

Response File – Climate of the Past Manuscript cp-2017-34 reviewer #2 comments

We thank the two anonymous reviewers for their time reviewing our manuscript and their insightful comments and suggestions.

Below we provide responses to each of the reviewers' comments and indicate our plans to revise the manuscript. Author responses are shown in ***bold italics***.

As seen below, referee #2 advocates a division of this paper into two separate ones. However, we hope that we have argued successfully for keeping the present structure, given that this is a review paper.

Referee #2

This paper attempts to provide a synthesis of palaeoclimate records spanning the last 2000 years in the Arctic region. In general, the content and subject matter are important and certainly well suited to *Climates of the Past*. However, prior to publication, I strongly recommend the authors undergo major revisions and resubmit their manuscript for further review.

Response: We thank the reviewer for her/his detailed examination of our manuscript and the very insightful comments. It seems that the reviewer has possibly misunderstood the purpose of this paper, which is being a review paper, aiming at highlighting the methods used to investigate hydroclimate variability in the Arctic region, as well as providing an overview of existing understanding of it. If this is unclear, we will make sure to highlight it in both the abstract and introduction of the revised version.

Major comments

The content of this paper performs two broad functions. The first 23 pages provide a brief background to Arctic climate research, followed by a long review of the techniques used to infer past climate variability in the Arctic. The second part of the paper consists of a synthesis of published hydroclimate reconstructions and model hindcasts for the region, spanning the last 2000 years. The paper's title and abstract only refer to the second component (the synthesis), thus the extremely long introductory review comes as some surprise. As a first step, I suggest that the authors consider cutting the paper in half and creating (1) a review of palaeoclimate techniques applied to the Arctic, and (2) a synthesis of the palaeoclimate data. With respect to (1), the authors must carefully consider whether this would represent a valuable addition to the literature beyond the several books and review papers on palaeoclimate techniques. However, in order to meet the objective described in the abstract, this paper needs to be shorter and more focused on the data synthesis.

Response: As stated above, this paper is not a research article, but a review article. The reviewer is right that the various methods used are described elsewhere in the literature, but, as far as we know, not collectively, with an Arctic focus. Our aim with this review paper is to provide a holistic

understanding of the complexity of attempting to infer past hydroclimate variability across the whole Arctic (and even at single sites). To achieve that aim, the archives as well as methods need to be described, and examples of hydroclimate inferences given. Consequently, this article could be seen as a “mini textbook” of Arctic paleohydroclimate. Thus, dividing this paper into two separate papers would be not meaningful. However, we will focus the “introductory review”, i.e. the archive description part, better in the revised version.

With respect to the palaeoclimate synthesis, this section warrants a more detailed and systematic approach than is provided in the current manuscript. This systematic approach should include reverting to a more traditional journal article format, with an introduction, methods, results and discussion. As a minimum, the methods section should provide a clear and detailed description of the process of identifying and screening the published records for the Arctic region, which is not satisfactorily clear. The results section should detail which records were considered, how many were included/excluded and for what reasons. The PAGES 2k network have provided very clear guidelines for this process, and the screening process is described briefly on pages 27-28, however a detailed description and summary is necessary in order for readers to appreciate how comprehensive the search has been. For example, are all records described here included in Ljungqvist et al. (2016)? If not, which additional records were included, and which were excluded?

Furthermore, the approach to deriving the new hydroclimate proxy synthesis, described perfunctorily on page 28, requires a much more detailed description and appraisal as is afforded here. In this respect, I have several questions which are not answered in the manuscript: (1) How was the age uncertainty in these records dealt with when deriving averages for the multiple records?; (2) How were the timesteps aligned in order to derive an average of the multiple records? Was this by linear interpolation or another approach? Were the data smoothed in any way, or binned? (3) The synthesis contains records that have an average sample resolution of <50 years, yet the resulting timeseries suggests variability at much higher frequencies – how is this possible? Is the synthesis weighted more heavily towards the annually resolved records? (4) The spatial coverage of records used is uneven, with certain regions being more heavily sampled than others. Of note, for example, are the several Greenland ice core records included in the synthesis. How does the regional synthesis deal with the bias towards those heavily replicated regions? (5) Finally – I would argue it is misleading to state that the results generated here are ‘not a reconstruction’. True, the hydroclimate timeseries isn’t calibrated against a particular climate signal, however it is a qualitative reconstruction of relative hydroclimate variability in the Arctic. Generally speaking, given the proliferation of numerical approaches to deriving regional and global syntheses of time-uncertain palaeoclimate records (see for example Anchukaitis and Tierney, 2012, Climate Dynamics), there is considerable un-realised potential in this research that could (and should) be investigated in more detail. If more involved numerical approaches are deemed unsuitable, then some justification as to why must be given.

Response: The aim of this particular exercise was to show the potential to derive higher-resolution hydroclimate information than provided by Ljungqvist et al. (centennial). See also the comments by Ljungqvist on this manuscript. It

is clear that the synthesis is biased, and this is partly the point: showing the uneven spatial representation leading to biases if the aim is to represent the whole Arctic.

Moreover, since at this point we do not intend to make a stand alone paper of the synthesis, we will not go into too many details here. Still, we will follow the reviewers' recommendations regarding clarification of methods and data used in the revised version. We do however, hope that a more thorough attempt to reconstruct past Arctic hydroclimate variability will be made as new records emerge. Hopefully, our paper can serve as an inspiration to that.

Related to the review of regional palaeoclimate records, I found the multiple plots of palaeoclimate timeseries (Figures 7-11) quite unhelpful, not least due to the variety of ways the data are plotted (including the use of various graphical styles and time axes being both vertical and horizontal). It would be much more helpful to view a smaller selection of these records in a single figure (maximum two if necessary) on a common timescale in order to assess the Arctic-wide synchronicity or otherwise. It would also be helpful to view the regional synthesis timeseries in comparison with the records from which it was derived, so the reader can get a feel for how certain records have influenced the synthesis.

Response: The figures are intended to highlight the nature of the regional hydroclimate information gained from different proxies (Figs. 7-10), as well as a regional comparison of a variety of hydroclimate proxies with different resolution (Fig. 11) in a review context. It would be possible to compile these into one of two figures, but we feel that this would be less meaningful. As, the figures are intended to highlight the various Arctic hydroclimate archives, and consequently we feel that it is better to show these as they are usually depicted. Thus, unless the editor objects, we will keep the figures as they are.

Parts of the manuscript read well, however I would advise the authors ask a native English speaker to proof-read the manuscript before resubmission.

Response: We will do that given the opportunity to revise the manuscript

Minor comments

Abstract: The abstract describes 'inadequate proxy data coverage' (Page 1, Line 37), yet then goes on to call for 'detailed regional studies, e.g. including field reconstructions'

Response: Yes, given the large regional hydroclimate differences within the Arctic, it would be more useful to focus on those regions that are presently well replicated rather than attempting a whole Arctic study, which would be regionally biased. We will clarify that in the revised version.

(P2, L3). How is the latter possible if there's inadequate data?

Response: See above comment

Section 2.2.1: I'm not entirely sure this section is necessary for this paper.

Response: Since this is a review paper, we feel that also mentioning the potential future impacts of hydroclimate changes are important to acknowledge, i.e. connecting the past to the future.

P4,L25: the Arctic's. Errors related to the articles (misuse or non-use of the and/or a) are frequent throughout the manuscript.

Response: Thanks, this will be corrected throughout

P5,L18: 'there are', not 'there is'; 'phenomenon, which also: : :'

Response: corrected

P6,L7: This sentence could be worded better – e.g.

Response: ???

P24,L11: 'extensive' -> 'extensively'

Response: corrected

P24, L11: 'Typically annual precipitation: : : have been the targets'. This is not a complete sentence.

Response:

P24, L15: 'Although potentially: : :'. Also not a complete sentence, and what is meant b the records not being available – not published?

Response: Yes, this is an awkward sentence, which will be revised. Also, networks of these are not yet available.

We revised the sentence as follows: Presently, there are few published hydroclimate reconstructions using other proxies, although these proxies have the potential to produce records with high temporal resolution.

P24, L20: 'Towards the west'. The spatial context is very vague here – do you mean western Canada?

Response: Revised as follows: In western Canada and Alaska, there was an increase in precipitation during the past 2000 years, whereas a long-term decrease was seen towards the east.

P24, L20: 'there seems to be'. Use of present tense. In next line, past tense is used. Ensure there's a consistent approach to tense (ideally use past when discussing past events) throughout.

Response: thanks, this will be corrected throughout

P24, L23: 'All show: : : ' What shows? Maybe better link up to previous sentence.

Response: thanks, will change to "They all show..."

P24, L26: 'Several'. Be more specific here when reviewing records. How many have been published?

Response: In this context we do not feel that it is not necessary to give the exact number since many of these are from locations below 60N, i.e. outside the PAGES 2k Arctic limit. The idea is to highlight the tradition of paleohydrological studies in this region, but if this is unclear, we will re-formulate this sentence in the revised version.

P24, L27: 'These..' merge with previous sentence.

Response: corrected

P25, L9: 'A visual inspection: : : ' As described above, it would be preferable to summarise what records exist before identifying those relevant to this synthesis.

Response: These are the presently available records containing hydroclimate information from the Arctic part of Fennoscandia (see above) and they are presented in Table 1. We will revise this sentence so that this is clear.

P26, L25: By this point, it would be useful to refer to a figure with some data.

Response: They are shown in Fig 11, but we will refer to that figure in this sentence.

P27, L16: 'variability' typo

Response: corrected

P27, L18: 'method outlined below'. As described above, it would be better to outline this in a proper methods section.

Response: see comments above

P28, first paragraph. As above, put this in the methods.

Response: see comments above

P28, L6: What is meant by 'even more important'?

Response: This sentence has been changed to "This drastic selection is necessary to allow for comparison of data at centennial scales and facilitates the time series analyses"

P28, L9: What is meant by 'e.g. tendencies'

Response: This sentence has been changed to "... offer the possibility to interpret hydroclimate variability in the Arctic from low to high frequencies."

P28, L17: 'This signal is not a signal of precipitations' This sentence needs some attention.

Response: This sentence has been changed to "This is not a signal of precipitation alone, but most likely combination of all processes related to the hydrological cycle"

P28, L22: The value of the Mann-Kendall test is not clear in this context.

Response: We think that the reason for using the M-K test is clearly stated (if that is what is referred to by the reviewer?)

P29, L3: Wavelet description. Unless you are using a non-standard wavelet package, I don't think it's necessary to provide such detail. That said, wavelet analyses are notoriously susceptible to errors related to unevenly spaced data – was this considered in your analysis?

Response: Agreed, the revised description of the wavelet will be less detailed.

P29, L16: 'To minimise the impact of the 1456-1485 CE event': : : Please provide more justification as to why it was necessary to filter out this event, and on the effects of that decision.

Response: This will be added to the revised version.

P29, L20: Comparing the North Atlantic and Alaskan records to the 'global' analysis, which constitutes both regions. This (as far as I can tell) is a flawed comparison, since surely the North Atlantic subset will be most similar to the global record, since 12 of the 17 constituent records are from the North Atlantic.

Response: Yes, that is completely true and also the reason for this exercise, as described in the opening sentence of this section. However, given appearances of the time series for the two regions (Fig. 16) in comparison to the "global" one (Fig. 14), this is already quite evident. We will remove Fig. 17 and briefly mention this in the revised text.

P30, paragraph 2. Comparing models with palaeoclimate data. This is a very brief and one-dimensional comparison given the importance of models for future projection. Much more detail should be provided on the similarities/differences and what that means for either the validity of the models or the palaeo- data.

Response: We agree that the one-dimensional comparison is brief, but spatial patterns and their temporal evolution over the past time is the main and the most important information that a grid reconstruction can convey. We

therefore compared the similarities/differences of the temporal evaluation between MCA and LIA in both the grid reconstruction and the model simulations. We then discussed the possible reasons that could cause the discrepancy of the different expression on the temporal evolution between the reconstruction and the models (See P30 L19-26).

P30, L30. At some point you need to justify why this new synthesis is an improvement on than L16, or indeed why it is necessary beyond L16.

Response: It is difficult to say which reconstruction is better. However, the new synthesis shows a shorter period of wet anomalies during the MCA, and the variance is much larger after ca 1200 CE. Given high heterogeneity of the spatial patterns of precipitation, the new synthesis provides a new hypothesis of the temporal evolution of the arctic precipitation after ca 1200 CE.

P31, L25: 'Quite flat' – a more scientific term could be used here.

Response: Agreed, the sentence will be changed to “This is in agreement with L16, albeit the new Arctic mean displays more variability during the LIA than L16

P31, L26-27: I fail to see why the absence of calibration for the new record would have any effect on the trend or variability within the record. The units and range would change, but the pattern would be identical before and after calibration.

Response: Depending on the trends of the included records, this could have a distinct impact on the reconstruction when fitted to observations during the calibration period.

P32, L1: 'not fully capturing the observed changes in the latter half of the 20th century'. Have you considered that other (non-climate) anthropogenic activities, such as recovery from acid rain, nutrient deposition or other atmospheric transport of pollutants may have influenced the recent signal in some proxies?

Response: Good point, this will be added to the revised version

P32, L12: 'this period did possibly undergo'. Mixed up nouns and verbs in this sentence – need to re-word.

Response: corrected

P32, L19: The paragraph on seasonal effects would be better merged into the proceeding text and not afforded a separate subheading.

Response: OK, changed

P33, L3: change 'unbalance' -> 'imbalance'

Response: corrected

P33, L9: Here you list future recommendations. Why not include these ideas in the bullet points listed below?

Response: Good point, thanks.

P33, L15: Bullet point 1 is two points. Also, by listing all records identified and screened in the results section, you would clearly make the point about data suitability and availability.

Response: Good point, thanks.

P33, L19: 'Proper Arctic2k hydro database. I thought this was the point of this paper?

Response: No, no such dedicated data base does yet exist.

P33, L23: 'Field reconstruction' – I got the feeling from reading this paper that a field reconstruction isn't really feasible due to a lack of spatial data coverage.

Response: There are potentials for some regions with good data coverage, e.g. Fennoscandia and parts of N America and possibly Greenland. But it is not possible for the whole Arctic.

P33, L25: Better collaboration between modellers and palaeo-data collectors is often called for. Can you be more specific as to what the two disciplines could do to improve collaboration?

Response: We will elaborate in the revised version

Tables 1 and 2: Why do we need two tables here? Why not merge? Also, are these all the published records from the Arctic, or just those you could access?

Response: We want to keep them separate because table 1 represents the data available for Fennoscandia and Table 2 the data used in the synthesis. These data are those that are available.

Table 3: this is unnecessary. Just indicate which records are used in table 2.

Response: Agreed

Figures 1-5. Five figures here is too many. Boil them down to one or 2 most important.

Response: We have replaced Fig. 1 by Fig. 3, and put Fig. 2, 4 and 5 together as Fig. 2.

Figures 7-11. See comment above.

Response: See comments above

Figures 12-13. Merge these figures to 1.

Response: Agreed

Figure 17. What are the red lines here? Best fit lines? If so, they don't appear to bisect the data as would be expected. Perhaps there's an issue?

Response: Fig. 17 will be removed (see response above)

Figure 18. It would be useful to map z scores, as is the case in the final synthesis. Also, I fear you may be over-interpreting the scale of the yellow-green change in Greenland in Fig. 18a – the range is just 0.2 hydroclimate index units (also explain what that unit actually is).

Response: Good point, we will map the z-scores instead.

Figure 20. I'm not sure this figure is necessary.

Response: Seasonality is an important issue in paleo climate reconstruction, since the archives may contain hydroclimate information for different seasons. So we chose to keep this figure.