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Interactive comment on "A new multi-variable benchmark for Last Glacial Maximum climate simulations" *by* Sean F. Cleator et al.

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Response to review 1

We thank the reviewer for their positive and helpful comments on our manuscript.

Comment: This is a relatively short paper that relies heavily on previously published work for data and methodology, which makes it hard to review in a very detailed fashion, because there is not much data included. The results presented are simply a number of global maps, with very little data in the text or supplementary information. As the previous studies have passed peer review this does not bother me too much, and the paper is clearly and well written. Hence I am happy to recommend publication with minor technical corrections. Response: As the reviewer points out, the pollen-based recon-

structions and the climate model simulations underpinning our reconstruction are in the public domain, and the data assimilation methodology is described in detail in another publication currently in review for JAMES and available at arXiv (arXiv:1902.04973v2, https://arxiv.org/abs/1902.04973v2). The general approach used for the CO2 corrections, which the reviewer describes as a significant contribution, was published in Prentice et al. (2017) – although we provide the equations for the implementation of this approach in the current paper in Appendix 1. Therefore, the new results in this paper are indeed the global maps of reconstructed climate variables. These data are archived and will be made publicly available – however, we realise that it may not have been obvious that the citation to Cleator et al. (2019b) represented the reconstruction data set. We propose to modify the last sentence of the abstract to make it clear that the reconstruction data are available as follows: The new reconstructions will provide a robust benchmark for evaluation of the PMIP4/CMIP6 entry-card LGM simulations and are available at DOI:10.17864/1947.206 We also note that, in response to other review comments, we have now also posted the code used to make the reconstructions at Zenodo: 10.5281/zenodo.3445166 We did not include a Data Availability section in the Discussion paper and we will also rectify this: Data availability: the gridded data for the LGM reconstructions are available from http://dx.doi.org/10.17864/1947.206; the code used to generate these reconstructions is available from (10.5281/zenodo.3445166).

Comment: The definition for the LGM given here is 21$\pm$1 ka, and this appears to be because previous work has used this temporal extent. However it is different from, for example, to the range used by Annan and Hargreaves (cited in the paper) of 21$\pm$2ka, and recent work on sea level (Ishiwa et al. 2019) suggest the 'real' LGM was 19.1-19.7 ka, with a plateau prior from 20.4-25.9ka, both pushing out past the time interval use in this study. I don't think there is anything in particular to be done about this – just to think about. . . Response: The reviewer indicates that the definition of the LGM used in our paper (21$\pm$1 ka) differs from the interval used by Annan and Hargreaves of 21$\pm$2ka, and there is recent work on sea level (Ishiwa et al. 2019) which suggests the 'real' LGM was 19.1-19.7 ka, with a plateau prior to this from 20.4-25.9ka. Our choice of this time interval reflects the fact that the LGM is conventionally defined in PMIP at 21 ka and most of the pollen- based reconstructions of this interval included in the Bartlein et al data set are from the 21±1 ka. We are aware that there is still controversy over the timing of the LGM, with both younger and older ages mooted for the actual maximum ice volume/sea- level lowering (see e.g. Peltier and Fairbanks, 2006; Clark et al., 2009; Lambeck et al., 2014). Even the recent work by Ishiwa et al. (2019) points out that the sea level drop after 19.7 ka was only 10m and that there was a long plateau with stable low sea level prior to this and encompassing the 21 ka interval. Since our aim is to produce a data set for benchmarking new PMIP LGM simulations, which will be run with boundary conditions for 21 ka (Kageyama et al., 2017), the exact date of the LGM is therefore not an issue. However, we agree that there is a difference between the true definition of the LGM and the convention used for modelling purposes, and that this is not clear from our introductory text, so we propose to expand our definition (lines 57-61) as follows: At the Last Glacial Maximum (LGM, conventionally defined for modelling purposes as 21 000 years ago), insolation was quite similar to the present, but global ice volume was at a maximum, eustatic sea level was close to a minimum, long-lived greenhouse gas concentrations were lower and atmospheric aerosol loadings higher than today, and land surface characteristics (including vegetation distribution) were also substantially different from today.

Comment: a general point I guess, that the paper refers to several new studies since the Bartlein paper on which the analysis is based, and there are more. It would be nice to think these could be assimilated into a future dataset to maybe close some of the large 'no data' holes in the results. . . Response: The reviewer points out that we refer to several new studies since the Bartlein paper on which the analysis is based, and there are more, and that it would be nice to think these could be assimilated into a future dataset to maybe close some of the large 'no data' holes in the results. We thoroughly agree that it would be good to plug the gaps, and this will be an effort for the future. The three papers that we cite at lines 361-363 (Flantua et al., 2015; Herbert and Harrison, 2016; Harrison et al., 2016) demonstrate that there are pollen records

available that would plug the gaps, but alas do not pro- vide quantitative reconstructions at these sites. The Izumi and Bartlein, 2016 paper provides an inversion-based reconstruction for North American – this region is already relatively well covered in the Bartlein et al data set. Similarly Mauri et al., 2015 provide a new gridded reconstruction for Europe – again a region that is well covered in the Bartlein et al data set. However, we are aware of new pollen-based quantitative recon- structions embracing the LGM for individual sites (e.g. in Africa, China, Russia, south- ern Europe) and compiling these reconstructions would certainly be a worthwhile effort in the future. Our method also lends itself to combining pollen-based reconstructions with other quantitative estimates of terrestrial palaeoclimate, and again this should be something that is done in the future. We will expand the paragraph describing future possibilities to expand the current data set to spell out some of these opportunities more clearly, as follows:

Some areas are still poorly covered by quantitative pollen-based reconstructions of LGM climate, most notably South America. More pollen-based climate reconstructions would provide one solution to this problem – and there are many pollen records that could be used for this purpose (Flantua et al., 2015; Herbert and Harrison, 2016; Harrison et al., 2016). There are also quantitative reconstructions of climate available from individual sites (e.g. Lebamba et al., 2012; Wang et al., 2014; Loomis et al., 2017; Camuera et al., 2019) that should be incorporated into future data syntheses. It would also be possible to incorporate other sources of quantitative information, such as chironomid-based reconstructions (e.g. Chang et al., 2015) within the variational data assimilation framework.

Additional references Camuera, J., JimeÌĄnez-Moreno, G., Ramos-RomaÌĄn, M.J., GarciÌĄa- Alix, A., Toney, J.L., Anderson, R.S., JimeÌĄnez-Espejo, F., Bright, J., Webster, C., Yanes, Y., JoseÌĄ S. CarrioÌĄn, J.S., 2019. Vegetation and climate changes during the last two glacial-interglacial cycles in the western Mediterranean: A new long pollen record from Padul (southern Iberian Peninsula), Quaternary Science Reviews, 205, 86-105, https://doi.org/10.1016/j.quascirev.2018.12.013. Chang, J.C., Shulmeis-

ter, J., Wood- ward, C., Steinberger, L., Tibby, J., Cameron Barr, C., 2015. A chironomid-inferred summer temperature reconstruction from subtropical Australia during the last glacial maximum (LGM) and the last deglaciation, Quaternary Science Reviews, 122, 282- 292, https://doi.org/10.1016/j.quascirev.2015.06.006. Lebamba, J., Vincens, A., and Maley, J.: Pollen, vegetation change and climate at Lake Barombi Mbo (Cameroon) during the last ca. 33 000 cal yr BP: a numerical approach, Clim. Past, 8, 59-78, https://doi.org/10.5194/cp-8-59-2012, 2012. Loomis, S. E., Russell, J. M., Verschuren, D., Morrill, C., De Cort, G., Sinninghe DamsteÌĄ, J. S., . . . Kelly, M. A. (2017). The trop- ical lapse rate steepened during the Last Glacial Maximum. Science advances, 3(1), e1600815. doi:10.1126/sciadv.1600815 Wang, Y., Herzschuh, U., Shumilovskikh, L. S., Mischke, S., Birks, H. J. B., Wischnewski, J., BoÌĹhner, J., SchluÌĹtz, F., Lehmkuhl, F., Diekmann, B., WuÌĹnnemann, B., and Zhang, C.: Quantitative reconstruction of precipi- tation changes on the NE Tibetan Plateau since the Last Glacial Maximum – extending the concept of pollen source area to pollen-based climate reconstructions from large lakes, Clim. Past, 10, 21-39, https://doi.org/10.5194/cp-10-21-2014, 2014.

Comment: L59: change to ‘lower, atmospheric aerosol. . .’ Response: We will make this change.

Comment L321: comma after ‘however’ (I think?) Response: We will make this change.

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