

Reviewer 2:

First, we thank Reviewer 2 for taking the time to read the manuscript and comment on it. Your contribution has been noted in the acknowledgement section:

“We thank the two anonymous reviewers and the editor Agnieszka Beszczynska-Möller for their comments, which greatly improved this manuscript.”

L3: Define “deep ocean”

After a comment that Reviewer 1 also had, we have specified here and replaced “deep ocean” with “close to the sill depth of 2500 m”.

L5: Suggest replacing “upstream basins” with “surrounding basins” or similar, as the basins can also be “downstream” in terms of the flow.

Excellent point, we have replaced it now with “adjacent basins”.

L22: Rapid warming of GSDW or less GSDW in the mixture? Related to my comment on the water mass definition (L76-77) below.

The fraction of “pure” GSDW has decreased, which has caused the overall warming. We replaced here “rapid warming of GSDW” with “rapid warming of the deep Greenland Sea”.

L31: Do you mean mixing in Fram Strait or exchange across the strait? I think exchange is a better word here.

Both are valid, e.g. von Appen et al., 2015 (<https://doi.org/10.1016/j.dsr.2015.06.003>) showed that strong mixing of these deep waters occurs at the sill. We have nonetheless changed that sentence to: “Fram Strait is thus a key region for exchange between the Arctic-derived EBDW, formed by shelf-slope convection and entrainment of intermediate waters, and waters from the Nordic Seas, such as GSDW, which was formed by open-ocean convection in the Greenland Sea gyre (e.g. Rudels, 2012; Langehaug and Falck, 2012).”

L36: “... GSDW now being a lighter ...”: I’m missing a reference here. Is this based on Somavilla et al., 2013? Then the word “now” is not appropriate. Rather specify when the transition happened.

We thank the reviewer for pointing this out. It is based on von Appen et al., 2015 (<https://doi.org/10.1016/j.dsr.2015.06.003>). We have now added the reference and specified when the transition occurred.

L51: “knowledge of ..., since 2012/2014, is lacking.”: why do you include two different years?

We wrote this way because von Appen et al., 2015 (<https://doi.org/10.1016/j.dsr.2015.06.003>) bases most of their study on mooring data that ends in 2012, and one mooring that ends in 2014. However, we acknowledge that the writing was confusing and have replaced “2012/2014” with “2014”.

L53-61: I found the start of this paragraph (L53-57) a bit difficult to follow because the main goal and focus of the paper are not mentioned in the introduction yet. It would be good to clarify this in the beginning of this paragraph (instead of later in L58-59).

We thank the reviewer for their suggestion, we now lead the paragraph by stating the overarching objective of this paper.

L73: Is there a typo in the east-west extension of the GS box in the text? It says 12W-12E (same as the FS box), but on the map it doesn't look like the GS box goes to 12E (rather 0E, which makes more sense too, in terms of excluding the NS).

This was indeed a typo, and it was supposed to say “0°”. We have now corrected it. We also note that this was just a typo in the text, and it has not affected the results in any way.

L76: exact choice “of” depth levels

Fixed

L76-77: I agree that it is suitable to use a property-independent definition to look at deep water changes in specific regions. However, I think it would be good to clarify that the deep waters you look at contain (are mixtures of) water masses with different origin. GSDW is often referred to in the literature as a class of water that was formed in the Greenland Sea prior to the 1980s. Your GSDW definition likely contains an increasing amount of other water masses such as EBDW and GSAIW. You do discuss this later on in the discussion but it would be good to include one or two sentences here to avoid confusion.

We thank the reviewer for raising a good point. We have now clarified: “Here we note that GSDW was a cold and fresh water mass formed by deep convection before the 1980's, and that the deep waters of the Greenland Sea since then contain an increasing amount of other waters, such as EBDW (von Appen et al., 2015). For the sake of simplicity, we nonetheless refer to the deep waters of the Greenland Sea as GSDW.”

L80-83: Please be consistent with the number of decimals you present for the salinity values (and temperature values). This is also the case in other parts of the manuscript (e.g., section 2.5 and the first paragraph of section 3.1).

We have now changed the values to be consistent in number of decimals when comparing numbers directly against each other.

L81: ... which “corresponds to a” change of ... in Practical Salinity ... (same for temp.)

Fixed

L95-98: Does this mean that you exclude deployments during the 2010-2022 period or are the deployments with Aanderaa RCMs before 2010 (which is why you start in 2010)? This is not clear. Also, the Aanderaa RCMs are dataloggers/platforms with point current meters and the option to install different types/versions of temperature sensors (etc.) with different specs. Which temperature sensor (product number) has the accuracy you refer to of +/-0.05degC?

We thank the reviewer for pointing this out, this was indeed not clear in the text. The deployments with the RCMs are before 2010, or 2011 (for F11). We have now made this clear. The RCMs were installed with thermistors of type Fenwall GB32JM19, which now also has been clarified in the text.

Table 1: “Not all data is always available during the deployments.” I think this needs some elaboration. Is it because of gaps in the deployments, sensor failures, or because you excluded deployments with RCMs or other reasons?

They were due to sensor failures; we have now clarified this in the text of Table 1.

L121: “... compare our results to previous studies, ...”: which results? I’m missing one introductory sentence about why you are doing the cross-correlation analysis (like the first sentence you have in section 2.4, L139-140).

This was indeed vague, we have now clarified: “In order to distinguish between the two water masses EBDW and GSDW, we followed a similar procedure to von Appen et al., 2015, where we normalised the daily-averaged temperature and salinity data from the moorings.”

L124: Remove one “the” in “We define the the upper and lower bounds...”.

Fixed

L124-126: “We define the upper and lower bounds by ..., to get estimates of the upper and lower bounds of water mass properties.”: The last part of this sentence is not needed/is a repeat of the start (ie. remove the part after “to get estimates”).

Done

L152-153: “The results were mostly robust to the choice of year (not shown), ..”: It is difficult to know what “mostly robust” means. Could you be more quantitative or give an example?

We have replaced “mostly robust” with “robust”. The results did not change except for one instance when the missing 2014/15 for HG-FEVI was replaced with data from 2021/22, which would represent a very anomalous year considering how much the temperature has changed over time.

L157: ..., which have “an” initial accuracy ...

Fixed

L175-176 and Fig 2: What does the density change correspond to in terms of potential density anomaly referenced to the surface? (particularly for the DW in the Greenland Sea).

It is somewhat difficult to assess due to large variability in the 1980's, however when referenced to the surface, the potential density of GSDW has remained relatively constant (Fig R2-1). However, since the halt of deep convection in the 80's, diapycnal mixing has been limited, and we see no reason to refer the potential density to the surface, since changes mainly occur isopycnally with EBDW. We have therefore not made any changes to the text.

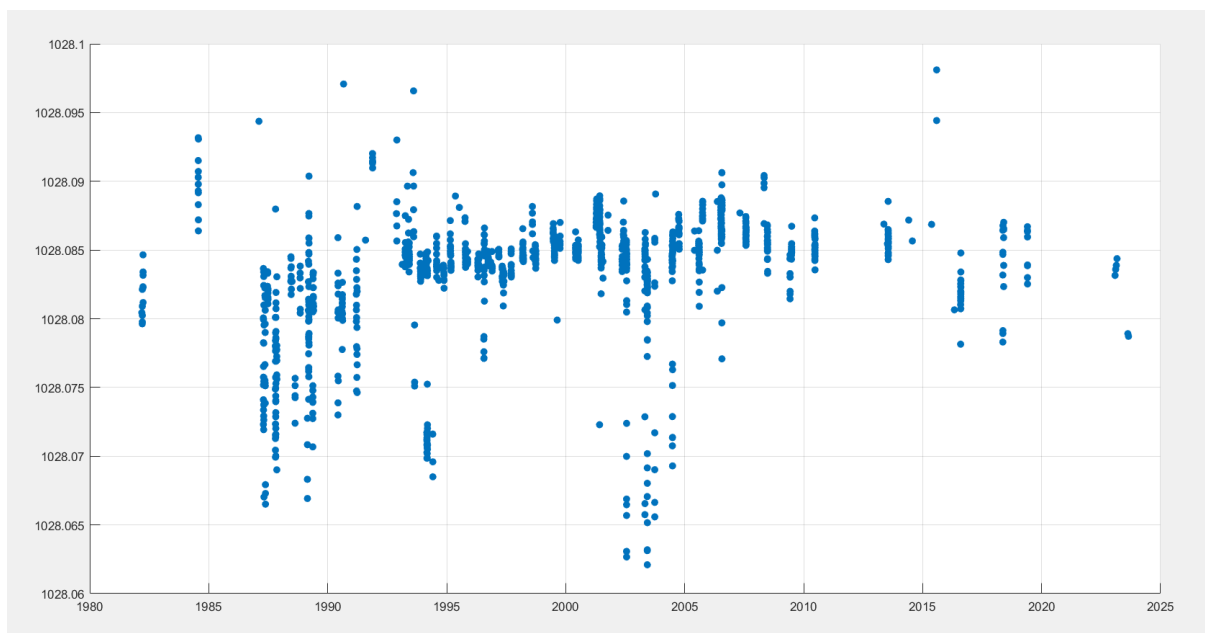


Fig R2-1. Time series of depth-averaged (2400-2600 m) potential density referenced to the surface.

L176-177: It is not clear from the data in fig.2d that the GSDW temp is higher than EBDW after ~2015. That is, I would just state that they have converged here. Evidence of larger GSDW temp comes primarily from the mooring data in Fram Strait and the cross-correlation analyses later.

Good point, we have changed the phrasing here to state that the temperatures have converged.

L217: either “flow switches” or “flows switch”

Changed

Fig. 4 caption: ... as defined “by the regime shift analysis” in Sec. 2.4.

Done

L226: Remove “in fact” before “EBDW-dominated”.

Removed

L230-231: If I understand it correctly it is primarily the seasonal cycle in velocity combined with the different rates of warming of GSDW and EBDW that leads to the stronger seasonality in temperature. What about seasonality in temperature in the upstream water masses?

Yes exactly, this is our hypothesis. It is possible that there is some level of seasonality in the upstream water masses, although we are not sure what could dynamically force such a seasonality. In any case, at present we have no way of assessing seasonality in the upstream water masses due to a lack of data. We have nonetheless added a sentence on how we cannot rule out a seasonality in the upstream water masses in the discussion at L301.

Equation 2: multiply by 1/2

Done. We note that this was a typo in the text only, and has not affected the results in anyway.

L242: ... direction of the “deep” flow in Fram Strait ...

Added

L248: ... associated “with” sampling ...

Added

L282: “However, the possibility remains that GSAIW is replacing GSDW.” Could you plot typical properties of GSAIW to check this? What about geothermal heating? Could this be another source of the increased temperature at 2500m?

After both yours and R1s comments regarding this we have added text to better explain: “However, the possibility remains that GSAIW is replacing GSDW. Previously, high rates of vertical mixing has been reported in the deep Greenland Sea, which would quickly homogenise any gradients in the deep ocean and form bottom mixed layers (Budeus and Ronski, 2009). However, this is not observed in recent observations (Somavilla, 2019). Instead there has been evidence for an upwelling cell at the JMCh, draining the deepest waters of the Greenland Sea into the Norwegian Sea (Somavilla, 2019). This would act to replace the deeper waters in the Greenland Sea with the above-lying intermediate waters, and is consistent with the deepening of isopycnals observed in the Greenland Sea (Brakstad et al., 2019; Somavilla, 2019)”

Considering the strong isopycnal deepening observed in e.g. Fig 5 of Brakstad et al., 2019 (<https://doi.org/10.1175/JPO-D-17-0273.1>), we are confident that GSAIW is replacing the deep waters. This is also consistent with results from Somavilla et al., 2013

<https://doi.org/10.1002/grl.50775>). If you look at Table 2., it is also showing a stronger warming from above rather than from below, suggesting that GSAIW is an extra heat source.

L312: ... play for understanding the changing Arctic. Remove “our” and “on” before and after “understanding”, respectively.

Done