HESS-2022-133 Revision 2, Reviewer 1: Author Response

Author responses

RV: L105: this equation appears to be erroneous: the 'x1000' factor is unnecessary when also using the per mil notation. See Coplen, 2011, p. 2554-2555.

AUTH: The variables on the right hand side of the equation (Rsample, RVSMOW) do not use per mil but are ratios of 18O/16O or 2H/1H (L106). These ratios need to be multiplied by 1000 to equate to δ notation on the left hand side (which we always present in units of ‰). While Coplen (2011) argues that it is confusing to add a multiplier because δ units are not naturally in ‰ units, we would argue that it is more appropriate to include the 1000x multiplier for this manuscript given that we only present isotope data using ‰ units, and most of the papers we cite also follow this convention. See Equation 2.2 in Kendall & McDonnell, 1998, p. 55

RV: Per mil notation works the same way as percentage notation: 46/100 = 0.46 = 46%. There is no 100x multiplier. Similarly, for the per mil notation no multiplier is necessary. Delta is dimensionless ratio, so there are no units that need correcting.

- We have removed the 1000x multiplier from the equation.

Minor comments:

L5. "hydrological and limnological": I'm not sure how one would define "limnological properties of the lake" – maybe stick with "hydrological and biogeochemical".

- Suggested change implemented.

L11: "The thickness of the freshet layer was not proportional to lake depth, which isolated a larger portion of pre-snowmelt lake water from mixing at deeper lakes." -> The thickness of the freshet layer was not proportional to maximum lake depth, so that a relatively larger portion of pre-snowmelt lake water remained isolated in deeper lakes.

- Suggested change implemented.

L15: poorly mixed -> partially mixed

- Suggested change implemented.

L41: "the flow of runoff into lakes", it would be helpful to have a more quantitative definition of 'freshet'. E.g. the volume of meltwater entering the lake. In the current version of the MS it seems that 'freshet' is used to describe both the volume of meltwater flowing into the lake, and the time (event) when this happens.

- "~~the flow of runoff into lakes~~" → "the volume of snowmelt-driven runoff flowing into lakes"

L66: "lake water isotope composition" -> isotopic composition of lake water and precipitation

- Suggested change implemented.

L72: “inform assessments of hydrological and limnological properties of thermokarst lakes”. What does this mean? I think it would be possible to be more specific here. This study describes which lakes retain meltwater and what the source of the meltwater is, which are important and novel results. But why do we want to know this? E.g. if more freshet is retained (e.g. because more lakes become closed basins), what does this mean for (annual) cycles of carbon, nutrients and energy in thermokarst lakes? Does it matter whether meltwater originates from snow or rain?

- We have reworded this sentence to specify how knowledge of how lake and watershed attributes influence snowmelt bypass will help others in their assessments of hydrological and limnological properties of lakes.
- “~~Identifying the lake and watershed characteristics that influence snowmelt bypass and the sources of freshet is likely to inform assessments of hydrological and limnological properties of thermokarst lakes.~~” → “Future assessments of hydrological and biogeochemical properties of thermokarst lakes can use the lake and watershed attributes we identify to affect snowmelt bypass and lake water sources to inform their results, given the distinct biogeochemical properties of freshet runoff (Finlay et al., 2006, Balasubramaniam et al., 2015) and the influence of snowmelt bypass on the amount of freshet runoff retained by lakes.” Sentence replaced.

L103: it might be good to mention that you are measuring stable isotopes only, to distinguish from radiotracer studies.

- “~~for isotope analysis~~“ → “for stable isotope analysis”

L110 and elsewhere: isotope composition -> isotopic composition (of water), or oxygen and hydrogen isotope composition

- “~~isotope composition~~” → “isotopic composition”, throughout manuscript.

L124: please see my response above about per mil notation

- We have removed the 1000x multiplier from the equation.

L143: I don’t understand this sentence. In other years the lakes were not exposed to meteorological conditions (weather?) during the open water season?

- The most recent meteorological conditions are used because they are what will have had the largest impact on the isotopic composition of the lake water. We did not use 2018 data because the lakes were ice-covered during the sampling campaign, barring the last few days (i.e., not an entire open-water season).

L155: paramtr -> parameter

- Suggested change implemented.

L247: “Shallower lakes likely had colder lakebed temperatures during freshet (Burn, 2005), which allowed more mixing between pre-snowmelt lake water and freshet inflow due to the reduction in

water density gradient between the bottom of the lake and the top of the lake." Wouldn't this result in a deeper mixing layer in smaller lakes, rather than the uniform thickness estimated here?

- This is true, but based on our results it seems that the colder lakebed temps at shallower lakes had a relatively small impact on total freshet retention when compared to lake depth. We have clarified this now.
- "~~S~~hallower lakes likely had colder lakebed temperatures during freshet (Burn, 2005), ~~which allowed~~ more mixing between pre-snowmelt lake water and freshet inflow due to the reduction in water density gradient between the bottom of the lake and the top of the lake." → "We hypothesized that because shallower lakes likely had colder lakebed temperatures during freshet (Burn, 2005), more mixing between pre-snowmelt lake water and freshet inflow would occur due to the reduction in water density gradient between the bottom of the lake and the top of the lake. However, the estimated thickness of the freshet layer was uniform across lakes, indicating that colder lakebed temperatures may not have contributed to greater mixing at shallower lakes." Added parts are underlined.

L255: the subarctic lakes in the study of Jansen et al. (2019) and the arctic lakes in Cortés and MacIntyre (2020) are within the size range of the lakes in this study. Could it be that the volume and loading of snowmelt also determines the fraction of lake water replaced by meltwater? Another aspect to consider is that chemical gradients in smaller lakes are often stronger under ice (compared to larger lakes), which increases density stratification and limits meltwater mixing and retention (Cortés & MacIntyre, 2020).

- We have deduced that the volume of freshet runoff does not impact the fraction of lake water replaced by freshet runoff because there was no relationship between relative watershed area (watershed area/lake area) and the fraction of lake water replaced by freshet runoff.
- We have added the bit about stronger chemical gradients in smaller lakes, which seems to suggest they can experience some bypass if they are more heavily stratified.
- "However, smaller lakes <1 ha, which are common in the Arctic (Pointner et al., 2019), likely do not experience snowmelt bypass because freshet is able to displace the pre-snowmelt lake water due to the small volume of the lake (Jansen et al., 2019, Cortes and MacIntyre, 2020)." → "However, smaller lakes <1 ha, which are common in the Arctic (Pointner et al., 2019), likely do not experience as strong a snowmelt bypass effect because freshet is able to displace the pre-snowmelt lake water due to the small volume of the lake (Jansen et al., 2019, Cortes and MacIntyre, 2020). However, smaller lakes also typically have smaller under-ice chemical gradients that increase density stratification and limit freshet mixing and retention (Cortes and MacIntyre, 2020)." Added parts are underlined.

L341: One might add that snowmelt in spring can constitute the largest annual influx of terrestrial organic matter to lakes in organic-rich landscapes (e.g. Townsend-Small et al., 2011, https://doi.org/10.1007/s10533-010-9451-4 and Olefeldt & Roulet, 2012 https://doi.org/10.1029/2011JG001819), and so the retention of meltwater could affect the NEP and ultimately climate feedbacks of these lakes.

- "Snowmelt also tends to have higher dissolved organic carbon (DOC) concentrations than summertime runoff (Finlay et al., 2006) and typically contributes the largest input of terrestrial organic mater to lakes in organic-rich landscapes (Townsend-Small et al., 2011;

Olefeldt and Roulet, 2012). Balasubramaniam et al. (2015) observed that thermokarst lakes dominated by snow-sourced water tended to have lower pH, higher conductivity and higher DOC concentrations than lakes dominated by rain-sourced water. Based on these observations, as snowmelt occurs earlier in the Arctic, lakes may experience decreases in DOC, and conductivity, and increases in pH. Such changes to lake biogeochemistry caused by shifts in freshet runoff retention could affect the productivity and ultimately the climate feedbacks of these lakes." Added parts are underlined.

L367: "likely to bypass" -> suggest nuancing this statement, since some meltwater is retained.

- "~~T~~he large volume of freshet that flows into lakes every year ~~is likely to~~ bypass ice-covered, open-drainage lakes due to limited mixing between lake water beneath the lake ice and freshet" → "A portion of the large volume of freshet that flows into lakes every year can bypass ice-covered, open-drainage lakes due to limited mixing between lake water beneath the lake ice and freshet." Added parts are underlined.

L370: "because freshet is unable to mix with deeper lake water": the authors make a strong case for this hypothesis but lack the conductivity and temperature observations to demonstrate the extent of mixing. I would suggest nuancing this statement a bit.

- "Our data show that as lake depth increases the amount of lake water replaced by freshet decreases, because freshet is unable to mix with deeper lake water when lakes are ice-covered and the water column is stratified." → "Our data show that as lake depth increases the amount of lake water replaced by freshet decreases, likely because freshet is unable to mix with deeper lake water when lakes are ice-covered and the water column is stratified, however we lack data demonstrating the extent of mixing in the lakes we studied." Added parts are underlined.

L371: "Additionally, the volume of freshet flowing into the lakes seems to have no observable impact on the amount of lake water replaced by freshet." How was this conclusion arrived at? Was the volume of freshet estimated somewhere?

- We assume this based on the relative size of a lake's watershed (watershed area/lake area) having no impact on the % of the lake water replaced by freshet. There were some lakes that had watersheds 17 times the size of the lake, while other lakes had watersheds only 1.9 times the size of the lake (Table 1). We assume that relative watershed size is a good proxy for the volume of freshet inflow lakes received. We now specify how we reach this conclusion.
- "Additionally, the volume of freshet flowing into the lakes seems to have ~~no observable~~ impact on the amount of lake water replaced by freshet." → "Additionally, the volume of freshet flowing into the lakes seems to have minimal impact on the amount of lake water replaced by freshet, given that the ratio of watershed area to lake area was not correlated with the percentage of lake water replaced by freshet." Added parts are underlined.