

Interactive comment on “On the freshening of the northwestern Weddell Sea continental shelf” by H. H. Hellmer et al.

H. H. Hellmer et al.

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Thanks to Referee#1 for his time providing very constructive comments on our ms. Our response follows, one by one, the list of the reviewer's comments.

P2-L20: Indicate in Figure 1 where is located the Wilkins Ice Shelf.

Authors: For this request we would have to extend Figure 1 far to the west taking too much space. However, we added the coordinates to the text (Introduction) where Wilkins Ice Shelf is first (and only) mentioned.

P3-L1 to 9: I think that older literature that first introduced and discussed about freshening in the Ross Sea must be cited, e.g. Jacobs et al. 2002, as well as the model study of Assmann & Timmermann 2005.

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Authors: In an earlier version of the ms, before we learned about Jacobs & Giulivi (2010), we used Jacobs et al. (2002) as reference. However, Jacobs & Giulivi (2010) is a more comprehensive study of the same phenomenon, and the first author himself indicated that the 2010-reference is more appropriate. The latest publication also documents more convincingly that the Ross Sea freshening is NOT due to an alias in the sampling method. Therefore, we do not consider the Assmann & Timmermann (2005) paper.

P3-L16: Indicate in Figure 1 where were located the Larsen A and B ice shelves. In fact, all locations used in the text must be cited in the figures.

Authors: The locations of Larsen A, B and C ice shelves, the Antarctic Sound, and the eastern basin of the Bransfield Strait are now shown in Figures 1(a/b). Other geographic features mentioned in the text are indicated in Figure 2.

P3-L19: I am not sure if you should abbreviate the first name when you cite a reference of personal communication.

Authors: We are not sure either, so we let it to the editor to decide.

P3-last paragraph: I think that you should remove the paragraph to section 2 (Data and methods). It seems more an explanation of the winter cruise.

Authors: This suggestion is valid, if only the first two sentences are considered. However, the following sentences present a short introduction to the main part of the paper, i.e. the analysis of hydrographic data from various cruises. Following the comment by Referee#2, we modified the last paragraph of the Introduction such that it now includes a sentence on the advantage of using tracers in physical oceanography.

P4-L3: Why the acronym US-DOVETAIL was not included in Table I?

Authors: Acronym added to Table 1.

P4-L4: Please cite what means CFC here and not at P6-L13.

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Authors: Done.

P5-L5 to 9: Please insert those regions on Fig. 2.

Authors: Done.

P5-L10: Insert a paragraph.

Authors: Not quite sure what is meant with this comment.

P5-L19: Cite what means IUP.

Authors: Done.

P5-L26: I think it is better to state: "... is better than 1.5% for both CFC-11 and CFC-12, which means 0.04 pmol kg⁻¹ and 0.03 pmol kg⁻¹, respectively. What are you trying to highlight with the sentence in parenthesis "(which ever is the greater)"? It needs clarification.

Authors: Corrected, and the misleading sentence "which ever is greater" deleted.

P6-L22: Insert here that theta/S means potential temperature/salinity.

Authors: Done.

P7-L11: "As source waters" of what?? Or are you trying to say "water types"?

Authors: To make it clearer it now reads "As source water types we consider . . ."

P7-L11 to 14: The sentence must be rephrased. Potential temperature, salinity, etc...are not water types (or source water types) used in OMP analysis, but they are parameters used as water masses tracers to quantify each water type used. Although OMP analysis was not the main method used in the m/s, I think you should briefly state about the weights used and the parameters that are more influencing the results, even you have cited the paper of Huhn et al. (2008) as a reference. In addition, the citation of recent papers using OMP analysis specifically in regions of the Southern Ocean, which talk about deficiencies and questions related to the method, should also be in-

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cluded in the text (e.g. Tomczak and Liefrink, 2005; de Brauwere et al. 2007; Kerr et al. 2009).

Authors: We agree - the whole paragraph was re-written. However, we did not add new references, as suggested, because in this context they all lead back to the Tomczak references we already use. In addition, we added the water mass variance (d) to Table 2.

P8-L20: Please clarify if the m/s results agree qualitatively or quantitatively with the results of Garcia and Mata (2005) in the Bransfield Strait. Also, in what sense the results reported for the northwestern Weddell Sea shelf waters could be compared with that of the Bransfield Strait? Please clarify this point in the text.

Authors: A sentence is added which states that the freshening observed by Garcia & Mata (2005) corresponds to the same period (1990-2005) and has a similar value (0.05). The less freshening might be caused by mixing with saltier deep waters as the cold shelf water descends from the continental shelf.

P9-L8-11: I cannot following the systematically increase of CFC in Figure 7. In fact, the bold symbols in this figure make complicate to see anything upper 500 m of depth. Clarify if the CFC unit is ppt or % (upper axis – that seems wrong in this case).

Authors: We agree and, therefore, the sentence was modified such that the 'systematic increase' was replaced by a more general statement on higher surface saturation to the north due to a less dense sea ice cover. Figure 7 has been corrected.

P10-L8 to P12-L6: Congratulation to the authors for the excellent discussion about possible reasons of freshening in Figure 8. However, I have some concerns that I would like to discuss. The authors does not discussed about the visible difference of the freshening trend seen between 1989-1997 and 1997-2006, with the former much more higher in magnitude. This is most evident by region I than region II, which have stations sampled more close to each other. I think that the authors must be including a

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paragraph in this context.

Authors: A more detailed discussion of the salinity profiles now happens at the beginning of Section 4.2 'Winter conditions' re the upper excursions in region II and re different strength of the freshening is discussed in a separate paragraph.

P11-L20: The shelf waters residence time of 1 yr derived in the m/s is much lower than the values previously reported in the literature (e.g. see M. Hoppema papers). This should be indicated and referenced by the authors in the text.

Authors: We would like to point out that we consider the residence time on the continental shelf in the western Weddell Sea, not in the deep ocean. A short just-across-the-hall talk with M. Hoppema confirmed that all his papers discuss residence times in the deep Weddell Sea.

P12-L8: Also considering the latter two topics above, why the authors do not show the SSM/I mean composites for the period 1989-1996, which is exactly the period of greater salinity change (1989-1997) in the stations of region I (Fig. 8)? What occur in the ice shelves and sea ice specifically during this decade? Should be significant for this difference?! The m/s needs discussion about that.

Authors: We replaced the figure showing sea ice concentration for the period 1997-2006 by one covering the years 1989-2006, the period in which the freshening was observed on the northwestern Weddell Sea continental shelf. The sea ice retreat is less pronounced when presenting sea ice concentration for 1989-1996, indicating a reduced influence of the sea ice cover on the 1989-1997 freshening. A discussion on the different degree of the observed freshening (re comment P10-L8 to P12-L6) is added to the Discussion. We also followed the advice of adding a 'difference' plot (re comment Figure 9) which shows that sea ice concentration reduced the most (10% - 50%) during the second period (1989 -2006) in our area of investigation at the tip of the Antarctic Peninsula.

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P12-L22: Please use a pattern for the units, e.g. m/a or m a-1 (L27).

Authors: Done.

Table 1: It should be cited the main study of all cruise/project if available, e.g. Dovetail (e.g. Muench & Hellmer 2002) or also which means each acronyms.

Authors: Based on the serious criticism by the second referee with regard to the confusing station nomenclature we intensively modified Table 1, including the suggestions mentioned here.

Table 2: Did you apply parameters weights in your analysis? Which parameter influences more your results? The conservation mass residuals were inspected? It is lower than what? As GMW is an important result for the discussion, a brief description of the approach used to determine the water types must be included, or the values were tacked out from the literature? This should be included in your text (P7). See also comments above.

Authors: Done on page 7 (see reply to comment P7-L11 to 14). I.e., the parameter weights, the influence of parameters to GMW fractions as well as the residuals are discussed. The description of the approach and where the values are from is covered by the phrase "identical to the approach in Huhn et al. (2008)".

Figure 1: Additional work is required to improve this figure. The axis of (a) & (b) must have the same fontsize. Please cite in the caption the upper figure not referenced, even we know that (a) & (b) are zooming in of this inset figure. The same for figure 1(b), please insert a rectangle in figure 1(a) into the area zoomed. It is necessary to insert some bathymetric lines in both (a) & (b) or a colorbar, mainly because of the bathymetry colors used in (a) & (b) are different and is preferable to be the same. The station numbers in (a) are under each other, please correct it to clarify to the reader. Why stations encircled by ellipse II (b) do not appear in (a)?

Authors: Figure 1 was intensively modified according to the suggestions of Referee

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#1. Two of the stations in ellipse II (red and green) do not show up in (a) because they are superposed by red dots, i.e. they share the same position with a summer station.

Figure 2: Some stations are not visible to distinguish from each other. For example, the stations inside the black square (that should be distinct by square, dot and triangles), and the stations encircled by red and magenta circles. I do not think that the map inset figure is necessary here, because it is previously indicated in Fig. 1. I suggest inserting maps zooming in the delimited areas cited above to clarify the stations position or the authors should improve the representation of the symbols set used.

Authors: Time was spent to improve the figure. However, due to the necessity to use a lot of stations from the few cruises to the northwestern Weddell Sea continental shelf, we are afraid we could not fully satisfy the referee's request.

Figure 3: The grid lines should be removed. Please clarify (and verify along the text) if you are considering < 500 m or $\mu 500$ m (see P6-L21).

Authors: Figure 3 was modified and we now use consistently < 500 m for the depth range on the continental shelf.

Figure 4: How did you define bottom layer to determine the mean salinity (thick lines)? Is it based on depth, density? Please quote in the caption. It is better if the line connecting the points are drawn thinner or dotted to avoid confusion.

Authors: We changed the figure, i.e. we added the mean salinity values for the bottom layer (dashed lines). The figure caption now reads: Fig. 4. Neon concentrations [nmol kg⁻¹] vs. salinity from the four southernmost AW_06 stations (black square in Fig. 2) and selected AS_05 stations (red circle in Fig. 2). The typical error of the Ne measurements is in the order of 0.07 nmol kg⁻¹. The dashed vertical black and red lines represent the mean salinity values for the bottom layer (lowest 50 m).

Figure 5: Why the surface sample at station #579 might be an outlier? It follows the same pattern present by #578, but with higher concentration of GMW. Please clarify

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this point because the stations are very close to each other. Why do not show the concentration of HSSW, WW and WDW? Do WDW appear to be necessary to include in the OMP run? If yes, why? The stations seems distant from the continental margins and the influence of WDW could be negligible. However, if the residuals are lower in the density interval of this water type, it is necessary to be included.

Authors: The surface sample at station #579 might be an outlier, because the measured He and Ne values are comparably high for surface water values (values way above surface water equilibrium) and tend to force the OMP to account for those high surface values by high GMW fractions. Accordingly, we extended the figure caption for a better explanation. In the text (P7-L17, after "comparable to those at the ISPOL site.") we discuss briefly the results for WDW, HSSW and WW as well: "Fractions for WDW are between zero and 10%, and HSSW and WW fractions are between 20% and 70%, whereas HSSW and WW have almost reverse profiles and add to 90% in the mean." The figure caption now reads: Fig. 5. Depth profiles of glacial melt water fraction [%] for the four southernmost AW_06 stations on the western Weddell Sea continental shelf (black square in Fig. 2). The surface sample at station AW_06-579 might be an outlier, because He and Ne samples both are comparably too high for surface water, which indicates contamination by air. To compensate for the high values, OMP overestimates the GMW value.

Figure 6: See Figure 3 comments.

Authors: The grids in all theta/S diagrams are removed.

Figure 7: See comments above P9-L8-11:

Authors: See reply to P9-L8-11

Figure 9: It is clear if the authors add a difference map between the decades, which I think that could clarify the sea ice concentration isolines around 64 S. A zooming area around the tip of the peninsula could also be included for this proposes. It is

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necessary to insert the latitudes in the map. See comment above about the SSM/I map for the period 1989-1996, it should be included, if add information to the discussion, or explained, if omitted.

Authors: We followed the advice of adding a 'difference plot', which nicely supports our argument of sea ice retreat at the tip of the Antarctic Peninsula playing a significant role in the freshening of the shelf waters. All sub-figures now come with latitudes and longitudes.

Figure 10: What the capital letters word "ADJACENT" means here, is it an acronym? Insert the correct cruise name in the legend, e.g. ANT XIII must be ANT XIII/4.

Authors: The word "adjacent" was typed in capital letters by mistake. However, to make that clearer, we replace "ADJACENT" by "in close proximity": Fig. 10. Ne [nmol kg⁻¹] profiles from repeat stations in close proximity on the continental slope (1000–1400m depth, magenta circle in Fig. 2) in the northwestern Weddell Sea slightly north of the WWOS stations in austral summers of 1996 (purple), 1998 (red) and 2008 (black). Ne concentrations increase systematically over the whole water column by roughly 0.1 nmol kg⁻¹ per decade.

References cited: Muench, R. and Hellmer, H.H. (2002). The international DOVETAIL program, Deep-Sea Research II 49 (21), 4711–4714.

Authors: Included.

Please also note the supplement to this comment:
<http://www.ocean-sci-discuss.net/7/C848/2011/osd-7-C848-2011-supplement.pdf>

Interactive comment on Ocean Sci. Discuss., 7, 2013, 2010.