Interactive comment on "Global aridity synthesis for the last 60 000 years" *by Florian Fuhrmann et al.*

Anonymous Referee #1

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The manuscript describes an effort to generalize aridity patterns for the last 60 Kyears from a dataset comprising a selection of paleoclimate records, including pollen assemblages, speleothems, and a variety of dust proxies, organized in 10 regions. An aridity index is calculated for each region based on those paleorecords, and is used as a target for comparison with climate model simulations. The motivation of the work described here is relevant, the aim ambitious, and the devised general strategy very interesting. However, the presentation quality is not adequate; in particular the methodology is not described with sufficient detail, so that it is difficult to make an informed assessment on the robustness of the approach and the results. Therefore I recommend a substantial revision of the manuscript.

General comments :

We acknowledge the anonymous referee#1 for his review and the constructive and helpful comments. We revised it in detail as described. We still wait for the second review before we start fundamental rearrangements. Our point-by-point response to referee#1's comments is provided in red in the attachment.

At this stage several passages in the text appear confusing, because of the use of the language, and sometimes contradictive. I provide some specific examples below, but I recommend carefully reviewing the entire manuscript in the spirit of addressing this comment.

The methods section is not satisfactory as it is now, since it resembles a short collection of sparse statements. It needs to be much more precise in detailing the different kinds of proxies used, and should be organized in a more organic way. It should also explain clearly what is the general strategy and what are the common rules used to (a) select and (b) treat the data and (c) the uncertainties. This is not discussed even in the supplement. Several datasets with potential relevance to this work are not even mentioned. The whole section should be substantially revised.

→ We will upload the revised method section as soon as possible. The Methods and data treatment will be described in detail, but we would like to answer your specific comments right now, see below.

In addition, I think that the scope of the work should be clarified. When I read "synthesis" I would expect a complete data collection and selection by means of transparent filters, before aggregating the results. If on the other hand the strategy is to pick specific records, which are deemed representative of specific regions, then I think that (a) a discussion is needed on why these particular records were selected, and what is the inherent uncertainty in the choice, and (b) the main title and scope should reflect more faithfully this approach.

→ The special issue, which is the manuscript belonging to emerged out of the Palmod project. One prerequisite for PalMod is to work with publically available datasets only – from the most cited papers. See also our comment to p2,l 4-5. We went through "web of science" for every region and sorted the available papers by citation count. Afterwards we downloaded available data starting with the most

cited paper. Well cited papers - where data were not available - were not included into the compilation. This was a prerequisite from PalMod, that is why the paper is presented in the special issue.

Concerning dust records, several proxies are used. While this may not pose a problem per se in the context of this study, a discussion is missing on other processes, in addition to "aridity", that could potentially affect the signal (changes in sedimentation rates controlled by productivity in the oceans and precipitation ice cores, etc.). What are the uncertainties related to the choice of specific proxies? In addition, any connection between sources of dust and specific paleodust records seems to have been disregarded, casting a doubt on the validity of certain regional interpretations (e.g. sources of dust to Greenland, EDML, Mediterranean Sea). These aspects should be thoroughly discussed.
→ We used the same basic method through all regions in absence of real errors within the datasets. Therefore we had to construct a "proxy" for the uncertainty. We will address this in the method section.

Specific comments :

1, 9 > "all regions show" it would be more appropriate to say "all the regions analyzed in this study show" → I agree, changed in the manuscript

1, 10 > not always WITH the same timing → changed

1, 11 > Perhaps what you mean is "Such discrepancies have been interpreted as regional effects, although stratigraphic uncertainties may affect some of the proposed interpretations"? Please clarify → I agree, changed in the manuscript

1, 14 > "both lines of evidence show great agreement": which lines of evidence? Agreement of what with what? → rephrased to: Indeed, geological archives and GCMs show great agreement of aridity pattern for the Holocene, LGM and for the late MIS intervals.

1, 16 > FOCI → yes

1, 20-21 > This sentence is awkward, please rephrase, e.g. Geological archives have the potential to provide information on the past states of climate variables at the global and regional level, and their evolution in time. → rephrased according to your suggestion

1, 26-27 > what do you mean by "ice sheets . . . are apparently also teleconnected with global sea level"? Please rephrase → rephrased to: which control at least the climate of the high latitudes, but are apparently connected with global Sea level changes

2, 1-4 > How did you screen ~2000 papers? Did you use some search algorithm and keywords? → The special issue, which is the manuscript belonging to emerged out of the Palmod project. One prerequisite for PalMod is to work with publically available datasets only – from the most impactful or cited papers. In a first step, at least every abstract of the most cited papers was read. Afterwards, we searched for available datasets to the belonging paper. In a second step, datasets in Pangaea, noaa-ncdc, global pollen database (Neotoma), ice core database from Copenhagen university, SISAL speleothem database and European pollen database (EPD) were downloaded. The most complete records well dated back to 60 000 yr 2bk and high resolution samples were used for the compilation. Keywords used in the database research were e.g. speleothem, palaeo, ice core, dust, aeolian, eolian, pollen etc.

→ this will be part of the revised methods section in detail.

2, 5-6 > Have you considered paleolake levels as a potential proxy as well? → No, because not every region offers available data for that kind of proxy. I can imagine using paleolake levels in further works on that topic, probably in other regions.

2, 7 > "Arid" rather than "desert" → rephrased to "thus indicate an arid climate"

3, 12 > "The synthesis" rather than "The comparison"? → yes

3, 12 > In this section you should explain in a very transparent way which are the rules for selecting specific records. And why specific one(s) are used to calculate the aridity index, rather than others (within a given region, e.g. Bunker vs Spannagel Cave in Figure 2). In addition, what are the rules to determine the time step of the aridity index, given that the 3 records typically have different time axes?

→ as you suggest, the "Methods" section will be completely revised. We will upload the revised version of the manuscript as soon as possible, but not before 20.11.19.

3, 14 > What do you mean by "we use the original stratigraphy"? Aren't you saying that you port the chronologies to the GICC05 time scale? In addition, there is no mention as to how this operation was carried out: did you use some software?

→ We did not port the chronologies. We just homogenized the age labels BP (referred to 1950, or sometimes to year of paper release), ka BP etc. to years b2k (years before the year 2000 CE), which belongs to the GICC05 notation. The sentence will be rephrased for better understanding to: "We used the original stratigraphy of all records, but homogenized the notation of the age scales to yr b2k if possible." We compare data on a multi-millennial scale, thus uncertainties between BP, ka and b2k age scales are not that important. We will incorporate the last sentence into the method section.

3, 19-20 > What do you mean by "the errors . . . below 4% in total"? → rephrased to "growth data we used for this synthesis, all are below 4 % uncertainty"

3, 27-29 > Please rephrase this sentence → rephrased to: "The time resolution of the pollen profiles is often low, but we have chosen the accessible highest resolution data of each selected region for the comparison. The record in addition must have been reliably dated to be selected."

4, 1 > What is the global climate structure? →" The global climate evolution with processing time…"

4, 4 > "For THE Northern Hemisphere . . ." and so forth, please review the use of the language throughout the manuscript → we do agree with this comment. The use of language will be revised after other referee comments or comments in general were made to avoid duplications.

4, 8 > Larger than what? → "Grains of sand-size can be deflated…"

4, 16 > Do you mean precipitation proxies? → yes, rephrased for precision to "from all available precipitation proxies"

4, 19 > "divided in three parts" is not clear at all. I guess what you are trying to say is that you assign each point in the pollen / dust time series to a category from 0 to 2, based on the current value of the rescaled record as a percentage with respect to the top value (which corresponds to 100%)? Is that correct? However, it is not clear what are those original values. One can only try to guess it is maybe the percentage of tree pollen is the whole pollen assemblage for a given point? What is it for dust? It could be many things since you indicated several different proxies for dust. In fact by looking at the

supplement it seems it depends on each different proxy. Also, you do not spell out how you calculate the aridity index, one can grasp from the caption of table 1 that is the sum of the three "scores" for speleothem, tree pollen, and dust. Your procedure and the rationale behind it should be explained in detail and clearly in the methods section. → See reply to 3, 12, section "Methods" will be revised in detail.

5, 2-9 > This section is also very confusing, it should be profoundly revised. First, you should probably mention that there are uncertainties on the age of the samples, and uncertainties on the specific values of the variables, in addition to their uncertainty as proxies for a particular system. Second, you should clarify which are the cases where you have an uncertainty estimate from the original study and what it refers to. Then you can talk about the case where you have to assign the uncertainty arbitrarily to each sample in your time series, and you should specify on what grounds you assign a particular values (it could be the reference to a paper using the same kind of proxy, for instance). Fourth, as a key to read Table 2, you should describe explicitly if you have only one record for each kind of proxy for each region, or else how you dealt with multiple records. Finally, it may be more interesting to use other records than the "chosen" one, where available, to calculate the aridity index, as a metric for uncertainty / intra-regional variability. → See reply to 3, 12

5, 14 > I am not sure what you mean by "one of the large feedback regions": please rephrase → rephrased to "Central Europe is related strongly to North Atlantic climate changes."

5, 19-20 > VARVE not warve → changed within the manuscript

6, 4-5 > What does the dust concentration in the NGRIP ice core have to do with aridity in central Europe? I don't think it is appropriate to make such a statement without further discussion. As you know, there are several hypotheses concerning the interpretation of the Greenland dust records (e.g. (Mayewski et al., 2014; Steffensen et al., 2008)), and the major source of dust to the Greenland ice sheets are not uniquely attributed to Europe, to say the least (e.g. (Bory et al., 2003; Rousseau et al., 2014; Svensson et al., 2000; Újvári et al., 2015)). In view of these aspects, please state explicitly what is the link in your line of reasoning (e.g. generalized aridity in the northern hemisphere, in Eurasia,…), and what are the assumptions you make (e.g. Europe is major dust source to Greenland?), justifying them with adequate references to the literature.

→ We agree. We would have liked to show a well dated loess record like "Nussloch" but numerical timeseries were not available at present.

→ p6,l4-5 rephrased to ". An intermediate dust content in the ELSA-Dust-Stack suggest an intermediate to low aridity, which is supported by a similar pattern of low dust concentration in the NGRIP ice core. This corresponds to an overlying process, affecting both regions during this time." The authors would not make a statement on the source region beyond the papers, which are mentioned above.

6, 22 > Tree pollen? → "complete absence of all pollen." The record is counted for the whole time span and there were no preserved pollen at all.

6, 23 > "precipitation was at the lowest values of the whole record": which record are you referring to? To speleothem records? The aridity index? → yes

6, 29 > Which speleothem? → specified to: "Speleothem growth in Spannagel and Bunker Cave"

S1-S9 > In these sections of the supplement I would expect to find more specific considerations on the selections of records (e.g. why data from (Pourmand et al., 2004) are not included in S1? Or (Skonieczny

et al., 2019) in S2? Or the loess records in the discussion about central Europe? What's the link between EDML dust and Oceania? Etc. . ..), before discussing those that are selected. Also, I did not find the details of how data are aggregated into the aridity index (e.g. why sometimes 4 records are considered, sometimes 2?). As mentioned already, the general rules for data selection should be spelled out clearly in the methods sections, and specific choices of notable datasets not included should be discussed in the supplement.

→ Like mentioned within the manuscript (introduction) and Supplement 11, as well as within the reply to 2, 1-4: Data needed to be publically available to be considered within the synthesis. I did not find related data in the publically available databases for Pourmand et al. 2004 for example. Therefore, the paper was not mentioned. Many popular records were not chosen, as they do not reach until 60 ka, do not belong to the selected regions or do have lower sample resolution, as the scope of the study was different (for example longer chronologies).

The aggregation of data could be written in more detail, I agree. But the aridity index was built up every time out of the three proxy types (speleothem, tree pollen, dust) beside St. Barbara basin, where no dust record was available. This will be spelled out in more clearness.

The rules will be explained in the revised method section in more detail than before.

8, 6 > RELATED information → yes, specified

8, 11 > The proxies show an opposing signal ? → rephrased to "where the proxies show an opposing signal to the other archives due to regional effects"

8, 13 > It is not clear how Figure 4 was produced. What is the role of the "additional information"? Are those the thin overlapping bars? → Fig. 4 is a graphical interpretation of Fig. 3 for better visualisation of the changes of the analyzed regions through time.

The additional information (Stebich et al., 2015 Pollen Sihailongwan Maar Lake) are Holocene pollen, because Mingram et al. (2018) does not show them. Therefore, we used the additional information after the construction of the aridity index to complete the aridity interpretation. Other additional information only were used within the interpretation of Fig. 3 and 4 to support statements on aridity.

9, 11-12 > Please rephrase → irrelevant to the topic of the paper, therefore deleted

9, 15 > "impair"? → see next reply to 9,21

9, 21 > How do you define a climate improvement? Please avoid terms like improvement and amelioration, impair?; expressions describing the changing state of the discussed variable should be preferred, such as drier, wetter, colder, etc.

→ climate improvement is used for warmer and wetter climate, according to better living conditions. Climate deterioration (impair etc.) is used for colder and drier climate, according to poorer living conditions. This will be added within the introduction.

10, 8 > representative of the Cariaco Basin → yes
11, 4 > WHEN both hemispheres → yes
14, 6-9 > Not clear, please rephrase → yes
14, 24 > SPATIAL trends → yes
16, 12 > All regions analyzed here → yes

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