Clim. Past Discuss., 10, C2270–C2280, 2015
www.clim-past-discuss.net/10/C2270/2015/

Climate of the Past
Discussions
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Interactive comment on "Dust deposition in Antarctica in glacial and interglacial climate conditions: a modelling study" *by* N. Sudarchikova et al.

N. Sudarchikova et al.

natalia.sudarchikova@zmaw.de

Received and published: 30 January 2015

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.

"Sudarchikova et al present a model study on dust deposition in Antarctica based on a global aerosol-climate model ECHAM5-HAM. It is a first attempt to simulate past interglacial dust cycles by investigating different interglacial (pre-industrial, 6, 115, and 126 kyr BP) and glacial (21 kyr BP) climate conditions. The main goals are to estimate the quantitative contribution of different processes such as dust emission, atmospheric

transport and precipitation as well as deposition changes in Antarcitca. The subject of the paper is within the scope of Climate of the Past. However, before this manuscript can be published major revisions to the manuscript should be performed by the authors according to the comments listed below.

The title of the paper suggests that the results of the model study are limited to dust depostition in Antarctica. However, a substantial part of the results and discussion (and figures) include global results (e.g. p 3722 lines 8-20, p 3724 lines 9-20, p 3726 lines 1-11). I suggest to either restrict the results and discussion to Antarctica, or change the title and main focus of the paper. Since Antarctica is a particular location in terms of atmospheric circulation, and dust sources for Antarctica are southern South America, South Africa and Australia, and, thus, independent from other source regions than those mentioned here, this can be done easily."

We agree with this suggestion. Possible change in title: Modelling of mineral dust for interglacial and glacial climate conditions with focus on Antarctica.

We think that it is still useful for readers in the modelling community to provide information about where our model lies in the spectrum of available models with respect to, for example, dust emission, so global totals and AeroCom comparisons will be retained. Specific information about measurements outside Antarctica will be removed.

"P3718, L1: "Paleodust records provide mostly local information". I strongly disagree. This would be the case if there were only local, i.e. Antarctic sources active for the dust records in Antarctic ice cores. However, there is a set of (East) Antarctic ice cores (EDML, EDC, Vostok, TALDICE,. . .) with which the entire region >50âŮę S can be investigated in terms of source regions/strength, transport effects etc. Thus, the entire dynamics of the high southern latitudes can be investigated, providing climate information far beyond a local scale."

We agree that this sentence can be misleading. The sentence has been revised: To understand better the changes in paleodust records, combination of observation analysis and model results can be a fruitful approach. Paleodust records can provide information about source and deposition regions, as magnitude, geochemical features and spatial variability of dust. The modeling approach is needed for more complete picture involving variations in atmospheric transport of dust and covering some "white spots on the map" with lack of data.

"P3718, line18. "no broad data sets of dust deposition exist". Please clarify that this refers to model simulation data sets. There are quite a few observational data sets from Antarctica available (see comment further down)."

Here we wanted to emphasize the lack of observational data covering all investigated interglacial periods. The sentence has been changed to: The dust cycle during past interglacial periods has not been investigated in many modelling studies (transient EMIC simulation in Bauer and Ganopolski, 2010). Global observations covering these time-slices are rare, compared to the glacial period.

"The model overestimates dust deposition flux in Antarctica by a factor of 2-3, according to the authors due to an overestimation of accumulation in Antarctica and thus wet deposition. The authors even say that a result of the pre-industrial simulation the dominant sink process of mineral dust in Antarctica is wet deposition (p 3723, line 26). Please clarify that this is a result of the model study and not an observation. The way this sentence is written this is not entirely clear. On p 3726, lines 15-18 this is written satisfactorily. However, it's not clarified here that again, this is based on an overestimated accumulation (especially for the LGM period we know that dry deposition is by far the most important deposition process). Please quantify this model bias (as has been done for the pre-industrial period) such that it can be compared to the pre-industrial results."

Following the reviewer's comment, the two sentences have been revised:

(page 3723, line 26) The model simulation suggests wet deposition is the dominant sink process of dust over Antarctica, which is similar to the modelling study of Albany

et al., 2012. However, observations in high-latitude polar regions at inland sites suggest dry deposition as the dominant sink process (e.g. Legrand and Mayewski, 1997, De Angelis et al., 1997) and wet deposition can be a major sink process for the coastal Antarctic sites (Wolff et al., 1998). The overestimated wet deposition in Antarctica (by a factor of 1.5-2.5), that is linked to the aerosol scavenging in mixed-phase and ice phase clouds, can partly explain this difference.

(page 3726, line 15) The relative contribution of dry deposition in Antarctica at LGM is increased, but model still overestimates wet deposition in that region (by a factor of 1.2-2 compared to observations).

"Sect 4.4.1: It is mentioned that the model is in good agreement with west Antarctic observations but underestimates dust deposition on the East Antarctic plateau. However in fig 5 there is only one observation shown from west Antarctica and only two observations for East Antarctica. In order to have a more robust comparison between model and observations I suggest to increase the number of observations, i.e. add as many ice core records as possible (again, the paper is focused on Antarctica. With only three observations a reasonable model evaluation cannot be performed.) Why is EDML not included in this section (whereas it is included in sect 4.4.2)? Or is it just not indicated in Fig.5?. Additional literature which could be used as references for glacial/interglacial dust deposition changes are Fischer et al, 2007, Rev. Geophys, Fischer et al. 2007 Earth Planet. Sci. Lett., and Schüpbach et al. 2013, Clim. Past. There, also dust (nssCa, resp.) data from Talos Dome can be found which could be included in the comparison, especially also for sect. 4.4.2 where the authors mention the scarce availability of dust records. There is also the Dome Fuji ice core covering all investigated periods (Watanabe et al 1999, Annals of Glaciology, or maybe even more recent publications). For West Antarctica, there also might be more data available (WAIS Divide, Byrd,. . .). Even the authors acknowledge that more observational records are needed for a complete comparison (conclusions p3733, line16)."

We restricted our comparison to paleorecords from particular cores that cover all investigated time-slices. The point of Reviewer is well taken and we will compare the modeled results with available measurements even if they cover only some of considered time-slices.

"Sect. 4.4.2: Here the authors suddenly switch from dust deposition flux (as used previously) to dust mass concentration (also in Fig. 6). I suggest to use flux consistently throughout the entire manuscript, since this is a better measure of atmospheric dust in Antarctica than the concentration of dust in the ice. Are the model results shown in Fig 6 dust deposition fluxes or modelled dust concentration in the ice? Be careful not to mix the two parameters."

The model results which are shown in Fig. 6 are dust concentration (calculated as dust deposition rate divided by precipitation). We agree with the suggestion to use dust flux for the paper.

"P 3728, lines12-14 The authors claim that very strong Australian emissions in the 6kyr and 126 kyr simulations cause an overestimation of the dust deposition at EDC. However, when looking at Fig. 8 I cannot see a single trajectory coming from Australia reach EDC. The only trajectories shown in Fig.8 reaching EDC are originating from South America. I acknowledge that the trajectories are based on modern meteorological data and, thus, it cannot be ruled out that the picture might be different for trajectories 6 kyr ago. Nevertheless, I would not expect such trajectories to be completely different from the modern ones. So, how can a change in Australian source strength have an effect on EDC, if the Australian" air parcels never reach EDC? Might there be an additional effect being responsible for the overestimation of dust deposition at EDC for the mentioned two time slices?"

The Reviewer is correct, trajectories are quite similar for all interglacial time slices. (Note that the model is a full atmospheric model and requires no modern meteorological data). In Figure 2 (below) we show every 2nd trajectory from each separate source. From this figure we can see that some trajectories from Australian source reached EDC

within 10 days, although the dominant number of trajectories are from South America. Based on our model results, the dust source strength in 6 kyr and 126 kyr in Australia was almost doubled compared to CTRL and stronger than the South American source. Thus we think it is possible that even a limited numbers of trajectories from the very strong source in Australia can bring a sufficient amount of dust particles to Antarctica. Based on comparison with observations and an addition experiment (see below (6 kyr Pref) and fig. 3) we conclude that dust deposition in EDC for 6 kyr and 126 kyr was overestimated due to too strong emissions from Australia. The influence of increased Australian source to dust deposition in Antarctica and EDC site particularly can be seen in fig.1 (for example, for CTRL and 126 kyr).

Fig. 1 Annual average dust deposition [μg/m^2] in the Southern Hemisphere for the pre-industrial and 126 kyr time-slices.

"The authors have done reasonable air mass trajectory calculations to analyse the atmospheric transport and to calculate the potential dust transport. This is a nice piece of work. However, the presentation of the results of these air mass trajectories in Fig. 8 are very sketchy. Maybe the figure could be improved by plotting the "mean trajectory" from each starting point, instead of the arbitrarily chosen every 10th trajectory. This might reduce the number of individual lines of the plot and simultaneously strengthen the message of the figure."

We improved the presentation of trajectories by showing every 2nd trajectory and each source separately (Fig. 2). Showing the mean trajectory will be misleading, because trajectories ending in different points in Antarctica and calculating the mean ending point will not give correct information.

Fig. 2 Ten day forward trajectories of air masses on 500 hPa originating over the South American, Australian and South African dust sources that reached Antarctica. Trajectories are shown for the CTRL simulation, austral spring season (SON). Note that only every 2nd trajectory is plotted.

Figure 4: The ratio of dust deposition at EDC and Vostok between the 6kyr time slice to CTRL is higher than between 21kyr and CTRL. Thus, from this figure I learn that dust deposition at these two locations was higher 6 kyr ago than 21 kyr ago, which is completely against any knowledge we have about dust in Antarctica. Something went wrong with the model here. Please clarify why this is the case or correct if it is wrong.

This is a case of sensitivity to the vegetation. Vegetation plays an important role in dust modeling because it determines the areas that are preferential for dust mobilization. Applying different vegetation maps, obtained from various vegetation models, result in different dust emission fluxes. Furthermore, very few vegetation reconstruction data in the Southern Hemisphere for the interglacial periods are available. Thus, vegetation information is a major source of uncertainty in our dust simulations. In 6 kyr simulation high dust deposition in Antarctica results from very strong emissions from one particular gridbox in Southern America. We made a new simulation, named 6 kyr Pref, in which emissions from this gridbox were suppressed. Emissions from South America thus reduced dramatically. Emissions from the Australian source increased slightly due to different meteorology. In Figure 3, simulated dust concentration in the Antarctic ice for 6 kyr and 6 kyr Pref were compared with records from three polar sites. The model overestimates the mid-Holocene to pre-industrial ratio for all three sites. In 6 kyr Pref, dust concentration in the EDML site is decreased significantly compared to the 6 kyr simulation, but still overestimates observed value. Dust concentration in the Vostok site is decreased as well. Dust concentration in EDC is increased compared to 6 kyr simulation, and even more overestimates the observations (due to slightly higher Australian emissions.)

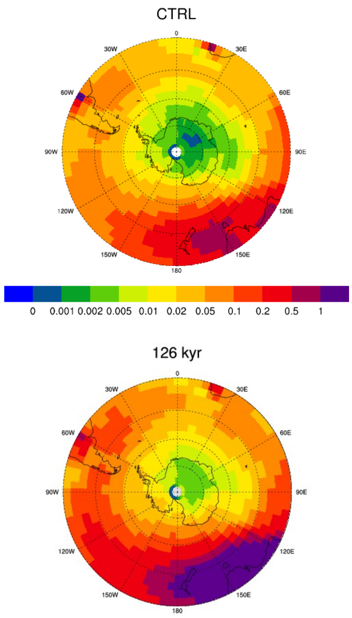
We propose to keep 6kyr simulation for the sensitivity reason, despite the shortcomings of this simulation.

Fig. 3 The ratio of dust concentration in the ice for the sites Vostok, EDML and EDC from model simulations (dark colors) and observations (light colors) for 6kyr, 115 kyr and 126 kyr with respect to pre-industrial period. Modeled data from 6 kyr Pref are in

light grey. Note, the cut of top of the figure for modelled 6kyr/0kyr EDML (light brown color), the ratio is about 8.

Please note the change of the e-mail address of the main author: natalia.sudarchikova@mpimet.mpg.de

Interactive comment on Clim. Past Discuss., 10, 3715, 2014.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150E
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Fig. 1.

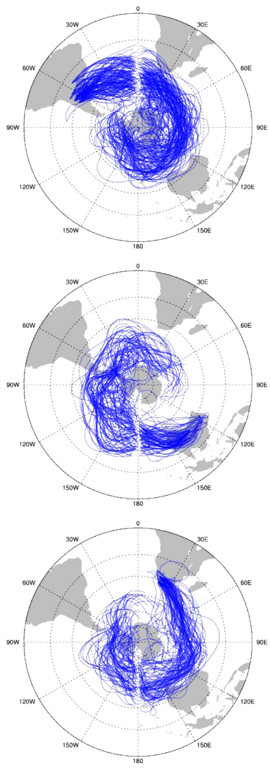
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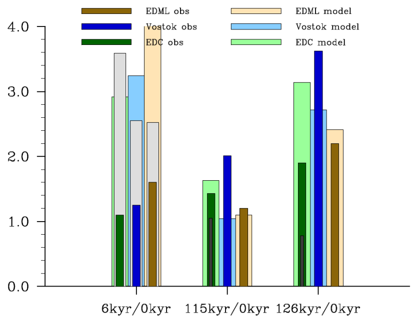
Fig. 2.



EDML obs
Vostok obs
EDC obs
EDML model
Vostok model
EDC model
4.0
3.0
2.0
1.0
0.0
6kyr/0kyr
115kyr/0kyr
126kyr/0kyr

Fig. 3.