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Supporting Information for

Inferring Advective Timescales and Overturning Pathways of the Deep Western Boundary Current in the North Atlantic through Labrador Sea Water Advection

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Introduction

This supporting information contains sections that further explain processing details performed on the hydrographic data presented in the study. The neutral density offset applied to the hydrographic data downstream of the Labrador Sea is explained with reference figures. The secondary processing scheme is outlined using an example occupation from the Line W dataset, showcasing the steps taken in the secondary cleaning process for hydrographic data. Section 3 explores the Mediterranean Overflow Water removal process showing removal from the Abaco dataset as an example, however this scheme is applied to all locations downstream of the Labrador Sea. Finally, the distance-weighted averaging scheme performed on Line W and Abaco transects is explained in detail.

S1: Neutral Density Offset

One focus of this study is to follow the advection of $LSW_{1987\text{-}1994}$ and $LSW_{2000\text{-}2003}$ along constant neutral density surfaces, assuming little to no diapycnal mixing. We define the core of each LSW class as the densest (ultimately the coldest and freshest) extent of the convective watermass in the Labrador Sea using the potential temperature and salinity anomalies derived from each occupation relative to the overall mean. The neutral density value of this core, defined as $\gamma_n = 27.99$ kg/m^3 for $LSW_{1987\text{-}1994}$ and $\gamma_n = 27.90$ kg/m^3 for $LSW_{2000\text{-}2003}$, is the isopycnal level we assume advection to occur on as this watermass advects out of the Labrador Basin to be observed at the other downstream locations. When looking at the anomalies of potential temperature and salinity of each hydrographic timeseries, we observe the core of both LSW classes at a lighter neutral density isopycnal at all locations south of the source region (Figure S1). For the Line W, Bermuda, and Abaco timeseries, this density offset is consistently 0.015 kg/m^3 lighter than the defined isopycnals from that of the Labrador Sea (Figure S1). This shift is likely a product of diapycnal mixing occurring outside of the Labrador Basin. To eliminate this influence and to keep the isopycnal value of each LSW core constant across all locations, a +0.015 kg/m^3 neutral density offset is applied to the Line W, Bermuda, and Abaco datasets (Figure S2). All neutral density data used in this study has been subject to this offset. If the LSW cores were not subject to this neutral density offset, the observed potential temperature and salinity characteristics and subsequent changes would be misrepresented from an isopycnal value that was not the true defined core, invalidating the advective analysis of each respective core.

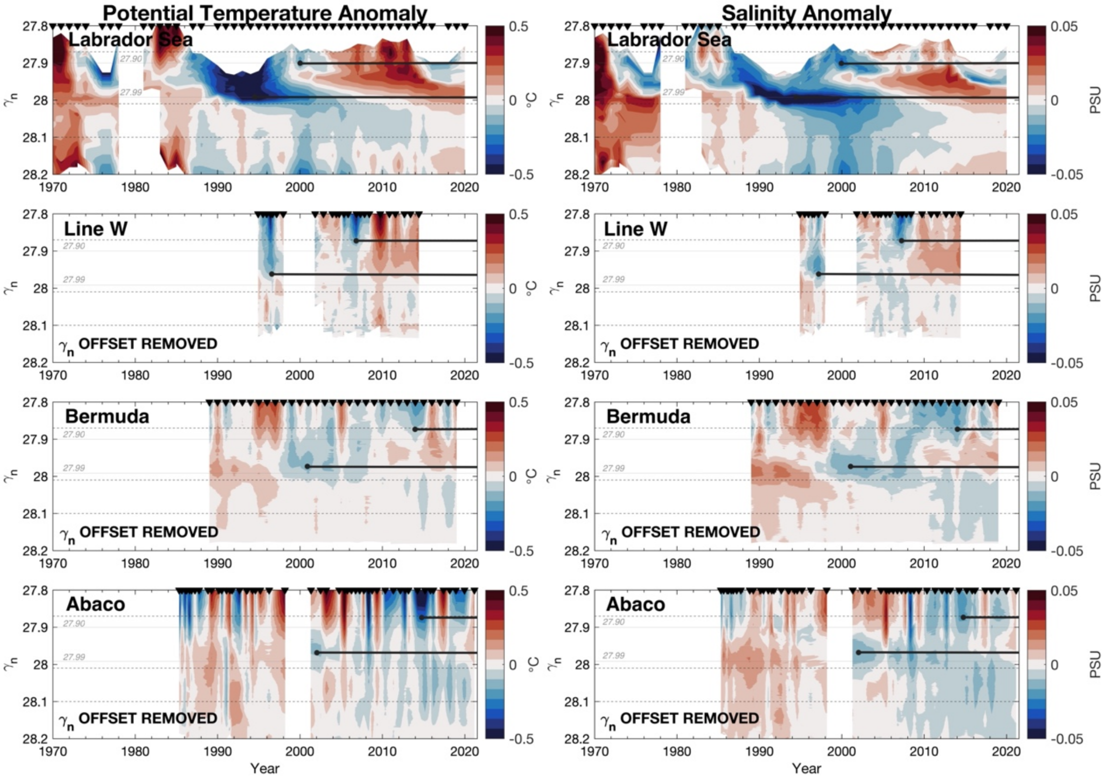

Figure S1. Potential temperature (left panels) and salinity (right panels) anomalies of the Labrador Sea (top), Line W, Bermuda, and Abaco (bottom) hydrographic time series in neutral density space over time. Dashed horizontal lines indicate the isopycnal boundaries between the defined intermediate, deep, and abyssal layers at γ_n = 27.87, 28.01, and 28.10 kg/m^3. Solid gray lines represent the γ_n = 27.90 and γ_n = 27.99 kg/m^3 defined isopycnal levels of LSW$_{1987\text{-}1994}$ and LSW$_{2000\text{-}2003}$, respectively. Black dots and lines showcase LSW$_{1987\text{-}1994}$ (denser) and LSW$_{2000\text{-}2003}$ (lighter) cores and their constant isopycnal advection in time at each location. This figure showcases neutral densities that *do not* account for the +0.015kg/m^3 offset presented in the final datasets. As a result, LSW cores at Line W, Bermuda, and Abaco locations are observed consistently lighter than the defined isopycnals of γ_n = 27.90 and γ_n = 27.99 kg/m^3. Hydrographic occupations are indicated by the black triangles at the top of each plot.

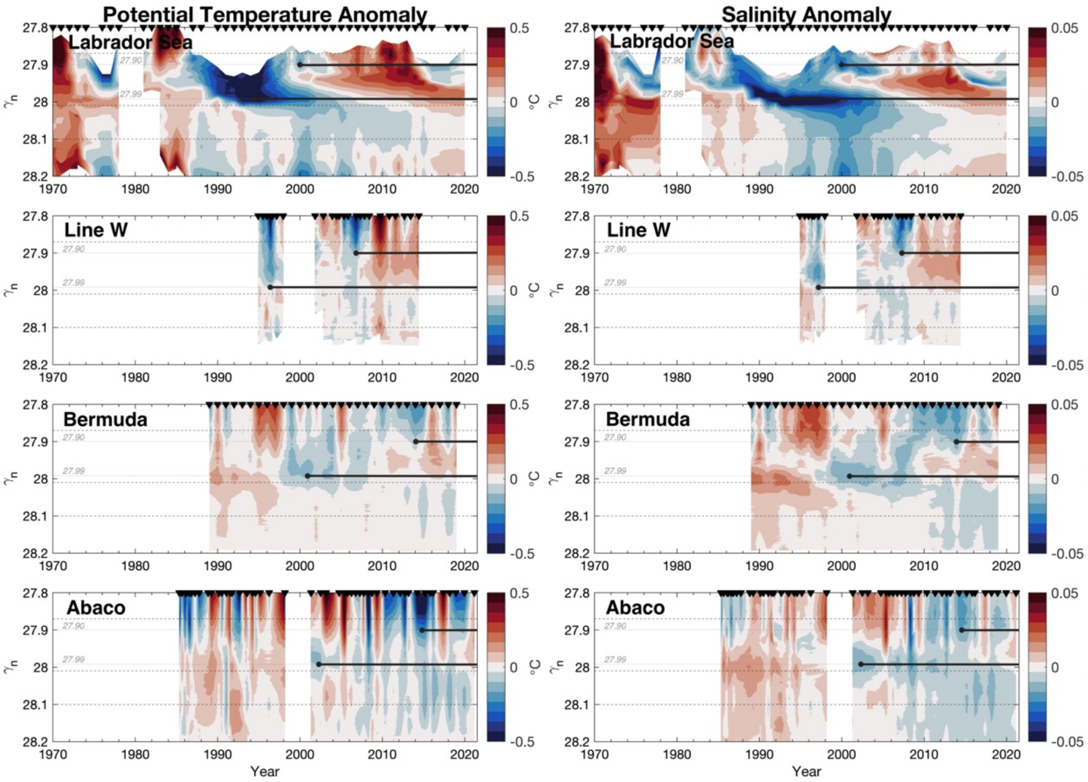

Figure S2. Potential temperature (left panels) and salinity (right panels) anomalies of the Labrador Sea (top), Line W, Bermuda, and Abaco (bottom) hydrographic time series in neutral density space over time. Dashed horizontal lines indicate the isopycnal boundaries between the defined intermediate, deep, and abyssal layers at γ_n = 27.87, 28.01, and 28.10 kg/m^3. Solid gray lines represent the γ_n = 27.90 and γ_n = 27.99 kg/m^3 defined isopycnal levels of LSW$_{1987\text{-}1994}$ and LSW$_{2000\text{-}2003}$, respectively. Black dots and lines showcase LSW$_{1987\text{-}1994}$ (denser) and LSW$_{2000\text{-}2003}$ (lighter) cores and their constant isopycnal advection in time at each location. This figure showcases neutral densities that account for the +0.015kg/m^3 offset presented in the final datasets and is identical to Figure 7 shown in the manuscript. Hydrographic occupations are indicated by the black triangles at the top of each plot.

S2: Secondary Phase of Cleaning for Hydrographic Data

A secondary round of processing and quality control is performed on all hydrographic data to limit short-term (< 1 year) variability within datasets, such as seasonal cycles or eddies, by focusing on individual yearly or bi-yearly hydrographic occupations (Line W and Abaco datasets) and monthly-sampled datasets (Bermuda). The Labrador Sea dataset was provided as annually-averaged hydrographic profiles of the central Labrador Sea and was already subject to prior rounds of quality control as described in Yashayaev (2007) and Yashayaev and Loder (2009, 2016). For the assembled Line W, Bermuda, and Abaco datasets, all profiles of potential temperature, salinity, and density are first compared to neighboring occupations in years prior and following to assess outliers due to seasonality, spikes, or sampling error (Figure S3). Line W and Abaco profiles are geographically constrained to the defined DWBC throughflow regions as described in the manuscript. All profiles of each occupation are then individually screened in pressure space for viability within the surrounding stations of each transect occupation (Figure S4); this threshold is dictated as the 2-standard deviation cutoff from the mean profile of each occupation, representing the 95% confidence interval. Profiles exceeding the threshold or displaying evidence of Gulf Stream, eddy, or Subtropical Gyre intrusion, for example, through evidence of significant potential temperature, salinity, and potential vorticity change and/or sloping of isopycnals along defined hydrographic sections are omitted from analysis (Figure S5). An example of the secondary cleaning process for a Line W occupation from May 2008 is shown in the figures of this section.

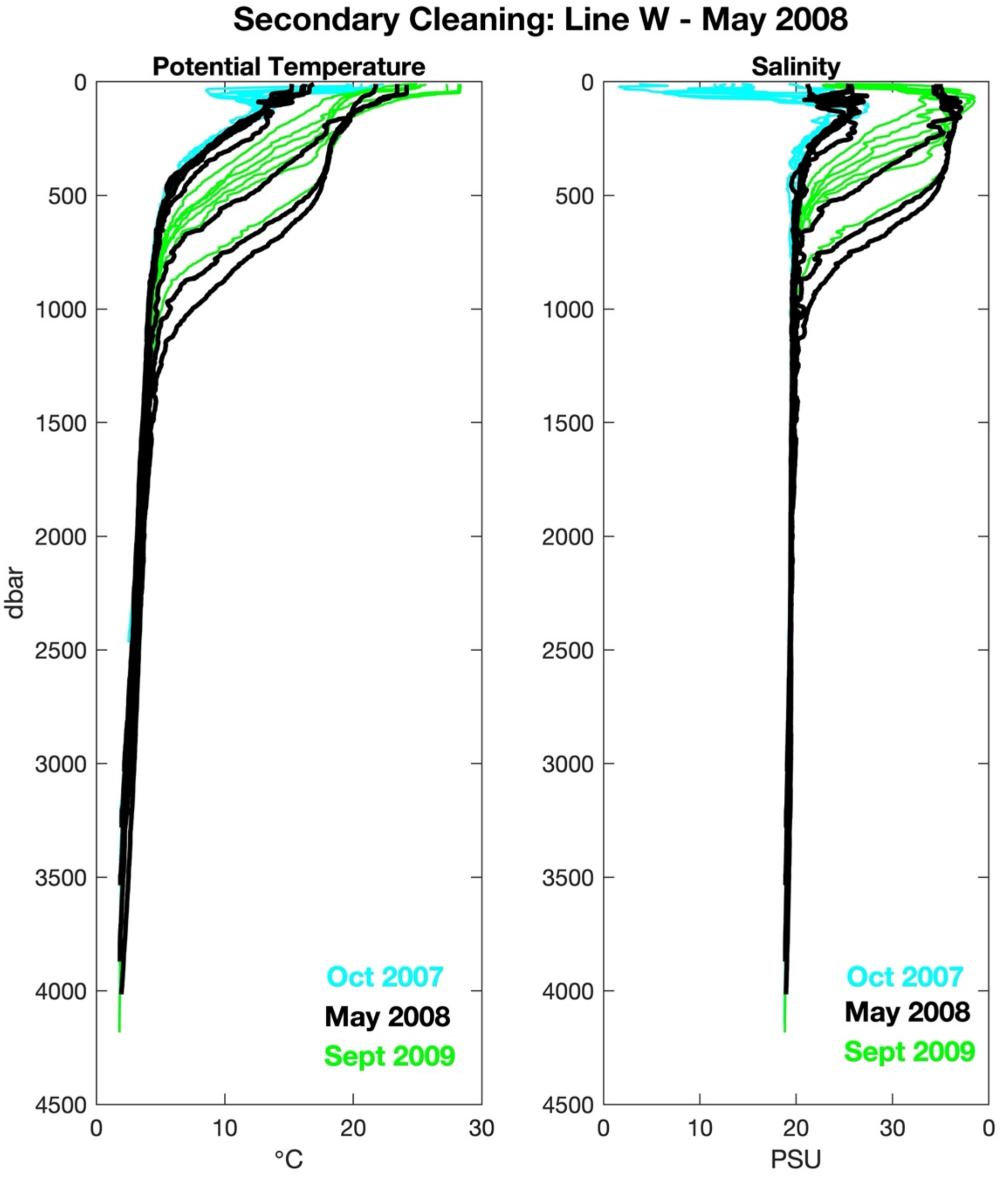

Figure S3. Example of the first round of secondary phase cleaning using inter-station comparison of a Line W occupation from May 2008 (black) and neighboring occupations in October 2007 (cyan) and September 2009 (green) showing potential temperature and salinity profiles with depth. Plotted stations represent the geographically-constrained DWBC throughflow section. Neighboring occupations are compared to assess seasonality and sampling error, if any.

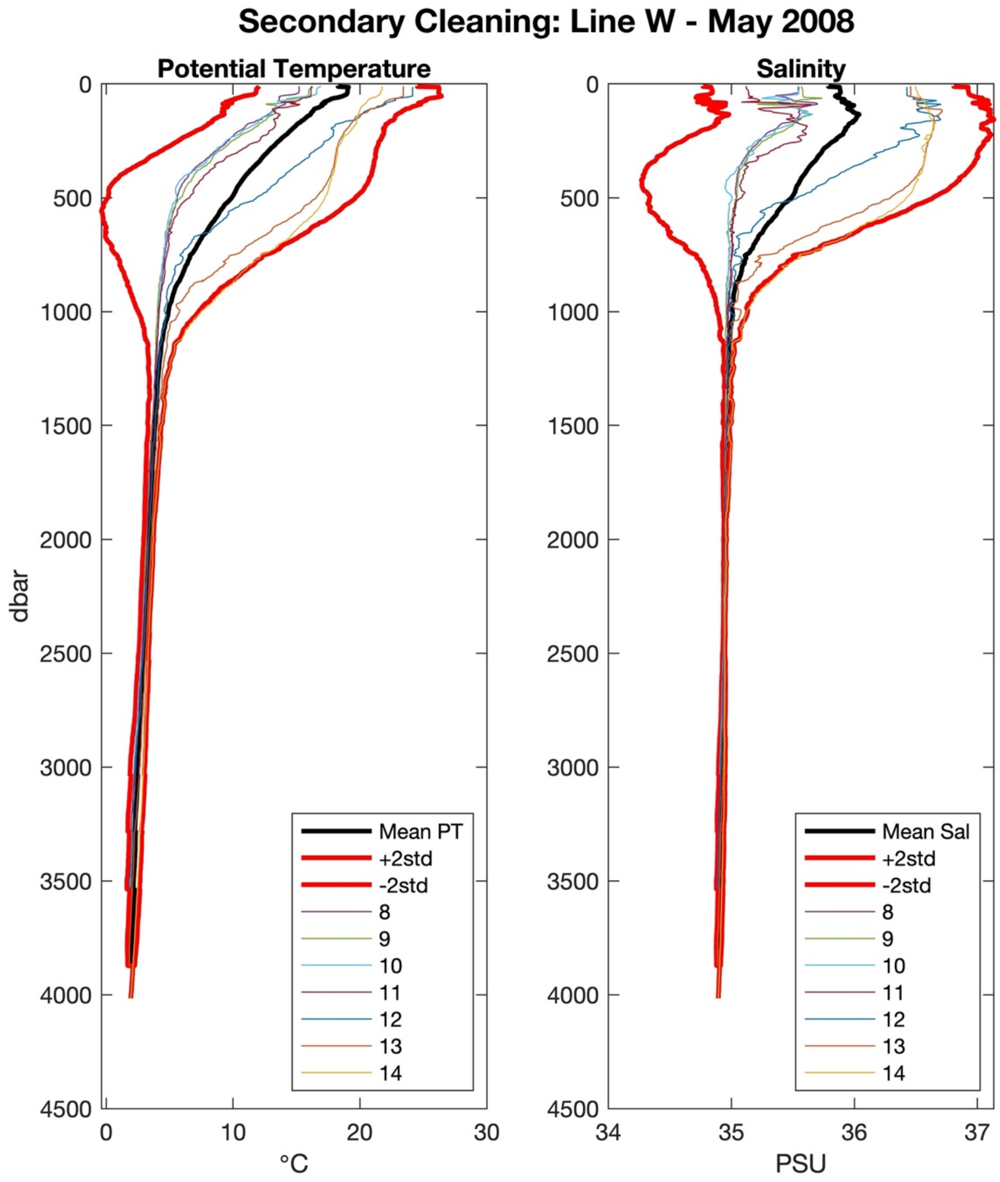

Figure S4. Example of the second round of secondary phase cleaning using intra-station comparison from a Line W occupation from May 2008 showing potential temperature and salinity profiles with depth. All profiles within the geographically constrained DWBC throughflow region (stations 8-14 in this example) are compared to a ±2 standard deviation (95% confidence interval, red line) from the mean of the stations (black line) to assess station viability. Stations that fall outside of the 95% confidence interval are omitted from analysis. In this example, station 14 exceeds the bounds and will be omitted.

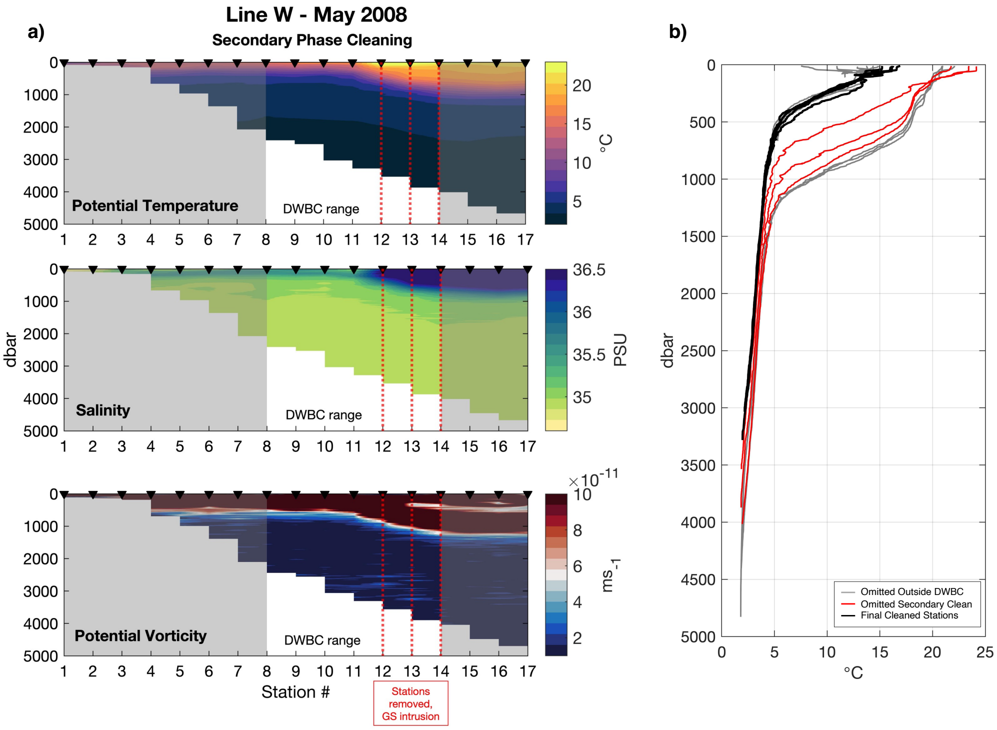

Figure S5. Example of the final round of secondary cleaning outcome using a Line W hydrographic occupation from May 2008. The hydrographic sections (a) showcase potential temperature (top), salinity, and potential vorticity (bottom) along the complete section sampled near-shore to offshore denoted by the station numbers. Gray shading indicates stations that were omitted from analysis due to the geographical constraint imposed on Line W (likewise for Abaco occupations) to focus only on the DWBC southward throughflow. Red dashed lines indicate stations that were omitted as part of the secondary cleaning phase due to Gulf Stream/Subtropical Gyre intrusion, showcased as an example in (b) as a shift to higher temperatures throughout the water column. In this example, only stations 8-11 are used for final analysis.

S3: Removal of the Mediterranean Overflow Water (MOW) signal from LSW

Mediterranean Overflow Water (MOW) occupies similar density levels as LSW. To capture the true LSW convective signal, the competing MOW signal is removed from the Line W, Bermuda, and Abaco locations to eliminate the warm and saline influence on the convective signal within the zonally averaged datasets. This step is completed after secondary cleaning. Given the time-varied sampling at each location, contribution of MOW within LSW can jump or be biased due to a change in station spacing (this is later accounted for with the distance-weighted averaging of the cleaned profiles, see section S4). We attempt to minimize the contribution of this external watermass to the averaged LSW characteristics through this removal scheme.

A wide-spread 'intermediate' layer is defined for each location (Table S1) downstream of the Labrador Sea where potential temperature and salinity of each cleaned station are averaged within these layer bounds. This wide-spread intermediate layer is made slightly larger than the neutral-density defined Intermediate layer of the study, capturing profile data from just above the Intermediate layer through the upper Deep layer for all locations downstream of the Labrador Sea. Averaged potential temperature and salinity values above the computed 25th percentile of the dataset that exceed the defined thresholds for each location are excluded from analysis due to MOW influence or intrusion. Figure S6 shows the exclusion process with the Abaco dataset, the same process is repeated for Line W and Bermuda datasets using their respective exclusion principles in Table S1. Failure to properly remove the MOW signal results in the layer-averaged potential temperature and salinity to be warmer and more saline (Figure S7).

Table S1. MOW Cutoff Criteria

	Line W	***Bermuda***	***Abaco***
Layer Avg. Bounds	700-2300m	1500-2300m	1100-2500m
Max. Potential Temperature Cutoff	>4°C	>4.1°C	>4.3°C
Max. Salinity Cutoff	>34.975	>35.02	>35.01

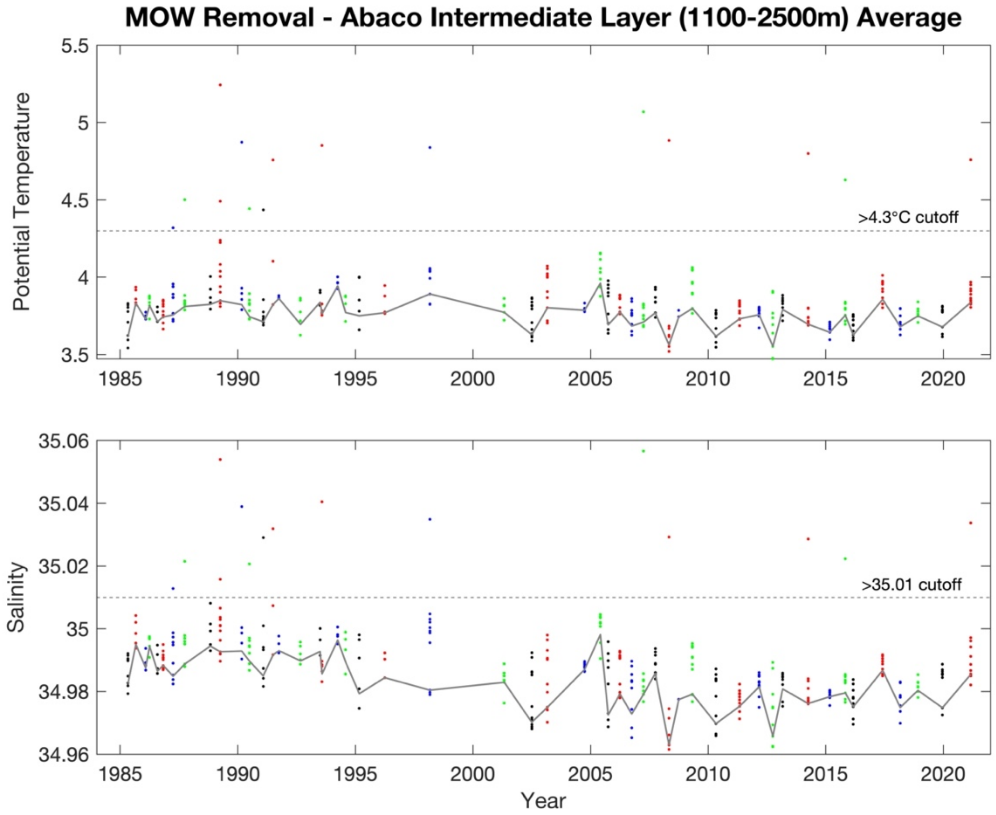

Figure S6. MOW removal in the Abaco dataset. Potential temperature (top) and salinity (bottom) averaged within the wide-spread intermediate layer (defined 1100-2500m for Abaco) for each station are plotted with time. Individual hydrographic occupations are grouped by color, alternating black, red, blue, and green. MOW exclusion criteria for Abaco are layer-averaged values that exceed 4.3°C and 35.01 PSU (dotted line) above the computed 25th percentile of values (gray line). All stations with intermediate layer-averaged values that exceed the defined cutoff are excluded from analysis due to MOW influence or intrusion.

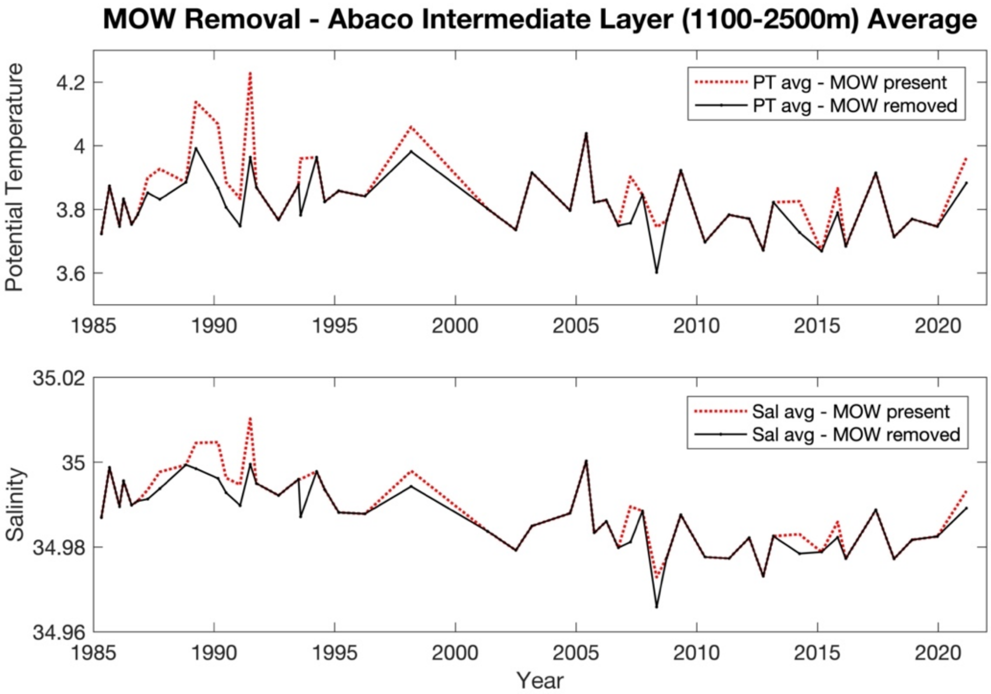

Figure S7. MOW removal comparison in the Abaco dataset. Potential temperature (top) and salinity (bottom) averages of each occupation using stations within the averaged intermediate layer (1100-2500m for Abaco) are plotted with and without the removal of the MOW signal. Without removing the MOW signal (red dashed line), average temperatures and salinities trend warmer and more saline. The intermediate layer-averaged potential temperature and salinity for each hydrographic occupation with MOW profiles removed is shown in black.

S4: Distance-weighted averaging of the Line W and Abaco Transects

Line W and Abaco sections are zonally averaged using a distance-weighted averaging scheme due to the spatial variability in transect sampling. Examples of the irregular station distances for Line W and Abaco are observed in Figure 1 of the manuscript. To reduce the impact of having one station or one side of the transect dominate the other and skew trends, individual stations are weighted by the relative distance covered over the DWBC-constrained transect length. First, the weighted distances between stations are computed using position coordinates, later computed to distance in kilometers:

$$Weight\ (distance\ covered)\ of\ Station\ B = \frac{(Sta\ B - Sta\ A)}{2} + \frac{(Sta\ C - Sta\ B)}{2}$$

The relative distance that each station bears reflects the weight it will have on each parameter. All parameters (potential temperature, salinity, potential vorticity, neutral density) of each profile are multiplied by the relative distance (i.e. weight) of that given station. Each weighted profile is then summed and divided by the total transect length (sum of respective distances of all stations) to obtain the final distance-weighted averaged parameter across the defined section.