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COMPARISON OF THE ^{2}H AND ^{18}O CONTENT OF ICE CORES FROM A TEMPERATE ALPINE GLACIER (VERNAGTFERNER, AUSTRIA) WITH CLIMATIC DATA

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With 2 figures

SUMMARY

Ice core drilling was performed on Vernagtferner, a temperate Alpine glacier in the Ötztal Alps, Austria, down to a depth of 81 m, close to the glacier bed. The cores were dated using ^{18}O and ^{2}H measurements as well as the computed deuterium excess, supported by ^{3}H measurements and stratigraphical features. In particular the deuterium excess showed pronounced annual variations. For the 81 m deep core an age of 80 ± 5 years was obtained, equivalent to a mean net accumulation of about 0.80 m water per year. The 5-year running means of the annual accumulation rates were compared with the precipitation data from the nearby meteorological station Vent back to the beginning of this century. To find a correlation between the isotope content of these annual layers and the climate, the ^{18}O and ^{2}H contents were compared with 5-year running temperature means (winter, summer, annual means) of Vent. The calculated ages of the core sections with enriched ^{18}O and ^{2}H contents coincide with a time shift of 4—5 years with the warm period occuring during the late fourties of this century.

VERGLEICH DES ^{2}H- UND ^{18}O-GEHALTES VON EISKERNEN EINES TEMPERIERTEN ALPENGLETSCHERS (VERNAGTFERNER) MIT KLIMADATEN

ZUSAMMENFASSUNG

Auf dem Vernagtferner, einem temperierten, alpinen Gletscher in der Ötztaler Alpen, Österreich, wurden Kernbohrungen bis nahe an das Gletscherbett niedergebracht. Die Eiskerne wurden aufgrund ihres ^{2}H- und ^{18}O-Gehalts sowie des daraus berechneten Deuteriumexzesses, unterstützt durch Messungen des ^{3}H-Gehaltes und durch stratigraphische Merkmale, datiert. Besonders deutlich ausgeprägte jahreszeitliche Schwankungen zeigte der Deuteriumexzeß. Für den 81 m langen Kern wurde ein Alter von 80 ± 5 Jahren bestimmt und daraus eine mittlere jährliche Nettoakkumulation für diesen Zeitraum von 0,80 m Wasseräquivalent berechnet. Die Niederschlagssummen seit der Jahrhundertwende, gemessen an der 8 km entfernten Klimastation Vent, sind in ihrem Verlauf mit den berechneten Akkumulationswerten vergleichbar. Die beste Übereinstimmung ergab sich dabei mit den 5jährigen übergreifenden Mittelwerten der Summe des Winterniederschlags für die Zeit nach 1940. Der Isotopengehalt der angenommenen Jahresschichten wurde mit 5jährigen übergreifenden Temperaturmittelwerten (Winter-, Sommer- und Jahresmittel) der Klimastation Vent verglichen. Dabei ergibt sich, daß die in ihrem ^{2}H- und ^{18}O-Gehalt deutlich erhöhten Kernabschnitte 4—5 Jahre vor dem wärmsten Abschnitt der späten vierziger Jahre dieses Jahrhunderts liegen.

1. INTRODUCTION

Since 1973, a glaciological and hydrological program has been carried out at the Vernagtferner in the Ötztal Alps (Austria). In March 1979 in cooperation with the Physical Institute of the University of Berne (Switzerland) ice core drilling was performed on the Vernagtferner (Oerter et al., 1982). The drilling site was situated approximately at 3150 m a. s. l. in the accumulation area of Vernagtferner, and the bottom of the deepest, 81.35 m long core was close to the glacier bed. This core was cut into sections of 2.5 m length, from which measurements of the ^2H and ^{18}O content (Stichler et al. 1982) as well as of the ^3H content (Oerter and Rauert 1982) were made. Additional measurements of ^{210}Pb content were carried out (v. Gunten et al. 1982). Moreover gamma-ray logging (Drost and Hofreiter 1982) was done in the field to check the core dating.

2. DATING OF THE ICE CORE AND ACCUMULATION RATES

The results of the ^2H and ^{18}O measurements are given by Stichler et al. (1982, fig. 3 and 4), who demonstrate that annual variations of the isotope content, and especially of the deuterium excess $d = 8\,\delta^{18}O - \delta^2H$, remain still well recognizable. They also discuss the variations of the deuterium excess due to evaporation and melting processes in a snow cover. Thus, counting the maxima of the isotope content yields the number of summer snow layers and in addition the amount of the yearly accumulation snow and ice. In this way the age of the core was determined to be between 83 and 75 years, which means that the oldest layer at the bottom was deposited at the turn of the century, between the years 1895 and 1903. Generally, this age is in good agreement with the date calculated by v. Gunten et al. (1982) with the aid of the lead-210 method. The proposed depth for the year 1963 is in accordance with the depth of the maximum ^3H content (Oerter and Rauert 1982).

On the basis of the yearly firn and ice layers the single annual accumulation rates for the time period 1896 to 1977 were calculated (fig. 1 b). The mean annual accumulation rate, calculated over the whole core, amounts to 0.76 m water equivalent (w. e.), while for 1931—1960 it was only 0.71 m w. e. The 5-year running mean values show a trend from higher accumulation rates at the beginning of the century to lower values in the younger, upper layers. Surely this is not only an effect of climate, but to a certain extent also of glacier movement. But the slope of the glacier surface in the surroundings of the drilling site is small, and nowadays the velocity does not exceed 5 m/a. So one can assume that even in greater depths the flow lines remain parallel to the ground. It further seems that the maxima of the calculated accumulation rates around the years 1900 and 1920 occur, after our time scale, several years late, compared to the glacier advances observed in that period (Patzelt 1970).

3. COMPARISON OF THE ICE CORE WITH CLIMATIC DATA

3.1 PRECIPITATION AND ANNUAL ACCUMULATION

Climatic data are available for the meteorological station Vent (1906 m a. s. l., approx. 8 km away from Vernagtferner), precipitation data back to the year 1890

(Lauffer 1966, Kuhn et al. 1979). Although no simple correlation between the amount of precipitation and the mass balance of a glacier exists, the amount of accumulated firn should be influenced by the amount of precipitation, either winter or summer or total annual precipitation. Therefore the single annual accumulation rates for the time period 1896—1977 (fig. 1 b) were compared with the annual sums of winter (October—April) and summer (May—September) precipitation (fig. 1 a) as well as the 5-year running means of the same data, where the comparison of the winter precipitation and the accumulated firn (fig. 1 c, table 1) yielded the best agreement.

Table 1: Matrix of the correlation coefficients yielded by the comparison of ice core data with meteorological data (fig. 1, 2) of different time periods. The table shows only the correlation coefficients for the 5-year running means, because none of the coefficients for the single annual values exceeds 0.4. The ^{2}H content and the deuterium excess d, respectively, are compared without a time shift against the temperature ($^{2}H(O)$, d(O), fig. 2 d) and with time shifts of 3, 4 and 5 years
A: layer thickness, annual accumulation, respectively; P: precipitation; T: air temperature
indexes: w: winter (October—April), s: summer (May—September), a: annual (October—September)

		A			
P_w	1898—1975	0.50			
	1945—1975	0.80			
P_s	1898—1975	−0.01			
	1945—1975	−0.10			
P_a	1898—1975	0.43			
	1945—1975	0.49			
		$^{2}H(O)$	$^{2}H(-3)$	$^{2}H(-4)$	$^{2}H(-5)$
T_w	1898—1975	0.20	0.38	0.40	0.42
	1940—1975	0.23	0.56	0.60	0.60
T_s	1898—1975	0.58	0.66	0.65	0.62
	1940—1975	0.67	0.85	0.83	0.78
T_a	1898—1975	0.42	0.58	0.60	0.61
	1940—1975	0.43	0.71	0.77	0.76
		d(0)	d(−3)	d(−4)	d(−5)
T_w	1898—1975	0	−0.38	−0.48	−0.52
	1940—1975	0.29	−0.42	−0.62	−0.71
T_s	1898—1975	−0.26	−0.56	−0.62	−0.65
	1940—1975	−0.08	−0.68	−0.76	−0.78
T_a	1898—1975	−0.09	−0.51	−0.62	−0.69
	1940—1975	0.19	−0.51	−0.69	−0.79

It can be seen in fig. 1 that in the years 1943—1977 the 5-year running means of the precipitation and the curve of accumulation firn coincide well, if the values are suitably scaled. The maximum of the accumulated firn follows the maximum of winter precipitation in 1918 with a delay on only two years. In the years 1920—1932 the

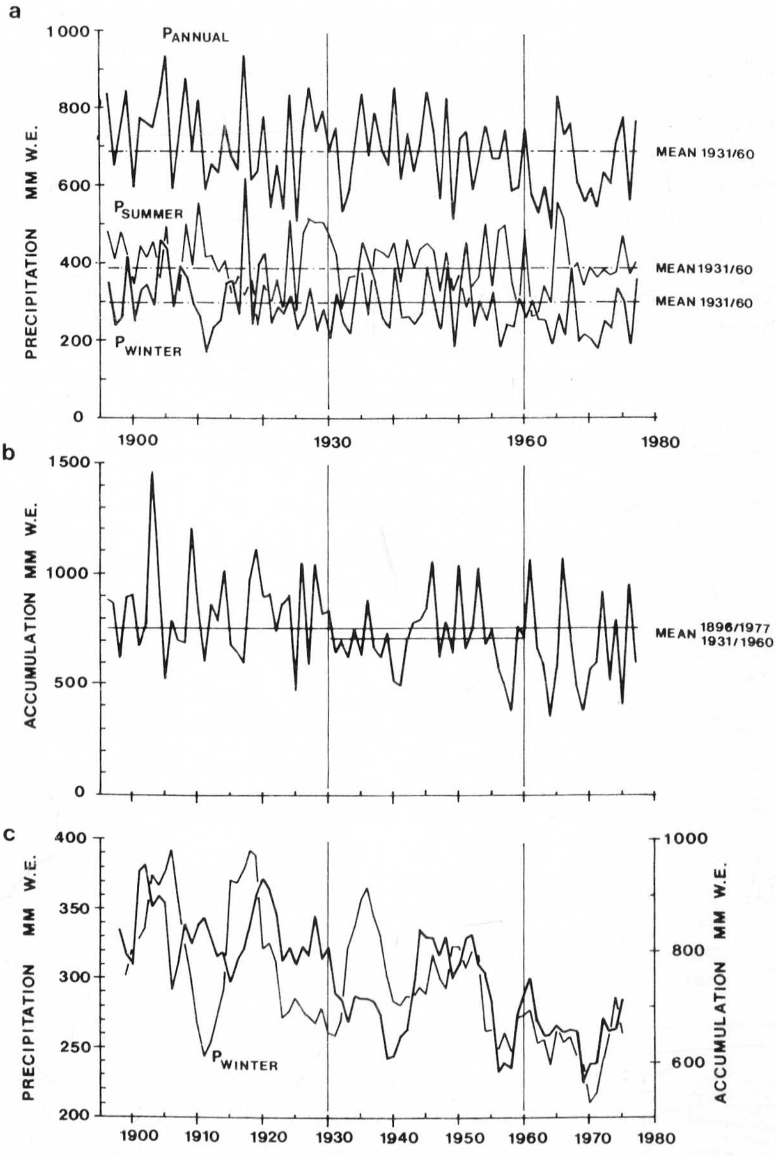

Fig. 1: Ice core Vernagtferner (Ötztal Alps, Austria) of 1979
a) Yearly means of winter (October—April), summer (May—September) and annual precipitation, measured at the meteorological station Vent (Ötztal Alps) (Lauffer 1966, Kuhn et al. 1979)
b) Yearly accumulation rates calculated from the ice core. The ice core was dated mainly by means of the ^{2}H and ^{18}O content (Stichler et al. 1982)
c) Comparison of the 5-year running means of winter precipitation at the meteorological station Vent (fig. 1 a) and the 5-year running means of the yearly accumulation rates as derived from the ice core

amount of accumulated firn exceeds the comparable winter precipitation while from 1932 to 1942 the winter precipitation becomes greater.

The relatively high accumulation rate of the firn layers of 1923—1931 may be due to the relatively high amount of summer precipitation during the same time or may be an indication that 2 years had not been recognized as annual layers of summer precipitation during the same time. The low accumulation rates in the layers of 1934—1937 may be influenced by high ablation (influence of Sahara dust falls 1935—1937?)[1]. Around the year 1911 we once more found a great discrepancy between precipitation and accumulation, here too, it seems that the very low winter accumulation was compensated by relatively high summer precipitation.

Summarizing one can say that in our case the amount of winter precipitation of the nearby meteorological station Vent is comparable to the accumulation rate, but there exists no strong correlation (table 1). In some periods it happens that other factors, e. g. summer precipitation, become dominant and disturb the simple correlation.

3.2 ISOTOPE CONTENT AND AIR TEMPERATURE

The ^2H and ^{18}O content of precipitation is correlated with the air temperature at one location (cf. Stichler and Herrmann 1978). The annual variation of the isotope content is due to the temperature variation during one year. The correlation between air temperature and ^2H content of precipitation is shown for the meteorological station Vent for the years 1973—1977 by Stichler et al. (1982). Long term variations of the temperature will also cause isotope content variations as it was proved, e. g. for Greenland ice cores. In this context one can ask whether or not the ^2H and ^{18}O contents of an ice core from a temperate glacier also still reveal a correlation with the temperature. The annual isotope variations are still recognizable, but strongly damped and not suitable for a correlation with the temperature. For the meteorological station Vent measurements of the air temperature are available back to the beginning of this century (Lauffer 1966, Kuhn et al. 1979). In fig. 2d the ^2H content of the ice core is compared with the mean air temperature of the months May—September of the station Vent (table 1). In the plot 5-year running means are used. Fig. 2a shows the means of summer and winter temperatures as well as those of the whole year, fig. 2b and c the yearly ^2H content as well as the deuterium excess d. The 5-year running means of the summer temperature show one clear maximum during the so-called small climatic optimum in the late forties of this century. The maximum of the ^2H content and the minimum of the excess d do not exactly coincide with the temperature maximum, but are shifted approximately 4 years back, i. e. downwards in the core. We do not know if this time shift is caused by a wrong dating of the core, or is due to percolating and possibly refreezing meltwater. The same time shift occurs also between the smaller peaks of the temperature and of the ^2H content. The deuterium excess d is inverse to the ^2H content, and the minima of the d curve, usually indicating summer-snow layers (cf. Stichler et al. 1982), correspond with the maximum of the ^2H content.

Summarizing one can say that obviously long term variations of the isotope content are due to temperature variations, but in the case of the Vernagtferner ice core both curves show a time shift of 4—5 years.

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[1] From the content of Al in the core section 39.77—39.94 m, which coincides with the year 1937 of our time scale, one calculates a maximal content of Al_2O_3 of 15 % (personal communication by P. Schramel), a value due to the composition of Sahara dust.

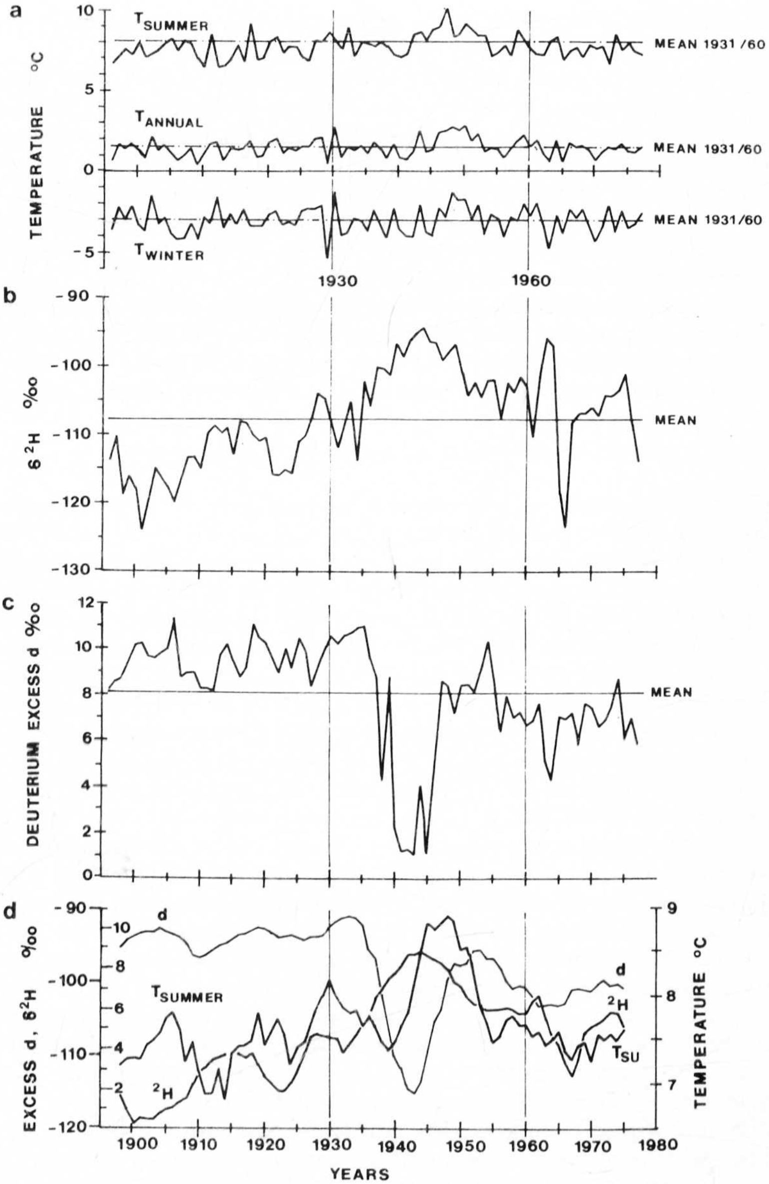

Fig. 2: Ice core Vernagtferner (Ötztal Alps, Austria) of 1979

a) Yearly means of winter (October—April), summer (May—September) and annual temperature, measured at the meteorological station Vent (Ötztal Alps) (Lauffer 1966, Kuhn et al. 1979)

b) ^{2}H content of the yearly firn and ice layers in the ice core. The ice core was dated mainly by means of the ^{2}H and ^{18}O content (Stichler et al. 1982)

c) Deuterium excess d of the yearly firn and ice layers in the ice core

d) Comparison of the 5-year running means of summer temperature at the meteorological station Vent and of the 5-year running means of ^{2}H content as well as of deuterium excess d from the ice core

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REFERENCES

Drost, W. and G. Hofreiter, 1982: Natural gamma logging of borehole I on Vernagtferner (Oetztal Alps, Austria). Z. Gletscherk. Glazialgeol. 18 (1): 49—54.

Gunten, H. R. v., E. Rössler and H. Gäggeler, 1982: Dating of ice cores from the Vernagtferner (Austria) with fission products and lead-210. Z. Gletscherk. Glazialgeol. 18 (1): 39—47.

Kuhn, M., G. Kaser, G. Markl, H. P. Wagner and H. Schneider, 1979: 25 Jahre Massenhaushaltsuntersuchungen am Hintereisferner. Inst. f. Met. und Geophys., Univers. Innsbruck, 80 pp.

Lauffer, I., 1966: Das Klima von Vent. Diss. Univers. Innsbruck.

Oerter, H. and W. Rauert, 1982: Core drilling on Vernagtferner (Oetztal Alps, Austria) 1979: Tritium contents. Z. Gletscherk. Glazialgeol. 18 (1): 13—22.

Oerter, H., O. Reinwarth and H. Rufli, 1982: Core drilling through a temperate Alpine glacier (Vernagtferner, Oetztal Alps) in 1979. Z. Gletscherk. Glazialgeol. 18 (1): 1—11.

Patzelt, G., 1970: Die Längenmessungen an den Gletschern der Österreichischen Ostalpen 1890—1969. Z. Gletscherk. Glazialgeol. 6 (1—2): 151—159.

Stichler, W. and A. Herrmann, 1978: Räumlich-zeitliche Variation der Isotopengehalte randalpiner Niederschläge. Verh. 15. Int. Tagung für Alpine Meteorologie, Grindelwald, 19.—23. 9. 1978. Teil 1: 271—275.

Stichler, W., D. Baker, H. Oerter and P. Trimborn, 1982: Core drilling on Vernagtferner (Oetztal Alps, Austria) 1979: Deuterium and Oxygen-18 contents. Z. Gletscherk. Glazialgeol. 18 (1): 25—37.

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