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Reply on RC2

Tillys Petit et al.

Author comment on "Role of air–sea fluxes and ocean surface density in the production of deep waters in the eastern subpolar gyre of the North Atlantic" by Tillys Petit et al., Ocean Sci. Discuss., https://doi.org/10.5194/os-2021-48-AC2, 2021

We thank Referee RC2 for her insightful reviews that have helped us improve the manuscript.

Dear editor and authors,

This interesting and well-written manuscript examines the effect of both buoyancy fluxes and the surface area of sub-polar mode water on the production of deep waters in the Iceland Basin, and makes a convincing attempt to quantify their inter-dependence. I recommend publishing the manuscript subject to minor revisions.

General comment

Overall, this manuscript is well-written, clear, and with few errors. I found the sensitivity experiment especially convincing visually but wondered if the authors had considered quantifying the results of the three experiments in some way?

We estimated a ratio of the variance in transformation for the experiments (2) and (3). The variance of each experiment was divided by the variance of the experiment of reference, experiment (1). The ratios at each grid point were then averaged over the Iceland Basin for the density range 27.3–27.5 kg m^{-3}, and over the Irminger Sea for the density range 27.5–27.6 kg m^{-3}. As suggested in Figure 4, we find a larger ratio of 0.92 in experiment (3) than in experiment (2), of 0.44. Similar results are obtained for the transformation of surface waters to a density > 27.55 kg m^{-3} over the Irminger Sea, with a ratio of 0.91 for experiment (3) and 0.41 for experiment (2).

We now discuss these estimations at l.243-245:

“Over the Iceland Basin, we estimate a ratio of the variance in SPMW transformation over the total variance of 0.44 for the experiment (2) and 0.92 for the experiment (3). […] Similar results are obtained for the transformation of surface waters to a density σ_θ > 27.55 kg m^{-3}, which is the averaged isopycnal of the maximum AMOC at OSNAP East (Fig. 4, lower row), with a ratio of 0.41 for the experiment (2) and 0.91 for the experiment (3) over the Irminger Sea.”

I found the figures generally very good and clear, although some colourbar labels were very small.

Colorbar labels are now bigger in all the figures.

Major comments

Figure 3: The captions and figures for (a) and (b) are mismatched - (a) is labelled Area on the x-axis but captioned buoyancy flux, and vice versa.

Thank you for pointing out the mismatch, the caption of Figure 3(a,b) now reads:

"Correlations between the SPMW transformation to densities higher than 27.4 kg m^{-3} in the Iceland Basin and the (a) surface area of 27.3–27.5 kg m^{-3} in the Iceland Basin, and (b) buoyancy flux over the surface area of 27.3–27.5 kg m^{-3} in the Iceland Basin. The dependence between the surface area and the buoyancy flux was removed to compute their correlations with the SPMW transformation. All correlations are computed using winter values (December to April)."

Minor comments

Figure 1(a): Labelling the isopycnals would help with identification. I assume that the darker shading is for greater sea surface density, but a greyscale colourbar would also help. Also, I assume that the black lines define the study domain described in lines 150--152 but stating this would be useful.

The isopycnals are now labelled in Figure 1a and the greyscale and domain of study have been better described in the caption, which now reads:

"Sea surface density (kg m^{-3}) averaged over winter (December to April) 1980–2019; contour interval is 0.1 kg m^{-3}. Dark grey shows dense surface water of σ_θ > 27.7 kg m^{-3} in the Irminger Sea. White dashed lines outline the isopycnals 27.3 and 27.5 kg m^{-3}. The OSNAP East section, divided into 7 coloured subsections, forms the southern boundary of our closed domain. The northern boundary is indicated by black lines."

Figure 1(b): This is a nice, clear plot and the descriptive caption and colour matching with Fig. 1(a) makes it very easy to understand.

Figure 1(c): A little more description in the caption would be helpful, e.g, 'Surface area (m^2) between the 27.3 and 27.5 kg m^-3 isopycnals over the Iceland Basin in January'

Done.

Lines 150--160: I'd be interested to know what the area of the study domain is, and how the surface area varies as a percentage of this domain.

The total area of the study domain is 9.13 10^{11} m^2. Thus, the mean surface area of the source water represents 40.2% of the total area and varies by 16.8%. It is now indicated in lines 150-160:

"The mean surface area of the source water over the Iceland Basin is 3.67×10^{11} m^2 (40.2% of the total area in the study domain) and is highly variable over the period 1980–2019, with a standard deviation of 1.53×10^{11} m^2 (Fig. 1c)."

Lines 164--166: Is the gyre boundary defined as the largest closed contour within a defined region?

We defined the gyre boundary as the largest closed contour over the entire subpolar gyre, without defining a specific region. The sentence is now clarified:

"Following previous work, the gyre boundary is defined as the largest closed contour of the monthly SSH field with 1-cm contour intervals over the subpolar gyre (Foukal & Lozier, 2017)."

Figure 2 (a):

- **Isn't W m^{-2} a unit of heat flux rather than buoyancy flux? I appreciate that it is common practice to map buoyancy flux to heat flux (see Figure 5.15 from Talley et al., 2011, see attached PDF) but if this is the case could it be stated explicitly.**
- **shouldn't positive heat/buoyancy flux lead to density loss (see Figure 5.15 caption)?**
- **The magnitudes of the buoyancy/heat flux seem very small, compared to those shown on this figure.**

I understand what the plot is showing from the descriptions in the text, but I'm somewhat confused by the plot itself. Some clarification would be appreciated.

Contrary to Talley et al. (2011), the buoyancy flux in Figure 2a is estimated following equation 1, the term in square brackets, and thus is in W m^{-2}. We apply the thermal expansion coefficient a to the net heat flux and invert the signs so that a positive buoyancy flux leads to a densification of the surface water. The term is then integrated over the surface area of a density bin to estimate transformation across the associated isopycnals, with positive transformation leading to a densification of the surface water.

We clarified the caption of Figure 2a, which now reads:

"Figure 2. (a) Buoyancy flux (W m^{-2}) and (b) potential vorticity (m^{-1} s^{-1}) averaged over the source density area in the Iceland Basin. Positive buoyancy flux leads to a densification of the surface water (term in square brackets in Equation 1). The isopycnals 27.3 and 27.5 kg m^{-3} do not outcrop over the Iceland Basin during summer. The dashed black line shows the potential vorticity 4×10^{-11} m^{-1} s^{-1}."

Lines 174--179: Saying buoyancy loss/gain rather than flux would be clearer.

Done. The sentence now reads:

“The 2014–2015 winter stands out among these profiles, as it is marked by both the strongest buoyancy loss (8×10^{-6} W m^{-2} in December; Fig. 2a) and the deepest SPMW (600 m in March; Fig. 2b). Conversely, the 2016–2017 winter is associated with a weak buoyancy loss (4×10^{-6} W m^{-2} in December) and a shallow SPMW (250 m in March).”

Lines 177--201: The approach here is convincing, comparing both SPMW thickness and surface area to buoyancy forcing. I think stating an explained variance of less than 30% is fine and would strengthen the argument further, given that R^2 = 0.27.

Done. The sentence now reads:

“Though a strengthening of the buoyancy forcing generally leads to an expansion of the surface area, the buoyancy flux in a given winter explains less than 30% of the surface density change in the Iceland Basin.”

Lines 201--203: It could be argued that 27% is sufficient contribution by buoyancy flux to surface density changes for them not to be regarded as independent, but I think the sensitivity experiments address this satisfactorily.

Figure 3: The (c-e) and (d-f) labels are a bit misleading, as (c-e) looks like (c, d, e) to me. I would prefer to see (c, e) and (d, f). Are these the same plots just zoomed in on the study domain and with slightly different scales? It might be helpful for the caption to say so.

Done. The caption now reads:

“(c, e) Variance in buoyancy flux (W m^{-2}) in winter, with (e) a zoom of (c) over the study domain. (d, f) Distribution of the interannual variability in SPMW transformation (Sv), with (f) a zoom of (d) over the study domain.”

Line 227: The almost inverse visual relationship of buoyancy flux and surface area variability within the study domain (Fig. 3 (e) and (f)) is interesting and supports the conclusion in 232--234.

Line 335: Isn’t ‘a large surface heat loss’ another way of saying a large buoyancy flux? Would this suggest investigating the relationship between the buoyancy flux of the previous winter with the SPMW transformation of the current winter (i.e., a one-year lag) as an additional contributor?

Indeed, an interesting follow-up study could investigate the indirect effects of buoyancy flux by considering a one-year lag for its local effects (remnant dense water formed by large buoyancy flux inside the study area during previous winters) and its remote effects (the advection of dense water formed by large buoyancy flux outside the study area during previous winters).

Yours sincerely,

Emma Worthington

References:

Talley, L.D., Pickard, G.L., Emery, W.J. (Eds.), 2011. Descriptive physical oceanography: an introduction, 6th ed. ed. Academic Press, Amsterdamâ□¯; Boston.