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Observation-based estimates of volume, heat and freshwater exchanges between the subpolar North Atlantic interior, its boundary currents and the atmosphere
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This manuscript presents an innovative analysis of recent North Atlantic hydrographic measurements along with ancillary data sets to quantify the overturning in the subpolar gyre.

I think this is a well-written and very interesting paper that significantly contributes to the understanding of water mass transformation in the subpolar North Atlantic. In my opinion, the analysis has two major weaknesses, namely (i) that the perimeter contour for large parts of the domain is oriented along the major boundary current system such that the cross-contour component of the flow is a small residual relative to the along-contour flow and (ii) that the perimeter contour has too coarse resolution to capture important components of the circulation, in particular the overflows through Denmark Strait and Faroe Bank Channel. I am not sure that these two weaknesses can be robustly addressed, but I think that at least a more extensive discussion of these two concerns is necessary. I also have a few other comments that I hope the authors will consider. Finally, I would like to emphasize that I think this manuscript ingeniously utilizes existing observations to address an important and challenging scientific question; I support the effort and encourage the authors to submit a revised version of the manuscript.

General comments:

Most of the major currents of the subpolar gyre boundary current system have substantial flow along the 1000 m isobath, such as the East Greenland (Le Bras *et al.*, 2020) and West Greenland Currents (Pacini *et al.*, 2020), and the dominant isopycnal slope along this depth contour is across the boundary current system. These currents are to varying extent subject to meanders and instabilities (e.g., Prater, 2002; Pacini and Pickart, 2022), which introduce substantial variability in the measurements. Quantifying the cross-slope geostrophic flow from the isopycnal slope along a depth contour that is characterized by substantial and vigorous dynamics is not optimal. Choosing a deeper isobath for the perimeter contour would likely alleviate the problem. While there are other good reasons for choosing the 1000 m depth contour, I think more robust estimates of cross-contour flow would be obtained along a deeper isobath. I will not advocate that the analysis is redone, but would like to see this issue more extensively discussed in the paper.

For the horizontal gridding along the perimeter contour, a resolution of 150 km was used. The coarse resolution may suffice for the large-scale, geostrophic interior-boundary exchange. However, very important contributions to this exchange occurs on much smaller spatial scales, in particular eddies and deep overflows from the Nordic Seas, but also currents such as the Deep Western Boundary Current are not resolved at this scale. While eddies may roughly balance in- and outward fluxes across the perimeter contour, the overflows and the water masses they entrain are crucial inflows into the subpolar gyre that will not have been properly accounted for. Downstream of Denmark Strait, the overflow plume has a spatial scale of much less than 100 km and rapidly descends beneath the 1000 m depth contour (Dickson and Brown, 1994; Girton and Sanford, 2003) – hence the Denmark Strait overflow cannot be the main source of inflow near Cape Farewell.

Specific comments:

Line 25:
Is the minimum overturning in fall mainly comprised of the overflows from the Nordic Seas, which would form a steady baseline with minimal seasonal variability, while the maximum in spring also includes dense water formed within the subpolar gyre? Or is the surface Ekman component also an important source of variability? I think it would be good to specify the cause of this seasonal variability already in the abstract.

Line 36:
Including the estimate of 305±26 TW across the Greenland-Scotland Ridge by Tsubouchi *et al.* (2021) would be another very relevant point of comparison here.

Line 48:
Another important component of the return flow from the Arctic Ocean and Nordic Seas is the surface outflow of Polar Water in the East Greenland Current (de Steur *et al.*, 2017).

Line 60:
The relatively low impact of water mass transformation in the Labrador Sea on the AMOC was known also prior to OSNAP (e.g., Pickart and Spall, 2007).

Line 64:
The importance of water mass transformation north of the Greenland-Scotland Ridge for supply of dense water to the lower limb of the AMOC should not be underestimated (e.g., Chafik and Rossby, 2019).

Line 99:
Another important dynamical consideration is that, apart from the overflows, most of the sinking occurs along the boundary (Spall and Pickart, 2000; Johnson *et al.*, 2019)

Line 148:
If the minimal search radius is 150 km, equal to the distance between grid points, most of the profiles are probably used in more than one grid cell. Did you apply any weighting to emphasize the contributions of profiles closer to the grid point or the perimeter contour?

Line 199:
This is a great approach to estimate the statistical uncertainty inherent in the data set. Providing the measurement errors that are also inherent in the data set, such that the magnitudes of the statistical and measurement uncertainties can directly be compared, would also be good.

Line 210:
Please provide some more details regarding the calculation of the surface Ekman transport. For example, what have you taken to be the depth of the Ekman layer?

Line 258:
Important flows on relatively small scale such as the overflows from the Nordic Seas and the East Greenland Spill Jet (Pickart *et al.*, 2005) are not properly resolved. Perhaps EN4 at 47°N is not the sole cause of the imbalance, if these features, along with the Deep Western Boundary Current, substantially contribute to the imbalance?

Line 283:
What are the length scales over which the satellite absolute dynamic topography product was smoothed? On line 183 it is stated that smoothing was applied to mimic the smoothing inherent in the hydrographic gridding

process. Is the resulting length scale of the eddy kinetic energy consistent with eddies scaled by the Rossby radius, or were all eddies, to the extent that they were represented in the raw satellite record, removed by the smoothing procedure?

Line 308:
Offshore fluxes of freshwater from the Greenland shelf into the interior Labrador Sea near Cape Farewell (Lin *et al.*, 2018) and farther north where the West Greenland Current encounters steep topography and becomes unstable (e.g., Fratantoni, 2001; Prater, 2002) are likely major contributors to the cold, fresh low-density layer. Both of these processes are primarily eddy-driven, hence postulating that a portion of the West Greenland Current crosses into the interior supbolar gyre may not be necessary. These processes will not be resolved at 150 km horizontal resolution. Given the turbulent nature of these fluxes, it is also not obvious that there will be a consistent geostrophic flux across the perimeter contour.

Lines 349 and 491:
Most of the Atlantic Water inflow from the subpolar gyre to the Nordic Seas takes place east of Iceland, roughly evenly split on either side of the Faroe Islands (Østerhus *et al.*, 2019). Given the course resolution of the perimeter contour, I think it is more appropriate to ascribe this flow to the Iceland-Scotland Ridge rather than the Wyville Thomson Ridge (note that Thomson is spelled without a p).

Line 351:
Note that there is also some flow of Atlantic Water northward through Denmark Strait (Jónsson and Valdimarsson, 2012; Semper *et al.*, 2022).

Line 352:
What is the magnitude of the retroflection of the East Greenland Current near Cape Farewell?

Line 357:
An export of 12 Sv from the subpolar gyre to the Labrador shelf is immense. Is this a realistic number? Could this be related to water sinking along the boundary (e.g., Johnson *et al.*, 2019) or merge with the boundary current system (a substantial portion of which appears to be inshore of the 1000 m isobath, Zantopp *et al.*, 2017)?

Line 450:
Good discussion of missing contributions. While the model has a much higher resolution, how confident can you be that it is able to realistically capture these features?

Lines 493, 631, and 696:
It is not obvious why there should be a lower layer inflow in the vicinity of Cape Farewell. This is too far south of Denmark Strait to be ascribed to the overflow (Dickson and Brown, 1994; Girton and Sanford, 2003), but perhaps the East Greenland Spill Jet (Pickart *et al.*, 2005) contributes? Please elaborate.

Line 525:
This estimate of advective flux across the Iceland-Scotland Ridge appears to be in reasonably good agreement with the estimate of Tsubouchi *et al.* (2021).

Lines 572 and 726:
There is substantial discussion of the high EKE west of Greenland in the literature (e.g., Fratantoni, 2001; Prater, 2002).

Line 599:
The overturning across the Greenland-Scotland Ridge would be another vital point of comparison (e.g., Østerhus *et al.*, 2019; Tsubouchi *et al.*, 2021).

Line 618:
How does the density surface of 27.30 kg/m^3 for maximum overturning compare to similar results from Lozier *et al.* (2019) and Petit *et al.* (2020)?

Line 623:
This is an important result, which substantially modifies the conclusions of Petit *et al.* (2020). Without velocity measurements, they considered this water mass transformation part of the overturning in the subpolar gyre, and concluded that more deep-water formation occurs in the subpolar gyre than in the Nordic Seas. You have demonstrated that a substantial portion of this intermediate-density water continues to the north, into the Nordic Seas, where it is further transformed. As such, densification in the subpolar gyre preconditions further water mass transformation in the Nordic Seas and is thereby important for the North Atlantic overturning, but it is not appropriate to ascribe that part of the water mass transformation to overturning in the subpolar gyre, since the water proceeds into the Nordic Seas in the upper layer rather than returning to the south at depth.

Line 639:
Overflow waters from the Nordic Seas become lighter as they mix with and entrain ambient water masses while descending to the abyss of the subpolar North Atlantic. I do not think there are other processes that can make the overflow waters significantly lighter. In general, the overflow waters are located too deep in the Labrador Sea, where the deepest convection occurs, to be accessed during convection in winter (Yashayaev, 2007). More importantly, for the overflow waters to be modified by convective mixing, the mixed layer would have to be sufficiently deep that it extends into the overflow layer. Since the ocean is stably stratified, the density of the mixed layer would then have to be at least the same as the density of the overflow layer. For this reason, deep convection would not make the overflow water lighter.

Line 642:
The deepest overflows are generally considered denser than $\sigma_\theta = 27.8$ kg/m^3 (Dickson and Brown, 1994).

Line 649:
This is a remarkably swift export of newly formed dense water, in particular considering that most of the transformation takes place within cyclonic gyres (e.g. Lavender *et al.*, 2000; Straneo *et al.*, 2003).

Line 656:
It is unclear to me how virtually all of the subpolar mode water is exported before undergoing further transformation to dense water, in particular considering that the residence time within the cyclonic gyres where most of the water mass transformation takes place may be on the order of years (Straneo *et al.*, 2003). Please elaborate.

Line 664:
Dense-water formation is not considered a “driver” of the AMOC (Kuhlbrodt *et al.*, 2007).

Lines 673, 681, and elsewhere:
Adding uncertainties to these estimates would be good.

Line 714:
Most high-latitude currents with substantial barotropic components closely follow density contours (e.g., Nøst and Isachsen, 2003). Instabilities in the West Greenland Current and formation of Irminger Rings may be a

more likely source of this signal (Fratantoni, 2001; Prater, 2002).

Line 727:
While deep convection at the boundary of the Labrador Sea may not have taken place in the 2000s, the boundary current system was ventilated during the more severe winters of the early- and mid-1990s (Pickart *et al.*, 1997).

Line 758:
I think it would be great to relate the overturning in depth space to the corresponding results obtained for the density space calculations. That would also integrate this section better within the rest of the manuscript.

Line 774:
This is the first proper discussion of the unresolved overflows. This is a major drawback of the coarse perimeter contour and likely has a substantial impact on the results. I think this discussion needs to be introduced much earlier in the manuscript.

Line 782:
More recent estimates of the Denmark Strait Overflow Water transport converge at values around 3.2-3.5 Sv (Harden *et al.*, 2016; Jochumsen *et al.*, 2017). This transport across the sill may then approximately double by entrainment as the dense water descends toward the abyss (Dickson and Brown, 1994). As such, VIKING20X may not be overestimating the overflow, although even in a relatively high-resolution model the overflows are probably not simulated very realistically.

Line 788:
More recent papers have made significant progress improving our understanding of the variability in Denmark Strait (Spall *et al.*, 2019; Lin *et al.*, 2020).

Line 792:
All of the reasons discussed in this paragraph may contribute, but the main cause of the poorly represented overflow water must be the low horizontal resolution along the perimeter contour.

Line 802:
Perhaps specify here that the dense water exiting the subpolar gyre in the North Atlantic Current continues to the north, into the Nordic Seas. As previously stated, this is an important result that demonstrates the importance of the subpolar gyre in preconditioning overturning in the Nordic Seas and thus modifies the conclusions of Petit *et al.* (2020).

Line 812:
The net sinking that occurs along the boundary (Spall and Pickart, 2000; Johnson *et al.*, 2019) may be another such process that is important to better understand, but difficult to address using this approach.

Detailed comments:

Lines 9, 105, 659, and elsewhere:
Oceans and Basins should be capitalized, also in plural.

Lines 16, 299, and 485:
Biscay is a province of Spain, I think Bay of Biscay would be more appropriate.

Line 28:
The acronym NAC should be defined at first usage.

Line 48:
"Arctic" by itself is an ill-defined term. Arctic Ocean would be better.

Lines 66, 134, 135, 138, 423, 460, 489, 492, and elsewhere:
I would have added at least one "the" to these lines.

Line 93:
"Deep mixing" is ambiguous. Do you mean convection/deep vertical mixing?

Line 149:
A search radius cannot be negative.

Line 198:
Is not an integral by definition cumulative?

Line 210:
Data are typically considered plural.

Line 223:
It should be: "...for an improve**d** representation..."

Line 225:
It should be: "...show **that** it realistically..."

Line 253:
It should be: "...surface Ekman **transports** capture..."

Line 257:
The Deep Western Boundary Current should be capitalized.

Line 275:
It should be: "...Using ERA5 month**ly** means..."

Line 290 and elsewhere
Scale-dependent is a compound modifier that should be hyphenated.

Line 316:
The comma should be removed.

Line 319:
The Labrador Current should be capitalized.

Lines 366 and 393:
Transport should not be capitalized.

Line 382:
The unit Sv is missing.

Line 463:
A comma is missing.

Line 592:
It should be: "...water **mass** transformation..."

S4:
Gulf Stream should be capitalized.

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