Global and Planetary Change 100 (2013) 278–290

Contents lists available at SciVerse ScienceDirect

Global and Planetary Change

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

# Combining ice core records and ice sheet models to explore the evolution of the East Antarctic Ice sheet during the Last Interglacial period

S.L. Bradley [a,*], M. Siddall [b], G.A. Milne [c], V. Masson-Delmotte [d], E. Wolff [a]

[a] British Antarctic Survey, Madingley Road, Cambridge, UK
[b] Department of Earth Sciences, University of Bristol, Bristol, UK
[c] Department of Earth Sciences, University of Ottawa, Ottawa, Canada
[d] Laboratoire des Sciences du Climat et de l'Environnement (IPSL/CEA-CNRS-UVSQ UMR 8212), Gif-sur-Yvette, France

ARTICLE INFO

*Article history:*
Received 24 August 2012
Accepted 5 November 2012
Available online 12 November 2012

*Keywords:*
Isostasy
Ice cores
Antarctic Ice Sheet
Eustatic sea level
Last Interglacial
Ice sheet models

ABSTRACT

This study evaluates the influence of plausible changes in East Antarctic Ice sheet (EAIS) thickness and the subsequent glacio-isostatic response as a contributor to the Antarctic warming indicated by ice core records during the Last Interglacial period (LIG). These higher temperatures have been estimated primarily using the difference in the δD peak (on average ~15‰) in these LIG records relative to records for the Present Interglacial (PIG). Using a preliminary exploratory modelling study, it is shown that introducing a relatively moderate reduction in the amount of thickening of the EAIS over the LIG period introduces a significant increase (up to 8‰) in the predicted elevation-driven only δD signal at the central Antarctic Ice sheet (AIS) ice core sites compared to the PIG. A sensitivity test in response to a large prescribed retreat of marine-based ice in the Wilkes and Aurora subglacial basins (equivalent to ~7 m of global mean sea-level rise) results in a distinct elevation signal that is resolvable within the ice core stable isotope records at three sites (Taylor Dome, TALDICE and EPICA Dome C). These findings have two main implications. First, EAIS elevation's only effects could account for a significant fraction of the LIG warming interpreted from ice core records. This result highlights the need for an improved estimate to be made of the uncertainty and size of this elevation-driven δD signal which contributes to this LIG warming and that these effects need to be deconvolved prior to attempting to extract a climatic-only signal from the stable isotope data. Second, a fingerprint of significant retreat of ice in the Wilkes and Aurora basins should be detectable from ice core δD records proximal to these basins and therefore used to constrain their contribution to elevated LIG sea levels, after accounting for ice sheet–climate interactions not considered in our approach.


## 1. Introduction

Global mean sea level (GMSL) during the Last Interglacial (LIG) is estimated to have been between 5.5 and 10 m higher than that during the present interglacial (PIG) (Kopp et al., 2009; Dutton and Lambeck, 2012). A number of recent studies have considered the possible contributions to this higher sea level. For example, thermal expansion of the ocean produced ~0.4 ± 0.3 m of GMSL rise (McKay et al., 2011) and melting from valley glaciers and small ice caps could have contributed up to ~0.6 ± 0.1 m (Radi and Hock, 2010). It is generally agreed that by far the largest contribution must have come from the major ice sheets; 0.4–4.4 m from the Greenland Ice sheet (Cuffey and Marshall, 2000; Otto-Bliesner et al., 2006; Robinson et al., 2011; Helsen et al., 2012; Quiquet et al., 2012; Stone et al., 2012; Helsen et al., submitted for publication) and 3–6 m from the Antarctic Ice Sheet (Bamber et al., 2009; Kopp et al., 2009; Gomez et al., 2010; Bradley et al., 2012). Recent findings from the NEEM ice core (NEEM community members, in revision) and from ice sheet simulations (Robinson et al., 2011; Helsen et al., 2012, Quiquet et al., 2012; Stone et al., 2012; Born and Nisancioglu, 2012; Helsen et al., submitted for publication) suggest a limited (~2 m) contribution of the Greenland ice sheet, thereby increasing the magnitude of the contribution required from Antarctica.

Until recently, the central East Antarctic Ice sheet (EAIS) was considered to have been relatively stable throughout the Pleistocene glacial–interglacial cycles, with changes in ice sheet surface elevation estimated to have been ~100 m (Haywood et al., 2002; Lilly et al., 2010; Liu et al., 2010). However, recent studies concluded that large areas of the EAIS may be susceptible to rapid mass loss (or retreat) and that the size of the ice sheet may therefore have been reduced during the LIG compared to the PIG (Jordan et al., 2010; Pierce et al., 2011; Pingree et al., 2011). This implies that the question of EAIS stability needs to be readdressed for the LIG. This study aims to explore this using a comparison between ice core observations and simulations of ice surface elevation changes (including that due to the isostatic response of the solid Earth, a process more commonly referred to as glacial isostatic adjustment (GIA)).

* Corresponding author. Tel.: +44 7889469890.
*E-mail address:* d80ngv@gmail.com (S.L. Bradley).

0921-8181/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gloplacha.2012.11.002

One proposed region of large and potentially rapid mass loss is within the Wilkes and Aurora subglacial basins (abbreviated within this study to W–A basins, see Fig. 1). Across this region, where the ice is grounded below sea level, the overlying ice sheet is more vulnerable to the impact of changes in ocean temperature. Only one study to date has explored the possible contribution to GMSL from the retreat of ice in this region. Gomez et al. (2010) estimated that if all marine-grounded ice was to melt within the W–A basins (see their Fig. 1) GMSL would increase by ~18 m. This is an extreme scenario and it is used here to highlight that this sector of the EAIS has the potential to add a significant contribution to GMSL (relative to the PIG).

There are a number of recent studies which have proposed that the surface temperature of the EAIS was significantly warmer during the four preceding interglacial cycles (MIS5, MIS7, MIS9 and MIS11) compared to the PIG (see Holden et al., 2010; Masson-Delmotte et al., 2010; Lang and Wolff, 2011). This finding is estimated primarily using the 800 kyr EPICA Dome C stable water isotope ice core record (δD) (see Fig. 2a Lang and Wolff, 2011) by comparing the magnitude of the Antarctic interglacial peak during each of these cycles to that during the PIG. For the LIG (or during MIS5), the six available EAIS ice core water stable isotope records (see Figs. 1 and 2) show an early interglacial δD peak above PIG levels at an average 15‰ (Holden et al., 2010; Masson-Delmotte et al., 2011). This feature is commonly referred to as the 'LIG overshoot'.

Isotope-temperature relationship studies have interpreted the LIG overshoot to suggest temperature anomalies at least 2–5 °C above present-day values (Jouzel et al., 2007; Sime et al., 2009; Masson-Delmotte et al., 2011; Uemura et al., 2012). However, a range of factors contribute to and drive the observed signal in these ice core observations and so a robust interpretation is not straightforward. These include changes in temperature, moisture origin (Stenni et al., 2010; Uemura et al., 2012) and precipitation intermittency (Laepple et al., 2011) and site elevation (resulting from both changes in ice thickness and movement of the solid land surface) (see Masson-Delmotte et al., 2011). While climate models do not produce significant Antarctic warming in response to LIG orbital forcing (Holden et al., 2010; Masson-Delmotte et al., 2010), when changes in West Antarctic ice sheet (WAIS) topography were combined with a bipolar seesaw linked with ocean circulation in such a models, an EAIS warming was produced comparable to the signal derived from ice cores (Holden et al., 2010).

Past research into interpreting the factors driving these higher δD peaks has attributed most of the signal to changes in Antarctic

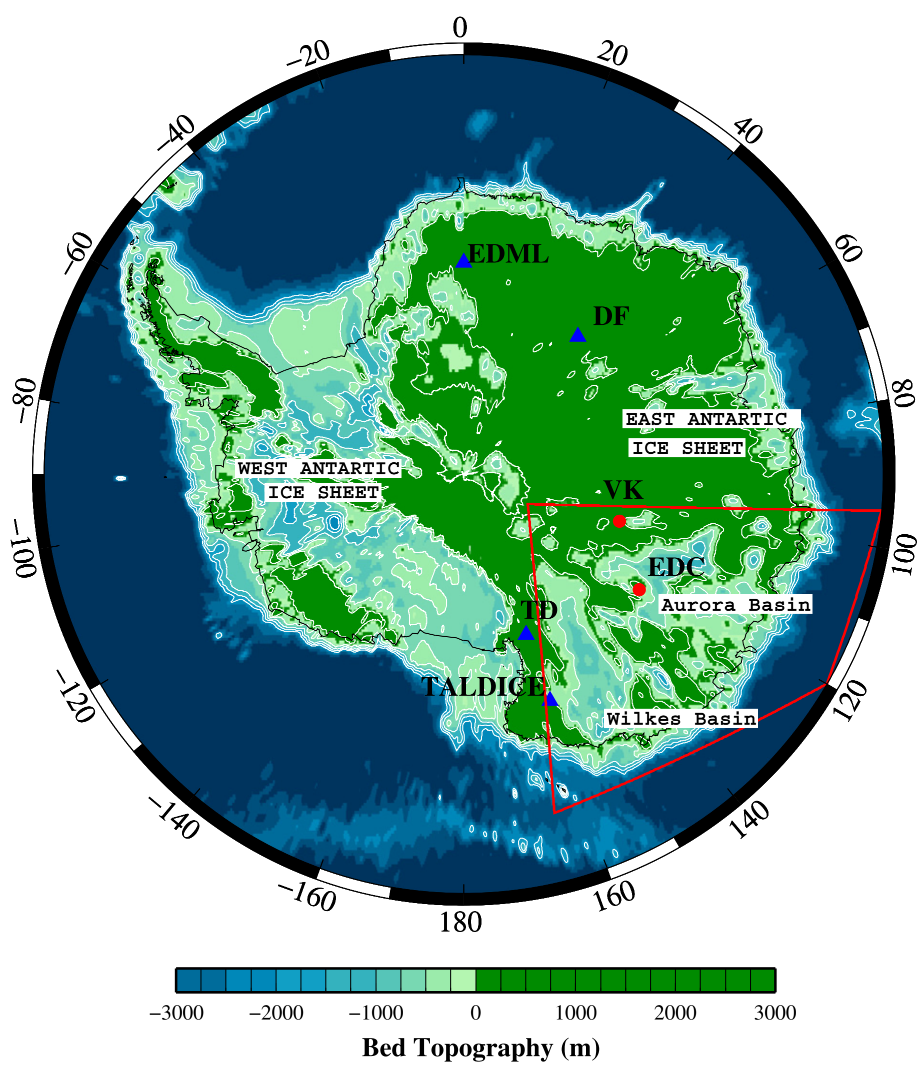


**Fig. 1.** Contoured bedrock topography (m) using the data set from Le Brocq et al., 2010. The location of the six ice core sites (summarised in Table 1) are shown, with associated abbreviated names and symbols. Also highlighted by the solid red box is the approximate location of the Wilkes and Aurora subglacial basins.