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

Dear Frederic Schenk,

We appreciate your critical feedback on our manuscript and address below the points raised by you (in italics).

Sincerely,
On behalf of the co-authors,
Gabriella Koltai

From carefully reading this very interesting study, it appears that the results provide important insights on the temporal changes in the amount and timing of snow fall at the study site during autumn and early winter during the YD. Koltai et al. estimate rather warm January temperatures of around -13.7_C for the YD and only a quite moderate change in seasonality of up to 5.7K relative to the AL. Based on these results, the authors "challenge the commonly held view of extreme YD seasonality" (e.g. line 15). While the inference of changes in snow cover over time are important by itself, I do not agree that the results can challenge seasonality changes from other studies: The inference of snow-rich conditions and that such a snow cover insulates the cave cannot be used with much confidence to estimate the full severity of winter temperatures and hence can neither reconstruct nor challenge seasonality changes in a general way.

There appears to be a misunderstanding about the input parameters the model is considering. The heat-flow model simulates the penetration of the ambient seasonal temperature signal to 50 m depth, and both winter temperature and the temperature buffering effect of a winter snow cover can be varied independently.
The different scenarios are based on regional proxy data reconstructions for the Allerød (Ilyashuk et al., 2009) and the YD (e.g. Affolter et al., 2019; Frauenfelder et al., 2001; Ghadiri et al., 2018; Luetscher et al., 2015). These studies suggest an approximately 3 to 10°C decrease in mean annual air temperatures (MAAT) during the YD compared to modern day. Our experiments take advantage of these studies and investigate under which climate conditions cryogenic cave carbonates (CCCs for short) could have formed at our alpine site (Cioccherloch Cave, Dolomites).
The heat-flow model simulates the penetration of the ambient seasonal temperature signal to 50 m depth. We used local meteorological data to characterize modern day conditions (see Table 2) and palaeotemperature estimates from Majola Pass (Ilyashuk et al., 2009) to define the input parameters for scenario 1 (Allerød interstadial climate). As a recent study by this reviewer (Schenk et al., 2018) suggested that YD summers remained relatively warm with a temperature decreases of 4.3°C in NW Europe and 0.3°C in E Europe relative to the preceding Bølling interstadial, we kept the July temperatures 3-4°C lower modern values (Table 2) and attributed most of the MAAT change to winter cooling. We used the output of this simulation as the starting condition for all early YD experiments. As a second step, we modeled the penetration of the seasonal signal without the presence of winter snow to provide an endmember for the YD cooling (scenarios 2a, 2b, 2d). The results show that the subsurface would be overcooled and prevent CCC formation latest 100 years after the start of the YD.

As a next step we included the buffering effect of a winter snowpack insulating the ground from the winter chill. This buffering effect (snow ΔT) was set to its maximum in scenarios 2c and 2e to test if a similar amplitude of cooling investigated in scenarios 2b and 2d (Table 2) would allow CCC formation given the presence of a winter snow cover. As discussed in the manuscript (lines 304-306), studies of modern permafrost areas suggest that even a 35 cm thick stable winter snow cover may result in a 5.5°C increase in mean ground surface temperature (Zhang, 2005 and references therein). Therefore, our snow ΔT values of 5°C and 4.7°C are considered realistic. With these two input parameters we characterize the maximum possible amplitude of winter cooling in the absence or presence of a winter snow cover. As the buffering effect of the snow is set to its maximum value to counteract the winter chill, we can indeed reconstruct the possible maximum amplitude of winter cooling with our approach.
In the revised manuscript we will expand the model description and also the description of the experiment.

In the best case, the results may be valid for the local cave or regional climate setting. However, the authors do not provide evidence for why the results from a cave record at a high elevation from the Southern Alps can generally challenge commonly held views on extreme YD seasonality in other regions and, i.e., not north of the Alps across the Euro-Atlantic region.

We do not fully understand this comment. By nature every paleoclimate proxy study is local in its significance, be it sediment from a lake, a glacier or a cave. By using proxy data for the YD from the well-studied Alps we compare our winter temperature estimates to other regional proxy data (MAAT and summer temperatures). We emphasize that our data are among the first winter proxy data for the Alps. And we clearly state in the title already that this study concerns a site in this mountain range. Nowhere does it challenge the climate interpretation of the YD in the "Euro-Atlantic region".
Our study provides physical, i.e. non-biological evidence for a maximum amplitude of ≤3°C cooling (in MAAT) at the Allerød-YD transition and argues for a maximum 5.4°C increase in seasonality for the Southern Alps (see Discussion), challenging the notion of extreme seasonality in this region put forward by previous authors working in the Alps (see Discussion). We stand by this interpretation.

As discussed by the authors, the timing and amount of snow cover over the cave has a major control on subsurface temperature changes. An early and/or thick snow cover will protect the cave from the most severe winter cooling like in January. It is therefore quite likely that the cave record fails to estimate the full winter cooling which would define the amplitude of seasonality change (this might also apply to other studies affected by ice or snow cover insulation). This would imply that the authors do not reconstruct the full seasonality. Hence, they cannot challenge seasonality results from other regions. It is unclear to me how assumptions in the thermal modelling can account for the combination of two unknowns: an unknown winter severity in the YD together with an unknown snow thickness. I think this should be clarified in the text.

Please see our comment above on capturing the full winter signal by the heat conduction model. In short: because CCC provide a very robust thermal reference point we can place reliable constraints on the amount of winter cooling at this sensitive site. Snow cover modulates the subsurface cooling and we consider this explicitly in the model.
We will attempt to improve the wording in the revised manuscript.

Line 37: "Siberian-like" would imply extreme seasonality which is typical for continental climates. Such a climate is reasonable for the YD north of the Alps as the major heat source is *shut off with an ice-covered North Atlantic Ocean. This does not need to apply to the Southern Alps, though.*

This sentence will be changed according to suggestion made by the colleague and Reviewer#2.

Line 39: Remove "however" as the sentence before is about winter and this sentence is about summer.

"however" will be removed.

Line 39-40: Replace "shutdown" with slowdown - the study assumes an AMOC slowdown of around 36% relative to the Alleröd. The 4.3 to 0.3 summer cooling refers to chironomid-based estimates and hence a notable summer cooling – the mild YD summers are based on plant indicator species and the climate model which suggest no overall summer cooling.

Thank you for spotting this mistake, will be corrected.

Line 49: The -10 K change in the northern Alps would be an indication that your record from the Southern Alps does not reflect the same changes – hence you cannot challenge large seasonality changes in general. If anything, your study reflects local or even only cave ambient temperatures/snow cover changes and additional information is required to claim these muted changes would generally apply to south of the Alps. Spagnolo & Ribolini (2019, see section 4.3) estimate a seasonality of 21 degrees for the maritime Alps at the ELA during the YD compared to 14.2 degrees today.

First, we do not challenge "seasonality changes in general". We compare or results to the Alps. Second, we are aware of the Spagnolo and Ribolini (2019) paper but do not see the suggested offset to our study. Our data suggest a maximum temperature cooling of ≤3°C in MAAT for the YD compared to the Allerød. If we assume a minimum 0.3°C change for July air temperature (see discussion lines 289-302), it is possible to calculate the maximum amplitude of seasonality between July and January air temperatures by using July air temperature and MAAT estimates. Thermal modelling in combination with proxy data of July air temperature shows that seasonality increased by a maximum of 5.4°C at the Allerød-YD transition (see discussion lines 289-302).
Spagnolo and Ribolini (2019) report a winter-summer temperature difference of 21 °C compared to the 14.2°C today, which is very similar to our result. Based on meterological station data the difference between July and January air temperatures at the altitude of Cioccherloch Cave is 17°C.

For the temperature estimates and the calculation of seasonality please see the table below for our site at 2270 m a.s.l.

	Modern	Allerød	YD
MAAT (°C)	2.5	0.5	-2.5
July air temperature (°C)	11	9	8.7
January air temperature (°C)	-6	-8	-13.7
Seasonal amplitude (°C)	17	17	22.4

We will provide further information to clarify how the value of 5.4°C was calculated. Note that there was a typo in the manuscript (line 301) and the correct value is 5.4°C.

Lines 62-63: While it is true that Hepp et al. 2019 claim the opposite, several comments by E. Schefuss, B. Zollitschka as well as D. Sachse and myself (see the online discussion: ("https://cp.copernicus.org/articles/15/713/2019/cp-15-713-2019-discussion.html) raise serious questions regarding the validity of that study. The extensively studied Meerfelder Maar nearby does not agree at all with the interpretation using a much more reliable chronology. I think this disagreement needs to be at least mentioned here (e.g. relative to Brauer et al., 1999; Bakke et al., 2009). Line 87: Again, there is no reason why the local cave record should "argue against strong winter cooling during the early YD" at other places and perhaps even not at the site itself.

We were aware of the discussion on the work by Hepp et al. (2019), however we felt that this study should be mentioned as well in order to provide a full literature review.

345-350: This might be true for the local setting in the cave insulated by a snow cover but might fail to reconstruct the full MAAT cooling which happened in air temperatures above the snow cover.

Please see our previous comments.

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