δ(^{18}O) and accumulation rate distribution in the Dye 3 area, south Greenland

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Abstract. Time series representing the last three decades of annual accumulation, annual means of total β-activity and δ(^{18}O), based on firn samples collected at five sites in the Dye 3 region, south Greenland, have been analysed to evaluate areal and temporal variations. The most interesting result is an unexpectedly high negative change of δ(^{18}O) per unit of elevation in the vicinity of Dye 3 [−3.0‰ δ(^{18}O) per 100 m].

La distribution du δ(^{18}O) et du taux d'accumulation dans la région de Dye 3, au sud de Groenland

Résumé. A partir des échantillons de névé prélevés en cinq sites de la région de Dye 3 (Groenland sud), et pour évaluer les variations spatiales et temporelles, on a analysé les séries chronologiques représentantes les trois dernières décades d'accumulation annuelle et de moyennes annuelles de l'activité β totale et de δ(^{18}O). Le résultant le plus intéressant est le changement très négatif inattendu de δ(^{18}O) par unité d'altitude au voisinage de Dye 3 [−3‰ δ(^{18}O) pour 100 m].

Detailed β-activity and δ(^{18}O)-profiles have been obtained by analysing firn samples collected in 1971 and 1972 at five sites near Dye 3 (65°11′N, 43°50′W), south Greenland, ranging in distance from 3 km northeast of Dye 3 to 58 km

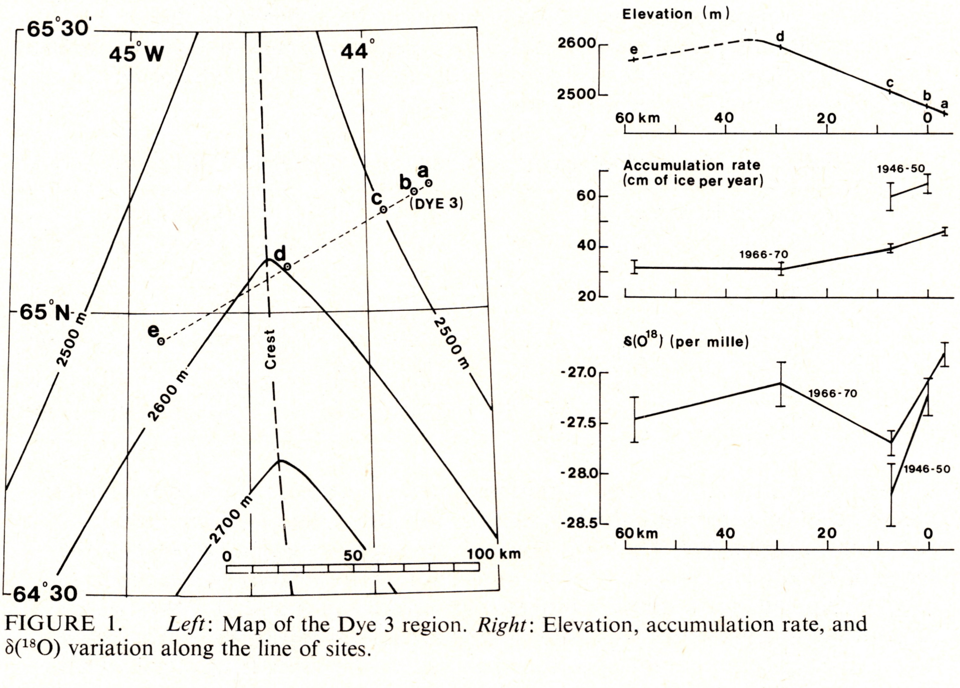

FIGURE 1. *Left*: Map of the Dye 3 region. *Right*: Elevation, accumulation rate, and δ(^{18}O) variation along the line of sites.

southwest of Dye 3. The four easternmost sites are located on an assumed flow line (Fig. 1). At three sites (*a*, *b* and *c*), two independent firn records were obtained (e.g. *a* and *a′*), giving a total of eight records, representing from 5 to 34 years of accumulation. The study comprises a total of 1600 and 200 samples measured for δ(^{18}O) and total β-activity, respectively.

The Dye 3 region is located in the percolated zone of the Greenland ice sheet, which complicates the dating of the firn both by means of seasonal $\delta(^{18}O)$ variations (Dansgaard *et al.*, 1973) and by total β-activity horizons (Table 1),

TABLE 1. Characteristic total β-activity horizons in Greenland

Time	Characteristic feature	Event
Spring 1955	Drastic increase	Castle test early in 1954
Winter 1960–1961	Relative minimum	Bomb moratorium
1963	Absolute maximum	Thermonuclear tests 1961–1962

(Crozaz *et al.*, 1966). However, by combining these dating methods with classical snow stratigraphy, a reliable dating has been obtained to determine the time series of net annual accumulation A, annual mean $\delta(^{18}O)$, and β-values at each site (Fig. 2). The similarities between the A, $\delta(^{18}O)$ and β-series, respectively, are confirmed by correlation and variance analysis, which furthermore reveals significant areal variations of the quantities.

In Fig. 3 the correlation coefficients r_A and r_δ between the A-series and $\delta(^{18}O)$-series, respectively, for the 5-year period 1966–1970 are plotted *versus* the distance s between sites. The figure shows r_A and r_δ decreasing from 0.8–0.9 for closely spaced stations to 0 for stations spaced 50–100 km apart. For longer periods (e.g. 12 years) r_A varies the same way, whereas r_δ decreases more slowly with s ($r_\delta \sim 0.6$ for $s = 60$ km). As to the β-series, r_β varies between 0.77–0.97 independent of s. The β-series from site a, though, differs from the rest of the β-series by lower β-activity in 1964 and higher in 1963, probably due to transmigration by percolation of radioactive elements from one layer to another. This is supported by the mean β-activity for the period 1962–1965 being essentially the same for the sites a and c (Table 2).

TABLE 2. Mean and variance of A, $\delta(^{18}O)$ (1966–1970) and β (1962–1965)

	Accumulation rate, A		$\delta(^{18}O)$		Total β-activity	
Site	$\bar{A}$ [cm of ice]	σ^2 [cm of ice]^2	$\bar{\delta}$ [‰]	σ^2 [‰]^2	$\bar{\beta}$ [dph/kg]	σ^2 [dph/kg]^2
a	44	146	−26.78	0.35	1102	7.06×10^4
a'	49	174	−26.86	1.37		
c	41	142	−27.61	0.77	1049	6.4×10^4
c'	38	217	−27.77	0.91		
d	31	34	−27.11	0.92	1325	5.6×10^4
e	32	65	−27.47	0.98	1269	26.8×10^4

The significance of the areal variations shown in Table 2 is tested by analysis of the variance, separating the variances ascribable to temporal and areal variations, respectively. This test, however, presupposes equal variance of the series involved. This requirement in connection with the above-mentioned r–s relationship calls for a division into two groups of the A and $\delta(^{18}O)$-series, group-I comprising series from sites a, b and c and group-II series from sites d and e. All β-series are grouped together, except the series from site a which is disregarded for the reasons mentioned above.

The analysis shows that generally the difference in levels of series obtained at the same site is not significant. Therefore, average series are calculated at each site. For A and $\delta(^{18}O)$ Fig. 1 shows means of these series and corresponding standard errors for different 5-year periods *versus* distance. Also shown in Fig. 1

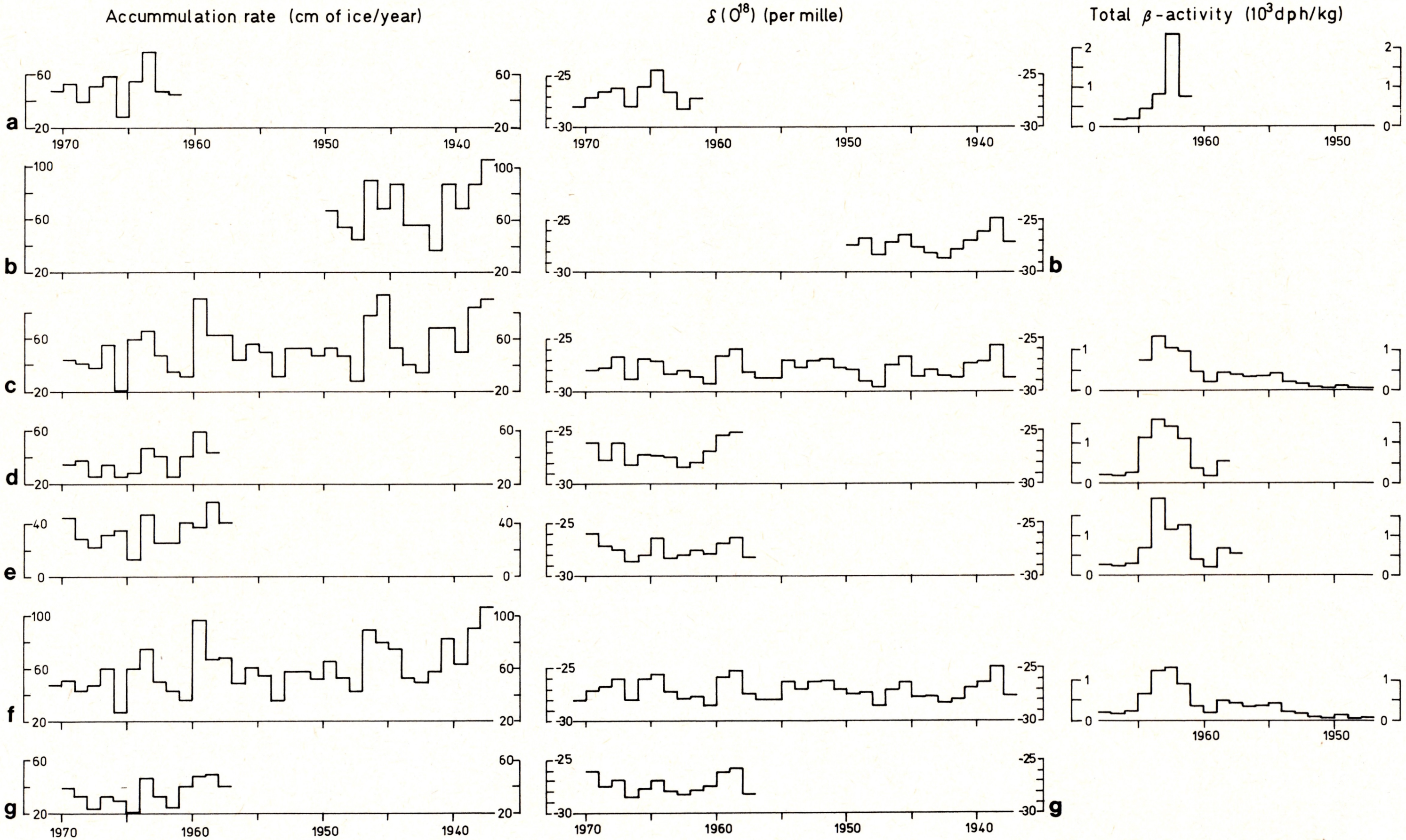

FIGURE 2. Time series of accumulation rate A, $\delta(^{18}O)$ and total β-activity. *a*, *b*, *c*, *d* and *e* refer to sites shown in Fig. 1. *f*, in the cases of A and $\delta(^{18}O)$ is the average of *a*, *b* and *c*, and in the case of β it is the average of *a*, *c*, *d* and *e*. *g* is the average of *d* and *e*.

is a smoothed elevation profile along the line of sites. The eastern slope of this profile, based on detailed measurements during GISP-1975 (Steve Mock, personal communication) is fairly accurate, whereas the western slope based on previously published elevation data (Bedel, 1954; Mock and Ragle, 1965) is more uncertain.

On the eastern slope the change of accumulation per unit of elevation ($\mathrm{d}A/\mathrm{d}h$) is (-10 ± 2) cm of ice/100 m. The western slope has significantly lower A than Dye 3. However, the data do not permit calculation of $\mathrm{d}A/\mathrm{d}h$ for the western slope.

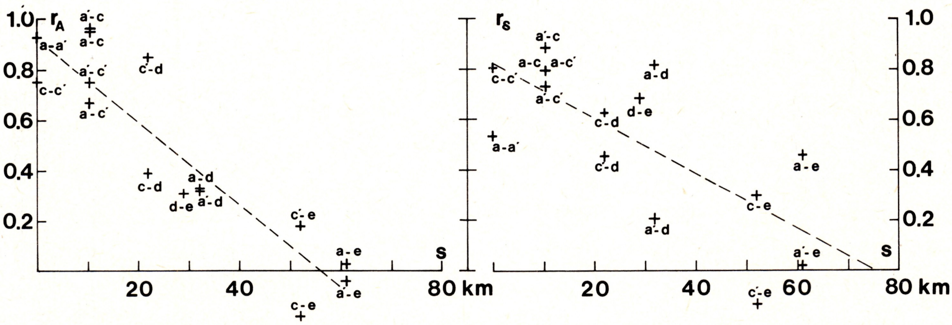

FIGURE 3. Correlation coefficients for accumulation rate series (*left*) and $\delta(^{18}O)$ series (*right*) as functions of distance s for the period 1966–1970.

The results from sites a, b and c indicate a gradient $\mathrm{d}\delta(^{18}O)/\mathrm{d}h$ of $(-3.0 \pm 0.8)^0/_{00}$ per 100 m, a value which differs significantly from the expected value of $-0.62^0/_{00}$ per 100 m (Dansgaard *et al.*, 1973).

The gradients over the distances a–d and d–e are $(-0.5 \pm 0.2)^0/_{00}$ and $(0.2 \pm 1.0)^0/_{00}$ per 100 m respectively which agree within the standard error with the expected value. There is no straightforward explanation for the high negative $\mathrm{d}\delta(^{18}O)/\mathrm{d}h$ near Dye 3. Maybe a contributing factor is the large surface undulation found in the region.

The specific total β-activity is significantly higher for group-II than for group-I series, indicating increasing β-activity with decreasing A (Table 2).

The analysis also provides estimates of the standard errors of A, $\delta(^{18}O)$ and β-values of (5–10) cm of ice, $0.6^0/_{00}$ and 150 dph/kg, respectively. The errors may be ascribed to uneven surface distribution of the snow (sastrugi) and to percolation. As regards β, the measurement error also gives a significant contribution.

A comparison of the variance calculated from these standard errors with the total variance of the series (Table 2), shows that the A and δ-series have a signal to noise variance ratio (f) between 1 and 3 for the short periods considered. (For longer periods a comparison of series from other Greenland ice cap stations indicates an f-ratio considerably less than 1.)

Besides the f-ratio we find the most important result of the present study to be the detection of the large negative $\mathrm{d}\delta(^{18}O)/\mathrm{d}h$ in the vicinity of Dye 3. Since a similar comparative study of firn cores collected near Milcent (70°18′N, 44°31′W) indicates that local $\delta(^{18}O)$ anomalies may have widespread occurrence in Greenland, this stresses the necessity of detailed surface studies upstream from intermediate and deep core drilling sites, because the climatic interpretation of deep $\delta(^{18}O)$-profiles depends on the $\delta(^{18}O)$ and A-distribution upstream.

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