RC2: 'Comment on cp-2024-37', Anonymous Referee #2, 09 Aug 2024

This is an interesting manuscript and a good start to stimulate further research on the timing and nature of Terminations. There is no doubt that speleothems have a great potential as they can be dated accurately and precisely with low age uncertainties. The manuscript tries to gather existing speleothem records in order to examine Terminations II, IIIA, III, IV and V in closer detail, with a focus on the sequence of events. I agree with the authors that a comprehensive overview on Terminations in speleothem is currently missing and this overdue. However, I have the feeling that the manuscript was put together quite hastily as the general structure is quite complex and many highly relevant figures are only provided as supplemental information and not in the main text (see comments below). I have the feeling that the authors should try to develop a more concise structure and to present their selection criteria for records more clearly. Furthermore, a more rigid statistical approach is required (see comments below).

Thank you for your comments on the relevance of such a study though we are sorry that you find the structure to be complex, that many figures are in the supplemental material, and that the selection criteria are not quite clear. We understand also that you would like to see a more rigid statistical approach. We will address your comments below and this will hopefully address these concerns.

Some parts on the interpretation of oxygen isotope values in section 2.1 should be moved to section 3. Furthermore, stronger emphasis should be given to the number of dates and sampling resolution of the selected key-records.

Section 2.1 gives only very concise interpretations as a justification for selecting the boundaries of different regions. The actual interpretations are elaborated in Section 3.

We fully understand your concerns regarding dates and sampling resolutions, especially given the nature of this study. That is why we have tried to balance the use of available records with uncertainties generated by low resolution records and those with poor age control. We had 2 choices with record selection, one was to select only the highest quality records at the risk of losing regions from the analysis, and the other was to consider the best records from the different regions with due consideration for their resolution (figures with low resolution records include sample points as markers where uncertainty grey bars are not available) and age control (all U-Th sample points and error bars for every record considered in the manuscript are shown in Figure 2 of the main manuscript and Supplementary Figure 2). We have gone with the second option. In addition to the more regular time series figures, Figure 7 explicitly highlights how the uncertainties in age control may be hindering our understanding of climatic events surrounding Terminations. We also provide uncertainty numbers in the text. Indeed, one of the goals of the manuscript is to highlight where records are available but could do with improvement in resolution and age control.

Many other speleothem records were not really considered in this overview, despite the fact that they could contribute some important additional information on the timing and nature of certain terminations. For instance the timing of the onset of stalagmite growth, e.g. the Sieben Hengste (Switzerland) record covering TII (Luetscher, M., Moseley, G.E., Festi, D., Hof, F., Edwards, R.L., Spötl, C., 2021. A Last Interglacial speleothem record from the Sieben Hengste cave system (Switzerland): Implications for alpine paleovegetation. Quaternary Science Reviews 262.) This record is very well dated and covers Termination II. Within the Alps, the Schafsloch record (Hauselmann et al., QSR, 2016) from Switzerland covering TII is not even mentioned in the text. There are also other speleothem records which could be useful and suited for this review, even if they cover only parts of

a Termination. I think the authors should have done a more comprehensive review of the existing literature. Though some of the records are shown as supplemental figures, it appears that the selection of records in the main text is somewhat arbitrary. Furthermore, the fact that many important figures are shown in the supplemental information doesn't really increase the readability.

The Sieben Hengste record is indeed an excellent one. We have plotted the original record in the supplementary information and the ice-volume corrected record in the main manuscript Figure 4. Based on Reviewer 1's comments, we have also explicitly stated this in subsection 2.2. This may be confusion created because it was not plotted in Figures 1 and 2 or shown in Table 1. We are sorry about this. The figure was getting too crowded to show the Abaliget, Sieben Hengste and Schneckenloch records. Therefore, we show the Abaliget record which covers the whole Termination with reasonable resolution and age control (as per our record selection criteria) in Figure 2 along with its age control, and do the same for the Sieben Hengste and Schneckenloch records in the Supplementary Information. The Schafsloch record is a really nice one as well and one of the first covering this time period from the region. We were already showing the Abaliget, the Sieben Hengste and the Schneckenloch records from this region in the manuscript. The Schafsloch record is of excellent quality but covers a shorter time period than the 3 other records already in the manuscript, that is why, as per our sample selection criteria, this record has not been shown.

We believe that we have been as comprehensive as reasonably possible for this manuscript. SISAL is the largest speleothem database, and as mentioned in the manuscript, the database was built parallel to working on this project so that we have made every effort to track down speleothem records covering Termination TII through TV. We have mined the database systematically for any record within the Termination time periods and selected the most suitable ones (per our criteria given in the Methods section) for further discussion in the manuscript and Supplementary information.

The selection criteria of records are certainly arbitrary in the sense that it doesn't follow rigid criteria of a particular number of U-Th ages or a particular resolution. As we mention in the previous comment, we did this so that we could consider more records from more regions with due consideration for linked uncertainties.

We spent quiet a lot of time debating which figures should go in the main manuscript and which should go in the supplementary information. We would be happy to add more figures to the main manuscript perhaps also aided by the Editor's suggestions.

It remains unclear to what extent different age models (COPRA/Bchron/Stalage etc.) have an effect on the timing of Terminations and it would be useful to show the effects on 2-3 records in the main text. If the effects are minimal, then one can exclude at least on potential source of uncertainty.

This is a really good point, and as you say, merits more work. For example, Figure 2 in Perez-Mejias et al, 2017 highlights the difference in modeled ages based on two age depth models, OxCal and StalAge, even in records where the uranium-thorium ages have low uncertainties. In this case the authors have elected to use a mixture of age-depth model methods for creating the final age model. It is for nuances like this that we choose to use the author generated age models as a priority as long as the authors have provided uncertainty data.

There is a non-trivial amount of analysis to be done using a function like change point and taking into consideration the uncertainties from all the age depth model ensembles. This work could also

consider millennial events surrounding Terminations. This is work we hope to do in the future and has been listed in the future work section. That analysis is beyond the scope of this manuscript. In this manuscript, we take the first steps i.e. (i) plotting the U-Th sample points with their measured uncertainties, (ii) indicating some low-resolution records and (iii) showing uncertainties resulting from age-depth models on the figure (iv) author-generated or the same age models wherever possible to try and minimise uncertainties resulting from the use of different age-depth models.

A stronger consideration of carbon isotope records would be also useful, particularly for speleothem records from temperate regions where vegetation and soil microbial activity are highly dependent on temperature and rainfall. The full potential of the speleothem isotope records is not exploited

We agree with this comment. d13C is really an under-utilised proxy in speleothems. The limitation in including further records in these figures has been the availability of trace element or calcium isotope data to evaluate the PCP effects. We cite some excellent recent work making the most use of this proxy:

Genty et al, 2006

Lechleitner et al, 2021

Stoll et al, 2023

And we will add a point to the future work section as follows:

Speleothem d13C proxy records, particularly from temperate regions, are showing great promise in reconstructing past changes in temperature and rainfall when coupled with other proxies such as Mg/Ca and dCa. Such records from the particularly data dense Northern temperate regions would add great value to research on Terminations.

Is section 2.3 really necessary as no 13C record is shown in the current version of the manuscript.

We are sorry for this confusion. The d13C records are mentioned in section 2.3 and the degassing corrected version of the records have directly been plotted in Figures 4 and 6. The correction itself is shown in Supplementary Figure 5 which is creating this confusion. We can move Supplementary Figure 5 to the main manuscript into Section 2.3. The Termination II La Vallina cave Garth speleothem record and the Termination III Ejulve cave Artemisa speleothem record d13C records have been discussed in the manuscript.

The Figure 7 is not always correct. For instance, for TII, there is only one temperature increase in Europe, whereas the text states “final step of temperature increase in Europe and North America” (lines 644-645. Please make sure that Figure 7 is indeed conform with the main text. Furthermore, please make clear how the amplitude of the change was calculated. Ice volume correction applied. In this figure, one could also display insolation forcing to reveal the phasing more clearly.

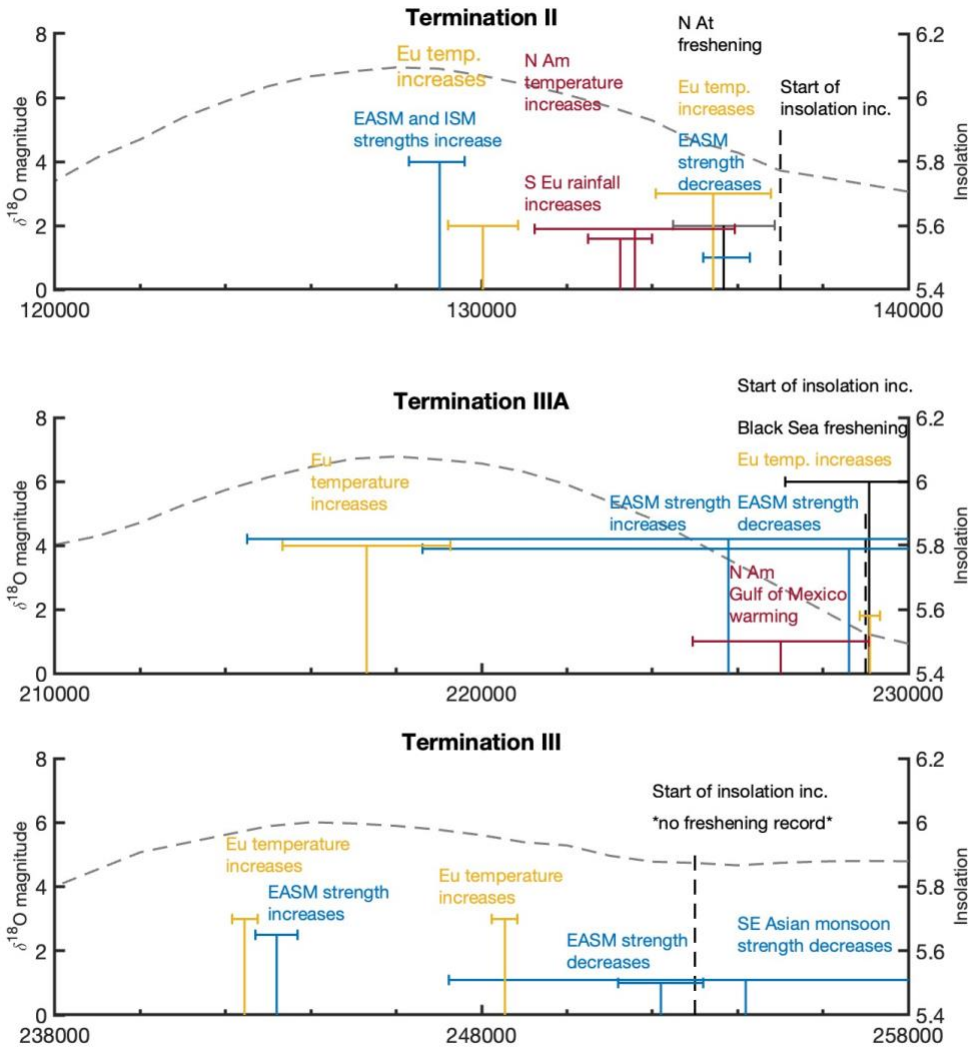
Thank you for spotting that. We have added the final step of temperature increase in Europe for Termination II now.

Figure 7 shows the amplitude as given in the individual Termination Figures 4, 5 and 6. And Figure 7 captures the climate changes from these figures that aid in the discussion of section 5.2. We have clarified this in the Figure caption now:

Figure 7: Sequence of **selected** global climatic events over Terminations. Ages and chronological uncertainties are represented on the X-axes. Amplitude of oxygen isotope changes that reflect the climatic events in speleothem records are plotted on the Y axes. **The amplitudes are taken from Figures 4, 5 and 6 for the respective Terminations.** The dashed line shows the start of insolation increase. [precip = precipitation; temp = temperature; N Eu = North Europe; S Eu = South Europe; N Am = North America; C As = Central Asia; ISM = Indian Summer Monsoon; EASM = East Asian Summer Monsoon; SE Asia = Southeast Asia; S Am = South America]

That's a really good idea regarding insolation! We will add that curve to the figure.

Thank you for your suggestions on this figure. These changes will make the figure much clearer!



The effects of the “ice volume-correction” should be also shown more clearly as this is an important aspect as ice-volume corrections can affect the overall structure of Terminations.

This may again be a case where we have moved some of the figures to supplementary information. The different sea level curves and ice volume effects of the different Terminations have been plotted in Supplementary Figure 3. The impact of the different ice volume corrections on all the records used in the main manuscript have been shown in Supplementary Figure 4. In the main manuscript itself, we have opted to show only the main record figures. So that the uncorrected records are shown in Figure 2. And the ice-volume corrected records, where the corrections do indeed make a difference to the structure of the Termination, are shown in Figure 4 with the Y-axis labelled d18Ocorr.

Specific Comments:

Section 3.1 Records of surface ocean freshening: In this section, the Corchia Cave record should be also mentioned.

A careful comparison of the d18Osw (from foraminiferal d18O and Mg/Ca) and the d18O of Corchia stalagmites over the last deglaciation has shown that d18Osw is not the dominant control of Corchia d18O (Stoll et al., 2022), so we have not included it in this section. Thus, we retain the section as is and discuss the regional signal from Corchia.

Lines 120-121: What is the specific rationale behind the use of single records and not composite records? Composite records are considered to be more robust than individual records.
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Composite records and stacks have been known to increase the robustness of records by strengthening regional signals versus drip-site specific noise and by expanding chronological control. We elected to use single records because they gave us more information on age control and measured d18O values without having to account for modifications made to either during the process of creating composites.