

A new deep ice core from Akademii Nauk ice cap, Severnaya Zemlya, Eurasian Arctic: first results

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ABSTRACT. The paper presents first results from the upper 54 m of a 723.91 m ice core drilled on Akademii Nauk ice cap, Severnaya Zemlya, Eurasian Arctic, in 1999–2001, supplemented by data from shallow ice cores. The glacier's peculiarity is the infiltration and refreezing of meltwater, which changes the original isotopic and chemical signals. Therefore, stratigraphical observations in these ice cores are more difficult than in those from central Greenland or Antarctica. However, the 1963 maximum of artificial radioactivity from atmospheric nuclear tests is clearly detectable in the deep ice core, and the $\delta^{18}\text{O}$ profile of a 12.82 m shallow core shows annual variations. Consequently, at least for the upper part of the main core, an almost seasonal time resolution of palaeoclimate record could be expected. The Chernobyl layer is detected by increased ^{137}Cs activity at depths of 11.81–12.51 m related to the AD 2000 surface. The resulting mean annual net mass balance is $53 \pm 2 \text{ g cm}^{-2} \text{ a}^{-1}$. Data from dielectric profiling of the main core show considerable peaks in conductivity; one of them is interpreted as a volcano event. According to the resulting chronology, this part of the core represents approximately the last 100 years.

INTRODUCTION

In the Eurasian Arctic, Severnaya Zemlya is the most eastern archipelago that is covered by a considerable ice cap. Akademii Nauk ice cap on Komsomolets island is the thickest and coldest on Severnaya Zemlya. Some earlier ice-core studies show that a continuous climate record covering the whole Holocene period could only be obtained on Severnaya Zemlya from this ice cap (Klement'yev and others, 1991). In 1986/87 the first and only ice core (761 m) was drilled to bedrock on Akademii Nauk ice cap (Klement'yev and others, 1988; Savatyugin and Zagorodnov, 1988). Investigations were carried out on this core with relatively low data resolution, and the potential of time resolution of the proxy data was uncertain. For this reason, a new ice-core drilling was started in May 1999 as a joint project of the Alfred Wegener Institute, Germany, the Arctic and Antarctic Research Institute, Russia, and the Mining Institute, Russia. The device used is the KEMS electromechanical ice-core drill, the same type used at Vostok station, Antarctica. A suitable drilling site was found at $80^{\circ}31' \text{N}$, $94^{\circ}49' \text{E}$ (Fig. 1) with the help of airborne radio-echo sounding data and synthetic aperture radar interferometry studies (Dowdeswell, 1999). The radar-measured ice thickness is approximately 720 m in this location. In 1999, the first 53.95 m of core were drilled, in 2000 the project was continued to 504.77 m, and in 2001 the drill reached the moraine at 723.91 m depth. A temperature of -10.2°C was measured in April 2000 at 10 m depth.

^{137}Cs AND ^{210}Pb RADIOACTIVITY

Analyses of ^{137}Cs and ^{210}Pb radioactivity have been carried out by Pinglot on samples of chips from the cutters retrieved from each run of the first 54 m of the 1999 drilling (weight 1–2 kg). In April 2000 a 13.83 m shallow core (SZ 2000-1) was drilled for determination of the radioactivity at a higher depth resolution. The samples for the radioactivity measurement were melted. After chemical preparation, the meltwater was filtered through ion exchange filters. Each filter sample was analyzed by low-level γ -spectrometry. Final values of the radioactivity were calibrated using international standards. Details of the technique were published in Pinglot and Pourchet (1995).

The maximum in ^{137}Cs activity occurred in 1963 and corresponds to the maximum rate of deposition from the atmospheric nuclear test series conducted in 1961 and 1962. The absolute maximum is found at a depth of 21.36–22.68 m related to the 1999 surface (Fig. 2a). It corresponds with a deposition rate of 420 Bq m^{-2} , which is slightly higher than the mean value from Svalbard glaciers. In the shallow core SZ 2000-1 the only occurrence of ^{137}Cs is at depths of 11.81–12.51 m related to the AD 2000 surface which corresponds with a deposition of about 1 Bq m^{-2} (Fig. 2b). Presumably this signal is caused by the Chernobyl accident on 26 April 1986. The mean annual net mass balance is calculated to $53 \pm 2 \text{ g cm}^{-2} \text{ a}^{-1}$ following this assumption. This is in good agreement with the value of about $45 \text{ g cm}^{-2} \text{ a}^{-1}$ calculated from the 1963 layer (Fig. 2a)

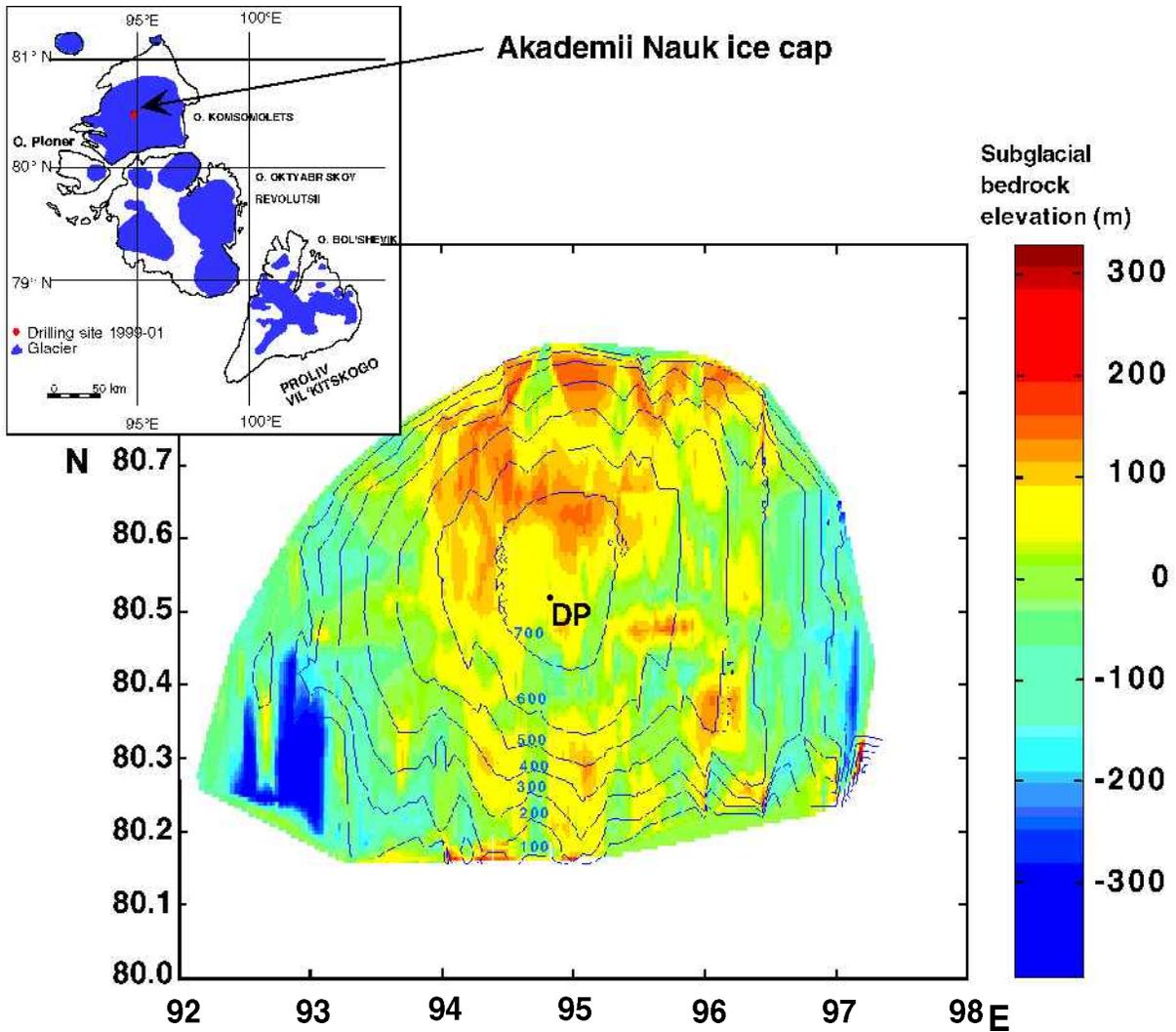


Fig. 1. Map of Akademii Nauk ice cap with surface and subglacial bedrock elevation and drilling site DP (ice thickness after Dowdeswell, 1999).

taking into account the low resolution of chip samples only taken from each run. Both values correspond to the annual mass balance visible in the $\delta^{18}\text{O}$ profile (Fig. 3).

The activity of the natural radioisotope ^{210}Pb (22 year half-life) is almost stable from the surface down to about 30 m. Then the activity decreases. This could indicate a decreasing trend of the ^{210}Pb flux over the last 100 years, also found in Greenland (Dibb and Clausen, 1997). At depths of 25.47–26.75 m, there is a high level of ^{210}Pb activity. This is the same depth at which a significant peak is found in the electrical conductivity profile, assumed to be caused by a volcanic event. The increased ^{210}Pb radioactivity may be related to increased dust indicated by increased ion content found in this horizon (personal communication from K. Weiler, 2001). Another possible interpretation is that due to summer melting the ^{210}Pb particles migrate to deeper firn layers and are stopped there by an ice layer, leading to an enrichment of ^{210}Pb in these layers.

ELECTRICAL CONDUCTIVITY (DEP)

The main core and all shallow cores drilled within the project on Severnaya Zemlya are analyzed by non-destructive methods. For profiling density and dielectric properties a

combined analyses bench developed by Wilhelms is used (Wilhelms, 2000). The optical transparency is measured by a line-scan camera system giving the possibility for a quantitative detection of melt-ice percentage found to be 40–50% in the top part of the core.

Data of electrical conductivity (dielectrical profiling (DEP)) determined in the upper 54 m of the main core are shown in Figure 4. The preliminary time-scale given here is made using the horizon of ^{137}Cs activity, which is taken as the year 1963 (marked in Fig. 4). The time-scale is calculated with a mean annual net mass balance of $50\text{ g cm}^{-2}\text{ a}^{-1}$ for lower parts of the core. The most significant peak in the electrical conductivity record is found at depths of 25.65–25.94 m. We assume that it is caused by the eruption of the Bezymianny volcano, Kamchatka, on 30 March 1956, which at this time was the only one with a volcanic explosivity index (VEI) of 5 (Newhall and Self, 1982). This interpretation corresponds with our suggested time-scale. On the other hand, the VEI 6 eruption of Katmai, Alaska, on 6 June 1911 is not clearly visible in the record. Percolation effects can possibly produce high levels of electrical conductivity. Detailed chemical investigations will be carried out in core sections with increased electrical conductivity.

Severnaya Zemlya 1999

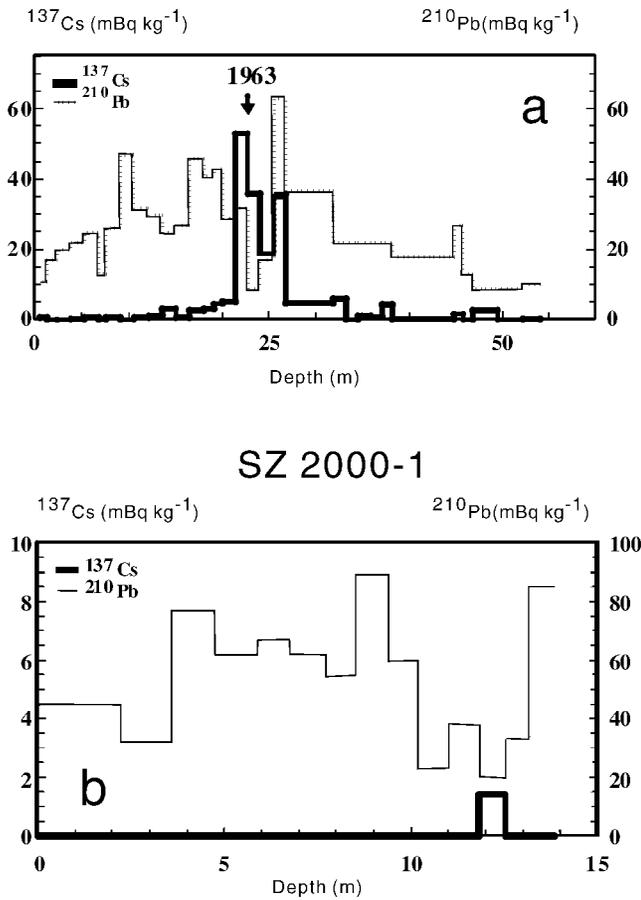


Fig. 2. Profiles of ^{137}Cs and ^{210}Pb activity on samples of chips from main drill (a) and of the shallow core SZ 2000-1 drilled in April 2000 (b).

STABLE ISOTOPES

Analyses of δD and $\delta^{18}\text{O}$ are made for the shallow core SZ 99-2 drilled in May 1999 near the main drilling site. The $\delta^{18}\text{O}$ profile is plotted vs depth in m.w.e. calculated using the gamma density profile of the core (Fig. 3). The annual net mass balance is readable directly in this representation if seasonal signals can be obtained. In case signatures are eroded by percolation and refreezing, the number of missing years can be estimated by assuming a mean annual net mass balance as we did for 1994 and 1995. The marked horizon refers to the respective layer with the increased ^{137}Cs activity in shallow core SZ 2000-1, taking into account the accumulation of 1999/2000. The age–depth relation in the $\delta^{18}\text{O}$ data is in good agreement with the result of the ^{137}Cs activity measurement. The isotope pattern is smoothed by infiltration water, but the winter minimum is preserved in almost every year.

CONCLUSIONS

The accumulation zone of Akademii Nauk ice cap is characterized by processes of summer melting. However, the $\delta^{18}\text{O}$ record of a shallow core shows clear seasonal signals almost every year, and horizons with artificial radioactivity are detectable. Thus the climate signal could be retained with almost yearly resolution, at least for the upper part of the core. The development of time-scales seems to be possi-

SZ 99-2

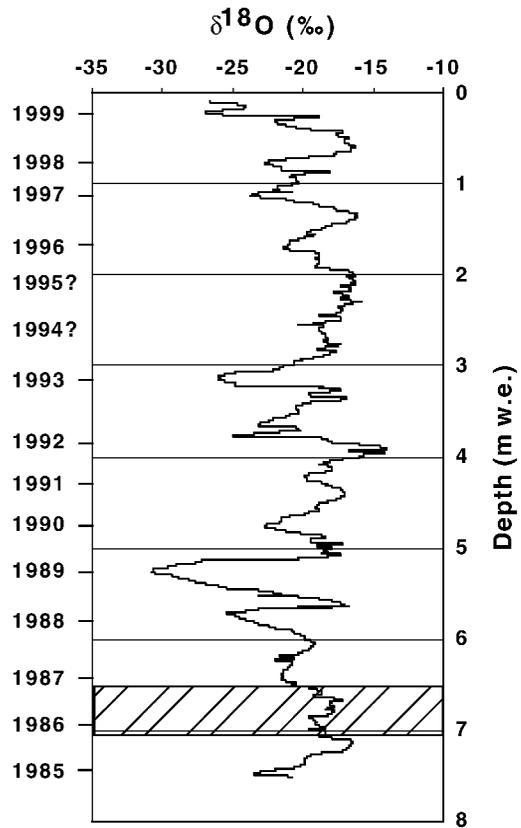


Fig. 3. $\delta^{18}\text{O}$ profile of the shallow core SZ 99-2. The marked horizon refers to the actual measured layer with increased ^{137}Cs activity in shallow core SZ 2000-1 (Fig. 2b).

Severnaya Zemlya 1999

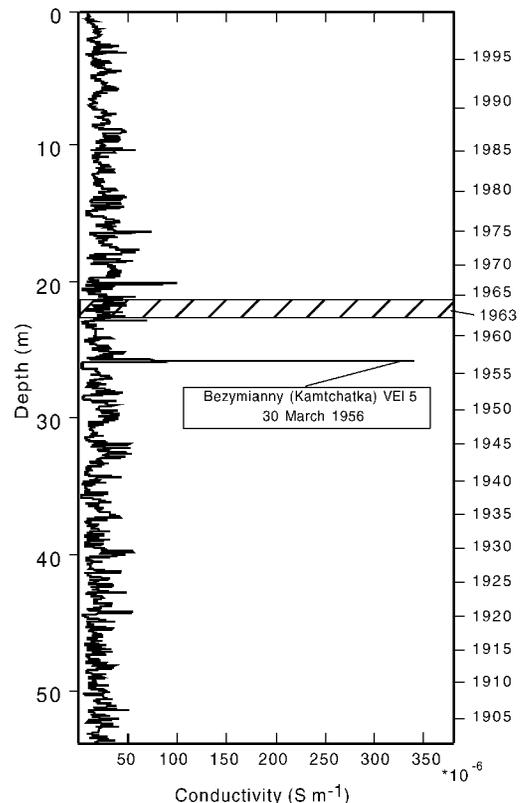


Fig. 4. Electrical conductivity (DEP) record with preliminary time-scale.

ble using isotope signatures and time markers like radioactive and volcanic tracers. Compared with other Arctic glacial areas of high melt (Koerner, 1997) the situation for paleoclimatic reconstructions seems to be promising.

The recent mean annual net mass balance is about $50 \text{ g cm}^{-2} \text{ a}^{-1}$ in the central area of the Akademii Nauk ice cap. This value comes from isotope stratigraphy and from the increased ^{137}Cs radioactivity from atmospheric nuclear tests and the Chernobyl disaster. It is in the order of the mean annual net mass balance of $43\text{--}44 \text{ g cm}^{-2} \text{ a}^{-1}$ observed by Zagorodnov with structural-stratigraphic methods for Akademii Nauk ice cap (Zagorodnov and others, 1990).

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REFERENCES

- Dibb, J. E. and H. B. Clausen. 1997. A 200 year ^{210}Pb record from Greenland. *J. Geophys. Res.*, **102**(D4), 4325–4332.
- Dowdeswell, J. A. 1999. *Airborne geophysical investigations of the ice caps on Severnaya Zemlya, Russian High Arctic*. Bristol, University of Bristol. Bristol Glaciology Centre. (Report 99-01)
- Klement'yev, O. L., I. M. Korotkov and V. I. Nikolayev. 1988. Glyatsiologicheskiye issledovaniya v 1987–1988 gg. na lednikovakh kupolakh Severnoy Zemli [Glaciological studies on the ice domes of Severnaya Zemlya in 1987–1988]. *Mater. Glyatsiol. Issled.* 63, 25–26.
- Klement'yev, O. L., V. Yu. Potapenko, L. M. Savatyugin and V. I. Nikolaev. 1991. Studies of the internal structure and thermal-hydrodynamic state of the Vavilov glacier, Archipelago Severnaya Zemlya. *International Association of Hydrological Sciences Publication 208* (Symposium at St. Petersburg 1990 — *Glaciers–Ocean–Atmosphere Interactions*), 49–59.
- Koerner, R. M. 1997. Some comments on climatic reconstructions from ice cores drilled in areas of high melt. *J. Glaciol.*, **43**(143), 90–97. (Erratum: **43**(144), p. 375–376)
- Newhall, C. G. and S. Self. 1982. The volcanic explosivity index (VEI): an estimate of explosive magnitude for historical volcanism. *J. Geophys. Res.*, **87**(C2), 1231–1238.
- Pinglot, J. F. and M. Pourchet. 1995. Radioactivity measurements applied to glaciers and lake sediments. *Sci. Total Environ.*, **173–174**(1), 211–223.
- Savatyugin, A. M. and V. S. Zagorodnov. 1988. Glyatsiologicheskiye issledovaniya na lednikovom kupole Akademii Nauk [Glaciological studies on the Academy of Sciences ice cap]. *Mater. Glyatsiol. Issled.* 61, 228.
- Wilhelms, F. 2000. Messung dielektrischer Eigenschaften polarer Eiskerne. *Ber. Polarforsch./Rep. Pol. Res.* 367, 1–171.
- Zagorodnov, V. S., O. L. Klementyev, N. N. Nikiforov, V. I. Nikolaev, L. M. Savatyugin and V. A. Sasunkevich. 1990. Gidrotermicheskiy rezhim i l'dobrazovaniye v tsentral'noy chasti lednika Akademii Nauk na Severnoy Zemle [Hydrothermal regime and ice formation in the central part of the Akademiya Nauk glacier, Severnaya Zemlya]. *Mater. Glyatsiol. Issled.* 70, 36–43.