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Holocene glacial discharge fluctuations and recent instability in East Antarctica

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ABSTRACT

Antarctica holds the largest ice sheet in the world, the East Antarctic Ice Sheet (EAIS), and plays a significant role in both local and global climate through the interactions between ice sheets, ocean, sea ice, and atmosphere. Our understanding of East Antarctica Holocene climate variability relies mainly on ice cores that however do not document glacial discharge history. Here, we present the first high resolution $\delta^{18}O_{diatom}$ record derived from two marine sediment cores retrieved on the East Antarctic continental shelf to reconstruct glacial discharge off Adélie Land and George V Land (AL–GVL) over the last 11,000 years from decadal to centennial resolution. Our results suggest multi-centennial glacier advances and retreats until 2000 cal yr BP, followed by a period of relative instability marked by two major glacial retreats centered at ∼1700 cal yr BP and ∼1980 CE. We suggest that the multi-centennial oscillations during the Early/Mid-Holocene reflect glacier fluctuations in response to long-term local seasonal insolation and short-term solar variability. We also propose that $\delta^{18}O_{diatom}$ variability over the last 2000 years was the result of a recent change in the AL–GVL region to increasing atmospheric influence, linked to ENSO intensification and teleconnections strengthening between low and high latitudes.

1. Introduction

Antarctica and its ice sheets have played, and continue to play, a major role in the global ocean–atmosphere system. The East Antarctic Ice Sheet (EAIS), the largest in the world, stores 79% of Antarctica ice and influences directly both Antarctic and global climate through interactions with the ocean, the sea ice, and the atmosphere of the Southern Hemisphere. Ice sheet morphology (e.g. through the presence of glacier ice tongues) has an important impact on sea ice cycle and thus on bottom ocean circulation and primary productivity. As such, a better understanding of the impact of glacier systems and the associated climate feedbacks of the east Antarctic region is important for future climate predictions (Denis et al., 2009a).

Scarce environmental reconstructions based on ice cores, marine sediments, lake sediments, and terrestrial records revealed that Antarctic climate shows three contrasted intervals during the Holocene (Mayewski et al., 2009): a Deglacial period (also termed the Early Holocene Climate Optimum), a Mid-Holocene warm period or Hypsithermal, and a Late Holocene period or Neoglacial cooling (Hodgson et al., 2009a; Denis et al., 2009a; Verleyen et al., 2011), followed by the recent climate warming.

The climatic periods are not always synchronous in the different regions of Antarctica due to the spatial heterogeneity in the intensities of the forcing mechanisms. As a result, the Antarctic climate system is regionally partitioned with heterogeneous surface air temperature trends and ice-sheet/glacier fluctuations on millennial to decadal timescales (Masson et al., 2000; Denis et al., 2009a; Hall, 2009; Mayewski et al., 2009; Verleyen et al., 2011). This partitioning was also monitored over the last 50 years whereby East Antarctica (EA) and Antarctic Peninsula (AP) surface air temperature increased by ∼1 °C and ∼3 °C, respectively (Turner et al., 2005a). However, even if EA currently appears less sensitive to recent global warming, numerical models predict that warming, and therefore melting of the EAIS, will greatly increase in the next decades, which will drastically impact ocean circulation (Summerhayes et al., 2009). Over the last few decades, the most profound changes in the ice-sheets result from glacier dynamics at ocean margins (Pritchard et al., 2009). Moreover, it has been

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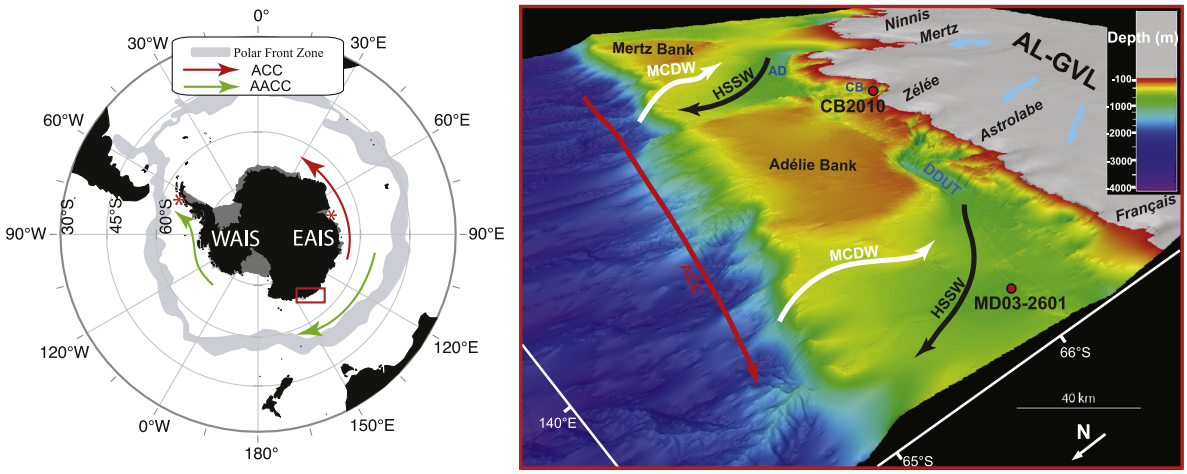

Fig. 1. Study area (modified from Beaman et al., 2011): location of cores MD03-2601 and CB2010 (red dots) and coastal cores from Berg et al. (2010) and Pike et al. (2013) (red asterisks), glaciers (in italic), katabatic winds (light blue arrows), and details of oceanographic currents and different water masses in the region. HSSW: High Salinity Shelf Water; MCDW: Modified Circumpolar Deep Water; ACC: Antarctic Coastal Current; AACC: Antarctic Circumpolar Current. Features include the Adélie Land–George V Land (AL–GVL), the Adélie Depression (AD), Commonwealth Bay (CB), Dumont d'Urville Trough (DDUT). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

evidenced that large parts of the EAIS margin are more vulnerable to external forcing than previously recognized (Miles et al., 2013). Hence, it is important to reconstruct the glacial discharge history (iceberg and brash-ice discharge together with basal melting of floating glaciers/ice shelves) to the coastal waters off EA in order to further improve numerical predictions.

We present the first high-resolution diatom oxygen isotope ($\delta^{18}O_{diatom}$) records obtained from two marine sediment cores collected on the Adélie Land–George V Land (AL–GVL) continental shelf (EA). The down core $\delta^{18}O_{diatom}$ records enable to reconstruct the glacial discharge history of AL–GVL at decadal to centennial resolution to better understand the relationship between East Antarctic climate variability and local glacier fluctuations. This could provide potential insights on the sensitivity of the EAIS to future climatic changes.

2. Material and methods

Two marine sediment cores (piston core MD03-2601: 66°03.07′S, 138°33.43′E; 746 m water depth; interface core CB2010: 66°54.33′S; 142°26.20′E; 780 m water depth; Fig. 1) were analyzed to investigate changes in glacial discharge during the Holocene on the AL–GVL in the Indian sector of the Southern Ocean. These high accumulation sites from the coastal continental shelf zones are located below one of the most productive ecological provinces in the Southern Ocean (Arrigo et al., 2008). Several glaciers, releasing freshwater to the surface water of the marine environment, dissect the coastal area off AL–GVL region. The Zélée, Astrolabe, and Français glaciers predominantly affect the MD03-2601 site off AL, whereas the CB2010 site off GVL is influenced by both the Mertz and Ninnis glaciers (Fig. 1). The two cores are located ∼200 km apart and are separated by the Adélie Bank. Piston core MD03-2601 is composed of a 4000-cm-long sequence of laminated diatom ooze, while interface core CB2010 is composed of a 30-cm-long of massive diatom ooze.

2.1. Chronology

The age model used for piston core MD03-2601 is based on seven Accelerator Mass Spectrometry ^{14}C dates of the humic fraction of bulk organic matter calibrated to calendar ages using CALIB 5.0 and a reservoir age of 1300 years (see Denis et al., 2009a for further details on the age model). Core MD03-2601 spans the period between 11,000 and 1000 calendar years BP (cal yr BP).

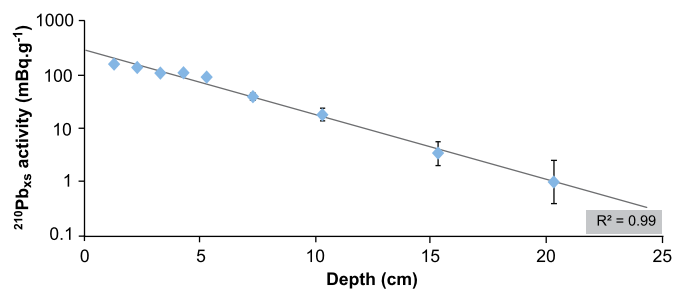

Fig. 2. Down core profile of $^{210}Pb_{xs}$ activity (blue diamonds). Error bars correspond to 1SD. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The age model of interface core CB2010 (Fig. 2) was developed from the excess ^{210}Pb activity ($^{210}Pb_{xs}$), which yields a mean sedimentation rate of 0.11 cm yr^{-1} and taking into account that the interface of the core is contemporaneous to the retrieval date as shown by the presence of an oxydated fluffly layer. $^{210}Pb_{xs}$ profile was determined as the difference of the total (^{210}Pb) and supported (^{226}Ra) activities in sediment, measured by low-background high-efficiency gamma spectrometry (Schmidt et al., in press). Individual sample ages were calculated by fitting a smooth curve to the chronological data. Core CB2010 spans the past 250 years.

2.2. Diatom extraction and analysis

Cores MD03-2601 and CB2010 were sampled every 32 cm and 1 cm leading to a sampling resolution of ∼80–100 years and ∼10 years, respectively. Diatoms were separated from the sediment and purified using a combination of previously published cleaning techniques adapted for our Antarctic marine samples (Juillet-Leclerc, 1986; Morley et al., 2004; Shemesh et al., 1995; Swann and Leng, 2009). Sediment samples were pretreated with 30% H_2O_2 for 4 h at 60 °C and 10% HCl for 2 h at room temperature, followed by sonication for a few seconds. Samples were then sieved and the 10–32 µm size fraction was retained for density separation by sodium polytungstate (SPT) (specific gravities from 2.1 to 2.25 g/ml) to separate diatoms from detrital minerals. Following oxidation of the labile organic matter coating the diatom valves by using a 1:1 mixture of HNO_3 (65%)/$HClO_4$ (70%) at 60 °C for 1 h, samples were centrifuged 8 times with deionized water and dried at 60 °C. All samples were subjected to light