

Dear reviewer,

Thank you very much for your letter regarding our manuscript entitled “A field study on ice melting and breakup in a boreal lake, Pääjärvi, in Finland”. We are truly grateful to the comments and suggestions from you. The manuscript has been carefully revised, and the language has been checked. The point-by-point answers to the comments and suggestions were listed as below.

Response to Reviewer 1# Comments

The study presents detailed observations on variations of lake ice properties during two melting periods in a boreal lake. The observations encompass ice structure, porosity, density, biogeochemical characteristics (pH, electrical conductivity, Chlorophyll a) and were performed at daily to weekly intervals covering the latest stages of the ice-covered period. The study design and the approach are relevant to the state-of-the-art of the lake ice studies. The newly collected data have a potential to make a valuable contribution to the current knowledge on the mechanisms of the seasonal ice cover melt.

The presentation of the results is however extremely hard to follow, too lengthy and poorly structured. Description of methods pops up in the middle of results presentation, while new introductory information and collateral results, which are only loosely connected to the subject of the study, unexpectedly start the discussion part. The authors should analyze, synthesize, summarize and---finally---present scientific results in a concise, well structured way.

Endless recitation of dry unbound numbers throughout long paragraphs, repeating the information presented in tables, without an integrated analysis of the field information is redundant and superficial. Last but not least: the poor language and style make the study hard to read. Overall, the style reminds that of a plain field report rather than a research paper. Many sentences are barely understandable because of poor English use. Reworking of the text with significant shortening, restructuring and language improvement is strongly recommended. The length of the ms should conform to the amount of the reported results, which suggest shortening it by 1/3-1/2. Below are some specific comments aimed to provide guidance on the revision. The comments are aligned with the text flow. The remarks on language and style are not exhaustive and serve just as the most evident examples.

Response: Thank you very much for your constructive comments and recommendation of the revision. We adjusted the structure of the manuscript to make it easier for readers to understand. We have adjusted our results, discussion and conclusions chapters. In chapter 3 (Results), we added sub-title for section 3.1 (Ice structure) to make it easier to follow. Considering also the comments of Reviewer 2#, in section 3.3 (Ice geochemistry), we presented the data of Table 5 in a vertical plot/plots which can show clearly the vertical structures and temporal variations of EC, pH, and Chl *a*. And we gave a short and clear explanation in the text instead of repeat the dry numbers throughout long paragraphs. We transferred chapter 4 (Heat budget)

to a new section 3.4. We removed all the results from the Discussion chapter to chapter 3 (Result), and give a revised discussion. Finally, based on the manuscript, we have rewritten the conclusions with a clear summary about what we have done, the result and the meaning. We cut the repetitive descriptions in the manuscript and shortened the manuscript by 1/3. And we have checked the language. Please, see our responses to your comments as follows for more details.

Comment:L49 “structure” -> “structures”

Response: We have revised “structure” by “structures”.

Comment:L56: “physics of climate sensitivity...” poor wording

Response: We have revised the sentence as: The timing of ice breakup is a question of atmospheric warming and falling albedo (Leppäranta, 2014), and its proper solution requires a quantification of the physical mechanisms that control the melting of ice.

Comment:L61: “seasonal” -> “seasonally”

Response: We have revised “seasonal” by “seasonally”.

Comment:L67: “productive” -> “production”

Response: We have revised “productive” by “production”.

Comment:L69: remove “the extent to”

Response: We have removed “the extend to”.

Comment: L72: “protects the ice.” from what? Remove “by its presence”

Response: Removed as suggested.

Comment: L73: “immediately when” -> “immediately after”

Response: Changed as suggested.

Comment: L79: “difficult conditions”: difficult for what?

Response: You are right, we didn’t make it clear here and we revised it as “ Due to the difficult fieldwork conditions on deteriorating ice cover, there has not been much in situ research during the ice decay period. ”

Comment:L80: “melt rate” -> “rate of melt” or “melting rate”

Response: We have revised “melt rate” by “melting rate”.

Comment:L86: “has reached” -> “reaches”

Response: We have revised “has reached” by “reaches”.

Comment:L171: “unfiltered” -> “unfiltered” (?)

Response: Changed as suggested.

Comment: L173: “high accuracy” -> provide the accuracy values.

Response: We have provided the values, for pH (0.01) and EC ($0.01 \mu\text{S cm}^{-1}$).

Comment: L176: “long wavelength” -> provide the wavelength range

Response: We have provided the wavelength (665 and 750 nm) for measuring Chl *a*.

Comment: L192: add the spatial scales and explain spatial scales in Fig. 2

Response: Thanks for your suggestion. We have added the spatial scales and the color scale in Fig.2.

Comment: L195-196: remove “As we can see from Fig 3a-f”, add “(Fig 3a-f)” at the end of the sentence.

Response: Considering also other comments of you, we have revised Fig 3a-f. Then we have removed “As we can see from Fig 3a-f”, and added “(Fig 3)” at the end of the sentence.

Comment: L200: “became more and more” -> “increased”

Response: We have revised “became more and more” by “increased”.

Comment: L207-208: “rachis-shaped” revise wording

Response: We have revised “rachis-shaped” by “cylindrical and spherical shaped”.

Comment: L212: Remove “Then”

Response: We have removed “Then”.

Comment:L213: “temperature rose...” Temperature of what? The same for L217

Response: We have revised “temperature rose...” by “air temperature increased...”.

Comment: L226-236: Fig 3 is not comprehensible and should be shortened to present the essential information only.

Response: Here we wanted to show how the ice structure changed during the melting period. We have adjusted Fig.3, preserving the essential information. Now a typical ice structure, April 1, at the beginning of the melting period is presented in Fig. 3, and the vertical ice structure of ice samples on April 26, April 29, and May 3, which can reflect the changes in ice structure, in Fig. 4.

Comment: L244-254: The paragraph mostly repeats information from Table 2 and should be shortened to 1-2 sentences.

Response: Thanks for your advice. There was too much repetitive information from Table 2 and we have adjusted this paragraph into 3 sentences: “In 2018, the ice decay period began at the end of March, and the final breakup took place on April 25. The thickness of ice was 42 cm on March 30, and on April 12 it was 35 cm with 5.3 cm snow-ice and 29.7 cm congelation ice (Table 2). Snow-ice melted in less than eight

days, and congelation ice melted fast after April 15. On April 24, rain greatly accelerated the melting.

Comment: L262: Equation 1 is wrong.

Response: You are right. We have modified the Equation 1 as:

$$Q = \frac{\rho_i L_f \Delta h}{\Delta t} = 13 \text{ W m}^{-2}, \quad (1)$$

Comment: L264-265: revise the style of the sentence

Response: We have revised the sentence as: The mean internal melt rate was 0.18 cm d⁻¹ equivalent ice thickness that was smaller than the surface and bottom melting, attributed to the low light transmittance of snow-ice.

Comment: L277-279: awkward phrasing. Revise the sentence

Response: We have revised the sentence as: The density profiles shifted toward lower level with time while the density always increased with depth (Fig. 5).

Comment: L303 and elsewhere: “S cm⁻¹” Is it “uS cm⁻¹”? Check the units across the entire text.

Response: You are right. We actually wanted to write “μS cm⁻¹”. We have now written “μS cm⁻¹” for all conductivity values and we checked all other units across the entire text.

L307: remove double “in”

Response: We have removed double “in”.

Comment: L315: shorten Table 5, remove information repeating Fig. 5

Response: Table 5 showed pH, EC and Chl *a* in vertical profiles of ice and in the lake water, and Fig.5 showed the mean value in ice and lake water in 2022. Considering also the comments of Reviewer 2#, we present now the Table 5 data in vertical plots which show clearly the vertical structures and temporal variations of EC, pH, and Chl *a*. Also, we made a short and clear explanation in the text for Fig.6 as follows: The vertical profiles of EC, pH and Chl *a* show that EC was larger near the snow-ice surface than in congelation ice in the early melting stage, but the difference was no more obvious after April 14. pH was always smaller in snow-ice than in congelation ice. Chl *a* content was less than 0.6 μg L⁻¹ with the maximum at the snow-ice – congelation ice interface.

Comment: L339, Section 4: The section represents the rare attempt to analyze the observed data beyond their straightforward listing. However, the heat budget model, as presented here, is rather crude and lacks support by background physics of the heat exchange between air and ice surface. The monthly climatic means of solar radiation are too rough for such a model and can be replaced by data from reanalysis or nearby weather monitoring for the actual dates. Assumption of constant albedo is also weakly

supported for the melting periods, especially with snowfall and rain events. Several approaches exist for albedo parameterization, with the simplest ones based on air temperature. Still, one could expect even more sophisticated albedo parameterizations, taking into account the detailed information on ice properties and drone images of the surface conditions. There is no clear model described for the long-wave radiation budget in the ice-air system and for the sensible/latent fluxes at the ice surface. By this, the inconsistency of the oversimplified model with the data (L376-378) is not surprising. The approach should be deeply revised based on the current knowledge on the surface heat budget.

Response: Thanks for your suggestion. We have revised this section based on your comments. The meteorological data from FMI from 2022 was used to analyze the heat budget of ice melting. Solar radiation is now from the daily observed values instead of using the monthly climatic means of solar radiation. The albedo was parameterized as $\alpha = 0.7$ for snow, 0.5 for dry ice and 0.3 for wet ice. After revising the input data for the heat budget model, the results of the model simulation are in good agreement with the observed results. Considering also the comments of Reviewer 2#, we present briefly the physical background physical and meaning of the model and formulae.

Comment: L388, Section 5.1: This section appears absolutely unexpected and does not fit in line with the general flow of the study. Section is an odd mix of newly presented data lacking a thorough analysis of their relevance, statistical significance and processing methods (Figs. 6-7) with unnecessary common places (L411-412), and information on ice phenology from other lakes irrelevant to the subject of the study. The whole section reads inorganic and should be either removed or deeply revised with proper redistribution between methods, results and discussion, including adequate analysis of data reliability.

Response: Thanks for your suggestion. We adjusted the structure of the manuscript and discussion. Section 5.1 has been compressed just to give background to the variability of ice breakup. The date of ice breakup is largely affected by the solar radiation and the thickness and structure ice and snow layers, and the time series shows that ice breakup has become earlier in the last 50 years (Fig.10). A brief comparison with other lakes is also given.

Comment: L430, Section 5.2: “comparisons with ice melting” - comparisons of what? The section title is senseless.

Response: Thanks for your advice. We have revised “comparisons with ice melting” by “Comparisons of ice melting with other lakes”

Comment: L453: “if further generalized...” This generalization is actually what the reader expects from the authors at this point: generalize your results and put them into the context of the present knowledge on the subject. The whole section should be deeply revised. Move Fig. 8 with the accompanying data to Results and write a new, more focused discussion.

Response: Thanks for your advice. We completely revised the discussion, generalize our results and compared the results of this manuscript with other studies carefully. Also, we have moved Fig. 8 with the accompanying data to Results (3.4. Heat budget).

Comment: L526-527: "...a surge of phytoplankton..." - Do you mean a phytoplankton bloom? If yes, can you demonstrate a correlation between pH variations and $Chl\ a$ content? This passage reads too speculative and unsupported. Revise it, demonstrating support by data analysis, or remove completely.

Response: We mean a phytoplankton bloom, but it's not possible to give the correlation between pH variations and $Chl\ a$ content based the present data. We understand that these sentences are somewhat confusing and unclear. Finally, we removed these sentences.

Comment: L555-556: Awkward sentence, should be revised or removed.

Response: We have revised "The present has filled to this gap of knowledge focusing on the ice decay in Lake Pääjärvi, a boreal lake in southern Finland, in 2018 and 2022." by "The field observations were made in Lake Pääjärvi, southern Finland, in 2018 (pilot study) and 2022 (main experiment)." And we have rewritten the conclusions and gave a clear summary about what we have done, the result and the meaning.

Finally, according to the adjustment of the structure and content of this manuscript, the references of this manuscript are also adjusted accordingly.