

Response to review comments to 'Impact of tidal dynamics on diel vertical migration of zooplankton in Hudson Bay' from Anonymous Referee # 3

We highly appreciate helpful comments and suggestions from Anonymous Referee #3. In the following, *the comments by the reviewer are in italics* and our responses to the comments are in normal characters. The revised manuscript text is underlined. **The line numbering (in bold)** is referenced to the marked-up manuscript version.

General

This work exploits acoustic data from an ADCP moored over an annual cycle, backed with zooplankton identification in sediment trap samples, to document the seasonal dynamics of zooplankton DVM at a seasonally ice-covered site in Hudson Bay. The data analyses sound complete but the highlighted results do not seem particularly novel in the way they are presented. Maybe one approach to deal with this perception is to work on a more thorough comparison of the patterns observed in Hudson Bay with other regions.

Hudson Bay is a very interesting and unique seasonally ice-covered region that was in general not sufficiently studied. Being one of the largest inland seas, there were very few studies on zooplankton composition and behaviour (Estrada et al., 2012; Runge and Ingram, 1991). While the phytoplankton and zooplankton assemblages in Hudson Bay resemble those in the Arctic Ocean, another unique feature that we discuss in our paper is interaction of zooplankton and particularly DVM with the strong tides that are characteristic of Hudson Bay.

More in-depth interpretation of the linkages between the acoustic observations and zooplankton biology would also help this work. In particular, tidal effects on DVM seem to be emphasized by the title but this does not appear that well in the Discussion.

Thank you for pointing out the importance on the emphasis on tidal dynamics on DVM. In this paper we tried to analyze the zooplankton response to spring tide from the acoustic VBS data. The possible interpretation was that the barotropic tide interacts with bottom topography generating tidal flow diverging and converging vertically. It seems that zooplankton tends to avoid spending additional energy swimming against the vertical flow. This response of zooplankton is consistent with the zooplankton tendency to stay away from the layers with enhanced water dynamics and to adjust its DVM accordingly, which we previously observed in Young Sound fjord in NE Greenland when there was polynya induced circulation in the fjord.

We attempted to cover the tidal background in Hudson Bay in introduction (**lines 73-75**), then in results we presented the tidal effect on VBS signal (**lines 178-179**), vertical velocity actograms (**lines 201-205**), wavelet analysis (**201-221**), discussion (**lines 335-358**) and conclusion (**lines 373-377**).

The structure of the manuscript needs to be better strengthened as there are pieces of different sections that should belong to other ones, as detailed in the specific comments. The title takes into account only one aspect addressed by this work. There is also an important issue that should be addressed either in the Introduction of

the Discussion: is the trap a valid way to identify the scatterers?

Sediment traps were successfully used for qualitative assessment of the species responsible for acoustic backscatter (Berge et al., 2009; Cottier et al., 2006; Ota et al., 2008; Wallace et al., 2010; Willis et al., 2006, 2008). It is an accepted and recommended practice to simultaneously use samples collected by sediment traps to better understand acoustic instruments backscatter signals (Makabe et al., 2016).

The sediment trap captures sinking zooplankton. There is a low probability that as the zooplankton sink they would reverse and search for a way out. When compared to literature on zooplankton in Hudson Bay (see Estrada et al. 2012), the species collected within this sediment trap are representative of the zooplankton community we would expect to find in this system. Gelatinous zooplankton recorded by Estrada et al. 2012 also occurred in the zooplankton samples, however, at low numbers (data not shown). It is possible that gelatinous species are underestimated due to issues associated with preservation. This is noted at **lines 244-251, 273-287** in the paper.

We revised the introduction of the Discussion adding the following lines:

Lines 282-287. The zooplankton caught in our sediment trap provide general information on the zooplankton community composition and its change over the course of the year near the mooring location. Sediment trap samples may not quantitatively reflect zooplankton composition in the water column due to species-specific collection efficiencies. Comparisons between net and trap samples from Franklin Bay indicate that the abundance of *L. helicina* and some species of copepods could be estimated from sediment traps whereas the abundance of other key species, such as *C. hyperboreus*, could not be accurately estimated from sediment trap samples (Makabe et al., 2016).

Specific comments

Title

The title does not reflect the scope of this work properly since the tidal effects was only one part of the Discussion

Besides mentioned portion of the Discussion, we covered the tidal background in Hudson Bay in introduction (**lines 76-78**), then in results we presented the tidal effect on VBS signal (**lines 183-184**), vertical velocity actograms (**lines 206-212**), wavelet analysis (**215-228**) and conclusion (**lines 402-406**).

Abstract

Line 13-14: Give the information on potential migrators instead of telling that they could be identified.

Thank you for this suggestion. We have added the following lines to the abstract:

Lines 13-15: The sediment trap collected five zooplankton taxa including two calanoid copepods (*Calanus glacialis* and *Pseudocalanus* spp.), a pelagic sea snail (*Limacina helicina*), a gelatinous arrow worm (*Parasagitta elegans*) and an amphipod (*Themisto libellula*).

Line 14: "migrating scatters"? what does that mean? How can a scatter migrate?

Corrected. Thank you for pointing this typo. We have changed to migrating scatterers.

Introduction

Line 20: I would remove “synchronized” from the sentence, as DVM doesn’t have to be synchronized to transport C and N to depth. Furthermore, “synchronized” is used in the following sentence that explains DVM.

Thank you for pointing it out. We have revised the beginning of introduction:

Lines 21-22: The diel vertical migration (DVM) of zooplankton is a synchronized movement of individuals through the water column and is considered to be the largest daily synchronized migration of biomass in the ocean (Brierley, 2014).

Line 28: Explain better why this question needs to be addressed

We added the lines in introduction on general DVM patterns (lines 30-35).

Lines 30-35: There are three general DVM patterns: (1) The most common one is *nocturnal* when zooplankton ascends around sunset and remains at upper depth during the night, around sunrise descending and remaining at depth during the day (Cisewski et al., 2010; Cohen and Forward, 2002). (2) Then there is a *reverse* pattern when zooplankton is ascending up at dawn and descending at dusk (Heywood, 1996; Pascual et al., 2017). And finally, (3) there is *twilight* DVM pattern when zooplankton is ascending at sunset, then descending around midnight, then again ascending and finally descending at sunset (Cohen and Forward, 2005; Valle-Levinson et al., 2014). This pattern sometimes is called *midnight sink*.

Line 39: remove “to” after “help”

Corrected (**line 49**)

M&M

Line 79: It is “Macrozooplankton” we are talking about here and not “Microzooplankton”

Thank you for pointing out that typo. Sure, we are not talking about microzooplankton. The samples collected in the sediment trap represent both mesozooplankton (0.5-2mm for our samples) as we macrozooplankton (>2 mm, e.g. the *Parasagitta elegans*).

Line 80: “Parasagitta” instead of “Sagitta”

Thank you for pointing out that typo. Corrected

Lines 83-85: This information does not fit in here in the description of the study area.

The authors should find a more proper place to use it if needed. The whole paragraph on zooplankton should be moved somewhere else.

We just follow similar introduction style like used in Estrada et al., 2012 and Harvey et al., 2001, where after physical description of the sampling site there is given info on zooplankton community composition in Hudson Bay.

Estrada, R., Harvey, M., Gosselin, M., Starr, M., Galbraith, P. S. and Straneo, F.: Late-summer zooplankton community structure, abundance, and distribution in the Hudson Bay system (Canada) and their relationships with environmental conditions, 2003–2006, Prog. Oceanogr., 101(1), 121–145, doi:<https://doi.org/10.1016/j.pocean.2012.02.003>, 2012.

Harvey, M., Therriault, J.-C. and Simard, N.: Hydrodynamic Control of Late Summer Species Composition and Abundance of Zooplankton in Hudson Bay and Hudson Strait (Canada), *J. Plankton Res.*, 23(5), 481–496, doi:10.1093/plankt/23.5.481, 2001.

Line 92: the sampling area of this trap is very small and may cause a bias in zooplankton catching toward the smaller individuals that need to be addressed.

This is a valid concern, but we should mention, that regardless of its compact size the trap caught a wide range sizes, including large shrimp and long zooplankton. Sediment traps are designed to capture the sinking flux of material from an area above the trap. Based on previous assessments of zooplankton in Hudson Bay, larger expected species (e.g., *Parasagitta elegans*) were present in the trap.

Line 137: a citation is needed to back the information on the size fraction effectively sampled by the ADCP

Thank you for this note. Corrected, added (Cisewski and Strass, 2016; Pinot and Jansá, 2001)

- “*Motoda*” instead of “*Motodo*”

Thank you for pointing out that typo. Corrected

Results Line 143: Does that mean that in a matter of a few days, the ice thickness reached 0.4 m?

Yes, that’s what happening normally in HB. Figure 2 shows that it took about a week for the ice to reach that thickness. Oceanic heat in the Bay delays ice growth, and from the onset of ice formation air temperatures are very low.

Line 145: remove “the” Line 146: replace “were” by “are”

Thank you for pointing these typos, we got them corrected.

Line 154: replace “scatters” by “scatterers”, here and elsewhere.

Thank you for pointing it out, we have corrected in the manuscript.

This sentence is a piece of the Methods and would fit better in the previous section.

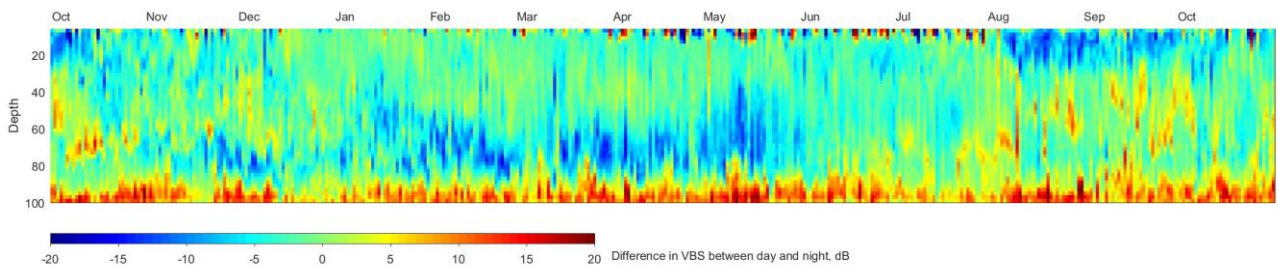
We would agree that it might be more appropriate in the methods, but in methods we described a general idea of calculation of volume backscatter strength, and here we are presenting a specifically applied results (VBS at noon, midnight and actograms).

Line 156: the part on DVM in this sentence is interpretation of Results and would fit better into the Discussion.

Here we just briefly point out the difference between noon and midnight VBS and expand it more in discussion.

Line 158: statistics?

For reviewers' reference we created a graph (below) of difference in VBS between noon and midnight (not included in the revised manuscript).



We have run F-statistics to find statistically significant difference and added to the revised manuscript:

Lines 175-177: The mean difference between noon-time and midnight VBS was $\sim 9 \pm 1$ dB at 96-100m depth layer and $-3 \text{ dB} \pm 1$ at 10-28 m layer. Running F-statistic test returned statistical significance with 95% confidence for VBS difference below 58 m and above 48 m.

Line 160: "midnight bottom scatters layer" by "layer of midnight bottom scatterers"
Corrected

Line 162: "maxima" instead of "maximums"
Corrected

Line 164: remove "observed"
Corrected

Line 166: "shape shows a similar overall shape..." too many "shape" and "overall" here
Changed this passage into:

Lines 187-190: Overall, VBS actograms show a similar shape to that of the under-ice solar illumination actogram (Figure 3i). This resemblance in shape is outlined by reduced VBS at 8 and 20 m actograms (Figure 3d-e) and enhanced at 60, 80 and 92 m actograms (Figure 3f-h) during dawn and dusk.

Line 205: remove brackets
Corrected

Line 208: It is "libellula", not "libellua"
Corrected

Line 208-209: This sentence does not provide results information.

We have moved this section to the discussion (**Lines 272-273**).

Discussion

The first paragraph of a discussion should give justice to the Results and novel knowledge provided by the work and entice the reader to learn more about the issue. I would turn the first sentence differently so that it would not look so much like it emphasizes

the weakness of the ADCP-based method to study zooplankton patterns.

Thank you for this good suggestion. I have added intro sentences to this section as follows:

Lines 238-243: The presence of seasonal ice cover acts as a barrier to using traditional zooplankton sampling techniques. But using both moored or ice-tethered ADCPs in high latitudes had been successful for studying zooplankton presence, behaviour and particularly DVM patterns (Darnis et al., 2017; Hobbs et al., 2018; Petrusevich et al., 2016; Wallace et al., 2010). Even though acoustic backscatter from the single-frequency ADCP does not provide any information on the identity of zooplankton species involved in DVM but signal strength can provide an indication of zooplankton presence provided there is information on the zooplankton species.

Line 215: Studies like the one by Makabe et al (2016) address the issue of the usefulness of sediment trap samples for the description of zooplankton community composition and seasonal change by comparing zooplankton caught in sediment traps with ones sampled by plankton nets. What is found in the trap samples does not necessarily give a good picture of the zooplankton composition in the water column. The trap might miss the importance of scatterers that are not well sampled by the small-aperture trap. Themisto might be quite under sampled by the small trap. Furthermore, traps are known to oversample pteropods that stop swimming and sink when they touch the mooring line. Some change in behavior influencing the depth range of zooplankton will also have an impact on trap catching efficiency. This has to be kept in mind and mentioned.

Makabe, R., Hattori, H., Sampei, M., Darnis, G., Fortier, L., Sasaki, H., 2016. Can sediment trap-collected zooplankton be used for ecological studies? Polar Biol., doi:10.1007/s00300-00016-01900-00307.

Thank you for pointing this out I have restructured and added the following paragraph:

Lines 282-287: The zooplankton caught in our sediment trap provide general information on the zooplankton community composition and its change over the course of the year near the mooring location. Sediment trap samples may not quantitatively reflect zooplankton composition in the water column due to species-specific collection efficiencies. Comparisons between net and trap samples from Franklin Bay indicate that the abundance of *L. helicina* and some species of copepods could be estimated from sediment traps whereas the abundance of other key species, such as *C. hyperboreus*, could not be accurately estimated from sediment trap samples (Makabe et al., 2016).

Line 235: DVM patterns have already been documented in another part of Hudson Bay (Runge and Ingram 1991). The authors should give credit to the pioneer study in this paragraph.

*Runge, J.A., Ingram, R.G., 1991. Under-ice feeding and diel migration by the planktonic copepods *Calanus glacialis* and *Pseudocalanus minutus* in relation to the ice algal production cycle in southeastern Hudson Bay, Canada. Mar. Biol. 108, 217-225.*

Thank you for pointing out that good pioneering paper, but it was from a different part of Hudson Bay (coastal areas of South East HB), where there is a significant freshwater inflow, which is different from our mooring location, and they showed a different/additional reason for migration. So, I added this paper to the references in the intro (**line 83**) rather than using it in this section.

Line 245: Well, we do not have the elements of information yet to tell if this pump is important or not. Importance would depend on the real scatterers, and depth and stratification state of the water column.

We have removed the word important.

Line 246: "DVM" and not "DMV"

Corrected

Line 247: "vertical transport of elements" instead of "vertical energy transfer"

Corrected

Line 248: I don't think that it is worth introducing the next sections in that way. Normally a logical suite of sub-sections should be enough.

Or replace by something like : "the acoustic data at hand are not valid to quantify zooplankton biomass involved in DVM. However, we can use them to document and understand better important aspects of DVM, such as: links between its seasonal cycle and dynamics of sea-ice cover and under-ice illuminance, and the effects of wind storms and tides on DVM patterns".

Thank you for this suggestion and we reworded this section following your suggestions.

Lines: 303-309: Regardless, there is a pump of carbon/nitrogen occurring within Hudson Bay based on zooplankton DVM, and seasonal differences (discussed in the next section) could impact this vertical transport of elements. The collected acoustic data at hand are not valid to quantify zooplankton biomass involved in DVM. However, we can use them to document and understand better important aspects of DVM, such as links between its seasonal cycle and dynamics of sea-ice cover and under-ice illuminance, and the effects of wind storms and tides on DVM patterns.

Line 252: "south" instead of "southern location". In any case, this sentence should be rewritten to improve its clarity. Make the message straighter.

Thank you for your suggestion, we have revised this passage as:

Lines 311-314: The mooring site is located 6° south of the Arctic circle and polar twilight zone. Hudson Bay located more south than other seasonally sea-ice covered Arctic and sub-Arctic regions where DVM was observed. In those locations, DVM during the winter was primarily controlled by twilight and the lunar light (Last et al., 2016; Petrusevich et al., 2016).

In general, there are too many figure citations in this section. If the Results section is clearly written, there is no need to cite those figures again. The Discussion should take on from the Results described in the previous section.

We have added to this section dusk and dawn VBS discussion (**lines 317-320**), so it would be convenient to keep the citations to the figures.

Lines 317-320: During dawn and dusk there was reduced VBS at 8 and 20 m actograms (Figure 3d-e) and enhanced at 60, 80 and 92 m actograms (Figure 3f-h). These dawn and dusk absences and enhancements can be interpreted as an indication of zooplankton swimming behaviour during these periods, following nocturnal DVM pattern. The increased backscatter at dawn and dusk at 60 and 80 m actograms was observed regardless the presence of ice cover.

Line 271: by definition, the trap does not measure abundance but a rate of capture or sinking in the case of inert particles. Thus, I fear that it can be too misleading to use the term “abundance” in that case even though it is mentioned that it is the abundance in the trap sample after 35 days of opening. This is because the rate will not necessarily be related to the abundance of organisms in the water column. This is a tricky issue that should be addressed carefully.

We agree that the abundance in the trap should not be understood as abundance in the water column. But it is accepted term being used for sediment trap catches, for example the paper *Makabe et al (2016)* paper you recommended is using term abundance both for net catches and for sediment trap catches. Also Schröter et al., 2019 is using term ‘abundance’ when dealing with sediment trap catches.

Schröter, F., Havermans, C., Kraft, A., Knüppel, N., Beszczynska-Möller, A., Bauerfeind, E. and Nöthig, E.-M.: Pelagic Amphipods in the Eastern Fram Strait With Continuing Presence of *Themisto compressa* Based on Sediment Trap Time Series, *Front. Mar. Sci.*, 6, 311, doi:10.3389/fmars.2019.00311, 2019.

Line 280: one alternate explanation that should be discussed is that of different feeding patterns. Some non-visual predators like chaetognaths might not need to move that much if their zooplankton prey change their migration patterns as well etc..

I have added the passage:

Lines 360-363: An alternative explanation of higher VBS at 8 m depth is a different feeding pattern for non-visual predators like chaetognaths (including *P. elegans*). While mature species are known to perform DVM, in some cases juvenile individuals were found near the surface during the daytime (Brodeur and Terazaki, 1999).

Brodeur, R. D. and Terazaki, M.: Springtime abundance of chaetognaths in the shelf region of the northern Gulf of Alaska, with observations on the vertical distribution and feeding of *Sagitta elegans*, *Fish. Oceanogr.*, 8(2), 93–103, doi:10.1046/j.1365-2419.1999.00099.x, 1999.

Line 281: Is it disruption of masking of the DVM signal? From the interpretation, it is not possible to understand if the storms act on the zooplankton responsible for the DVM patterns, or if other physical action produce backscatter that prevent the visualization of DVM. The paper should relate storms to zooplankton behavior or change the title of this sub-section, which then would much less relevant.

This is a valid point, so we changed the title of that sub-section to: 5.3 Masking of DVM signal in the upper layer by storms (**line 348**).

Line 288: remove "present"

Corrected

Line 291: "amount of" and not "amount in"; "provides" and not "provide"

Thank you for pointing those typos. Got them corrected.

We would like to thank Anonymous Reviewer #3 for all these helpful comments.

Regards,

On behalf of all authors

Vladislav Petrushevich