Global and Planetary Change 84-85 (2012) 3–7

Contents lists available at ScienceDirect

Global and Planetary Change

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

# Recent melt rates of Canadian arctic ice caps are the highest in four millennia

David Fisher [a,*], James Zheng [a], David Burgess [a], Christian Zdanowicz [a], Christophe Kinnard [b], Martin Sharp [c], Jocelyne Bourgeois [a]

[a] Natural Resources Canada, Northern Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8
[b] Centro de Estudios Avanzados en Zonas Aridas-CEAZA, Casilla 599-Campus Andres Bello, Colina El Pino s/n La Serena, Chile
[c] Earth and Atmospheric Sciences, University of Alberta, Edmonton,Ab, Canada T6G 2E3

ARTICLE INFO

*Article history:*
Received 3 January 2011
Accepted 13 June 2011
Available online 30 June 2011

*Keywords:*
Ice core
Melt layers
Holocene
Warming
Ice caps

ABSTRACT

There has been a rapid acceleration in ice-cap melt rates over the last few decades across the entire Canadian Arctic. Present melt rates exceed the past rates for many millennia. New shallow cores at old sites bring their melt series up-to-date. The melt-percentage series from the Devon Island and Agassiz (Ellesmere Island) ice caps are well correlated with the Devon net mass balance and show a large increase in melt since the middle 1990s. Arctic ice core melt series (latitude range of 67 to 81 N) show the last quarter century has had the highest melt in two millennia and The Holocene-long Agassiz melt record shows that the last 25 years has the highest melt in 4200 years. The Agassiz melt rates since the middle 1990s resemble those of the early Holocene thermal maximum over 9000 years ago.



## 1. Introduction

Ironically, paleo-climate records usually suffer because their recent end points are too far in the past to connect with the contemporary climate change discussion. Since the ice-core melt percent series are simple and have been extensively used in climate reconstructions many of the ice core sites across the Canadian Arctic have recently been re-drilled to overlap the old records some of which ended in the 1960s. With the up-to-date series it is clear that the last quarter century's melt rates in the high accumulation zones (~1800 m asl.) of Canada's Arctic ice caps have been the highest in many millennia and since the middle 1990s, the melt percent and net mass balance losses (Devon Ice Cap) have accelerated very sharply.

## 2. Sites and methods

For high elevation accumulation regions of Canadian Arctic ice caps (Fig. 1a and Table 1) there is usually some part of the summer when temperatures are high enough to produce surface melt that re-freezes at depths of a few tens of centimeters. Because re-frozen melt has few bubbles compared to ice that forms by compression of un-melted firn, it is easy to recognize (Koerner, 1977; Koerner and Fisher, 1990; Fisher et al., 1995). Fig. 1b shows recent ice layers from the Agassiz site.

Routine quantitative measurements of density and melt features in the ice cores have resulted in many records of melt-feature percentage, (MF). This percentage denoted, MF, pertains to some number, N, of annual increments of total length N $\lambda$ (where $\lambda$ is the annual accumulation rate in ice-equivalent/year). The MF for N years is defined:

$$MF = \Sigma[\text{N years of melt features in ice equivalent}] / (N\lambda) \times 100.$$

Two methods have been used to calculate the MF series. Only bulk-core densities are available for deep cores and most of the new cores, in which case MF is calculated using “Method-1” (Supporting Online Material, SOM). For the Agassiz-2009 extension-core there are densities for the stratigraphic elements at sufficient resolution so “Method-2” can be used, (SOM). For both methods and in all cases there was substantial multi-decadal overlap between the deep and new cores, (see Fig. 2). The time scales used for the various ice cores are found in the literature cited in Table 1. The Agassiz record which is the longest and most accurate has been tied into the Greenland chronology (Vinther et al., 2008, 2009). Fig. 2 shows 5 year MF-averages for all sites. Melting produces statistically very “noisy” series, which must be averaged over several nearby sites or over many years in order to produce reasonably robust series, (see eg. Fisher et al., 1985; Fisher and Koerner, 1994).The deep core MF is shown in black and the extension MF in gray. All the deep core stratigraphies were produced by the same experienced observer (R M Koerner) but the extensions were produced by various people in the author list. As described in the SOM, the pure ice layers (MF = 100%) are easy to see (and comprise about 70% of the melt,

* Corresponding author. Tel.: 1 613 996 7623.
*E-mail addresses:* fisher@nrcan.gc.ca, dafisher2@sympatico.ca (D. Fisher).

0921-8181/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2011.06.005

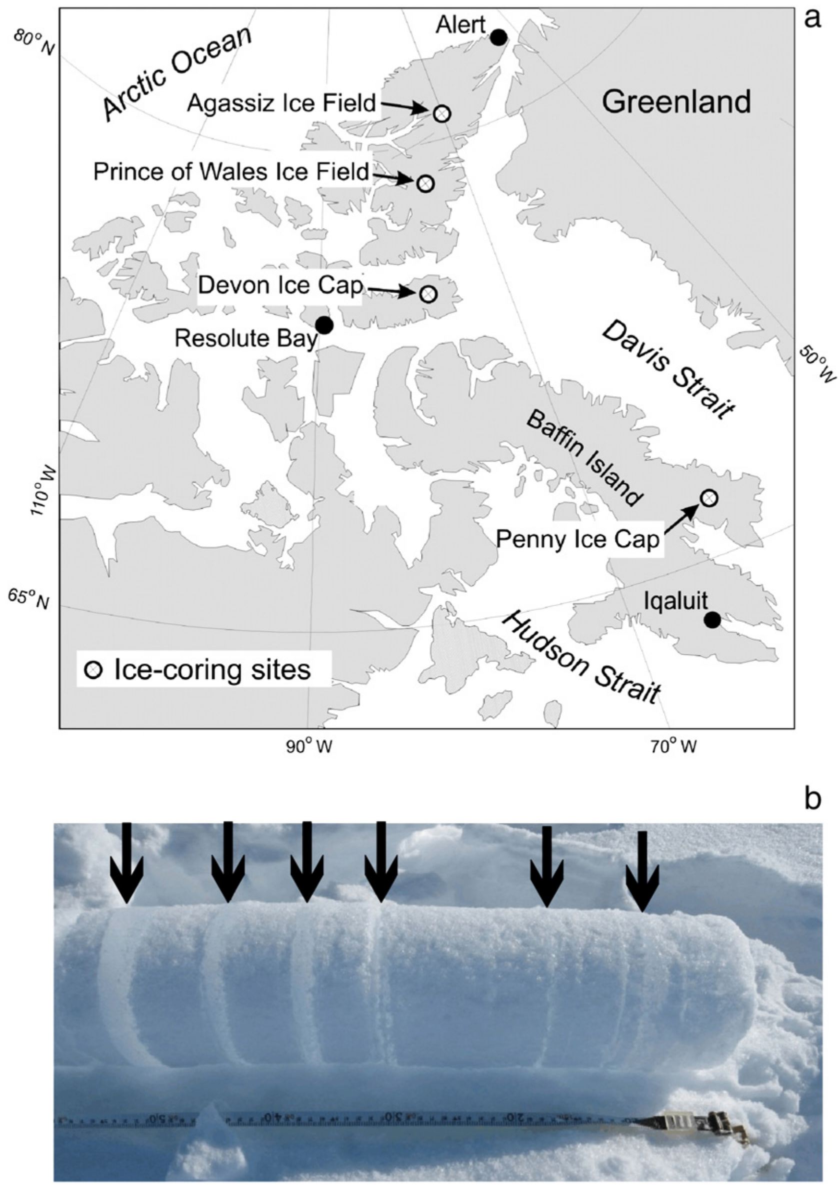


**Fig. 1.** a, Location map for the drill sites in the Canadian Arctic. b, Arrows show examples of the bubble-free ice layers from the Agassiz site in firn laid down in the recent warm period, post 1993.

see Fig. 1b). But when only bulk density is available, accessing the amount and density of partial melt features like "icy firn" is subjective. The MF appropriate to the "icy firn" category was adjusted so the new core overlap averages were close to the old, (SOM). This did not have to be done for the Agassiz extension where sufficient density data was available.

**Table 1**
Site information.

| Name | Latitude | Longitude | Elevation | Deep cores years | Hand cored in years | Accumulation rate (cm(ice)/a) | Refs |
|---|---|---|---|---|---|---|---|
| Devon72/73 | 75.47 | 82.5 | 1800 | 1971,72,73 | 2004,06,10 | Recent 25 long term 24 | [a,b] |
| Devon99 | 75.32 | 81.64 | 1903 | 1999 | None | 16.7 | [c] |
| Agassiz 1984/87 | 80.7 | 73.1 | 1730 | 1984,87 | 2009 | 1962–09 13.78 pre-1962 10 | [d,e,f,g] |
| Penny 1995 | 67.253 | 65.77 | 1860 | 1995 | 2010 | 37 | [h,i] |
| Prince of Wales 2005 (POW) | 78.4 | 80.4 | 1630 | 2005 | None | 30 | [j] |

[a] (Koerner, 1977.
[b] (Paterson et al., 1977.
[c] (Kinnard et al., 2006).
[d] (Fisher et al., 1983).
[e] (Vinther et al., 2008).
[f] (Vinther et al., 2009).
[g] (Fisher et al., 1995).
[h] (Fisher et al., 1998).
[i] (Goto-Azuma et al., 2002).
[j] (Kinnard et al., 2008).