

## ***Interactive comment on “Arctic freshwater fluxes: sources, tracer budgets and inconsistencies” by Alexander Forryan et al.***

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Received and published: 9 April 2019

Review of A. Forryan et al “Arctic freshwater fluxes: sources, tracer budgets and inconsistencies” by Wilken-Jon von Appen

The paper combines several different lines of investigation that have existed in the literature and that have come to partially contradicting results. The authors demonstrate where these contradictions stem from. As a result, this paper is a major advance in the understanding of the cycle of H<sub>2</sub>O and of salt in the Arctic Ocean. This is based on data from summer 2005 and it is implied that that data represents a steady state situation. This is the right first step, but it should be pointed out as such with a discussion of the implications of the steady state assumption. Nonetheless, the resulting numbers

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are useful to the oceanographic community. Furthermore, it is demonstrated that P\* (calculated from measured nitrate and phosphate concentrations) is not really useful to distinguish “Atlantic” from “Pacific” waters in the Arctic. This points to the order of magnitude of non-Redfield ratio biogeochemical processes in the Arctic Ocean whose order of magnitude cannot otherwise be observed directly. There are, however, also a few issues with this paper, in particular with respect to “freshwater”. These mostly concern Figures 12/13. As I describe in detail below, I would leave those out. The manuscript is well written and straightforward in its presentation. But I have a few suggestions, which I think could improve the clarity of the manuscript (“what exactly are the authors doing at each step in the manuscript and why?”). Therefore, I would definitely like to see this manuscript published, but only after a major revision. Furthermore, while sea ice is important in this paper, it is clearly within the discipline of oceanography (physical and chemical). Therefore, I would suggest publication in Ocean Science rather than The Cryosphere. I encourage the editors and chief editors of the two journals to see whether there is a way to transfer the manuscript without restarting the peer review process from scratch.

Line by line comments

p2l7 “(liquid) freshwater fluxes” and p2l23 “freshwater” Please give a clear definition of what you mean by freshwater. Is this H<sub>2</sub>O? At this point there are too many different (sometimes meaningful) definitions in the literature that you cannot assume the readers know exactly which one you are using here.

p4l12-14 This equation appears to only hold for 1 constant salinity at the inflow and another constant salinity at the outflow from the box. For the Arctic Ocean, that is clearly not given. To me it is not clear from this manuscript or from Bacon et al 2015 whether  $\bar{S}_{bar}$  is an area mean or a transport weighted mean salinity over the boundary. I would appreciate it if the authors could clarify this here.

p5l2-3 and l6-7 “accurate estimates of freshwater flux require the definition of an appro-

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appropriate reference salinity (S<sub>bar</sub>)” and “the boundary-mean salinity is the only appropriate reference salinity” I do not think that either of these sentences is correct. But rather than arguing over whether they are correct, I would suggest to leave them out as they are in fact not crucial to anything that follows later in the manuscript.

p5l29 Nd isotopes and REEs have also been used as conservative tracers of different rivers in the Arctic Ocean, e.g. doi:10.1016/j.gca.2016.12.028

p6l14-17 Again, while this is an appropriate step to take at this point (and better results might not be obtained from data at this point), it should still be pointed out that this is not perfect and there are in fact possibly large systematic errors arising from the sampling locations and/or spatially (potentially) insufficient sampling. It would be nice to mention these points with at least a few sentences.

p7l8 The correct statement would be that this “conserves volume and salt transports”, not that it “conserves volume and salinity transports”!

p7l14 Please say what you mean by the plus/minus here. E.g. it could be standard deviation or standard error.

p7l15 “1.0 +/- 0.2” not “1 +/- 0.2”

p7l18 “Sv” not “sV”

p7l24 Please state where your information on sea ice export is from, e.g. satellite observations of sea ice drift and sea ice volume?

p8l5 “nutrient and delta18O data were optimally interpolated” Comment on whether the spatial distribution of the data was sufficient or whether there could be interpolation issues.

p8l9 “grid cells as hydrographic stations” I see where this is coming from, but it is still a strange way to formulate it.

p8l15-27 For me this was totally incomprehensible upon first reading. The terms “3EM”,

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“4EM” and “4EM+” are not self explanatory. I would strongly advise to make a diagram or a table. A suggestion would be a table like this (columns could not be formatted in plain text, so the individual lines of the table are grouped together):

Model name

Constraints

End members that are solved for

Comments

new line

3EM

Volume conservation, salinity data, delta18O data

Seawater fraction, meteoric water fraction, ice melt water fraction

Seawater is water with S=35 irrespective of whether it enters from the Atlantic or the Pacific

new line

4EM

Volume conservation, salinity data, delta18O data, P\* data

Atlantic water fraction, Pacific water fraction, meteoric water fraction, ice melt water fraction

Atlantic water and Pacific water are defined to have identical S and delta18O end member characteristics, but different P\*

new line

4EM+

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Volume conservation, salinity data, delta18O data, P\* data

Atlantic water fraction, Pacific water fraction, meteoric water fraction, ice melt water fraction

Atlantic water and Pacific water are defined to have different P\* and similar, but not identical S and delta18O end member characteristics

I would also already add a sentence like the following one here, because (anyways for me) it was not clear why you do these two versions with 4EM and 4EM+: "4EM+ is degenerate (meaning that numerical values are strongly affected by small perturbations) because the distinct source salinity and delta18O values of Pacific water are on a mixing line between the meteoric and Atlantic Water end member quantities.

p9l14 1 sentence here why you use Pest: in order to judge the method, not for use in the method itself

p10l5 Again, I think this would be much clearer if you could refer to the table as I suggested above.

p11l14 refer to Table 2 in this sentence

p12l16 Again, area mean or transport weighted mean?

p14l1 m/s (see my comment below on Figure 6)

p14l11 It might be helpful to remind the reader that your +/- values stem from the Monte Carlo simulations.

p15l2 Also, here 1 sentence would be in order repeating what the difference between 4EM and 4EM+ is and why you do both calculations.

p15l22-23 and l25-26 Please don't just show both sets of numbers, but also comment on which one you think makes more sense.

p16l16 Add a sentence such as: "Both of these numbers should be approximately 0 and

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therefore, we consider this a model/methodological/data(?) mistake for the following reasons. . ."

p16l21 You are only looking at data from 1 summer month. Discuss whether all of this should be balanced in the quasi-synoptic view of the data you use.

p17l16-18 Neither of these views seems plausible for the West Spitsbergen Current. Should the Atlantic water salinity not rather match the WSC closely?

p18l14-15 Should this not be considered everywhere?

p19l2 "solid (sea ice) fraction" instead of "solid, sea ice, fraction"

p19l27 "(at least when considering full depth assessments)" It is not clear why that caveat is necessary and why the sentence is not correct without the added information in brackets.

p20l6 How can a river be a sink? Processes on the continental shelf near the river could be sink processes.

p20l20 no ":"

p20l25 Explain how I would see that from Figure 3 and what degenerate means in that context.

p21l1 "boundary mean salinity" Again, where do I "see" that in Figure 3?

p21l6 Refer to Table 7

p21l12-24 This text and the associated Figures 11-13 should in my opinion be removed from the manuscript as it is unclear what you mean by "oceanic origin freshwater". Additionally, there is no insightful information contained in them.

p22l17 "Carmack et al. (2016, Appendix)"

p23l6 "salt conservation"!

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Tab1 Why is there a larger line break after the first line of delta18O and salinity?

Tab1 2nd line under ice melt: What is “surf”?

Tab3 Similar to p7124, where is the information about -0.040Sv solid ice melt from?

Fig2 I think the other piece of interpolated data that your study is based on is cross-sectional velocity. I would recommend to add this as a top (4th) panel to Fig2. In that case the reader does not need to refer back to TB12 to get that information

Fig2 caption I1 “P\*” should be with a superscripted “\*\*”

Fig2 caption I4 Repeat what the main Arctic water masses are so that the reader does not need to refer back to TB12.

Fig2 caption Add: “Note the broken scaling of the y-axis.”

Fig3 Your 3EM model solves the classical end member decomposition in the triangle that is drawn in panel a. Your 4EM models essentially are the same, only that they solve the end member decomposition in the tetrahedron that would result if you were to extend panel a in the vertical with the vertical axis being P\*. Since you can't add a 3 dimensional figure to the paper, I would recommend to at least add plane views of this tetrahedron with the data and dashed lines plotted into the panels just as you are doing in panel a right now. Common axes can be aligned with each other. My suggestion: 4 panel figure. top left panel as your panel a. top right panel x-axis P\* y-axis delta18O, bottom left panel x-axis salinity y-axis P\*, bottom right panel your current panel b. Also please substitute the current legend in panel b by a legend for the dashed lines and comment in the figure caption that all symbols and lines are the same in all panels. The 18 in the y-label of panel a should be superscripted not subscripted.

Fig3 caption I4 “Dashed thick”

Your units in Figs 6/8/10 and 11a/b are wrong. They should be “Sv/m/km” or more conventionally “m/s”. Note that you only arrive at units of transport (Sv) after integrating

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the data in the figures in the horizontal and vertical dimensions. Same applies for Figs 12/13 where your units should be  $m^2/s$  or Sv/km or similar.

Fig7 What is plotted in panels 7a and 7b is different from what is plotted in panels 5a and 5b, yet the values in the Met. and Ice Melt columns of Tables 3 and 5 are identical. In my opinion, only either one of those can be correct.

Fig11/12/13 can in my opinion be deleted from the manuscript. One of the reasons is that I do not understand what the black line in Fig12/13 is supposed to be.

Fig12/13 (if you keep them) Add green line to legend.

p48l14-16 A correct reference to this data publisher contains the complete DOI and it is not a tech report. Compare how the citation is provided on the webpage of the data set. In addition, you have the wrong title which means that it took me some time to find the data set you are referring to! “Kattner, Gerhard (2011): Inorganic nutrients measured on water bottle samples during POLARSTERN cruise ARK-XXI/1. PANGAEA, <https://doi.org/10.1594/PANGAEA.761684>”

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Interactive comment on The Cryosphere Discuss., <https://doi.org/10.5194/tc-2018-247>, 2019.

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