Interactive comment on **"Global aridity synthesis for the last 60 000 years"**

by Florian Fuhrmann et al.

Anonymous Referee #3

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Fuhrmann et al. collected published proxy data to assess changes in regional aridity for various regions. To make the data comparable and reduce the complexity, the authors developed an aridity index that is compared with modelled precipitation anomalies between MIS3 and the LGM and MIS3 and the preindustrial. Generally, the compilation and homogenization of aridity records and their comparison with the results of model experiments is an interesting approach. However, as outlined below, I feel that (i) the methods are not sufficiently described to allow a proper assessment of the approach and significance of the results, (ii) that the authors use unreasonable generalizations for the definitions of time slices and regions, and (iii) that there is no significant new information added by the paper. I recommend to reconsider the paper only after a fundamental revision.

→ We acknowledge Referee#3 for his review and constructive and helpful comments. They have greatly improved the manuscript, especially the use of some definitions. We have incorporated the suggestions within the manuscript. See our point-by-point reply to your comments in red in the PDF.

1) Parts of the paper are written in a very confusing style. For example, on p3/l14 the authors describe that they "...use the original stratigraphy of all records". On p3/l16 they say "Speleothems are used for synchronisation between different archives of one region" which implies changes of the original stratigraphies.

→ We uploaded an updated version of the manuscript, which incorporates a fundamentally revised method section. Your suggested point is spelled out now in detail (p4, l2). The linguistic revision will take place as soon as the scientific content of the manuscript has been accepted.

2) Aridity index. The calculation of the aridity index is not sufficiently described, but as I understand from Table 1, the authors assign an integer value between 0 and 2 (or 0 and 1 for speleothem growth) to the different proxy records and then add the values(?). What do the authors mean with "...the original values have been recalculated into percentages, proportional to the maximum value of each specific dataset..."? Is the aridity index only calculated from speleothem growth, pollen and dust, or are other parameters included? In the methods section it is stated that "...isotope data like d18O, Sea Surface Temperature (SST) reconstructions or Ice Raft Debris (IRD) data are added to complete the picture." Are those records part of the aridity index? If not, to what have you included those data?

→ The revised method section includes an detailed explanation on the used proxies, generation of the aridity index and all your mentioned points. Additional information are explained now on Page 10, lines 13ff. They only were used for generating Fig. 4, even in the previous version of the paper.

3) Uncertainty estimation. The uncertainty estimation needs better explanation. If the aridity index is binned into integer values between 0 and 5 (as I speculate), does it make sense that the error is smaller than 1 in some cases as for example shown in figure 2f?

→ Yes, we could also quantize the errors. This would highlight the absolute classification error. Since no error is larger than 1.5 this results in rounded errors of 0 or 1. The chosen style emphasizes the reliability of the underlying data, since in the worst cases the aridity index is of by one bin.

→ For example, Fig. 2f that you mention has different errors. During the phase of 15 000-25 000 the error is about 1, while around 45 000 it is much smaller and around 50 000 it increases again.

4) Title: The title is misleading and not a good representation of the content. The data collection is far from being "global" since some of the most important regions (i.e. the Amazon) and much of the tropics (where aridity matters most) are not represented. I would suggest to find a title like "Regional aridity synthesis for the last 60 000 years"

→ We agree on your comment and rephrase the title: "Aridity synthesis for 10 selected key regions of the global climate system during the last 60 000 years"

5) I find some of the generalizations and associations of records with specific regions strange and do not understand why this is done at all: For example in Figure 5 the Susah Cave (located at 33N/22E close to the Mediterranean) is labeled with NW Africa, and a Bahamas cave with the Cariaco Basin. The Cariaco Basin is under the influence of the ITCZ, the Bahamas are not. These are different systems and thousands of km apart and do not necessarily anything to do with each other. The power of a compilation of high-resolution aridity records is that we may understand the regional response of the climate system to specific perturbations or forcings. Here, this useful information is compromised through an unreasonable combination of records from different systems and a very broad definition of time slices (see below).

→ This paper emerges from the PalMod project, that is why it is presented in this special issue of CP, which belongs to the project. One prerequisite of PalMod was to work with publically available datasets only – from the most cited papers. We see that these archives are climatically not fully homogeneous, but drastic changes should be visible within the archives of one region. We had to choose the most complete, highly cited and well dated (back to 60 000 yr b2k) records with highest sample resolution, which are available for the chosen regions. The reality is that this has been the best possible approach to summarize the regions in as small and detailed a way as possible with publically available data.

6) The used LGM definition (24 to 14.7 ky) is very unfortunate and should be revised. The LGM has been previously defined to extend from 23 to 19 ka (Mix et al. 2001, Quat. Sci. Rev., 20, 627-657). This time interval has been chosen, because the climate is comparably stable. The LGM definition of the authors, however, merges the actual LGM with Heinrich Stadial 1, during which the climate system was exposed to significant changes in external forcings and internal perturbations. The global deglacial warming starts at about 18.5 with the onset of HS1 shortly before the deglacial increase in atmospheric CO2 (Shakun et al. 2012, Nature, 484, 49-54). The distribution of orbital insolation changes significantly and we see a change from a relatively strong AMOC to a weak AMOC with the onset of HS1 (McManus et al. 2004, Nature, 428, 834-837). Very likely, even the deglaciation of the Southern parts of the Ice sheets starts already during HS1 as evidenced by records related to river discharge at some of the more southerly locations (i.e. Menot et al. 2006, Science, 313, 1623-1625).

→ Reviewer#2 also mentioned the misleading LGM definition, we rephrased the sentence to (p1, l26): "This is achieved to a large extent for the Holocene, 0 - 11 700 years before 2000 CE (yr b2k), but mechanisms operating during the MIS2 (24 000 - 12 500 yr b2k) or the flickering climate of MIS3 (60 000 – 24 000 yr b2k) are not fully understood." The LGM definition (now: p2,l31) is as follows: "Mix et al. (2001) define the LGM from comparably stable conditions to last during the time interval of 23 000 to 19 000 yr b2k. Clark et al. (2009) define the LGM from maximum ice sheet extend and sea level low stand to 26 500 to 19 000 yr b2k for most parts of northern and southern hemisphere. We follow the wider definition of Clark, which encompasses the regional differences in the results of this work."

7) Comparison to model experiments. In my view, a comparison to model experiments only makes sense, if there is a coherency between the changes in boundary conditions applied to the model and those expected for the reconstructed time slices. This is not the case here: The model experiments have been performed with fixed boundary conditions. By contrast the definitions of the time slices (LGM: 24 000-14 700 yr b2k, MIS3: 60 000 – 24 000 yr b2k) are so broad that huge changes in boundary conditions and perturbations are present within each time slice. Hence it is impossible to pin down potential reason or mechanisms for the changes. The authors have done an effort to specifically compile high-resolution records and yet they lose all the information through unreasonable broad time slice definitions.

→ Unfortunately, no time transient model experiments were finished for MIS3 right now. Palmod for example is trying to fulfil this right now. As we mentioned, the models represent timeslices (see Tab.3, 42 ka and 32 ka) in comparison to LGM or PI and were accounted to be representative for this period.

More specific points:

-p1/l11: "In comparison, the MIS2 interval becomes arid in all northern hemisphere records, but the peak arid conditions of the Last Glacial Maximum (LGM) differ in duration and intensity among regions." This is not true. MIS2 includes the B/A interval which is clearly very humid. Peak arid conditions in much of the northern Hemisphere tropics occur during HS1, which should not be confused with the LGM.

→ We did not use the MIS and LGM definitions in a completely consistent way. We now follow strictly the following definitions, which are now incorporated into the introduction: The boundaries of the MIS have been developed by Imbrie (Imbrie et al., 1984) and Martinson (Martinson et al., 1987) with refinements by Thompson and Goldstein (2006), which we use for this paper. It is the begin of MIS3 at about 60 000 yr b2k and the end at about 24 000 yr b2k. MIS 2 was defined from 24 000 yr b2k to 12 000 yr b2k.

→ We have rephrased the sentence according to your note: "In comparison, most of the MIS2 interval becomes arid in all of the northern hemisphere records, but the peak arid conditions of the Last Glacial Maximum (LGM) and Heinrich event 1 differ in duration and intensity among regions."

-p1/l17: "two focus" must be "two foci" → We agree, it is changed.

-p2/l13: "We present the 10 key regions..." Key for what? Many important "key" regions of global importance (i.e. the Amazon) are missing

→ Unfortunately, no global data coverage with the prerequisites of the PalMod Project were available. We mentioned this in the revised Method section in detail as well as in the introduction.

P2/l5 of the revised manuscript: "We have screened published paleoclimate literature of the last 30 years to detect and select 10 key areas, for which enough information from various lines of evidence is available to bring the information about past aridity to a synthesis. We define these key areas by the proxy availability, i.e. pollen, dust and speleothem growth must provide three independent sources of information related to past precipitation. These areas were selected because they were the smallest possible regions meeting the criteria set out in the methods chapter."

See as well the reply to your comment 5)

-p4/l1: “The global climate structure is well documented within Greenland and Antarctica ice cores”. I disagree with this statement. Ice cores represent the high latitudes. There is very little info about the tropics and subtropics, i.e. the strength of the monsoons, neoglaciation etc.

→ Indeed, NGRIP represents Northern Hemisphere while Antarctica represents Southern Hemisphere. But many authors see evidence for atmospheric teleconnections for example between Arabian Sea and Greenland (for example Bjerknes, 1969; Pourmand et al., 2004; Markle et al., 2017; Sirocko et al., 1996; Zhou et al., 1999). Lots of records show GI / GS signals, even in tropics or subtropics and hence an underlaying influence on several areas. Also, the majority of NGRIP-dust is expected to come from east Asian deserts (Mayewski et al., 2014; Steffensen et al., 2008 or comments of referee#1), located around the 40th latitude.

-P5/l14: “Central Europe is one of the large feedback regions to North Atlantic climate changes” Do the authors mean that Central Europe is amplifying North Atlantic climate changes?

→ We rephrased this sentence to: “Central Europe is related strongly to North Atlantic climate changes”.