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Climate of the Past Discussions

Interactive comment on "Hydroclimatic variability in the Levant during the early last glacial ($\sim$ 117–75 ka) derived from micro-facies analyses of deep Dead Sea sediments" *by* I. Neugebauer et al.

I. Neugebauer et al.

inaneu@gfz-potsdam.de

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Response to Referee #2:

We would like to thank the referee #2 for his/her positive comment on our manuscript. The reviewer raised some intriguing questions that we addressed partly in the manuscript and in more detail in the following:

'The point that, in my opinion, could benefit from further or more explicit comment is the interesting finding that during the studied time interval, lake level changes are in phase with Greenland and European climatic and environmental changes. This is in contrast to the well-known prevailing opposition, as expressed in this introduction to the

paper: "The lakes expanded during glacial intervals... whereas interglacials are generally characterised by lake contraction". This switching of phasing across the glacial inception period is not explicitly stated (although it may be implicit in discussion of forcing factors in section 5.4 and also in the final conclusion point in section 6). In general, the long interstadial episodes of the early last glacial share many characteristics with interglacials (for example, with forest development in long southern European pollen records), but here the hydrological pattern is opposed.

Can the authors comment further on why this switching may occur (i.e. expand further on the global boundary conditions under which the Dead Sea experiences dominant Atlantic-Mediterranean climate impacts), . . .?'

Reply: This is a very good point that we missed to discuss because at first we considered that a bit too speculative. However, the reviewer comment encouraged us to change our opinion and revise the discussion in the last paragraph of section 5.4 by pointing out more clearly the shift from an 'in-phase behaviour' (cold North Atlantic, dry Levant) during the early last glacial (millennial time scales) to an 'out-of-phase behaviour' (cold North Atlantic, wet Levant with high Lake Lisan levels) during the Pleniglacial (longer time scales of ten thousands of years).

In our opinion the Dead Sea always experienced dominant Atlantic-Mediterranean climate impacts, however, in different ways. We agree to the reviewer that the shift in climate response in the Levant at the onset of MIS 4 is related to changes in climate boundary conditions. The biggest change that occurred during that time is the build-up of the Northern hemisphere ice sheets, which may have crossed a certain threshold in elevation to trigger a major change in northern hemisphere atmospheric circulation by splitting up the Jetstream, as already shown by Webb III et al. (1993). This should have forced the Westerlies sufficiently far south that Mediterranean cyclones were funnelled towards the central Levant, which led to doubling of annual rainfall in this region (Enzel et al., 2003, 2008; Rohling, 2013).

In contrast, during the early last glacial period winter rains increased in the eastern Mediterranean during periods of maximum insolation and seasonality (see e.g. Kutzbach et al. 2014), i.e. broadly coinciding with the warmer interstadials. On the other hand, during periods with lower insolation and seasonality winter rains decreased and the climate became dryer in the Levant during cold periods. This in-phase response function of the hydroclimate in the Levant to northern hemisphere orbital forcing collapsed only when the atmospheric circulation got re-organised and shifted towards the south at the time when the ice sheets became a morphological barrier for large-scale wind systems. As aforementioned, we consider this a hypothesis of which some parts are supported by data and modelling, which as a whole should be further tested by both further modelling and more high-resolution proxy records from this region.

'. . . what the wider implications are for pan-Mediterranean climate gradients, . . .?'

Reply: Climate gradients in the Mediterranean are complex, different on different time scales and determined by different boundary conditions. As we mainly focus on millennial-scale changes, this question is beyond the scope of this paper, but we like to share some ideas within the frame of an open discussion:

On Holocene decadal to centennial timescales, a seesaw pattern in the Mediterranean with climatic gradients from West to East and Northeast to Southeast has been observed (e.g. Roberts et al. 2012; Neugebauer et al. 2015). These gradients are likely related to complex and not yet fully understood teleconnections between the North Atlantic Oscillation, the Siberian High Pressure System and the eastern Mediterranean Cyprus Lows. The superimposed, long-term millennial- and multi-millennial-scale climate fluctuations, however, seem to be similar across the Mediterranean and forced by orbital insolation, although the responses in the different regions of the Mediterranean may be delayed or different in intensity (e.g. Roberts et al. 2011). On a glacial-interglacial time scale it is the change in boundary conditions causing a southward shift and funnelling of the Mediterranean cyclones particularly to the Levant during glacial times that results in the observed difference to other parts of the Mediterranean.

Besides different boundary conditions and forcing factors, i.e. the complex climatic mechanisms, another equally important factor further complicates the reconstruction of Mediterranean climate gradients. This is the use of different proxies and different climate archives, which often exhibit different responses to climate, challenging a regional comparison of these records. Last but not least, chronological synchronisation is another crucial issue that still requires improvements.

'. . . and whether it may be a predictable feature of glacial inceptions during earlier climatic cycles?'

Reply: This is also an interesting idea, but it leads us even more into a speculative discussion. Since earlier glacial inceptions have experienced similar boundary conditions, one should assume that the Dead Sea level has reacted similarly as during the last early glacial period. However, one should also keep in mind that, even if glacial-interglacial cycles are broadly similar, there are also clear differences in the characteristics of individual interglacials and glacials. For example, the southward extend, and probably even the height of the Fennoscandian ice sheet during the last three glaciations exhibits significant differences. If this might have influenced the boundary conditions of the atmospheric circulation is unknown. Therefore, and since we do not have any confidence for predictable features of earlier glacial inceptions, we do not include this discussion in the paper. Instead, we consider this as an intriguing problem for further research.

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