REVIEWER 1

The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2019-304-RC1, 2020
Interactive comment on "Methane Pathways in Winter Ice of Thermokarst Lakes, Lagoons and Coastal Waters in North Siberia" by Ines
Spangenberg et al.
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This paper describes ice on three distinct water bodies, in particular examining the methane within the ice and the physical properties associated with understanding the observed methane concentrations. I am expert in the growth of ice on water bodies, but not on the suite of chemical techniques involved in the study and my comments below need to be read with this in mind. I believe that the study is interesting and deserves publication but could be made easier for the reader to understand, especially those not already expert in every aspect of the work.

Comment 1: The paper deals with three distinct water bodies which are expected to show different characteristics. Yet there is nothing in their abbreviated names that helps the reader immediately recognize which water body is being described. Why not call the sites Bay, Lake, Lagoon, or some abbreviation that is easily recognizable, such as BY, LK, LG?

> Response: We changed the abbreviated names to Tiksi Bay (BY), Polar Fox Lagoon (LG) and Goltsovoye Lake (LK) throughout the paper. We have also changed the names and numbers of the cores to reflect the water body and sequential geographic position of each core.

Comment 2: In addition a number of cores are taken at each site, and interesting behavior is shown in these data in Figures 3-5. However the naming of the cores could better reflect their position and make it easier for the reader to interpret this behavior– for example the TB cores could be labeled from N to S, while GL cores from E to W.

> Response: we have relabeled the cores but used the abbreviations suggested in the previous comment (e.g. BY-1, BY-2, etc.) always in a uniform manner following compass direction. This has been applied consistently to all figures, the text, online data, and tables. We added the compass directions to the bathymetric profiles as well, to help the reader assign order to direction.

Comment 3: In my opinion there was too much description of the shape of graphs etc at the expense of what the reader might expect to learn from that particular type of behavior in the graph. I understand that the paper is the work of a thesis, but while such description is appropriate for a thesis it extends the length of a journal article unnecessarily. For example, sections 4.2.2, 4.2.3, 4.2.4, 4.3.1 and 4.4.1 give detailed description of what can be seen by looking at Figs 3, 4 and 5, and Table 2. What I wanted to know was what can be scientifically deduced from the observed values of parameters, or form of graphs. I suggest that the authors replace these detailed descriptions with the scientific evidence provided by the particular behaviors.

> Response: We have tried to be strict in separating the reporting of results from their interpretation. The interpretation of the results is therefore only found in the discussion section. We take this comment to mean that the results section is unnecessarily long and we have made numerous edits to shorten the sections mentioned (please see track changes section).

Comment 4: I felt that the authors tended to make rather grandiose statements that were not obviously dealt with in the paper e.g. statements regarding ice as a barrier to methane fluxes and the importance to warming in the Arctic. I suggest that authors carefully consider what can be deduced from their work and focus on the aims of their study.

We agree that there is definitely room for us to hone our objectives, discussion and conclusions in order to be more precise about what we did, why, and what its implications were. Please see our answers below regarding the objectives, discussion and conclusions, where we detail the deletions and editing we have undertaken. We feel the paper has been slimmed down and become more precise in its aim and conclusions.

Comment 5: I do not have the expertise to critically review the chemical techniques used in this paper and whether they are appropriate and carefully carried out. I'm afraid that the editors must seek advice another reviewer for that expertise.

Technical Corrections

p. 1: Abstract: Please rewrite, taking into consideration the Comments above.

Adopted, see track changes version.

p.1, line 3: ".. provide insights on methane pathways in winter ice cover.." But at the end of the paper I had not recognized what these insights were, nor could I find it in the Abstract.

We agree that this was imprecisely worded. We have replaced the 3rd and 4th sentences of the abstract:

"The fate of methane in these waters and is poorly understood. We provide insights into the methane pathways in the winter ice cover on three different water bodies in a continuous permafrost region in Siberia."

with:

"How methane concentrations and fluxes in these waters are affected by the presence of an ice cover is poorly understood. To relate water body morphology, ice formation, and methane, we studied the ice of three different water bodies in locations typical of the transition of permafrost from land to ocean in a continuous permafrost coastal region in Siberia."

p.1, line 10: "except for three"

Corrected.

p. 1, Line 14: Comment that "methane oxidation may decrease methane concentrations during winter" Where? In the ice? In the atmosphere? Both? Is this the evidence for the winter pathway but I have not recognized it?

Response: the sentence has been re-worded and we have added "...on the lower ice surface."

p. 1, Line 14-16: I could not follow how methane pathways in freshwater systems led to the understanding of permafrost carbon feedbacks in global warming – this seemed to be a huge leap to me – but perhaps I show my lack of knowledge of permafrost.

This sentence was deleted.

p. 2, Line 27-28: This is not a sentence

Corrected.

p. 3, Line 20-23: Here the authors clearly outline the three aims of the paper. I am clear that they have achieved the first aim, but I am unclear regarding aims 2 and 3. I return to this comment in the Conclusions.

Response: we agree, and have made the following changes:

P 3 lines 18—22: we have changed the **objectives** of the study to be more precise and focussed, from

"*This study aims to clarify the role of an winter ice cover for methane cycles of three different stages in the lake-lagoon-shelf transition in a region of rapidly thawing permafrost in northeast Siberia. Our objective is to demonstrate how methane is distributed within seasonal ice from Tiksi bay (TB), Polar Fox Lagoon (PF), and Goltsovoye Lake (GL), to better understand 1) how freezing processes differ between the three water bodies, 2) what the relationships between freezing dynamics and methane concentration in the ice are, and 3) the potential importance of methane oxidation in different water bodies.*"

to:

"To improve our understanding of how water bodies function as CH4sources or sinks, this study aims to clarify the role of the winter ice cover for CH4 in three different stages in the lake-lagoon-shelf transition in a region of thawing permafrost in10northeast Siberia. Our objective is to demonstrate how CH4 is distributed within seasonal ice from Tiksi Bay (BY), Polar Fox Lagoon (LG), and Goltsovoye Lake (LK), to better understand 1) how freezing processes differ between the three water bodies, 2) how freezing affects CH4 concentration in the ice, and 3) to gain an indication of which processes change CH4 concentrationduring the ice cover season."

p. 3, Line 20-23: "The Bykovsky.."

Corrected.

p. 4, Line 3: please give approximate depths

Added depth range in parentheses.

p. 5, Table 1: The Table implies that PF had a temperature constant to 0.01 oC over its 4 m depth. I found this unlikely. Please justify.

Response: you are correct. We changed this value to 0.8 °C, which is certainly all that the measuring device allows.

p. 5, Lines 10-16: I don't see the point in telling us about data collected that is not analysed in the article.

We removed references to other studies and their sample material.

p. 5, Lines 15: What does "res" mean?

Typographic error: corrected.

p. 6, Sect 3.2: I think information about transport and storage of the cores is missing (e.g. temperature) and seems as important as other details that are provided.

We added "...transport in the frozen state..."

p. 6, Line 11: Define EC first time used.

Adopted.

p. 6, Line 12: "as soon as possible" is not very specific

Adopted.

p. 7, Line 2: "Slope"

Adopted.

p. 7, Line 23: "100 ppm that were"

Adopted.

p. 7, Line 27: "from the same bottle"

Adopted.

p. 8, Line 14: What is the "ice-free transect area" and why was it needed as scale in the photos?

We apologize for that error, and changed the sentence from:

"*A measurement tape at the side of the ice-free transect area served as scale in the images*"

to

"A measurement tape at the side of the cleared transect area served as scale in the images and to measure the sizes of seeps and bubble types."

which refers back to the clearing of snow from the ice transect.

p. 8, Line 22: What are "the cores of the water bodies"?

Changed to: "We compared variability of measured parameters within each ice core as a function of depth below the ice surface, and between sets of cores from each water body."

p. 8, Line 27: "identified"

Corrected.

p. 8, Line 27: How is regelation ice from snow melt identified?

Added: "...based on the appearance of the ice during sampling."

p. 8, Sect 4.1: Difficult to follow as the reader needs to keep referring to which core numbers are from which site. A sketch of the ice types would reduce the need for detailed description and give a better overall view of the structure of the ice covers.

We have renamed the cores to be explicit about which site they come from and simplified the language in this section.

p. 9, Figure 2: Why does PF look so small on this figure? On Figure 1 no dimension of PH seems to be less than GL? In addition it would be good to label geographic location on the transects, i.e. N, S, NW etc

We have added compass directions to the bathymetric profiles.
PF (LG) appeared so small, because we showed the ice AND water (i.e. most of PF was occupied by ice), but since the ice was shown in white, it sort of disappeared. We have represented the ice with a light gray tone to make this clearer. We also discovered a mistake in water depth for TB (BY) and have corrected this in the figure.

p. 9, Line 2: remove "on"

Adopted.

p. 10, section 4.2.4 & p. 15, 4.4.1: I suggest replacing "stable" with "constant". "Stable" implies "firmly fixed" and I am not sure that this is what you wish to imply. If you do mean "stable" then I think you need to justify why you expect no change under any change in circumstances.

Adopted.

p. 10, Line 12: spelling "composition"

Adopted.

p. 12, Fig 3: It is very interesting that PF is colder than GL. Is this because it is shallower?

We have expanded the discussion of ice core temperature to explain the difference, adding: "In addition, temperature increased towards the bottom of the ice (Fig. 3). The bottom ice offers a protected environment with favourable conditions for microbial metabolism: relatively warm temperatures, contact with liquid water and permeable ice. The latter permits migration of gases and nutrients, similar to marine ice, where most bacteria are located in the lowest centimetres of the ice (Krembs and Engel, 2001). At LG, the bottom ice temperature decreases during the winter. This occurs because the temperature of the underlying water remains in equilibrium with a dynamic freezing point that decreases with increasing salinity when LG is cut off from Tiksi Bay. The ice surface temperature at the time of coring was primarily a function of snow cover and air temperature. The ice coring locations for LG exhibited colder ice surface temperatures and steeper gradients compared to ice coring locations at LK. Ice has a high thermal conductivity and is susceptible to quick temperature changes. Since ice temperatures were also observed for windswept areas at LK, decreasing air temperatures from 8 April 2017 (final LK coring day) to 11 April 2017 (LG coring day) could explain the generally colder ice temperature profiles at LG. "

p. 15, Fig 6 caption: "free". Has the ice free area been marked on Fig 1?

Thank you for finding the error and for the suggestion regarding the overview figure. We also changed "ice-freed" the caption of Fig. 6 to "snow-cleared". The scale in Fig. 1 is too small to allow proper representation; the position of the bubble transect is marked in Fig. 2, to show the overlap to the ice core sites.

p. 15, Line 13-14: Is this statement tested in the present article, or is this speculation to introduce the Discussion?

We have deleted:
"It may act not only as a barrier, but also as a source or sink for methane or as a habitat for microbes that facilitate methane consumption."

p. 16, Line 10-11: It was not at all obvious to me how the data presented showed that the type of water body determines the circulation of methane. Please explain.

We have re-structured and re-written parts of the abstract and conclusions, and hope that we more clearly explain how the data show differences in methane pathways from sediment to ice.

p. 16, Line 15: Suggest replacing "impact" with "setting"

Adopted.

p. 16, Line 18: ". . .(2018), while in winter, when the connection.."

Adopted.

p. 16, Line 26: Why would the freezing velocity be approximately constant? It is likely to decrease as 1/(ice thickness).

The poorly worded point here was that the fractionation primarily reflects the composition of the water beneath the ice, rather than the smaller effect of shifting freezing rate. We have changed the first 2 sentences from:

"*Firstly, in an open system such as TB, the water circulates freely beneath the ice cover, impeding the enrichment of lighter water isotopes in the remaining water. Therefore, the isotope composition of the initial ice should remain more or less constant, and hence also that of the ice with depth (Gibson and Prowse, 1999), assuming the freezing velocity is roughly constant.*"

to:

"Firstly, in an open system such as BY, the water circulates freely beneath the ice cover. The isotope composition of the ice should remain more or less constant over the winter (Gibson, 1999), and reflect the fractionation resulting from freezing of Tiksi Bay water."

p. 16, Line 24-29: The authors note that they have not taken into account the freeze fractionation influences (e.g. see Toyota et al., 2013), based on the assumption that the freezing velocity is roughly constant. If this is not necessary please provide an order of magnitude calculation to convince the reader that this is a small effect.

Toyota, T., I.J. Smith, A.J. Gough, P.J. Langhorne, G.H. Leonard, R.J. Van Hale, A.R. Mahoney, and T.G. Haskell. (2013) Oxygen-isotope fractionation during the freezing of seawater. Journal of Glaciology. Vol. 59, No. 216, 2013 doi:10.3189/2013JoG12J163

Added text:

"Oxygen isotope fractionation during the freezing of sea water has been addressed by Toyota et al., (2013), through laboratory experiments and field observations. These authors demonstrate a general dependency of increasing isotope fractionation with decreasing ice growth rate. Therefore, faster freezing induces less isotope fractionation as compared to slowly formed ice at a later stage of sea ice formation. The difference between both is within 1‰ for a large range of ice growth rates."

p. 17, Fig 7: Very nice helpful sketches. They might be useful earlier in the manuscript.

We consider these sketches to be part of the outcome of the study, which require the explanations given in the discussion. They are based on the results, and were not a priori knowledge of the site or the processes that we would discover.

p. 18, Line 2: "alone"

Deleted.

p. 18, Line 5: "may capture"

Adopted.

p. 18, Line 5-7: Interesting observation that may be compared with the results of Smith et al., (2016). Smith, I.J., Eicken, H., Mahoney, A.R., Van Hale, R., Gough, A.J., Fukamachi, Y., Jones, J. (2016). Surface water mass composition changes captured by cores of Arctic land-fast sea ice. Continental Shelf Research, 118:154-164, doi:10.1016/j.csr.2016.02.008.

Added the text:

"Episodic advection of meteoric water during the winter season was also detected in land-fast sea ice cores from Barrow, Alaska (Smith et al., 2016)."

p. 18, Line 7: "indicative for the preceding freezing process (Souchez and Jouzel,1984)." I'm not sure what this means? Does this mean that freeze fractionation should be taken into account?

Changed to: "This is reflected in the regression lines of the d18O-dD plot for BY, which differ in slope for the two sections (Fig. 8) and indicate a shift in fractionation (Souchez and Jouzel, 1984)."

p. 18, Line 9: "Tab ??". This is not at all obvious from Fig 8.

Corrected. We have added a table of regression line statistics to show the basis for distinguishing groups of lines.

p. 18, Line 18: "but with the carbon isotope signature". I could not see much change in the carbon isotope?

Here the word “same” was missing and has been added.

p. 18, Line 29: “(Lacelle, 2011)”

Adopted.

p. 18, Line 29: Again, this is not at all obvious from Fig 8.

We have added a table of regression line statistics to show the basis for distinguishing groups of lines.

p. 20, Line 29: “was”

Adopted.

p. 21, Fig 8: The changes in slope appear to be important but cannot be seen on the plots as currently displayed. Please consider how to display this information to match the Discussion. Why is global rather than local meteoric line used?

To make the data less ambiguous, we have added a table with regression line coefficients (Table 3).

p. 22, Fig 9: Is it not possible to write down the equation of the model displayed?

The equation is in the methods section (Eq. 1). We have added a cross-reference to it in the figure caption. All parameters used for the Rayleigh model are given in the figure caption, i.e. the reader is provided with all information used to generate the plot.

p. 22, Conclusions: Please return to the aims of the study here, and show how they have been moved forward.

We have considerably changed the conclusions, please see track changes version.

p. 23, Line 8: It is not obvious to me how the data provided has shown that the ice examined “acts primarily as a barrier to methane fluxes to the atmosphere, a barrier that is effective for most of the year but also will be effected by rapid changes due to Arctic warming and associated ice thinning.” Please make this clearer in the Discussion and/or Conclusion.

We have deleted this sentence.

p. 23, Line 8: What does “providing a habitat for methane oxidation” mean? Again this needs to have been explained earlier in the paper.

Changed to “...providing a habitat for methane oxidizing microorganisms.” This is also described in an expanded form in the discussion on Page 19, lines 13-16:

“In addition, temperature increased towards the bottom of the ice (Fig. 4). The bottom ice offers a protected environment with favourable conditions for microbial metabolism: relatively warm temperatures, contact with liquid water and permeable ice. The latter permits migration of gases and nutrients, similar to marine ice, where most bacteria are located in the lowest15centimetres of the ice (Krembs and Engel, 2001). At LG, the bottom ice temperature decreases during the winter. This occurs because the temperature of the underlying water remains in equilibrium with a dynamic freezing point that decreases with increasing salinity when LG is cut off from Tiksi Bay. “

and lines 25-26:

“During freezing of the ice cover, its growth rate decreases (cf. Anderson, 1961), providing more time and space for bacterial25metabolism. CH4uptake from the water into the bottom of the ice and its oxidation there may have continued over the winter until the ice break-up. CH4oxidation ceases when concentrations are too low for oxidation to be efficient (Cowen et al., 2002; Valentine et al., 2001), at values ranging from0.6 nMto10 nM. CH4concentrations in the ice above130 cm (Fig. 6) were lessthan10 nM, suggesting that ice is an effective sink for CH4in this type of water body during winter.”

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