Quaternary Science Reviews 29 (2010) 324–337

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Atmospheric decadal variability from high-resolution Dome C ice core records of aerosol constituents beyond the Last Interglacial

Matthias Bigler[a,b,c,*], Regine Röthlisberger[d], Fabrice Lambert[a,b], Eric W. Wolff[d], Emiliano Castellano[e], Roberto Udisti[e], Thomas F. Stocker[a,b], Hubertus Fischer[a,b]

[a] Climate and Environmental Physics, Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland
[b] Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland
[c] Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
[d] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK
[e] Department of Chemistry, University of Florence, Via della Lastruccia 3, 50019 Sesto Fiorentino, Italy

A R T I C L E I N F O

Article history:
Received 9 February 2009
Received in revised form
1 September 2009
Accepted 4 September 2009

A B S T R A C T

Along the EPICA Dome C ice core, we measured concentrations of different water-soluble aerosol constituents and deduced total depositional flux records. Here we present high-resolution sodium, calcium, ammonium and nitrate data covering the last 173,000 years. The first three of these species are passive tracers and reveal source and long-range transport changes whereas nitrate is deposited reversibly. However, it can be used to check isotope-derived accumulation rate estimates, a prerequisite to calculate total depositional fluxes. During the last two transitions from glacial to interglacial periods, changes in the total depositional flux differ strongly for different aerosol species. The largest changes are observed in the terrestrial aerosol proxy non-sea salt calcium, only moderate changes occur in the marine sea salt indicator sodium, while ammonium, a proxy for marine bioproductivity, remains rather constant. In agreement with previous studies, we find that only considerable glacial–interglacial changes at both, the terrestrial and the marine sea salt aerosol source can explain the observed pronounced changes. The unprecedented high-resolution of our data allows for the first time the examination of decadal variability back to the penultimate glacial period. On the one hand, we find occasional fast shifts occurring within a few years; here we present such an event in the calcium record from the penultimate glacial period. On the other hand, we examine variation coefficients and pairwise correlation coefficients, both determined in 200-year windows. They generally reveal only moderate changes. During glacial periods, slightly lower variation coefficients are found, concurrent with slightly higher correlation coefficients, which points to a more uniform and stronger coupled atmospheric long-range transport of the different aerosol species to the East Antarctic Plateau and less influence of cyclonic activities during cold periods. The opposite is observed for interglacial periods with probably even reinforced importance of cyclonic influences during the Last Interglacial period, the Marine Isotope Stage 5.5. This period reveals no evidence for abrupt climatic changes in any of the species, however, the marine sea salt aerosol indicator sodium shows a distinct minimum followed by a pronounced increase. This pattern is explained by significantly reduced sea ice production in the Indian Southern Ocean sector, which is believed to be the dominant source of sodium deposited in Dome C during warm periods.

1. Introduction

1.1. Atmospheric circulation over glacial and interglacial periods

The centred position of Antarctica around Earth's South Pole and the lack of significant landmasses in a broad longitudinal band enable a well-developed westerly circulation, driven primarily by strong pole-equator sea level pressure gradients (King and Turner, 1997). It shows a present-day near-surface wind maximum at

* Corresponding author at: Climate and Environmental Physics, Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland. Tel.: +41 (0)31 631 8673; fax: +41 (0)31 631 8742.

E-mail addresses: bigler@climate.unibe.ch (M. Bigler), regine.rothlisberger@googlemail.com (R. Röthlisberger), lambert@climate.unibe.ch (F. Lambert), ewwo@bas.ac.uk (E.W. Wolff), emiliano.castellano@unifi.it (E. Castellano), udisti@unifi.it (R. Udisti), stocker@climate.unibe.ch (T.F. Stocker), hfischer@climate.unibe.ch (H. Fischer).

0277-3791/$ – see front matter
doi:10.1016/j.quascirev.2009.09.009

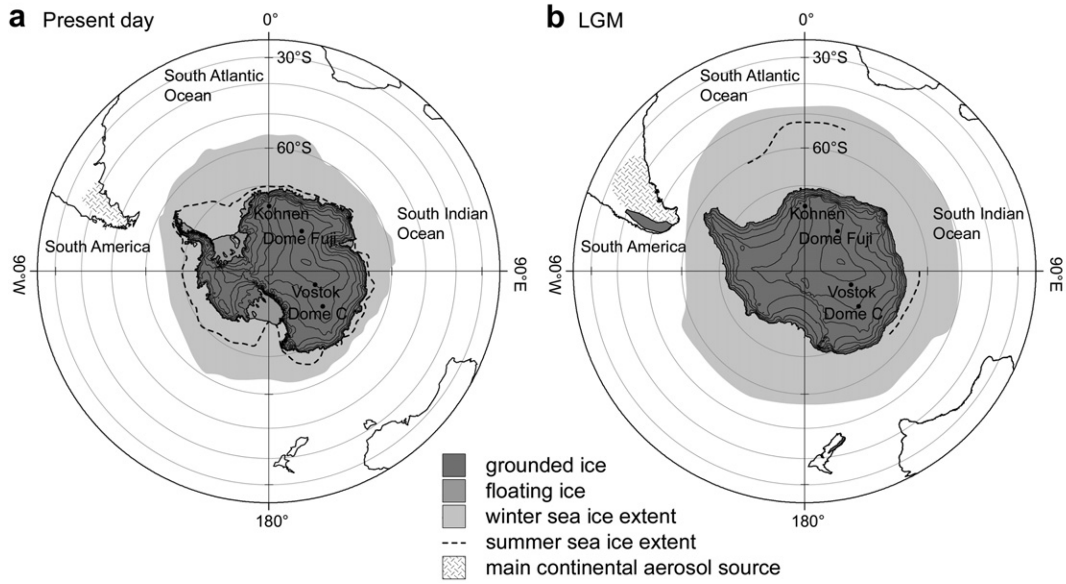

Fig. 1. Antarctica with the deep ice core drill site Dome C (among others) and the surrounding southern hemisphere for (a) present-day and (b) LGM. Ice sheets (with 500 m height contour lines) and coast lines are according to Huybrechts (2009), winter and summer sea ice extent from Gersonde et al. (2005). The potential southern South American (SSA) source region of terrestrial aerosol to East Antarctica is hatched (Iriondo, 2000).

around 50°S leading to the Antarctic circumpolar ocean surface current (Shulmeister et al., 2004). An important mode of pressure variation in the westerly circulation is the Antarctic Annular Oscillation (AAO)[1] (Thompson and Wallace, 2000). It is mainly considered sub-decadal, but exists also on decadal and longer time scales (Simmonds, 2003; Shulmeister et al., 2004), and it seems to be connected to the interannual variation of storm tracks in the Southern Hemisphere (Rao et al., 2003). These cyclonic activities play an important role in the atmosphere–ocean–sea-ice-interactions and the poleward transport of heat and moisture (Simmonds, 2003).

Over glacial–interglacial cycles, topographic conditions (Fig. 1), such as extent and shape of the Antarctic ice sheet and exposed continental shelves (due to the lower sea level), did not change very much (Huybrechts, 2009). In contrast, glacial–interglacial winter and summer sea ice extent varied markedly, though, in the Indian sector of the Southern Ocean (SO) mainly the winter extent (Gersonde et al., 2005). However, the general circulation pattern in terms of atmospheric transport paths and transport times most likely did not change fundamentally: Shulmeister et al. (2004) examined past westerly circulation patterns in the Australian sector of the SO based on different terrestrial and marine records and found evidence of some strengthening during the Last Glacial Maximum (LGM), followed by some weakening in the early Holocene and a return to stronger circulation afterwards. In contrast, South American proxy data lead to inconsistent conclusions regarding position and strength of the westerlies at the LGM in this sector of the SO (Wolff et al., 2010, and references therein). Modelling results of aerosol transport support the assumption that changes in the meridional transport were only moderate between LGM and Holocene, however, again showing somewhat inconsistent results. While Lunt and Valdes (2001) find a lower transport efficiency and small interannual variations during the LGM compared to present-day (based on analysis of back trajectories initialized in Dome C), Krinner and Genthon (2003) state that long-range transport occurred preferentially in the mid-troposphere and was slightly faster during the LGM (based on general circulation model simulations). Yet, both models simplify deposition processes during transport, as they consider solely dry deposition of aerosols en route. Based on the joint use of ice core data from opposite sites of East Antarctica and a simple conceptual transport model, Fischer et al. (2007b) found that transport effects accounted for maximal a factor of two changes in aerosol fluxes between glacial and interglacial periods with most of the effect due to the change in precipitation, hence, wet deposition en route.

1.2. Marine Isotope Stage 5.5

The characterization of the Last Interglacial period along with the related transitions is of great interest (Broecker and Henderson, 1998), as it is often used as an analogue for a possible warmer future climate. It corresponds to Marine Isotope Stage (MIS) 5.5, approximately simultaneous to the Eemian period in European Pleistocene stratigraphy. The onset of MIS 5.5 has been defined as the stratigraphic limit between the Middle and the Upper Pleistocene (Gibbard, 2003). Although other interglacial periods may show a greater similarity to the Holocene in terms of their orbital parameters (Loutre and Berger, 2003), the MIS 5.5 plays a key role in paleoclimatology due to better availability and resolution of different records (van Kolfschoten et al., 2003). However, data covering MIS 5.5 are still not abundant enough to draw a complete picture, especially for southern high latitude areas, a region which acts as an important player in global climate change involving different feedback mechanisms. Global model simulations together with local paleorecords suggest that MIS 5.5 was on average warmer compared to the modern preindustrial climate (Jansen et al., 2007), while relative sea levels were at least 3 m above the present level (Stirling et al., 1998). In Antarctica, the temperature offset was probably even higher (Overpeck et al., 2006), especially during the early MIS 5.5, estimated to be +4.5 °C based on water isotope measurements on the Dome C ice core (Jouzel et al., 2007). Of particular interest are investigations whether the MIS 5.5 climate was smooth (like the Holocene) or experienced abrupt

[1] Also referred to as High-Latitude Mode (HLM) or Southern Annular Mode (SMA).