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Discussions

Interactive comment on "Structure and drivers of ocean mixing north of Svalbard in summer and fall 2018" *by* Zoe Koenig et al.

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This manuscript presents a particularly interesting set of turbulence observations from north of Svalbard in the Arctic that cover the 2018 summer and autumn period. The authors investigate the vertical structure of mixing, heat fluxes and seasonal changes, and identify the processes driving the variability in the turbulence field. Both the wind and tidal supplies of energy are estimated with parameterizations derived and discussed. An attempt to extrapolate to the whole Eurasian Basin is made and interesting areas are identified that could be investigated in further work. The current lack of turbulence measurements in the Arctic is highlighted as the main limitation to pan-Arctic parameterization as well as the difficulty in accounting for lateral processes and fluxes, and for extreme events such as storms. The quality of the English in the text is excellent. The

Abstract and Introduction are good, the Data & Methods and Observations sections are excellent. The Upper layer Dynamics section is fine. The section on Mixing in the AW layer is very interesting. The Tidal Mixing section presents a very nice analysis and tools. The Discussion is hard to link to this particular study's findings. The Summary section is excellent. The figures are excellent and have great detail. It was a pleasure to read through this work.

Thanks for these comments

Major comments: -Introduction: Sort out the introduction part on the various sources and intensity of turbulence in the Arctic (see individual comments further down).

Agreed. We rearranged the introduction as suggested below

-Discussion: Currently the discussion section reads in parts (see individual comments) more like a literature review than a discussion around how your findings fit in current research and their wider impact and implications. You have excellent results and just need to rewrite this section a little. In its current form, the manuscript is already very good and presents a trove of findings for this region on the topic of turbulence. However, the manuscript would benefit from some sorting in parts, better highlight of key findings throughout (done well in the Summary), and better framing of this study's results in the discussion. I recommend that the manuscript is accepted subject to minor revision and look forward to seeing a revised version.

We have rearranged the discussion as suggested below

Individual comments Abstract: - Well written overall. The first sentence could do with rewriting to better reflect the beginning of your introduction. Right now you fit too much in that sentence and loose some of the meaning.

We changed the first sentence of the introduction: 'The Arctic Ocean has major implications on global scale as the Arctic Ocean is a main sink for heat and salt. Ocean mixing contribute to this sink by mixing the Atlantic and Pacific-origin waters with surrounding

waters.'

1.Introduction: - L23: You state 'In the near future we may enter a new regime, in which the interior Arctic Ocean is entirely ice free in summer and sea ice is thinner and more mobile in winter'. I would argue that 'may' here is inappropriate and 'will' is more suitable. 'May'creates doubts around the likelihood of this happening. Please rephrase to better reflect current research findings such as the latest estimate from Guarino et al. (Guarino,M., Sime, L.C., Schröeder, D. et al. Sea-ice-free Arctic during the Last Interglacialsupports fast future loss. Nat. Clim. Chang. (2020). https://doi.org/10.1038/s41558-020-0865-2) of 2035 for first ice free summer, or average from CMIP6 models of 2046 with a range of roughly 2030-2065.

We changed 'may' to 'will' and we added the reference Guarino et al., 2020

- L31-37 and L38-46: In both these paragraphs, you describe the various sources and intensity of mixing in the Arctic. These two sections could do with merging and a better ordering of the different sources and intensity discussed.

We merged the two paragraphs and we ordered better the sources and intensities. We also removed part of the description of the sources and intensities as we found that it did not serve the rest of the manuscript.

- L65: Consider adding the following reference somewhere here: 'The lack of sea ice is mainly due to heat from the Atlantic layer reaching the surface'. Duarte, P., Sundfjord A., Meyer, A., Hudson, S. R., Spreen, G., & Smedsrud, L. H. (2020). Warm Atlantic water explains observed sea ice melt rates north of Svalbard. Journal of Geophysical Research: Oceans, 125, e2019JC015662. https://doi.org/10.1029/2019JC0156622.

We added the reference

2.Data and Methods: - L105: Unclear what 'In total, we collected 31 profiles.' Do you mean ship CTD profiles? Or VMP profiles or ? This doesn't match other number of VMP profiles stated earlier in the manuscript.

Thanks for spotting this mistake. We deleted this sentence

- L126: Pls define 'g' in equation (4) if not previously defined.

We added the definition of g: 'where alpha and beta are respectively the thermal expansion and salinity contraction coefficients, and g is the gravitional constant.'

L129-130: You state here that 'We used the profiles collected from the ship's CTD system (Sea-Bird Scientific,SBE 911plus on both cruises) to check and correct the temperature and salinity from the VMP'. But earlier on L107 you state 'A good agreement was observed and no correction was made.'. Please rewrite to make both statement consistent.

Thanks for pointing it out. We deleted 'correct' in the first sentence.

3.Overview of observations: - L172-173: Unsure you need this statement here considering you have explained it clearly it in the figure caption.

Agreed. We deleted this sentence

- Figure 3: Add what the red line is MLD in the caption.

We added in the caption that the (now) green line is the mixed layer depth.

4. Upper layer dynamics: - L252: Add the definition of Dml in the text. Currently it only appears in Fig.6 caption. Can you make it clearer in the text how you obtained your estimate of the relationship between Dml and E10: it's a linear fit of Dml from the VMP data and E10 from the shipwind speed measurements.

We added the definition of Dml and clarify that we apply a linear fit

5. Mixing in the Atlantic Water layer: - L264: Should 'in present conditions of a warming Arctic' not be 'in the new conditions of a warming Arctic'?

Changed as suggested.

- Fig.7 is great

Thanks!

- L274-275: This statement is confusing ‘vertical turbulent heat fluxes are negative(less than 5Wm-2)’ You might want to rephrase to ‘vertical turbulent heat fluxes are negative (0 to -5Wm-2)’

Changed as suggested.

- L282: Which section are you speaking about when you say ‘...the heat loss due to vertical turbulent heat fluxes is about... across the section’?

We are talking about the cross-isobath section. We agree that ‘across the section’ is more confusing than helpful and we deleted it.

- L282-285: Why is your estimate of heat loss due to vertical turbulent heat fluxes(1.2x10ËĘ5 W/m) so much lower than Kolas estimates from the same cruise (9.1x10ËĘ7W/m and 9.6x10ËĘ6 W/m)?

Here we estimate the heat loss only due to vertical turbulent heat fluxes. Kolås et al. (2020) estimate the along-path change of heat content, that takes into account not only the vertical turbulent heat fluxes but also the other fluxes that can impact the heat content.

6. Tidal mixing: - Fig. 8 caption: ‘Average profiles of a) dissipation rate, b) turbulent heat flux and c) diapycnal diffusivity k for small’ Also add Espi and F_H after the variable’s names.

Done

- L326-366: Nice analysis of the vertically integrated dissipation rate in bottom 250m.

Thanks

7. Discussion: - Fig.10 caption: I suggest removing the first word ‘Typical’. Also, what is the back-ground shading on the small map, topography? This map is useful and

should be listed in the caption.

‘Typical’ reinforce the idea that we use u_rms. The background shading on the small map is topography, we added this information in the caption.

- L358: Subsection title ‘Pan-Arctic estimates of tidally-driven dissipation rates’ is not representative of results presented which are ‘instead of presenting Arctic-wide maps we concentrate on the Eurasian Basin from north of Svalbard into the East Siberian Sea’. Please change section title to represent better the content. Also edit L355 in the previous section announcing the ‘pan-Arctic estimate’.

We changed the title of the subsection to ‘Estimates of tidally-driven dissipation rate in the Eurasian Basin’ and we edited l.355: ‘An Eurasian-basin coarse estimate will be given ...’.

- L398-405: Great findings.

Thanks

- L410: Rephrase sentence ‘In the future, sea ice meltwater is expected to increase and turbulent mixing near the surface to decrease’ to better justify/explain the expected decrease in mixing (due to increase stratification). - L 423: ‘and an earlier onset of stratification which might be indirectly linked to bloom development’...due to.... Please add details. - Section 7.2: I m unsure about the contribution your results make in this theme of ‘impact of meltwater on the near surface mixing’. Consider better linking to your observations or moving this section as context in your introduction in a condensed form.

We agree that this discussion is not really relevant to our analysis. We deleted section 7.2.

- L433: I m unsure about how this statement ‘Vertical turbulent heat fluxes are not the main source of cooling of the Atlantic Water layer in the Arctic. Ivanov and Timokhov (2019) reviewed that from the Yermak Plateau to the Lomonosov ridge, 41% of the

Atlantic Water heat is lost to the atmosphere, 31% to the deep ocean and 20% is lost laterally.' fits with the previous 'heat loss due to turbulent vertical mixing represents less than 10% of the total heat loss of the Atlantic Water' . Would the 10% not be part of the 31% deep ocean and 20% laterally? You seem to imply they are different when you state 'Vertical turbulent heat fluxes are not the main source of cooling of the Atlantic Water layer in the Arctic'. Please tidy up these two paragraphs so the reader can follow your thoughts. Again, further down you discuss eddies and their roles. But is the heat export from eddies not included in the 20% lost laterally from Ivanov and Timokhov (2019)?

Yes, you are right. We are mixing different informations. We found that turbulent vertical mixing represents less than 10% of the total heat loss of the Atlantic Water layer, but indeed we do not specify where the heat is lost, so these 10% are not to be compared with the percentages from Ivanov and Timokhov (2019). We changed the sentence: ' Ivanov and Timokhov (2019) estimated that from the Yermak Plateau to the Lomonosov Ridge, 41% of the Atlantic Water heat is lost to atmosphere, 31% to deep ocean and 20% is lost laterally. Heat loss resulting from vertical heat fluxes contributes to the heat loss to atmosphere and to deep ocean, but not to the lateral heat loss. '

- L444 and 445: The numbers you quote there (10ËĘ-8 and 40W/mËĘ2), are they from Kolas and Fer or from this study? Again, how does this section of the discussion(7.3 AW heat loss) exactly links with your findings. Currently this reads a lot like an (excellent) literature review, rather than you putting your new findings in context...

These numbers were from Kolås and Fer. We agree that this section looks more like a literature review, and we tried to better put our new findings in context. We mainly changed the last 2 paragraphs:

'West of Svalbard, Kolås and Fer (2018) found that the measured turbulent heat flux in the WSC was too small to account for the cooling rate of the Atlantic Water layer, but reported substantial contribution from energetic convective mixing of an unstable

bottom boundary layer on the slope. Convection was driven by Ekman advection of buoyant water across the slope, and complements the turbulent mixing in the cooling process. The estimated lateral buoyancy flux was about $10-8$ W kg-1 (Kolås and Fer, 2018), sufficient to maintain a large fraction of the observed dissipation rates, and corresponds to a heat flux of approximately 40 W m-2. We can expect similar processes to extract heat and salt from the Atlantic Water core north of Svalbard. Such processes can explain why turbulent heat fluxes are only responsible for 10% of the Atlantic heat loss north of Svalbard. Furthermore, large heat loss during extreme events should not be ignored. For example, Meyer et al. (2017) found that the average heat flux of about 7 W m-2 across the 0âŮęC isotherm increased during storms, exceeding 30 W m-2. During our survey without extreme wind events, the turbulent heat fluxes represent only a small portion of the heat loss of the Atlantic Water.'

8. Summary: - L459-460: Consider adding 'The vertical decay scale of the diffusivity is 22m *for those strong tidal currents*, compared to 18m for weaker tidal currents.'

Thanks, done

- L470: Consider adding details 'More in situ observations from different sites *in the Eurasian Basin and elsewhere in the Arctic* are needed to confirm our results.'

Thanks, done

- L475: Can you add 'of the *expected/estimated* total heat loss of the Atlantic Water layer'.

We added 'estimated'

- L475-476: Can you explain better the relation between the first part of the sentence and the later part? I understand you mean to say that increased vertical mixing during storms might partially close the budget but don't make up the whole 'missing' heat loss which might be mostly lateral fluxes. So that both lateral fluxes and extreme conditions such as storms, frontal systems etc should be investigated. But this will not super clear

in the current form of the sentence.

We reformulate the last sentence: ‘Increased vertical mixing during storms would add to this figure. However, integrated studies addressing lateral mixing processes, frontal systems as well as extreme conditions such as storms are needed to close the heat budget in this region.’

Please also note the supplement to this comment:
https://os.copernicus.org/preprints/os-2020-77/os-2020-77-AC1-supplement.pdf

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