Author Comments

We thank the reviewers and editor for their encouraging and helpful comments. We address each of these comments below and outline how any highlighted issues will be addressed prior to resubmission.

The authors have also identified two further issues which we will address prior to resubmission:

1. The uncertainty in the trends presented in Figure 5 were calculated with confidence intervals of 1-sigma, as opposed to the 95% confidence intervals stated in the figure caption.
2. We found instances of unphysical density values near the seabed on the Canadian in July 2006. This is likely due to flag or fill values from GLORYS12 hydrographic fields being mistakenly interpolated onto the grid. Only five grid cells were affected, so this has no qualitative effect on the results.

Editor comments

As a personal note, I would like the authors to rethink the message that this piece of text in the conclusion might send to the community. *There is, however, an urgent need to make ocean observing more sustainable, as reflected by changes to funding landscapes and government priorities across the North Atlantic towards reduced ship-time, lower emissions, and greater use of autonomous and low-cost platforms. Under these constraints, it is far from clear that the present AMOC monitoring infrastructure can be maintained in the long term. SCOTIA provides a blueprint for a lightweight, reliable and sustainable subpolar AMOC observing system for the coming decades."*

I understand the advantages of SCOTIA for going further back in time, which is great. Or perhaps even as an additional array so more details about the AMOC could be understood. However, to me these sentences do suggest too much that SCOTIA is suggested as a replacement for OSNAP. Even though it is said above that it should not. I will not hold this against you but would like you to think about potentially rephrasing this paragraph more carefully

We appreciate this feedback from the editor which will help us promote SCOTIA without reflecting negatively upon OSNAP. We are long-serving and committed contributors towards the international OSNAP programme and are strong advocates for its continuation. We fully acknowledge and share the concern that SCOTIA could be misinterpreted as an intended replacement for OSNAP.

Even though the primary focus of this paper is really extending backwards in time, we felt it was important to address this issue directly in our discussion to avoid creating ambiguity over how SCOTIA and OSNAP can coexist. We feel that removing this passage of text altogether would leave an "elephant in the room", because whether SCOTIA will continue, what form it will take, and how that affects OSNAP, are all natural questions for a reader, especially given the uncertainty over science funding on both sides of the Atlantic. Indeed, Reviewer 1 asks "*Could SCOTIA be used to inform a minimal or reduced array design for maintenance in the future?"*.

With these points in mind, we have reworded the text in question to read:

"There are, however, increasing pressures to make ocean observing more sustainable, as reflected by changes to funding landscapes and government priorities across the North Atlantic towards reduced ship-time, lower emissions, and greater use of autonomous and low-cost platforms. Under these constraints, it is far from clear that the present AMOC monitoring infrastructure can be maintained in the long term. The approach presented here might provide a useful template for a lightweight and sustainable subpolar AMOC observing system for the coming decades."

Although subtle, these changes (i.e. "*urgent need*" to "*increasing pressure*") hopefully clarify that it is not the authors desire to reduce the number of in situ ocean observations.

Furthermore, and in response to Reviewer 3, we have been careful to clearly highlight the advantages of the full OSNAP array in both the introduction and the discussion.

Reviewer 1

General comments

The manuscript introduces a new transatlantic section, the Scotland-Canada overturning array (SCOTIA), to compute subpolar overturning transports combining existing moorings from the OSNAP array, CTD profiles, Argo data, satellite ADT, and GLORYS reanalysis. One of the main advantages of this new estimate is that the monthly gridded merged product to analyze AMOC variability on SCOTIA extends the subpolar AMOC record back in time before the OSNAP measurements started providing the possibility of analyzing long-term AMOC variability and trends at subpolar latitudes.

The extended record at SCOTIA is compared with the twenty year (2004-2024) AMOC record at 26N from the RAPID array and with the ten year record (2014-2024) from OSNAP in the subtropical and subpolar North Atlantic, respectively. Five key metrics (maximum of overturning streamfunction, density at which this maximum occurs, *northward heat and freshwater transports, and density flux) are analyzed to validate SCOTIA against OSNAP on seasonal and longer time scales. SCOTIA provides an overturning structure and variability consistent with that from the full OSNAP array, offering an alternative configuration for observing subpolar AMOC and the associated heat and freshwater fluxes, allowing near-real-time updates to be generated based on the latest Argo and satellite data following mooring recovery. Given the logistical and funding difficulties often associated with maintaining sustained ocean monitoring systems, these results offer and alternative way of estimating AMOC transports in the subpolar North Atlantic with a focus on decadal and longer variability, and to extend the AMOC record back in time before OSNAP started. One of the main results from SCOTIA is that subpolar AMOC varies on pentadal to decadal timescales with an amplitude comparable to that observed in the subtropical North Atlantic.*

These analyses are very valuable and useful for the AMOC community. The manuscript is well written and well organized. My impression is that the manuscript could benefit from more discussions or clarifications on to what extent SCOTIA relies on the actual mooring design at OSNAP, and if possibly SCOTIA could serve to inform alternate, or minimal, OSNAP array design. Please find some specific comments below.

Specific comments:

Line 50: it may be useful to mention here that the resulting blended gridded product has monthly temporal resolution (compared to the daily resolution from OSNAP). Line 5 and other places: I am hesitant if SCOTIA should be considered as a "new subpolar observing array" or as an alternate blended product based on combinations of in situ hydrographic profiles, moorings, satellite altimetry, and reanalyses products.

We have added that the product has monthly temporal resolution. Note that the OSNAP gridded fields and MOC timeseries also have monthly resolution.

We have changed “new subpolar observing array” to “new subpolar observing configuration”.

Lines 125-127: Are there are attempts to regionally validate GLORYS temperature, salinity and velocity data near the shelf?

The use of GLORYS on the Canadian and Scottish shelves is the same as for the OSNAP array (Lozier et al. 2019, supplementary material).

Global validation for GLORYS is presented here:

https://doi.org/10.3389/feart.2021.698876

As GLORYS assimilates various observations, a robust and independent regional validation would require in depth knowledge of which observations are assimilated and how they are used in the GLORYS processing, which is beyond the scope of the work presented here.

Lines 233-243, and other places: Given that all OSNAP mooring data are included on the SCOTIA estimates, I suggest adding some discussion on how independent are OSNAP and SCOTIA time series, and how this may impact the interpretation of the correlation coefficients.

Could tests for minimal array design be done?

We agree that this warrants further discussion. Firstly, to avoid ambiguity, not all the OSNAP mooring data are included in SCOTIA estimates. SCOTIA uses around 15 moorings compared to around 50 in the full OSNAP array. Specifically, SCOTIA does not use the OSNAP moorings adjacent to Greenland or the Reykjanes Ridge.

However, there is still an overlap in the data used to generate the two products (besides hydrographic moorings, they both use the same ERA5 and GLORYS reanalysis fields), so they cannot be treated as wholly independent estimates.

Testing for a minimal subpolar AMOC array would require a set of robust Observing System Simulation Experiments (OSSEs) using high-fidelity numerical model output. This is beyond the scope of the work presented here, but is something we intend to pursue in future.

We will add a paragraph into the discussion discussing the differences in the methodology, as well as array configuration, between SCOTIA and OSNAP, and to what extent they can be considered independent.

Line 235: please clarify, SCOTIA MOC shows higher variability compared to OSNAP MOC on which time scales?

This statement is in relation to the standard deviation of each time series, given in the figure 4 legend, which is not timescale specific. We have changed "variability" to "variance" to remove this ambiguity.

We intend to add a panel to figure S6, showing power spectra for the SCOTIA and OSNAP timeseries over the overlapping period.

Figure 4a, 4b (MOC or maximum overturning and density of maximum overturning, respectively), Line 245, and other places: please mention which correlation coefficients are statistically significant. SCOTIA and OSNAP (MOC) records agree fairly well with a correlation of ~0.66. The correlation considering the density of maximum overturning diminishes to nearly 0.3, implying that a small portion of the variance is shared between the two compared records. Visual inspection of the time series shown in 4b indicates that sometimes the records are out of phase.

Good idea. Correlation coefficients that are significant at the 95% confidence interval are now in bold, and this is specified in the figure caption.

I suggest adding more interpretation for the comparisons in Figure 4a and Figure 4b.

We intend to add some text here along the lines of:

"We note that sigma_MOC is very sensitive to local fluctuations in the velocity field on short timescales. On 5-10 year timescales, which is our primary interest, we see good agreement between the two."

Figure 3b: There is little discussion in the text about the comparisons of the MOC seasonal cycles from SCOTIA and OSNAP. Is it possible to separate the seasonality from the interior transport and from the Ekman component?

We intend to add AMOC-Ekman seasonality as dashed lines.

We will also add text saying something like:

Fox et al. (2025) showed that, at OSNAP, the seasonality in AMOC is intimately coupled to the density of the upper ~500m at the western boundary. The agreement in the timing and amplitude of the seasonal cycle between OSNAP and SCOTIA is therefore unsurprising, as the two products are informed by the same data in this western boundary region.

I suggest adding a comparison of the seasonal cycles from the heat and freshwater transport to better understand the overturning variability from both estimates at seasonal timescales.

Understanding the seasonal cycle in heat and freshwater fluxes is not one of the aims of this paper. Upon final publication, we will make the SCOTIA data product public so that these can be easily diagnosed by anyone interested.

Line 252: correlations for the density of the maximum streamfunctions are slightly lower that this value.

Thanks, we have removed this statement.

Lines 264-274: How dependent is SCOTIA estimate on the maintenance of the full mooring array in the future? Could SCOTIA be used to inform a minimal or reduced array design for maintenance in the future?

See answer above regarding how the SCOTIA array differs from the OSNAP array.

Regarding SCOTIA informing a minimal array please see our response to the editor above.

Figures:

Figure 1: it may be useful to add schematics of the main ocean currents and pathways to better illustrate the dynamical connections between the arrays in the North Atlantic.

We feel that schematic arrows of currents are subjective and often ambiguous, and would rather keep our figures objective and data-focused.

Figure 2: panel b: I suggest using different colour for the CTD (black dots) and mooring (vertical black lines) profiles respectively, to better appreciate the spatial and temporal distribution of the different data sources.

Agreed. CTDs are now shown in blue.

panel d: please indicate in the figure caption what shading represents.

The figure caption already states that it is the standard deviation.

Figure 3: please add in the Figure caption that these comparisons are made for the OSNAP period 2014-2022. How does the SCOTIA MOC seasonal cycle for the full period since 2004 compare to the estimate between 2014-2022?

This is already stated in the final sentence of the figure caption.

We have added that these results are not qualitatively different when considering the full SCOTIA period. Investigating time-varying seasonal cycles is not the main point of this work. However, we include the figure here:

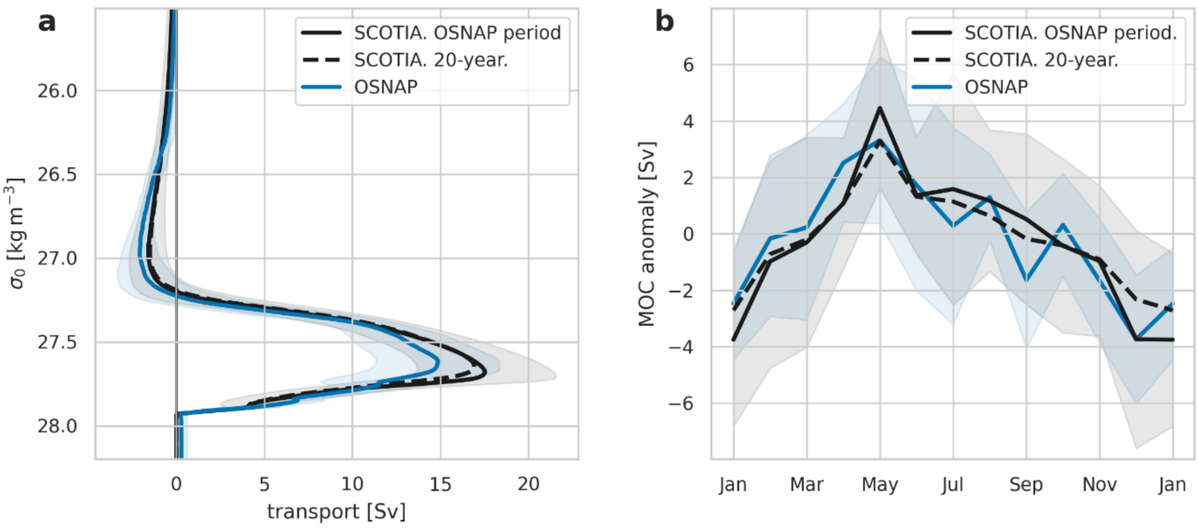

Figure 4: Please indicate in the figure caption what blue shading represents.

This has been added, thanks. It represents the uncertainties provided with the OSNAP data product.

Technical corrections:

Line 4: remove "the" between "amplitude" and "interannual"

Fixed, thanks.

Line 13: I suggest adding "in the upper ocean" for the transport of warm water northward or an indication that this text refers to the upper limb of the AMOC.

We have deliberately avoided saying this, as we are not considering a subtropical circulation regime where ocean depth is an appropriate threshold for the upper/lower AMOC limbs. At the subpolar latitudes on which we focus, the upper limb can be over 1400m deep while the lower limb can reach the surface.

Line 21: I suggest highlighting that these are continuous daily observations

We have added "with 12-hourly temporal resolution".

Line 29: revise referencing --> (McCarthy et al., 2025).

Fixed, thanks.

Line 51: To generate the corresponding velocity field…

Fixed, thanks

Line 397: Please remove one "either"

Fixed, thanks

Reviewer 2

General comments:

This paper introduces a new subpolar overturning array, SCOTIA. The array uses part of the OSNAP mooring array, but runs south of Greenland and additionally makes use of CTD, ARGO and reanalysis data. One of the added values of this array is that it allows to reconstruct subpolar overturning for the last 20 years, and therefore to compare it over this entire time period with subtropical overturning at RAPID. Additionally, it could provide a lightweight option for continued subpolar overturning monitoring.

This is a high quality paper, and the 20 year timeseries of subpolar overturning at the OSTIA section will likely be of interest for everyone working on overturning in the subpolar north Atlantic and meridional connectivity of the AMOC. I found the methods section very comprehensive, and the graphics very good. I would recommend the paper to be published with minor revisions. My comments can be found below, divided in minor comments and typos.

Minor comments

L220 : What are "these processes"? Does it refer to processes mentioned a few sentences before? Maybe repeat in the sentence to clarify.

Thanks. We have changed the sentence to read *"To assess how the difference in location impacts overturning and transport metrics on the SCOTIA and OSNAP lines, we again turn to output from the Viking20x model"*

L244: I do not understand what is meant with "increased power of the two sections". Do you mean that there is added value in using the two sections rather than one? Maybe reformulate / clarify what is meant.

We have removed this statement.

L251: Here, the authors write that heat fluxes show the least correlation of all metrics studied between scotia and osnap. However, the correlation given here (r=0.352) is higher than the correlation found for the density of maximum overturning (r=0.320, L245), which was described as "showing many similarities" between the two time series

Agreed. This point was also raised by Reviewer 1. We have removed the statement that heat flux shows the lowest correlation.

L373-379: I am a little bit confused here about the discussion on the definition of LSW with a fixed density range. The authors first say that according to fig 9, the most prominent feature of low frequency overturning at SCOTIA is increased southwards transport in the denser LSW class between 2014-2022. They link this to results from Yashayaev et al 2024 showing LSW formation over that same time period. They then move on to ask why results in fig 8 suggest that the most variability takes place instead in the deep overflow waters, and attribute this discrepancy to the definition of LSW with a fixed density range. I'm a bit confused because this fixed density range is also applied in fig 9, where we clearly see the increase in transport in the denser LSW class. Why is the fixed density range an issue for fig 8 but not fig 9? I must be missing or misunderstanding something, and it would be nice if the authors could clarify this paragraph.

This is an inherent shortcoming of using fixed density thresholds as water mass criteria. Here, LSW, ISOW and DSOW are really just labels for different regions of density space, and might not necessarily correspond to the regions these waters were formed.

Firstly, we want to reassure the reviewer that figures 8 and 9 are consistent with each other. We have made a couple of changes to try and clarify this issue (in bold).

1. *"Precise definitions of these deep water masses can be complex, involving overlapping ranges of density, depth, temperature, salinity and oxygen and nutrients, **which might also change with time.**"*
2. *"So why do our results in Fig. 8d suggest the **source of this signal** lies mostly in the deep overflow waters? **This is partly because Fig. 8d shows only the total***

> ***LSW transport (the sum of LSW(u) and LSW(l)), whereas Fig. 9a reveals that the increased southward transport of LSW(l) is compensated by a reduced, or even northward, transport of LSW(u).*** *This is* ***also likely an artefact*** *of our LSW definition occupying a fixed density range, since LSW production shows significant variation in density, the 2014-2018 period showing production of some of the densest classes of LSW seen since the early 1990s (Yashayaev, 2024)."*

L 399-403 The authors identify an anomalously high overturning at SCOTIA in 2016-2020, which they associated with increased Labrador Sea Water southwards transport. Is that a result that necessitated the use of SCOTIA, or could it also have been inferred from the existing OSNAP observations (given that the time period is covered by OSNAP)? If so, it would be nice to more clearly state what the role of SCOTIA (the longer timeseries allow to put this higher overturning in a broader context?) is in this result.

Good point. We have reworded the second sentence of this paragraph to read:

"This longer time series allows us to identify that the subpolar MOC during 2016-2020 was anomalously high, and was associated with both an increased γ_{MOC} and an increased southward transport of lower Labrador Sea Water."

L409 Similarly, I would appreciate a little more information on the role of specifically the use of SCOTIA in this result. Is this a result that is made possible specifically by the use of SCOTIA, because it provides a longer timeseries for instance, or is it a side result, that is demonstrated here with SCOTIA but could have been deduced from other available data? I think more clearly connecting these results with the use of SCOTIA would strengthen the case for the usefulness of this new array.

True, this feature occurs during the OSNAP period. However, it only becomes strikingly anomalous after running the timeseries through a 5-year lowpass filter. This wouldn't really work on the 8-year OSNAP time series, as the resulting timeseries would have too few degrees of freedom to say anything significant.

L415 Here the authors say that the SCOTIA array, because of its position, cannot discriminate between convection in the Irminger and Labrador basins. Could this impossibility to discriminate between different basins create issues in the previous discussion, which focuses on the Labrador Sea only?

We here define LSW according to a fixed density range. As such, waters within this density range were not necessarily formed in the Labrador Sea.

As discussed in Yashayev (2024), a variable density range might be more appropriate when considering the different "vintages" of LSW associated with the variable depth of Labrador Sea convection. However, the problem of water mass classification then becomes far more complicated. Our water mass labels are intended to be a simple way to orient the reader.

Typos / reference issues

Thanks for spotting these! They are all fixed unless otherwise stated below.

L4 : Either an "of" is missing or there's a "the" too much

L8: "subtropics" should likely be "subtropical"

L25: should "be" be "been"?

L50: Missing "the"

L51: "generate corresponding the velocity field", the "the" is misplaced

L54: "extending back 2004", is a "to" missing?

L127: The reference uses the first name, not family name of the author. The issue is also present L505 in the reference list. For that item, the first names of authors and the first letter of their family name are listed rather than the contrary.

We agree this is strange. But note that our citation is consistent with the citation format from the article url:

Frontiers | The Copernicus Global 1/12° Oceanic and Sea Ice GLORYS12 Reanalysis

L222: An "are" seems to be missing

L228: "Figs. 3" should be "Fig. 3"

L275: Should there be a 4.1 here? This part has heading 4. , then several paragraphs, then heading 4.1(L319), but no 4.2 . Adding a 4.1 heading here might also help the reader in identifying the arguments made in each part.

L349 "Susan Lozier et al, 2022" should be "Lozier et al 2022"

Reviewer 3

The authors main result, namely that they find "*no statistically significant MOC decline in the 20-year SCOTIA record*" should be set in the context of other work in the subpolar North Atlantic that has focused on trends, notably the following:

Fu, Y., Li, F., Karstensen, J., Wang, C. (2020), A stable Atlantic Meridional Overturning Circulation in a changing North Atlantic since the 1990s, Science Advances, 6, eabc7836.

Thank you for this suggestion. We plan to include this comparison in the revised manuscript, in the second paragraph of the discussion.

In the introduction, the authors write:

Furthermore, the OSNAP section crosses a region with more complex topography than at RAPID, so relies more heavily on direct velocity observations in several narrow, barotropic boundary currents. As a result, the OSNAP array is highly resource intensive, currently comprising around 50 hydrographic moorings compared to just 9 at RAPID.

I think it would be fair to mention that the resource intensive array delivers more than expense. The arrays allow for the separation of the Labrador Sea overturning, separate from that in the eastern subpolar North Atlantic. They also allow for the measurement of freshwater transport along both sides of Greenland, and for a measure of the overflow transports downstream of the Greenland-Scotland Ridge. While two of these are mentioned in section 5, I think it is important to point out these advantages in the Introduction, otherwise only the downside (the expense) is stressed.

We fully agree that the advantages of the full OSNAP array should be clearly highlighted. We have added the following sentence, with several relevant citations, to the introduction:

"This configuration allows subpolar overturning to be partitioned into contributions from processes occurring east and west of Greenland (e.g. Lozier et al., 2019; Li et al., 2021; Fu et al., 2023, 2025), and captures the volume transports of both freshwater and dense overflow water by the Greenland boundary currents (e.g. Pacini et al., 2020; Foukal and Pickart, 2023; Koman et al., 2024; Sun et al., 2025)."

In section 5 (Discussion), the authors write:

By omitting observations of the boundary currents around Greenland, the SCOTIA methodology cannot discriminate between convection in the Irminger and Labrador Basins (Lozier et al., 2019), or capture signals in the overflow transports immediately downstream of the Greenland-Scotland Ridge (Koman et al., 2024). SCOTIA should not, therefore, be considered a substitute for the OSNAP array, which resolves these features, but rather an additional, partially independent measure of subpolar overturning with the advantage of providing a longer-term perspective.

While this discussion is generally fine, I think it is important to also mention that OSNAP allows for the monitoring of the freshwater fluxes on both sides of Greenland. This monitoring is particularly relevant given our expectation of increasingly fresh water along the Greenland shelves/slopes in the years ahead.

We agree with this point and, together with the reviewer's previous point, feel this this gives a nice symmetry between the introduction and discussion. The sentence now reads:

"By omitting observations of the boundary currents around Greenland, the SCOTIA methodology cannot discriminate between convection in the Irminger and Labrador Basins (e.g. Lozier et al., 2019; Li et al., 2021; Fu et al., 2023, 2025), resolve freshwater fluxes on the shelf and slope either side of Greenland (e.g. Le Bras et al., 2018), or capture signals in the overflow transports immediately downstream of the Greenland-Scotland Ridge (e.g. Pacini et al., 2020; Foukal and Pickart, 2023; Koman et al., 2024; Sun et al., 2025)".