High-resolution ice core records from the Prince of Wales Icefield, Ellesmere Island.

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INTRODUCTION

This project aims to use detailed chemical and oxygen isotope stratigraphic analysis of ice cores to understand the interactions between climate, sea ice, and glacier mass balance in the eastern Canadian Arctic over the past millennium.

Two ~20 m ice cores, spanning 1965 to 2000, one 176.5 m core covering the last 1000 years, and a series of seasonal snow samples have been recovered from the Prince of Wales Icefield (PoW), Ellesmere Island, Nunavut (Fig. 1 & 2). Comparison of chemical and isotopic proxies from the short cores with empirical mass balance, sea ice extent, aerosol chemistry and climate data will be used to constrain the relationships between core proxies and real world environmental conditions over the last 1000 years.

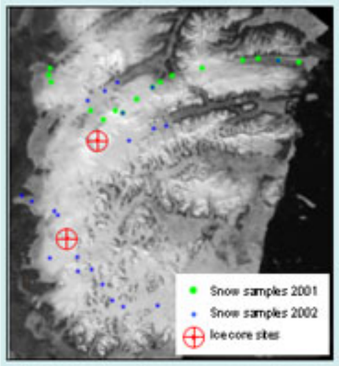

Fig. 1: Location of snow sample and coring sites, PoW, Ellesmere Island. (Image: F. Cawkwell, U of A).

Fig. 2: Extracting the long core at the north summit, spring 2005. (Image: J. Zheng, GSC).

SEASONAL RESOLUTION VIA MULTIPROXY ANALYSIS

Oxygen isotope records can be interpreted as a reflection of local temperature. Variation in oxygen isotopes can thus be used to identify annual layers, via summer/winter cycles (as in Fig. 5).

The concentration of chemical species in the ice also shows seasonal variation, as levels of individual aerosols vary differently over the annual cycle (Fig. 3), leading to characteristic ionic concentrations in seasonal snow (Toom-Sauntry & Barrie, 2002).

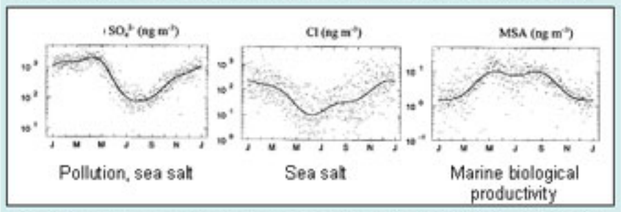

Fig. 3: Sample atmospheric aerosols collected at Alert 1980-1995, with best fit model (Sirois and Barrie, 1999).

If known seasonal peaks in chemical species, such as the winter/spring sulfate peak, or the summer methanesulphonate (MSA) peak (Fig. 3), can be identified, the records can be partitioned seasonally (Fig. 4). Interaction between different components of the climate system can thus be investigated.

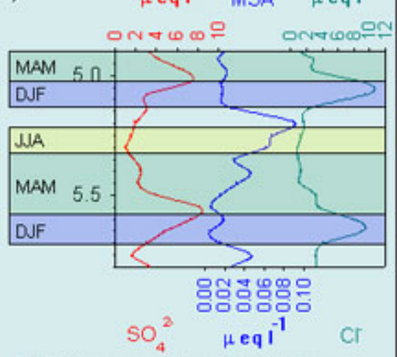

Fig. 4: Anion records from PoW North summit (4.8-6.0m) showing interpreted seasons.

RESULTS AND EXAMPLES FROM NORTH SUMMIT SHORT CORE

Oxygen isotopes were analyzed at the Niels Bohr Institute, of the University of Copenhagen, and ion analysis was carried out at the University of Alberta using a Dionex IC 2500. Samples were taken at 5 cm intervals. In order to capture seasonal resolution in ice core chemistry a minimum of eight samples per annual cycle is recommended (e.g. Paterson, 1994, p.333; Pohjola et. al., 2002), although some researchers have used fewer (e.g. Fischer, 2001). The high accumulation rate at PoW facilitates such high resolution analysis, and allows us to resolve subannual variation using multiproxy analysis, which is invaluable if one record fails to show the expected interannual pattern (Fig 5b-d).

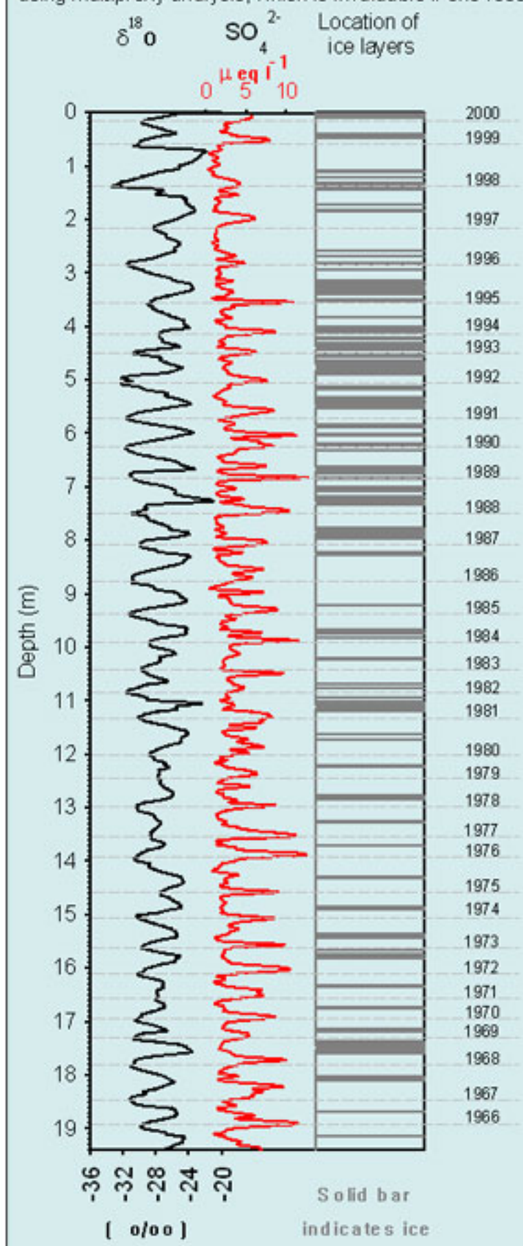

Fig. 5a: $\delta^{18}O$ and SO_4^{2-} sampled in 5 cm sections from the North summit short core. Ice layer stratigraphy is also shown.

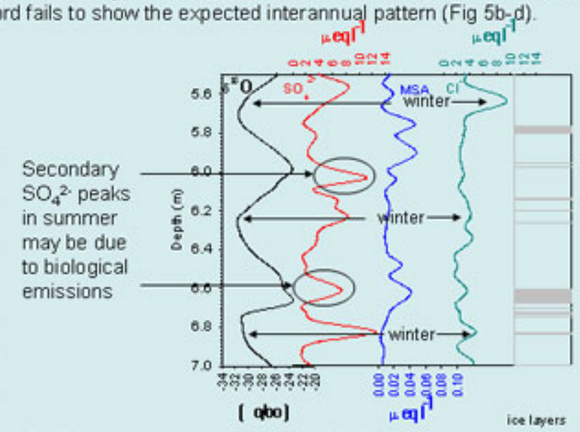

Fig 5(b): Interannual variation in SO_4^{2-} emissions can result in multiple peaks which could be misinterpreted as annual layers, but $\delta^{18}O$ and MSA both show only 2 summer periods over this depth.

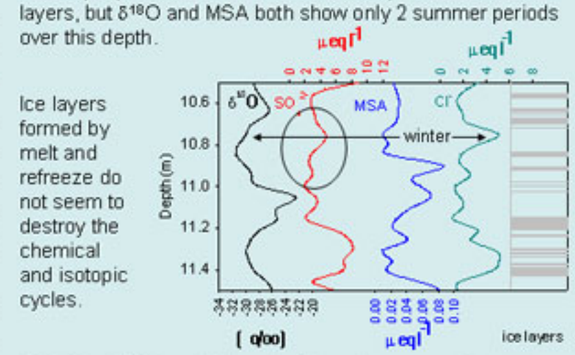

Fig 5(c): $\delta^{18}O$, low MSA and a Cl^- peak suggest winter layer around 10.8 m, but there is only a subdued SO_4^{2-} peak. This could indicate an unusual pattern of pollution distribution.

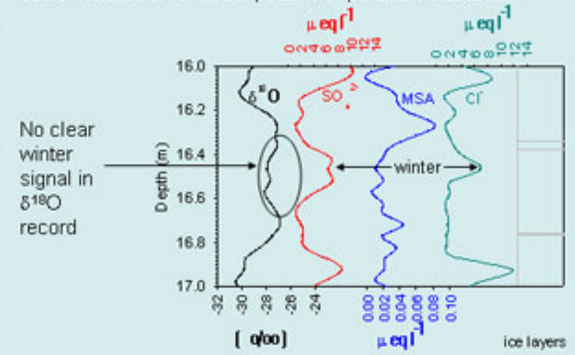

Fig 5(d):, Peaks in Cl^- and SO_4^{2-} occurring between ice layers and MSA peaks, suggest winter layer around 16.5m, despite not being reflected in the temperature proxy.

Obtaining records of chemical analysis such as these requires a minimum sample volume of 40 ml per annual layer to get 8 samples per annum. This becomes more of a challenge at depth in the long core as annual water equivalent layer thickness decreases with depth due to plastic deformation (Nye, 1963), so it becomes progressively more difficult to obtain the volumes required for sub-annual resolution further down the core. This problem is compounded because (1) the drill contaminates the outer core, so only a small portion of the inner core can be used for chemical analysis, and (2) it is difficult to cut very thin samples using traditional band saw ice core sampling techniques, which also waste a millimeter or two of core material with each cut of the blade.

CAN WE GET 1000 YEARS OF SEASONAL RECORDS

To produce sub-annual records for the last 1000 years, a semi-automatic system (Fig. 6) is used to melt the core incrementally, with minimal wastage. A core segment is placed on a heated melter head within a freezer unit. Meltwater from the inner core is collected in the inner well and pumped to one set of scintillation vials for chemical analysis, while meltwater from the outer core is simultaneously pumped to separate vials for stable isotope analysis.

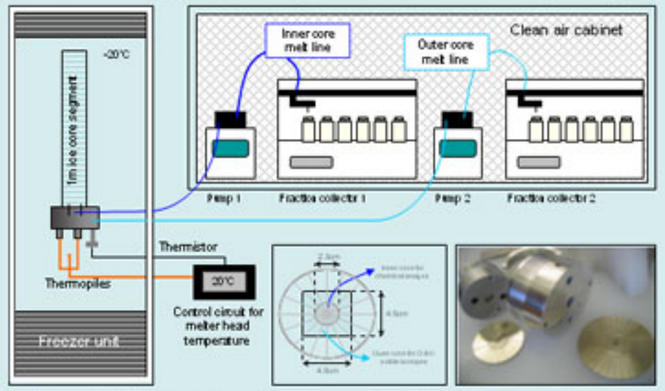

Fig 6: Schematic diagram of the melter system used to melt the PoW long core

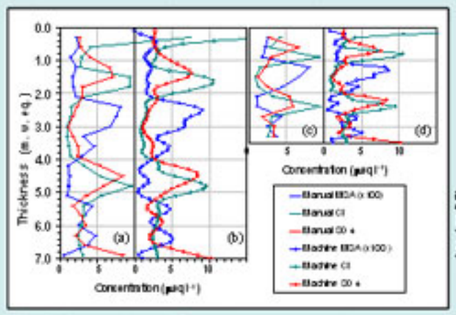

Fig 7: Comparison of 5 cm increment manual and melter resolution records of data in Fig 4. (a) & (b) at c. 5 m ice eq. depth; (c) & (d) at c. 105 m ice eq. depth in the core.

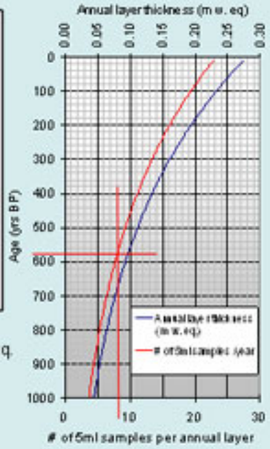

Fig 8: Calculated annual layer thickness and sample resolution with age.

The sampling resolution permitted by the melter allows us to capture interannual variability of ionic species at depths at which manual sampling procedures would not reliably distinguish peaks, as they would be represented by single points only (Fig. 7 (c) & (d)).

The sample resolution that we can produce over the last 1000 years can be predicted using Nye's (1963) formula to calculate the annual layer thinning with depth in the long core, assuming constant vertical strain rate. Using the melter system to obtain 5ml samples from the inner core for chemical analysis, this model predicts at least 8 samples per year will be possible for the last ~560 years, and > 4 samples per year will be possible back to 1000 years ago (Fig. 8).

Using the melter system will enable us to better resolve both the annual layers and the lags and leads existing between different environmental proxies, and thus to explore the interactions between the components of the Canadian Arctic climate system that are driving the variations in the proxies.

REFERENCES

- Fischer, H. (2001) Imprint of large-scale atmospheric transport patterns on sea-salt records in northern Greenland ice cores. *Journal of Geophysical Research*, 106, No. D20, pp 23977-23984.
- Paterson W. S. B. (1994) The Physics of Glaciers 3rd Edition. Butterworth Heinemann, Oxford.
- Pohjola V. A. et al. (2002) Reconstruction of three centuries of annual accumulation rates based on the record of stable isotopes of water from Lomonosovfonna, Svalbard. *Annals of Glaciology*, 35, pp 57-62.
- Nye, J. F. (1963) Correction factor for accumulation measured by the thickness of the annual layers in an ice sheet. *Journal of Glaciology*, 4, No. 36, pp 785-788.
- Sirois, A. and L. A. Barrie (1999). Arctic lower tropospheric aerosol trends and composition at Alert, Canada: 1980-1995. *Journal of Geophysical Research*, 104 No. D9 pp.11599-11618.
- Toom-Sauntry, D. and L. A. Barrie (2002). Chemical composition of snowfall in the high Arctic: 1990-1994. *Atmospheric Environment*, 36 No.15-16 pp.2683-2693.