Comments by reviewer #1

We thank reviewer #1 for their constructive comments, which will improve the manuscript. Our response to the individual comments including proposed changes to the manuscript are given below.

In this paper, the authors present evidence of fine-grained cryogenic cave minerals (CCMs) found in Cove Cave in northeast Greenland. They provide evidence for their ability to date these fine-grained CCMs, unlike previous studies, and ultimately demonstrate that these CCMs likely formed during a short, but extreme, melting event on the Greenland Ice Sheet in 1889, which would have provided sufficient liquid water in the cave to form these minerals.

I'm not an expert in geochemistry, or dating, so my review is general and focuses mainly on the plausibility of the 1889 melting event on the Greenland Ice Sheet providing sufficient meltwater to the Cove Cave system.

General Comments:

1. The authors describe how CCMs are a paleo-permafrost proxy and their importance to mid- and lower-latitude sites. What do the presence of CCMs in this northern-most location tell us about permafrost in this high-latitude site? It's clearly interesting that these CCMs appear to have formed during a short-term extreme event on the ice sheet in 1889. A little more context of why this is an important finding in the Discussion and Conclusion sections would be helpful for the broad audience of this journal.

In contrast to coarse-grained CCMs, the fine-grained form (our samples) cannot be used as a palaeo-permafrost proxy. We will change the phrasing in the introduction so that this point comes across more clearly. However, the presence of CCMs tells us two very interesting things: 1. They show that conditions leading to widespread melting reached the study area in northeast Greenland, 2. The fact that they formed during this short-term extreme event in probably a matter of days, provides hints about the rate of formation (which is a highly understudied field), while also demonstrating that they cannot be used as a permafrost proxy because the presence or absence of permafrost is generally not influenced by short-term weather conditions. We will include these points in the Discussion and Conclusion sections.

1. The authors present 5 potential scenarios that could have produced the CCMs found at Cove Cave and walk the reader through the logic that eliminates 4 of those scenarios. They then cite publications (Clausen et al., 1988; Fischer et al., 1998; Neff et al., 2014; Keegan et al., 2014), which all describe a widespread melting event that occurred in the dry snow zone of the Greenland Ice Sheet in 1889. They hypothesize that this widespread melting event provided liquid water to the Cove Cave system, which allowed the formation of the CCMs found. Indeed, the studies cited identify a widespread, extreme melting event on the ice sheet that created surface meltwater, but it's initially concerning that the study sites in these references are pretty far from Cove Cave. Looking at available records from closer ice core sites B19 (Hatvani et al., 2022)

and Tunu (Grieman et al., 2018), it doesn't look like it was particularly warm in that region of the ice sheet in 1889 and there wasn't a lot of deposition of vanillic acid (VA; an indicator of forest fire activity) which would suggest a decrease in albedo due to black carbon. The closest ice core record would be from Flade Isblink, and the authors report that this record does not suggest excess melting in 1889, but a recent publication shows that there was a high concentration of black carbon in 1889 at Flade Isblink (Eckhardt et al., 2023). Understandably, the perfect ice core record does not exist to prove the theory that these CCMs were formed due to excess meltwater from the 1889 widespread melting event that occurred at higher elevations on the Greenland Ice Sheet. With the increased concentrations of black carbon at the Flade Isblink site so close to Cove Cave, it does appear that the melting event could have happed in this region too. I suggest including the Flade Isblink black carbon record to bolster this hypothesis.

Thank you for making us aware of this recent publication. We will certainly include the newly available record from Flade Isblink.

Specific comments:

Line 21: add 'Cove Cave' before 'CCMs' here to let the reader know you're talking specifically about the Cove Cave CCMs again here

Will do.

Line 25: why is 'weather' in parentheses here? I'd suggest removing the parentheses

We put it in parentheses to also account for the deposition of black carbon but realise that the parentheses might be confusing. We will remove them.

Lines 53-56: for ease of reading, I suggest breaking this up into two sentences like '…in northeast Greenland. Cove Cave is currently…'

Will do.

Line 68: remove 'therefore'

Will do.

Line 258: 'sublime' here should be 'sublimated'

We will change that.

Line 294: a comma is needed after 'than'

We will put that in.

Line 297: 'were' should be 'where' here

We will change that.

Figure 1: are the blue lines indicating ice margins referring to present-day ice margins, or ice margins from the former presence of additional ice caps that are mentioned in the last sentence of the figure caption?

They are indicating ice margins from the former presence of additional ice caps. To make this clearer we will change the figure caption and add "(light blue polygon)" and "(blue lines)" to the respective sentences.

References:

Eckhardt, S., Pisso, I., Evangeliou, N., Zwaaftink, C. G., Plach, A., McConnell, J. R., ... & Stohl, A. (2023). Revised historical Northern Hemisphere black carbon emissions based on inverse modeling of ice core records. *Nature Communications*, *14*(1), 271.

Grieman, M. M., Aydin, M., McConnell, J. R., & Saltzman, E. S. (2018). Burning-derived vanillic acid in an Arctic ice core from Tunu, northeastern Greenland. *Climate of the Past*, *14*(11), 1625-1637.

Hatvani, I. G., Topál, D., Ruggieri, E., & Kern, Z. (2022). Concurrent Changepoints in Greenland Ice Core δ18O Records and the North Atlantic Oscillation over the Past Millennium. *Atmosphere*, *13*(1), 93.