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Supporting Information for

On the origin of Water Masses in the Beaufort Gyre

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Introduction

Validation of the 1/12° NEMO model, based up on satellite altimetry (Armitage et al., 2016) has already been performed in the Arctic Ocean (Kelly et al., 2018). Modelled sea surface height (SSH), observed SSH and the model's barotropic streamfunction were compared to demonstrate that the modelled circulation is generally in agreement with observations. Here, we expand on that work by investigating the spatiotemporal variability of modelled SSH compared to the same observational dataset. We perform Empirical Orthogonal Function (EOF) analysis over the period 2003-2012 to compare to the EOF analysis presented in Figure 8 of Armitage et al (2016) and hence further validate the performance of NEMO in the Arctic Ocean. Additionally, we present the NEMO modelled mixed layer depth (1979-2012) for comparison with Peralta-Ferriz and Woodgate (2015) as extra validation to support the analysis undertaken in the main part of this paper.

Supporting information:

S1: Validation of Arctic SSH Spatiotemporal variability

Validation of the 1/12° NEMO model, based up on satellite altimetry (Armitage et al., 2016) has already been performed in the Arctic Ocean (Kelly et al., 2018). Modelled sea surface height (SSH), observed SSH and the model's barotropic streamfunction were compared to demonstrate that the modelled circulation is generally in agreement with observations.
Here, we expand on that work by investigating the spatiotemporal variability of modelled SSH compared to the same observational dataset. We perform Empirical Orthogonal Function (EOF) analysis over the period 2003-2012 to compare to the EOF analysis presented in Figure 8 of Armitage et al (2016) and hence further validate the performance of NEMO in the Arctic Ocean.

Figure 8 of Armitage et al (2016) shows that the dominant non-seasonal mode of variability is characterized by an out of phase relationship between the Beaufort Gyre region and the East Siberian and Laptev Seas especially close to the coast. Little to no variability in the Kara and Barents seas is accounted for in this mode.

To validate the interannual variability in SSH, we performed EOF analysis of the modelled annual mean SSH fields (annual means to remove the seasonality) between 2003 and 2012. Only data from the region south of 81N (so as not to consider regions not observed by satellite) and excluding data between 20E and 90W (to remove the North Atlantic) were considered.

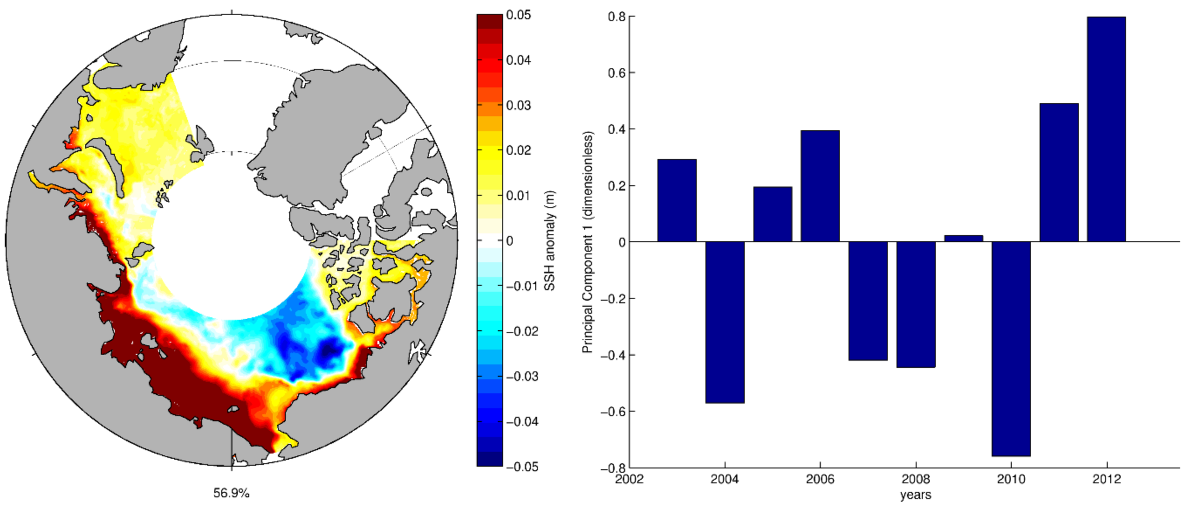

***Figure S1**: 1st mode of EOF analysis of modelled SSH, 2003-2012. This mode describes 56.9% of the modelled variability*.

From Figure S1, we see that NEMO produces a similar pattern in spatiotemporal variability. We note that, as in the Armitage dataset, the main mode of variability shows an out of phase relationship between the Eastern Eurasian shelf seas and the Beaufort Gyre region. As with the Armitage analysis, we see little variability in the Barents Sea. The immediate vicinity of the coastlines in both the Kara and Beaufort Seas are in phase with the East Siberian and Laptev in our analysis, whereas they appear neutral in this data set. Aside from this discrepancy, NEMO shows agreement with Armitage et al (2016).

S2: Validation of Mixed Layer Depth

Peralta-Ferriz and Woodgate (2015) conducted an extensive study of observed mixed layer depth (MLD) throughout the Arctic Ocean between 1979 and 2012. For validation purposes pertinent to the results presented in this paper, we compare our modelled mixed layer with the those observations.

To do this, we took the September and March mean mixed layer depths between 1979 and 2012, and averaged them to produce the figure below:

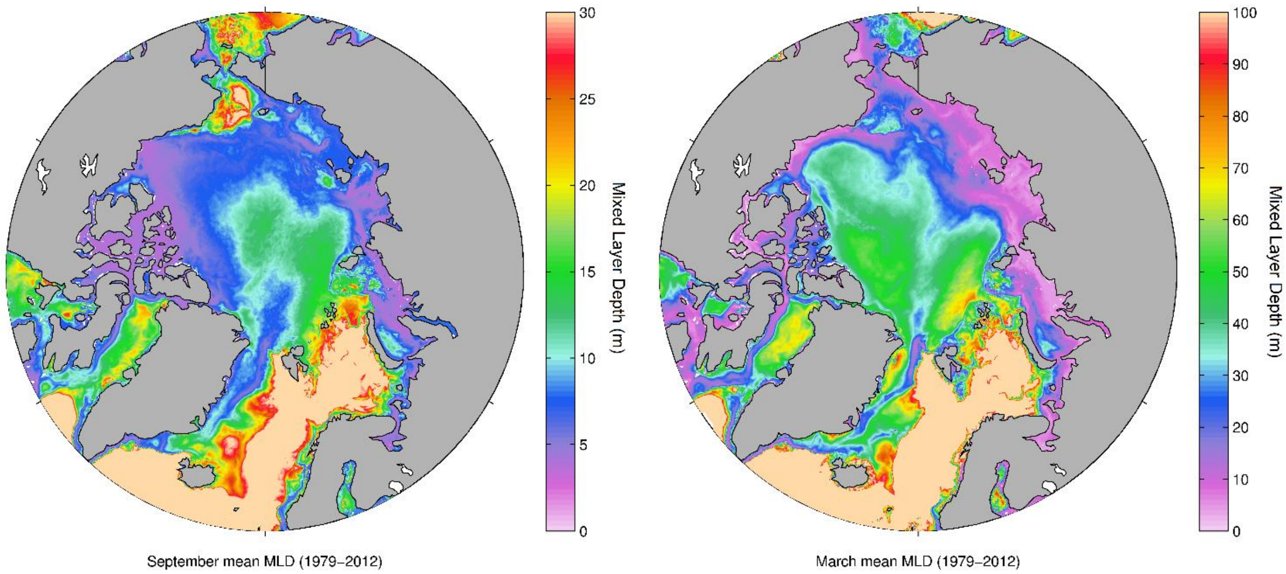

***Figure S2**: NEMO modelled monthly mean mixed layer depth (m) for September (left) and March (right), averaged over the period 1979-2012, as in Peralta-Ferriz and Woodgate (2015). Note the different color scales in each case.*

This can be directly compared to Figure 14 of Peralta-Ferriz and Woodgate (2015). They divided the Arctic into six regions: Chukchi Sea, Southern Barents Sea, Canada Basin, Makarov Basin, Eurasian Basin, and Barents Sea. In each region, a typical summer and winter MLD is quoted. We compare these values with those shown in Figure S2.

Chukchi Sea

Peralta-Ferriz and Woodgate (2015) quote the Chukchi Sea MLD as 12m (summer) and 35m (winter). The modeled winter mixed layer depth is in reasonable agreement, with the cyan region corresponding approximately to the 35m derived from observations. However, parts of the Chukchi Sea show an MLD shallower than 20m (purple regions). The modeled summer MLD varies between approximately 15m (greens) to 30m (reds). In small patches in the south of the Chukchi Sea, the summer MLD is deeper than the winter MLD, however the overall pattern agrees with the observations of a deeper winter mixed layer. This region was unobserved in Peralta-Ferriz and Woodgate (2015).

Southern Beaufort Sea
The observed MLD is quoted as 8.5m (summer) and 29m (winter). The modeled summer MLD varies between approximately 3m (purple) and 10m cyan, whereas the winter MLD varies from <10m at the coast to 30m at the shelf slope.

Canada Basin
Here, the MLD was observed at 9m (summer) and 33m (winter). From Figure S2, the NEMO modeled summer MLD is 5-10m in the Canada Basin, and the winter MLD is 30-45m.

Makarov Basin
Peralta-Ferriz and Woodgate recorded MLDs of 16m (summer) and 52m (winter). In NEMO, we found a small underestimate (10-15m) during the summer, and good agreement (40-60m) during the winter.

Eurasian Basin
In the Eurasian Basin, the observed mixed layer depths were 22m (summer) and 73m (winter). As with the Makarov Basin, this is slightly underestimated by NEMO during the summer (typically 10-20m). During the winter, the modeled MLD in the Makarov Basin varies between 40m towards the Lomonosov Ridge and 80m towards the Barents Sea.

Barents Sea
Finally, Peralta-Ferriz and Woodgate quote MLD values of 18m (summer) and 170m (winter) in the Barents Sea. Figure S2 shows the Barents Sea as saturated (>30m in summer, >100m in winter) in order to allow for easier comparison of the other regions. NEMO overestimates the summer MLD compared to Peralta-Ferriz and Woodgate at 30-50m, although the winter MLD of 150-250m is in better agreement with the observations.

In summary, aside from over-estimates of the summer MLD in the Chukchi and Barents Seas, the modeled mixed layer depth in NEMO is in good agreement with the observations presented in Peralta-Ferriz and Woodgate (2015).