Name of research institute or organization:

Labor für Radio- und Umweltchemie der Universität Bern und des Paul Scherrer Insituts

Title of project:

VITA Varves, Ice cores, and Tree rings – Archives with annual resolution

Project leader and team

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Project description:

VITA (Varves, Ice cores and Tree rings – Archives with annual resolution), the subprogram of the National Center of Competence in Research on Climate (NCCR Climate) aims to compare proxy climate records obtained from trees, lakes, peat bogs and glaciers (http://www.nccr-climate.unibe.ch/). Within VITA, one of the main interest deals with the question if the archives can be used as proxies for temperature. If yes, with what resolution (annual, seasonal or even sub-seasonal)? How good are the records and do they reflect extreme events? And finally, how do the different proxies compare? The site selected for ice coring was the Fiescherhorn glacier in the Berner Oberland (FH, Swiss Alps, 46°33'3.2''N, 08°04'0.4''E; 3900 m asl.). The top 108 m have been analyzed for δD with increasing resolution for increasing depth to compensate for layer thinning. The obtained record led to a more accurate dating for this part of the core compared to the one based only on the concentrations of ammonium and calcium. The time period covered by this 108 m (out of 150 m) is 1939-2002 with an uncertainty of ±1 year.

In ice cores from cold glaciers like the FH δD and $\delta^{18}O$ data can contain information about atmospheric temperature and the behavior pattern of the water cycle. However, there are factors such as strong seasonality in precipitation, wind erosion and sublimation which may complicate the interpretation. More detailed information about stable isotopes in water can be found elsewhere and will not be discussed here (Schotterer et al., 1995; Stichler and Schotterer, 2000). In this work, we focus on δD.

In a first attempt FH02 δD annual averages were compared with instrumental temperature data from the nearby Jungfraujoch (JFJ) meteo station for the years 1939 to 2002 (Fig. 1). The correlation of the two data sets is very low (r^2=0.18). Because of the ±1 year dating error, a simple correlation analysis is probably not a good measure to obtain information about the quality of the record. In addition, there are obvious outliers (e.g. 1948). Such outliers could be due to problems during sample preparation or analysis but they could also reflect a change in the seasonal distribution of precipitation, loss of snow by melting or strong winds etc. (Schotterer et al., 1997). For the time period presented here, we would be able to improve the correlation by calibrating our record through re-dating and exclusion of outliers. However, if we go further back in the record and time we will lose this possibility due to the lack of instrumental data. Therefore, in a first step we focus on long term trends.

First, a correction of the δD values for the 320 m altitude difference between the two sites (FH: 3900 m asl.; JFJ 3580 m asl.) was made, using a value of 11.6 ‰ per 100 m. This corresponds to a value of 0.2 ‰ per 100 m in $\delta^{18}O$ (Schotterer et al., 1995; Schotterer et al., 1997). The relationship between δD and $\delta^{18}O$ is described by the following equation: $\delta D = 8 \times \delta^{18}O + 10$ ‰ (Dansgaard, 1964). Using the two datasets a δD/temperature relationship of 13.66 ‰ per °C was obtained, corresponding to a value of 0.46 ‰ per °C in $\delta^{18}O$ which is slightly lower than the 0.5 to 1 ‰ per °C presented in other studies (Schotterer et al., 1997; Rozanski et al., 1993). A similar value of 0.43 ‰ per °C in $\delta^{18}O$ resulted for the much better correlated period 1963-1969 (r^2=0.57, see Fig. 1). The measured long-term warming from 1939 to 2002 of 0.92 °C at JFJ agrees well with the calculated 0.72 °C from the FH02 record even though yearly averages do not correlate.

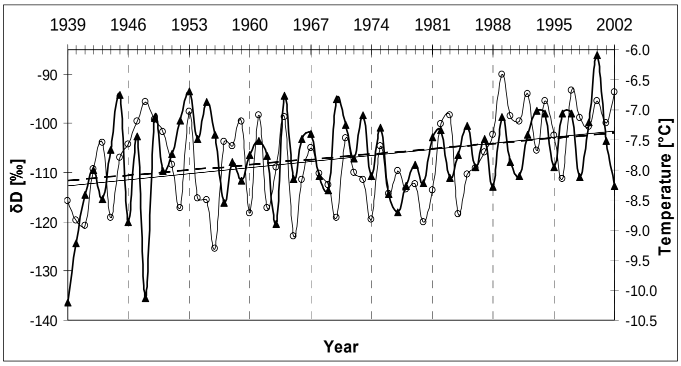

Fig. 1: Annual averages of the FH02 δD record corrected for altitude (thick line, triangles) compared to annual temperatures measured at JFJ (thin line, circles) for 1939-2002. Trends are shown by linear regressions (FH: dashed line; JFJ: solid line).

Almost all glaciers in mid- and low-latitude regions are disappearing rapidly (IPCC, 2001). Consequently these valuable glacier archives of past climate and environmental history are at risk. The European summer heat wave 2003 (Schär et al., 2004) offered the opportunity to study the effects of increased air temperatures and absence of summer precipitation on the glaciochemical record of the Fiescherhorn glacier, where a bedrock core was obtained in December 2002 (see above). The maximum firn temperature at this glacier is only -2°C, and melt water percolation events have been observed already in the 2002 core as well as in previous cores (Palmer et al., submitted). The extreme summer 2003 can therefore be regarded as model case for future scenarios of elevated temperatures.

A 14 m shallow core (FH04) was recovered on 28 and 29 May 2004 from a site close to where the bedrock core was drilled in 2002 (FH02). The upper 4 m of the shallow core consisted of low-density dry firn without ice lenses and was attributed to winter precipitation deposited after the summer 2003. Only the lowermost 10 m of compact firn with a few ice lenses were analysed in this work. The core segments were sampled with 6-7 cm resolution. Concentrations of major ions were determined using standard ion chromatography and $\delta^{18}O$ was analysed by stable isotope ratio mass spectrometry.

The overlap between the FH04 and FH02 was identified using the $\delta^{18}O$ profiles (Fig. 2), indicating that FH04 covers the period summer of 2000 to beginning of 2003, i.e. 2.5 years of accumulation (6 m weq). The annual accumulation deduced from FH04 is slightly lower, probably due to removal by melt water (Tab. 1).

Since precipitation amounts during that summer were essentially zero, no direct signal of the extreme temperatures was recorded in the Fiescherhorn glacier. However, the high air temperatures induced melting of the snow surface and percolation of the melt water through the upper firn layer. This resulted in a significant downward movement of ionic species, as illustrated by comparing the accumulated fluxes of SO_4^{2-} from the FH04 core and the corresponding FH02 core section (Fig. 3). From the originally deposited 2.69 µeq. cm^{-2} SO_4^{2-}, 79% was moved to deeper firn layers by melt water percolation. The melt water percolation caused a fractionation of the investigated ions, since they were affected differently (Tab. 2). Cl^-, NH_4^+, $HCOO^-$, and NO_3^- where not or much less influenced than Na^+, SO_4^{2-}, Ca^{2+}, and Mg^{2+}. This elution sequence is in agreement with earlier results from Grenzgletscher (Eichler et al., 2001). Such an extreme event can thus destroy the ion signature of several years. Obviously the enriched melt water was not stopped by re-freezing in the 10 m firn layer studied here. It is therefore unclear whether the firn temperatures were too high to stop the melt water somewhere in the entire firn layer or whether drainage at the firn-ice transition at ~44 m depth occurred. The $\delta^{18}O$ record, as matrix parameter, was essentially unaffected, except for the spring 2003 accumulation which seems to be lost by melting.

Tab. 1: Accumulation in m water equivalent (weq).

Year	FH02	FH04
	m weq.	
2002	2.71	1.97
2001	2.54	2.47

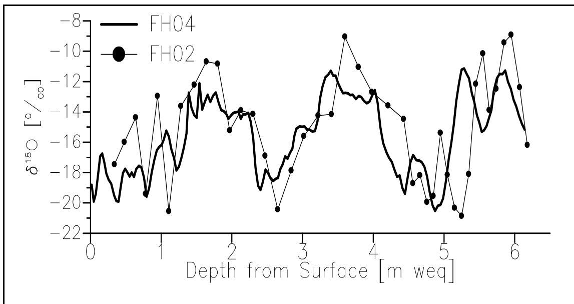

Fig. 2: $\delta^{18}O$ profiles of the FH04 and FH02 cores.

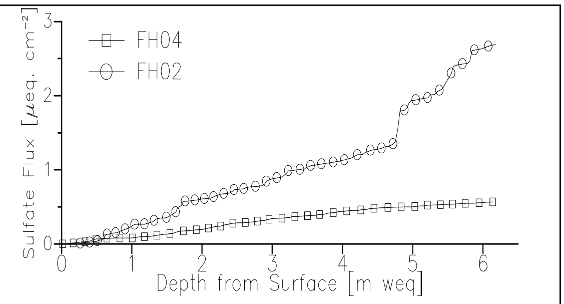

Fig. 3: Accumulated SO_4^{2-} fluxes.

Tab. 2: Accumulated fluxes of ions in the FH04 and FH02 cores and the amount removed by melt water (%).

Core	**Cl^-**	**NH_4^+**	**$HCOO^-$**	**NO_3^-**	**Na^+**	**SO_4^{2-}**	**Ca^{2+}**	**Mg^{2+}**
	µeq. cm^{-2}							
FH04	0.49	1.96	0.46	1.52	0.14	0.57	0.63	0.08
FH02	0.49	2.67	0.65	2.42	0.41	2.69	3.15	0.41
% removed	0%	27%	29%	37%	66%	79%	80%	81%

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References

Eichler, A., et al., Tellus **53B**, 192 (2001).
IPCC, The Scientific Basis, Cambridge University Press, p. 129 (2001).
Schär, Ch. et al., Nature **427**, 332 (2004).
Schotterer, U. et al., Gas Wasser Abwasser **9,** (1995).
Stichler, W. and U. Schotterer, Hydrol. Process. **14**, 1423 (2000).
Schotterer, U. et al., Climatic Change **36,** 519 (1997).
Dansgaard, W., Tellus **16**, 436 (1964).
Rozanski et al., Geophys. Monograph **78**, 1 (1993).

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Climate reconstruction, high-alpine

Internet data bases:

http://lch.web.psi.ch/
http://www.nccr-climate.unibe.ch/

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Scientific publications and public outreach 2004:

Refereed journal articles

Barbante, C., M. Schwikowski, T. Döring, H.W. Gäggeler, U. Schotterer, L. Tobler, K. Van de Velde, C. Ferrari, G. Cozzi, A. Turetta, K. Rosman, M. Bolshov, G. Capodaglio, P. Cescon, C. Boutron, Historical record of European emissions of heavy metals to the atmosphere since the 1650s from an Alpine snow/ice core drilled near Monte Rosa, Environ. Sci. Technol. 38, 4085-4090 (2004).

Collaud Coen, M., E. Weingartner, D. Schaub, C. Hueglin, C. Corrigan, S. Henning, M. Schwikowski, U. Baltensperger, Saharan dust events at the Jungfraujoch: detection by wavelength dependence of the single scattering albedo and first climatology analysis, Atmos. Chem. Phys. **4**, 1–16 (2004).

Eichler, A., M. Schwikowski, M. Furger, U. Schotterer, H.W. Gäggeler, Sources and distribution of trace species in Alpine precipitation inferred from two 60-year ice core paleorecords, Atmos. Chem. Phys. Discuss., 4, 71-108, (2004).

Olivier, S., K. Fifield, H.W. Gäggeler, P. Santschi, M. Schwikowski, U. Schotterer, L. Wacker, S. Bajo, T. Papina, Plutonium from global fallout recorded in an ice core from the Belukha Glacier, Siberian Altai, Environ. Sci. Technol. 38, 6507-6512 (2004).

Priller, A., M. Berger, H.W. Gäggeler, E. Gerasopoulos, P.W. Kubik, Ch. Schnabel, L. Tobler, E.-M. Wild, P. Zanis, Ch. Zerefos, Accelerator mass spectrometry of particle-bound ^{10}Be, Nuclear Instruments and Methods in Physics Research B 223–224, 601-607 (2004).

Schwikowski, M., C. Barbante, T. Döring, H.W. Gäggeler, C. Boutron, U. Schotterer, L. Tobler, K. Van de Velde, C. Ferrari, G. Cozzi, K. Rosman, P. Cescon, Post-17th-century changes of European lead emissions recorded in high-altitude Alpine snow and ice, Environ. Sci. Technol. 38, 957-964 (2004).

Tositti, L., S. Hübner, H.J. Kanter, W. Ringer, S. Sandrini, L. Tobler, Intercomparison of sampling and measurements of ^{7}Be in air at four high-altitude locations in Europe, Appl. Radiat. Isot. 61, 1497-1502 (2004).

Book sections

Schwikowski, M., Reconstruction of European air pollution from Alpine ice cores. In: Earth Paleoenvironments: Records preserved in Mid- and Low-Latitude Glaciers, Eds. L.D. Cecil, J.R. Green, and L.G. Thompson, Kluwer Academic Publishers, Dordrecht, pp. 95-119 (2004).

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