Responses to Reviewer 1

The authors use statistical analysis of observations and reanalysis data to support their hypothesis that warmer and drier summer weather in Europe can be linked to freshwater anomalies in the North Atlantic subpolar gyre region during the preceding year. The proposed mechanism for this link is a northward shift of the North Atlantic current leading to a similar deflection of the jet stream and therefore altering the advection pathway of maritime air masses. The foundation of the analysis are freshwater indices derived from a mass balance equation that are used to identify freshwater anomalies in relation to simultaneous sea surface temperature (SST) anomalies linked to the North Atlantic Oscillation (NAO).

I understand that this is a re-submission of an earlier version of the manuscript, but I was not involved in the previous review process. Therefore, I cannot assess how the manuscript has been improved, but rather provide a fresh pair of eyes.

We strongly thank the reviewer for providing a fresh pair of eyes and reviewing our manuscript. The review was extremely thorough and detailed. Moreover, the comments and suggestions were constructive and have helped us to improve the manuscript.

I. General Comments and Suggestions:

1. One of central results of this study is the description of “a coherent, deterministic mechanism that links North Atlantic freshwater events to European summer weather” (l. 315-316). However, the actual role of the identified freshwater anomalies in the subpolar gyre remains unclear. Given the lack of salinity observations, SST anomalies in relationship to the NAO are used as proxy for freshwater anomalies. In turn, a substantial part of the described link between the freshwater anomalies and European summer weather is based on the enhanced meridional SST gradient between the subpolar and subtropical gyre, and its influence on the storm track over the North Atlantic. This raises the question to what extent the freshwater anomalies actually influence the proposed mechanism and the downstream response?

   Thank you for asking about the role of the freshwater anomalies. In the previous version, we only showed that freshwater is statistically linked with subsequent European summer weather and proposed a dynamical explanation. In the revised manuscript, we are more specific about the role of freshwater and use a more cautious narrative. Therefore, we have implemented four main changes:

   (1) We have included a description of the drivers of freshwater anomalies. Thus, we provide a physical explanation for the start of the chain of feedbacks. Since the identified drivers (runoff for F_E events and circulation changes for F_W events) are not otherwise linked to European summer weather on the investigated timescales, and occur exactly one year in advance, they challenge the idea that an unknown third mechanism drives both freshwater anomalies and warmer European summers without the two being physically connected.

(2) We have included an analysis of the involved timescales of variability and considered alternative drivers of European summer weather acting on these timescales. Thus, we now show that surface freshening has a trend (Fig. 1a), superimposed on substantial interannual variability that is reflected in the variability of runoff, obtained from the Greenland climate model MAR (Version 3.12, forced with ERA5). Consistent with the identified drivers of freshwater anomalies, the variability of the summer cold anomaly is significantly correlated with the runoff from the preceding summer (July and August): $r \approx 0.59$, $p \approx 9 \times 10^{-8}$ over the last 70 years, which remains significant after detrending ($r \approx 0.45$, $p \approx 1 \times 10^{-4}$). After considering alternative drivers acting on these timescales, we conclude:

"Combined, the close relationships between the freshwater trend, the SST trends in summer and winter, the superimposed, high interannual variability of the cold anomaly in summer and of runoff in the year before, point to runoff as a potential trigger of the cold anomaly in summer (Fig. 1c). No other currently known mechanism in the tropics, stratosphere or outside the North Atlantic region, has such high interannual variability, is simultaneously characterised by a strong and significant trend over the last 70 years, leads to fresh and cold anomalies in winter, and occurs exactly one year before the characteristic summer SST pattern."

(3) To assess whether runoff is a trigger of the SST pattern, rather than only a predictor, we have included an analysis of the ocean-atmosphere feedbacks that contribute to the evolution of the SST pattern in summer. After investigating the surface heat and momentum fluxes and their influences on the ocean and atmosphere with ERA5, remote sensing data, in-situ hydrographic observations from the cold anomaly region, and with the models, we find that the momentum fluxes and the resulting wind-driven transports contribute to the intensification of the SST signal, while surface heat fluxes are, in turn, driven by the SST anomalies, contributing to the baroclinic instability in the atmosphere. Thus, we conclude:

"The large-scale SST pattern in winter and its evolution from winter to summer can be explained by air-sea coupling over the full North Atlantic. On the one hand, wind-induced transports and in-situ hydrographic observations from the cold anomaly region demonstrate the relevance of atmospheric forcing in intensifying the SST signals over the North Atlantic. On the other hand, model simulations, forced with prescribed, observed SST reveal the importance of the SST for the large-scale atmospheric circulation, including European summer weather. Given the importance of the involved ocean-atmosphere feedbacks, freshwater cannot be understood as the sole driver of European summer weather. It can, however, initiate the chain of ocean-atmosphere feedbacks that, in turn, affects European summer weather."

(4) We are more cautious about the wording. Throughout the analyses, we refer to freshwater as a predictor. In the conclusion, we discuss evidence that points to freshwater as a trigger rather than only a predictor, but we are explicit about the involved uncertainties, and we have removed phrases that may previously have caused confusion.

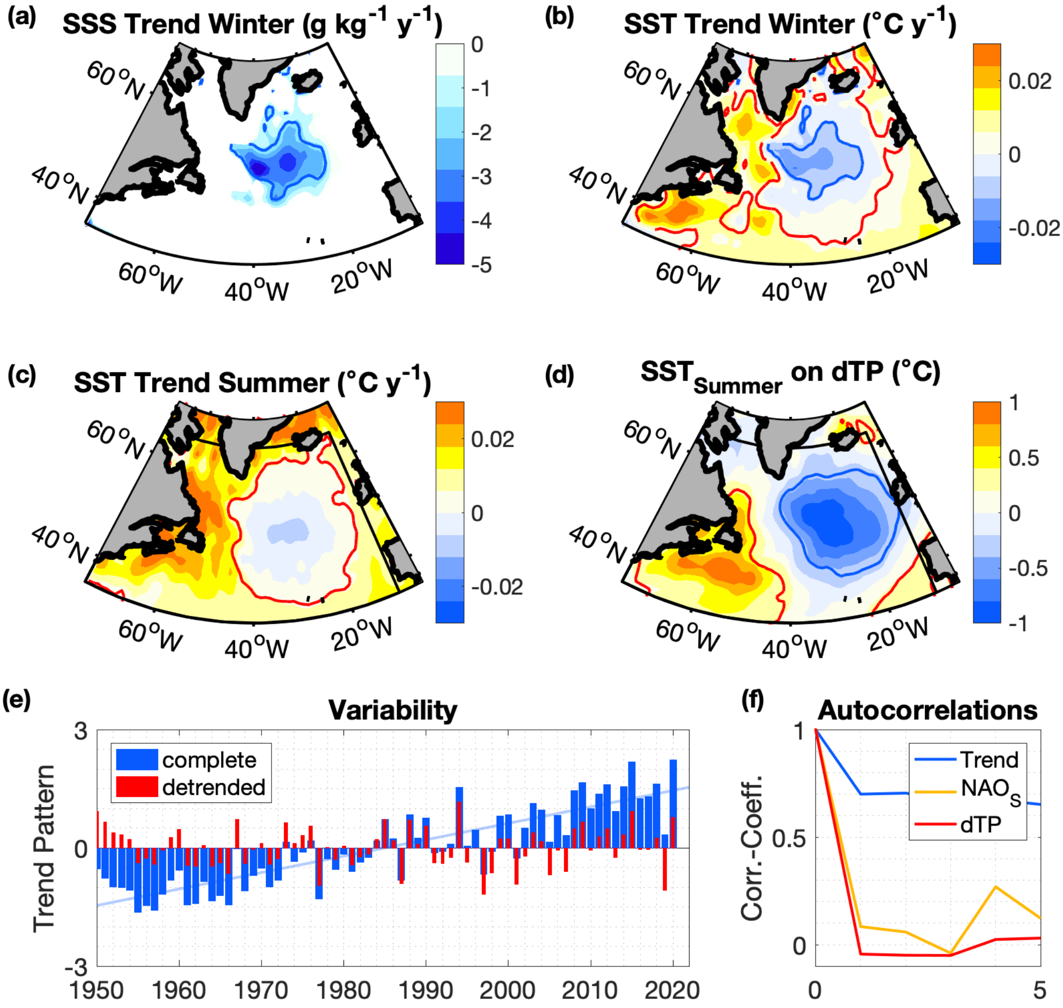

Figure 1: (a,b,c) Linear trend of (a) the SSS, obtained from a surface mass balance, and (b,c) the SST in (a,b) winter (January to March) and (c) summer (July and August) over the last 70 years. (d) Regression of the SST in summer onto the time variability of the detrended SST trend pattern in summer (shown by the red bars in e), obtained by (1) projecting the spatial variability of the SST in summer onto the trend pattern, between 35 °N and 65 °N and between 10 °W and 70 °W (shown by the box in c), and by (2) detrending the resulting time series. Thus, the dTP time series represents the high-frequency component of the variability of the SST trend pattern. Contour lines in panels a-d delineate the regions that are significant at the 95% confidence level. (e) Variability of the SST trend pattern in summer (blue bars) and the de-trended time series (red bars). (f) Autocorrelations of the time variability of the trend pattern (blue bars in e), the detrended time series (red bars in e) and the full (un-detrended) summer NAO in July and August.

2. At times, it is difficult to follow the analysis which might be in part due to the overall structure of the manuscript and lack of some details in the text (often they are only mentioned in figure captions). Additionally, some of the terminology is unclear or inconsistent throughout the manuscript which is possibly an artifact from the refactoring of the previous version. Hopefully, the comments below will help to streamline the text and make it more accessible for the reader.

Thank you for providing very specific comments below on the exact places in the manuscript that have been unclear. We have now clarified each of these instances and took care to include all details in the text. In addition, we have removed all inconsistencies in terminology that you have spotted.

3. Some of the figures are hard to read as individual panels are small or details are obscured. For most maps, the colorbars and axis labels take up valuable “real estate”. I suggest to decrease their size and use the free white space to increase the maps wherever possible. Furthermore, I recommend to decrease the thickness of the coastlines since they can be quite distracting, especially on maps with vectors. It might also be worthwhile to mention differences in color scales in the caption wherever it can help guide the reader (e.g., Figure 2).

   Thank you for these suggestions. We have now reduced the size of the axis labels and font sizes around the colour bars, decreased the thickness of the coastline and increased the map sizes for specific figures. Thus, we ensured that all relevant signals are included in the maps. We also mention differences in colour scales wherever they occur.

II. Main Comments:

1. Section 3/Appendix A: It took me a long time, including going back and forth between the main text and appendix to follow the approach. Given the importance of the freshwater indices as foundation for the subsequent analysis, I suggest to combine Sections 3.1, 3.2, with Appendices A1, and A2 to describe the derivation in the main text including the clarification of the following points:

Thank you for indicating that the derivation was difficult to follow. We have now combined Appendices A1 and A2 with Sections 3.1 and 3.2.

1. l. 126: Please state this equation.

   The equation is now fully stated.

2. l. 129: I think that M is not the same “downward mixing”, but rather entrainment of water masses below the pycnocline into the surface ocean mixed layer as a result of a deepening mixed layer. In the context of this sentence, you refer to increased stratification due to large freshwater anomalies that inhibits a deepening of the mixed layer due to convection.

   We are now more precise and specify "vertical mixing and entrainment".

3. l. 135-137: This sentence becomes only understandable after reading the appendix.

   We have removed this sentence.

4. Section 3.2/Appendix A2: The whole derivation of the freshwater indices is based on the NAO. I can’t help but notice the striking similarity between the spatial pattern of the cold anomaly in the subpolar gyre for F_E and regression pattern of SST anomalies on the North Atlantic SST Index of the Atlantic Multidecadal Oscillation (AMO) in that region (see Fig. 11 in Deser et al., 2010). The AMO has been in its warm phase since the mid-1990s and thus during the time of most of the F_E years. This raises the question to what extent longer-term climate variability influences the relationship between the NAO and freshwater anomalies and if this can be utilized in the design of the freshwater indices?

Thank you for this suggestion. We did indeed attempt to divide the full period in high and low AMO phases. However, this did not turn out to be useful. We found that the summer NAO already filters out the interannual variability of freshwater and that the targeted approach of subsampling was more effective in optimising the indices.

In a related study, we find that the trend of the cold anomaly over the last 70 years has recently overtaken the AMO signal and now has a larger amplitude than the AMO. This has far-reaching implications for North Atlantic climate variability, including a shift of power towards interannual timescales. While a detailed analysis of the AMO signal is beyond the scope of this manuscript, we now mention its relationship to freshwater anomalies in the revised manuscript.

Overall, we find that freshwater can explain the variability of the cold anomaly pattern on a range of timescales, including that of the AMO, due to the different causes of freshwater. Thus, it may also not be desirable to completely filter out this signal.

5. l. 152-153: How do you estimate the correlation between the index and freshwater anomalies and how well the index represents the initial freshwater anomalies if they "are not known a priori" (cf. l. 148-149)? I think you are referring to SST anomalies which serve as proxies for the freshwater anomalies.

Yes, you are right. We present the correlation together with the uncertainty since both estimates belong together. We first estimate the freshwater anomalies from the SST anomalies and obtain an uncertainty of 4% and 6% respectively. We then calculate the correlation between the estimated freshwater anomalies and the NAO index. This is now clarified in the text.

6. l. 156: Please define F_E and F_W explicitly. Without going through the appendix, the reader might ask themselves why there are two indices? What do the subscripts refer to? How are the two related?

Since we have removed the appendices, all relevant information about F_E and F_W is now included in the main text.

7. l. 160: Please refer to Appendix A3 to show how these uncertainty estimates were obtained.

We have now shifted part of Appendix A3 and A4 into the results section. Thus, the results section now includes a detailed explanation of the freshwater anomalies, their uncertainty estimates, and how they were obtained.

8. l. 161-162 & Figure 3: I think Figure 3 deserves more prominence in the text as these are the actual freshwater anomalies your hypothesis is based on. I suggest to move this sentence into its own paragraph and add more details, e.g., by being explicit that the shown salinity anomalies are estimate based on the surface mass balance (I think?), how you obtained the relationships, and what the white areas represent. Please define SSS.

Thank you for pointing out the importance of Figure 3. We have now shifted it into its own section in the results and clearly explain it. We also define SSS as the sea surface salinity.

9. Figure 2: Panels (a) and (b) should be the same as Panels (a) and (e) in Figure A1, but the structure of the largest values looks different. Is this just because of the differences in the color scale?

Yes, we had adjusted the colour scale in Figure A1e to make it the same as that of Figure A1b. However, we agree that the choice of the colour scale concealed the structure of the largest values. After combining the Appendix with the approach section, we have removed this figure.

10. Equation (A2): Please define ρ_0.

We now define it as the density before the start of the winter.

11. l. 350: Strictly speaking, given Equation (A2) is the result of an integral over time, h_n is the mixed layer at the end of winter.

Thank you for spotting this. We have now corrected it.

12. l. 359-361: How realistic are these conditions and at what timescales do you expect this assumption to hold?

At this location in the text, it is only a motivation. It is an objective of the approach to achieve these conditions, but we do not make any assumptions. We have now rephrased the sentence for clarification.

Moreover, after evaluating the mass balances, we find that (on interannual timescales) these conditions always hold within a reasonable uncertainty range. Even for the cases without any subsampling, the results hold with an uncertainty of up to 10%. Since this is an important result, we have now added:

"The result implies a remarkably close connection between freshwater and SST anomalies. A demonstration of this result with hydrographic observations is included in the Appendix, where we find that, even in the case of the most extreme air-sea fluxes, it is possible to infer freshwater anomalies from the SST with a reasonable uncertainty that is below that of currently available satellite products."

13. l. 369 & l. 371: “lower NAO index” and “higher NAO index” – do these refer to the magnitude and/or phase of the NAO?

They refer to the phase. To clarify this, we have replaced all instances of "NAO index" by "NAO state" or "phase".

14. l. 375-377: It would be helpful for the reader if you add a sentence how the relationship was obtained. This is partially described in the caption of Figure A1, which makes it more difficult to follow the arguments in the text.

Thank you for pointing this out. We have now rephrased this sentence to clarify that the relationship was not "obtained" in that we did not take any steps or created it ourselves. Instead, we observe this relationship from visual inspection of the scatter plot.

15. l. 377: How did you determine the threshold?

We determined it from visual inspection of the relationship between the summer NAO meridional SST gradient. We have now rewritten this paragraph to clarify it.

16. l. 377-378: I think it is important to also mention the significant positive SST anomaly in the subtropical gyre/western North Atlantic (Figure A1a) which has a substantial contribution to ΔSST for NAO < -0.5.

Thank you for pointing this out. It is indeed important, and we now mention it at the location you indicated.

We also explain the development of the warm anomaly through air-sea coupling in more detail in Section 4.3. Overall, we are now more explicit about the role of large-scale atmospheric feedbacks contributing to the SST signal beyond the subpolar region.

17. l. 380-400: The description of the optimization process is unclear. I understand the rationale of increasing the signal-to-noise ratio, however, the selection of included years appears very subjective. How did you choose the number of years to include in the index? How did you select the discarded years? What about the two outlier years?

Thank you for indicating that the optimisation process was insufficiently described. As you correctly point out, the objective of the process is to increase the signal-to-noise ratio.

To better describe the process, we now further explain: "There is a trade-off between the number of years included and the resulting correlation. Here, we selected N=17 years as a reasonable compromise for obtaining a high correlation of 0.90 while keeping a relatively large sample size, reflected in low p-values ($p < 2.6 \times 10^{-6}$). Selecting N=16 or N=18 increases the p-value again. However, the results are not sensitive to this choice."

To add further support for the subsampling, we have included a new section in the results that links the two sub-sampled indices to physical causes of freshwater anomalies, supporting the optimisation process with a dynamical explanation.

The two outlier years correspond to years where the NAO index was not a useful indicator for the fresh and cold anomalies. However, upon investigating both years more closely we found that the relationship between the salinity and temperature anomalies still holds.

18. l. 387: Please define the SST gradient in the text.

We now define the SST gradient in the text and explain that it refers to the difference between the subtropical warm and subpolar cold anomaly regions, enclosed within the 95% confidence lines.

19. l. 388-389: It is unclear what you mean by "spatial gradients are more robust to local variations in the surface fluxes". What if the spatial gradient is the result of local heat flux variations as one might expect from the response to the NAO (e.g., Cayan, 1992; Marshall et al., 2001; Deser et al., 2010).

Thank you for pointing out that the sentence was unclear. By using spatial gradients, we filter out the uniform warming effect of increasing greenhouse gases. Another advantage of using spatial gradients is that the area, used for the derivation of the indices is based on overall larger areas and therefore less sensitive to regional fluctuations in surface currents or fluxes. This is now clarified.

We also point out that the surface fluxes do not contribute to the SST patterns. The surface fluxes were evaluated as part of the mass balance. Over the cold anomaly, the surface flux anomaly is positive implying that the ocean loses less heat. Thus, the ocean anomalously cools the atmosphere rather than the other way round.

20. Figure A1: It would be more intuitive and consistent with the text if you wrote NAOS < -0.5 in the title of Panel (a) and in the caption. Do you include the significant cold tongue off western Africa in the calculation of ΔSST?

The change in the title you suggest would not simply be a change in nomenclature. Instead, it would change the sign of the regressor. Thus, everything in the figure would be opposite. The sign of all the obtained SST anomalies would be reversed. However, the point of the figure is to show that we obtain similar anomalies as in panel b, where the sign of the NAO is opposite.

The cold tongue can be understood as a feedback since the associated large-scale atmospheric circulation anomaly induces upwelling off western Africa. However, we do not include the cold tongue off western Africa in the calculation of the SST gradient. We have now clarified this in the text. Also, throughout the manuscript we are more explicit about the large-scale atmospheric feedbacks that contribute to the SST pattern.

2. Section 4.1:
    1. The circulation anomaly you describe (Figure 4b) is reminiscent of the positive NAO phase for which the atmospheric variability patterns and corresponding ocean response are known (e.g., Cayan, 1992; Marshall et al., 2001), and are in line with your findings. It would make this section stronger if you make an explicit link of your results to the winter NAO.

Thank you for pointing this out. Following your suggestion, we now make an explicit link to the winter NAO.

2. Changes in the wind field associated with the NAO not only change the Ekman transport as you discuss (l. 198), but also lead to changes in latent and sensible heat fluxes. Can you elaborate to what extend these changes in air-sea heat fluxes are important for creating and maintaining the meridional SST gradient?

We now state that we do not find any significant impact of the surface heat fluxes on maintaining the SST gradient, neither in winter nor in summer. On the contrary, we find that the SST anomaly drives the surface flux anomalies. Since the cold anomaly is associated with a positive heat flux anomaly, it implies reduced ocean heat losses. Thus, it contributes to the baroclinic instability in the lower troposphere. This is now clarified in the description of the air-sea feedbacks, both in winter and in summer.

3. l. 200: It is unclear why you bring in the second winter. A short motivation will help to keep the reader on board.

   Thank you for suggesting this. We now motivate the investigation of the second winter with the climatic importance of North Atlantic Current shifts.

4. l. 210-213: From the presented figures, I cannot see a northward shift of the North Atlantic Current during the first winter (I think it shows up nicely int Figure 4d for the second winter). Is it possible that different timescales between heat fluxes and Ekman transport can explain the differences between the first and second winter? A SST gradient which is set up in the first winter and shifted northward during the second year seems also more in line with the summer SST pattern that you describe in Section 4.2 (l. 227-229).

   Thank you for pointing out that this was unclear.

   The Ekman transports are an instantaneous response. They already lead to a warm anomaly in the first winter after the freshwater index. However, the northward current shift is only visible in the warm anomaly to the south of the cold anomaly (the Gulf Stream deflection point). It does not extend across to the east coast.

   We now clarified in the text: "The water inside the North Atlantic Current is not anomalously warm but it occurs at an anomalously northward location. Thus, the northward shift of the North Atlantic Current is reflected in the warm anomaly to the southwest of the subpolar cold anomaly. The warm anomaly is already visible in the first winter after the summer NAO but it does not extend to the east coast."

   We also investigated the surface heat fluxes (shown in the appendix) but they were not able to explain the SST patterns. This is now clarified.

3. Section 4.2: This section seems rather short given that it addresses one of the main results of the study. It would be helpful for the reader if you add more details and clarify the following points:

Thank you for your suggestions. Following your suggestions below, we have now expanded the section.

   1. l. 231: “more northerly location” compared to what?

      "More northerly compared to the previous summer". This is now clarified.

   2. l. 237, 238, 241: “cold anomaly” in the ocean or atmosphere?

      We referred to the negative SST anomaly. This is now clarified.

   3. l. 240: “over Europe” is rather vague (e.g., the warm and dry anomalies (Figures 6c and d) occur in different regions). See also next comment.

      Following your comment below, we are now more specific.

4. l. 241: Is it actually true that “the overall patterns are similar after F_E and F_W freshwater anomalies”? The significant air temperature anomalies one year after F_E extend across the Iberian Peninsula all the way to northern Africa while they are more centered around over France and Great Britain after F_W. Similar the the dry anomaly occurs over the Alps and eastern Europe during the first summer after F_E, but more over Baltic region after F_W which is more similar to second summer response after F_E.

Thank you for suggesting this. We are now more specific and say that the mechanism is the same, but it occurs over a different region, consistent with the underlying SST anomalies. We now exactly specify the regions in the text.

5. It seems like that patterns after F_W are one order of magnitude smaller compared to the patterns after F_E. Is this an artifact of the smaller correlation in the construction of the freshwater indices or is it due to the stronger meridional SST gradient that exists in the F_E subset with significant positive SST anomalies in the subtropical gyre region?

Yes, you are right that the magnitudes of the obtained signals in European summer weather are carried over from the larger magnitudes in the freshwater and SST signals.

Please note these are not absolute anomalies but regressions. The large magnitudes result from steep regression slopes. These steep regression slopes occur because the underlying changes in the F_E index are much smaller compared to the changes in the F_W index. An implication of this is that, once the seasonal surface freshening (or the F_E index) exceeds a critical threshold, a relatively small further increase is linked to relatively large feedbacks. This is now better explained in the text, both in the section where we introduce the indices and where we describe the subsequent European summer weather.

6. Is there a reason why you show the zonal wind at 700 hPa for the F_E subset and the meridional component for the F_W subset?

The winds closely follow the SST fronts, indicated by the arrows. To best show the link between the SST and the wind field, we selected the wind component that best matches the shape of the underlying SST pattern. This is now clarified.

4. Sections 4.4 and 4.5.: I have to admit that I got lost here. In general, I am wondering whether the analysis of the model simulations adds any additional information that warrants its inclusion in the manuscript.

Following your suggestion, we have removed the previous model analysis. We have now replaced it by another analysis in which the link between the selected SST anomalies for the model analysis and the freshwater anomalies is clearer.

Since we have removed the analysis, the comments below no longer apply.

1. l. 271: It is not clear which pattern (F_E or F_W) you project the on.
2. l. 273: Most of the analysis in Sections 4.1 and 4.2 is focused on the first summer after both F_E and F_W years with only a brief discussion of the second summer after F_E. It is unclear why you construct a new index for the analysis of the model simulations based on the SST pattern in the second summer.

3. l. 289: cold anomalies in the ocean or atmosphere?
4. l. 294-295: Given your derivation of the freshwater indices using the surface mass balance, any cold anomaly coinicides with a freshwater anomaly, by construction. Your analysis of the observations points out the importance of the the meridional SST gradient and its influence on the position of the jetstream. This raises the question whether the freshwater anomalies are just side effect of the mechanism that sets up the SST gradient. It is unclear to me how the model simulations help to answer this question.

In the new analyses, we examine the link between the freshwater anomaly in winter and the SST anomaly in summer more thoroughly. While the freshwater anomalies can explain the initial trigger of the chain of events, the final SST anomalies in summer can only be understood as the result of large-scale air-sea coupling processes. Thus, we are more cautious in the wording in the revised manuscript.

III. Additional Comments and Suggestions:

1. l. 37, l. 83, l. 84: It would be more appropriate to use “grid spacing” instead of resolution (e.g., Grasso 2000).

Thank you for pointing this out. We have corrected this now.

2. l. 44: It’s not just cold air, but also stronger winds that increase heat fluxes.

This is true but in the preceding sentence we explain that the air is always colder than the ocean in winter. This naturally implies a mean climatological ocean heat loss. We do not exclude that stronger winds also increase the surface fluxes. They are just not relevant in the context of this paragraph. We have now rewritten the sentence more clearly.

3. l. 46: Please summarize the conditions here or refer to the derivation of the freshwater indices.

We now state the conditions.

4. Section 2.1: Please add details about grid spacing, temporal resolution, and any processing (e.g., calculation of anomalies, spatial interpolation, etc.). This would help make the study more reproducible. It might also be worthwhile to specify in this section which months you refer to by “summer” and “winter” throughout the text, especially since they are different from the standard definitions June-August (JJA) and December-February (DJF), respectively.

Thank you for these suggestions. This is now included in the data section.

5. l. 63: How did you combine the two datasets given their different temporal and spatial resolutions?

We did not combine them ourselves but downloaded the merged dataset from NCAR. This is now clarified by including the link to the datafile in the data section.

6. l. 94-97: This sentence is unclear. I do not understand why warm anomalies due to shift in the jet stream “must” be balanced by a cold anomaly elsewhere.

In contrast to greenhouse gas warming, freshwater-linked temperature anomalies do not result in a net imbalance in the Earth's surface energy budget. The warming over Europe is balanced by a cooling over the ocean since the underlying baroclinic wave activity consists of an anticyclonic anomaly on one side of the jet stream, and a cyclonic anomaly on the other side. Thank you for pointing out that this was unclear. We have clarified this in the revised manuscript.

7. Here are a few wordings that are either inconsistent or remnants of the previous version of the manuscript:

Many thanks for spotting the below inconsistencies. We have now clarified all instances.

    1. l. 185: “in winters after stronger freshwater anomalies” – based on the construction of your freshwater indices, the anomalies should occur during winter.

    We have removed this sentence.

    2. l. 211, 271, 316, 498, 499: what are “freshwater events”?

    We have replaced "freshwater events" by "freshwater anomalies" everywhere.

    3. l. 273, l. 419: What are “melt-driven” or “melt-induced” events? How are they connected to F_E and F_W?

    Thank you for spotting this. We have removed the terms "melt-driven" and "melt-induced" at both locations. Also, we now added a section that explains the term.

    4. l. 421: What are “circulation-induced freshwater events”?

    We have removed the term.

8. Figure 4: I suggest to mask out the Ekman transport vectors over land. This would make it more intuitive that they refer to an ocean variable

Indeed, thank you. We have now masked them out.

9. l. 253: Please add a reference for the statement that “most current coupled global climate models have large freshwater biases”.

We have now added references.

10. l. 408: Do you integrate the wind stress or resulting Ekman transport over the winter period?

Yes, we do. We have now clarified this in the text.

11. l. 429: In l. 412-413, you define the heat flux (Q) as positive downward. A positive surface buoyancy flux (B) anomaly means Q needs to be positive (unless it its overcompensated by the freshwater flux), i.e., the ocean gains heat.

Yes, this is true for the anomalies. However, in the mean winter, the subpolar ocean loses heat. Thus, we considered it more appropriate to state "the ocean loses less heat" instead of "the ocean gains heat".

12. l. 439-440: What is the uncertainty in the freshwater fluxes due to the constant mixed layer depth used in your analysis?

We assume that you are referring to "constant" as in "constant over different years", not "constant over the winter" since we do not assume the mixed layer depth to be constant over the winter.

The influence of a variable mixed layer depth over different winters on the results can be understood by considering two cases:

(1) If the mixed layer depth is positively correlated with the NAO indices (that means the mixed layer would be deeper for larger indices), the terms on the righthand side of the mass balance equation would be even less relevant and the actual uncertainties of the freshwater anomalies would be even smaller than the ones provided.

(2) If the mixed layer depth is negatively correlated with the NAO indices (that means the mixed layer would be shallower), we do not need to evaluate the mass balance. In that case, the combination of shallower mixed layers and negative temperature anomalies implies that salinity anomalies must dominate stratification.

In this scenario, the freshwater anomalies even overcompensate the density increase by the temperature anomalies. However, shallower mixed layers also imply that less ocean heat is available to drive the atmosphere, reflected in the positive surface flux anomalies. Since the identified surface flux anomalies are very small and not significant, we conclude that this overcompensation is negligible up to the uncertainty range provided in the text.

In the text, we have now added: "Since for both F_W and F_E, the surface buoyancy flux anomalies are positive, the ocean loses less heat ("M drives B"), and the mixed layer is slightly shallower and lighter for increased indices, when averaged over the cold anomaly regions. As shown above, however, the density changes implied by the surface fluxes associated with both F_W and F_E are over one order of magnitude smaller than the density changes implied by the cold anomalies. Thus, the change in the mixed layer depth, and any overcompensation of the density anomaly – by a surplus of surface freshening, a slowdown of the buoyancy-driven overturning circulation, pre-existing density anomalies, or any other buoyancy-driven mechanism – is negligible on the timescales considered."

13. Figure A4: It is unclear whether these are composites just for the winters before the warmest summers or also the difference with the coldest summers.

For consistency with the heat wave composites, the composites refer to the difference between the ten warmest and the ten coldest summers. This is now clarified.

14. l. 498: This goes back to my first general comment (I.1.): If the SST pattern drives the observed atmospheric response, what is the role of the freshwater anomalies?

We are now more specific in the role of the freshwater anomalies (please see first comment for more details).

IV. Typos/Wording:

l. 53, 301: "ocean atmosphere" to "ocean-atmosphere"

This is now corrected.

l. 273: "over the central North Atlantic" to "in the central North Atlantic"

This is now corrected.

References:

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