Ocean Science Discussions

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Comment on os-2022-18

Anonymous Referee #3

Referee comment on "Exceptional freshening and cooling in the eastern subpolar North Atlantic caused by reduced Labrador Sea surface heat loss" by Alan D. Fox et al., Ocean Sci. Discuss., https://doi.org/10.5194/os-2022-18-RC3, 2022

In this study, the authors investigated mechanisms of the exceptional freshening event in the eastern subpolar North Atlantic using a high-resolution VIKING20X model run. The authors conducted a thorough study starting with a Lagrangian tracking analysis that leads step by step to the conclusion that the freshening event in the eastern subpolar gyre is due to reduced heat loss in the western subpolar gyre. Overall, I find the manuscript logically organized with convincing conclusions. However, I believe several general concerns need to be addressed before the manuscript can be accepted for publication.

General comments:

1. This study is based on the high-resolution VIKING20X-JRA-Short hindcast simulation, which is able to capture the great freshening and cooling event in 2014-2016. The pattern and timing of the freshening and cooling from the model is very consistent with those derived from EN4. However, the magnitude of the freshening and cooling in the model is substantially larger than in EN4. Since the hindcast is a free run without data simulation and bias correction, the authors argue that the model serves as a dynamically consistent tool to examine the freshening event.

This leads to my first concern: given the large simulated bias in the magnitude of the freshening/cooling event, the model could be overly sensitive to a certain mechanism (e.g., heat loss in the Labrador Sea) that contribute to the freshening, while it may underestimate other mechanisms (e.g., AMOC). The authors point out that warm and salty bias prior to the 2014-2016 event is a common feature of hindcast simulations. However, this is not a valid argument that we shall expect a stronger freshening in the model than in observation. Can the authors explicitly explain the reason for this much stronger freshening in the model? Do other realizations of the VIKING20X hindcast simulations show a similar freshening event? If the answer is yes, can the same mechanism explain the freshening? In any case, a clearly stated disclaimer is needed in the discussion to remind readers that compared to observations, model bias both prior to and during the freshening event is strong. The proposed mechanism may be subject to model bias.

2. In section 5.2, the role of the AMOC in driving the freshening is discussed. It is concluded that the weakening Gulf Stream source, determined via particle tracking, is associated with the AMOC in the subtropics and is not related to the subtropical gyre circulation. What I find missing here is the AMOC in the subpolar north Atlantic. What is the role of the subpolar AMOC in the great freshening event? Does the subpolar AMOC also weakens around a similar timing in VIKING20X? How is the magnitude and time of the weakening (or maybe strengthening) of the subpolar AMOC in the model compared to the subtropical AMOC? The authors have studied the great freshening event in the subpolar North Atlantic, used OSNAP East section as the termination of the Lagrangian tracking method, and determined that the Labrador Sea heat loss plays a key role in driving the freshening event. However, the authors have avoided investigating the AMOC in the subpolar North Atlantic.

3. I do not find Section 6.3 convincing. First, I do not see how the modeled isopycnal depths "agree closely" with observation. The model has substantially shallower isopycnals, particularly at large depths. This means that the model has a substantially higher density in the Labrador Sea. However, I cannot understand how the model can have fresher and warmer water and at the same time higher density throughout the water column.

Minor comments:

- I do not think it is necessary to start the introduction with the "warming hole". It might be more straightforward if you directly start with text describing the recent "freshening and cooling" event.
- In Figure 2d, why is there direct-path water crossing 60°W.
- Section 5 need to be reorganized. Both section 5.1 and 5.3 are subpolar-gyre-related mechanisms. And what does it mean by basin-scale in section 5.2? Gyre circulation is also basin-scale.
- Line 364, how is "subtropical gyre recirculation" defined?
- Line 377, I do not think there is a consensus on whether the AMOC has declined since the 1990s. Models and proxies suggest that AMOC has declined (e.g., Rahmstorf et al., 2015; Ceasar et al., 2018, 2021), while observation-based reconstructions have not found a significant AMOC decline (Fu et al., 2020; Worthington et al., 2021; Caínzos et al., 2022).
- Lines 459, please specify the density of the "lighter" waters.
- Lines 461, it is confusing to call waters lighter than 27.50 kg m^{-3} as the "lightest" waters.
- In Section 6.2, it is concluded that due to reduced heat loss over the Labrador basin, transformation from lighter to denser water mass is weakened. Therefore, the steady inflow in the upper layer (<27.65 kg m^{-3}) must be balanced by an enhanced outflow also in the upper layer. Does this indicate that the overturning in the Labrador Sea

weakens, while gyre circulation in the Labrador sea strengthens? This leads back to Section 5.1, lines 335-340, where it is found that the SPG is not responsible for the freshening. How would the authors reconcile the discrepancy here?

- 14 needs to be reorganized. Fig. 14(d,e,f) is cited before Fig. 14(a,b,c).
- Line 536, salinity issue does not make temperature comparison reliable, the sentence needs rephrasing.

Reference:

Rahmstorf, S., et al. (2015). Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nature Climate Change, 5(5), 475–480

Caesar, L., et al. (2021). Current Atlantic meridional overturning circulation weakest in last millennium. Nature Geoscience, 14(3), 1–120

Caesar, L., et al. (2018). Observed fingerprint of a weakening Atlantic Ocean overturning circulation. Nature, 556(7700), 191–196

Fu, Y., et al. (2020). A stable Atlantic meridional overturning circulation in a changing North Atlantic ocean since the 1990s. Science Advances, 6(48), eabc7836

Worthington, E. L., et al. (2021). A 30-year reconstruction of the Atlantic meridional overturning circulation shows no decline. Ocean Science, 17(1), 285–299

Caínzos, V., et al. (2022). Thirty years of GOSHIP and WOCE data: Atlantic overturning of mass, heat, and freshwater transport. Geophysical Research Letters, 49, e2021GL096527