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Revised estimates of Greenland ice sheet thinning histories based on ice-core records

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ABSTRACT

Ice core records were recently used to infer elevation changes of the Greenland ice sheet throughout the Holocene. The inferred elevation changes show a significantly greater elevation reduction than those output from numerical models, bringing into question the accuracy of the model-based reconstructions and, to some extent, the estimated elevation histories. A key component of the ice core analysis involved removing the influence of vertical surface motion on the δ^{18}O signal measured from the Agassiz and Renland ice caps. We re-visit the original analysis with the intent to determine if the use of more accurate land uplift curves can account for some of the above noted discrepancy. To improve on the original analysis, we apply a geophysical model of glacial isostatic adjustment calibrated to sea-level records from the Queen Elizabeth Islands and Greenland to calculate the influence of land height changes on the δ^{18}O signal from the two ice cores. This procedure is complicated by the fact that δ^{18}O contained in Agassiz ice is influenced by land height changes distant from the ice cap and so selecting a single location at which to compute the land height signal is not possible. Uncertainty in this selection is further complicated by the possible influence of Innuitian ice during the early Holocene (12–8 ka BP). Our results indicate that a more accurate treatment of the uplift correction leads to elevation histories that are, in general, shifted down relative to the original curves at GRIP, NGRIP, DYE-3 and Camp Century. In addition, compared to the original analysis, the 1-σ uncertainty is considerably larger at GRIP and NGRIP. These changes reduce the data-model discrepancy reported by Vinther et al. (2009) at GRIP, NGRIP, DYE-3 and Camp Century. A more accurate treatment of isostasy and surface loading also acts to improve the data-model fits such that the residuals at all four sites for the period 8 ka BP to present are significantly reduced compared to the original analysis. Prior to 8 ka BP, the possible influence of Innuitian ice on the inferred elevation histories prevents a meaningful comparison.

1. Introduction

1.1. Holocene thinning of the Greenland ice sheet

Vinther et al. (2009) applied a novel procedure to determine ice surface elevation curves of the Greenland ice sheet (GrIS) at four ice core locations (GRIP, NGRIP, DYE-3 and Camp Century; see Fig. 1a). These observationally-constrained curves depict a Holocene thinning history that is considerably more rapid and of greater amplitude than that indicated from the output of numerical ice models. The discrepancy is large, several hundred metres at some core sites, and brings into question the accuracy of both the ice models and the thinning curves. This paper revisits two aspects of the Vinther et al. (2009) (shortened to Vinther et al. in the following) analysis in order to assess their impact on the resulting thinning curves and whether it can account for some of the discrepancy mentioned above.

In the original Vinther et al. analysis, the thinning curves were derived by considering the climate records in two ice caps, Agassiz and Renland (henceforth AR), situated on either side of Greenland (Fig. 1a). After estimating and removing the contribution of vertical land motion to the AR δ^{18}O records, the elevation-corrected δ^{18}O

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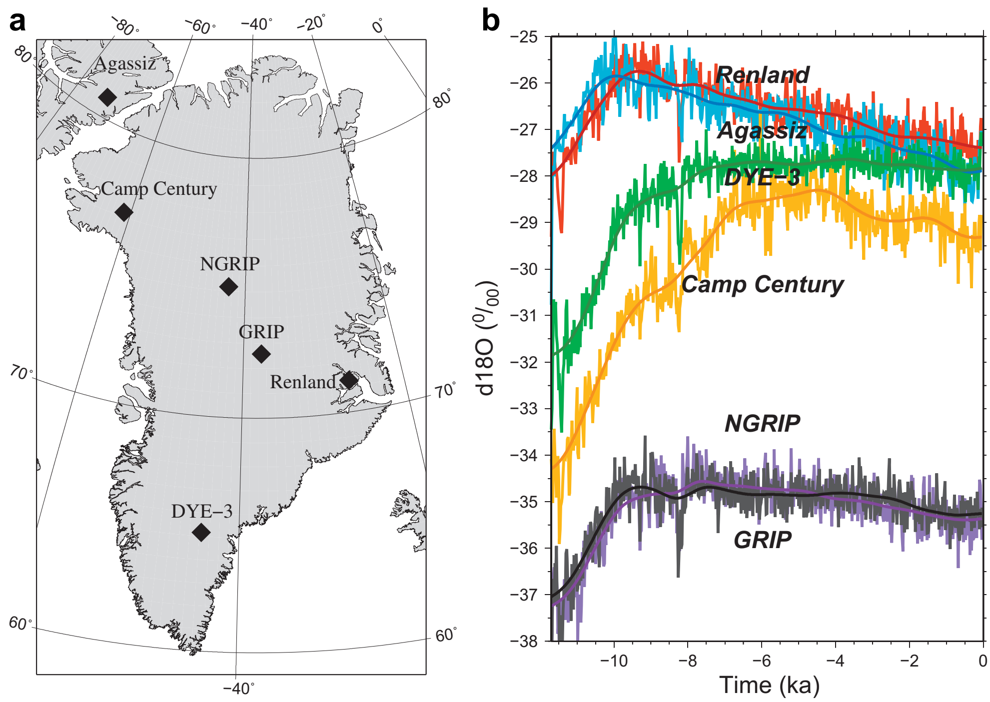

Fig. 1. (a) The location and names of the relevant ice cores discussed in this study. (b) The synchronized $\delta^{18}O$ records for all the sites shown in (a); both raw and smoothed (Gaussian filtered) signals are shown.

records were applied to infer a homogeneous $\delta^{18}O$ field for the entire region. As discussed below, the AR ice caps have topographical constraints that limit their former vertical extent (thickness) (Johnsen et al., 1992; Fisher et al., 1995). Consequently, no elevation correction for thickness changes of either ice cap was applied in the Vinther et al. analysis.

A synchronized stratigraphical timescale for the Holocene (GICC05) of DYE-3, GRIP, NGRIP, Camp Century, Renland and Agassiz was made by matching prominent volcanic reference horizons in electrical conductivity measurements (Vinther et al., 2006, 2008) and gaussian filtered to capture millennium scale variations (Fig. 1b). By removing the uplift-corrected AR $\delta^{18}O$ records from the $\delta^{18}O$ records at Camp Century, DYE-3, GRIP and NGRIP, changes in ice surface elevation were isolated at these sites. The two aspects of the original analysis investigated in this paper are (i) the accuracy of the elevation corrections applied at the AR ice caps and (ii) the resulting inference and application of a $\delta^{18}O$ profile for the entire region.

The main contribution of this study is to assess the accuracy of the land uplift correction applied in the original Vinther et al. analysis and determine the impact of this on the estimated thinning curves. The post glacial uplift estimated for AR in Vinther et al. was conducted using observations of past changes in relative sea level (RSL) in nearby fiords. The Agassiz bedrock elevation history is based on a set of data dating back to 9.5 ka before present (BP; relative to AD, 2000) and extrapolated to 11.7 ka BP using the observed exponential decay time for RSL change (Dyke and Peltier, 2000). Similarly, the uplift estimated for Renland was obtained using past changes in sea level in nearby fiords (Funder, 1978). Using RSL as a proxy for vertical land motion will lead to some degree of error due to the contribution from vertical motion of the sea surface. We improve upon this method here by modelling RSL observations from Ellesmere and Devon Islands and north–west Greenland (Fig. 2) to calibrate a glacial isostatic adjustment (GIA) sea-level model for this region. The calibrated model is then applied to determine land uplift histories at the appropriate locations (not necessarily at the ice core sites – see Section 1.2).

The second contribution of this study relates to the temperature reconstruction from the individual AR $\delta^{18}O$ records and the

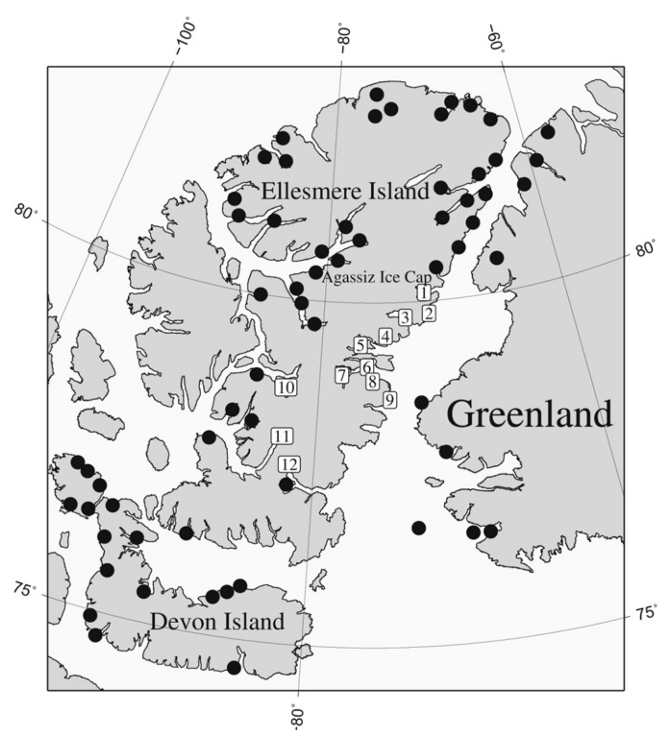

Fig. 2. The distribution of sites (black circles and 12 numbered sites) across the Canadian Arctic and Greenland which had sufficient sea level proxy information to constrain our glacial isostatic adjustment (GIA) model.