Reviewer 3

This study investigates a relationship between freshwater anomalies in the North Atlantic and summer European climate up to several years later. The proposed mechanism involves cooling over the subpolar region and warming over the subtropical region that increases the meridional temperature gradient, leading to enhanced baroclinicity that alters the atmospheric circulation. The physical relationships are plausible and there are some interesting implications for predictability. However, I find the approach and manuscript quite confusing, and I believe major revisions would be required before publication.

We sincerely thank the reviewer for reviewing the manuscript and providing many helpful comments and suggestions! The main concern is that the approach was not clear. To address this concern, we will first motivate the approach more clearly to use a surface mass balance to infer the variability of freshwater. We will also simplify the mass balance analysis and add more explanations to make it easier for the reader to understand how this link is derived. Further details are included under the specific comments below.

Main points

1) I am not clear on whether the analyses actually address the role of freshwater events on European climate. The authors spend quite a bit of time establishing that the relationship between the NAO index and the freshwater events in the period studied is robust and useful (mainly based on previous studies), and hence that the NAO index can be used as a proxy for freshwater anomalies. The justification/explanation comes back in several places throughout the manuscript, perhaps drawing more attention to it than the authors intended. However, I did not fully follow many some aspects of the justification (e.g., a number of other possibilities are eliminated in L86-87, but the explanation is quite brief and as far as I can tell, only focuses on Ekman processes). The main question I was left with was, why not just use an index of freshwater anomalies? Perhaps there is an obvious answer here, but it didn't come through to me in the manuscript, and makes statements like L102-103 quite unsatisfying.

We thank the reviewer for pointing out that the motivation of using a surface mass balance to infer freshwater variability was unclear. In the revised version, we will motivate this approach more clearly and go through the derivation in more detail.

Currently available data products for the sea surface salinity have large biases, short time spans or poor spatial and temporal resolutions. For instance, satellite products have biases of up to ~1 g kg^{-1} in the polar regions and are only available since 2011 (Bao et al., 2019).

To overcome these challenges associated with freshwater analyses, we take advantage of the influence of freshwater on the SST in order to infer its variability. Specifically, we select conditions that are associated with pronounced cold anomalies in the subpolar region, and then estimate the extent to which freshwater has contributed these cold anomalies. In the following, we outline the main steps, which will also explained in the main manuscript, rather than only the appendix:

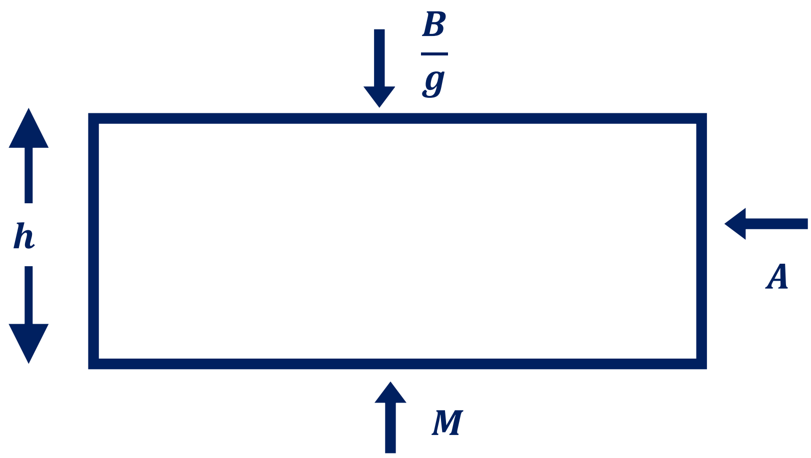

Figure 1: Mass budget for a mixed layer of depth h in the cold anomaly region. $\boldsymbol{A}$ corresponds to horizontal advection, $\boldsymbol{M}$ is an anomalous density flux from beneath the mixed layer, and $\frac{\boldsymbol{B}}{\boldsymbol{g}}$ refers to the density contribution from the surface buoyancy flux.

(1) We start with conservation of mass: $\frac{\partial}{\partial t}\int_{-h(t)}^{0}\rho dz = -\frac{B}{g} + M + A$, *where B is the buoyancy flux through the surface, g is the gravitational acceleration, ρ is density, M is the mass flux through the base of the mixed layer, and A is horizontal advection (e.g. Griffies and Greatbatch, 2012).*

(2) Next, we discretise the mass equation and integrate over the winter, using a variable mixed layer depth evolution from h_0 to h_n:

$$\rho_n = \frac{h_0}{h_n}\rho_0 + \left(-\frac{B_n}{g} + M_n + A_n\right) \cdot \frac{\Delta t}{h_n}$$

Here, the subscript $n \in 1..N$ refers to the n'th winter of an arbitrary subset of N winters. Before the winter, the mixed layer (h_0) is several tens of metres deep while during the winter, it reaches several hundred metres. Therefore, the density anomaly in the initial shallow mixed layer is distributed over a much larger depth range and the first-term on the right-hand side is negligible compared to the other terms. Any density anomalies beneath the initial, shallow mixed layer are included in M_n.

(3) We then linearise the equation of state: $\rho_n \approx \rho_m[1 - \alpha(T - T_m) + \beta(S - S_m)]$, where T is the temperature, S is the salinity, and α and β are the thermal and haline expansion coefficients. The subscript m refers to an arbitrary reference state, which, for simplicity, is chosen to be the mean over the subset.

(4) In order to infer the salinity, we select indices that are well-correlated with a cold anomaly in the subpolar North Atlantic but not with the potential drivers of density anomalies on the right-hand side of the equation. As an educated guess, we start with indices that we expect to be well-correlated with freshwater in the North Atlantic. Thus, we find that the freshwater indices F_M and F_C are associated with pronounced cold anomalies.

(5) After evaluating each term in the mass balance for the cold anomaly region, we find that the density increase, resulting from the cold anomaly, is more than one order of magnitude larger than any of the potential drivers on the right-hand side of the equation.

This implies that, for the selected indices, there is no anomalous density increase in the cold anomaly region but that the density increase implied by the cold anomaly must be balanced by a density decrease associated with a fresh anomaly $\alpha(T - T_m) \approx \beta(S - S_m)$.

The second question is how the terms on the right-hand side of the mass equation were assessed. Buoyancy fluxes are evaluated using ERA5 and were found to be negligible (Fig. A1c and A2c). Moreover, away from the boundaries, advective transports must be forced either mechanically through winds or by density gradients. As the reviewer points out, Ekman transports driven by the winds were shown to be negligible.

Buoyancy-driven flows, on the other hand, are the response to existing density gradients in the ocean but cannot create strong gradients on their own (e.g. Wunsch and Ferrari, 2004). In the analysis, we show that the surface buoyancy flux is too weak, not significantly correlated with the freshwater indices, and inconsistent to drive the cold anomaly (Figs. A1c and A2c). Thus, it will not create an anomalous buoyancy-driven flow.

On longer timescales, the freshwater forcing can lead to a reduction in the buoyancy-driven overturning circulation (e.g. Stommel, 1968). In this case, the density decrease associated with the freshening would even exceed the density increase associated with the cold anomaly $\beta\Delta S < \alpha\Delta T$*. However, the resulting reduction in the overturning circulation would lead to a positive surface heat flux anomaly in the subpolar region, such that the ocean loses less heat to the atmosphere (e.g. Gulev et al., 2013). The reduction in ocean heat losses can be understood by considering that freshwater increases the stratification and thus reduces the amount of heat that is available to the atmosphere.*

As shown in the mass budget, we do not find a significant heat and, in turn, buoyancy flux anomaly (Figs. A1c and d and A2c and d). For instance, the buoyancy flux anomaly associated with F_M *events results in a mass decrease of* $\sim$*7 kg* m^{-2}*, while the cold anomaly implies a mass increase of* $\sim$*204 kg* m^{-2}*. Thus, the freshwater anomaly implied by the cold anomaly is more than one order of magnitude larger than the freshwater anomaly implied by a potential slowdown of the overturning circulation. In turn, this means that the freshwater increase resulting from a slowdown of the overturning circulation is negligible on the timescales considered, consistent with Argo float observations and earlier studies (e.g. Zou et al. 2020).*

We conclude that neither wind- nor buoyancy-driven flows can account for the cold anomaly. On the spatial scales and interannual timescales considered, by far the strongest advective transports of heat and freshwater in the interior subpolar region result from geostrophic flows, both within eddies and as part of the subpolar gyre circulation. However, they do not contribute to the mass budget since geostrophic flows are along density contours.

Next, the term M_n *is assessed. Therefore, we first evaluated entrainment due to upwelling from the surface winds. When averaged over the cold anomaly region, the vertical Ekman velocity amounts to* $\sim -1.8 \cdot 10^{-7}$ *m* s^{-1}*. Since it is negative, there is enhanced downwelling, rather than upwelling. Multiplied by a typical vertical density gradient of* $5.0 \cdot 10^{-4}$ *kg* m^{-4} *across the pycnocline and integrated over the winter, the resulting change in the surface density is more than 3 orders of magnitude smaller than the density change, resulting from the cold anomaly.*

Moreover, in the absence of mechanically forced upwelling, and anomalous surface buoyancy fluxes, denser water from below the mixed layer cannot be entrained due to gravity. The mixed layer can only entrain water of the same density as the surface density. Thus, if anomalously cold water is entrained from below and contributes to the observed cold anomaly, it must also be anomalously fresh.

Subsurface density anomalies can still passively influence the surface density by determining the volume of entrained water and thus, the mixed layer depth, which modulates the influence that the *surface buoyancy fluxes have on the surface density. To rule out the possibility that differences in the mixed layer depth have substantial feedback on the surface density, we considered three cases:*

1) The mixed layer depth in winter is uncorrelated with the freshwater indices: In that case, differences in the mixed layer depth will not significantly influence the regressions and we can approximate the mixed layer depth with the mean mixed layer depth in winter h_m. Using an average mixed layer depth, obtained from Argo floats (Holte et al., 2017), we found that the terms on the right-hand side of the mass equation are about two orders of magnitude smaller than those on the left-hand side.

2) The actual mixed layer depth is positively correlated with the freshwater indices: In that case, the deeper mixed layers would imply that the terms on the right-hand side of the mass equation become even more negligible since the density anomalies on the left-hand side are multiplied by the mixed layer depth.

3) The mixed layer depth is negatively correlated with the freshwater indices: In order to justify having shallower mixed layers, the surface density anomalies must be negative for increased freshwater indices. In turn, this means that the density anomaly associated with the freshening would even exceed the density increase associated with the cold anomaly: $\beta \Delta S < \alpha \Delta T$. Thus, there is no need to evaluate the mass equation further. Considering that the ocean in the subpolar region in winter is always warmer than the air, an increased stratification would limit the amount of heat available to drive the atmosphere, implying reduced ocean heat (and buoyancy) losses. As shown above, the freshwater anomaly, implied the surface fluxes is about two orders of magnitude smaller than the freshwater anomaly, implied by the cold anomaly. Thus, it is negligible.

Lastly, to demonstrate that the surface mass balance yields a good approximation of the salinity anomaly, we consider the last two decades, when sufficient Argo float observations are available to test the results. During the strongest observed cold anomalies over this period, which occurred in the winters 2015 and 2016, the correlation between the temperature and salinity anomalies has a p-value of $p = \sim 5.0 \cdot 10^{-242}$, with the regression of salinity on the temperature closely matching the regression predicted by the mass balance analysis (Fig. 2). The approximation, obtained with this method has a root mean square error of ~ 0.09 g kg^{-1} and is thus more accurate than any currently available data product for the sea surface salinity. In addition, it provides longer time series, higher resolution, and better coverage than the available in-situ data.

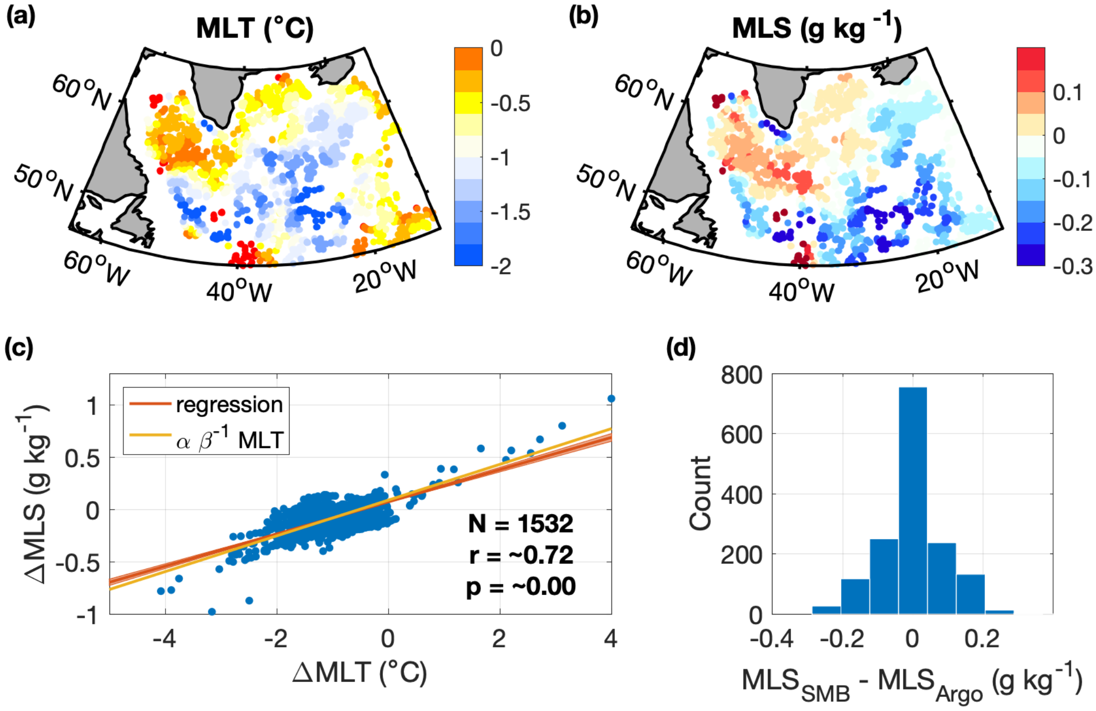

Figure 2: Demonstration of the surface mass balance. (a) MLT and (b) MLS are the mixed layer temperature and salinity anomalies during the winters 2015 and 2016, obtained from Argo float profiles (Holte et al., 2017). (c) The red line corresponds to the regression of the mixed layer salinity anomalies on the mixed layer temperature anomalies, while the yellow line corresponds to the approximation obtained from the mass balance analysis. (d) Histogram of the error of the mass balance analysis, corresponding to the difference between the calculated and observed salinity anomalies. The associated root mean square error is ~0.09 g kg^{-1}.

Bao, S., Wang, H., Zhang, R., Yan, H., & Chen, J. (2019). Comparison of satellite-derived sea surface salinity products from SMOS, Aquarius, and SMAP. Journal of Geophysical Research: Oceans, 124(3), 1932-1944.

Griffies, S. M., & Greatbatch, R. J. (2012). Physical processes that impact the evolution of global mean sea level in ocean climate models. Ocean Modelling, 51, 37-72.

Gulev, S. K., Latif, M., Keenlyside, N., Park, W., & Koltermann, K. P. (2013). North Atlantic Ocean control on surface heat flux on multidecadal timescales. Nature, 499(7459), 464-467.

Holte, J., Talley, L. D., Gilson, J., & Roemmich, D. (2017). An Argo mixed layer climatology and database. Geophysical Research Letters, 44(11), 5618-5626.

Stommel, H., & Rooth, C. (1968, April). On the interaction of gravitational and dynamic forcing in simple circulation models. In Deep sea research and oceanographic abstracts (Vol. 15, No. 2, pp. 165-170). Elsevier.

Tziperman, E. (1986). On the role of interior mixing and air-sea fluxes in determining the stratification and circulation of the oceans. Journal of Physical Oceanography, 16(4), 680-693.

Wunsch, C., & Ferrari, R. (2004). Vertical mixing, energy, and the general circulation of the oceans. Annu. Rev. Fluid Mech., 36, 281-314.

Zou, S., Lozier, M. S., Li, F., Abernathey, R., & Jackson, L. (2020). Density-compensated overturning in the Labrador Sea. Nature Geoscience, 13(2), 121-126.

2) In general, it would be extremely helpful to clarify what this study is about and to choose an analysis strategy that directly addresses the problem. The idea of circulation-induced versus melt-driven freshwater events in section 4.5 came as a surprise to me. In fact, I only realized that F_M and F_C (introduced earlier) are related to this, but had spent quite a bit of the manuscript until then puzzled by the names. Is it really the NAO index that's used to discriminate between these types of events? These ideas should probably be introduced in section 1, as they seem to motivate quite a bit of the study. Interestingly, section 1 as written seems more focused on sea ice loss and the origin of summertime freshwater, but later, the manuscript states that this isn't the focus of the study.

We thank the reviewer for pointing out that the motivation for using the freshwater indices was unclear. We will clarify the motivation in the manuscript:

The objective of this study is to show the relationship between freshwater and its downstream effects, not between the index and the freshwater. The index is used as tool to demonstrate the influences of freshwater. In order to fulfil its purpose, the index must describe the variability of freshwater sufficiently well. Therefore, the summer NAO is intentionally sub-sampled to obtain a strong relationship between the freshwater and its index. Taking advantage of the near-linear relationships between the freshwater and these two indices (or subsets), we can then use the indices as a tool to demonstrate the influences of freshwater with linear regressions in the subsequent part of the analysis.

Moreover, a high sensitivity of the subpolar cold anomaly to the freshwater index is a necessary requirement for the surface mass balance analysis. If this sensitivity would be too small, the terms on the right-hand side of the mass equation would not be negligible and it would not be possible to infer the variability of freshwater.

We also thank the reviewer for making us aware that the reason for distinguishing between F_M and F_C events was unclear. As the reviewer points out, the origin of the freshwater is not investigated in this study, and this will be clarified in the revised manuscript. However, the cause of the freshening can be inferred from the freshwater indices. Since we find that freshwater has two main drivers that are of equal importance, we need two indices.

Freshwater anomalies associated with F_C are characterised by an enhanced offshore advection of fresh, polar water into the subpolar region. We have now shifted the associated figure, showing the circulation anomaly, to the beginning of the analysis, when we introduce the freshwater indices. This circulation anomaly results from the increased windstress curl in the subpolar region during positive NAO years (e.g. Häkkinen et al. 2011).

Freshwater anomalies associated with F_M, on the other hand, are characterised by more freshwater inside the currents, rather than a change in the currents themselves. This additional freshening is quantified by the negative summer NAO (without sub-sampling) and corresponds to the anomalous seasonal freshwater that is added to the subpolar North Atlantic during autumn. It was derived using a similar mass balance analysis but using seasonal differences, rather than absolute anomalies (Oltmanns et al., 2020).

The anomalous seasonal freshening associated with a more negative summer NAO applies to all years, without sub-sampling them. However, smaller freshwater anomalies are mixed down before a significant fresh and cold anomaly in winter develops. Therefore, we cannot use the negative summer NAO to obtain absolute anomalies (unless we sub-sample it and only use strong events).

The additional seasonal freshening, associated with the negative summer NAO, must be due to runoff, melting or precipitation minus evaporation. After comparing the associated runoff and precipitation anomalies, we find that P-E is anti-correlated with the negative summer NAO, while runoff and melting are correlated (e.g. Hanna et al. 2013). For instance, the correlation between the negative summer NAO and runoff from Greenland and Canada over the last 40 years is r=~0.63 with a p-value of $p=\sim 1.5 \cdot 10^{-5}$*, obtained from the Greenland climate model MAR (Fettweis et al., 2013). However, we do not differentiate between these sources. We only refer to them as* F_M *events and do not specify whether it is melt from sea ice or glacial ice or runoff, or where the melting originally occurred.*

So, by (1) showing the change in the ocean circulation, we can link the freshwater anomalies associated with F_C *events to a change in the subpolar gyre circulation. By (2) showing the seasonal freshening associated with the negative summer NAO, we can link the freshwater anomalies associated with* F_M *events to increased seasonal freshwater input into the currents. By (3) comparing the likely roles of runoff and melting with precipitation anomalies, we can link the increased freshwater inside the currents to more runoff and melt from sea ice and glacial ice.*

We will add a section in the manuscript to derive these links more clearly and thus motivate the naming of the indices. In this section, we will also include further references on the cause of freshwater anomalies, supporting the naming, and the seasonality of freshwater export into the subpolar region during autumn (e.g. Fratantoni and McCartney, 2010; Schmidt and Send, 2007; and references therein). We will also clarify that the additional freshwater during F_M *events has multiple origins related to enhanced seasonal runoff, sea ice and glacial melting, but not precipitation.*

Fettweis, X., Franco, B., Tedesco, M., Van Angelen, J. H., Lenaerts, J. T., van den Broeke, M. R., & Gallée, H. (2013). Estimating the Greenland ice sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR. The Cryosphere, 7(2), 469-489.

Fratantoni, P. S., & McCartney, M. S. (2010). Freshwater export from the Labrador Current to the North Atlantic Current at the Tail of the Grand Banks of Newfoundland. Deep Sea Research Part I: Oceanographic Research Papers, 57(2), 258-283.

Häkkinen, S., Rhines, P. B., & Worthen, D. L. (2011). Warm and saline events embedded in the meridional circulation of the northern North Atlantic. Journal of Geophysical Research: Oceans, 116(C3).

Hanna, E., Jones, J. M., Cappelen, J., Mernild, S. H., Wood, L., Steffen, K., & Huybrechts, P. (2013). The influence of North Atlantic atmospheric and oceanic forcing effects on 1900–2010 Greenland summer climate and ice melt/runoff. International Journal of Climatology, 33(4), 862-880.

Schmidt, S., & Send, U. (2007). Origin and composition of seasonal Labrador Sea freshwater. Journal of Physical Oceanography, 37(6), 1445-1454.

Other points that may or may not be relevant once the main comments are addressed:

3) If the negative NAO index is kept: It's quite confusing to talk about more negative or more positive values of the negative NAO index. I think it's fine to flip the NAO index, but perhaps the text should just talk about higher or lower values of the NAO. Also, I don't think the NAO index was detrended, but 2m temperatures were detrended. What is the reason for this? If trends are kept in, then the autocorrelation needs to be accounted for in subsequent statistical analyses.

We thank the reviewer for making us aware that the removal of the trend was insufficiently explained. Since freshwater has a trend, trends are part of the dynamic signal we are interested in. For instance, a trend in the freshening would lead to a trend in the cold anomaly, and in turn, a trend in the jet stream shift and so on.

For the air temperature, however, there is an additional, large trend due to increased greenhouse gas concentrations. In contrast to the temperature trend that results from the jet stream shift, the warming trend due to increased greenhouse gases is distributed relatively uniformly. Thus, it can be separated from the warming trend due to the trend in the jet stream shift by averaging the temperature over a sufficiently large area before removing the trend.

The removal of the trend in the air temperature is thus based on the assumption that any potential warming trend associated with an SST anomaly over the North Atlantic must be balanced by a cooling trend over the ocean, if the warming and cooling are linked to the same atmospheric instability.

We agree with the reviewer that, for consistency, this trend should be removed from all variables. However, we found that neither the SST nor the other atmospheric variables have a significant trend when they are averaged over a large area. For instance, P-E in summer has a trend of $\sim -2.9 \cdot 10^{-4}$ $\pm 3.0 \cdot 10^{-4}$ *m year*$^{-1}$ *when it is averaged over the same area, which is not significant. Likewise, the SST has a trend of -0.0046 ± 0.0062 °C year*$^{-1}$ *when it is averaged over the North Atlantic (from 0 to 65 °N), which is also not significant. Removing these trends prior to the analysis does not lead to any notable differences in the results.*

However, upon checking again, we found that the absolute dynamic topography (ADT) also has a significant positive trend when averaged over the North Atlantic. The identified increase is likely due to the long-term ice loss of glaciers, and thermal expansion (Church et al., 2001). In the revised version, we have therefore also removed the ADT trend. This did not appreciably affect the results.

In the revised version, we will explain the removal of the trend in more detail in the method section. We will also specify the region used for the averaging and point out that the results are not sensitive to the choice of the region as long as the region is sufficiently large. In addition, we will clarify that none of the other responses (apart from the air temperature and the ADT) has a significant trend when it is averaged. We thank the reviewer for making us check all potential trends again to ensure consistency in the analysis.

With regard to the summer NAO, we find that it has a weak trend of 0.01 year^{-1}*. However, for the reasons stated above, we think that removing this trend would not be meaningful. It is used as an indicator for freshwater. Thus, any manipulation of this time series would affect its representation of the freshwater anomaly and therefore be counterproductive.*

Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., ... & Woodworth, P. L. (2001). Changes in sea level. In , in: JT Houghton, Y. Ding, DJ Griggs, M. Noguer, PJ Van der Linden,

X. Dai, K. Maskell, and CA Johnson (eds.): Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel (pp. 639-694).

4) Some of the oceanography concepts could be better explained for the non-oceanographers, and the same goes for the atmospheric concepts. e.g., L89 "the mass increase, implied by the cold anomaly,..."; L112-115 connection between poleward vorticity transport and momentum tranfer from STJ to EDJ, L138-140 is there some relevant theory for the time scales behind the delay in the shift of the North Atlantic Current?

We thank the reviewer for making us aware that some concepts need to be better explained. In the revised version, we will provide more background information and associated references.

Regarding your question on the shift in the North Atlantic Current: We do not find a delay in the shift. The signal in the absolute dynamic topography shows that the shift already occurs in the first winter (Fig. 3 below), as expected from the mechanism (specifically the Ekman convergence in the inter-gyre region, leading to a more anti-cyclonic inter-gyre gyre circulation, Marshall et al., 2001). However, in the first winter after the events, the resulting northward shift of the North Atlantic Current is not seen all the way to the eastern side of the North Atlantic in the SST field, as it is partly covered by the cold anomaly. We will clarify this in the revised manuscript.

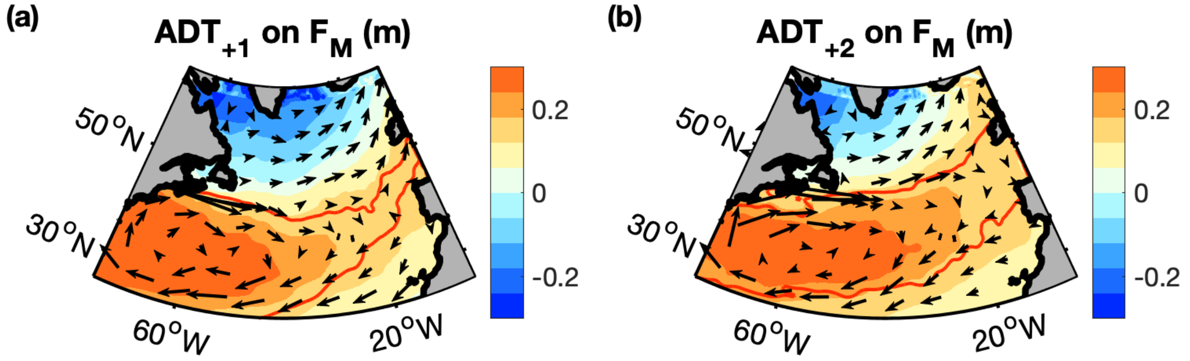

Figure 3: Regressions of the smoothed absolute dynamic topography in (a) the first winter and (b) the second winter after the freshwater events (January through to March) on F_M. Contours show the 95% confidence levels. The arrows in (c) and (d) indicate the direction of the smoothed geostrophic velocity associated with the underlying absolute dynamic topography.

Once the forcing of the wind-driven Ekman transports ceases, the inter-gyre circulation anomaly is maintained by geostrophic balance. The decay of the flow anomaly therefore depends on the strength of the initial signal.

In the revised version, we will add further references that provide more details on the individual steps, particularly on the wind-driven ocean gyres and inter-gyre gyre circulation. We will also include a smoothed version of the ADT figure in the appendix to help to clarify how the northward shift was derived. In addition, we will show both winters in the same figure, so they are easier to compare.

5) L 148 "succesfully extracts..." Perhaps related to my general confusion about F_C and F_M, I don't have a good feel for how downstream effects from other drivers and IV would influence F_M, so this statement is difficult to understand.

The sentence is meant to confirm that the method of first establishing an index with a strong relationship to freshwater, and then using this index to demonstrate the downstream effects of freshwater, was successful. Specifically, it was successful in identifying a coherent mechanism, where all the individual steps follow the chain of events expected from theory and earlier studies.

In the revised version, we will rephrase this sentence accordingly. We will also be more cautious in our conclusions and acknowledge the potential existence of other (yet unknown) drivers.

6) L224: This first line of the conclusions is not representative of the main message of this study, is it?

We will remove this sentence in the revised version.

Technical points:

-L61: "well-correlated" should be quantified if the NAO is kept

Thank you for this suggestion. In the revised version, we will add the corresponding correlation coefficients between the freshwater indices and the freshwater, rather than only the SST.

-Fig 1a is encapsulated in Fig. 2a - maybe don't need both?

It may be easier for the reader to interpret Figure 1 and Figure 2 if panel a is kept in both. The colouring may help understand the approach in Figure 2, and it adds a reference for the strength of the regression amplitudes in Figure 1. However, we will carefully consider removing one of the panels in the revised version to remove any redundancy.

-L84: Fig 2d is SSS?

Thank you for pointing this out. We will correct the figure reference.

-L127: the increase in sea level height is just in the subtropical gyre?

The increase in sea level height and associated circulation anomaly is strongest in the inter-gyre region, between the subtropical and subpolar gyre. Positive and negative anomalies in the sea level height therefore indicated northward and southward shifts of the boundary between the subpolar and the subtropical gyres, and thus the North Atlantic Current (Marshall et al., 2001). We will clarify this in the revised version.

Marshall, J., Johnson, H., & Goodman, J. (2001). A study of the interaction of the North Atlantic Oscillation with ocean circulation. Journal of Climate, 14(7), 1399-1421.

We again thank the reviewer for all the helpful comments and suggestions, helping us to improve this manuscript!