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Multiple sources of Greenland dust throughout the Holocene

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Abstract

It is contested that the mineral dust found in Greenlandic ice cores during the Holocene stems from multiple source areas. Particles entrained above a more productive, primary source dominate the signal's multi-seasonal average. Data in sub-annual resolution, however, reveal at least one further source.

Whereas distinct inputs from the primary source are visible in elevated concentration levels, various inputs of the secondary source(s) are reflected by multiple maxima in the coarse particle percentage. As long as the dust sources' respective seasonal cycles are preserved, primary and secondary source can be distinguished.

Since the two source's ejecta eventually detected differ in size, which can be attributed to a change in atmospheric residence times, it is suggested that the secondary source is located in closer proximity to the drilling site than the primary one.

Keywords: Greenland; source regions; ice core.

1. Introduction

In ice cores. a plethora of proxies for paleoclimatic conditions is archived. Air trapped in the ice during firnification allows for direct measurements of the concentrations and isotope ratios of paleoatmospheric gases , while the isotopic composition of the ice matrix itself is related to paleotemperatures.

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Impurities in the ice matrix are comprised of particulate and soluble aerosols. Both - the precipitation and the aerosols deposited on the ice sheets - can reveal information about their respective sources at lower latitudes and about processes undergone during transport (e.g., Fischer et al., 2007).

Among the plethora of aerosols archived as impurities in the ice matrix, insoluble aerosols are particularly intriguing: The mineralogical composition of bulk dust samples as well as the elemental and isotopical composition of individual dust grains carry information characteristic for the dust's source region (e.g., Biscaye et al., 1997). Thus, by enabling the geographic localisation of their sources, dust grains offer the unique possibility to constrain paleoatmospheric transport patterns (e.g., Muhs, 2013).

The paleoatmospheric dust load is archived in a variety of different archives (Pye, 1987). Ice sheets, however, preserve their information at a remarkably high temporal resolution (e.g., Legrand & Mayewski, 1997), such that even the seasonality of the aerosols' respective inputs can be reconstructed (e.g., Svensson et al., 2006).

Below, selected sections of the NEEM (NEEM members, 2013) dust record obtained during the 2009 and 2010 field seasons, employing the Bernese Continuous Flow Analysis system (CFA, Kaufmann et al., 2008), are analysed. Our interpretation takes its point of departure in the assumption that next to the bulk sample's mineralogy and the individual grain's composition, also a sample's grain size frequency histogram carries information on the particles' provenance (Pye, 1987, p.129).

2. Data acquisition

The data supporting the claim of a multi-source contribution to the Greenlandic dust load was obtained by connecting a laser sensor (LS) to the University of Bern's CFA system (Kaufmann et al., 2008).

Over the last decades, CFA has become a well-established technique for aerosol quantification in ice cores. In order to exploit the high resolution with which the paleoatmosphere's composition is preserved, a piece of core is melted continuously and the melt water is analysed for an array of impurities.

The LS, an attenuation-based optical flow-through detector for microparticles in ice cores, was developed by Ruth et al. (2002) in collaboration with Klotz GmbH (Bad Liebenzell, Germany). However, publishing the first LS-acquired data set, Ruth et al. already reported a mismatch between size distributions obtained with different LSs and resistive pulse measurements using the Coulter counting technique.

It has to be stressed that the minimum particle size qualifying for what in the following is referred to as the coarse particle percentage (CPP) is not exactly known. Instead of the absolute sizes in the range from .8 to 10 μm yielded by the instrument, we followed Lambert et al. (2008) and chose to report relative sizes and size differences only. Therefore, the CPP is defined as 5 times the detection limit of the Bernese LS.

3. Results and discussion

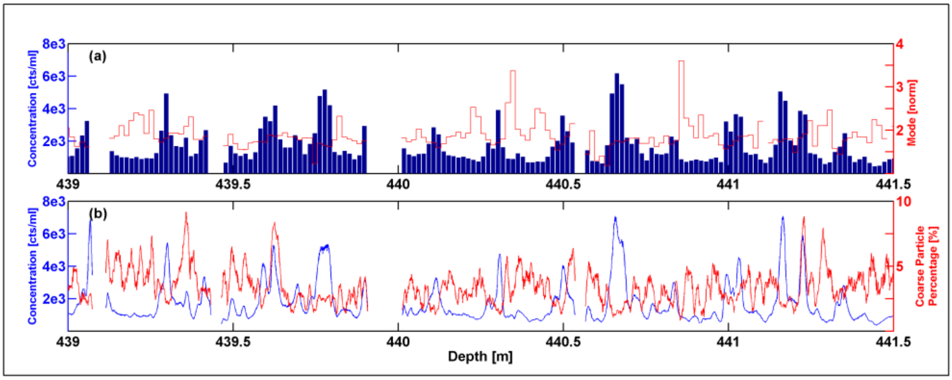

Fig. 1. Seasonality of dust concentration and particle size as archived in the NEEM core during the recent Holocene (here 2095 to 2080 years b2k).

Parameters commonly used to describe dust records obtained from ice cores are the concentration (in ng/g or counts/ml^{-1}) and the mode of an assumed mono-modal lognormal distribution (e.g. Steffensen, 1997).The NEEM records in 1.5cm depth resolution shown in Fig. 1a demonstrate that the size distribution's mode and the number concentration are slightly anti-correlated in recent Holocene ice.

The primary annual dust input to Greenland responsible for concentration maxima occurs during few major deposition events, presently taking place in spring (Mosher et al.,1993). Maxima in CPP outside of the spring season can be attributed to either a source shift or changes in the particles atmospheric residence time.

As larger modes of mono-modal distributions are a consequence of an increased CPP, the pattern shown in Fig. 1a is reflected in Fig. 1b. The CPP series, however, does not require binning over a certain depth interval and consequently does not compromise the data's high resolution. Therefore, the subsequent analysis is based on the CPP.

Steffensen (1997) already hinted at the annual patterns depicted in Fig. 1. Analysing firn samples covering 5 years, Steffensen found the CPP to be significantly higher during autumn|winter, when concentrations are lower - an observation he attributed to the increased relative importance of another source.

This source was further hinted at by Bory et al. (2003b), who, analysing snow pit samples, also noted that "*a different source area [...], plays a role during most of [the] year, and during the low-dust season [. . .] in particular*". Fig. 2a shows the results of their isotopic analysis of individual dust grains collected in a 2 m deep snow pit.

The resemblance of the respective phasings of (a) the Ca^{2+} record - a proxy for dust concentrations (e.g., Ruth et al., 2002)) - and the εNd0 and (b) the number concentration and CPP in Fig. 2b is remarkable. This suggests that the CPP reflects a variation in the dust's source region, rather than a change in its transport time.

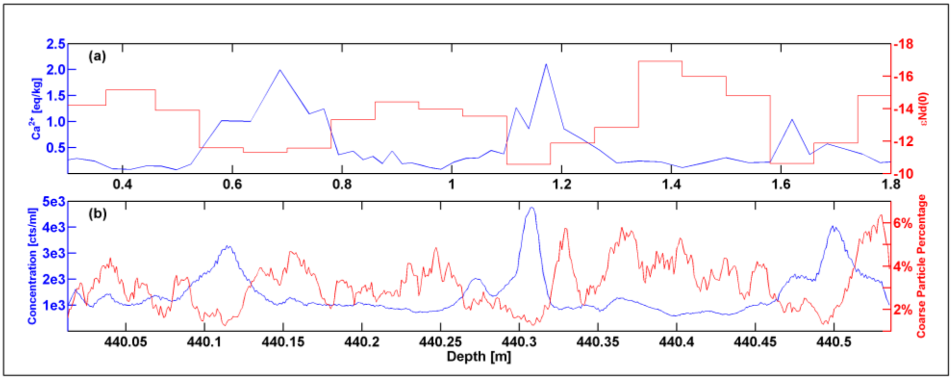

Fig. 2. (a) Bory et al. (2003b) found that from 1998 to 2001 dust concentration - for what Ca^{2+} is a proxy - and the dust's source region, reflected in the grains neodymium content, vary seasonally. (b) Close-up of the dust concentration on its CPP shown previously in Fig. 1b.

Apart from preserving the data set's high resolution, the proposed method to identify variations in the dust's source region offers an additional advantage: It can be easily applied to core depths where discrete sub-annual sampling is impractical or even prohibited by compressed annual layers.

Fig. 3 shows the dust's concentration and its CPP in 2.5 m long segments of the NEEM core representative for the early Holocene and the last glacial maximum (LGM), respectively. It becomes clear that the size distribution's mode and the number concentration are still slightly anti-correlated in the early Holocene (Fig. 3a), while they are correlated during the LGM (Fig. 3b).

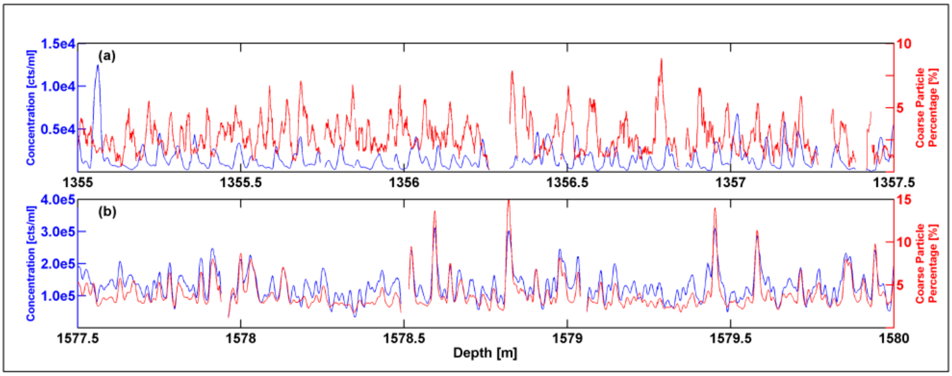

Fig. 3. CPP data from the early Holocene (a) and the LGM (b) suggesting multi-sourced dust input throughout the Holocene.

Based on Fig. 3, it is suggested that not only one source has contributed to the Greenlandic dust load during the Holocene. It needs to be pointed out, however, that the high degree of correlation between the concentration and the CPP during the LGM does not rule out the possibility of additional sources also during the last glacial. The loss of seasonality is common to all aerosol records obtained from glacial ice (e.g., Andersen et al., 2006). Therefore, the high degree of correlation between the number concentration and the CPP could simply mean that both sources' inputs are archived in the same layer.

4. Conclusion

An alternative to the distinction between various source regions by analysing the dust samples' mineralogical, chemical and|or isotopic composition was proposed. The presented data indicates that on a sub-annual scale distinction between different sources by attributing maxima in the number concentration to one and maxima in CPP to the other is feasible. This approach gains further credibility as it mirrors known seasonal patterns in the dust deposits' isotopic composition.

Taking advantage of the recently obtained high resolution dust record as archived in the NEEM ice core employing CFA, this hypothesis was tested. The results suggest that multiple sources are likely to have contributed to the dust input to Greenland throughout the Holocene. Previously, this could only be speculated about because isotopic studies cannot reproduce the high resolution of CFA systems.

This approach only works as as long as seasonality is preserved, but it does not rule out multi-source input during glacials. Whereas during warmer stages frequent precipitation scavenges the polar atmosphere throughout the year and archives also seasonal differences in source strengths, a shift towards more dry deposition during stadials takes place (e.g., Andersen et al., 2006; Rasmussen et al., 2006).

Thus, sporadic precipitation events might merely represent the isolating layer between horizons of dry deposition or, in other words, the degree of correlation between various sources contributing to the aerosol load as archived in the Greenlandic ice sheet might be a function of the relative amount of dry deposition.

The input of a second source in addition to the dominant Asian one (Biscaye et al., 1997) is uncontested in the literature. Indeed, based on snow pit studies intraregional sourcearea variability has been reported (Bory et al., 2003b, a) and experimental data suggesting intercontinental source variability also exists (e.g., Mosher et al., 1993; Lupker et al., 2010).

As the seasonal variation in particle size is rather large - otherwise we would not be able to tell the primary and secondary source's input apart - the data can be interpreted as a change in atmospheric residence time. Our results consequently suggest a secondary source not in the primary one's proximity.

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