Dear David Thornally,

Here you will find our responses to the second round of review of our manuscript egusphere-2022-959. We appreciate the work you and the reviewers have put in, helping us to improve the manuscript.

The reviewer comments are shown in black, and our responses are shown in blue.

We have also corrected some minor inconsistences and typos found when while reading through the text again.

Best regards,
Bjørg Risebrobakken
On behalf of all co-authors

Review 2 of the manuscript entitled "The role of buoyancy forcing for northern North Atlantic SST variability across multiple time scales"

The manuscript is much improved. I do, however, have some further minor comments and technical comments.

We thank Pepijn Bakker for his second review of our manuscript. We appreciate his positive feedback and are glad that he sees significant improvements of the manuscript following the first round of review.

Minor comments:

In section 2.4 the model setup and results for the reference experiments is described. I think this is a good and clear setup. A bit confusing that figure 5 and accompanying text, which seems to be part of section 2.4, does in fact already present results from a non-reference experiment. Consider making a clear seperation between the methods and the results.

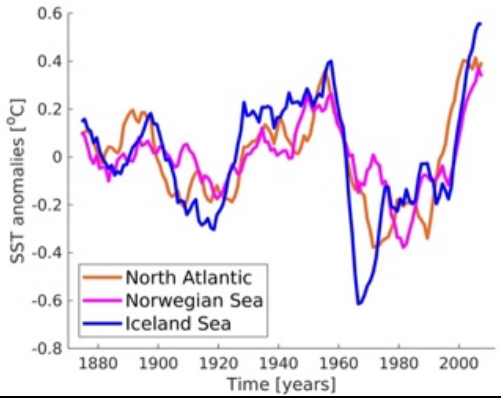
We see that it may cause confusions that Figure 5 included some of the results. We have made a new Fig 5 which only shows a reference experiment and the defined domains, to better separate the methods and results. The text/figure caption has been corrected accordingly.

Figures 6 & 7: How sensitive are these results (spatially coherent versus spatially non-coherent) on the definition of the multi-decadal analysis period? It seems to me that in figure 6 you can also pick periods of the same duration for which you will find spatially non-coherent results?

Information on the robustness has been added to section 3.1.

The spatially coherent SST anomaly relationship between the North Atlantic, the Norwegian Sea and the Iceland Sea (Figure 6) are robust. Correlations between the time series from the three regions are positive and significant. This relationship holds for different filtering of the time series (running mean with a 5-year window, 10-year window, and 15-year window). The correlation increases, the more the time series are filtered.

Please see the attached figures that show:
1) The filtered anomaly time series for different filters: the more smoothing, the clearer is the positive correlation between the time series.
2) The correlation between the anomaly time series (description below each plot tells which time series and which filter that has been applied).



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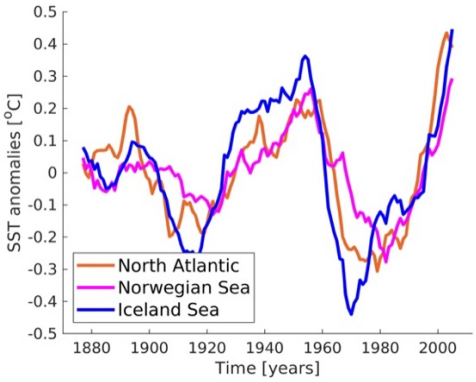

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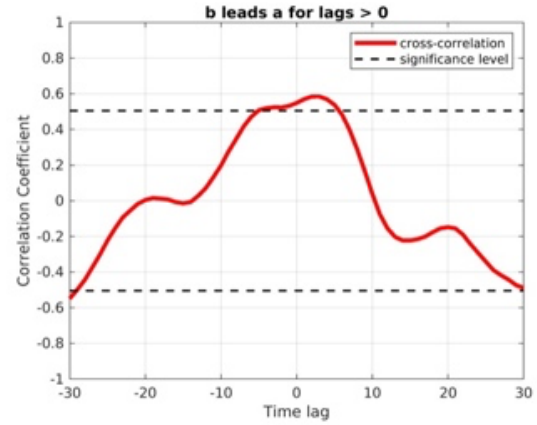

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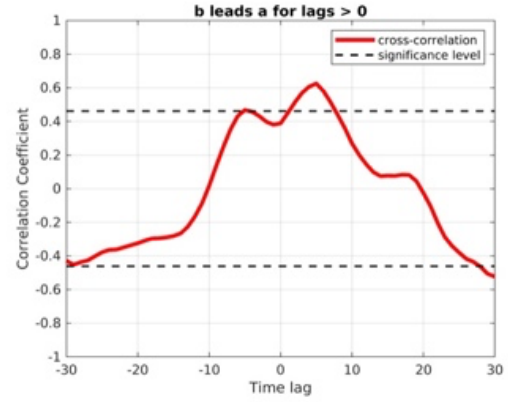

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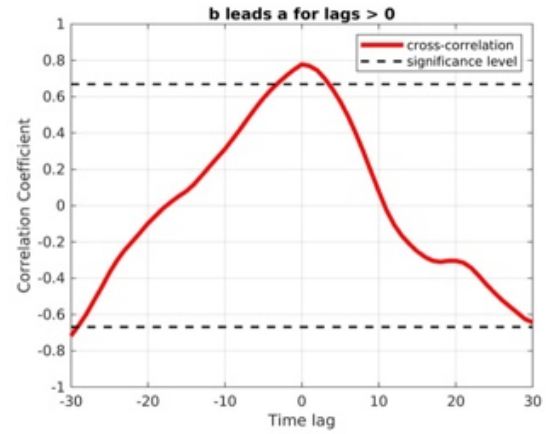

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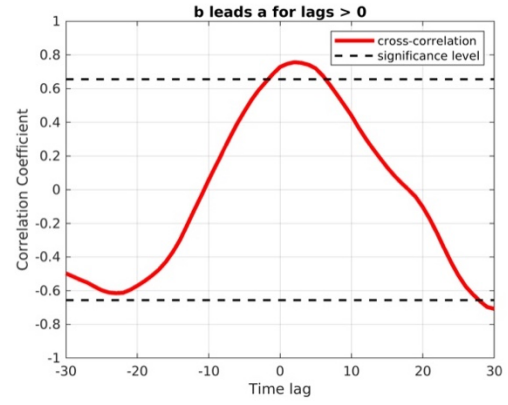

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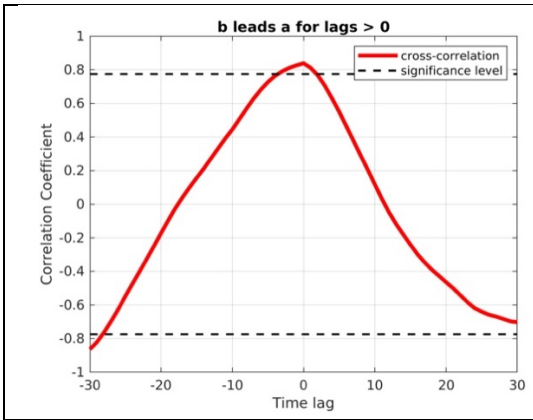	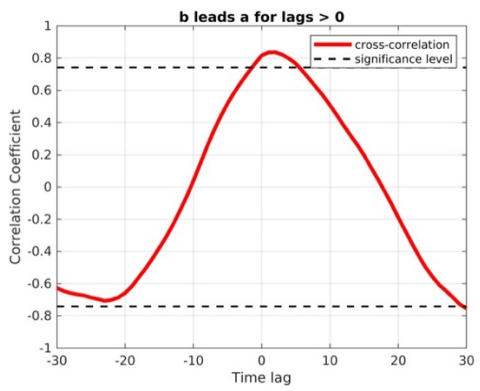
hadisst_corr_filt_15yr_aIS_bNA	hadisst_corr_filt_15yr_aNS_bNA

New text section 3.1: The spatially coherent SST anomaly relationship between the North Atlantic, the Norwegian Sea and the Iceland Sea is robust, showing positive and significant correlations between the detrended time series (both the Norwegian Sea and the Iceland Sea is correlated with the North Atlantic). The relationship also holds for different filtering of the time series, i.e., running mean with a 5-year window, 10-year window, and 15-year window (not shown).

Similarly for figure 7, if you would not be forced to use 2068-2098, but could shift this frame back and forth in time by several decades, would you find very different results? Some discussion on this sensitivity (and perhaps thus the effect of decadal variability on multi-decadal averages) would make the manuscript stronger.

In contrast to the results in Figure 6, the results in the last three decades in Figure 7 are not robust across the whole time period. Thus, the spatially incoherent SST anomaly relationship, found in CNRM-ESM2-1 SSP126 and and NorESM2-MM SSP585 in the last three decades, is sensitive to the time period chosen. This means that choosing another time period, e.g., 2038-2068, would not give the same results. Correlations between the time series from the three regions are non-significant, and this is found for different filtering of the time series (running mean with a 5-year window, 10-year window, and 15-year window). The same results are found for all four experiments, except for NorESM2-MM SSP126 (indication of a positive correlation between the North Atlantic and the Iceland Sea) and NorESM2-MM SSP585 (indication of a positive correlation between all regions only if time series are detrended, but then the spatially incoherent SST anomaly relationship is lost). A new paragraph addressing this has been added to Section 3.2.

New paragraph, Section 3.2: The spatially incoherent SST anomaly relationship found in CNRM-ESM2-1 SSP126 and NorESM2-MM SSP585 in the last three decades (2068-2098) (Fig. 7) is sensitive to the chosen period and are not robust over the whole projected period (2023-2098). Correlations are overall non-significant between the time series from the three regions. Positive correlations are indicated for NorESM2-MM SSP585 (both the Norwegian Sea and the Iceland Sea is correlated with the North Atlantic), but only if time series are detrended. In the latter case, the spatially incoherent SST anomaly relationship in the last three decades is not found in NorESM2-MM SSP585.

For the analysis of the pliocene data, observations and CMIP results, the North Atlantic region is defined as a region roughly between Ireland and the southern tip of Greenland. This would roughly correspond to the norther half of the subpolar gyre. In the results of the MITgcm, the same region is however defined as the very southern part of the model domain. This seems to

correspond to the southern side of the subtropical gyre. Looking at figure 9, it seems that this definition could make a lot of difference. What is the rationale of using this definition of the North Atlantic region in the MITgcm and how does it impact the results?

The reviewer is correct from a geographical point of view. To better motivate and explain the rationale for the MITgcm experiments including and how we set the three domains we have rephrased how this is explained in Section 2.4.

Updated text replacing the last two paragraphs in the previous version of the manuscript:

For the MITgcm, the Norwegian Sea domain is defined as a box in the eastern boundary current region, while the Iceland Sea domain is represented by the interior ocean north of the ridge (Fig. 5). The definition of these domains, as the domains used for the observations and CMIP6 results (Section 2.1; Fig. 1), are directed by the location of the Pliocene sites, representing the Norwegian boundary current and interior Iceland Sea.

The definition of the North Atlantic domain is somewhat different; it is for simplicity defined as the North Atlantic restoring region (Fig. 5), restored to 6°C for all experiments (Fig. 4a). With this restoring, the state of the North Atlantic source water eventually becoming the inflow to the Nordic Seas, is essentially known. Also, the model North Atlantic is much less directly impacted by the prescribed changes in buoyancy forcings than the Nordic Seas (Fig. 4; and also less impacted in consequence, as evident in Fig. 9). Directly related, it is the relative temperature (density) difference of the model ocean that constrains the flow and thus the results. (The nonlinearity of the equation of state will only be in effect for large excursions in the absolute values of the restoring temperature and salinity between the different experiments.)

In short, the MITgcm experiments assess the state of the Nordic Seas, and including that of the Norwegian and Iceland seas, relative to that of the North Atlantic. The summary of experiments in Table 1 reflects this relative perspective.

We identify spatially coherent/noncoherent SST anomaly relationships between the North Atlantic, Norwegian and Iceland Seas by comparing the temperature of the sensitivity experiment with the relevant reference experiment. Change in a region is classified as an SST anomaly when the temperature change between two experiments exceeds $2\sigma(SST_{reference\_experiment})$, with σ calculated after temporally averaging the model SSTs. The North Atlantic is restored to constant temperatures as mentioned above. Even if it deviates (slightly) within what is allowed for by the restoring (see Section 2.4), it remains essentially constant and this non-anomalous. Thus, as also alluded to above, change in SST anomaly relationship between the three regions exists if there is a temperature change in either the Norwegian Sea or the Iceland Sea, or both, larger than 2σ.

Lines 625-626: Doesn't this line imply that the changes are related to transient changes rather than equilibrium states?

No, it was not the intention to give the impression that the differences in amplitude for the SST anomalies between decadal scale observations and hundreds of thousands of years is related to transient change rather than equilibrium. To avoid confusion, we have deleted this sentence.

Technical comments:

Line 260: 'Has'

Corrected

Line 303: How is sigma defined? Calculated after annually averaging the model SSTs?

Yes, sigma is calculated after averaging the model SSTs. A specification is added to the text.

Line 304: 'restores'

Corrected

Line 326: 'SST anomaly'

Corrected

Figure 9: in the panel of G1,P4-REF-2, I'm wondering if the scematic showing cooling in the North Atlantic, warming over the iceland basin and no change over the Norwegian current, is indeed correct. Looking at the anomaly map these signals are not apparent.
Thanks for noticing this mistake, the schematic used here was not the correct one. The figure has been updated. We changed the inserts so nonsignificant changes is shown consistently in the same manner, realizing that there were a small room for misunderstanding between the figure (as it was) and the text.

Line 624: 'iare'
Corrected

Line 794: mention the period that the observational data covers, not just the starting year.
Corrected

Code/Data availability: it seems that this section is not yet complete.
You are right that part of the information was missing here. This has been corrected.
Updated text on data and code availability:
All reconstructions are previously published. Information on availability is given in the Supplement.
The observation-based SST data set from the Met Office Hadley Centre can be accessed from the following link: https://www.metoffice.gov.uk/hadobs/hadisst/.
Data from the current generation of global climate model simulations is available through the most recent Coupled Model Intercomparison Project Phase 6 (CMIP6), and can be accessed from Earth System Grid Federation (https://esgf-node.llnl.gov/search/cmip6/).
The MITgcm source code is an open sourced, freely available model code (https://mitgcm.readthedocs.io/en/latest/getting_started/getting_started.html). Due to the size of the model results, simulation data is avaialabl upon request.