Mem. Natl Inst. Polar Res., Spec. Issue, **54**, 203–207, 2001

*Scientific note*

# Sudden climatic change

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***Abstract:*** Studies of ice cores have shown that sudden climate changes (using $\delta^{18}O$ as a temperature proxy), were a common feature of past climate. Interplay between the Atlantic "conveyor belt" (or Thermohaline Circulation) and ice sheet melt-water is seen as the factor responsible for at least some of these sudden climatic changes. The Younger Dryas, 12.7–11.5 ky BP, is a well-studied example of such an event. Dansgaard-Oeschger events may be similarly explained. More recent research has attributed a sudden cooling, registered by a $\delta^{18}O$ step in 8.2 ky old ice in the Camp Century, Dye-3, GRIP and Agassiz ice cap cores, to sudden drainage, into the Atlantic, of glacial lakes on the southern margins of the decaying Laurentide ice sheet.

The question is whether a similar event could be triggered in the future by global warming and ice cap/Greenland ice sheet melt. In this paper, it is argued that all the classic sudden climatic change events occurred in the presence of the great Pleistocene Ice Sheets. It is unlikely that future melting of the northern circumpolar ice caps, glaciers and ice sheets would generate sufficient melt water to cause a similar event.

## 1. Introduction

Climatic change has come to the forefront of scientific research in response to the ongoing debate concerning the effect of industrial emissions of greenhouse gases on the radiative properties of the atmosphere. Models show that by increasing the concentrations of gases such as $CO_2$ and $CH_4$ in the atmosphere, climate will warm to levels high enough to seriously disrupt global society. Studies of past climates have, and are, playing a significant part in this debate. Only by putting ongoing climatic change in perspective can one determine how serious that disruption might become.

Paleo climate studies have been given a significant boost by recent successes in drilling deep ice cores from ice caps and ice sheets. For example, cores, covering 400000 years from Vostok, Antarctica (Jouzel *et al*., 1993), have demonstrated the strong relationship between air temperatures and $CO_2$. In this case, $CO_2$ is seen as an amplifier rather than an initial cause of the temperature change. Cores from Greenland (Dansgaard *et al*., 1971, 1985; Johnsen *et al*., 1992) have also indicated that climatic change during the Pleistocene period was often rapid and dramatic. It is these kind of changes that are the concern of this note. This because if changes of several degrees C have occurred before they may occur with any future perturbations of climate. The consequences for society would be disastrous. This paper argues that the abrupt changes recorded in the Greenland cores, all occurred in the presence of the great Pleistocene ice sheets. It has been suggested that the link between the ice sheets and climatic change was most probably meltwater releases from one of those ice sheets. The meltwater manifested itself climatically by either shutting or dramatically slowing down the northward, surface circulation of the Atlantic Ocean.

## 2. Sudden events

Abrupt changes in $\delta^{18}O$ (now termed *'Dansgaard/Oeschger events'*) were first found in Pleistocene ice from the Camp Century core (Dansgaard *et al.*, 1971). They were present also in the Dye-3 core from southern Greenland (Dansgaard *et al.*, 1985) and again in the summit-Greenland cores of both GISPII (Grootes and Stuiver, 1997) and GRIP (Johnsen *et al.*, 1992). GRIP also found similar abrupt events in Eemian Interglacial ice and considered them climatic (Johnsen *et al.*, 1998). However, study of the $CH_4$, $\delta^{18}O$ of $O_2$ records in the Eemian ice of the Vostok GRIP and GISPII cores (Chappellaz *et al.*, 1998), strongly suggests the interglacial events are dynamic (due to uneven ice flow over the bed) rather than climatic.

However, the sharp, unarguably climatic, (Dansgaard/Oeschger) events in the Pleistocene ice are thought to be the consequence of interplay between the big ice sheets, the Thermohaline circulation in the Atlantic, and consequent cooling of the air masses reaching Greenland and the north Atlantic coastline (*e.g.* Stocker and Marchal, 2000). Marshall and Clarke (1999) considered that high run-off variability from the north American continent may have kept the Thermohaline circulation in a similarly variable state; run-off variability itself was most likely ice-melt rather than rainfall dominated. In contrast, in the absence of the great Pleistocene Ice Sheets, the present (Holocene) interglacial period has had a relatively stable climate.

However, the Greenland and Canadian Arctic (Fig. 1) records have shown one dramatic climatic excursion 8.2 ka (thousands of calender years) ago. This event effected the sharpest $\delta^{18}O$ (temperature) excursion in the Holocene part of the ice core stable isotope records which represented a 4–8°C drop in temperature in central Greenland (Alley *et al.*, 1997). Because the event occurred in a period that is, by definition, termed an interglacial it suggested that "warmth is not a guarantee of climate stability" (Alley, 2000). Thus, similar events could occur in the near future, especially when anthropogenic greenhouse forcing is perturbing climate. However, Barber *et al.* (1999) have related the 8.2 ka event to catastrophic drainage of massive lakes that were marginal to the Laurentide ice sheet. These lakes were released by the final collapse of the Laurentide ice sheet which had hitherto, dammed the natural drainage of these lakes to the sea. Barber *et al.*'s (1999) research shows that, although the event occurred in a warmer world, it was still triggered by a Pleistocene ice sheet albeit in its decaying stages. This scenario is *very* different to the present world where the large ice sheets have long disappeared.

The question is whether increased warming will cause sufficient melting of the Greenland Ice Sheet and the circum-polar ice caps to cause another upset of the Thermohaline circulation and a dramatic climatic change. Firstly, one should stress that the climate change picture over this period shows substantial variations in the patterns of circum-polar warming. While the western Canadian Arctic, Alaska, and Siberia are warming substantial-

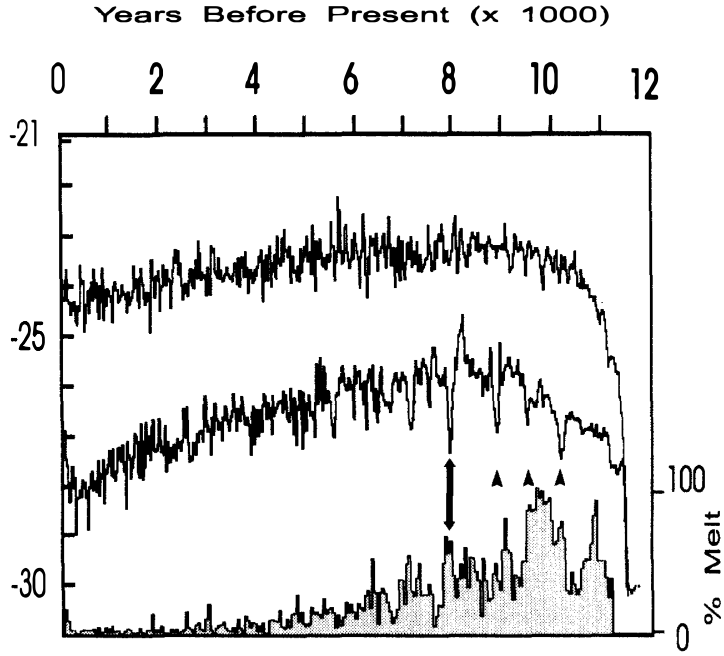


*Fig. 1.* *Holocene records of stable isotopes ($\delta^{18}O$) for Penny Ice Cap, Southern Baffin Island (top), (Fisher et al., 1998), and Agassiz Ice Cap, Northern Ellesmere Island (middle) (Fisher et al., 1995), and melt% for Agassiz Ice Cap (bottom) (Koerner and Fisher, 1990). As a temperature proxy, the less negative the $\delta^{18}O$ values or the higher the melt percentage, the warmer the temperature. The melt percentage is assessed from the percentage of ice layers in an annual layer of ice in the core. The discrepancies, in terms of temperatures, represented between the ice melt% and the $\delta^{18}O$ values in the early Holocene, are believed due to the "contaminating" effect of melt water from the Laurentide ice sheet, on the latter (Koerner, 1988; Fisher, 1992). The double-headed arrow points to the 8.2 ka event. The 200 year discrepancy in the timing with the accurately-dated Greenland cores for this event, is due to slight dating errors in the Canadian cores. The three separate arrows point to possible similar events in the early Holocene. Extrapolation back from present-day $\delta^{18}O$ and Melt% values (where the mass balance of the ice caps is presently slightly negative) to the early Holocene shows warmer and hence more negative balances then.*

ly, the same is not true for the Eastern Canadian Arctic and round to the east, to Svalbard (Dowdeswell *et al.*, 1997). Mass balance measurements on the ice caps in the Canadian Arctic (Fig. 2) and Svalbard do not show any trends of increased melting over the past 40 years although they do have slightly negative mass balances (Dowdeswell *et al.*, 1997; Koerner and Lundgaard, 1996). Secondly, the early Holocene was a period of very warm temperatures. Ice core records (*e.g.* Fig. 1) in conjunction with modern glacier mass balance measurements (Fig. 2) indicate that glacier mass balances were very negative at that time. The Greenland Ice Sheet, circumpolar ice caps, and the decaying Pleistocene ice sheets were all discharging far more melt water into the north Atlantic region than could be conceived of even in the warmer world of the anthropogenically warmed future. The Laurentide ice sheet alone was discharging melt water at an *average* rate, equivalent to about 1.0 cm sea level rise a year (Marshall and Clarke, 1999). This compares to sea level rise over the last 100 years of 1.0–2.0 mm/yr (Warrick and Oerlemans, 1990). Yet there is no evidence of a

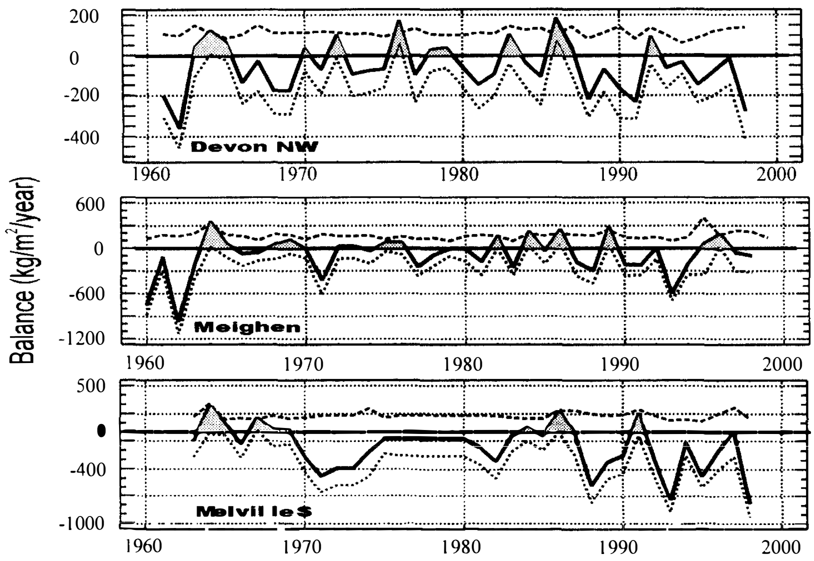


*Fig. 2. Mass balance of 3 Canadian ice caps. The top line of the three in each profile, represents **winter balance**, the middle line **net** (winter minus summer) **balance**, and the lowermost line **summer balance**. The records show no, overall, significant trend in any of the profiles, although the balance is slightly negative.*

major, *prolonged* shut-down of the Thermohaline circulation during the 10000 years of ice sheet retreat.

This is not to deny that the Thermohaline circulation is unlikely to be affected by future warming, rather that if it is affected, it will not be in the same way as the dramatic events of the past, registered in the ice core records.

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*(Received July 25, 2000; Revised manuscript accepted August 22, 2000)*