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## Reply on RC1

Dirk Nikolaus Karger et al.

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Author comment on "CHELSA-TraCE21k – high-resolution (1□km) downscaled transient temperature and precipitation data since the Last Glacial Maximum" by Dirk Nikolaus Karger et al., Clim. Past Discuss., <https://doi.org/10.5194/cp-2021-30-AC2>, 2021

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### REVIEWER 1:

Review of "CHELSA-TraCE21k v1.0. Downscaled transient temperature and precipitation data since the last glacial maximum" by Karger and others

#### Summary

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The manuscript describes an approach to produce high-resolution climate data by downscaling the output of a long simulation of a general circulation model using additional data sources. Most of the text is rather technical, a description of the downscaling process and validation of the resulting temperature and precipitation data. The paper ends with a potential use case of the produced dataset, the application to a problem in paleo-biology.

#### General comments

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Overall, I appreciate the manuscript as an interesting contribution to facilitate paleo modelling work, which relies on high resolution past climate data. In my view, however, there is a number of severe shortcomings in the paper that need to be addressed before it can be published.

My first question was if the manuscript is well placed in the context of CP. The manuscript largely reads like a model description paper and may be better placed in a journal specialised for such content (e.g. GMD). The comments I will raise further on will not depend on this decision. But I will suggest revisions that bring out the modelling aspect even more, asking for further details that are currently lacking.

Response: The manuscript has actually been transferred from GMD from the editors as the fit was considered higher with CP.

The manuscript is giving a good overview of 'what' is done, but has severe shortcomings in explaining 'why' and 'how'. I believe there is need to improve on describing the motivation for most of the decisions and clarifying the details of the processes (see

specific comments below). The use of symbols is confusing and inconsistent and should be improved. The aim should be to put interested readers in the position to understand and reproduce the work that has been done. Additional figures/illustrations may help to achieve that.

Response: We will include a figure highlighting the downscaling procedure in a revised manuscript.

There may be a conceptual problem with the reconstruction of past surface elevations for glaciated regions. It is not clear to me why past sea surface elevation (i.e. global sea-level) is needed to correct the elevation (l109). The surface elevation of a glaciated region is the result of changing ice thickness and changing bedrock elevation. Neither of these changes is related (linearly) to sea-level changes. A better explanation is needed to justify the presented approach.

Response: The model we present includes the ice thickness from ICE6G as indicated in line 108. The sea level is included as the high resolution DEM is based on a current bathymetric DEM. Not including the sea level changes would result in an orography that still has today's sea level, which is incorrect for past time steps. The model does not include a changing bedrock on the high resolution (1km) elevation however. We will add a comment on this in the revised manuscript.

The same applies to the coupling with temperature, which appears to modify the elevation estimate. Again, this is not well motivated and described.

Specific comments

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Abstract

l12 Suggest to start a new sentence after (ICE6G) and lay out in simple terms what the temperature coupling entails. This has not become clear to me throughout the manuscript. The amount of ice at a certain place is not determined solely by local temperature, if that is what is happening here.

Response: The amount of ice is of course a balance of precipitation fluxes and temperature changes, which can be physically modelled with a numerical model. This is however not feasible at 1km resolution due to computational limitations and not due to the approach presented here. We use mean annual temperature as a proxy for an interpolation approach. The entire approach is still an interpolation and needs a local correction which we describe in lines 149ff. We see from the reviewer comments however that there have been several misunderstandings on the interpolation procedure and our focus on a mathematical description may not have been easy to understand. We therefore will also include a figure highlighting the interpolation algorithm better.

l13 At this stage the reader will not know what CCSM3-TrCE21k and CHELSA stand for. This requires a bit more explanation already in the abstract.

Response: Agreed. We will include a short description.

l16 Here the species distribution is described as a validation of the dataset, while later it is an application of the forcing data. Which one is it?

Response: Both. Paleoclimate models often get validated by specific proxy variables, as we are lacking direct measurements. Applying the dataset to model the distribution of

species is the 'application'. Checking if the results make sense is not a 'validation' as such, but a 'plausibility test'.

I31 It is not clear to me how satellite data can be used to 'bridge the gap between the coarse GCM output and the high resolution needed'. The two sources are distinct and have their own biases. Can you explain?

Response: Maybe this is misleading at this point. Can be deleted.

I43 'ice shields' --> 'ice sheets'. Correct this also in the rest of the manuscript.

Response: Will be changed

I43 'along the poles' --> 'in polar regions'

Response: Will be changed

I58 How does a simulation that starts at 21k-BP with 100 yr time steps come out at 1990?

Response: This is based on the timesteps of CCSM3 TraCE-21k. The last timestep for the 20th century goes until 1990. We will add the information in a revised manuscript.

I59 Isn't paleo-orography an \*input\* to the downscaling procedure? Here it looks like an output.

Response: The output of one timestep (t) is the input for the next time step (t+1).

I62 It would be useful to distinguish between the model (CCSM3), the specific simulation (TraCE-21k) and the output of that model for a specific simulation (CCSM3 TraCE-21k).

Response: Will be changed

I69 Should add here that the model is run with a fixed topography (which one? PD, LGM) and fixed land-sea mask (if that is so). Is the fixed land-sea mask not a problem for the downscaling? How does your process deal with regions that change from land to ocean with deglacial sea-level rise?

Response: No, there is no fixed topography. The modelling of the paleo-orography is explained in paragraph 3.1 and 3.2. This is also why we include the sea level in the estimation of paleo-orography.

I73 What does the acronym CHELSA stand for?

Response: Climatologies at High Resolution for the Earth's Land Surface Areas. Will be included.

I76 Explain what GPCC stands for.

Response: Will be included.

I78 ICE-7G appears to be available since 2018. Can you explain why you are using ICE6G? What is the difference between ICE6G and ICE6G\_C and why did you chose the 'C' variant?

Response: ICE6G\_C was the latest version when we made the calculations. ICE-7G was

not available at that point. An update is not feasible at this point due to the high computational demand.

I78 Same point as above, is ICE6G\_C the model the simulation or the data?

Response: The output of the model (the data).

I80 To my knowledge ICE6G is not a dynamic ice sheet model and does not explicitly model changes in ice thickness.

Response: That is not what is stated on their webpage: "Each file contains information for points on a 1x1 degree global grid. The model's ice thickness field is given by the variable stgit." <https://www.atmosph.physics.utoronto.ca/~peltier/data.php>

I82 Topography update is every 500 years, but according to I57 climate updates every 100 years. How do you deal with this issue?

Response: This is indeed not described. The nearest time step has been used. We will add this at the respective point.

I85 It could be useful to explain here or elsewhere that the given extent mask is not necessarily in agreement with ICE6G at LGM. When is LGM defined in Ehlers et al., (2011). Is there a possible temporal mismatch with ICE6G?

Response: This is correct. We will mention this.

I88 What year do you assign to this dataset, what does 'current' mean specifically?

Response: This cannot be clearly stated as GLIMS does not give this information.

I94 What does 'derived' mean. What is different and what is the same compared to the original CHELSA V1.2. Again, is CHELSA V1.2 the algorithm (as stated here) or the dataset originating from it?

Response: As stated.

I96 Why is GMTED2010 not described as input data in section 2? It should.

Response: Will be included.

I98 Why is the Miller data not described as an input dataset in section 2? It should.

Response: Will be included.

I100 Could state here that the details 1-4 are described in the following sub-sections. It would be useful to describe the overall process in a flow diagram or other schematic to make it easier to understand the different steps. Add motivation at every step why things are done the way they are and how in detail.

Response: We will include such a diagram in the revision and make sure to better describe each step.

I102-104 It seems that this part still belongs to the general intro section 3 assuming that 3.1 is only about orography.

Response: Orography is both bedrock elevation + glacier thickness.

I105 Explain what the purpose of combining Ehlers and ICE6G is. Motivate this by laying out your assumptions (do you trust Ehlers more than ICE6G in terms of accuracy?). What does Ehlers give you that ICE6G doesn't and vice versa? It may be useful to illustrate the whole process with a figure for one or several example location. Maybe a cross section through the margin of an ice sheet?

Response: We will include such a figure. Ehlers gives a high resolution that can be used to delineate glacial boundaries at 1km. ICE6G gives a temporal signal of the elevation only of the major ice sheets.

I106 Explain the choice and significance of taking 100 samples? How many samples are left (on average, max) after removing the outliers. Is ICE6G distributed at 1 degree resolution? If so mention it in section 2.2. If not, why work at that resolution?

Response: It's the native resolution. 100 samples is arbitrary in this case. It seemed a good compromise between size of the resulting sample and accuracy.

I106 Not clear what "extracted the height of the glacier plus the surface elevation" means. Maybe 'height of the glacier' is ice thickness? Or is it height as in surface height? Is  $e_{t}^{\text{ice}}$  the surface elevation or the surface elevation + glacier height?

Response: Will be clarified.

I107 What does the subscript 't' stand for?

Response: Timestep. Will be clarified.

I107 Explain why these points are omitted. What is the reason for further extracting the point locations on the boundaries?

Response: Otherwise there would be a surface elevation of a glacier where there is no glacier.

I108 What does 'DEM' stand for and what is the data source for it?

Response: Digital Elevation Model. Will be described. Data source is GMTED2010.

I109 Is 'past sea surface elevation' from Miller? Explain why this correction to sea-level is needed. As mentioned in the general comments, I don't understand why this is done and suspect a conceptual problem. Please explain this.

Response: Please see our response above. We don't understand what the conceptual problem could be, please elaborate what you expect. Our intent was to a) provide evidence for land where there was land in the past, and b) to use accurate and realistic elevation data for modelling climate.

I116 What does subscript 'c' stand for.

Response: Will be explained.

I have tried to give exhaustive comments on page 4 to show the level of detail that is in my mind required to make this a useful description. Similar comments could be made in the sections that follow.

I120 Explain up front why the B-spline interpolation is needed and what the main ideas of the iterative approach are.

Response: A B-Spline interpolates data to higher resolutions, the iterative process (hence: Multilevel B-Spline) makes sure that the error of the interpolation decreases.

l131 What is this 'change factor'? Explain what it serves for in the approach.

Response: Will be explained.

l131 What time period is  $\tau_{\text{cur}}^{\text{mod}}$  averaged over? Why do you resample to 0.5 degree resolution?

Response: Will be explained.

l138 What is the significance of levels 26 and 20. What pressure/altitude do they represent?

Response: Will be explained.

l146 The main ideas of that temperature coupling process have to be explained. What assumptions go into that approach? How is temperature assumed to modify orography?

Response: The assumption is that increasing temperatures are related to melting of glaciers (and vice-versa).

l155 Where does 'glacial melt' come from in this approach?

Response: Probably better explained as reduction in glacier thickness.

l166 What process is assumed to modify orography?

Response: In this case only the changes in size/thickness of the glaciers.

l195 in l184 the grid is described to have 4km resolution. Why the change to 3km?

Response: Simply a typo, will be corrected.

l225 text here appears to be repeated in l227.

Response: Will be corrected.

Figure 1

Suggest to (additionally) show anomalies relative to the present day. For now, it is difficult to make out clear differences in these plots.

Response: This will be included in a revision

Suggest to show the present day reference temperature field for comparison.

Response: If we show anomalies, that's not needed anymore

The '-' in 22k-BP should be removed. It reads like a minus sign.

Response: Will be removed

Is this a perceptually uniform colour map? If not, consider using one (e.g. <https://www.nature.com/articles/s41467-020-19160-7>)

## Figure 2

Results should be shown relative to a long-term average rather than one year (1990). If this is the case, what period is the data averaged over?

Response: 1950-1990

I288 Motivate why it is needed to project the data to another map? Details like projection parameters can be presented elsewhere (table, appendix).

Response: Will be excluded

I290-294 What is the underlying physical assumption for the 1/0 assignment? Clarify.

Response: Will be clarified. 0 means there is no glacier, 1 means there is glacier. This binary information is then tested. Why does this need a physical assumption? Please elaborate.

I314 Is the strong correlation maybe related to the fact that the data was bias corrected to a similar product? How do you explain such impressive match?

Response: The bias correction certainly has an influence as well, but so does the downscaling. The CHELSA model decreases the bias and increases the correlation usually (for more details see. e.g. Karger et al. 2017, 2020, 2021 Scientific Data);

I334 'idiosyncratic' Strange choice of word. Reformulate?

Response: Will be changed

## Figure 5

The strong mismatch at LGM could suggest that the lapse rate correction plays out in an unexpected way. It should be checked if that mismatch arises from climate model bias, lapse rate corrections or the bias corrections that are applied in the process.

Response: It could be all of the above plus inaccuracies in the proxies. It cannot be disentangled at this point, as we have no data to check the degree of bias in LGM climate simulations (the coarse resolution model output, which is input to the downscaling algorithm) or the proxy data.

I344 It is not clear to me how glacier extent is meant to validate the downscaling process. It may serve to validate ICE6G and may reveal a mismatch between ICE6G and Dyke, but that is not really at stake here. Could you explain how that comparison can constrain your approach? How does unmodified ICE6G compare to Dyke. Is that improved with your modifications?

Response: We compare the 1km predictions estimated using our algorithm, not ICE6G. We can include ICE6 G as well, but only for limited time steps.

I360 This section comes with unexpected new concepts and models (GLM, KISSMig) that were not introduced before. After going through the technicalities of the sections before, this is a steep change of register. In the abstract this part is introduced as another aspect

of the model validation, while here it is written as a use case for the produced dataset. In either case, I suggest this part has to be better linked with the rest of the paper or, maybe better, extended and conceived as a separate paper.

Response: Its part of the validation with the idea that it simultaneously presents a case study as a plausibility test. We will add more basic information about the reasons for applying this case study and about the underlying models used such as KISSMig.

I381 Why is yet another projection needed in this case? Motivate.

Response: Since KISSMig is a grid based dynamic species migration model, it uses an equal area projection to avoid spatial bias in the simulations..

I418 What trends are to be preserved? Clarify. Reference to (Hempel et al., 2013) is probably better placed in the description in section 3.2.

Response: Will be changed.