Reply on RC2
Denis L. Volkov et al.

Author comment on "Interannual to decadal sea level variability in the subpolar North Atlantic: The role of propagating signals" by Denis L. Volkov et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-354-AC2, 2022

We thank the reviewer for his/her time to review the manuscript and for the feedback. We have tried to address all reviewer’s concerns by expanding the Discussion and Conclusion sections and by adding additional/clarifying sentences throughout the manuscript. Our answers to the reviewer’s comments are shown below in bold font.

Comments
The introduction presents the AMOC and North Atlantic gyres, and how they have varied over time, but the results in the paper do not connect back to these circulations. To give one example: what is the state of these circulations during the identified characteristic time intervals? A discussion section may be required to put the results in the paper in an AMOC and gyre context. The authors should also explore the possibility of using the observed AMOC time series to do so.

Reply: We thank the reviewer for this remark. In order to address it, we have changed the “Conclusions” sections to “Discussion and Conclusions”, and we have added some discussion that hopefully links the results of the paper with what is said in the Introduction. We note, however, that the main objective of this paper is to revise the definition of the North Atlantic SSH tripole by accounting for signal propagation, as it applies to the subpolar North Atlantic. The detailed investigation of the tripole-related changes in circulation, the role of the AMOC, and air-sea interactions goes beyond the scope of this study and requires separate dedicated studies. The use of the AMOC time series in the SPNA is problematic, because the only AMOC time series, based on direct measurement by the OSNAP array, are still very short.

The reader is also minimally provided with the implications of the results. Adding this may be easier after reconnecting the presented results to changes in the North Atlantic circulation (comment above).

Reply: In the Discussion and Conclusions section, we have added sentences and paragraphs regarding the implications of the results for the use of tripole and subpolar gyre index, as well as how the results link to inter-gyre exchange.

The CEOF analysis applied to the SSH is technically straightforward to understand. But, what does this signal propagation tells us about the two-way coupling or communication
between the two gyres during its evolution? And can this mainly be attributed to advection?

Reply: In the Discussion and Conclusions section of the revised manuscript, we have included the following paragraph: “It should be noted that due to geostrophy both the SSH and the general ocean circulation are linked, and both adjust to persistent atmospheric forcing. For example, an increase of SSH along the European coast starts when the negative (cyclonic) SLP anomaly is centered over the eastern coast of Greenland and the atmospheric circulation near the eastern boundary is likely to cause downwelling (phase 0° in Figs. 8 and 11). As the cyclonic SLP anomaly weakens and moves towards the Labrador Sea (phase 45° in Figs. 11), the subpolar gyre weakens and contracts and the positive SSH anomalies near the eastern boundary expand westward (phase 45° in Fig. 8). It has been reported that this situation can facilitate inter-gyre exchange (Häkkinen et al., 2011; Piecuch et al., 2017). Specifically, in response to a weakening of the subtropical high and subpolar low pressure centers, the subtropical and the subpolar gyres weaken, sea level decreases in the subtropical gyre and increases in the subpolar gyre, the subpolar front moves westward, and the eastern boundary region in the SPNA widens, entraining more warm and saline waters from the subtropical gyre. Consequently, positive SSH anomalies emerge first near the eastern boundary of the SPNA and then expand westward as the subpolar gyre continues to weaken (phases 45° to 180° in Fig. 8). The opposite occurs when the subtropical and the subpolar gyres strengthen (phases -135° to 0° in Fig. 8). As demonstrated by the CPC1 (Fig. 9), the local maximum SSH anomalies occurred in the eastern SPNA around 1996, 2004, and 2009, and they reached the western SPNA 1-2 years later. The most recent increase of SSH in the eastern SPNA since 2014 and in the western SPNA since 2016, that remains present in 2020, represents a recovery from an exceptional cooling and freshening that occurred in the SPNA in 2012-2016. This means that the recent conditions are favorable again for inter-gyre exchange.”

We also conclude in the end that the observed interannual-to-decadal variability of SSH, including the westward propagation of SSH anomalies, is the result of a complex interplay between the local wind and surface buoyancy forcing, and the advection of properties by mean ocean currents.

While the CEOF analysis applied to oceanic variables is "easy" to grasp, this is not the case for atmospheric variables and on long time scales (there is no such predictability in the atmosphere, is there?). Because of this, I am really struggling in interpreting the results presented in Fig. 11.

Reply: In the revised version of the manuscript, we have replaced wind stress curl in Fig. 11 with sea level pressure. We believe that the new figure is visually more comprehensive with respect to the tripole-related shifts of wind forcing patterns. Our observation is that the westward propagation of SSH anomalies corresponds to the shifts of wind forcing patterns in the same direction. Given this observation, it is possible that the observed propagation is simply an oceanic response to persistent low-frequency NAO-like wind forcing that is not stationary (as described by the conventional NAO index). However, in the presence of the mean cyclonic circulation in the SPNA, advection also plays an important role, as also demonstrated by (mainly) halosteric SSH anomalies in Figs. 12-15. Furthermore, persistent wind forcing leads to baroclinic adjustment with associated changes in heat and freshwater contents and in geostrophic circulation. We agree that our study does not provide a conclusive answer to what process is more important in driving the tripole-related changes in the SPNA: wind forcing, buoyancy fluxes, or advection. This question is beyond the
Minor comments

Why does EOF2 show a strong signal on the shelves?

Reply: This is an interesting question, similar to the one posed by reviewer 1. The EOF2 shows a strong signal over shallower areas, which are present mainly in the eastern and northeastern SPNA. The western SPNA is largely deep. The SSH anomalies depicted by EOF2 first emerge near the eastern boundary, which is probably due to the associated atmospheric circulation pattern as well as to the fact that the subpolar gyre contracts or expands allowing more or less subtropical waters to enter the SPNA. We believe that the likely influence of advection is reflected by the bands of high explained variance along the flanks of Reykjanes Ridge and along the East Greenland Current (Fig. 5b). In the Discussion and Conclusions section of the revised manuscript, we have added the following sentences: “It appears that while the overall propagation is westward, SSH anomalies associated with EOF1 and EOF2 first spread over the shallower areas in the east-northeast, including the currents along the eastern and western flanks of the Reykjanes Ridge and the East Greenland Current (EOF2; Figs. 2b and 5b), and then propagate towards the deeper parts of the Irminger Basin and Labrador Sea (EOF1; Figs. 2a and 5a). This suggests that advection by the mean currents in the SPNA is an important factor to consider and that the transfer of signals from the currents to the interior parts of the basins may be due to eddies.”

260: How different is the variability of the SSH between the Iceland and Rockall Basins as compared to that of the Irminger Sea?

Reply: The SSH time series in the regions are highly correlated at the time scales considered. Therefore, we have removed the paragraph mentioning that the regions are dynamically distinct.

315: What is the reason for the 10-month lag?

Reply: We have added the following sentences to the first paragraph of Section 4.4: “The lag probably indicates the oceanic adjustment time to a variable wind forcing. Regression of SLP and 10-m winds on the PC1 displays a familiar NAO dipole pattern with a cyclonic (negative) anomaly in the subtropical high and an anticyclonic (positive) anomaly in the subpolar low SLP centers (Fig. 10a). The weaker/stronger subtropical high and subpolar low associated with weaker/stronger westerly winds in the midlatitude North Atlantic lead to lower/higher sea levels in the subtropical North Atlantic and higher/lower sea levels in the SPNA.”

325: Can the authors quantify the Ekman-induced SSH anomalies?

Reply: This would require the estimation of the reduced gravity, which is latitude dependent, and would make the manuscript even longer than it is now. We prefer to keep the main focus on the observed propagation and limit the analysis
of wind forcing to establish a statistical relationship with the tripole-related changes of SSH. The mechanistic details of the relationship between the shifting wind forcing patterns and the tripole evolution in the SPNA are left for a future study.

Figure 11: reversing the colormap is confusing.

Reply: We have replaced the wind stress curl in Fig. 11 with sea level pressure, so the colormap is not reversed anymore.

Figure 12: please add more details to the caption.

Reply: We are not sure what additional details the reviewer means, but we have modified the caption a little bit by listing abbreviations used in the figure panels and by indicating that steric sea level was estimated from EN4 data and the buoyancy fluxes are provided by the ERA5 reanalysis.

Please assess and add significance to the regression figures throughout.

Reply: In Figs. 10 and 11 of the revised manuscript, we have plotted arrows only at locations where regression coefficients are significant at 95% confidence.

Please improve the text whenever possible. It is hard to follow at multiple places in the results, especially when describing the results in the context of previous work. A discussion section would have helped to avoid this.

Reply: We have done a substantial revision of the Discussion and Conclusions sections as well as we have added clarifying sentences throughout the manuscript. We hope that the revised version has been improved and become more comprehensive.