

Interactive comment on “Freshwater in the Arctic Ocean 2010–2019” by Amy Solomon et al.

Anonymous Referee #3

Received and published: 12 January 2021

General The authors compute freshwater content (FWC) for the whole Arctic Ocean from hydrography and for the Beaufort Gyre from altimetry and GRACE. They argue that Arctic Ocean freshwater content has stabilized since 2010. They review various processes that might explain the timing of the stabilization including for example runoff, precipitation, moisture flux, and sea ice changes, but they do not seem to make a firm conclusion as to causality. Overall the paper seems incomplete and lacking in thoroughness.

I found it hard to reconcile the time series of Beaufort Gyre and whole-basin FWC with prior studies, particularly over the major freshening event centered on 2005-2008. In Figure 3, the increases in FWC for the whole-basin and Beaufort Gyre are virtually the same. Nothing in the time series records for the reviewed processes is shown to explain this change. Other studies have found that the increase in FWC in the Beaufort Sea is offset by decrease in FWC in the rest of the Arctic Ocean to the extent

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that the increase in whole-basin FWC averages much less than Beaufort Sea FWC increase. Why is there this departure from past results? The authors don't recognize this question, and the author's FWC results are given with insufficient background on the hydrographic data distribution and details on the remote sensing to tell us. Further, no comparisons of hydrography-derived FWC with satellite-derived FWC are done for identical regions and identical times. Such comparisons could rule out issues due to using the different data types. I can't recommend publication without a clearer and more thorough evaluation of the data approaches, a more complete review of past interpretation of the 2005-2008 freshening and a stronger set of conclusions.

Specific Issues line 55 -It seems like this should read more like $S)S'/Sref$ where $S'=S-Sref$ Line 85 - The Tsubouchi result is interesting. One might think the problem using a fixed reference salinity is dwarfed by the problem of hydrographic data coverage. The authors don't explain their remote sensing approach, but might be noteworthy if the remote sensing of FWC with ocean bottom pressure versus dynamic ocean topography is really a measure of steric pressure, which for the Arctic Ocean correlates well with FWC relative to a fixed Sref.

Line 119 - One might add: For example, Rabe et al. (2011) and Morison et al. (2012) found that from the early to late 2000s, the increase deep basin freshwater content in the BG was largely balanced by a decrease in the rest of the Arctic Ocean.

Lines 120-127 - The differences between the models is significant, especially in Fig. 2b. Is this caused by using $S=34.8$ as a lower bound for the integration. It seems like this would be a problem particularly if the distributions of Atlantic water on the shelves are different between the models. Also, although nearly all the models show a freshening in the BG, many show no changes at all in the large regions of decreasing freshwater content described by Rabe et al. (2011) and Morison et al. (2012).

Line 145 - Measuring freshwater content change from altimetry and GRACE ocean bottom pressure was earlier described and validated with repeat hydrographic mea-

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surements by Morison et al. (2012)

Lines 154-166 - Caption for Fig 3 says nothing about GRACE OBP. Was it used in Fig. 3 or not?

Figure 3 and discussion of same - The BG record is said to be from altimetry and the whole basin is from hydrography. That's understandable given the time spans, but unfortunate. In recent years particularly, hydrography from the BG is plentiful but in situ observations, are few in the Amundsen, Nansen, and Makarov basins where we expect freshwater content has declined as BG FWC has increased. It would be helpful to compare satellite derived and hydrography derived FWC for identical BG and whole-basin regions to test the methodologies. It would also be illuminating to do the remote sensing comparisons over the whole basin including the Russian shelves where prior results and the modeling results of Figure 2 suggest decreased FWC acts to balance Beaufort Gyre FWC increase.

Figure 3. As stated above, his result, specifically the correlation of the increase in BG and whole-basin FWC from about 2004 to 2008, does not agree with the findings of Rabe et al. (2011) and certainly Morison et al. (2012) who found that the increase in BG freshwater over that time was largely compensated by decreasing trends in FWC in the Nansen, Amundsen, and Makarov basins, so much so that the whole deep basin average FWC trend could be accounted for by the loss in resident sea ice. In Fig. 3, the whole-basin FWC change around ~2007-08 seems biased by the relative lack of observations outside the Beaufort Gyre to look like the BG FWC change. The result would be more convincing if we were given information on spatial sampling and possible sampling biases. Also the same-area technique comparisons mentioned above might make the result more credible.

Line 275 to 277. How does melt from Greenland get into the deep Arctic Basin? Virtually all the flow around Greenland is nominally southward, away from the Arctic Ocean.

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Lines 320-322 - Eddy fluxes have little to do with stabilizing the BG. Rather the feedback driven by the difference between surface geostrophic velocity and ice velocity balanced against dissipation by internal ice stress stabilizes the gyre at a time scale that is a small fraction of that due to eddy fluxes. See: Dewey, S., et al. (2018). Arctic ice-ocean coupling and gyre equilibration observed with remote sensing. *Geophysical Research Letters*, 45. <https://doi.org/10.1002/2017GL076229>

Lines 325-327 – The authors had better define what they mean by upwelling. Some, as seemingly here, mean upwelling in terms of what happens at the coast or surface (anticyclonic means upwelling) and some define it by what happens to the pycnocline in the center of the gyre (anticyclonic = downwelling).

Summary Section - I can agree that FWC content may have stabilized after 2010, but for reasons mentioned earlier, I don't think the changes in FWC 2005-2008 for the whole basin and the BG should be so similar. I can believe the ice is more mobile in recent years, but I don't understand how Greenland melt has any effect on Arctic Ocean FWC. The paper does not cover regional variability very well.

Interactive comment on Ocean Sci. Discuss., <https://doi.org/10.5194/os-2020-113>, 2020.

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