Reply to the 2nd anonymous referee's comment on

Krätschmer, S., van der Does, M., Lamy, F., Lohmann, G., Völker, C., and Werner, M.: *Simulating glacial dust changes in the Southern Hemisphere using ECHAM6.3-HAM2.3*, Clim. Past Discuss. [preprint], https://doi.org/10.5194/cp-2021-73, in review, 2021.

Review of Simulating glacial dust changes in the Southern Hemisphere using ECHAM6.3-HAM2.3 by Krätschmer, et al. for Climate of the Past.

The authors of this study use the ECHAM climate model to investigate the global variability of mineral dust emission, transport, and deposition across three different mean climates. (modern, pre-industrial, and LGM), with a particular focus on the Southern Hemisphere. The land model component includes dynamic vegetation that determines dust source locations, thereby permitting prognostic determination of changing dust source strength and location through time, and their LGM simulation includes enlarged coastlines to include exposed continental shelf among the potential dust sources. For each of their simulations the authors compare their results to observations and other model results, sometimes finding agreement and sometimes not. Their simulation of the LGM, and investigation of how it differs from the PI, is noteworthy as there are limited model studies of this time period that include dynamic dust sources. Of particular note are a series of results regarding the spatial variability of the provenance of dust deposited on Antarctica and the Southern Ocean. These results are a valuable contribution to the ongoing discussion regarding the relative contributions of South American and Australian sources through time, and thus the appropriate interpretation of archives of paleodust from the region. As this is a topic with some disagreement, the addition of results from a new model is welcome.

Overall I found the paper very well written and organized, and enjoyable to read. I do have some unanswered questions as well as some minor suggestions for the authors, so my recommendation is acceptance upon minor revisions.

Dear referee,

thank you very much for reviewing our manuscript and the helpful suggestions you provided. Please find below our replies to your comments.

Primary comments

1. **The paper would benefit from more time in the introduction and conclusion spent reviewing what is known and the disagreements regarding dust provenance to Antarctic and the Southern Ocean. I was pleased when the authors brought up many of the studies when discussing their results, but I felt the bigger picture was somewhat overlooked. Specifically, there are conflicting studies regarding whether South America or Australia is the primary source of dust (and for that matter how much is contributed by Antarctic sources), and the relative role of dust source strength and transport efficiency. I think the authors have room here to set up and then answer some questions about how these discrepancies can be resolved by considering the time-varying relative strength of sources, the transport efficiency, and the spatial distribution of their influence. I think much of this information is already contained in the paper, but an explicit consideration of the debate would be valuable. One additional source to consider is Markle, et al. (2018).**

   Since the provenance studies for dust in the Southern Hemisphere are an important part of our study, we agree and will include a brief overview on the conflicting studies regarding whether South America or Australia is the primary source of dust already into our introduction section. As written in our reply to Eric Wolff's comment on our manuscript [1], we will not be able to give

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[1] https://cp.copernicus.org/preprints/cp-2021-73/cp-2021-73-AC1-supplement.pdf

an ultimate answer on the question whether changes in source strength or transport efficiency eventually led to the observed increase in mineral dust aerosol concentration during the LGM found in marine sediments and Antarctic ice cores. Considering the fact that more than 90% of the dust deposition in the Southern Ocean region occurs due to precipitation in our model, we agree with Markle et al. (2018) that "precipitation in the mid-latitudes is the principal barrier to aerosol reaching the poles". However, we disagree that changes in the hydrologic cycle are the primary driver since we also find substantial and required changes in source strength by a factor of 16 for both Patagonia and Australia, which we can trace back well to changes in vegetation, wind speed, soil moisture and extension of the source areas. Moreover, the authors find the best agreement between their modeling results and data "at multi-centennial and longer timescales", while our study captures only a 30-year period under LGM conditions and thus considers in particular processes on much shorter timescales. We will include those aspects in our revised manuscript.

2. **What about New Zealand? I was surprised that the LGM simulations don't seem to include an expanded dust source from the exposed continental shelf around New Zealand, nor any discussion of it as a dust source during that period. Neff, et al. (2015) and Koffman, et al. (2021) would be relevant to this discussion.**

   We are aware of the ongoing discussions on New Zealand as a potential dust source especially for the South Pacific during the last LGM (e.g. Lamy et al., 2014). Our model yields annual dust emissions of less than 1 Gg yr^{-1} from New Zealand during the LGM, which is effectively negligible compared to the simulated emissions of 748 Tg yr^{-1} (Australia) and 36 Tg yr^{-1} (Patagonia). The low emissions in our model also explain why New Zealand appears to not represent a dust source at all during the LGM in Fig. 1b (*paper*).

   One reason to consider is that New Zealand's geographical expanse is rather small and thus only marginally captured by our model running in the spatial resolution of T63, which corresponds to a grid box size of approximately 180 km (Sidorenko et al., 2015). Consequently, New Zealand's source strength and the according contribution to the dust deposition in the Pacific sector of the Southern Ocean during the LGM (Koffman et al., 2021) might be underestimated in our model. The study of Neff and Bertler (2015) uses a trajectory modeling approach for the years 1979 to 2013 based on reanalysis datasets for the according pressure fields. Additionally, the authors mention in their study that they investigate solely the trajectories without taking into account emission and deposition processes, which does not enable us to compare our simulation results for the LGM to the results of their study.

   However, we agree that our findings concerning New Zealand's role as a dust source during the LGM should be included in our study and we will do so in our revised manuscript.

3. **The authors cover many of the modeling studies of dust transport to the Antarctic in their discussion of provenance, but there are also studies that take an isotopic approach that should be discussed as well. Wengler et al. (2019), McGee et al. (2016).**

   The study of Wengler et al. (2019) provides lithogenic flux data only for the Holocene, stating that surface sediments near New Zealand "most likely indicate a combination of Australian dust and riverine input from New Zealand". Since our model only considers aeolian dust fluxes, we cannot compare our simulation results for PI and LGM.

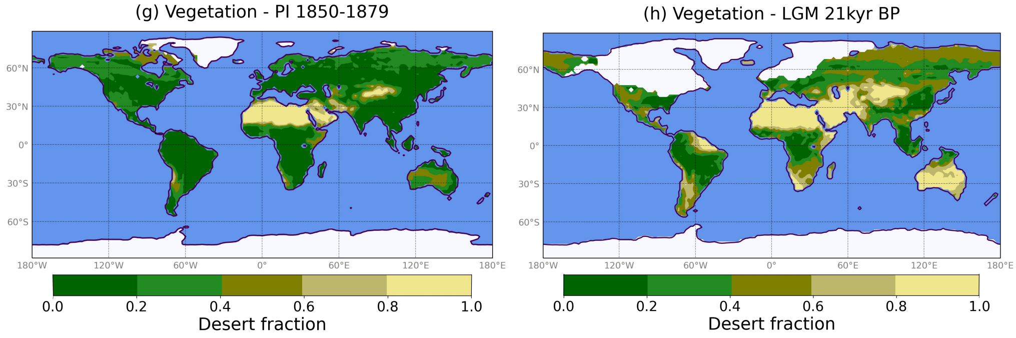
   However, we will include in our revised manuscript that the reconstructed dust fluxes used in our study for comparison with our simulation results (DIRTMAP, Kohfeld et al. (2013)), which are based on the assumption of relatively constant proportions of ^{232}Th in continental lithogenic materials, might be overestimated by 30–40 % in regions receiving fine-grained dust from Patagonia and Australia (McGee et al., 2015).

Minor comments

1. **How is land tiling / vegetation coverage determined for the newly exposed continental shelf? Essentially, is the newly exposed land always a dust source, or can it become vegetated?**

As mentioned in our manuscript, we perform a restart for our LGM experiments using restart files, which represent a dynamic equilibrium of our model for the according topographic, vegetation and climate conditions obtained after several hundred years of simulation (line 172).

Generally, the land fraction of *each* grid cell can become vegetated according to the rules and equations for dynamic vegetation implemented in the land surface and vegetation model JSBACH, which are described in detail in Reick et al. (2013), paragraph 3 "*Natural Land Cover Change*". In short, the process of increasing / decreasing vegetation for each grid cell depends on several factors like meteorological conditions (temperature, precipitation, humidity, …), competition among the different plant functional types (PFT), the respective time constants for growth and lifetime for each PFT etc.. One of the leading principals is the so-called *universal presence*, i.e. seeds of each PFT are always on the land fraction in each grid cell available and the factors mentioned before determine the respective proportion of each PFT per grid cell. The land fraction of each grid cell can be further divided into a vegetated and a non-vegetated (desert) fraction. The latter has been used by (Stanelle et al., 2014) to determine the area for dust emissions in each grid cell, which are additionally influenced by several meteorological factors like wind speed, soil moisture etc.. The following maps show the desert fraction for each grid cell for PI and LGM.



(g) Vegetation - PI 1850-1879

(h) Vegetation - LGM 21kyr BP

2. **Since additional land area during the LGM is credited as one of the causes of increased dust emission, I would like some information, similar to the reported wind and precip changes, that tells me how much additional land there is in each region (and possibly some discussion of how much of the dust is being created from this new land).**

Please find the according information in the following table.

	Additional land area LGM [Mio. km^2]	**Dust Emission [Tg yr^{-1}] PI 1850-1879**	**Dust Emission [Tg yr^{-1}] LGM 21kyr BP**	**Dust Emission [Tg yr^{-1}] on additional land areas**
Globally	19.5	923	5159	230
Australia	1.8	47	748	92
Southern Africa	0.04	12	63	5
Patagonia	0.8	2.3	36	29

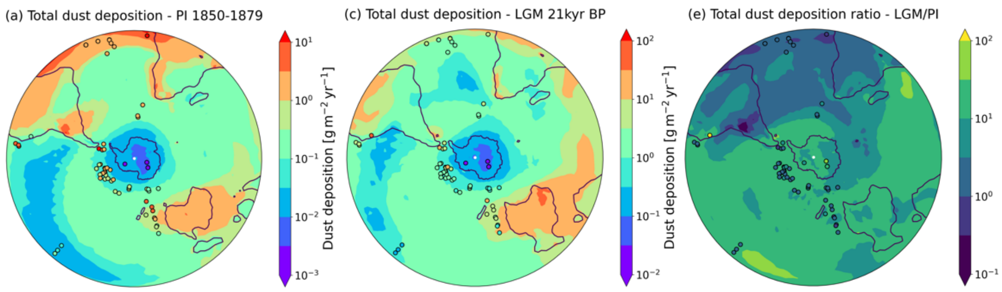
Globally as well as in Australia and Southern Africa, the additional land areas as a consequence of the lower sea level during the LGM contribute only a small proportion to the additionally emitted dust. Consequently, the main reasons for the increase are changes in vegetation (see maps above) and meteorological factors, for instance precipitation patterns and wind speed. In Patagonia, however, the additional land area, mainly consisting of drylands (see vegetation maps), contributes substantially to the absolute dust emissions, which can also be seen in Fig. 1b (*paper*).

3. **In Figure 3, why are the simulated dust deposition values so stratified? The observations appear continuous across a couple orders of magnitude, while the simulated deposition values appear to form horizontal lines.**

   The stratification of the simulated dust deposition values indicate that the model is not able to capture the observed variation for both PI and LGM, in particular in the Pacific / Pacific SO region. Since the measurement locations are rather close to each other, the discrepancy might be caused by a shortcoming in the representation of the deposition process on a small scale in our model. However, it should be taken into account that we compare aeolian dust deposition fluxes onto the ocean surface to marine sediment data, i.e. aside from potential shortcomings in our model, horizontal dust transport processes in the ocean during sedimentation as well as dust flux contributions due to glacier erosion and fluvial inputs are not considered and might play a crucial role (e.g. Trudgill et al. (2020))

4. **Continuous colorbars on log plots are difficult to accurately interpret. The maps in Figures 3 and 1 would be much easier to read if the colorbars had discreet steps (while keeping the log scale). In Figure 1 it didn't bother me to much because I was more interested in the qualitative pattern than the quantitative values, but Fig. 3e I wanted o know where the one contour was, which is quite difficult to tell. I would suggest colorbars similar to those in Figs 2 and 5.**

   Thank you for this suggestion, please find the accordingly adjusted plots (Fig. 3a, c, e) below.



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