within the Weddell Sea, NADW is transformed, and part of it becomes WDW after entering the Weddell Gyre (Carmack, 1974); hence, the 36% value of WDW in ECCO2 is an overestimation, because it surpasses the total percentage of its more widely distributed source water (NADW)."* – Page 7, Lines 31-32 and Page 8, Lines 1-3.

While discussing the Western Pacific water masses in the same section, the following was added:

"Tomczak and Liefrink (2005) analyzed the mean AABW contribution in the Western Pacific sector using ocean observations from the SR03 World Ocean Circulation Experiment transect (between 130°E and 150°E, and from 44°S to66°S). The study found that AABW fills approximately 30% of the sector, a percentage lower than the 43% found in ECCO2 in 2012." – Page 9, Lines 25-28

P11, line 26: Thanks for the citation, but that is not really relevant here. Cite rather Kjellsson et al. (2015), doi: 10.1016/j.ocemod.2015.08.003, or Heuzé et al. (2015), doi:10.5194/gmd-8-3119-2015

Thank you. The citation was corrected to refer to Heuzé et al. (2015).

Figure 8: caption does not say which reanalysis you are showing.

The proper model identification was added to the caption.

Figs 5,6,7,9,10: present all results for similar water masses with the same vertical range(i.e. , same range for all subpanels of surface water, same range for all subpanels with AABW

All graphs of water mass volume percentages were edited to present the same vertical axis length as suggested.