

Authors reply to

Journal: Climate of the Past

Title: Statistical downscaling of a climate simulation of the last glacial cycle: temperature and precipitation over Northern Europe

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Referee #1

We would like to thank the Referee for the constructive and good comments. Below are our replies to the comments

General comments

Korhonen et al. perform statistical downscaling of an EMIC simulation of the last glacial cycle climate evolution. A statistical downscaling method, Generalized Additive Models, previously used by e.g. Vrac et al (2007), is utilized. Previous studies rely on the assumption that the statistical relations are valid for the range of glacial to interglacial boundary conditions, whilst Korhonen et al include different explanatory variables in the statistical downscaling to account for the presence of an ice sheet. The inclusion of the shortest distance to an ice sheet margin as an explanatory variable is novel, and potent. The manuscript describes an interesting approach to downscaling low-resolution simulations of climate on glacial-interglacial time scales. The manuscript is however difficult to follow, and descriptions of the methodology and discussion of the results need to be substantially improved to meet the standards of the Climate of the Past.

Major comments

Comment: A general discussion on different techniques for statistical and dynamical downscaling is lacking. The discussion should include reference to the recent discussion on the added value of downscaling, e.g. Racherla et al (2012).

Reply: Yes, this is good proposal

Comment: The methodology is not well described. The climate model simulations used must be better described, and the choice must be motivated. Further, the use of two geographical regions must be better described and motivated. Also, the methodology used in determination of which explanatory variables should be used in the GAM and the benefits of including the shortest distance to the ice sheet (rather than the continentality used by Vrac et al, 2007) is not described or discussed.

Reply: We tested about 50 combinations of predictors and found the presented best. All the predictors were physically reasonable. Due to the northern location we tested the effect of including the term distance to the ice sheet.

To widen the validation of the models we tested the monthly GAMs in predicting adjacent months' temperature or precipitation.

The annual GAMs (calibrated only with LGM and recent past climate data) were tested to predict the 44 kyr BP annual mean temperature and precipitation and the results were compared to simulations with RCA3. See in supplementary materials 1 and 2.

Comment: To avoid the problem of lacking observations (temperature, precipitation, ice sheet position) for the glacial climates, Korhonen et al. utilize results from global climate modelling and from dynamically downscaled global climate modelling. This choice is not discussed in the manuscript, although a number of issues warrant a discussion

Reply: In earlier work GAMs have been developed using observed data only. However, if we want to have GAMs valid also for e.g. glacial periods we need data depicting those conditions. The climate model data used in this work enables this.

Comment: The ice sheet extent and topography implemented in the RCA3, CCSM4 and CLIMBER-2 - SICOPOLIS simulations differ. How is this treated in the current work? How does it influence the results?

Reply: In the calibration of the GAMs we implement the ice sheet extent and topography corresponding to the calibration data, e.g., when calibrating by RCA3 data we implement the RCA3 ice sheet extent and topography. Further, when predicting by the GAMs we implement the ice sheet extent and topography by SICOPOLIS. If the GAMs were calibrated by SICOPOLIS ice sheet data, we would have problems near the ice sheet margins as they differ in the SICOPOLIS simulation and RCA3 and CCSM4.

Comment: In the text, the authors state that they use both the most recent CCSM4 LGM simulation and the RCA3 downscaling of a CCSM3 LGM simulation to represent the LGM climate. The use of these two data sets is not clear. Are the two datasets combined, or used separately? In combination with a clear description of the use of the two data sets, the authors should briefly discuss the differences in the simulated climate between the two. The global CCSM3 simulation downscaled by Kjellstrom et al (Brandefelt and Otto-Bliesner, 2009) differs substantially from the standard CCSM3 simulation referred to in the manuscript (Otto-Bliesner et al., 2006), and presumably it also differs from the CCSM4 LGM simulation (Brady et al., 2013). These differences are important to discuss in relation to the usage of a combination of results from these simulations.

Reply: These two datasets were used separately. The CCSM4 LGM simulation was used for the annual GAMs over the Western Eurasia. The RCA3 downscaling of CCSM3 LGM simulation was used in the monthly GAMs over Northern Europe.

Comment: The RCA3 and CCSM4 simulations are used here to replace observations. Why were these specific global (and dynamically downscaled global) simulations chosen? How does the simulated climate compare to other modelling of the LGM (PMIP2; Kageyama et al 2006, and PMIP3; Annan and Hargreaves (2013), Brandefelt and Otto-Bliesner, 2009) and MIS3 (van Meerbeeck et al, 2009)? How does it compare to proxy reconstructions (e.g. Annan and Hargreaves, 2013)?

Reply: Thanks for this comment. Justification of the model choice can indeed be improved. Chapter 2.3.2 can include the justification and a suggested reference.

“Different phases of the Palaeoclimate Modelling Intercomparison Project (PMIP) provide detailed information on the relative performance of climate models in past climate conditions. In particular, CCSM3 model compares generally well in the PMIP3 (Kageyama et al. 2006) and it is within the ensemble spanned by participating models, for instance, regarding the simulated temperature of the warmest and coldest month in the latitude-longitude sectorial averages of interest. We thus conclude that for the present study, choice of CCSM3 is equally well justified as selection of any other model in the PMIP ensemble.”

Ref.

Kageyama, M., A. Laîné, A. Abe-Ouchi, P. Braconnot, E. Cortijo, M. Crucifix, A. de Vernal, J. Guiot, C. D. Hewitt, A. Kitoh, M. Kucera, O. Marti, R. Ohgaito, B. Otto-Bliesner, W. R. Peltier, A. Rosell-Melé, G. Vettoretti, S. L. Weber, Y. Yu and MARGO Project members, 2006. Last Glacial Maximum temperatures over the North Atlantic, Europe and western Siberia: a comparison between PMIP models, MARGO sea-surface temperatures and pollen-based reconstructions. Quaternary Science Reviews, 25, 2082-2102. doi:10.1016/j.quascirev.2006.02.010.

Minor comments

Comment: Times should be given in a consequent manner, e.g. with kyr BP. 'kyr' should be defined the first time it is used.

Reply: This can be corrected, (1000 years) kyr

Comment: Abstract. The abstract reads very much as a listing of what was done without a statement of the aim of the study.

Reply: Text will be edited

Comment: Introduction; page 3373; lines 2-6. The authors state that GCMs cannot be used for simulations of full glacial cycles; Smith and Gregory (2012) however used an AOGCM in a transient simulation of the last glacial cycle. Further, the references to simulations of the distant past climate represent an odd selection. Please refer to some article describing PMIP2 and/or PMIP3 results. The ordering of the references is also odd, it is neither alphabetic nor based on publication year.

Reply: Smith and Gregory (2012) used prescribed ice sheets, whilst CLIMBER-SICOPOLIS system simulates also ice sheets, i.e., climate and ice sheet models are coupled, and the ice sheet is reconstructed by the model system, not prescribed.

Reference to PMIP3:

Braconnot et al, The Paleoclimate Modeling Intercomparison Project contribution to CMIP5, CLIVAR Exchanges No. 56, Vol. 16, No.2, May 2011, pp 15-19.

Braconnot et al, Evaluation of climate models using palaeoclimatic data, Nature Climate Change 2, 417-424 (2012), doi:10.1038/nclimate1456.

The references are now ordered based on publication year:

(Renssen et al., 2005; Otto-Bliesner et al., 2006; Liu et al., 2009; Kjellström et al., 2010; Singarayer and Valdes, 2010; Strandberg et al., 2011; Smith and Gregory, 2012; Braconnot et al., 2011; Braconnot et al., 2012)

Smith and Gregory (2012) has been added to the reference list.

Smith R S, Gregory J, 2012. The last glacial cycle: transient simulations with an AOGCM. Climate Dynamics, (December 2011). doi: 10.1007/s00382-011-1283-y.

Comment: Introduction; page 3373; lines 7-20. The division between AOGCMs and EMICs must be better described. What is meant by an AOGCM, which components of the climate system are dynamically modelled and which are assumed constant? Similarly for EMICs; these exist in many flavours, some e.g. including global bio-geo-chemical cycles. Please improve the description and discussion of differences and similarities between different types of models.

Reply: The text was indeed too general to be useful. The characteristics and deficiencies are made explicit.

Comment: Introduction; page 3373; lines 21-29. Please elaborate on the deficiencies of EMICs; both resolution and modelling simplifications (such as the use of statistical descriptions of the atmospheric dynamics) may influence the validity of the simulated climate and climate evolution. Further, I wonder if c. 50 km horizontal resolution is really representative of regional climate simulations, or if this is just the resolution of the RCA3 simulations utilized in the present study.

Reply: Revision due to "Minor 4" covers this remark, we believe.

Comment: Introduction; page 3374; line 12. AP is not defined. Further, the articles by Martin et al. describe the future 1000 yr, rather than the future 100 yr.

Reply: After Present (AP). The reference Martin et al. shall be removed, as it is not yet published.

Comment: Introduction; page 3374; lines 20-25. Since the simulated regional climate is strongly dependent on the global climate simulations, the global climate simulations used by Kjellstrom et al and Strandberg et al should also be cited.

Reply: The global climate simulation used by Strandberg et al. was Brandefelt and Otto-Bliesner. (2009). Kjellström et al. describe the global simulation in the same paper as the regional climate simulation Ref: Brandefelt, J. and Otto-Bliesner, B. 2009. Equilibration and variability in a Last Glacial Maximum Climate simulation with CCSM3. Geophys. Res. Lett. 36, L19712. doi: 10.1029/2009GL040364.

Comment: Section 2. It is not clear which type of data from the different models /observations are used; what is meant by temperature - T2m or something else?, are the variables included in the calibration of the statistical model monthly means for each grid point (giving 12 values for each variable and grid point)? How many years were the RCA3 data averaged over?

Reply: Temperature was T2m. The variables included in the calibration of the monthly GAMs were monthly means of each grid point. The variables included in the calibration of the annual GAMs were annual means of each grid point. For RCA3 model: 50 model year average.

Comment: Sect. 2. Two regions are mentioned in Sect. 2, western Eurasia and northern Europe. The purpose of using two different regions is not described. Please motivate the definition of these regions, why were these particular regions chosen, why are there two regions, how are these incorporated in the analysis?

Reply: The areas are based on the areas of climate simulations used in the study. RCA3 covers Northern Europe and CCSM4 Western Eurasian.

Comment: Equation 3. Does log mean natural logarithm or base 10?

Reply: Here log means natural logarithm.

Comment: Sect 2.2. Page 3378 The description of the CLIMBER-2-SICOPOLIS model is not detailed enough. Please detail the different components somewhat more, and relate to the discussion in the introduction on different types of models.

Reply: Thanks for the comment. We have now substantially revised the text in the Introduction, and believe the revision covers this comment, too.

Comment: Sect. 2.3.1. The authors must comment on the choice of CRU (land-only) data in combination with very low resolution data over the ocean. Why is not NCEP or ERA re-analysis data, which has much higher resolution, used?

Reply: By the time this work was done, these data were easier to get. Practically in land- grid points ERA 40 and CRU data are the same. We have mentioned possible use of NCEP and ERA re-analysis data in the future work.

Comment: Sect. 2.3.2. To avoid mis-understanding, please refer to the articles describing the CCSM3 simulations used as boundary conditions to the RCA3 simulations. In the current writing, one may conclude that the LGM boundary conditions were those reported by Otto-Bliesner et al, 2006.

Reply: Text will be edited

Comment: Sect. 2.3.2. Line 13. What is meant by historical climates? Is this a simulation of the pre-industrial or recent past climate or what?

Reply: Historical climate means here recent past.

Comment Equations 6-10. The equations are somewhat confusing. Please indicate which variables are functions of the location and which are not.

Reply: Variables Y_m and Y_0 are functions of location.

Comment: Sect. 3. For clarity, please divide the results section into subsections.

Reply: This will be done.

Comment: Sect. 3. The results, skill scores etc. are given one after the other with very little discussion on how they relate to observations and other studies. E.g. how do the skill scores related to the results of Vrac et al (2007) and Martin et al (2013)? Any improvements?

Reply: The residuals of monthly precipitation and temperature of our predictions (Figures 3 and 5) were in the same range as in the Figures 3 and 4 of Vrac et al. (2007). However, the most evident improvement is that we have applied data from different phases of climate cycle; LGM and warm climate.

Comment: Sect. 3. As mentioned earlier, it is not evident why two different regions were studied and how the different simulations were used for the different regions. This description must be improved.

Reply: The areas are based on the areas of climate simulations used in the study. RCA3 covers Northern Europe and CCSM4 Western Eurasian.

Comment: Sect. 3. The spatial patterns may be relatively well captured by the GAMs, but the absolute values are off in large regions. Please comment on this and discuss the results in relation to other studies of statistical and dynamical downscaling. What is the use of downscaling in a region where the temperature is several degrees off from the observed?

Reply: In a landscape having large topographic variation all the downscaling methods have large challenges to capture the abrupt changes. However, the method applied here captures most of the spatial patterns of downscaled fields taking into account that geographical predictors that are used to predict the spatial variation have a relatively coarse resolution and the very coarse resolution of downscaled parameters.

Comment: Sect. 3. and Fig. 6. You have not explained the difference between GAM Western and GAM Northern, and also, you do not discuss the 1-3 degree difference between the temperatures in these!

Reply: The difference between GAM Western and GAM Northern is due to the difference of the driving model: CCSM4 versus RCA3.

Comment: Sect. 3. Page 3382; Lines 8-10. I do not agree on the interpretation of Fig. 2a. The spline function plotted reduces the precipitation (regardless of the location I suppose) in months of low precip simulated with CLIMBER, and enhances the precipitation in months of high CLIMBER-simulated precip. This means that the spline function increases the amplitude of the precipitation annual cycle (which is reasonable since CLIMBER-2 has such low horizontal resolution and thus simulates smoothed precipitation variability in time and space).

Reply: We thank about this good analyses and text can be edited accordingly.

Comment: Sect. 3. Page 3382; Lines 15-17. I am a bit curious about the shape of the elevation component of the GAM in Fig. 2c. It shows that precip is higher than the CLIMBER-2 precip for moderate elevations, but lower than CLIMBER-2 for an intermediate elevation range of c. 1000-2200 m. Can this be explained in meteorological terms? Is it somehow connected to the inclusion of glacial climates with thick ice sheets? What does the cpline function look like if only present observations are included?

Reply: Unfortunately we have no lines drawn for the case only present observations were included. The impact of elevation on precipitation may have meteorological explanation. At relatively low elevations <750 m topography enhances precipitation, between 750 and 2000 m at top of glaciers climate is characterized with smaller precipitation amounts and again when we go above 2500 m (mountain tops) precipitation increases as a function of elevation

Comment: Figure 2. Please insert a thin black line at s equals 0 in subplots 1,c and d to illustrate above and below CLIMBER-2 simulated precipitation. Also, in subplot d. it may be easier to read the plot if the directions were indicated with S, N, E and W.

Reply: Good proposal.