Reply to Referee #1

We thank referee #1 for the helpful comments. We specially thank the referee for the thorough English correction. We have addressed the referee's concerns as explained below.

Main / Science comments:

(1) The main problem I have with the manuscript is section 4.1, and the interpretation of an increase in the proportion of ISOW.

(i) The authors use time-invarient SWT definitions. However, it is known that the LSW definitions in particular vary temporally related to the intensity and depth of winter convection in the Labrador Sea. LSW has become warmer and more saline recently – as noted by the authors e.g. P10, L21-24. Surely an alternative explanation for the apparent increase in the proportion of ISOW is that it is an artefact of a salinification of the LSW source water whilst the eOMP uses a constant SWT? (And potentially also as a result of an increase in the salinity of Faroe Bank Channel bottom water: Hansen et al., 2016, Ocean Science, 12, doi: 10.5194/os-12-1205-2016)

We have performed a new OMP run where we slightly modified the temperature and salinity (TS) properties for LSW and ISOW to match those found in the most recent period and we revised the standard deviations of the properties that define the SWTs taking into account the temporal variability. We have used the results of this new OMP run as the final results of the manuscript. Even using the TS properties for LSW and ISOW closest to those observed in recent years, we obtained proportions of ISOW higher than the mean values reported in the literature. Therefore, we are confident that the higher than expected concentrations of ISOW is a real feature, which is consistent with the increase in the volume transport of ISOW observed in the OSNAP array (Johns et al., 2017; Zou et al., 2017). We have added this result in the manuscript: "The uniform increase in ISOW is consistent with the increase in volume transport of ISOW observed in the OSNAP array (Johns et al., 2017; Zou et al., 2017)".

(ii) I also disagree with the statement on P11, L8-10 that the observed salinization of the deep-bottom waters of the section supports the idea that more SPMW is entrained into ISOW. Firstly the eOMP results (Fig. 6) does not show increased SPMW in the ISOW region. Secondly Zunino et al., Fig 7 suggests to me that the salinification has occurred in the LSW rather than the ISOW.

We agree that the statement was not formulated correctly. Our OMP setting does not allow us to disentangle the causes of the changes in the properties of ISOW. As indicated in the answer to the previous comment, we have performed a new OMP run using new TS properties for ISOW and LSW. The TS properties of ISOW have been changed according to the observed warming and salinization in ISOW after crossing the Faroe Bank Channel (Hansen et al., 2016). This warming and salinization were due to a change in the properties in both the Nordic Seas waters and in the Atlantic waters entrained in the overflow (Hansen et al., 2016). Regarding the salinization reported by Zunino et al. (2017), their figure 7 shows a salinity increase in LSW and in deeper levels corresponding to ISOW. We have rewritten the entire section and the paragraph corresponding to ISOW now reads as: "Below σ_3 = 41.25 kg m^{-3}, the decrease in the contribution of LSW in 2014 with respect to 2002–2010 is balanced by an increase in ISOW (Fig. 6b). This water mass redistribution responds both to the salinization of LSW (e.g., Yashayaev and

Loder, 2017), and to the lower density of LSW formed in recent years that occupies shallower positions in the water column. García-Ibáñez et al. (2015) also reported how the progressive salinization of LSW since the late 1990s resulted in a progressive decrease in LSW and increase in ISOW. East of 22ºW, the increase in ISOW compensates the decrease in NEADW$_L$, which is linked to a decrease in silicic acid in the range of 20–35 µmol kg^{-1} (i.e., in the mixing zone between ISOW and NEADW) in 2014 compared to 2002–2010 (Fig. S2). The uniform increase in ISOW is consistent with the volume transport increase in ISOW observed in the OSNAP array (Johns et al., 2017; Zou et al., 2017)".

(2) Similarly, I think that the ISOW transport discussed in Section 4.2 and the conclusion is higher as a result of the LSW (and ISOW?) salinification, rather than because of an increase in ISOW per se.

See answer to comment 1(i).

(3) I feel that the final paragraph of section 2.3 discussing the robustness of the eOMP is important, but there are points that I don't understand:

(i) what standard deviation did you perturb the SWTs by? (i.e. what is the standard deviation in Table 1).

We have added the information in the supplementary material and we have referenced it in a footnote added in Table 1.

*"**Text S1***

The standard deviations (STD) of the potential temperature and salinity that define the source water types (SWTs) were taken from the literature. For Central Waters and SPMWs, the STDs were set as ± 0.6ºC for temperature and ± 0.06 for salinity, according to the thermohaline variability reported by Robson et al. (2016) for the first 700 m of the water column of the subpolar gyre. For LSW, the STDs were set as ± 0.4ºC for temperature and ± 0.01 for salinity, to include both the thermohaline properties used in García-Ibáñez et al. (2015) and those used in this work. For SAIW, the STDs were set as ± 0.5ºC for temperature and ± 0.03 for salinity, based on the variability of the thermohaline of its source waters, i.e., Central Waters and LSW (Iselin, 1936; Arhan, 1990; Read, 2000). For MW, the STDs were set as ± 0.2ºC for temperature and ± 0.07 for salinity, according to the work of Carracedo et al. (2016). For ISOW, the STDs were set as ± 0.1ºC for temperature and ± 0.02 for salinity, to include both the thermohaline properties used in García-Ibáñez et al. (2015) and those used in this work. For DSOW, the STDs were set as ± 0.16ºC for temperature and ± 0.008 for salinity, according to the work of Jocchumsen et al. (2012). For PIW, the STDs were set as ± 0.2ºC for temperature and ± 0.03 for salinity, according to the work of Falina et al. (2012). For NEADW$_L$, the STDs were set as ± 0.03ºC for temperature and ± 0.003 for salinity, according to the work of García-Ibáñez et al. (2015). For NEADW$_U$, the STDs for potential temperature and salinity were calculated using the STDs of its components: MW, LSW, ISOW and NEADW$_L$ (Sect. 2.3 of the main text).

For oxygen, the STDs were set equal to 3% of the saturation value (Najjar and Keeling, 2000; Ito et al., 2004), whereas for nutrients they were obtained by one of the following methods:

a) For to LSW, ISOW and NEADW$_L$, the STDs for the nutrients was calculated using the STDs in the water samples with more than 95% of those SWTs, following Karstensen and Tomczak (1998). This method was used when the number of water samples for a SWT was greater than 50.

b) For the Central Waters, DSOW and SPMW, which are defined by more than one SWT (multi-SWTs), the multi-SWT contributions were obtained by adding the contributions of their respective components. Then, water samples with proportions of the multi-SWT greater than 95% were selected. The property values of each component of the multi-SWT were subtracted from the values of the water samples and linear regressions were performed between potential temperature and nutrients. The STDs of the multi-SWT nutrients were taken equal to the error of the intercept. We used the STDs of the properties of the multi-SWTs to each of their components.

c) A modification of the methodology (b) was applied to MW, where samples with proportions greater than 75% were selected to perform the linear regressions.

The STDs of the nutrients of SAIW were assigned equal to those of the Central Waters, because not enough water samples presented proportions greater than 95%. The STDs of the nutrients of $NEADW_U$ were calculated using the STDs of its components: MW, LSW, ISOW and $NEADW_L$ (Sect. 2.3 of the main text).

References:

Carracedo, L. I., Pardo, P. C., Flecha, S., and Pérez, F. F.: On the Mediterranean Water Composition, J. Phys. Oceanogr., 46, 1339–1358, https://doi.org/10.1175/JPO-D-15-0095.1, 2016.

Ito, T., Follows, M. J., and Boyle, E. A.: Is AOU a good measure of respiration in the oceans?, Geophysical Research Letters, 31, L17305, doi:10.1029/2004GL020900, 2004.

Jochumsen, K., Quadfasel, D., Valdimarsson, H., and Jónsson, S.: Variability of the Denmark Strait overflow: moored time series from 1996–2011, Journal of Geophysical Research, 117, C12003, doi:10.1029/2012JC008244, 2012.

Najjar, R.G., and Keeling, R.F.: Mean annual cycle of the air-sea oxygen flux: a global view, Global Biogeochemical Cycles, 14 (2), 573–584, doi:10.1029/1999GB900086, 2000".

(ii) re. the uncertainties in the last column of Table 1 – is this the uncertainty introduced if just that SWT is perturbed? What does this tell us about total errors e.g. if more than one SWT is perturbed at the same time?

*The uncertainty shown in the last column of Table 1 results from perturbing the properties of all the SWTs and of all the water samples at the same time. During the perturbation process, the values of all the properties defining the SWTs and the values of all the samples are modified, and the OMP is solved for each perturbed system, obtaining the proportions of each SWT. The process is repeated 100 times, with the average of the 100 OMP solutions being the final result and the average standard deviations the uncertainty shown in Table 1. We have changed the text to make it clearer: "the properties **of both** each SWT and **each** water sample were perturbed". This allows a joint assessment of the sensitivity of the OMP analysis to both measurement errors and variations in the physical and chemical properties of the SWTs, as indicated in the manuscript.*

(iii) I find the last sentence in the paragraph about the correlation coefficients difficult to follow. Is it the same as in Garcia-Ibanez et al., 2015? If so the corresponding sentence in that paper is clearer: 'the model's ability to reproduce the measured values is given as the correlation coefficient (r2) between the measured (water samples) and the expected values for the SWTs properties (values of the properties of each water sample obtained by substituting Xi's in equation 3). The r2 values are higher than xxx indicating again the reliability of our method.'

Thank you for your comment. As you mention, it refers to the same content as in García-Ibáñez et al. (2015). We have rewritten it accordingly: "We tested the robustness of the methodology through a Monte-Carlo simulation (Tanhua et al., 2005), where the physical and chemical properties of both each SWT and each water sample were randomly perturbed within the standard deviation of each parameter (see Text S1 and Table S1). This allowed an assessment of the sensitivity of the eOMP analysis to potential measurement errors and temporal variations in the physical and chemical properties that define the SWTs (Leffanue and Tomczak, 2004). A hundred Monte-Carlo simulations were performed and the eOMP equation system was solved for each of them. The average standard deviation of the Xis (last column in Table 1) is lower than 12%, which indicates that the methodology is robust. Additionally, our eOMP analysis is consistent since its residuals (r in Eq. 3) lack a tendency with depth (Fig. S1), with the standard deviations of the residuals being slightly higher than the measurement errors (Table 1). Besides, the ability of our eOMP analysis to reproduce the measured values is given as the correlation coefficient (R^2, Table 1) between the measured values *(water samples) and the expected values for the SWT mixing (values of the properties of each water sample obtained by substituting Xis in Eq. (3)). The R^2 values are higher than 0.993, which again indicates the reliability of our eOMP analysis".*

(iv) Table S1. I don't understand how these standard deviations were generated? It says they are almost the same as the accuracies, but in section 2.1 the given accuracies are quite different to those in table S1. Maybe expand table heading?

*The standard deviations of the properties of the water samples were taken close to the accuracy of each property. The difference between the accuracy of the measurement (θ 0.001, S 0.002, $Si(OH)_4$ 0.1, NO_3 0.1, and O_2 2) and the standard deviation (θ 0.01, S 0.01, $Si(OH)_4^0$ 0.3, NO_3^0 0.2, and O_2^0 1) is based on the fact that these standard deviations are used in the weighting process of the OMP. The OMP equations are weighted according to the accuracy of the property and/or to the variability in the region of study (Leffaune and Tomczak, 2004). Therefore, the standard deviations listed in Table S1 represent both the accuracy of the measurements and the variability in the study region. However, we have revised the standard deviation of temperature and salinity, to be in agreement with the general requirements of global datasets such as Glodapv2 (Olsen et al., 2016). We have changed the standard deviation of temperature and salinity to 0.005 and 0.002, respectively. We have changed the heading of Table S1 accordingly: "Standard deviations of the properties of the water samples (ε in Table 1) were obtained by considering ~~ε almost equal to~~ **both** the accuracy of each ~~property~~ **measurement and the variability in the study region**".*

Minor Comments:

(1) P7, L3-8: mention that very little SAIW4 is seen in the section, almost looks like it's not present from Fig. 4h

*Thank you for your comment. We have added '...with $SAIW_6$ being the main end-member **and $SAIW_4$ only found over the Greenland Slope with less than 35% of contribution (average of 11 ± 7 %; n=55)**' (P7, L4 in the previous version of the manuscript).*

(2) P7, L18: also suggest referencing de Jong and de Steur, 2016, GRL, 43, doi10.1002/2016GL069596 for measurements in the Irminger Sea.

Thank you for your suggestion. We have added the citation.

(3) Section 3.2: Why have you only calculated volume transports for the Greenland-Portugal part of the section?

We have been able to determine that the computation of the transports through the Greenland-Portugal transect of GEOVIDE was robust despite the subsampling of certain regions. A subsampling the previous OVIDE transects was performed in a similar way and it was verified that even with this subsampling the transports of the major currents were estimated correctly (see Zunino et al., 2017). This was not possible for the transect in the Labrador Sea for which we had no reference. Therefore, the velocity field for the Labrador Sea has not yet been solved.

(4) P8, L30: Can you say anything about how errors associated with the eOMP will contribute to the water mass volume transport errors? Or are the water mass volume errors a lower bound estimate because no errors in the eOMP are taken into account?

*We have calculated the errors associated with the eOMP (the uncertainties listed in the last column of Table 1) in the water mass transports using a Monte-Carlo simulation. Then, we have propagated both errors (those associated with the uncertainty in the velocity field and those associated with the uncertainty of the water mass proportions) to calculate the uncertainty of the water mass transports. We have changed the sentence to take this change into account: "Errors were computed by ~~weighting the velocity~~ **propagating both the uncertainty of** ~~errors by in~~ the X_is **(listed in Table 1) and the uncertainty of the velocity field**".*

(5) P9, L5: please could you add a few words / sentence describing how Zunino et al. defined the AMOC intensity?

We have added the following: "The AMOC intensity is defined as the maximum of the surface-to-bottom integrated stream function computed in density coordinates (Zunino et al., 2017)".

(6) P10, L33: reference should really be de Jong and de Steur, 2016 rather than Yashayaev and Loder, 2016. de Jong and de Steur, 2016 present results from the Irminger Sea whereas Yashayaev and Loder, 2016 focus on the Labrador Sea.

Thank you for suggesting this citation. We have performed the change.

(7) Section 4.2 Think need to mention that most changes in water mass volume transports between 2014 and 2002-2010 mean are within errors, with the exception of PIW and maybe just ISOW.

We have added the following text at the end of the first paragraph: "Most of the changes in the net water mass volume transports between 2014 and the 2002–2010 mean are within the errors and, therefore, are not significant, with the exception of SAIW, PIW and ISOW, which are further discussed".

(8) P12, L22: please add more up-to-date reference for the DSOW transport estimates, Jochumsen et al., 2017, JGR Oceans, 122, doi:10.1002/2017JC012803.

Thank you for suggesting this citation. We have performed the change.

Comments figures:

(1) Figure 3: please can you check the colour for group 10, as it seems to be different between a and c?

Thank you for highlighting this inconsistency. We have performed the change.

(2) Figure 3: there seems to be one dot on the Canadian Shelf that has been assigned to group 4 when it looks as if it maybe more appropriate to be assigned to group 1?

Thank you for your comment. It was an error in the file. It has been corrected.

(3) Figure 4 caption: don't think need '(on a per one basis)'

Deleted.

(4) Figure 4 caption: 'Consult Table 1. . ..' rather than 'Confront Table 1. . ..'

Done.

(5) Figure 5 caption: 'Consult Table 1. . ..' rather than 'Confront Table 1. . ..'

Done.

(6) Figure 5 caption: Add sentence about what error bars are

Thank you for your suggestion. We have added the following text to Figure 5 caption: "Error bars represent the error in the net water mass volume transport for 2014 and the standard deviation from the average net water mass volume transport for 2002–2010".

(7) Figure 5: consider moving IrSPMW down, so have all water masses that contribute to upper limb of AMOC, and then all water masses that contribute to lower limb (?)

Thank you for your suggestion. IrSPMW has been moved between $NEADW_L$ and PIW.

(8) Figure 6 caption: don't think need '(on a per one basis)'

Deleted.

(9) Figure 6 caption: 'Consult Table 1. . ..' rather than 'Confront Table 1. . ..'

Done.

(10) Figure 6: consider using different colour-scale e.g. one that has white around 0, warm colours for positive anomalies and cool colours for negative anomalies.

Thank you for your comment. We have changed the color scale following your suggestion.

(11) Figure S1: please make axis lines thicker

Thank you for your suggestion. We have increased the axis thickness.

(12) Figure S1: what are the units for plot a?

The total residual from the OMP is dimensionless. The total residual is the value of the squared 2-norm of the residual of the linear least square equations.

(13) Figure S2: consider using different colour-scale e.g. one that has white around 0, warm colours for positive anomalies and cool colours for negative anomalies.

Thank you for your comment. We have changed the color scale following your suggestion.

English / Typo suggestions:

(1) P2, L7: insert word '...that enable us to trace back...'

Done.

(2) P2, L15: insert word '.... as in the subpolar...'

Done.

(3) P2, L22: replace 'in' with 'of' '... consisted of 78...'

Done.

(4) P2, L23-24: don't need to mention Short, Large, etc stations.

The sentence has been deleted.

(5) P2, L25: mention what SBE43 is

The information has been added.

(6) P2, L25: insert word '...was used as a reference...'

Done.

(7) P2, L25: insert word '...reference for the physical...'

Done.

(8) P2, L27: replace 'in' with 'at' '...performed at all...'

Done.

(9) P2, L28: don't need CFA abbreviation as not used again in manuscript

Deleted.

(10) P2, L29: 'dividing' not 'diving'

Done.

(11) P2, L30: please give the accuracy for nutrients in µmol kg-1 rather than µM

Done.

(12) P3, L21: insert 'that' '... NEADW that can be...'

Done.

(13) P3, L33: don't use 'IcSPMW' anywhere else in the paper. Do you mean SPMW7?

Thank you for making us notice this inconsistency. We have replaced 'IcSPMW' with '$SPMW_7$'.

(14) P4, L14: 'constraint' not 'constrain'

Done.

(15) P4, L22-25: don't think you need these lines. Mention it separating out biological and mixing components will be valuable when interpreting TEI distributions but then don't show in manuscript!

Thank you for your comment. We have deleted those lines.

(16) P5, L6-8: re-order words '...Iceland Basin, with the θ-S of SPMW8 being representative of that formed within the Iceland Basin...and the θ-S of SPMW7 to that found over the eastern...'

Done.

(17) P5, L18: 'crossed' not 'crossing'

Done.

(18) P5, L26: remove 'set'

Done.

(19) P5, L29: 'was' not 'were' '...NEADWU was...'

Done.

(20) P6, L6: change to '...allowed an assessment of...'

Done.

(21) P6, L19: change word order '... (Fig 4a.b), with ENACW12 being...'

Done.

(22) P6, L28: insert 'to' '…NAC leads to the formation...'

Done.

(23) P7, L4: change word order '. . ., with SAIW6 being the...'

Done.

(24) P7, L10: insert 's' '...LSW concentrations reaching...'

Done.

(25) P7, L11: insert 'the' '...from the surface...'

Done.

(26) P7, L15: change word order '... with the first 1000 dbar of the Irminger Sea being dominated...'

Done.

(27) P7, L16: 'mixture' not 'mixing'

Done.

(28) P7, L18: insert 'water' '... LSW-like water...'

Done.

(29) P7, L23:24: change word order 'Some authors refer to the admixture... found over and around the Reykjanes Ridge as Icelandic Slope Water…'

Done.

(30) P8, L22: 'hydrographic' rather than 'hydrological' ?

Yes. We have replaced 'hydrographical' with 'hydrologic'.

(31) P9, L5: insert words '... intensity of the AMOC...'

Done.

(32) P9, L24: insert 'our' 'Since our OMP analysis...'

Done.

(33) P9, L24: remove 'the' '... time invariant properties...'

Done.

(34) P10, L6: add 's' and 'it' '...greater depths it is LSW...'

Done.

(35) P10, L17: add 'the' '.. at the expense...'

Done.

(36) P10, L29: add 'with the' '(Fig 6e), with the redistribution...'

Done.

(37) P11, L7: change 'con la'

Thank you for making us notice this mistake. We have replaced 'con la' with 'and'.

(38) P11, L16: do the authors mean Greenland Slope rather than Greenland Shelf?

Yes. We have replaced 'shelf' with 'slope'.

(39) P12, L14: insert 'an' '... to an average...'

We have replaced 'to an' with 'with the'.

(40) P13, L1: change to '... allows identification of the water...'

Done.

(41) P13, L20: insert 'with the' '...2002-2010, with the increase related...'

Done.

(42) Abstract, P1, L19: insert 's' '...colder end-members of the...'

Done.

(43) Abstract, P1, L21: insert 'with the' '... 2002-2010, with the increase...'

Done.

(44) Abstract, P1, L25: 'identification of' not 'identifying'

Done.

References:

Johns, W., Houk, A., Koman, G., Zou, S., and Lozier, S.: Transport of Iceland-Scotland Overflow waters in the Deep Western Boundary Current along the Reykjanes Ridge, Geophysical Research Abstracts, 19, EGU2017-9415, 2017.

Leffanue, H., and Tomczak, M: Using OMP analysis to observe temporal variability in water mass distribution, Journal of Marine Systems, 48 (1), 3–14, doi:10.1016/j.jmarsys.2003.07.004, 2004.

Olsen, A., Key, R. M., van Heuven, S., Lauvset, S. K., Velo, A., Lin, X., Schirnick, C., Kozyr, A., Tanhua, T., Hoppema, M., Jutterström, S., Steinfeldt, R., Jeansson, E., Ishii, M., Pérez, F. F., and Suzuki, T.: The Global Ocean Data Analysis Project version 2 (GLODAPv2) – an internally consistent data product for the world ocean, Earth Syst. Sci. Data, 8, 297-323, https://doi.org/10.5194/essd-8-297-2016, 2016.

Yashayaev, I., and Loder J. W.: Further intensification of deep convection in the Labrador Sea in 2016, Geophys. Res. Lett., 44, 1429–1438, doi:10.1002/2016GL071668, 2017.

Zou, S., Lozier, S., Zenk, W., Bower, A., and Johns, W.: Observed and modeled pathways of the Iceland Scotland Overflow Water in the eastern North Atlantic, Progress in Oceanography, 159, 211–222, doi:10.1016/j.pocean.2017.10.003, 2017.

Zunino, P., Lherminier, P., Mercier, H., Daniault, N., García-Ibáñez, M. I., and Pérez F. F.: The GEOVIDE cruise in May-June 2014 revealed an intense MOC over a cold and fresh subpolar North Atlantic, Biogeosciences, 14, 5323-5342, doi:10.5194/bg-14-5323-2017, 2017.