

Paleoclimate in continental northwestern Europe during the Eemian and Early-Weichselian (125-97 ka): insights from a Belgian speleothem

By Stef Vansteenberge, Sophie Verheyden, Hai Cheng, Lawrence R. Edwards, Eddy Keppens, and Philippe Claeys

This manuscript provides a valuable contribution to our understanding of climate change in NW Europe during the Last Interglacial. The authors have done a thorough analysis of stalagmite Han-9 and worked to place this record in the context of other proxy records from Europe over this time interval. I feel that the manuscript should be published following moderate revision. There are grammatical mistakes throughout that I have partially addressed in my enumerated comments. The authors should run a spelling and grammar check to identify additional errors that I did not address. Some of the key figures, particularly the age model and Fig. 7 require additional notations/interpretations to support the discussion and Fig. 6 is redundant (as the same data appears in Fig. 7) and should be deleted. I feel that the discussion regarding interpreting the stable isotope data could be more streamlined and the authors need to be consistent about how they interpret these isotopes. I have suggested adding interpretation notation onto Fig. 7 to help the reader (and the authors) understand the interpretations. Particularly the discussions of $\delta^{18}\text{O}$ are somewhat contradictory and inconsistent. The age model is also a source of concern, particularly after Growth Hiatus II. I suggest possibly eliminating (or substantially reducing) discussion of the isotope data after Hiatus II due to dating uncertainties. I suggest that the age model across Growth Phase II could also be improved. As for Fig. 7, the authors need to add a few additional records and reorganise to help with their interpretations and better support their discussion. I believe they have de-emphasised the Han-9 data in Fig. 7 and this should be remedied by reorganising the records and setting all Y-axes to the same length. With some additional work, this record could provide a valuable contribution to our understanding of European climate during the Last Interglacial.

General Comments

Section 4.1 Speleothem morphology: This entire section is rather unclear.

The U/Th dates between 0 and 176 mm dft are unusable. I recommend not interpreting your record past Hiatus 2.

I lack confidence in the Hendy Tests (see Dorale and Lu, 2009). The first potential problem is that the drill bit is 300 microns and the reported growth rates are 20, 40 and 150 microns. This suggests that at worst the authors are averaging 15 years and at best, 2 years. Another potential explanation for the very flat Hendy Test results for $\delta^{13}\text{C}$ is that these tests only extend to 15 mm from the central growth axis which is likely within the splash cup and not enough distance (even under conditions of kinetic fractionation) for degassing to occur as the drip progresses toward the flanks. Also, the variability in the $\delta^{18}\text{O}$ data along a (presumably) single growth axis is nearly 25 % of the total $\delta^{18}\text{O}$ variability through time. This is less than inspiring. I suggest that a better test for kinetic fractionation is to look at how $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ covary (or anticorrelate) over the length of the record. Superficially I did this and it appears that there are intervals of strong anticorrelation such as during the 'Eemian Optimum' and other periods of covariation such as after Hiatus II. Perhaps a running

Pearson's could shed some light on when conditions favoured kinetic fractionation and this in itself provides valuable climate information. The presence of kinetic fractionation really only comes into play when aiming to apply the palaeotemperature equation. If this is not the goal (and I believe it is not here) then the presence or absence of kinetic fractionation does not rule out but can contribute information to the overall palaeoclimate interpretation.

For the Age Model, the authors might want to try COPRA to see if it handles the hiatuses better. Did the authors run StalAge over the two growth intervals separately? I don't see why StalAge would interpolate incorrectly over the last 2 dates in Growth Phase II if it were run over the two growth intervals separately. I suggest that short of trying COPRA, the authors should rerun StalAge over Growth Interval II alone and see if the age model is more true to the U/Th dates and errors over that interval. I think that the current linear interpolation is unsatisfactory. Again, I would limit discussion of Growth Phase III due to dating uncertainties.

Section 5.3 'A late onset of the Eemian' seems to be special pleading. Han-9 begins growing during the Eemian....in fact, well into it. I don't think there is enough evidence to support a late onset and would delete any of the discussion to this effect.

Discussion of controls on Han-9 $\delta^{18}O$: 1) Lower T will cause lower $\delta^{18}O$ due to rainout, distillation, etc. 2) ice build-up will sequester ^{16}O , leaving behind a higher ocean $\delta^{18}O$ (source moisture) and driving rainfall $\delta^{18}O$ higher, 3) lower T would cause lower in-cave T and drive stalagmite $\delta^{18}O$ higher (Craig equation) but this effect is trivial. Effects 1 and 2 act against each other but one would win out (unless they cancel each other out entirely!). It is likely that lower T and increased rainout/fractionation will win, and rainfall (and thus Han-9 $\delta^{18}O$) will be more negative during colder conditions. It seems that the authors are arguing both sides in the manuscript but they need to pick one interpretation that applies to the whole record.

It's interesting and somewhat puzzling that Han-9 growth seems to be restricted to intervals between Insolation max and mins but not during (i.e., no growth centred on 104, 115, and 127 kyr). It would be interesting to know if there is some explanation for this.

The authors use 'ka' and 'kyr BP' in the manuscript. Select one and be consistent throughout.

I find the match between Han-9 $\delta^{13}C$ and the pollen record particularly compelling at least until Growth Phase III when dating (and possibly the data) inaccuracies dominate.

I disagree with stating that the start of Hiatus I marks the 'end of the Eemian', (such as the authors have done in the Conclusions and possibly elsewhere), rather, the authors could state that Han-9 ceases growth (Hiatus I) at 117.3 kyr, before the end of the Eemian as recorded by other proxies (references) suggesting that a critical threshold was reached in which conditions no longer favoured Han-9 deposition. This was possibly linked to a change in vegetation dynamics.

Enumerated Comments

Line 15: suggest changing to 'the Alps' rather than 'the Alpine region'. Change throughout.

Line 20: change 'content' to 'composition'

Line 22: delete 'the' before 'Han-9 growth'

Line 27: change 'the speleothem d13C' to 'Han-9 d13C' and change 'a stop in' to 'cessation of'

Line 28: change to 'suggesting a transition to significantly drier conditions'

Line 29: delete 'the' between 'both' and 'isotope'

Line 30: reference to 'stalagmite morphology' in this sentence seems out of place. What about it?

Line 38: change to 'were similar to or higher than those of the Holocene period and Present Day'

Line 62: change 'scaled' to 'scale'

Line 68-69: remove 'the' before AMOC and Atlantic Meridional Overturning Circulation.

Line 76: change to 'Speleothems are ideal for' and 'the ability to construct accurate'

Line 77: change to 'their potential to yield high resolution (up to seasonal scale) palaeoclimate records'

Line 77: Change to 'Several stalagmite stable isotope proxies from Europe record optimum climatic conditions during the Eemian (Meyer et al, 2008; Couchoud et al, 2009) and D/O climate events during the Early Weichselian (Bar-Matthews....)'

Line 84: change to 'Belgium that expands the European'

Line 109: change to 'consists of C3 type'

Line 115: change to 'facilitating access'

Line 129: change to 'provided a solid foundation for understanding'

Line 134: change to 'age-depth model with additional sampling locations selected based on the preliminary age model and the...'

Line 145: Change 'In function' to 'As a function'

Line 153: Sentence beginning 'Every eight samples' is unclear. Rephrase this sentence. How was a double measured in a 'different batch' every 8 samples???

Line 161-2: Change to 'up to 365 mm dft, the calcite was well-laminated alternating between thick whiter and slightly darker layers.'

Line 163: change to 'stalagmite. From 365 mm dft, the calcite becomes progressively...'

Line 174: Change to '..present. Thin-section locations were chosen as representative of the typical morphologies displayed in the ...' See Comment for Fig. 3

Line 186: Change to 'The results of U/Th dating are shown'

Line 196: Change to '....with an average of -5.91 %'

Line 197: Change to 'lower amplitude variability in both d13C and d18O occur in the lower part ...'

Line 198: Change to 'present from ~400 mm dft upwards, corresponding to a distinct transition in morphology.'

Lines 219-221: This discussion of why a linear interpolation is justified is unclear.

Line 229: I suggest the authors revisit the age model over this interval as suggested in the general comments. This will likely change the growth rate reported here.

Line 248: Change to 'more specifically, less respiration'

Line 250: Change to 'This interpretation has also been attributed to d13C excursions...'

Line 254: Change to '...discrimination, in which changes of up todiscrimination (Wong and Breker, 2015).

Line 259: This is a very negative view of d18O in speleothems. I suggest rewording this sentence to something like "In mid-latitude Europe, several different processes (including temperature and precipitation) influence speleothem d18O variability (McDermott, 2004).

Line 264: change 'whereas' to 'and'

Line 266: Sentence starting with 'Combining these data...' does not make sense to me. Rephrase.

Line 274: change to '...an interglacial-glacial transition, other processes acting on longer timescales (i.e., fluctuations in global ice-volume) should also be considered.'

Line 283: Change to 'per mil'

Line 284: Change to '...the influence of glacial/interglacial and stadial/interstadial transitions on vegetation type.'

Line 286: Change to '...is interpreted to reflect vegetation activity in response to changes in temperature and precipitation.'

Line 305: Change to 'prior to the start'

Line 306: Change to 'In the BDInf speleothem from southern France (Couchoud et al, 2009) (Fig. 1 A), the ...'

Line 309: Change to 'Eifel Maar record (Sirocko et al., 2005), located only ...'

Line 335: I would say 'gradual decrease in stalagmite diameter' because it is not particularly striking in Fig. 2.

Line 338-9: Change to '...speleothem morphology support an increase in speleothem growth rate, possibly in response to an increase in'

Line 355: Sentence fragment starting 'As the increase....' Rephrase.

Line 367: I would add in here a mention of MD03-2664 once it is added to Fig. 7

Line 386: Change to 'long-term increasing trend until....'

Line 387: Change to ‘..trend, sub-millennial scale variability ranging between....’

Line 388: I would argue that the long-term trend is still visible in d18O over this interval and that d13C and d18O are strongly anticorrelated (something that your running Pearson’s will reveal). The pattern of d18O and d13C variability will be more obvious when you expand the y-axes in Fig. 7. Again, I would highlight the time intervals you are discussing in the main text so that it is easier for the reader to cross reference.

‘Both minima’ –this is incorrect. D13C exhibits a maximum close to -4 per mil while d18O exhibits a minimum close to -7 per mil.

Line 427: Change to ‘...resulting in a longer duration of the Eemian according to other records’

Figures

Figure 3: Figure 2d shows 6 thin sections. Which ones are shown here in A-C. Suggest labelling Fig. 2d more clearly so one can more easily cross reference Figs. 2d and 3 A-C.

Figure 5: The section after Hiatus 2 is almost unusable. The error envelope shown (grey shading) does not cover the entire interval of age inversions and increased dating error. This needs to be expanded to cover the whole interval. I recommend excluding this growth interval from your discussions/interpretations. There is nothing obvious in Table 1 to explain why the dating is so imprecise over this interval.

Also, in Figure 5, it would help if the authors would label the datapoints. The Age model discussion in section 5.1 refers to DAT-#'s quite a bit and it would help if the reader could make quick reference to a well-labelled Fig. 5.

Label Fig. 5 growth intervals and growth rates

Figure 6: This figure is redundant considering that the same data are provided in Figure 7. I suggest deleting. In Figure 7 just darken slightly the non-averaged d18O and d13C curves...they are a bit too light to see right now.

Figure 7: This figure is not very well laid out and could be vastly improved. The Han-9 data is minimised with compressed axes while the previously published datasets are at the forefront. Consider compressing the published data and expanding the axes on the Han-9 isotope data. I suggest making all of the axes the same length.

It might be informative to move the Insolation record down over (or between) the Han-9 datasets.

The U-Series datapoints should be plotted on 2 lines only (or one when they are not overlapping). The way they are now, suggests that there is some monotonic increase through time. Misleading.

I suggest adding in the Yuan et al 2004 Dongge Cave data. I know this is a SE Asian Monsoon dataset but it tracks Greenland ice core data quite well and could help fill in some blanks.

Add interpretations to figure. For instance, along axes like Han-9 d13C add down arrows (towards heavier d13C values) labelled with ‘increasing C4 plants’, ‘Colder/drier’, and ‘increasing PCP’,

'decreasing soil bioproductivity'. For Han-9 d18O add down arrows (towards lighter d18O values) decreasing ice volume

Make certain that all axes are pointing in the correct direction regarding a uniform interpretation for the figure.

The authors highlight the hiatuses but not the actual climate info. I suggest just labelling the data breaks as 'Hiatus 1' and 'Hiatus 2' (if the authors choose to keep growth phase III), but using shaded rectangles and more obvious labelling to highlight the climatic episodes discussed in the text (i.e., the Eemian climatic optimum from 120 to 125). Perhaps helpful to the reader would be to have the climatic periods identified (for instance in Paragraph 1 of the Introduction) in horizontal shaded rectangles at the bottom of the figure below the pollen data.

In caption add d18O to 'NALPS speleothem record'. Add (SST) after 'Sea Surface Temperature' in B) if this is the first mention. Otherwise, just use SST.

I suggest adding in the Irvani et al 2012 Fig. 3 b MD03-2665 Planktonic d18O record to Fig. 7, possibly overlapping with the Sanchez and Goni SST record. There is a lot more detail in the Irvani record and it is discussed in the text.