Submission of reply to the comments made by Reviewer #1
Ms. Ref. No.: CP-2020-107
Title: Cryogenic cave carbonates in the Dolomites (Northern Italy): insights into Younger Dryas cooling and seasonal precipitation

Reviewer #1

We are grateful for the positive and helpful comments and we address below the points raised by this referee (in italics).

Sincerely,

On behalf of the co-authors,
Gabriella Koltai

<u>*Main comments*</u>

This is an interesting manuscript investigating the internal climatic structure of YD, which in my opinion warrants publication, but I do think further reflection is probably in order. Since much of the paper's discussions/conclusions are drawn from the results of the thermal modeling experiments, it would be helpful if the method is presented in more details (maybe some references would also be appropriate). This could be done by adding additional text in the manuscript or supplemental material section.

The section of the thermal model will be expanded in the revised manuscript and each modelled scenario will be described in the method section.
The thermal model was developed by Alexander H. Jarosch (a colleague who will be a co-author on the revised manuscript). The code is freely available and the relevant references are provided in the manuscript (line 131, lines 365-367).

The attempt to characterize the early YD climate, basically using only two (at most three) dated CCC may be a little too far reaching, especially given their associated errors. I think authors need to present more convincing evidence for their early YD discussion since three of the scenarios (2b to 2d) are somehow marginally supported by only two CCC samples. This situation is in great contrast with the late YD, for which ~7 dated samples exist. Better explaining why and how scenarios 2b to 2d are really relevant to the discussion would be helpful.

We would like to emphasize that only the cleanest samples were selected for ^{230}Th dating to avoid large uncertainties due to high amounts of initial ^{230}Th. Some of the samples still yielded somewhat larger uncertainties (up to 2.7%). We tried to reduce the error on FOS12-A3 by doing a replicate measurement. Due to the small size of this sample, however, the remainder of this crystal had to be analysed, which resulted in low ^{230}Th/^{232}Th atomic ratios and hence a larger ^{230}Th age correction. Replicating the ^{230}Th ages of the other two samples (FOS12-B4 and FOS12-C) was not possible as there was not enough sample left. During the review process, however, we dated two more CCCs from heaps A and C. These analyses yielded ^{230}Th ages of 12.34±0.2 ka and 12.33±0.2 ka BP, confirms the existing data and will be included in the revised manuscript.

During original manuscript preparation we critically evaluated our age data (lines 158-169) and provided discussion on whether CCCs in Cioccherloch Cave represent one prolonged period of

CCC deposition lasting for 400-600 years or two distinct phases centred at ~12.6 and 12.2 ka BP. The start of CCC formation in Cioccherloch Cave is at 12.60±0.2 ka and the precision of this ^{230}Th age is 1.5 %, meaning that CCC deposition commenced earliest at 12.8 ka and latest at 12.4 ka BP (2 sigma uncertainty range). This in combination with the two new ages provides strong evidence that CCC formation indeed started during the early Younger Dryas and conditions allowing CCC formation may have been met for hundreds of years. Such prolonged periods of CCC formation are not unique to Cioccherloch Cave and have been reported form several alpine caves (e.g. Luetscher et al., 2013; Spötl and Cheng, 2014; Spötl et al., in review).

Our model run simulations for the early YD (scenarios 2a-2e) explore the prerequisites for CCC deposition under different climate conditions. We emphasize that all scenarios are based on published regional proxy records providing temperature estimates for the YD cooling (lines 186-208). CCC formation at Cioccherloch Cave can be best explained by scenarios 2c and 2e, arguing for a maximum 4.5 to 5°C drop in MAAT relative to today.

Authors are using various input parameters for their thermal modeling and end up presenting MAAT,ΔMAAT, MAET,ΔT, snowΔT, etc., point at which tracking all these values in sections 4.4.1 to 4.4.3 is rather difficult and easy to mix up digits. Further-more, they don't always match with what is reported in Table 2 or figures caption (e.g., scenario 2d and 2e is said to be forced with a MAAT of -1.5◦C in the caption of figure3 (line 534), but in Table 2 it appears to be -2◦C; line 535 reads "...ΔT of 4.5◦C" for scenario 2e, but in Table 2 the value is 4.7◦C. The presentation of data in these sections needs to ve revised and made clearer. One way would be to add all values use in Table 2 so that is easier to track them. On the same vein, I see authors derived and reported in Table 2 the mean annual effective temperature, but nowhere in text these values are discussed.

Thank you for pointing this out. The method section will be expanded with the description of each scenario and the input parameters will be consistent throughout the text, figures and Table 2.

I found Figure 3 to be rather difficult to understand. Some minor improvements, such as placing "early YD" in the right side of the plot and making the blue dashed line more visible, would certainly improve it. However, as expressed above, it is unclear to me which of the CCC really characterize scenarios 2b, c, and d, as I see only two ages with 400 to 600 yrs error that could be assigned to early YD.

The reviewer probably refers to Figure 5. We will follow the suggestion and improve the figure.

Specific comments

I also have many small comments and suggestions that I think would improve the language and clarity of the manuscript .I suggest using throughout the text, figures and captions capital letter C in Cave when is a proper name (e.g., Hölloch Cave, Milandre Cave, etc.).

Cave names will be written with capital C in the revised manuscript.

Line 60: what do you mean by "certain proxy properties"?

We refer to the Ti count rate and varve thickness.

Line 67: Authors could probably make use of the recently published study of Cheng et al. 2020 in PNAS

Thank you for the suggestion, we are of course aware of this publication (two of the co-authors are the authors of it) but we did not want to cite it before the manuscript was printed. Will be included in the revised version.

Line 77: CCC are in fact speleothems not cave sediments, thus, I urge authors to consider them as such.

Will be corrected.

Line 84: maybe "CCC form in caves with perennial ice..." will be more clearer to readers than "CCC form within perennial cave ice..."

We disagree as the suggested change would modify the meaning of the sentence. It is important to emphasize that CCCs form inside the cave ice bodies.

Line 105: Methods - is there any other way of presenting the information in this chapter without breaking it so heavily and have only 2-3 lines for various subchapters?

We looked at the manuscript guidelines and also at other manuscripts published in this journal and think that breaking the methods down into subsections is still the best way to present them.

Line 129: Thermal modeling - additional information and references are needed in order to better understand the method (e.g., what might be the effect of taking 0.5 or 1for dT/dz? What are the uncertainties of the results associated with this model?)

and

Line 131: a reference to whoever generated the heat flow model would be appropriate
Line 135 Equation 1 - if authors consider dT/dz = 0 then Q is 0 regardless of thermal conductivity, right? Do I miss something on how this equation really helps?

and

Line 136: thermal diffusivity (how fast heat diffuses through a material) is not the same with thermal conductivity (ability of a system to transport heat energy). Authors define thermal conductivity as "c" in Equation 1, but then set the thermal diffusivity of lime-stone to 1.2x1010ˆ-6. What value was actually used for Eq. 1, which once again, ifdT/dz is assumed 0, Q would be 0

About references on the model, please see our comment above. The model description section will be modified to clarify these misunderstandings. The model solves the basic heat equation

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2}$$

where here α is the thermal diffusivity and T temperature and z the vertical coordinate. This is a standard model approach well known and understood. The numerical errors are minimal.

Equation (1) in the manuscript describes the relation between heat flux and thermal gradient. This equation, however, is not solved in the model. The thermal gradient (dt/dz) was set to zero as a lower boundary condition of the model.

As mentioned above the method section will be expanded in the revised manuscript to avoid any misunderstanding.

Line 150 - 153: For consistency, use XX‰ or XX ‰ but not both ways.

The space in line 150 will be deleted.

Lines 180-223: I feel that the presentation of these scenarios could be clearer if all values are included in Table 2 or those already in this table are presented in text as well. Right now, I see, for some scenarios, different values in text, table, and/or caption of figures 3 and 4.

This will be improved.

Lines 274-275: what do you mean by "Scenario 2e including provides...

"Scenario 2e including a winter snow cover provides…". Thank you for pointing it out.

Line 301: it was not immediately clear to this reviewer how the value of 5.7◦C was derived. Please add text to clarify.

Thank you for spotting this mistake. There was a typo in the sentence and in fact this value is 5.4°C. Text will be added to clarify how this value (5.4°C) was derived.

Lines 346-347: my suggestion for rewording this part of the sentence: "...CCC in the Dolomites, which in contrast to many studies from Central European caves, formed not during..."

The text will be changed following the reviewer´s suggestion.

Line 358: add "for" at "advocates for a mild..."

Thank you for the suggestion.

Line 542 - Figure 4 - winter snow cover (ΔT = 2◦C) is mentioned in this caption, but it is not in Table 2 for scenario 3a

This will be corrected.

References

Luetscher, M., Borreguero, M., Moseley, G.E., Spötl, C., Edwards, R.L., 2013. Alpine permafrost thawing during the Medieval Warm Period identified from cryogenic cave carbonates. Cryosphere 7, 1073–1081. https://doi.org/10.5194/tc-7-1073-2013

Spötl, C., Cheng, H., 2014. Holocene climate change, permafrost and cryogenic carbonate formation: Insights from a recently deglaciated, high-elevation cave in the Austrian Alps. Clim. Past 10, 1349–1362. https://doi.org/10.5194/cp-10-1349-2014