Clim. Past Discuss.,
doi:10.5194/cp-2016-135-AC1, 2017

Climate of the Past Discussions
Open Access
EGU

Interactive comment on "Hydroclimate of the Last Glacial Maximum and deglaciation in southern Australia's arid margin interpreted from speleothem records (23–15 ka)" *by* Pauline C. Treble et al.

Pauline C. Treble et al.

pauline.treble@ansto.gov.au

Received and published: 30 March 2017

Anonymous Referee #1 Received and published: 27 December 2016

General Comments High resolution and precisely-dated records of hydroclimate variability spanning the LGM to present across the southern and central portions of Australia are important but rare. This stalagmite record helps fill that spatial and temporal gap. The study rests on a foundation of data (the stable isotopes and trace element analyses are robust) and the dates are as good as can be expected given the constraints of the stalagmites (low 238U and moderate to high 232Th). The study is limited

Printer-friendly version

Discussion paper

by a lack of observational data for the cave environment, dripwater, and precipitation. The claim that tropical moisture can regularly supply moisture as far south as this cave site is, to me, quite a remarkable claim and is an interesting argument that should be tested, perhaps by a modeling study.

Response: We thank Reviewer 1 for their positive comments above and the highly constructive comments that follow. We agree that a modelling study is worthwhile but is outside of the scope of this current paper. We will add to the Conclusions that a future modelling study is warranted. Lead author Treble recently presented this study at the Australian Meteorological and Oceanographic Conference (February 2017) where she discussed the need for a follow-up modelling study. She has spoken to a number of modellers who are indeed interested in following this up. In the context of this current study, we highlight that modelling studies by Lee et al. (2011) and Sime et al. (2013) have been cited in the paper and the model study by Mohtadi et al. (2014) will also be added, following Reviewer 4's suggestion. These models show that the ITCZ was displaced southwards during HS1, consistent with our observation of greatest recharge to Mairs Cave, hence strengthening our interpretation that tropical moisture is involved. In Section 2 'Regional setting' we describe how tropical moisture is implicated in the majority of recharge events to the location of Mairs Cave in the present day, and that it dominates the moisture input derived from the westerlies (the study by Pook et al., 2014 was cited). Thus tropical moisture indeed reaches this far today and presumably could have in the past, particularly during periods such as HS1 when the ITCZ was displaced further south.

In terms of presentation, the writing is somewhat formulaic and the figures – particularly the two composite data plots (Fig 3 and 6) – fail to paint a clear picture or advance an argument. These should be reworked to more clearly articulate the idea they are designed to promote. Figure 1 should be expanded to include some of the geographical landmarks mentioned in the text.

Response: Locations Naracoorte, Kangaroo Island, Strzelecki Desert, Lake Mungo

and the location of the marine core from Mohtadi et al. (2014) will be added to Fig 1. Other sites mentioned in the text already appear on Fig 1. See response to specific comments by Reviewer 1 regarding Figs 3 and 6 below, also responses to Reviewer 2 (comment 4) and Reviewer 3 (comment on L245).

Specific Comments 31 – “prevented” might be too strong a word to use here. Marine sediments record continentally-sourced eolian debris that track atmospheric circulation quite well. Response: ‘prevented’ will be replaced with ‘hindered’.

37 – Interpreting flood layering as a signal of enhanced recharge is not necessarily straightforward. The hydrological response of catchments and streams to extreme rainfall events during overall dry intervals, for example, can be quite distinct and more severe than during overall humid intervals thanks to a number of complex geomorphic feedbacks and/or changes in the seasonality of these rainfall events. It seems conceivable, at least, that increased flood events could represent extreme events during periods of enhanced aridity rather than enhanced rainfall. Response: We agree with Reviewer 1. At L37 (abstract), ‘enhanced recharge’ will be replaced with ‘recharge’. Interpretation of flood bands at lines 308-314 and 639-644 is consistent with the above.

39 – perhaps write “18O and 13C enrichment” rather than “isotopic enrichment” Response: We will replace with suggested.

41 – The nature of the changes in isotopes that accompany enhanced precipitation were described. I suggest also adding a phrase discussing what the nature of the calcite fabric changes are (e.g.., faster-growing, less dense, and less optically translucent calcite during periods of enhanced rainfall). Response: We will change line 41 to read ‘A hydrological driver is supported by calcite fabric changes. These include the presence of laminae, visible organic colloids and occasional dissolution features, related to recharge, as well as the presence of sediment bands representing cave floor flooding. A shift to slower-growing, more compact calcite and an absence of lamination is interpreted to represent reduced recharge.

55 – That tropical rainfall could influence Lake Eyre is reasonable given the size and location of its catchment. Rain can fall hundreds of km north of the lake. And clearly the ITCZ was pushed south during periods such as HS1. But is there any independent support (a modeling study, for example) for tropical moisture actually falling so far south? This seems remarkable and difficult to imagine. Response: A paper by Pook et al 'A synoptic climatology of heavy rain events in the Lake Eyre and Lake Frome catchments' was cited in support of tropical moisture being a significant contributor to recharge events to Lake Frome under modern boundary conditions. The Pook paper is referenced in Section 2 'Regional Setting' at lines 234 and 240 and again to support our arguments in the Discussion at lines 875 and 970. To strengthen this argument, we will add the following to the Regional Setting: 'In a study of the synoptic climatology of heavy rainfall (>25 mm/day) to this region (Lake Frome) over the period 1950-2014 (n=25), Pook et al. (2014) demonstrated that 53% of these events involved tropical and/or a pre-existing subtropical cloudband.' The Pook paper clearly support that tropical moisture can indeed reach this far, that it is implicated in the majority of recharge events to this region, and that it dominates the moisture input derived from the westerlies.

93 – This kind of discussion is somewhat problematic as it seems to suggest that the Westerlies exist in one of two different "mean states" when in reality, couldn't they plausibly contain the same average position with some time periods being characterized by considerably greater spatiotemporal variability. Response: We agree, although in this case we are simply presenting the interpretations given by previous studies for the benefit of outlining existing data in the Introduction.

115 – At least at present. There were long stretches of time when Lake Eyre was massive and presumably the shape and location of the boundary between the dry interior and the wetter continental margin was profoundly different. Response: We will insert 'presently' after 'Southern Australia'.

136 – It is awkward to use the phrase "relatively small catchment" to describe the few

tens of square meters of landsurface that represents the catchment for a speleothem after discussing the hundreds of thousands of square kilometers of the Lake Frome catchment. These scales exist in different universes. By this standard, speleothems have pin-point, microscopic catchments. Response: Agree, we will re-phrase point i. to read 'being recorders of local recharge,'

197 – higher ET and not simply higher precip? Response: We are unsure what is being referred to here as L197 reads 'This was attributed to higher recharge owing to reduced evapotranspiration.' We will change to 'owing to increased effective precipitation as a result of reduced evaporation' which is consistent with the wording in Ayliffe et al. (1998) which is the study being referred to here.

213 – Each cave has its own distinct hydrological characteristics, and at finer scales, hydrology can vary within a cave. At this point, I am somewhat skeptical of the utility of a distal (1000 km away) cave as a proxy for Mairs Cave. Response: We agree that hydrology can vary significantly between and within cave systems owing to variability between karst hydrological flow paths, as Reviewer 1 points out here. However, the processes that we are referring to from the Wellington monitoring study is the resulting non-linear relationship between climate and drip/speleothem isotopic data in semi-arid regions, owing to evaporation of water held in karst stores between recharge events and recharge thresholds required to replenish karst water stores, as outlined in lines 160-180. All flow paths that result in speleothem growth, store water in the vadose zone, otherwise it would be highly unlikely that continuous speleothem growth would result, particularly in semi-arid regions. We therefore argue that the processes identified in the Wellington study are highly applicable to this study.

245 – the reader would benefit from a more detailed explanation of the IOD, ENSO, and the interaction between the two and its impact on regional climatology. Response: Following from the additional text that we will insert in the site description (see response to L55 above), 'In the Pook et al. study, 90% of the heavy rainfall events that fell over the Lake Frome catchment occurred when the Southern Oscillation Index was in a positive

(towards La Nina) phase.' IOD events are defined L236-239

249 – what is the importance of the rainfall coming first from the Indian and then the Pacific ocean? This section seems to end abruptly. Response: We will expand this sentence to read 'Eighty percent of the resulting rainfall came from the eastern Indian Ocean during the first four days before switching to the western Pacific Ocean, as shown by trajectory analysis (Figure 1d).'

442 – doesn't fluid thickness reflect the geometry of the stalagmite growth surface as much as it reflects drip rate? Response: We will add several further sentences and references to explain the relationship between crystal tips and the thickness of the growing film. This will strengthen our interpretation of relative changes in drip rate from crystal tip morphology.

452 – is this 0.3‰ offset a function of the discrepancies between the two stable isotope labs? Response: See L338 in Methods: 'Reproducibility between instruments was cross-checked by running aliquots of fifteen MC-S1 powders on each instrument resulting in <0.2‰ offset (ïĄď18O and ïĄď13C).'

466 – This is a pretty big offset. Could it be due to the different stable isotope labs? Response: See above. What about effects of growth rate on d18O as have recently been discussed? Response: Day and Henderson (2011) investigate this effect on calcites grown under laboratory-controlled conditions for temperatures ranging from 7-35°C. Importantly, they show that this effect is important for warm caves only. No offset was observed at 7°C which is close to the estimated temperature of Mairs Cave at the LGM (MAT=17°C today minus LGM lowering of 6-10°C).

475 – The figure does not really show such a correlations between the two stals. I would remove this line. Response: We will remove the word 'align' and replace this sentence as follows 'MC-S2 also contains similar features but a close comparison is hampered by the relatively poorer precision of the MC-S2 chronology over this interval.'

514 – Is there no way whatsoever to calculate expected calcite d18O values based on measured cave temp and regional precip d18O values? This is a much more reliable method than any sort of Hendy approach, in my opinion. Response: We agree that this is an appropriate approach when younger speleothem material is being interpreted and when rainfall isotopic composition is able to be determined at a cave site. Neither is the case for this study. Estimated LGM temperatures were 6-10°C for southern Australia, according to the literature (references given in manuscript). This in itself would translate to an uncertainty of 1‰Ȧdd to this, the much large uncertainty in the isotopic composition of the source (rain) water at the LGM, and this would result in an uncertainty of at least several per mil in this calculation – too large to address the question. A further point is that we argue in this study that rain δ18O has been modified by post-infiltration processes, adding further uncertainty to the above. Although there are limitations with the Hendy test, it is suitable for indicating whether isotopic fractionation is happening across the growth surface of the stalagmite. In this study, the parallel isotopic transects in the stalagmite indicate that this is not happening and hence further support our interpretation that the isotopic disequilibrium is occurring in the parent waters i.e. in the karst water store (see Discussion L617-620).

644 – Presumably these waters would need keep the stalagmites submerged for considerable lengths of time to produce noticeable corrosion. Response: We cannot determine this in the paleo record. Co-author Silvia Frisia has documented these sorts of fine dissolution features in after several months which could be consistent with sort of cave flooding that we are invoking here.

689 – I don't understand this line of reasoning? Rain that is 5‰ (!) lighter than normal is quite a marker. Response: We will clarify lines 686-691 to read 'However, we consider that in a semi-arid environment, moisture source variation cannot be reliably fingerprinted owing to the additional isotopic impact of evaporation of water in karst stores between recharge events (Cuthbert et al., 2014a,b), as well as the likely scenario that recharge will be biased to intense (δ18O low) rainfall events in order to over-

come non-linear karst recharge thresholds in environments such as these (Markowska et al., 2016). Thus, while the δ18O minima that occur throughout the Mairs Cave record are related to recharge, and the overall isotopic variability to water balance, the magnitude of these minima cannot be judged as an isotopic fingerprint i.e. tropical versus mid-latitude derived moisture, as in this environment, the isotopic relationship between climate and the resulting speleothem record will be exaggerated by infiltration and post-infiltration processes.' We will also strengthen our reasoning by adding 'resulting in 18O-enrichment of several per mil' after 'Cuthbert et al. (2014a,b) showed that dripwater δ18O may be dominated by evaporation of water held in karst stores,' at L173

906 – I need to see some additional evidence for such a dramatically southward displacement of the monsoon during HS1. If this were the case, there should be a good deal of geomorphic evidence from across the Australian center. What about a modeling study? Response: Please see our response to first comment from Reviewer 1 regarding modelling studies. We are uncertain as to what Reviewer 1 is picturing by 'a dramatically southward displacement of the monsoon during HS1'? The monsoon itself does not have to extend as far south as the cave location in order to generate recharge from tropically-sourced moisture. Today, tropical moisture regularly penetrates the continental interior as troughs, as outlined in the '2. Regional Setting' (lines 230-241). A more southerly-displaced ITCZ, such as during HS1, could raise the availability of tropical moisture to form similar features. This appears in the Discussion (lines 882-886). Regarding geomorphic evidence, such evidence is sparse as outlined in the Introduction. A comparison of our data and the existing (sparse) geomorphic data for the region is given in Section 5.2.1. The agreement between the records, in terms of highlighting a pluvial period is remarkable. For example, the growth interval of the stalagmites overlaps with a highstand at Lake Frome when the lake was 15-20 times modern volume between 18-16 ka. Today, the majority of intense rainfall events that fall over the Lake Frome catchment are derived from tropical moisture (see response to comment 55 above) and it is known from numerous studies that the ITCZ was displaced further

Printer-friendly version

Discussion paper

south during HS1 (see lines 840-856).

Figure 3 and 6 – It is difficult to understand what big picture argument is being made by these figures. They seem more like collections of data that do not necessary have much or anything to do with one another other. Additional information is required in the figure and/or the figure caption to tie things together. For example, the green rectangle is supposed to denote a wet period, but looking at the assembled data, I see no clear evidence to support this argument. Response: The data in Fig 3 are multi-proxy data from the same two speleothems. It seems illogical to say that they have nothing to do with each other. We believe that presenting multi-proxy data for speleothems, even if they are complex, offers a more robust opportunity to interpret speleothems. with regards to Fig. 3, the evidence from the Mairs Cave speleothems for a wet period during 18.9-15.8 ka is outlined in Section 5.1.2. With regards to Fig 6, this illustrates the comparison between the Mairs Cave data with regional data from other studies in Section 5.2.1 (the Flinders silts, the Lake Frome highstand, paleosol development in the surrounding desert) and with the tropical speleothem record and the southern Australian marine record in Section 5.2.2. The green bar in Fig 6 is an important graphical tool for highlighting the similarity in timing between the pluvial period interpreted in the Mairs Cave record that coincides with transitions in these other records, strengthening our argument that this region was wetter during this period. It is not important to have the green bar on Fig 3 and this can be removed. We will also implement the suggestions made by Reviewers 2 and 3 to improve the clarity of this figure and strengthen our interpretation.

Figure 5 – The spectral work seems to be thrown in almost as an afterthought. What is the relevance of these periodicities? The centennial variability is interesting but the spectral analysis doesn't really inform this part of the work. Response: The main purpose of the spectral analysis was to describe the main periodic components in the time series. Its inclusion here is justified by the appearance of patterns in the time series plots which look periodic and, by quantifying the periodicity, we hope that future

studies may more easily be able to compare with this site.

Technical Corrections 34 – reword as “providing for the first time a detailed: : :” Response: We will rephrase.

36 – delete “for the first time” Response: We will make this correction.

44 – I assume this means “16.0 ka”? Response: Apologies for the oversight, this will be changed to 15.8 ka.

78 – delete the semicolon. Response: We will make this correction.

82 – delete the comma Response: We will make this correction.

83 - delete the comma Response: We will make this correction.

84 – ITCZ already defined in Abstract. Response: We will make this correction.

86 – delete the comma Response: We will make this correction.

125 – replace the semicolon with a comma Response: We will make this correction.

126 – “contribute” Response: We will make this correction.

133 – This discussion should be accompanied by a map, perhaps as an inset in Figure 1. Response: We will add shading on Fig 1a to indicate the catchment area of Lake Frome.

137 – While “relative” refers, I assume, to stream sedimentary sequences discussed above, use of this term here seems a bit awkward. Response: We will delete ‘relative’ as it is unnecessary.

141 – delete everything on this line “iv” Response: We will make this correction.

145 – Reword as “revealing the timing and structure of ice age terminations” Response: We will reword.

155 – The use of commas in this line makes it difficult to follow. Response: We will

place brackets around ‘due to evaporation’ instead of commas.

163 – I believe Rasmussen did some work in Carlsbad Caverns, as well. Response: We could not find any published journal article on this.

166 – “, and hence” Response: We will correct.

202 – remove second comma Response: We will make this correction.

204 – same comment as for line 197 Response: We will change ‘reduced evapotranspiration’ to ‘increased effective precipitation’ as for L197.

236 – missing a period after “years” Response: We will insert period.

237 – “Eastern” should be “eastern” Response: We will make this correction.

243 – “AD 1974” Response: We will insert 1974 CE.

243 – “Lake Frome and Lake Callbonna” Response: We will make this correction.

246 – again, the reader needs a better map Response: See response to L133 above.

247 – do you mean rainfall “records” were broken? Response: ‘totals’ will be changed to ‘records’

259 – delete “formations” and pluralize “speleothem” Response: We will reword.

265 – “AD 1998” Response: We will insert 1998 CE.

268 – what is a “pool-formed decoration?” Please explain. A photo would also be helpful. End sentence after “decoration” Response: ‘calcite pool-formed decoration’ will be changed to ‘calcite deposits in rims indicating former pool levels’. ‘as well as reports from cavers’ will be deleted. Unfortunately we do not have a photo of this from the field.

268 – delete “as well as reports from cavers” Response: We will make this correction.

268 – reword as “In addition, cavers report 3 m of water in the entrance shaft in 1974:

: :" Response: We will reword.

284 – delete "of unknown duration and frequency" Response: We will make this correction.

287 – repair the comma splice Response: Will replace with 'MC-S1 was sawn from a flowstone-covered boulder. Approximately 10-15 mm of its base was not recoverable owing to the saw cut.'.

300 – this is an incomplete phrase that doesn't match with (i) Response: Will replace with 'a cessation in sediment delivery by floodwaters'.

346 – no need to include Australian National University again on this line Response: We will make this correction.

347 – "by a slit" Response: We will make this correction.

350 – "laser was" Response: We will make this correction.

354 – delete "using" Response: We will make this correction.

354 – are these ppm? Response: Will insert 'ppm'.

405 – delete comma Response: We will make this correction.

406 – within error of each other? Response: Yes, we will reword.

407 – quantify "significant". Response: This can be easily determined from Table 1. It would be too distracting to add detailed quantifications of each growth hiatus to the text here.

414 – repetition of "growth" in this line is awkward. Response: We will correct by deleting second instance of 'growth'.

422 – instead use "composed"? Response: It is the same meaning.

424 – do mean "flank" as in the vertical sides of the stalagmite or flank of the top growth

surface? Response: Vertical sides. Will clarify by inserting 'vertical' before 'flank'.

425 – what is geometric selection? Response: We will add a definition as follows: 'whereby only crystals best aligned for mass-transfer processes within the environment of deposition continue to grow at the expense of neighbouring crystals (cf Kantor, 1997; Gonzalez et al., 1992; Self and Hill, 2003).'

525 – replace "s" with "s.d." Response: Will relace 's' with 'sigma' to avoid confusion.

618 – "parent dripwaters, perhaps by incomplete equilibration or: : :" Response: We will reword.

621 – delete comma Response: We will make this correction.

621 – "supports the argument that considerable" Response: We will make this correction.

669 – delete comma Response: We will make this correction.

673 – what does "natural" refer to here? Response: The term is unnecessary. We will delete 'natural'.

761 – why include "hydrologically"? Response: Hydrologically effective precipitation is a common term used to refer to precipitation in that contributes to recharge. It is particularly relevant to karst in these semi-arid environments.

769 – delete open paren Response: We will make this correction.

784 – delete the comma Response: We will make this correction.

861 – "support the argument that" Response: We will reword as suggested.

Interactive comment on Clim. Past Discuss., doi:10.5194/cp-2016-135, 2016.