Clim. Past Discuss.,
https://doi.org/10.5194/cp-2020-145-AC2, 2021

Interactive comment on "Precise timing of MIS 7 sub-stages from the Austrian Alps" *by* Kathleen A. Wendt et al.

Kathleen A. Wendt et al.

kathleen.wendt@uibk.ac.at

Received and published: 5 March 2021

We greatly appreciate the excellent insight provided by reviewer #2. Below is a list of individual comments and questions followed by our responses:

1. In my opinion, the authors misuse the terms 'transition' and 'termination'. The point I want to make is that speleothems do not preserve terminations or other MIS transitions per se. Ocean sediments do

We agree that our interpretation and use of the term "termination" was used too liberally in our original text. As the reviewer correctly pointed out, this paper is a study of d18O changes speleothems from the central European Alps. Although evidence suggests that Spannagel d18O is highly sensitive to changes in the North Atlantic realm,

speleothems (as with all terrestrial archives) cannot be used to directly date changes in the ocean-cryosphere system. To this end, we have revised the manuscript to avoid such sweeping statements. We also expanded the first paragraph of our discussion section (starting on line 156) to emphasize that Spannagel d18O records the regional expression of climate changes associated MIS 7 sub-stages and terminations.

2. The authors do refer to ocean records in the ms (LR04, MD01-2444: Figure 4) but do not determine exactly how the Alpine speleothem 18O proïňĄle links to these records, apart from references to alpine warming coeval with SST increases (and the converse). . . The case for a link between the cave and ocean records through the whole time interval must be better developed.

We agree that an expanded discussion of this topic is needed. North Atlantic sediments show clear evidence of SST warming and the deposition of ice-rafted debris associated with TIII and TIIIa (e.g. Martrat et al. 2007; Channell et al. 2012). The onset of these oceanic changes occurs within age uncertainties with an abrupt enrichment of d18O in Spannagel speleothems. The temporal agreement between marine and terrestrial records suggests that warming in the North Atlantic realm associated with TIII and TIIIa triggered warmer winter temperatures in the European Alps. This pattern is consistent with later terminations (e.g. Spötl et al., 2002 Geology). It is also clear, however, that Spannagel d18O does not remain coupled with North Atlantic SSTs throughout the entirety of MIS 7, such as during MIS 7d. This observation highlights the multiple driving forces that influence winter temperatures in the central Alps. We have added a discussion of the complex link between the North Atlantic and central Alps in the first paragraph of the discussion section.

3. Regarding the interval of stable d18O values between 247 and 242 ka: to which part of the ocean record does this correspond? Is it the 'late MIS8 glacial' before the termination actually starts (it would seem so, based on the authors' claims of a short termination that starts after this isotope plateau), or is it really part of the period of ice-sheet melting associated with the termination, as implied in Cheng et al. 2016 and

2009, and Pérez-Mejías et al. 2017? If the latter, which in my opinion (based on all the evidence) is more realistic, the quoted ages and durations of T3 and potentially other transitions listed in table 1 have little meaning.

We agree - our record cannot rule out the possibility that the depleted isotope plateau between 247 and 242 ka is associated the onset of ice sheet melting associated with TIII. It is therefore incorrect to define the timing and duration of TIII in the strict terms outlined in our first draft.

To avoid confusion, we have re-worded table 1 (see attached) and adjusted our wording throughout the text to emphasize that the well-dated shifts in Spannagel d18O may reflect the precise timing of climate changes in the North Atlantic realm during TIIIâĂŤbut that they cannot define the exact ocean-cryosphere changes forcing them.

4. From what I can determine, it seems that the speleothem did not even capture all of T3, if you take into consideration previously published speleothem records (Cheng et al. 2009 and 2016 and Pérez-Mejías et al. 2017). It obviously captures all of 7e, the 7e/d transition and the 7d/c transition (T3a), etc. but exactly how do the boundaries of these transitions in the ocean record tie to the speleothem 18O?

If one defines TIII as the period of maximum IRD deposition in the North Atlantic between 243-240 (e.g. Channell et al. 2012), then the period between the onset of speleothem deposition at 247.3$\pm$0.2 ka and the abrupt 3‰ increase of Spannagel d18O from 242.5 to 241.9 ($\pm$0.3) ka is well within uncertainties of the IRD deposition event. This time frame is also consistent with the abrupt changes with vegetation productivity in the Iberian Peninsula (241.6–240.7 $\pm$1.6 ka; Pérez-Mejías et al. 2017) and Chinese Monsoon intensity (242.8–241.01 $\pm$0.9 ka; Cheng et al. 2009, 2016) – both of which are interpreted by the authors as the periods of maximum North Atlantic warming associated with TIII. Spannagel may not cover all of the earlier events leading up to TIII, but we disagree with the statement that Spannagel does not fully capture TIII.

5. In the context of the above, I would like the authors to carefully consider exactly what

the abrupt speleothem 18O changes mean at this high altitude cave? For instance, are the abrupt increases examples of Bølling-Allerød-like or YD-Holocene-like events? Hard to say – age uncertainties, although small in percentage terms, are still too large to test whether the true duration of these events are comparable. But this is tantalising and really important because it implies that T1 was not alone with its two rapid NH temperature jumps, and that T3 likely had at least one comparable rapid warming (at least in this part of the N Hemisphere) well after it started. We know from T1 that the BA transition occurred âĹij5 kyr into the termination.

Comparisons of the millennial scale shifts in North Atlantic climate have been previously examined in Pérez-Mejías et al. 2017 and Cheng et al. 2007. For example, Cheng et al. 2007 define the timing of weak and strong monsoon intervals: YD-III and BA-III. Pérez-Mejías et al. 2017 suggest that the S8.2 IRD event in the marine record triggered Heinrich Stadial-like conditions in southwestern Europe, similar to Heinrich Event 1 prior to TI and Henrich Event 11 prior to TII. Our findings support the timing of these shifts in North Atlantic climate. However, we agree with the reviewer that further comparison and discussion is needed in our manuscript. We have expanded the discussion of millennial scale events leading up to TIII in the "onset of deposition" discussion section (line 187). We also highlighted the intervals YD-III, BA-III, and Heinrich Event-like S8.2 in figure 5 and added an explanation to its associated caption.

6. There is an alternative explanation the authors should consider too: is the speleothem 18O acting like an 'on-off' switch, i.e. does it represent binary swings between (i) periods when the glacier is present above the cave (when basal meltwaters with low 18O values derived from strongly 18O-depleted glacial or stadial snowfall occurring 1000-1200 m higher than the cave itself, near the Hintertux glacier summit âĹij3500 m a.s.l.) and (ii) periods when the glacier retreats during interglacials and interstadials and exposes the cave recharge area to direct inïňĄltration (at âĹij2300 m) of isotopically enriched rainfall and in situ snowfall? This could explain the almost square-wave form and amplitude of the speleothem isotopic series (otherwise for the

MIS7a-MIS6 transition, for example, we must consider 20 deg C or more of temperature depression plus a little extra for possible changes in moisture source, given the >6 per mil decrease in speleothem 18O). This raises the question of whether the sharp increases and decreases in d18O are really a local effect of ice retreat, whose phasing with respect to regional warming and cooling (e.g. the rises and falls in SST in MD01-2444) is not as closely coupled as the authors think.

The reviewer proposes an interesting hypothesis. However, several lines of evidence argue against this. As outlined in Spötl et al (2008), there is strong evidence that the cave was continuously buried by the local glacier during MIS 7 (and actually most of the Pleistocene – see Spötl & Mangini, 2007 EPSL). The sampling location of SPA 121 was underneath glacier ice up to the end of the 19th century and was very close to the ice margin still at about 1920 AD (i.e. well within an interglacial).

It is incorrect that the precipitation that fed cave dripwaters fell 1000-1200 m higher. The highest summit of Hintertux glacier (Olperer) is 3476 m, whereas the glacier basin (main accumulation area) is located at about 2800-3000 m. This is only a few hundred meters above the speleothem sampling site.

Another line of evidence is that the C isotope composition remains within the limited range of host rock values over tens of thousands of years (except for some of the cold periods when we see high values, which are very likely kinetically controlledâĂŤas discussed in the responses to reviewer #1). If the area above the cave would have become deglaciated e.g. during MIS 7a, we would expect colonization of alpine vegetation above the cave within a few decades, as shown by many recent observations. This would result in a drop in d13C values, which is not observed. The reviewer also mentioned the possibility of intermittent waxing and waning of the Hintertux glacier, thereby resulting in meltwater and sediment pulses. While this is an interesting to consider, there is currently no evidence in the petrography of the stalagmite nor in the d18O values for melt water pulses.

Regarding the large decreases in d18O: TII records from Spannagel show a shift of about 3.5 to 4 per mil (Spötl et al., 2002 Geology; Holzkämper et al., 2004 GRL). This amplitude is similar to the shifts observed in SPA 121 during MIS 7, with the exception of the 4.5 per mil decrease at the end of MIS 7a. Following the termination of SPA121 growth, an additional 1.5 per mil decrease is recorded in stalagmite SPA 183 – resulting in a 6 per mil decrease in d18O between MIS 7a and 6. The difference in absolute d18O values between SPA 121 and SPA 183 was previously addressed in reviewer 1's responses. In short, we interpret the cumulative 6 per mil decrease as a signal for regional cooling that was amplified by kinetic isotope fractionation effects.

Interactive comment on Clim. Past Discuss., https://doi.org/10.5194/cp-2020-145, 2020.

Marine Isotope Stage	Onset of associated climate changes in the European Alps (ka)
TIII	242.5 ±0.3
MIS 7e	241.8 ±0.3
MIS 7d	234.3 ±0.3
TIIIa	216.8 ±0.3
MIS 7c	215.7 ±0.4
MIS 7b	211.7 ±0.4
MIS 7a	201.8 ±0.3
MIS 7/6 transition	197.1 ±0.2

Fig. 1. Table 1: The onset of regional climate changes associated with MIS 7 sub-stages and the MIS 7/6 transition, as defined by the Spannagel δ18O record (see text for detailed definitions).