Isotope measurements on firn and ice cores from alpine glaciers

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Abstract. An investigation was made of the extent to which stable and radioactive isotopes (^{3}H, ^{18}O, ^{210}Pb, ^{137}Cs and ^{90}Sr) can be used to determine accumulation rates and ages of temperate glaciers in the Alps. The ^{3}H and ^{18}O data obtained from Jungfraujoch Glacier cores (3470 m a.s.l.) indicate that the seasonal variations, as they are observed in precipitation, collected at the time of fall, are not preserved. In addition, unexpectedly strong horizontal variations in isotopic concentrations have been found. Based on bomb-produced radio-isotope layers, an average accumulation rate of 60 cm water equivalent has been determined. In ice cores from the Plaine Morte Glacier (2750 m a.s.l.), too, no seasonal variations could be found. Average accumulation rates between 5 and 15 cm water equivalent have been determined for the period 1963–1972. In one core the pre-bomb tritium level was reached. The horizontal and vertical distribution of ^{210}Pb and ^{137}Cs is strongly influenced by dirt layers. This has to be taken into account when these isotopes are used for dating firn and ice from alpine glaciers.

Mesures des isotopes dans des névés et des carottes de glaciers alpins

Résumé. Nous avons étudié l'étendue des possibilités offertes par des isotopes (^{3}H, ^{18}O, ^{210}Pb, ^{137}Cs et ^{90}Sr) dans la détermination de taux d'accumulation pour les glaciers tempérés alpins. Les données recueillies à l'aide de carottes au Jungfraujoch (3470 m) révèlent l'absence de couches saisonnières. Le dépôt des isotopes accuse une forte variation horizontale. Les couches d'isotopes produits à l'aide de bombes thermonucléaires permettent la détermination d'un taux moyen d'accumulation correspondant à 60 cm d'eau. On ne remarque aucune variation saisonnière dans les carottes de la Plaine Morte (2750 m). Pour la periode 1963–1972 le taux moyen d'accumulation y correspond à 5–15 cm d'eau. Dans une des carottes le niveau de tritium d'avant l'ère thermonucléaire est atteinte. La distribution horizontale et verticale du ^{210}Pb et du ^{137}Cs est influencée par des couches sales: ce fait doit être pris en considération lorsque des résultats isotopiques sont employés à des fins de datation.

INTRODUCTION

Measurements of stable and radioactive isotopes in ice cores from polar regions allow ice dating and the determination of accumulation rates (Picciotto *et al.*, 1964; Aegerter *et al.*, 1969; Dansgaard *et al.*, 1973; Merlivat *et al.*, 1973). The first attempts on alpine glaciers were made in 1957 on the Jungfraujoch firn (Oeschger *et al.*, 1962). Since then extensive stable and radioactive isotope studies have been carried out by many including Aegerter (1966) and Ambach and Eisner (1965). The main problems regarding the interpretation of the isotope data are: percolation of meltwater and disturbance of precipitation deposits due to strong winds.

EXPERIMENTAL

Three cores were taken on the Jungfraujoch Glacier (3470 m a.s.l.) in 1972 and 1974. In each case the penetration of crevasses necessitated cessation of the drilling at depths between 9 and 19 m. In 1972 three cores were drilled on Plaine Morte, a 15 km^2 flat glacier at only 2750 m a.s.l. The drilling was performed with a SIPRE drill and the samples were taken to the laboratory in frozen state. The core P3 from Jungfraujoch was cut into 12-cm pieces and placed in polyethylene bottles; chemical carriers were added to avoid the loss of radionuclides. ^{90}Sr and ^{210}Pb were measured with low background proportional

counters, the growth of the daughter nuclides was followed for further identification. The ^{137}Cs activities were determined with a 60 cm^3 Ge-(Li) detector. Low tritium concentrations (< 10 TU) were measured after 20-fold electrolytical enrichment (blank value: 0.25 ± 0.10 TU).

RESULTS AND DISCUSSION

Jungfraujoch (Fig. 1)

No clear seasonal variations are observed, either in $\delta(^{18}O)$ or in tritium. This is due to wind erosion, as is evident from a comparison of measurements of stake readings covering the same time span as that of the core samples. Another striking feature is the difference between the tritium and $\delta(^{18}O)$-records determined at sites less than 100 m apart. This must be attributed to a very irregular accumulation caused by strong winds. In addition, summer melting, indicated by ice lenses, causes a smoothing of the isotope variations. The bomb horizons of 1963 and, in P3, also those of 1958–1959 and 1954, can clearly be identified. They allow the determination of a mean annual accumulation rate of

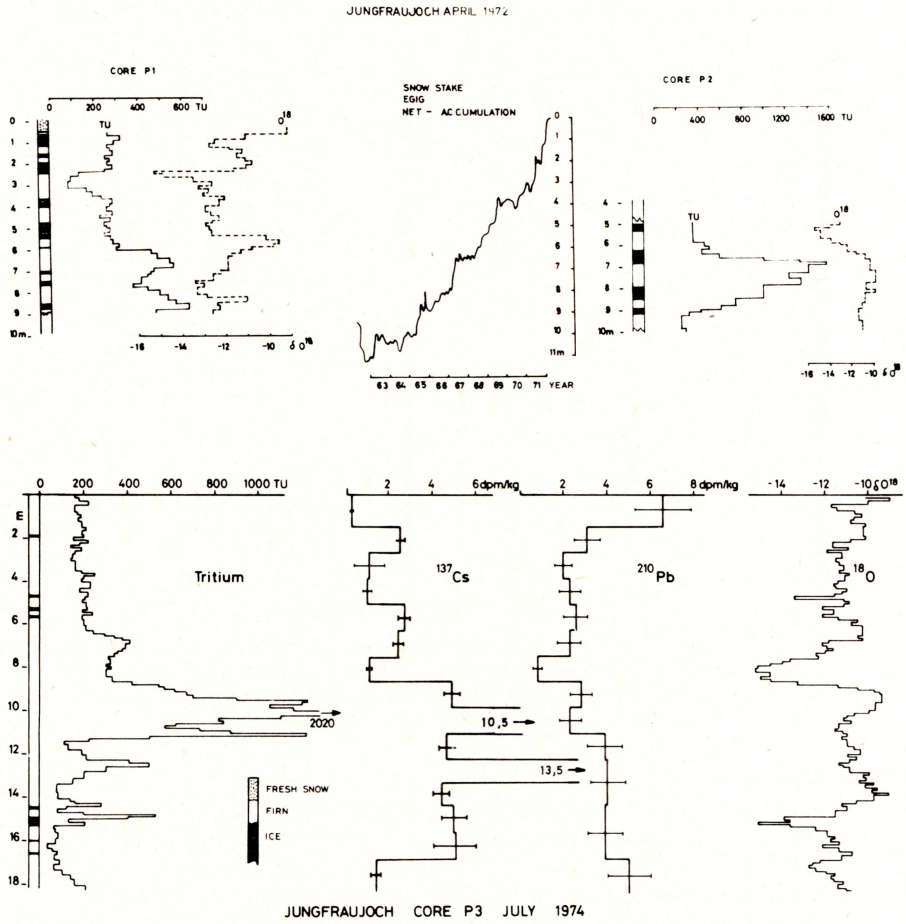

FIGURE 1. Isotope measurements on three cores from Jungfraujoch. The tritium values are decay-corrected to the day of sampling. ^{137}Cs and ^{210}Pb values are not decay-corrected. Errors indicated comprise 1 standard deviation.

about 60 cm water equivalent, in good agreement with earlier results from this region (Ambach *et al.*, 1971). The mean $\delta(^{18}O)$-value is about $-12.5^0/_{00}$. This is surprisingly high, considering that the average annual value for the precipitation at a nearby station (Grimsel) at approximately 2000 m a.s.l. is $-14^0/_{00}$, and that due to the higher altitude the average $\delta(^{18}O)$-value should be considerably below that of Grimsel. Missing winter precipitation could not account for the observed discrepancy since at Grimsel the mean $\delta(^{18}O)$-value for the months April–September is $-12.1^0/_{00}$. At present we do not know the explanation for this inverse altitude effect.

In P3 ^{137}Cs-activity and tritium-activity show a peak at the same depth. This is to be expected, as both isotopes are mainly produced by nuclear weapon tests. The average specific ^{210}Pb-activity is about 4 dpm/kg and corresponds to that known from similar investigations on the Kesselwandferner (Crozaz, 1967). ^{210}Pb-values as a function of depth are irregular and no clear decrease with depth can be seen (the time span covered by the core corresponds to approximately one half-life of ^{210}Pb).

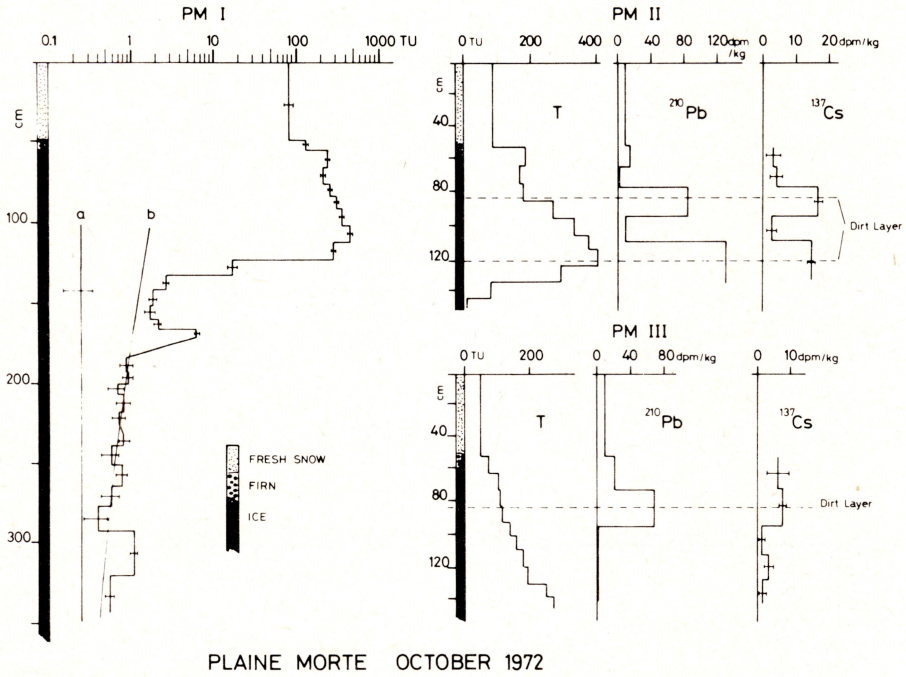

FIGURE 2. Isotope measurements on three cores from Plaine Morte. Line *a* for core PMI: blank value for the tritium measurements. Line *b* exponential fit for values below 185 cm depth, assuming 5.8 cm water equivalent per year, converging to blank (line *a*) at high depth. Line *b* yields a pre-bomb tritium concentration of 2.3 TU.

Plaine Morte (Fig. 2)

On the large flat area of the Plaine Morte Glacier wind erosion is not as important as on the Jungfraujoch. At this relatively low altitude, years with positive and those with negative accumulation alternate and intermittent melting processes are expected to influence the isotope distribution. No seasonal variations in $\delta(^{18}O)$ and tritium can be observed. The mean $\delta(^{18}O)$-value for the cores PM I and PM II is $-13.3^0/_{00}$, i.e. lower than at Jungfraujoch in spite of the lower altitude. If we attribute the tritium maximum of the core PM I to

1963 we calculate an average annual accumulation of 5 cm water equivalent which is only about 3 per cent of the average annual precipitation. The average tritium concentration in the PM I core between 60 cm (1971) and 125 cm (1963) depth is 317 TU. This value corresponds within 20 per cent to the average tritium concentration in the precipitation during that period. From 125 cm to 170 cm depth the tritium values are rather low when compared to those known for each annual precipitation in the period 1955 to 1963. Below 185 cm the low tritium concentrations indicate that the contribution by bomb tritium is very small or missing. The values show the expected decrease with depth due to radioactive decay. They correspond to a tritium concentration of 2–3 TU at the time of deposit provided the mean accumulation rate was fairly regular. ^{210}Pb and ^{137}Cs-activities show a very irregular horizontal and vertical distribution, being enriched in dirt horizons (^{210}Pb shows in PM II values up to 131 dpm/kg). Since the average values for these isotopes are much higher for Plaine Morte than for Jungfraujoch it is believed that the dirt layers act as an absorbent and thus concentrate the two nuclides.

Surprisingly, in PM I a high concentration of ^{137}Cs was found 3.0 m below the bomb tritium level. This phenomenon is difficult to explain (penetration through a crack in the ice?).

CONCLUSION

Problems not encountered in polar regions complicate the interpretation of isotope data on samples from temperate glaciers. Some of the difficulties are related to the poor knowledge on the concentrations and seasonal variations of ^{3}H and $\delta(^{18}O)$ of precipitation at high altitudes, and the big scatter of e.g. ^{210}Pb concentrations between individual snow falls (0.3–9 dpm ^{210}Pb/kg in the Bern region). In addition by processes in firn and ice the isotope concentrations are continuously changed. Dirt horizons act as a filter for ^{210}Pb, ^{137}Cs and ^{90}Sr, and it is well known that some clays absorb ^{137}Cs quite specifically. Also the chemical behaviour of these isotopes, when dissolved in meltwater, seems to be different.

Our results show that the concept of a closed system is not valid for isotope studies in temperate glaciers. Therefore, the interpretation of the data has to be based on additional considerations regarding input and output with respect to the individual chemical and physical behaviour of the isotopes.

Acknowledgement. This work was supported by the Schweizerischer Nationalfonds.

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