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Climate of the Past
Discussions

Interactive comment on "Enhanced Mediterranean water cycle explains increased humidity during MIS 3 in North Africa" *by* Mike Rogerson et al.

Anonymous Referee #1

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General comments

This manuscript presents new analyses of the stable isotopic composition of fluid inclusions in a speleothem from Susah Cave, Lybia. The stable isotopic compositions and dating of this speleothem had previously been published revealing three major periods of speleothem deposition (Phase I- III) covering the time intervals between 65-61 ka, 52.5-50.5 ka and 37.5-33 ka, respectively. Phases I and III coincide with periods of low precession parameters (high northern hemisphere summer insolation) whereas Phase II suggests increased moisture availability in a phase of high obliquity. The comparison of the fluid inclusion stable isotopic composition and d-excess values with stable isotopic compositions of present-day rainfall from the region and the stable isotopic values of speleothem carbonate suggest that the rainfall sources were different in

the precession triggered humid phases (I and III) than in the obliquity triggered phase (II). Consistent strontium isotope compositions across all three phases indicate that there was no major shift in Sahara dust transport to Susah Cave. The shift of moisture sources between the main deposition phases is therefore attributed to a change in the contribution from mainly westerly rainfall systems in Phase II to a mix of westerly and convective eastern sources in Phases I and III.

This is the first study of fluid inclusions in speleothems in northern Africa and the research presented is both within the scope of Climate of the Past and relevant. The scientific methods are valid and well-described, however clarity manuscript could be improved by changing the structure especially in the Discussion section. The data presented here lead to some substantial and new hypotheses about rainfall moisture sources during wet periods in the northern African coastal regions, however the current structure of the manuscript makes it hard for the reader to follow the arguments and there are a few important points concerning the precesses leading to humid periods in northern Africa and the factors influencing the stable isotopic composition of rainfall that need to be clarified/included. Proper credit is given to related work, however in some places in the manuscript the distinction between analyses done for this study and analyses of Hoffmann et al., (2016) could be made more clear (see Technical corrections).

The formation of north African pluvials and sapropels and the time period covered by the samples: The section 'Past climate changes in North African hydroclimate' in the Introduction gives a good overview of general climatic variations across North Africa in the past. However I disagree with some of the statements made in the paragraph starting in line 66. The authors state that records of past lake levels and vegetation (pollen) suggest wet conditions across the Sahara an that this wetting was caused by a northward shift (up to 30-35N) of tropical rainfall associated with the ITCZ, they then continue to counter this interpretation with model studies that have shown that tropical rainfall only extended as far as ∼25N. I don't see this contradiction as in my understanding of the causes of North African pluvials tropical rainfall only extended far enough north to reach the southern edges of central and northern Saharan drainage basins, providing an initial source for moisture that was then recycled within the region (e.g. Rohling et al., 2004, 2002). A northward shift of the tropical monsoon belt to ~25N would be enough for this. I would also like to see a bit more detail about what the lake and vegetation records from the Sahara suggest for the actual time period covered by the speleothems. Most of the statements in the overview of past climates in the region are very general and refer to sapropel events, however the speleothems do not cover any periods of actual sapropels. In fact, most sapropels occur during interglacial phases and the speleothems here formed during a glacial time. A short discussion of the effects of the different boundary conditions and how it could affect northern African moisture should be included. I also think there should be a section in the introduction about the present-day rainfall systems in the region and at the rainfall sampling stations that are used in the discussion. This section should also summarize the publication by Celle-Jeanton et al. (2001) and explain how the different rainfall end members were defined (the publication is cited in text as Celle-Jeanton et al., 2003 but there is only a publication from 2001 in the reference list, which one is correct?). What are the characteristics of the end members? How were they defined – e.g. GNIP data are usually sampled at monthly intervals, how were high rainfall events at Bet Dagan separated from that and how much rainfall is high rainfall? Do the end-members have different local meteoric water lines and d-excess? How were the different moisture sources assigned to monthly rainfall - Back trajectories, analyses of daily synoptic charts? What factors other than moisture source drive the variation of d18Oppt and d2Hppt at the rainfall stations? How were the averages shown in Figure 9 calculated – simple arithmetic mean or amount-weighted means? What synoptic processes were involved in the formation of rain clouds – convection, advection? What circumstances lead to convective rainfall in the region? Further adding to the point above, it seems that the discussion of factors influencing stable isotopic composition of rainfall is focused on only the effects of rainfall amounts, temperature and moisture source. These

are important factors, but I think one important factor is missing and that is the effect of cloud formation processes on the stable isotopic composition of rainfall. One conclusion of the manuscript is that during phases of high precession, rainfall at Susah cave originates from a combination of western Mediterranean and eastern Mediterranean sources with a small addition of Atlantic rain. Present-day rainfall at Bet Dagan is considered to represent the end-member composition of the eastern Mediterranean source. As a mechanism for the transport of moisture to Susah Cave from the east, strong regional convection is suggested. However present-day rainfall in Bet Dagan is dominated by mid-latitude winter storms. The cloud formation processes of these winter storms and convection will affect the stable isotopic composition of the resulting rainfall (Aggarwal et al., 2016) and this difference is not considered in the manuscript.

The discussion is structured in a very confusing way. At the moment the discussion of the d18Oppt and d2Hppt are in one chapter and only in the second discussion chapter we are told "The primary difference between these end-members is the level of Dexcess. . .". I think the arguments made for the mixing of the different end members would be much more clear if the discussion of the stable isotopic composition and the d-excess would be combined including clear definitions of the values for the three depositional phases of the speleothem and the modern rainfall end-members. One example for this is the sentence starting in line 249 which states that Phase II fluid inclusions are inconsistent with Bet Dagan rainfall, however in Figure 9 (which is referenced in the sentence) most of the values plot right next to the Bet Dagan mean values. It is not clearly stated here why the Bet Dagan mean cannot represent the same rainfall source as Susah cave and including the d-excess values right away would solve this problem.

There seems to be a discrepancy between some of the statements in the manuscript with regards to the Atlantic rainfall source. It is stated that a small Atlantic source of rainfall can be assumed for Susah cave and that this conclusion is likely transferrable to any site on the continental margins of the Mediterranean (Lines 276-279). On the other hand, moisture sourced from the Atlantic is also suggested as the only possible source for a freshening of the surface water of the Mediterranean that counteracts the ice volume effect. I think this needs to be clarified. This should also include an argument why runoff from northern Africa originating from recycled monsoon rainfall is not an option. Another contradiction is between the statements in lines 304 -306 and 325-328. First it is stated that increased convection during phases with a low precession parameter must be related to a northward shift of the ITCZ, then the convection is attributed to enhance internal convection.

Specific comments by chapter

Introduction - The central North African speleothem record

2. The last paragraph of the section starting in line 123 is not really about 'the central North African speleothem record' but rather an introduction to fluid inclusions and should maybe be in its own chapter.

Material and methods

The speleothems carbonate stable isotopic composition were published by Hoffmann et al., (2016), so the sentence about their measurement in line 145 can be removed. Results Fluid inclusions

I think this section should include a clear defienition of the three depositional phases, giving the range of values of fluid inclusion stable isotopes and d-excess. This would make the comparison of the much easier.

Calcite carbon isotopes

As mentioned before, these were included in the Supplement of the publication by Hoffmann et al. (2016) and are not results of this study. I think this section can be cut.

Technical corrections

I have a few technical comments about the text: The abbreviation used for the d-excess parameter is not consistent throughout the manuscript Similarly, the stable isotopic

composition of rainfall is called δ18Oppt and δ2Hppt in the text, but in Figure 5a the axes labels are δ18Oprecip and δ2Hprecip. Throughout the manuscript the authors talk about precession maxima and minima – precession is a directional value and does not have high or low values, what is referred to here is the precession parameter which has maxima and minima. I saw in several places that there was no '.' after et al. For future submissions I would recommend changing the formatting of the reference list to help reviewers find the references they are looking for I would also add some the title of the publication and author list a the top of the supplementary information.

Figures

I think that the Figures could be improved a lot, some of them are not easy to read and a bit confusing.

Figure 1: I think adding some more information to the map would be useful – e.g. where are the different moisture sources that are considered end members contributing to Susah rainfall and what does the present-day atmospheric circulation look like?

Figure 4: The actual data presented by this publication is plotted behind the carbonate stable isotope data in this figure and it looks like the shading indicating the three main deposition phases is also overlaid onto the data presented. This makes it really hard to see the actual data being presented. Same applies to Figure 10.

Figure 5a: I find this Figure hard to read. It looks like the Sfax "Atlantic rainfall", Sfax "Mediterranean rainfall", Tunis GNIP and Sfax GNIP are all very similar. The small crosses used for the Sfax GNIP data are unlikely to be visible once this is scaled down for the pdf version of the publication (this also applies to Figure 5b and 9) Figure 5b: I find it almost impossible to distinguish between the different speleothem deposition phases in this Figure. I think splitting it into three subfigures would make sense. In each subfigure I would still include all the data but plot only the data for one of the Phases with black error bars and black borders of the dots while the other two are shown in grey. I would also make sure that the Phase that is being highlighted is plotted on top of everything else. Similar problems apply to Figure 9 – I think Figure 9 might actually be cut and the few points shown there could be included here.

Figure 6: would it not make sense to show which of these samples are from which depositional phase?

Figure 7: The actual data presented are much more visible here than in Figure 4 and 10, but there are no data between 20000 and 30000 years and that part could be cut, also here the shading for the boxes marking the main growth phases could be plotted behind the data rather than overlaid on them.

Figure 8: The two subfigures are over one another here, the second panel should be moved down a bit. It looks like the d13C record is duplicated between ∼33000 and 36000 years. I don't think this is explained in the paper.

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