Mineral dust variability in Antarctic ice for different climate conditions

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Abstract

This study aims to understand the dust deposition changes on the Antarctic ice sheet in different climatic stages. To this end high resolution dust concentration and size profiles from the EPICA-DML ice core over the transition from the last Glacial to the Holocene (T1) were combined with model experiments for four interglacial time slices and the Last Glacial Maximum (LGM). A strong decrease in dust concentration (factor 46) and a slight increase in dust size was observed during T1. A strong coupling between transport and intensified sources during the Glacial could be derived from the seasonal variability of concentration and size and its phase-lag. This strong coupling vanishes during the Holocene.

The model simulates increased dust deposition in Antarctica for all past interglacial time slices compared to the pre-industrial period. The major cause for the increase is enhanced Southern Hemisphere dust emission, but changes in atmospheric transport are also relevant. The maximum dust deposition in Antarctica is simulated for the LGM, showing a 10-fold increase compared to preindustrial conditions.

Keywords (6-10)

Mineral dust, Antarctica, glacial and interglacial periods, climate model, ice core, atmospheric transport

Introduction

Polar ice cores represent a unique archive for the deposition of aeolian dust particles in the past, as the mineral dust were transported over long-distances from desert regions to the polar ice sheets (e.g. Lambert et al. 2008) and are less influenced by local atmospheric conditions then other archives. While the total dust deposition is a first order measure of dust mobilization hence climate conditions in the dust source regions (Fischer et al. 2007b),, particle size distributions are influenced by transport efficiency.

The overall goal of this study is the quantitative interpretation of Antarctic ice core dust records from the inception to the end of interglacial periods in terms of changes in dust mobilization and transport. In the present study we use ice core dust concentration, size and chemical composition as well as model analysis for selected time slices and combine the two in order to assess the dust input to the Antarctic ice sheet quantitatively. This yields information about the emissions in the dust source regions as well as about changes in atmospheric circulation patterns responsible for dust transport to Antarctica on time scales ranging from seasonal to stadialinterstadial. In this project variability on these timescales and their reasons are investigated. This contributes to Interdynamik key question 1: “What are the amplitudes of natural climate variations on timescales of several years to millennia and how do patterns of climate variability vary in time and space?” The results presented here were obtained in the DFG-Interdynamik project “Mineral dust in the southern ocean (MISO)”.

Material and Methods

Using the EPICA Dronning Maud Land (EDML) ice core, continuous profiles of dust concentration and size were obtained using a Laser Particle Counter (LPD, Klotz Company Bad Liebenzell) and evaluated to provide a full picture of dust transport changes over T1. Generally, the LPD uses scattering and shadowing of laser light as detection method, which is calibrated using spherical latex particles. Thus, the analysis od non-spherical dust particles in ice cores could be affected by shape artefacts. Here we performed an additional calibration, where we compared the LPD results with Coulter Counter data, that measures the size as volume directly, from the same depth intervals and corrected for the shape. In previous studies only nss-Ca was used as dust proxy in the EDML ice core (Fischer et al 2007a), which represents the soluble fraction of the dust. Here, we analysed particulate dust, representing the insoluble fraction of the dust. The main advantage of the particulate dust is the possibility to obtain additionally the dust size, as an indicator for the transport intensity.

The atmospheric general circulation model with online coupled interactive dust scheme ECHAM5/HAM (Stier et al., 2005) was used to study the dust cycle for the interglacial time slices 6 ka BP (before present, where present is defined as 1950, mid-Holocene), 126 ka BP (Eemian) and 115 ka BP (last glacial inception). Additionally, a pre-industrial control simulation (CTRL) was performed. The glacial time slice 21 ka BP (LGM) has been simulated as well. The model resolution was T31 (approx. 3.75° × 3.75°). SST and sea ice distribution were taken from equilibrium simulations with the coupled atmosphere-ocean model ECHAM5/MPIOM (Mikolajewicz et al., 2007). The setup followed the PMIP2 protocol (http://pmip2.lsce.ipsl.fr, Braconnot et al., 2007). For time slices 115ka and 126ka greenhouse gases insolation was changed accordingly, greenhouse gas concentration were kept at 6ka level. The vegetation distribution was specified according to simulations with the dynamical vegetation model LPJ (Smith et al., 2001) forced with output from the coupled model. A land grid point was defined as a potential dust source, if the maximal vegetation cover was below 25%. A detailed description of the model setup can be found in Sudarchikova (2012).

Key Findings

The measured dust concentration decreases at EDML over T1 by a factor of 46, i.e. in a similar range as in Dome C and at Vostok (Lambert et al. 2008, Petit et al. 1999). The previously used non seasalt Calcium (nss-Ca) record (Fig. 1, Fischer et al. 2007a) yields slightly lower values due to analytical uncertainties in the Holocene samples. An absolute minimum of the dust concentration occurs at ~11 ka BP, which is in line with other records from the east Antarctic plateau (EAP). Larger sizes (~2.3

µm) were found during the Holocene compared to the Glacial (~2 µm). This is in line with observations for Dome C (Delmonte et al. 2002). At EDML an absolute minimum in the dust size occurs at 16 ka B.P. This can also be identified in the EPICA Dome C ice core (EDC), but due to the seasonal resolution in the EDML core, which is not present in EDC, it is more pronounced in EDML. During the Holocene and until MIS 3 seasonal signals in the dust concentration and size can be observed, with amplitudes of the dust concentration up to a factor of 30.. During the Glacial a clear correlation between the seasonal cycles of dust concentration and size can be found (r = 0.8). During T1, beginning from 19 000 yr BP, the correlation decreases to values below 0.4 in the Holocene.

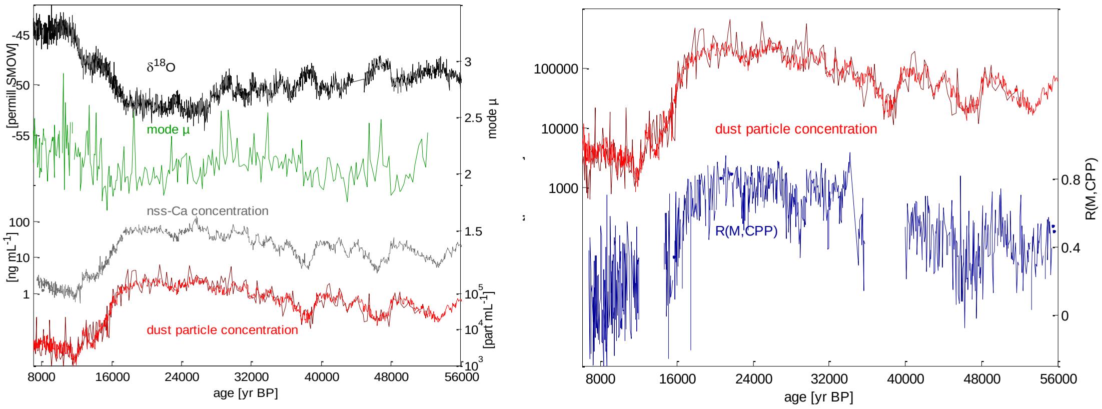

Fig. 1: Dust profile over T1 in the EDML ice core. Oxygen Isotopes, dust concentration (M) and size (as coarse particle percentage (CPP: mass in the size range 3-5 µm devided by the mass concentration in the size range 1-5 µm))and non-seasalt Calcium concentrations (nss-Ca) (Fischer et al. 2007a) (left), dust concentration and phasing of dust concentration and size (right). For the phasing the correlation coefficient (R) between the dust concentration M and the size (CPP) was calculated over 1 m intervals each.

For all time slices the simulated dust deposition in Antarctica is increased relative to the pre-industrial CTRL (Fig. 2 b). In the mid-Holocene, dust deposition is increased by a factor of 3.8, and in the Eemian by a factor of 2.7. Dust deposition in the last glacial inception is only slightly enhanced. The highest dust deposition in Antarctica is simulated for the LGM, showing a 10.2-fold increase compared to CTRL.

The modelled increase in dust concentration (dust deposition rate divided by precipitation) fits to the results from ice cores for 115 ka and 126 ka (see Fig. 2a). However the model overestimates the 6 ka to pre-industrial ratio substantially likely due to overestimation of the South American and Australian dust sources. The prescribed vegetation is the main source of uncertainty in our model simulations of the dust cycle for past time slices. The dust concentration in Antarctic ice for the LGM is further enhanced by the strongly reduced precipitation.

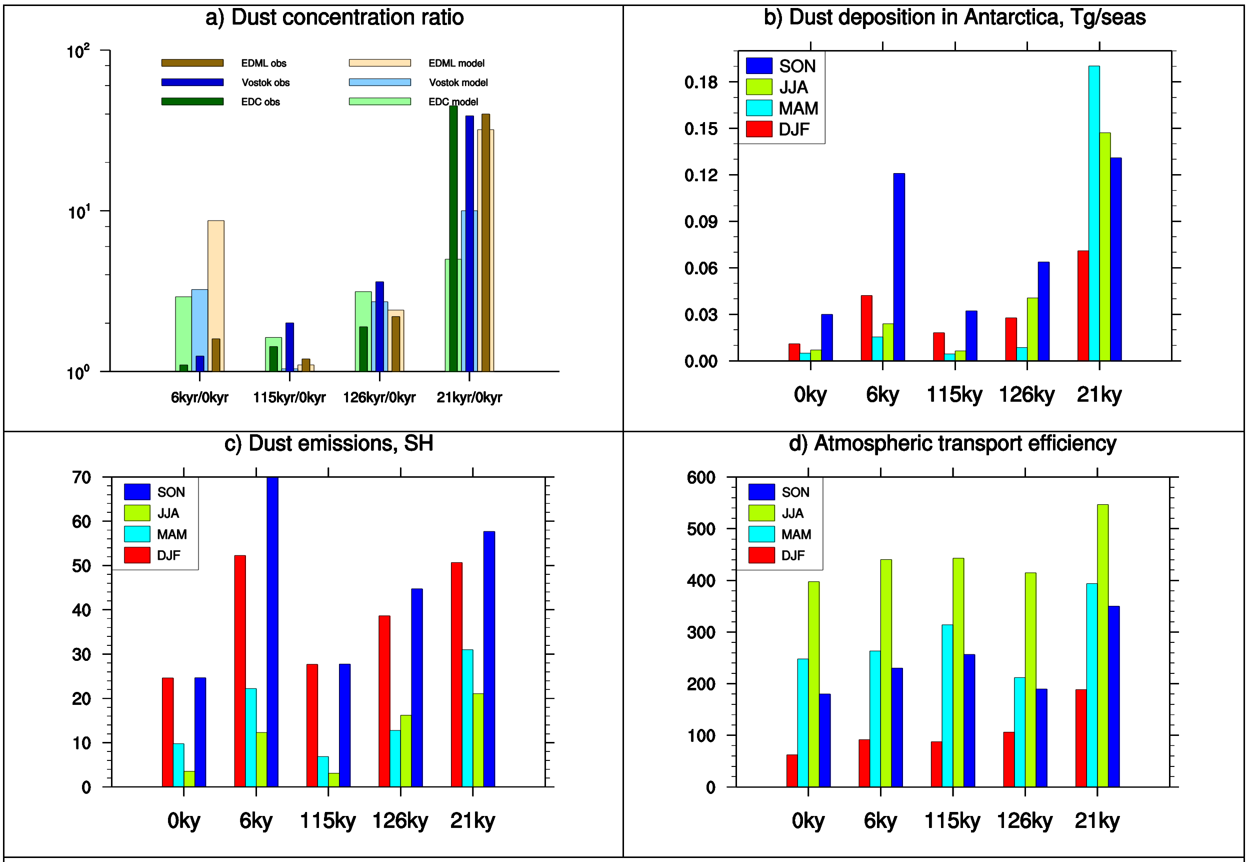

Fig. 2 a) Ratios of dust mass concentration in the Antarctic ice for model simulations and observations for 6 ka, 115 ka, 126 ka and 21 ka with respect to pre-industrial. The records shown in dark colours represent Coulter Counter data from the literature. Data from the closest model grid point is shown in light colours. b) Integrated modelled dust deposition in Antarctica [Tg/season]; c) modelled SH dust emissions [Tg/season]; d) Number of trajectories/season originating at 500 hPa and 800 hPa from dust source grid boxes and reaching Antarctica within 10 days.

Approximately two thirds of the increase in dust deposition over Antarctica for the mid-Holocene and Eemian is attributed to enhanced Southern Hemisphere dust emissions (Fig.2c), predominantly from the Australian source (not shown). Atmospheric transport efficiency (described by the number of air mass trajectories originating above the Southern Hemisphere grid points with dust emissions and reaching Antarctica within 10 days) is shown in Fig. 2d. Slightly increased transport efficiency in 6 kyr and 126 kyr causes the remaining one third of the increase in dust deposition in Antarctica. In general, the annual cycle of emission and the efficiency of the atmosphere to transport dust particles to Antarctica are out of phase for the considered time slices. In the LGM simulation, dust deposition over Antarctica is significantly increased due to 2.6 times higher Southern Hemisphere dust emissions, doubled atmospheric transport efficiency and 30% weaker precipitation over the Southern Ocean (not shown).

The ice core reconstruction cannot pinpoint the absolute season of dust input to the Antarctic ice during the LGM, but it can pinpoint the onset of the decoupling of transport and emission. A shift between the maxima of dust concentration and size suggests that a different seasonality of dust emission and transport intensity may have contributed to the dust variability over T1. The different phasing of intense transport and high dust concentration in the ice starts very early during T1 (~19 000 yr BP, Figure 1) simultaneously with the onset of the decrease in dust concentration. The changes in the seasonality of dust concentration in the ice obtained by the model support this finding.

According to the ice cores, for the whole EAP the same dust provenance (southern South America) is dominant during the Glacial, whereas during the Holocene different source regions could be detected in different areas of the EAP. For the Indian sector of the EAP Australia plays a major role. For the Atlantic sector some contributions from other sources outside the South American continent could be detected. However, the major contribution originates from southern South America.
The South American dust sources are dominant until 15 000 yr BP. From that time on contributions from sources outside South America can be detected (Wegner et al. 2012). At that time the dust concentration in Antarctic ice cores are almost on Holocene levels. The model suggests a major influence of South America to EDML during the Holocene (not shown).

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