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Ocean Science Discussions

Interactive comment on "Export of Arctic freshwater components through the Fram Strait 1998–2010" *by* B. Rabe et al.

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We thank the anonymous reviewer and Laura de Steur for their efforts in commenting on our manuscript.

After careful consideration of all points made by the reviewers, we have compiled a revised version.

In particular, we added a section on errors to summarise and expand the error-related discussion. Several figures were updated, added or removed. Furthermore, we added an additional survey from 2011 to the analysis. The manuscript title was changed accordingly.

We gave additional details in the manuscript, where suggested by the reviewers, while

trying not to duplicate already published information. Extensive reference is made to the companion paper, Dodd et al. (2012), which has now been published in JGR-Oceans.

We hope that we have been able to answer all the reviewers' questions to your satisfaction.

Kind Regards,

Benjamin Rabe and co-authors

In the following, we will reply to each of the reviewer's comments in turn. For ease of cross-reference, we added item numbers to the comments by Laura de Steur – we attached a PDF of her comments with numbers. Throughout our reply, cross-reference will be made, as appropriate, using the heading and the referenced point number, e.g. "GR1-2." refers to the General comments by reviewer 1, point 2..

1 General comments

1.1 Reviewer 1 (GR1)

1. We have included a section in the Methods section to explain all sources of uncertainties and derived final error estimates. Transport errors for similar analyses as in this work were presented in Rabe et al. (2009), and errors for freshwater component inventories from the dataset used in this work were made by Dodd et al. (2012). Hence, reference is made to these published works, where appropriate. The combined error of the liquid freshwater and component transports is

now given in Table 4 in the manuscript.

2. Some details were added to the corresponding subsections in the Methods section. We chose not to reiterate further details of the methodology for estimating freshwater component fractions, as this is well explained in the companion paper (Dodd et al., 2012) and has been used and discussed numerous times in the literature (e.g. Ekwurzel et al., 2001; Yamamoto-Kawai et al., 2008).

3. All abbreviations are now given in full at first appearance in the manuscript, and the table of abbreviations was updated.

4. We have carefully revised our discussion of time variability throughout the manuscript. In particular, we have explicitly stated that the analysis concerns a limited number of one-month averages from moorings and snapshot hydrographic sections. In accordance with the results presented in Dodd et al. (2012), we added an additional year, 2011, as the corresponding velocity data from moorings became available only this autumn. While we agree with the reviewer that seasonal snapshots of (now) only 6 years out of 13 makes conclusions about trends difficult, we nevertheless attempt to discuss multi-year variations in the data in the context of other observations and model results from the same time period. Consistency between different observed or modeled parameters does not allow one to make final conclusions about causal relationship, as the reviewer correctly points out; however, we believe it is still valid to discuss any of those relationships, although they may be difficult to prove statistically, in the context of known facts about the physics of the Arctic ice-ocean-atmosphere system. As the reviewer states, "it is valid to speculate". We hope to have made it clear in this revision which parts are more speculative and which are more firm conclusions.

5. The paper by Dodd et al. (2012) has been accepted for publication in a peer-reviewed journal. We, therefore, continue to cite this work. We have given additional explanation about the differences between Dodd et al. (2012) and this

work. Here, we reiterate the primary differences: Dodd et al. (2012) present 10 sections of tracer observations and derived liquid freshwater fractions in the Fram Strait. They discuss the tracer data in detail and draw conclusions from this and variations in liquid freshwater inventories in relation to observations elsewhere in the Arctic Ocean and the Denmark Strait. This work calculates the actual volume transports in the western Fram Strait and puts the results in context of other observations and studies of the oceanic and atmospheric circulation in the Arctic. Both approaches have their caveats: whereas Dodd et al. (2012) uses data in almost all of the 13 years, this work only uses data in only 6 years. On the other hand, this work presents transports of the different freshwater components, giving an indication of the actual export of each component out of the Arctic Ocean. Therefore, this work includes a discussion of the dynamics related to these freshwater exports, to the extent possible with this dataset.

1.2 Reviewer 2 (GR2)

We added some details of the methods to Sect. 2; in particular, a separate section on uncertainties (see point GR1-1. above). Rabe et al. (2009) presented an evaluation of the merit to include vmADCP velocity data in the FEMSECT inverse, in addition to using time-mean moored current meters. As the errors of the inverse solution are generally reduced when using vmADCP or lADCP, this work does not present such a comparison. A comment was added to Sect 2.5 to state this fact.

Regarding seasonal variability and the representativeness of our results for whole years or interannual and longer term variation, we added several remarks to the manuscript; for example, the abstract and conclusions now contain references to the fact that the transports from the hydrographic surveys and one-month mooring averages are seasonal snapshots (see also GR1-4).

As the reviewer states, Dodd et al. (2012) has now been published.

2 Specific comments

2.1 Reviewer 1 (SR1)

1. We kept the reference to Dodd et al. (2012) in the abstract, but added the information about the components at that point in the abstract. As the reviewer states, "It might be a matter of taste" if citations appear in an abstract. As Dodd et al. (2012) is the companion paper, where part of the results are used in this study, we believe it best to reference Dodd et al. (2012) in the abstract.
2. We are not sure which publication is meant by the reviewer's reference to Jahn et al. (2009). In Sect. 1.1, two references are made to Jahn et al. (2010), who did study the Arctic Ocean liquid freshwater export in a coupled climate model (CCSM3). Further reference to this article is made later on in the manuscript during the discussion. The purpose of the introduction is to merely give an overview of the state of the art from observations and models, while not going into too much detail. Numerous good reviews of the subject are given elsewhere (e.g. Mauritzen, 2012).
3. All abbreviations have now been spelled out at first appearance in the manuscript.
4. See above.
5. See above.
6. Some detail was added to explain an end-member balance and reference made to other published works.
7. Dodd et al. (2012) explain that the Arctic-wide mean salinity of sea ice is not possible to determine accurately with available observations. Hence, the value of 4 by (Østlund and Hut, 1984) is used. $\delta^{18}O$ is set to a constant value, as sea ice

meltwater and brine largely form in regions remote from the Fram Strait. This is different for studies near the regions of ice formation, as explained in Dodd et al. (2012). We added some explanations / references to the Methods section.
8. Rabe et al. (2009) presented similar results for a subset of years and a subset of freshwater components. The FEMSECT results were discussed in detail there and were given in Losch et al. (2005), so we do not believe a detailed discussion of FEMSECT and the data used (e.g. vmADCP in addition to velocity observations from moorings) is necessary in this work. We presume by "box model" the reviewer refers to inverse methods similar to that used in Ganachaud and Wunsch (2000) and references therein. However, in addition to certain methodological advantages by the inverse method of FEMSECT over other inverse methods, our observations are not suitable to form a closed box. Hence, a section inverse model, FEMSECT, has been used. A sentence was added to the methods section stating some of the advantages of FEMSECT in relation to other inverse models, mentioned in Losch et al. (2005).
9. The duration of each hydrographic survey of the Fram Strait section near 79^oN is now given in Table 2.
10. This is described in the new section on uncertainties. We chose the averaging times for the velocity data from the moorings to best represent the conditions during the hydrographic survey, while averaging over short-term variability that may have affected the synopticity of the hydrographic survey. The final time periods were chosen to be centred around the times of each hydrographic survey.
11. The sentence was changed to better reflect the relative size of the errors. See also revised / new section on uncertainties.
12. The inverse error estimates are described in Losch et al. (2005) and Rabe et al. (2009). We adjusted the error estimates for each year in Table 4 to reflect both

errors from the inverse estimate and from the fraction calculations; however, this is only relevant for Pacific Water (PW in the manuscript), where the fraction error is an order of magnitude larger than the one for the other liquid freshwater components.

13. Figure 2 was corrected.

14. We added an extra figure showing the baroclinic component of velocity in each of the FEMSECT solutions. This is briefly discussed with respect to variation in the density field between sections.

15. A detailed analysis of the velocity timeseries in the Fram Strait and atmospheric circulation patterns is beyond the scope of this work. We, instead, refer to existing studies dealing with the subject; for example, the model study by Jahn et al. (2010) discusses the subject of atmospheric forcing of the volume and liquid freshwater transports through the Fram Strait. Jahn et al. (2012) contains a comparison of different ocean-sea-ice coupled simulation models with respect to the volume-driven and salinity-driven components of the freshwater transports. Regarding seasonal timescales, observations are also included in the analysis by Jahn et al. (2012). We are not aware of any other observational study dealing with regional atmospheric forcing effects on the upper ocean (not sea ice) dynamics in the western Fram Strait.

16. This was corrected.

17. This was corrected. A note was added, that the corresponding processes are discussed in Sect. 4.1.

18. Both the results from our freshwater component transports as well as the analysis of the inventories (Dodd et al., 2012) suggest that the ratio of meteoric water (MW in the manuscript) and FIFB changed from 1998 to 2011; the difference between

the transport ratio in 1998 and in 2009 is significantly larger than the respective transport errors. Although we now analyse an additional survey, the number of surveys is still small and, hence, correlation difficult to justify statistically. We, therefore, removed any correlation analysis from the manuscript, but, instead, give a more qualitative description of the variability. We also added a discussion at the end of Sect. 3 and an additional point at the end of the conclusions to note the potential problem that seasonal variability may influence the variation between our surveys.

19. This was corrected.

20. This was corrected.

21. If we consider the transports and errors in Table 4, the range of ratios is still significantly different in 1998 and 2009 (see SR1-18).

22. We added “variability” to the comparison, as neither the trend nor the variability in river runoff are sufficient to explain the liquid freshwater transport variability we observe in the Fram Strait. Note, however, that Overeem and Syvitski (2010) do not actually give the variability in the total continental runoff from all rivers into the Arctic, but only show timeseries of the four largest rivers. Inflow transports to the Arctic via the Bering Strait, however, have now been updated (Woodgate et al., 2012), so the text has been adjusted accordingly.

23. We have removed the comparison of our transports with the timeseries of the Arctic Oscillation; hence, Figure 6 was removed. The reasons are similar to the arguments for removing the correlations. A discussion of our results in the context of the Arctic atmospheric circulation is still included in some references to the literature (e.g. Sect. 4.1).

24. The connection between the upper ocean advection driven by changes in the atmospheric circulation and the ratio of different liquid freshwater components in

the Fram Strait is that processes in the production regions of those components will be reflected in the composition of freshwater exported from those regions to the Fram Strait. If the atmospheric circulation causes changes in the advective pathways of freshwater, we would expect a change in the freshwater composition in the Fram Strait. Our results give some evidence to support this hypothesis.

25. The section was renamed to "Exports from the Arctic and circulation at lower latitudes". Our study uses observations in the western Fram Strait. While we make a comparison to model studies and observations elsewhere, we cannot provide a comparison of transports on either side of Greenland. To date, there is only one work, although yet unpublished, that attempts to estimate the variability of liquid freshwater export from the Arctic west of Greenland in the 1990s and the first decade of 2000 (P. Holliday, personal communication, 2012). Although direct observations from 1998, similar to those in the Fram Strait, are lacking on the other side of Greenland (Davis Strait), the above mentioned work found several indicators from hydrographic observations and model simulations that the southward liquid freshwater transports decreased in the Davis Strait between 1998 and 2008. In contrast, the corresponding transports in the Fram Strait showed no clear trend over the same time period (de Steur et al., 2009), and our results suggest that no such trend occurred from 2008 to 2011. Ice-ocean numerical simulations are in good agreement regarding liquid freshwater storage variability in the Arctic Ocean and generally show a strong relation between the variability in export and in storage. However, the distribution of exports between the passages on either side of Greenland varies strongly between different models (Jahn et al., 2012).

26. The combined errors are now explained in a new section as well as given in Table 4.

2.2 Reviewer 2 (SR2)

1. Page 2750 Line 7: We included the standard deviation of the transport estimates contributing to the mean. As reviewer 1 noted, it is a matter of taste, if a reference to published work is made in an abstract. As Dodd et al. (2012) is the companion paper, with some of the results from that study needed for our calculations, we believe this reference should remain in the abstract. Note that no other reference to published work was made in the abstract.

2. ... Line 16: Variation in Pacific Water transports are now discussed with respect to variability, not trend. Whereas the question raised at the end of the abstract partly results from this work, information from other work is needed to arrive at this question. It merely puts our work in context; however, as our results cannot answer that question, it only briefly explored in Sect. 4.3.

3. Page 2751 Line 12: "subpolar" was added before "gyre".

4. ... Line 21: We do not know which further references should be included here, as several have been given in this paragraph. We cannot provide a complete account of the literature here, but will be happy to include specific references if suggested by the reviewers.

5. Page 2752 Line 18: What is meant here is that identifying the composition leads to further insight into Arctic-wide freshwater processes and circulation. If we changed "By distinguishing..." into "To distinguish..." or similar, the meaning of the sentence would be changed in that to distinguish the freshwater composition required insight into Arctic-wide freshwater processes and circulation. This is indeed true, as well, since we require this knowledge to do an end-member balance in the first place; however, this is not the intended meaning here.

6. Page 2752 Line 12: The use of the two terms has been corrected throughout the manuscript. Simply put: $FIFB = -FSIM$, where FSIM is the water mass fraction due to the net effect of freezing (sea ice brine) and melting (sea ice melt). in the regions of ice production and melt. As ice formation dominates the water mass inventories of FSIM at each of our hydrographic stations, we prefer to sometimes express FSIM as FIFB, just multiplying FSIM by -1. We have now clarified the use of the two terms by referring to FSIM or FIFB if the net effect is meant (i.e. the water mass we can distinguish by the end-member balance) and just "sea ice melt" and "sea ice brine" if only the effect of melt or formation is meant.

   If only positive FSIM fractions were used for the calculation of the transports ("FSIM positive" in Figure 4f and white crosses in Figure 5), the result would be at least an order of magnitude lower than the FIFB transports. We now note that FSIM positive transport was higher in 2009, 2010 and 2011 than in the previous three surveys. We use this as an indicator for potentially enhanced influence of sea ice melt on transport, notably a reduction in FIFB transports due to the dilution of the FIFB signal in part of the water column around the regions of ice formation. However, the FSIM positive transports themselves are not significantly bigger than the transport error. Dodd et al. (2012) mention the fact that the presence of positive values of FSIM in the Fram Strait from 2009 suggest that sea ice melt was enhanced, relative to the earlier surveys.

7. Page 2754 Line 16: "79^oN" was changed to "near 79^oN". The exact along-section locations of the moorings used for each inverse solution are now shown in Fig. 7.

8. ... Line 18: We agree with the reviewer that a barotropic tidal model cannot resolve baroclinic tides. We are not aware of any published work comparing the velocity observations from the moorings in the western Fram Strait and the AOTIM-5 tidal model. The only work known to us is a Masters thesis (Behrendt, 2008), where the author concluded what is stated in Sect. 2.2; in particular, that

the discrepancy between modeled and observed (by moorings) tides is not important for the upper layers, where the bulk of freshwater is observed. An analysis of the moored timeseries over several months or years is beyond the scope of this work.

9. ... Line 25: We changed the criteria for selecting the mooring data: we now average over at least two weeks of data, although many moorings spanned the full month used for each average. Hence, detiding is not necessary, as variability due to semi-diurnal tides and the spring-neap cycle are eliminated.

10. ... Table 3: Only that part of the Fram Strait mooring observations from AWI / Germany is in the PANGAEA database, not the part from NPI / Norway. Hence, the e-mail of Edmond Hansen (NPI principal investigator) is given. Although our results are only considering the Fram Strait west of 4^oW (largely NPI moorings), the inverse solution was calculated using the whole Fram Strait array. FEMSECT attempts to find the optimal solution regarding both the dynamics (thermal wind with barotropic reference velocity) and the observations. The dynamical constraint may change the solution even several hydrographic stations away from each observation (hydrographic station or mooring). In addition, FEMSECT has a horizontal roughness criterion on temperature and salinity (see Losch et al., 2005), having a similar, although not dominant, effect on the final solution.

11. ... Table 3: For 2009, both vmADCP and lADCP data were used (now corrected in Table 3). The sensitivity of the results to what / how much data is used is reflected in the transport error from the inverse model, included in the section transport errors in Table 4 (errors for transports in 2010 are higher than in 2009).

12. ... Table 3 and elsewhere: The spelling of "Beszczynska-Möller" was unified throughout the manuscript.

13. Page 2755 Line 1: Abbreviations are now spelled in full at first occurrence (see

GR1-3.). Some detail on the differences in the end-member calculations in relation to previous work is given. We now refer to the published work of Dodd et al. (2012) for further details regarding the end-member balance.

14. ... Line 12: See SR1-7 for an explanation.

15. ... Line 15: Only a subset of the data in Dodd et al. (2012) is used due to the absence of shipboard velocity data in the remaining years presented there. A sentence was added to Sect. 1.3, referring to the discussion in Rabe et al. (2009). We do not want to duplicate results in this work that are published elsewhere; hence, our reference to Dodd et al. (2012). Perhaps this was not evident before Dodd et al. (2012) was published, for which we apologize.

16. ... Line 17: See previous point.

17. Page 2756 Line 1: We have added an explanation why time-mean velocities from moorings were chosen instead of instantaneous values. In short, FEMSECT combines all available measurements, bearing in mind a chosen a-priori observational error. This error determines the weight given to any data point in the inverse solution as well as the final inverse error. The a-priori errors were taken to be $0.01\ ms^{-1}$ for the mooring data and $0.1\ ms^{-1}$ for vmADCP and lADCP data. These are the same as used in Rabe et al. (2009), where the latter is not an instrumental measurement error (which is much smaller than the value given here) but based on the standard deviation of the time-averaged velocities (vmADCP were averaged with 1 hour intervals). Hence, while the mooring observations are a better representation of the time-mean state throughout the survey, the individual vmADCP and lADCP profiles are available at better spatial resolution. If only instantaneous velocity values were chosen for the velocities from moorings, these data, at least those in the upper $300\ m.$, would not add much information to the inverse solution, as their a-priori error would have to be set to the same value as the error for the shipboard measurements. Rabe et al. (2009) discussed

in detail the choice of data sources; in particular, the difference between inverse solutions using only mooring observations and those with additional velocity data from the survey (vmADCP). The latter had by far the lower inverse error. Also discussed there was the extent of the mooring observations and the estimated transport missed if only the section over the spatial extent of the moorings were used. The FEMSECT error estimate includes the type of observation available at any given grid point, i.e. for parts of the shelf where no moored observations are available, the transport error from the inverse solution will be higher. The final error is just the sum of the values for each grid cell (triangle). See also point SR2-10 for details of how the data influences the final solution.

18. ... Line 2: All the velocity data from the moorings used in our current manuscript has at least 14 days of observations within the one-month average. The location of the mooring observations used are now detailed for each survey in Fig. 7 (see also SR2-7).

19. ... Line 4: The typo “did not fill the all...” was corrected.

20. ... Line 4: Fig. 7 was added to illustrate a typical grid used in the FEMSECT inverse. Testing with a finer vertical grid did for the 2005 data did not yield significantly different results; hence, this option was discarded to not put unnecessary load on computing resources.

21. ... Lines 15-20: The reason for the combined Pacific Water transport being higher than the estimate from the inverse volume transport alone is now explained in Sect. 2.5 and the caption of Table 4. Sect. 2.5 was added to the Methods to describe the uncertainties in our transport estimate. The fraction of Pacific Water from the end-member balance is largely based on the nutrient data, distinguishing Atlantic Water and Pacific Water. The error of that method is about 10%, whereas the error for the remaining water mass fractions is only about 1% (Dodd et al., 2012). The inverse transport error is much higher than the latter, but similar to

the former. Hence, only for Pacific Water does the error in the water mass fraction calculation significantly add to the inverse transport error.

22. ... Line 24: All the CTD stations, where δ^{18}O and nutrient samples were taken, are shown in Dodd et al. (2012), which is why station locations were not repeated here. The horizontal location of all CTD stations (also those without the above measurements) that were used in the inverse estimate are now shown in Fig. 7 by the FEMSECT grid, as the horizontal spacing of the grid is based on these stations.

23. ... Line 26: The suggested references were added (we presume "Aagaard&Coachman (1986)" refers to Aagaard and Coachman, 1968).

24. Page 2757 Line 6: Aagaard and Coachman (1968) observed an east-west movement of the East Greenland Polar Front in time. This is now mentioned in the text.

25. Page 2757 Line 20: We agree that the mesoscale variability described in Jónsson et al. (1992) largely holds for the eastern Fram Strait. Our manuscript states at the end of Sect. 3.1: "however, the latter largely affect the mesoscale variability on timescales of 1–2 months (Jónsson et al., 1992), and little is known about these processes on the shelf in the Western Fram Strait." This was included merely to state that little is known from direct observations of the influence that wind-driven Ekman circulation has on the transports in the western Fram Strait, despite the importance for freshwater transports mentioned by Rudels (2010).

26. Page 2758 Line 3: As stated earlier (SR2-15), we do not want to present duplicates of the published work by Dodd et al. (2012) here.

27. ... Line 6: We also found it difficult to find a good name for the "transport densities"; however, this is exactly what they are, equivalent to the depth-integrated

velocity at each point along the section (or the horizontal derivative of the cumulative volume transports, hence "transport density"). The purpose of this is to show the influence of the velocity at each point along the section on the overall transport for each section. The cumulative transport curves show the transports, in units of mSv.

28. ... Figure 2: The isopycnals in Figure 2 are now shown in white, as suggested. The size of the panels was not optimized for Ocean Science Discussions, as this is primarily meant for online viewing, and, hence, it's easy to zoom in. All figures are now optimized for the publication format of Ocean Science, i.e. two-column, spanning the whole page width where appropriate. Hence, we did not additionally mark the location of 10.6^oW here, to avoid too much information on these plots; however, that location is now marked in Fig. 4. The baroclinic component of the FEMSECT solution corresponding to each survey is now shown in Fig. 3 (see also SR1-14).

29. ... Line 9: This was rephrased in the text, as Dodd et al. (2012) show that there is generally less liquid freshwater near the surface in 2009 and 2010 than in the remaining surveys.

30. ... Line 12: The reasons for choice of longitude limits for the transports are given and discussed in Rabe et al. (2009). We chose to use the same limits, as the 2005 survey, included in Rabe et al. (2009), extended furthest west of all surveys under study (see also Figure 2). The reason for going to 4^oE was to capture any southward transport of meltwater lenses east of the East Greenland Front. This can be seen, for example, in meteoric water transports in 1998 (Figure 3b).

31. ... Line 15: "R09" was replaced by Rabe et al. (2009), as we want to limit the amount of abbreviations used in the manuscript mainly to water masses.

32. ... Line 17: This is now explained in the text with respect to the additional trac-

ers in the water mass calculations (Sect. 2.3) as well as the choice of velocity observations from moorings (Sect. 2.4).

33. ... Line 19: We included the transport range from previously published observational estimates, as the total number of individual estimates shown in Dickson et al. (2007) Serreze et al. (2006) would be too large to be repeated here.
34. ... Line 21: We have clarified the use of FSIM and FIFB throughout the manuscript (see SR2-6).
35. Page 2759 Line 1: "east of about 6.5^oW" was corrected.
36. ... Line 4-8: See SR2-6 and SR2-34.
37. ... Line 10-12: We state that after 2005, Pacific Water again was observed at levels significant in relation to the 10% error in fractions from the end-member balance. The discussion refers to the potential overestimate of Pacific Water fractions using the ratio of nitrate to phosphate to distinguish Pacific Water and Atlantic Water. The problem stems from sedimentary processes at the Laptev Sea continental slope (Bauch et al., 2011). Hence, this fact may represent a caveat of the end-member method used in Dodd et al. (2012) that goes beyond the the 10% error mentioned previously. However, there is evidence from an ice-ocean general circulation model (NAOSIM) that more Pacific Water indeed reaches the Fram Strait again after 2005, with a temporary drop in 2009 and 2010. We have adjusted the text to now state these facts more clearly.
38. ... Line 19-27: The definitions of "section inventories" and "section transports" are explained in the manuscript, and the manuscript was corrected to avoid ambiguity.
39. Page 2760: Line 9: "respective relation" – this sentence was rewritten.

40. Line 11-15: reference is now made to Jahn et al. (2012) regarding not only the AOMIP model results but also the seasonality of liquid freshwater transports from year-round mooring observations.
41. Line 25: the vertical integral of only positive portions of FSIM transport is an order of magnitude lower than that of only negative portions of FSIM. Whereas the former is of similar order as the transport error, we discuss the occurrence of positive FSIM fractions near the surface with respect to potential mixing of enhanced sea ice melt with sea ice brine (from ice formation) near the regions of ice formation (see Sect. 3.2.5 of the manuscript and SR2-6 in this reply).
42. Page 2761 Line 5: Potential effects of seasonality are now discussed in the manuscript (e.g. Sect. 3.3; see also GR1-4 in this reply).
43. ... Line 17: Citations have been corrected, where necessary.
44. ... Line 20: Corrected – the variability in the appearance of Pacific Water in the Transpolar Drift.
45. ... Line 24: The phrasing was corrected (see also SR2-2).
46. Page 2762 Line 10: "import" changed to "advection".
47. ... Line 15: This was corrected.
48. ... Line 15: Sentence was rewritten.
49. Line 2763 Line 5: The only directly observed evidence of enhanced sea-ice melt on an Arctic-wide scale that we are aware of is in the recent publication by Korhonen et al. (2012): "The decrease in salinity is likely to result from the recent changes in ice formation and melting. In contrast, in the Eurasian Basin where the seasonal ice melt has remained rather modest, the freshening of both the

Polar Mixed Layer and the upper halocline is mainly of advective origin." No quantitative estimate of the effect on the liquid freshwater storage of the upper Arctic Ocean basins was given. However, they mention an increase in the liquid freshwater inventory due to sea ice melt of about $1\ m$ only in parts of the Arctic Ocean basins. In contrast, the observed change in liquid freshwater storage in all of the upper Arctic Ocean basins from the 1990s to the time period 2006 – 2008 (Rabe et al., 2011) is equivalent to a spatially averaged inventory change of about $2\ m$. We added the reference to Korhonen et al. (2012) to the manuscript in Sect. 4.1 as part of the discussion on sources of net sea ice melt observed in the Fram Strait.

50. ... Line 10-12: The observational study by Timmermans et al. (2011) suggests that more sea ice melt was exported from the Beaufort Gyre to the Eurasian Basin north of the Fram Strait in 2010 than in several previous years.

51. ... Line 25: The approximate $12\ yr$ increase in Arctic continental runoff is stated in the manuscript.

52. ... Line 27: mSv is now used throughout the manuscript instead of Sv.

53. Page 2765 Figure 6: Figure 6 was removed (see also SR1-24).

54. ... Line 10-11: This paragraph was generally changed.

55. Page 2766: This was corrected.

56. ... Line 17-20: See SR2-57.

57. Page 2768: The reference to the observational evidence for potentially reduced southward liquid freshwater transports on the western side of Greenland has been adjusted in Sect. 4.3 and 5. We agree with the reviewer that the variability of liquid freshwater transports there are, as yet, unknown. The unpublished study by

P. Holliday hints at a reduction, while it is not yet possible to observe this directly in the moorings in the Davis Strait, as these observations do not span a sufficient number of years. In addition to model results, the study by P. Holliday found a relation between variability in the observations in Davis Strait and variability in the salinity from hydrographic stations north of the Labrador Sea. The changes in the salinity from the latter, that span a longer time period than the observations in Davis Strait, hint at a reduction in transports.

58. ... Line 15: We believe that the question puts our work into a wider context. Even though the question of future changes in Arctic freshwater exports in relation to Arctic freshwater storage changes does not only rely on our work, it does not suggest any results in our study that we did not show. See also SR2-2.

59. Table 1: "freshwater part" was now rephrased.

60. Table 2: The reference to "R/V Oden" was removed.

61. Table 3: Locations of the mooring observations used for the inverse estimates are now given in Fig. 7. For 2009, both vmADCP and lADCP data were used (now corrected in Table 3; see also SR2-11).

62. Table 4: We now explain in Sect. 2.4 that we refer to "observed" transports as those derived from the FEMSECT inverse solution throughout the manuscript, as long as our results are concerned.

63. Figure 1: Fig. 1b is already too busy to include individual station locations; instead, station locations are now evident in the FEMSECT grids given in Fig. 7 (see also SR2-22).

64. Figure 2: See SR2-22 and SR2-63.

65. Figure 3 + 5: Font size was increased in both figures. Cumulative transports are now displayed in wider format.

66. Figure 4: We think that with error bars for any of the transports this figure would become too busy. The errors are given in Table 4. In addition, throughout the manuscript, we note the fact that we are only looking at six surveys, representing the transports of individual months in different years.

67. Figure 5: We hope to have clarified this figure in the manuscript.

68. Figure 6: Fig. 6 was removed.

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