

Interactive comment on “Dust deposition in Antarctica in glacial and interglacial climate conditions: a modelling study” by N. Sudarchikova et al.

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Response to Reviewer 1

We thank both reviewers for reviewing our manuscript and providing constructive suggestions for improving text and figures. The comments by Reviewer are shown in quotation marks, our response is a text without quotation marks.

“This paper attempts to simulate the dust cycle in Antarctica by using the global aerosol-climate model ECHAM5-HAM. I have several concerns about the approach adopted, in particular because the model aims to extrapolate the physics that hold for tropical regions to the Antarctic domain, without paying attention to the specificity of

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the dust cycle in Antarctica.”

We disagree with this assertion. ECHAM5 is a global model that implements a discretization of the governing equations of atmospheric motion, which contain no regional specificity, together with a comprehensive suite of parametrizations applicable to all conditions from the surface to the stratosphere at all latitudes. See Roeckner et al. (2003) for a full description of the ECHAM5 model. The aerosol module HAM (Stier et al., 2005) simulates the full aerosol life cycle: emission, atmospheric transport, and sink processes, namely wet deposition by rain and snow, sedimentation and dry deposition. For dust, emission is calculated online based on the physical characteristics of the surface, vegetation cover, soil moisture, snow cover and wind speed. These schemes are also global in scope and contain no latitude-specific adaptations.

“I will focus here on some major weak points. First, when dealing with dust reaching the remote, high-elevation Antarctic sites such as Dome C and Vostok cited in the text, one has to consider that the altitude of dust transport is well above the levels where most washing out occurs: decay of ^{222}Rn of continental origin suggests a transport duration as long as 3 to 4 weeks. This should be comparable to the time of transport of dust to inner sites, while the authors suggest a much shorter time of about 10 days. Such a short transport time is reasonable only for marine aerosol. Therefore, a first important critic is related to the duration of fine particles transport from the source areas to the interior of Antarctica.”

The time duration of 10 days for atmospheric transport from Southern Hemisphere dust sources to Antarctic continent is similar to the lifetime of mass-less radioactive tracers transported over a similar route and distance in Krinner et. al., (2010). Krinner and Genthon (2003) also shown that the simulated tracer age ranges from 5 to 9 days (figure 8 therein). Reijmer et al., (2002) used a method based on 5 days backward trajectories from 5 Antarctic sites (EDC, EDML, Vostok, Byrd and DML05) to source regions of moisture which lie between 60 and 50° S.

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We do not agree that 10 days distance is only reasonable for the marine aerosol. Long-range transport of aerosol takes place with the characteristic speed of free tropospheric winds (about 10 m/s), which corresponds to a distance from source of the order of 8000 km within 10 days. This is sufficient for dust transport from the source regions to Antarctica. The residence time of particles in the atmosphere may be longer than that, depending (as the Reviewer points out) on the exposure of the particles to wet deposition and on the height to which the particles are transported. In the analysis, we used trajectory levels of 500 hPa and 800 hPa, which are subject to wet removal, so that an assumption of longer residence times is not warranted. Also, when comparing model results with observations taken at high-altitude sites, coarse model orography, which can severely limit the model's ability to reproduce actual surface conditions at such sites, should be taken into account.

The most important sink processes of atmospheric aerosol are wet deposition and sedimentation, which are not applicable for ^{222}Rn , and the sink process of ^{222}Rn is radioactive decay, which is not applicable to aerosol. ^{222}Rn is thus not a reliable guide to aerosol-related quantities (such as lifetime).

In general, our concept is to apply a similar method of trajectory analysis to all time slices in order to capture relative changes between different paleo periods.

“A second issue concerns LGM climate: the “dust source productivity” increased during LGM with respect to Holocene of a factor 3 to 5, as documented by Martinez-Garcia et al., 2009, 2014, Lamy et al., 2014, Jaccard et al., 2013. These authors all provide evidence for an LGM/Holocene dust source change that is in this order of magnitude, and it is not clear how/if the authors have taken this literature into account.”

Dust emissions, in our study, are calculated by the model taking into account vegetation, soil characteristics and wind speed. Based on this information the model gives 2.6 times higher emissions from the SH dust sources at LGM compared to current climate, which is close to the low end of mentioned by the Reviewer data. We will compare our

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simulated results with the literature mentioned above.

“When considering a change in snow accumulation rate in Antarctica of a factor 2 between LGM and Holocene, the remaining factor (about 5) that is missing to explain the 30-to-50 fold increase registered in Antarctic ice cores during LGM can be attributed to transport efficiency, and to a longer lifetime of dust in the atmosphere during the last glacial period (as suggested also by Petit Delmonte 2009). In this work it is not clear how/if the authors have considered an increase of dust residence time in the atmosphere related to the reduced atmospheric water vapor.”

The influence of the hydrological cycle is addressed in section 4.5.2, where we note that precipitation over the Southern Ocean is 30% weaker in LGM compared to the preindustrial. We do accept that this provides no direct quantitative information on the dust flux to Antarctica and will improve this in the revised paper.

“Other points that are equally important include the use of a mass mean radius of 1.75 micron, that is obviously too coarse with respect to dust in central Antarctica (mass mean radii around 1 micron), and another size bin that seems a bit small for mineral dust.”

In our model the aerosol size distribution is represented using the modal method, not the bin method (or sectional method). For the dust emissions we use two modes: accumulation mode with $0.05 < r (\mu\text{m}) \leq 0.5$ and coarse mode with $0.5 < r (\mu\text{m})$ (Stier et al., 2005). The two modes cover the whole size range of 0.05um to 10um. We accept that the paper should be clear that the stated mass-median radii of $0.37 \mu\text{m}$ and $1.75 \mu\text{m}$ are the emitted particle sizes from dust sources, not the predicted size after various aerosol microphysical processes (for example, coagulation). The model has no prescribed particle size for such particles. Also, aerosol sink processes in the model are size-dependent, so that these emission radii are not of relevance for comparison with observations. This will be clarified in the revised manuscript.

“Further, the authors seem to ignore literature on Antarctic dust between 2001 and

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2014, and they use DIRTMAP as reference for “observations”. Dust flux to plateau sites (Dome C area) in preindustrial times is around $0.2 \cdot 10^{-3}$ mg/m² per year (Delmonte et al., 2013), that is much lower than the Holocene mean at Dome C and Vostok ($0.4 \cdot 10^{-3}$) mg/m² per year, Delmonte et al., 2005). Today, DIRTMAP values that are taken as “reference” for the observations are considered too high and cannot be used for comparison. A direct consequence of this is that the model overestimates observations of a factor that is much higher than the one stated in this paper.”

We restricted to our comparisons to paleorecords from particular cores that cover all investigated time-slices. Now we will compare the modeled results with available measurements even if they cover only some of considering time-slices. DIRTMAP database is widely used in the global model comparison, for example in Mahowald et al., 2006, 2011, Albani et al., 2011 etc. We know of no paper that recommends not to use this database. We agree that additional data are needed for more complete comparison. In particular in Antarctica we will add more data, e.g. TALDICE dataset (Schupbach et al., 2013).

“Normalization to CTRL values is reasonable, but: -The 3.8 increase in dust flux (wrt CTRL) at 6 kyrs BP seems very large for central Antarctica and there is no clear evidence for this in Holocene data from Vostok and Dome C (Delmonte et al., 2005) - or you have a reference for this? -LGM dust flux as clearly admitted, is underestimated. In EPICA Dome C the LGM/Holocene flux ratio is around 22-23 while the LGM/preindustrial flux ratio would be up to 45! Probably the lack of glaciogenic dust sources accounts for this discrepancy only in part, but a role is probably played by mineral aerosol residence time in the atmosphere. As far as the simulation does not reproduce properly observations during LGM it seems not clear why the authors decided to extend the simulations to older, climate periods where the dust cycle in Antarctica is less well known. On the whole, the simulation presented does not take into account some important constraints for the dust cycle in Antarctica it seems necessary to deeply revise this approach.”

Although our model does not perfectly match to the data retrieved from ice core measurements, the simulation for LGM is comparable to the results from other modeling studies. LGM global dust emissions are similar to other modeling studies: Werner et al., 2002, Mahowald et al., 2006, Li et al., 2010. LGM dust deposition over Antarctica in our study is in agreement with study by Albany et al., 2011 and higher compared to modeled results from Li et al., 2010 and Werner et al., 2002. In addition, dust deposition data retrieved from ice cores have their own uncertainty, which should also be considered when using these data to constrain the model. As a first attempt to simulate the past interglacial periods, we think it is acceptable to use a model that is comparable to currently available GCMs for paleo-climate studies. One should also bear in mind that a model grid cell covers an area of thousands of square kilometers, and the limitations that this places on comparisons with measurements taken at a single point.

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