Available online at www.sciencedirect.com
ScienceDirect
Earth and Planetary Science Letters 260 (2007) 340–354
EPSL
www.elsevier.com/locate/epsl

Reconstruction of millennial changes in dust emission, transport and regional sea ice coverage using the deep EPICA ice cores from the Atlantic and Indian Ocean sector of Antarctica

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Received 12 March 2007; received in revised form 31 May 2007; accepted 1 June 2007
Available online 12 June 2007
Editor: M.L. Delaney

Abstract

Continuous sea salt and mineral dust aerosol records have been studied on the two EPICA (European Project for Ice Coring in Antarctica) deep ice cores. The joint use of these records from opposite sides of the East Antarctic plateau allows for an estimate of changes in dust transport and emission intensity as well as for the identification of regional differences in the sea salt aerosol source. The mineral dust flux records at both sites show a strong coherency over the last 150 kyr related to dust emission changes in the glacial Patagonian dust source with three times higher dust fluxes in the Atlantic compared to the Indian Ocean sector of the Southern Ocean (SO). Using a simple conceptual transport model this indicates that transport can explain only 40% of the atmospheric dust concentration changes in Antarctica, while factor 5–10 changes occurred. Accordingly, the main cause for the

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0012-821X/$ - see front matter
doi:10.1016/j.epsl.2007.06.014

strong glacial dust flux changes in Antarctica must lie in environmental changes in Patagonia. Dust emissions, hence environmental conditions in Patagonia, were very similar during the last two glacials and interglacials, respectively, despite 2–4 °C warmer temperatures recorded in Antarctica during the penultimate interglacial than today. 2–3 times higher sea salt fluxes found in both ice cores in the glacial compared to the Holocene are difficult to reconcile with a largely unchanged transport intensity and the distant open ocean source. The substantial glacial enhancements in sea salt aerosol fluxes can be readily explained assuming sea ice formation as the main sea salt aerosol source with a significantly larger expansion of (summer) sea ice in the Weddell Sea than in the Indian Ocean sector. During the penultimate interglacial, our sea salt records point to a 50% reduction of winter sea ice coverage compared to the Holocene both in the Indian and Atlantic Ocean sector of the SO. However, from 20 to 80 ka before present sea salt fluxes show only very subdued millennial changes despite pronounced temperature fluctuations, likely due to the large distance of the sea ice salt source to our drill sites.

Keywords: paleoclimate; ice core; Antarctica; sea salt; mineral dust

1. Introduction

Antarctic glacial/interglacial temperature changes have been reconstructed over up to eight glacial cycles using deep ice cores drilled on the Antarctic plateau (Petit et al., 1999; Watanabe et al., 2003; EPICA community members, 2004; Brook et al., 2005; EPICA community members, 2006; Jouzel et al., in press) and on coastal ice domes (Steig et al., 1998; Morgan et al., 2002). Such climate records are generally interpreted as being representative for the whole SO region, which plays a key role in glacial/interglacial climate changes (Blunier et al., 1997; Knorr and Lohmann, 2003; Stocker and Johnsen, 2003) and the global carbon cycle (Archer et al., 2001; Köhler et al., 2005; Toggweiler et al., 2006). However, while the large-scale glacial/interglacial changes are imprinted in all those records (Watanabe et al., 2003) the influence of different air mass origin allows us to reconstruct also regional differences in climate evolution (Morgan et al., 2002). Moreover, while temperature changes have been documented in many Antarctic ice cores, regional information on accompanying environmental changes is still limited. Especially, temporally resolved information on a dust induced iron fertilization of marine phytoplankton productivity (Martin, 1990) and on reduced gas exchange and decreased mixing of the ocean due to an increase in sea ice cover (Toggweiler, 1999; Stephens and Keeling, 2000; Köhler et al., 2005) is needed to constrain the carbon cycle/climate feedback. Independent information on mineral dust deposition and sea ice coverage in different regions of Antarctica can be deduced from aerosol records in deep Antarctic ice cores (Petit et al., 1990; Delmonte et al., 2002; Röthlisberger et al., 2002; Wolff et al., 2003; Udisti et al., 2004; Wolff et al., 2006; Fischer et al., 2007).

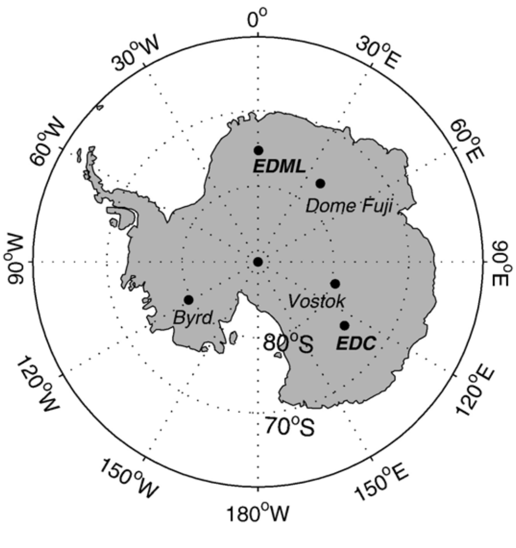

Fig. 1. Map of the Antarctic continent indicating the EPICA drill sites in Dronning Maud Land (EDML) facing the Atlantic sector of the SO and at Dome C (EDC) facing the Indian Ocean sector of the SO together with previously drilled deep ice cores on the Antarctic plateau.

Within the European Project for Ice Coring in Antarctica (EPICA) two deep ice cores have recently been drilled (Fig. 1). The core at Dome C (EPICA community members, 2004) (EDC: 75°06′S, 123°21′E, 3233 m above sea level) in the Indian Ocean sector of Antarctica comprises undisturbed ice core records over the last approximately 800 kyr (Jouzel et al., in press). The second ice core was drilled at Kohnen station in Dronning Maud Land (EPICA community members, 2006) (EDML: 75°00′S, 00°04′E, 2882 m above sea level). With a snow accumulation rate 2–3 times higher than at EDC it provides higher resolution records down to Marine Isotope Stage (MIS) 4. Moreover, due to its location it represents the first ice core closely linked to climate changes in the Atlantic sector of the SO.

In the following, we report on mineral dust (represented by non-sea salt calcium ($nssCa^{2+}$)) and sea salt aerosol (represented by sea salt sodium ($ssNa^{+}$)) records derived from both ice cores in decadal to centennial