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Deriving Glacier Mass Balance and Recent Climate Conditions from Shallow Ice Cores

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ABSTRACT

Reconstruction of the variations in snow accumulation rates on terrestrial ice masses is an important component when evaluating recent global climate change and its influence on sea level. Determining snow accumulation rates necessitates density measurements of ice retrieved from ice cores drilled on the surface of glaciers and ice sheets. Where the depth of known age marker horizons, due to ^{137}Cs fallout or volcanic eruptions, is known, density measurements allow the calculation of snow accumulation, which facilitates identification of annual layers, and thus, mass balance. There is a need to develop a method to reconstruct the recent mass balance of high Arctic glaciers as the current record is spatially and temporally "patchy." Using shallow ice cores will provide a basis for investigating regional patterns in glacier mass balance history in the area.

Keywords: glacier, mass balance, climate change

1. INTRODUCTION

Glaciers are of great value in climatological studies as they respond continually to climatic fluctuations through mass balance induced changes in volume. Since climatic change is expected to be the greatest in circumpolar areas in the next few decades, and because the current data record is spatially and temporally "patchy," there is a need to develop a method to reconstruct the recent mass balance of high Arctic glaciers.

Using shallow ice cores will provide a basis for investigating regional patterns in glacier mass balance history in this area. It also can be used to generate data sets that will allow testing of numerical model predictions of mass balance variability and its relationship to climate forcing over the recent past. It can also be used to generate data sets that will allow testing of numerical model predictions of mass balance variability and its relationship to climate forcing over the recent past.

The current research is deriving recent glacier mass balance and climate conditions from shallow ice cores taken from John Evans Glacier, Ellesmere Island, NT, during the spring/summer of 1999. This poster paper examines two shallow ice cores from John Evans Glacier, one from the accumulation area (1150 masl) and the other from just above the equilibrium area (950 masl). Both cores pre-date 1963, which is being used as the marker horizon for this study.

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2. LOCATION

John Evans Glacier is a polythermal valley glacier situated on an unnamed peninsula on the eastern edge of Ellesmere Island, NT (Figure 1). The glacier is approximately 20 km long and covers an area of 162.8 km^2, spanning an elevation range from 50 to 1500 masl, varying in thickness from 150 to 350 m.

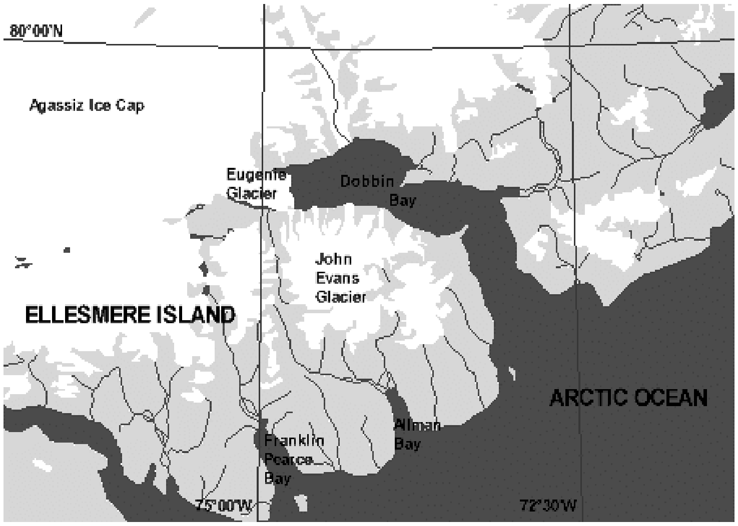

Figure 1. Location of John Evans Glacier on Ellesmere Island, NT, Canada.

3. PHYSICAL STRATIGRAPHY AND ICE CORE ANALYSIS

Determining the physical stratigraphy of ice cores obtained from John Evans Glacier during the summer of 1999 was a tedious and time-consuming task. Cores were brought back to the coldroom at the University of Alberta where they were dissected lengthwise and placed on a light table for careful analysis. With many of the ice cores, it was fairly easy to differentiate layers (Figure 2). Many of these layers are a function of warmer temperatures when the snow melted, accumulating meltwater and refreezing to form an ice lens. Thus, these lenses can be used to determine annual layers, and when many ice lenses occupy a small section of the core, they can be used to identify the spring melt. Used in conjunction with anion analysis, (as certain anions peak during certain times of the year), physical stratigraphy is an extremely important tool in identifying annual layers.

The core taken from 950 m (asl) has very little firn due to the amount of melt during the spring months (Figure 3). This further confirms that this core was taken from close to the equilibrium line area. This melting makes water chemistry somewhat difficult due to a smoothing effect.

Figure 2. Ice core segment from 1150 masl. Note the ice layers in the firn.

Figure 3. Ice core segment from 950 masl. Note that there is very little firn, suggesting that melt has taken place.

4. SHORT TERM ACCUMULATION RATES

δ^{18}O PROFILE

Identification of colder and warmer climate periods are made available through analysis of the oxygen isotope (δ^{18}O) record in glacial ice. Provided there is no significant melting to smooth the isotope signal, the δ^{18}O record can be used with recent climate data to assist in the identification of annual layers.

High resolution δ^{18}O analysis is currently underway (in collaboration with B. Spiro, UK) on multiple ice cores to assist in the estimation of shorter-term accumulation rates on John Evans Glacier. Figure 4 shows the results thus far from the core taken at 1150 masl.

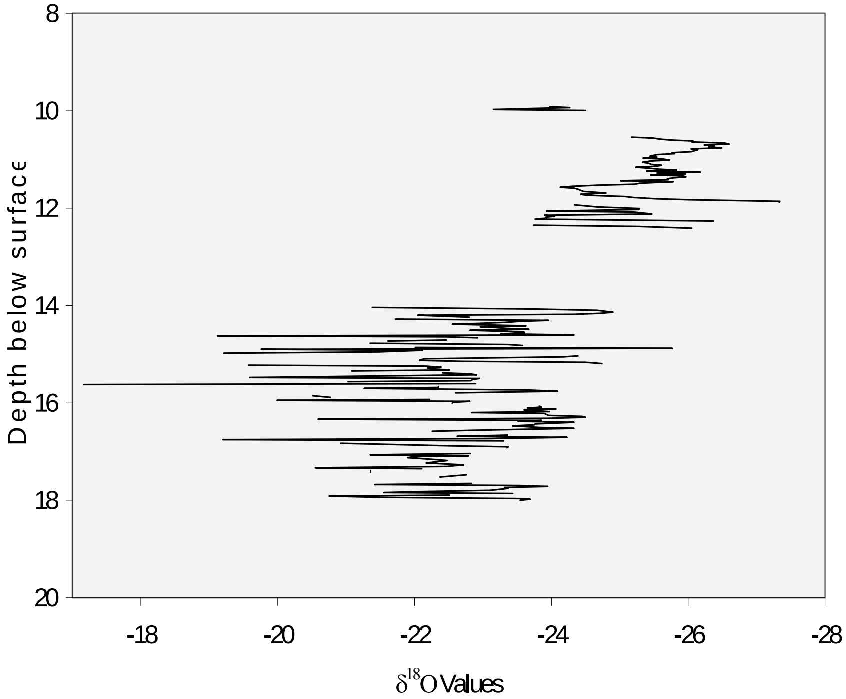

Figure 4. δ^{18}O profile showing cooler and warmer periods.

ELECTRICAL CONDUCTIVITY MEASUREMENTS

Determination of short-term accumulation rates requires the ability to identify annual layers or reference horizons of known age (such as volcanic eruptions) in ice cores. One such technique is the use of electrical conductivity (ECM) profiling. ECM (1- to 5-mm resolution) has been measured on numerous cores from John Evans Glacier. Figure 5 displays the ECM profile from 1150 masl, revealing prominent peaks around 5, 8, 10 to 11, and 13 m below the surface. Anion analysis corresponds to these prominent peaks, allowing for seasonal interpretation.

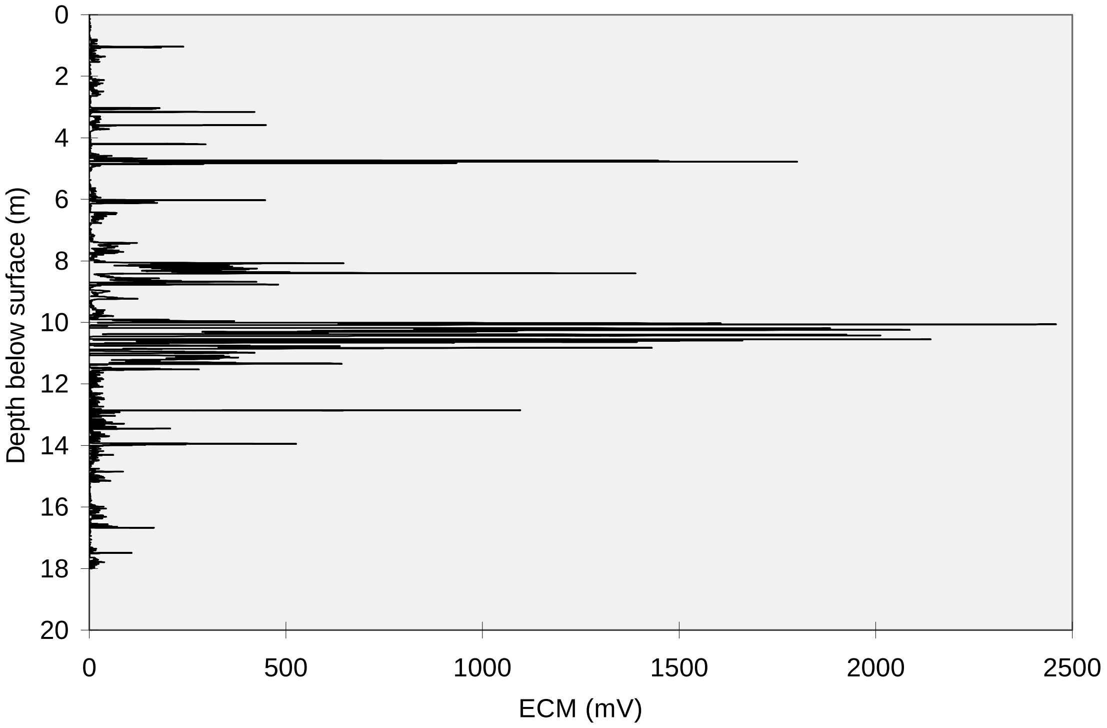

Figure 5. ECM profile taken at 950 masl.

5. RECONSTRUCTION OF MEAN EQUILIBRIUM LINE ALTITUDE BY DOWN BORE-HOLE GAMMA-RAY SPECTROMETRY

The long-term mean elevation of the equilibrium line (ELA) on John Evans Glacier has been reconstructed using field measurements of ^{137}Cs down bore-hole gamma (γ)-spectrometry. The ^{137}Cs detected on the glacier is a by-product of the 1963 atmospheric bomb tests, and is thus an identifiable marker horizon of known age in the accumulation area. Below the ELA, this horizon has melted out, while above the ELA, the ^{137}Cs layer is still highly detectable.

Bore-hole γ-spectrometry on a series of bore-holes around an assumed ELA revealed the long-term mean ELA to be 800 masl, approximately.

Each of the γ-spectrometry profiles is displayed in Figure 6. Background cosmic activity causes the ^{137}Cs levels to increase towards the surface. There is a discernable peak in ^{137}Cs in the 1150, 1100, 1050, 1000, 950, and 900 masl profiles, and no obvious ^{137}Cs peak at 800 masl, beyond background.

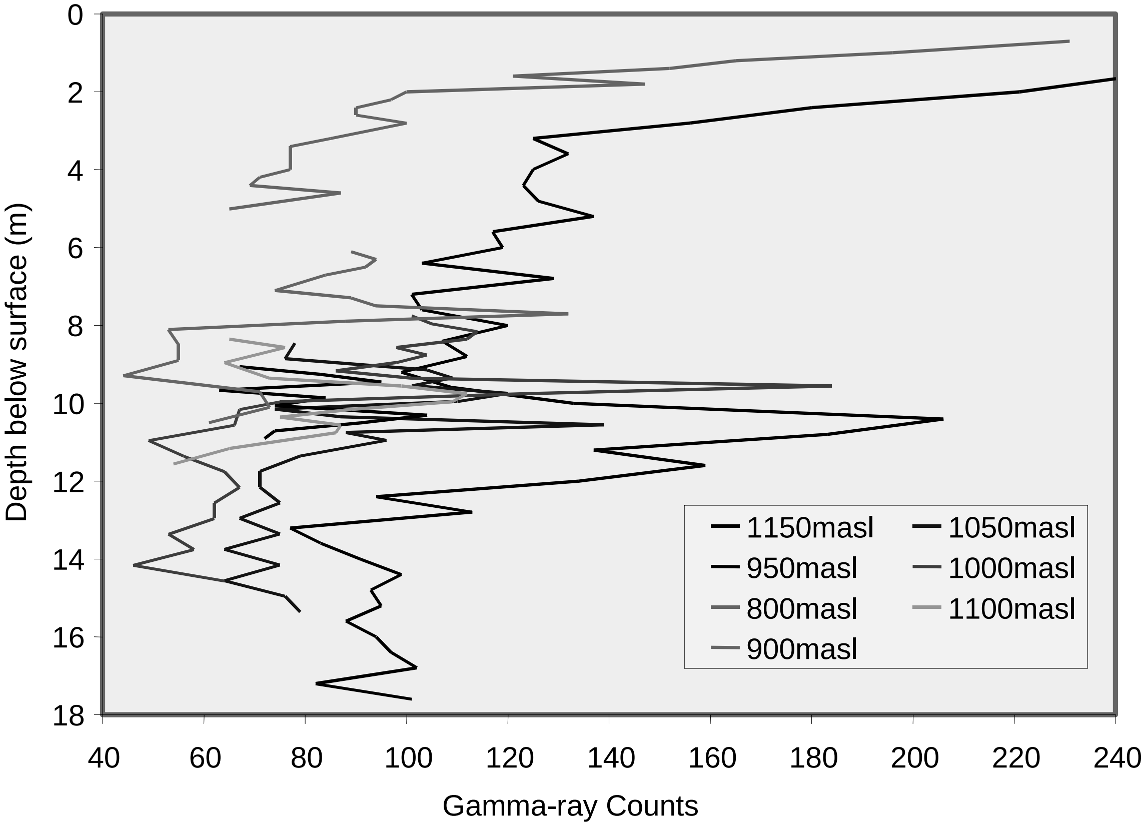

Figure 6. ^{137}Cs profiles obtained at each ice bore-hole during the 1999 filed season.

6. COMPARISON OF TRITIUM AND ^{137}CS γ-SPECTROMETRY AT 950 MASL

By identifying the 1963 bomb peak in the area above the ELA, the mean accumulation rate at that location can be estimated. Two approaches have been used: (i) down bore-hole ^{137}Cs γ-spectrometry (Figure 6) and (ii) laboratory measurements of tritium (^{3}H) concentrations. ^{3}H measurements have been used to identify the bomb peak at 950 masl.

Figures 7 and 8 compare the ^{3}H and the ^{137}Cs profiles at 950 masl, showing close agreement. The ^{3}H profile remains a work in progress at the time of writing.

7. ANION ANALYSIS: CHLORIDE, NITRATE, AND SULPHATE

Chloride (Cl^-), nitrate (NO_3), and sulphate (SO_4) are excellent markers of seasonality in ice cores, especially from the accumulation area where the anion profile has not been smoothed out due to melting and leaching of snow water down the ice core column. Figure 9 displays the results from anion analysis on the core taken from 1150 masl. The Cl^- and SO_4 analysis show numerous peaks corresponding with the spring season in the high Arctic, as both Cl^- and SO_4 peak during the spring months.

Figure 10 displays the data collected from anion analysis on the ice core from 950 masl. Again, the Cl^- and SO_4 peaks are very dominant and correspond to the spring months. Using this data, one can carefully interpret annual layers.

These results will be used with all of the other data to determine annual layer thickness and therefore, to construct recent mass balance on John Evans Glacier.

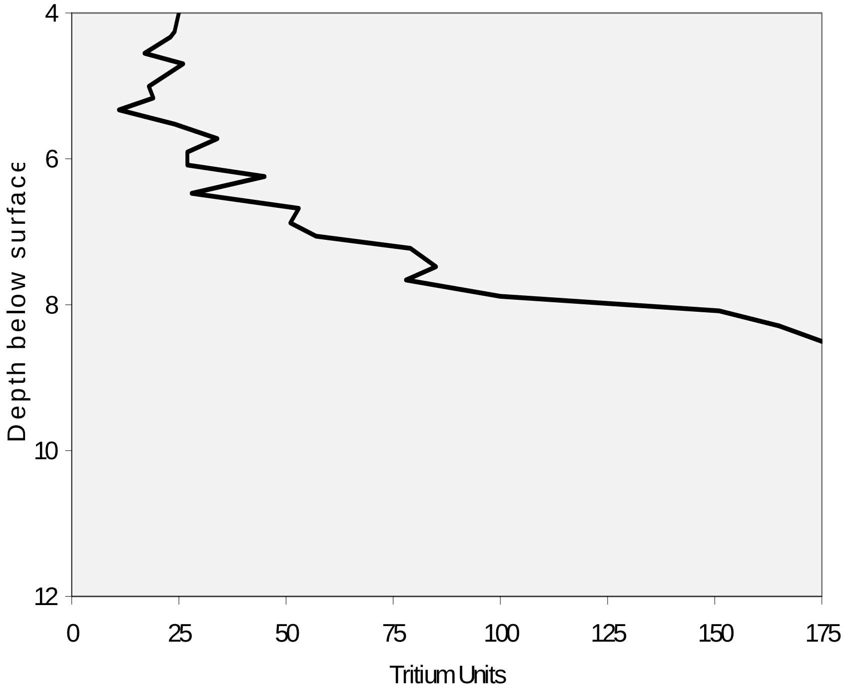

Figure 7. ^{3}H profile from ice obtained at 950 masl in 1997.

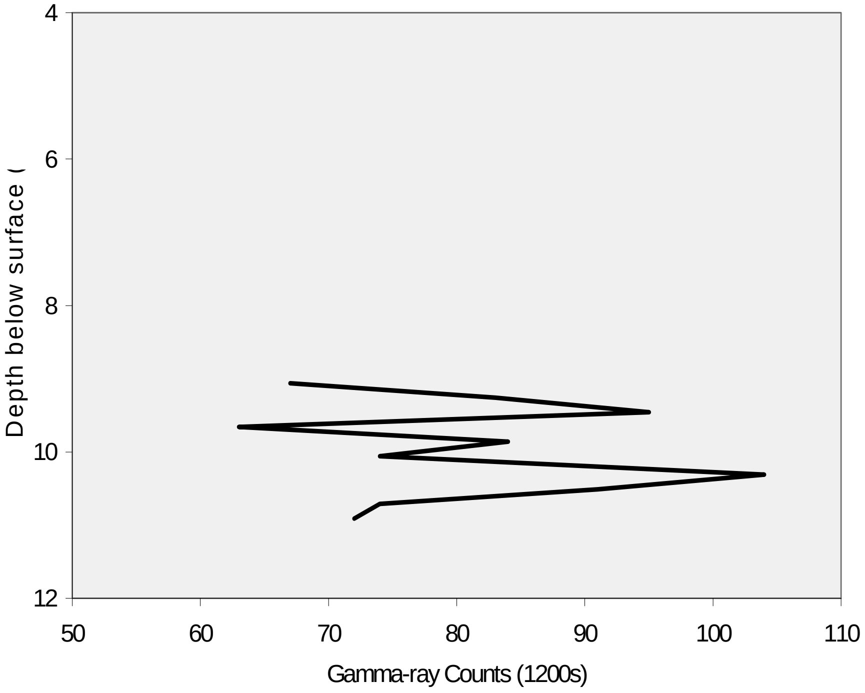

Figure 8. γ-spectrometry profile of bore-hole at 950 masl 1999.

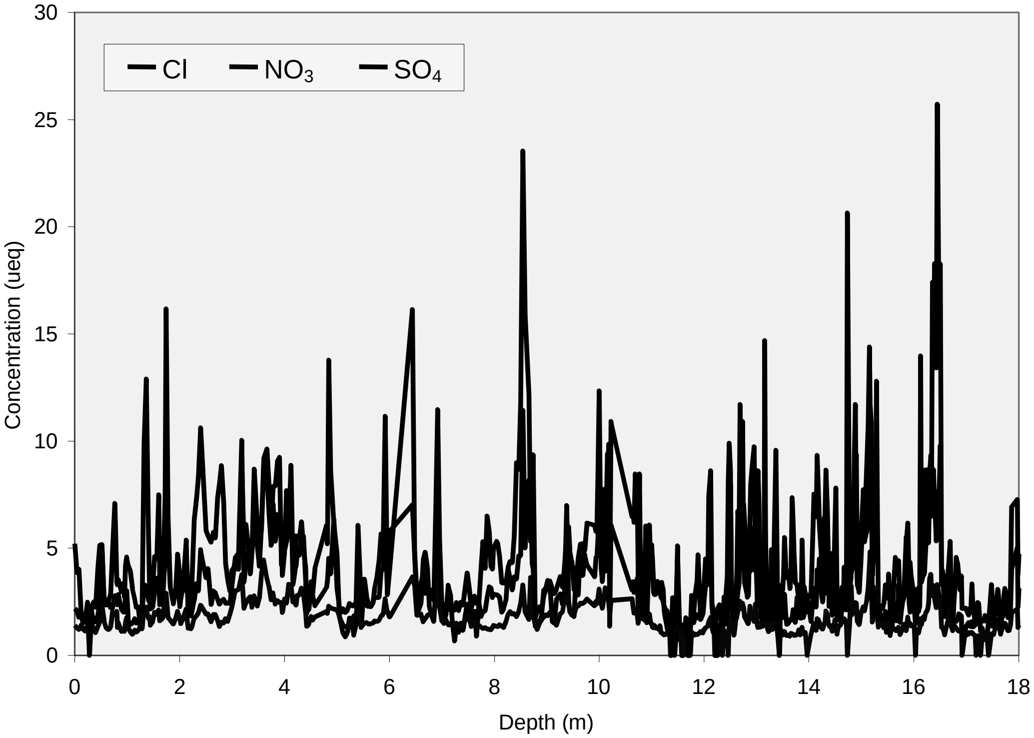

Figure 9. Anion analysis from 1150 masl. 1963 lies at approximately 11-m depth.

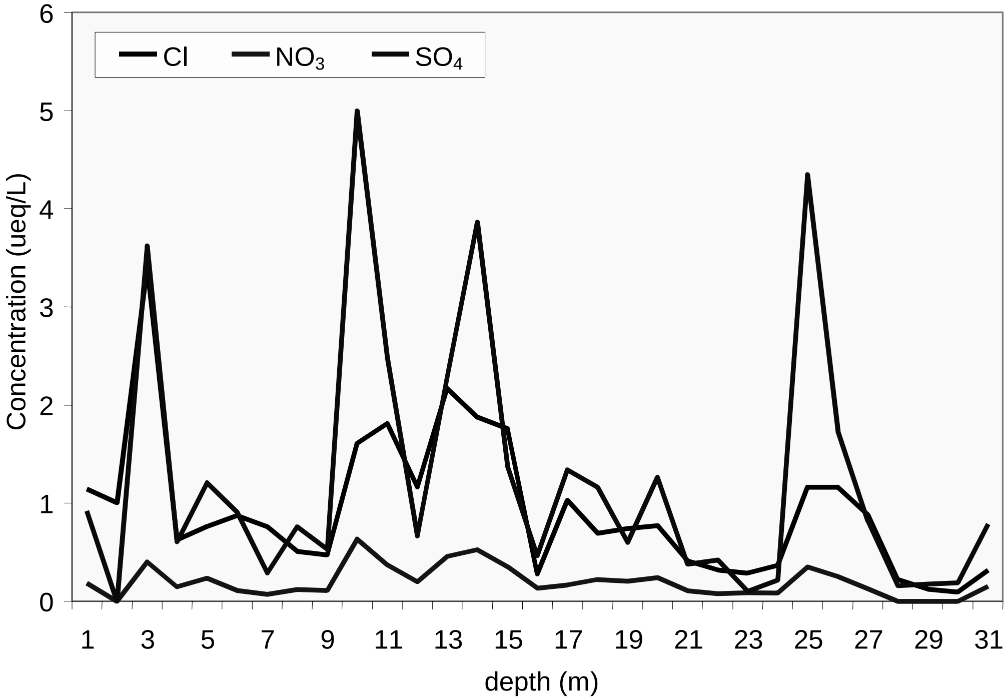

Figure 10. Anion analysis from 950 masl.

8. CONCLUDING REMARKS

Reconstruction of the recent mass balance history of John Evans Glacier, through identification of known age marker horizons and annual layer detection from electrical conductivity profiling, density measurements, and various physical and chemical analyses of shallow ice cores, offers the possibility to extend Arctic mass balance history. Analysis of shallow ice cores demonstrates the feasibility of a cost-effective, non-time consuming (compared to stake-derived mass balance), and field-obtainable method to reconstruct the recent mass balance of high Arctic glaciers. The two ice cores used in this study demonstrate the feasibility of using shallow ice cores from high Arctic glaciers, especially from areas well above the equilibrium line.

REFERENCES

Dunphy PP, Dibb JE, Chupp EL, 1994. A gamma-ray detector for in-situ measurements of ^{137}Cs radioactivity in snowfields and glaciers. *Nuclear Instruments and Methods in Physics Research* **A353**: 482–485.

Koerner RM, 1979. Accumulation, ablation, and oxygen isotope variations on the Queen Elizabeth Islands Ice Caps, Canada. *Journal of Glaciology* **22**: 25–41.

Pinglot JF, Pourchet M, 1995. Radioactivity measurements applied to glaciers and lake sediments. *The Science of the Total Environment* **173/174**: 211–223.

Pinglot JF, Pourchet M, 1981. Gamma-ray bore-hole logging for determining radioactive fallout layers in snow. *International Atomic Energy Agency, Vienna.*

Taylor K *et al*., 1992. Ice-core dating and chemistry by direct-current electrical conductivity, *Journal of* Glaciology **38**: 325–332.

Wilhelms F, 1996. Measuring the conductivity and density of ice cores. *Reports on Polar Research* **191**, from the Alfred Wegener Institute for Polar and Marine Research, Germany [ISSN 0176-5027].