SEASONAL VARIATIONS IN THE TRITIUM ACTIVITY OF RUN-OFF FROM AN ALPINE GLACIER (KESSELWANDFERNER, OETZTAL ALPS, AUSTRIA)

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ABSTRACT. Run-off water of a glacier consists of components of different origins: melted snow (in some cases firn layers deposited during previous years), melted old glacial ice, spring water and rain. Water from melted snow differs from that of old glacial ice in having comparatively high tritium values. For this reason, there is a significant decrease in activity due to melt water from the ablation area during the summer ablation period. Diurnal variations of activity were also measured. With simplifying assumptions, the melt-water portion from the accumulation area and that from the ablation area have been calculated for different conditions.

RÉSUMÉ. *Variations saisonnières de l'activité du tritium de l'eau d'écoulement d'un glacier alpin (Kesselwandferner, Alpes d'Oetztal, Autriche).* L'eau d'écoulement d'un glacier consiste en composés de différents origine: neige fondue (dans certains cas, de couches de névé déposées durant des années antérieures) vieille glace fondue, eau de source et pluie. L'eau de la neige fondue diffère de celle de la vieille glace par des valeurs comparativement fortes en tritium. Pour cette raison, un abaissement significatif de l'activité due à l'eau de fonte de la zone d'ablation, arrive durant la période estivale d'ablation. Des variations diurnes de l'activité furent aussi mesurées. Avec des hypothèses simplifiees, la portion d'eau de fonte de la zone d'accumulation et celle de la zone d'ablation ont été calculées pour différentes conditions.

INTRODUCTION

The radio-active fission products deposited by atmospheric fall-out on a glacier can be used to study the glacier as a hydrological system (Ambach and others, 1968). Tritium activity will be of special importance, because tritium as a tracer is particularly suited for hydrological purposes.

Tritium activity in the run-off water of a glacier is due to: melt water from snow of the near-surface layer, melt water from old tritium-free glacial ice from the ablation area, spring water and rain water. Water production at the bottom of the glacier is negligible ($0.6\ \mathrm{g\ cm^{-2}\ a^{-1}}$); in special cases only is it necessary to consider rain water. Due to the different activity of the components of this mixture and the varying contribution of these components to the run-off water, variations of activity in the run-off result. From these variations, as a quantitative evaluation, the composition of the mixture can be calculated.

To study the activity variations in the run-off, water samples were taken from the run-off at intervals since autumn 1965 near the glacier snout of the Kesselwandferner and from different springs in the surroundings (sketch map; cf. Lang, 1966). Seasonal and diurnal variations in midsummer and variations of tritium activity of the run-off water due to atmospheric influence were the subjects of studies.

Previous run-off measurements on the Kesselwandferner and the near Hintereisferner had been carried out by Rudolph (1962) and Lang (1966) in order to determine the variations in discharge. In this connection, however, measurements of radio-activity were not carried out.

SEASONAL COURSE OF TRITIUM ACTIVITY

Spring water at Hochjoch-Hospiz

The spring is located at approximately 2 600 m a.s.l., 1 000 m from the snout of the Kesselwandferner; its drainage area is not glacierized and it is independent of the Kesselwandferner. Figure 1 shows the seasonal variation of the tritium content of the spring water as compared with the tritium content of precipitation at Vienna (I.A.E.A.). From the fact that the tritium content of the spring shows a distinct winter peak, it is concluded that the average flow time of the spring water is approximately 6 months. This result is confirmed by comparing the amounts of tritium concentration in the spring water with those of precipitation at Vienna.

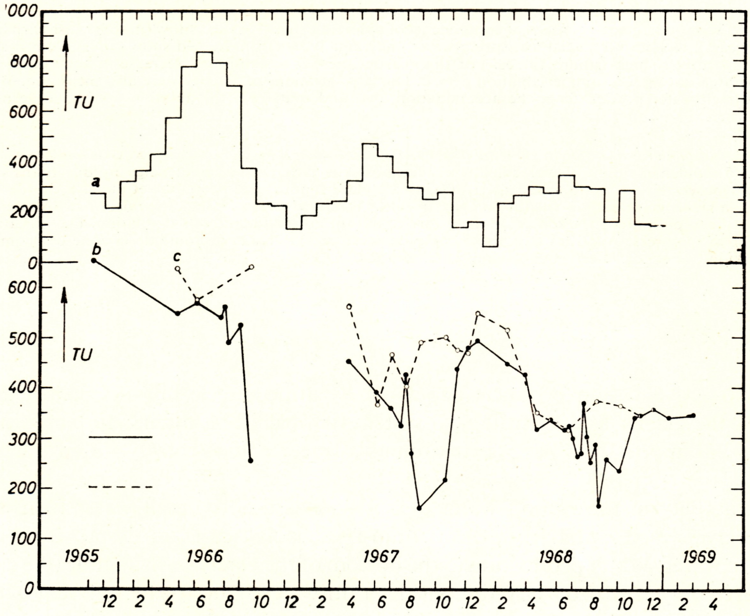

Fig. 1. Seasonal variations in the tritium activity of: (a) precipitation at Vienna, (b) the glacial run-off and (c) the spring at Hochjoch–Hospiz.

Run-off water of the Kesselwandferner

A comparison between the tritium concentration of the spring water (Hochjoch-Hospiz) and that of the glacial water (Fig. 1) reveals striking seasonal variations with especially low tritium activity during summer and autumn. These minima are due to the melt water from tritium-free old glacial ice in the ablation area. The rapid increase of tritium in late autumn indicates that the run-off of tritium-free melt water from the ablation area takes place in the course of a few weeks. Whether discharge during late winter is pure spring water or a mixture of spring and melt water from the accumulation area can, in the present case, hardly be decided from measurements of the tritium activity, for both spring and melt water show approximately the same tritium concentration. The decrease in tritium concentration in the run-off water during late winter coincides with a similar decrease observed in spring water. This parallel allows the conclusion that already in January and February the discharge contains a high percentage of spring water, because in the case of predominating melt water from the accumulation area, the tritium activity of the run-off water should remain constant until the beginning of the next melt period. A comparison of the minima in tritium activity between the summers of 1966, 1967 and 1968 shows that the decrease in the 1966 summer began very late as a result of the particularly bad weather. In the 1967 summer a comparatively higher amount of melt water from ice could be observed as compared with the 1968 summer; this observation is confirmed by comparing the meteorological conditions.

DIURNAL VARIATIONS OF TRITIUM ACTIVITY IN THE RUN-OFF WATER OF THE KESSELWANDFERNER

During the period of ice ablation, diurnal variations in the activity of discharge also occur as a result of the changing amount of melt water from the ablation area. Figure 2 shows the diurnal variations for the sampling period of 20/21 August 1968. The variation ranges from 150 to 250 T.U., the minimum occurring at 12.00 h. The increase in the tritium concentration observed after 16.00 h shows the decrease in that portion of melt water originating from the ice of the ablation area. However, the maximum values of tritium activity do not reach the value of the tritium activity of firn during the night; they remain lower by approximately 100 T.U. as a result of melting of ice during the night (air temperature at midnight: 4.9° C).

The high tritium value at the beginning of the sampling period (316 T.U. on 8 August) is due to the preceding period of bad weather with snowfall in the ablation area during 2 days at least. The snow cover was, however, very thin. Therefore, in the morning hours of 20 August it melted following a considerable rise in temperature (station at Vent, 1 900 m a.s.l.; 07.00 h: 1.5° C; 14.00 h: 14.0° C) and in the course of the day it produced tritium-free melt water by ice melt.

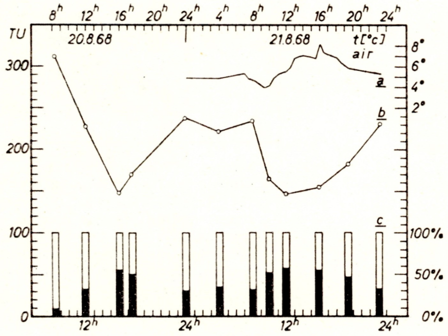

Fig. 2. (a) Temperature of air at the glacier snout. (b) Diurnal variation of the tritium activity of the run-off from the Kesselwandferner. (c) Relative portion of run-off water from melted ice and snow—the black column represents the relative portion from melted ice, the white column the relative portion from melted snow.

VARIATIONS IN THE TRITIUM CONTENT OF THE RUN-OFF DURING THE ABLATION PERIOD DUE TO ATMOSPHERIC CONDITIONS

Ice melt ceases as a result of new snow in the ablation area. Therefore, run-off activity is increased. The 1968 summer is a good example (Fig. 3). Following a period of fine weather, ice melt in the ablation area set in during the last 10 days of June and lasted until 15 July. In the course of this period an area of 0.6 km^2 (personal communication from Prof Dr H. Hoinkes) in the ablation area became free of snow. The tritium-free melt water showed a decrease in the tritium concentration of the run-off from 323 to 236 T.U. During the following period of bad weather between 15 and 26 July, snow also fell in the valley. As a result of this snowfall (the ablation area was covered with snow during 13 days), ice melt was interrupted and the tritium activity rose from 263 to 369 T.U. During a subsequent period of fine weather the new snow in the ablation area disappeared in a few days (26 until 29 July). Later, apart from a few interruptions, the ablation area remained free from snow. The moment at which the extension of the snow cover reached its minimum coincided with that of minimum tritium activity, amounting to approximately 150 T.U. Even on 10 October, the difference between the tritium concentration in run-off and spring water was remarkable; because of the south-east exposure of the ablation area, ice still melts at this time of the year. The following sampling (carried out on 2 November) revealed a considerable increase in tritium activity of the run-off. Variations due to atmospheric conditions can, however, be evaluated only qualitatively, for the sampling time lies between 10.00 and 14.00 h and, in the case of diurnal variations in activity, the values obtained do not allow a strict comparison. Measuring accuracy of tritium activity is approximately ±10%.

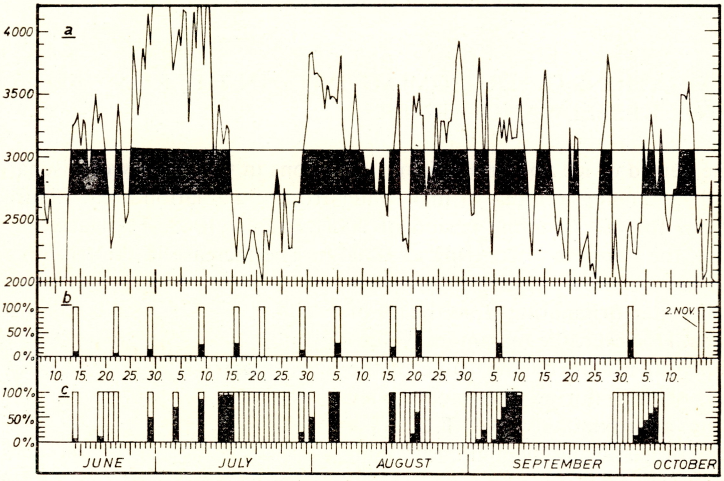

Fig. 3. Variations in tritium activity of the run-off from the Kesselwandferner due to atmospheric conditions. (a) Altitude of 0° C according to the Munich radio-soundes. (b) Relative portions of water from melted ice and snow—the black column represents the relative portion of run-off water from melted ice, the white one that from melted snow. (c) Snow cover of the ablation area; 100% corresponds to the ablation area at the moment of minimum extension of the snow cover. The black column signifies the relative portion of the ice cover, the white column that of the snow cover.

QUANTITATIVE EVALUATION

Quantitative evaluation is made by the following equation:

$$A_t(q_S + q_I + q_G + q_R) = A_S q_S + A_I q_I + A_G q_G + A_R q_R.$$

A = tritium activities (T.U.) and q = amount of run-off water. The subscripts t, S, I, G and R signify, in the same order, total, snow, ice, ground (spring) and rain.

The application of this equation to activities of the run-off of the summer ablation period allows the following simplifications:

$$q_G \ll q_S + q_I; \qquad q_R \ll q_S + q_I; \qquad q_S + q_I = q_t.$$

Furthermore, for longer periods without melt $q_I \sim 0$ is approximately true. From activity measurements of the old glacial ice (Ambach and others, 1968), it is known that $A_I = 0$. Under these conditions, the following equation is obtained:

$$A_t/A_S = q_S/q_t.$$

A_t/A_S and q_S/q_t are functions of time.

Measurement of A_t/A_S allows the calculation of the variation with respect to time of the portion of run-off water from the accumulation area (q_S) (Figs. 2 and 3). A_S corresponds to the activity of the melting layer of old snow. Assuming great retention of the firn, entailing a comparatively long mean flow time of the melt water from the accumulation area, for A_S a value constant with respect to time holds. As an approximation, the value for tritium activity of the run-off can be assumed for A_S which is determined after the melt water has disappeared from the ablation area early in winter. Therefore, it is possible to extrapolate the winter peak of tritium activity to the preceding summer to obtain a value for A_S. This extrapolation is confirmed by the fact that the peakvalue of 21 July also reaches approximately this value (6 days permanent snow cover in the ablation area, therefore $q_I \approx 0$). As an approximation for A_S, in the 1968 summer the value 350 T.U. can be assumed, and about 450 T.U. for the 1967 summer.

A quantitative evaluation is carried out as follows:

(a) Sampling at 12.00 h with a minimum extension of the old snow cover ($A_t = 150$ T.U.).
From $q_S/q_t = A_t/A_S$ it is obtained:
Portion of melt water from the ablation area: $q_I = 57\%$.
Portion of melt water from the accumulation area: $q_S = 43\%$.

(b) Calculation of the portion of melt water from the accumulation area for samples taken during day and night hours (20/21 August). The variation in the values of activity in the course of the night reflects the variation of the composition of the run-off water. By applying the conditions given above

$$\frac{\left(\dfrac{q_s}{q_t}\right)_n}{\left(\dfrac{q_s}{q_t}\right)_d} = \frac{\left(\dfrac{A_t}{A_s}\right)_n}{\left(\dfrac{A_t}{A_s}\right)_d} \quad \text{holds.}$$

Subscript n refers to night values, subscript d to day values.
With $A_{tn} = 240$ T.U., $A_{td} = 150$ T.U., $A_{Sd} = A_{Sn} = 350$ T.U. the following results are obtained:

Run-off during night hours:
Portion from ice melt $q_I = 31\%$.
Portion from snow melt $q_S = 69\%$.
Run-off during day hours:
Portion from ice melt $q_I = 57\%$.
Portion from snow melt $q_S = 43\%$.

Figure 2c shows the diurnal variations in the relative portions from ice and snow melt. Moreover, the calculation of those portions of samples taken between June and November 1968 is shown in Figure 3b with respect to atmospheric conditions. For purposes of comparison, this figure shows the relative portion of the snow cover in the ablation area (Fig. 3c) and the altitude of 0° C (Fig. 3a). In Figure 3c, 100% corresponds to the ablation area at the moment of minimum extension of the snow cover.

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