THICKNESS CHANGES OF SWISS GLACIERS
(Aerial photogrammetric maps)

Silvretta, Verstancla and Chamm glaciers, surveys 1959 and 1973; 1:10,000 (1976)
Limmern and Plattalva glaciers, surveys 1947 and 1977; 1:10,000 (1981)
Gries glacier, surveys 1961 and 1979; 1:10,000 (1984)

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1. Introduction

The maps present some of the results from investigations carried out in connection with the technical consultancy work of the VAW for hydroelectric power companies. In the cases of Limmern and Plattalva glaciers, studied since 1944, measurements of precipitation and discharge from springs were combined with studies on the glacier mass balance in order to find out why the discharge volumes from the river, measured at the Pantenbrücke run-off gauging station, were much lower (by some 30%) than those computed on the basis of measurements in surrounding areas. The studies on Silvretta glacier, which started in 1959, were necessary in order to evaluate the available water mass in high altitude catchment basins. Gries glacier has terminated, since 1966, in an artificially dammed lake. For this glacier, hydro-glaciological studies were started in 1960 with two main aims: a) to predict the probability of a glacier advance as far as the dam site, as a function of time (cf. Bindschadler, 1981), and b) to estimate the frequency of particular annual run-off volumes. In addition to the studies outlined above, all these mapped glaciers belong to the network of long-term observations on glacier fluctuations in Switzerland (Kasser 1981).

The maps were analysed in order to get values of total changes in area, volume and mean thickness (computed from 100 m altitude intervals) as an overall check for the mass balance study results, which were obtained from glaciological measurements on stake networks installed on 4 of the 6 mapped glaciers. The main results of such comparative studies on Gries, Limmern, Plattlava and Silvretta glaciers have been published in the glaciological yearbooks of the Swiss Glacier Commission, in which

the maps were also originally published (Kasser et al. 1982, Siegenthaler 1983 and 1984).

2. The contents of the maps

The maps are printed in 6 colours at a scale of 1:10,000. All the glaciological measurement points are numbered and the entire hydrological catchment basin is shown with contour intervals of 10 m, and extra contours at 5 m intervals in the very flat areas. The topography of the first survey is shown in black lines on all maps, and lakes are black hatched. The contours, glacier borders, crevasses and lake edges from the second survey are given in red, and the lake areas in blue. At intervals of 20 m, the areas between old and new contour lines of identical altitudes are shown in green (increase in glacier thickness) or in yellow (decrease in glacier thickness). The catchment basin is outlined in violet, as are all the measurement points on the glacier. The numbers with these points indicate the average annual specific mass variation for the time period between the two surveys and the horizontal flow velocity of the stakes for one particular year. The positions of the glacier margins are given for both surveys and all glaciers; the limits of firn and of fresh snow are given for both surveys in the case of Gries glacier, but only for the second survey for the other glaciers. Likewise, moraines and conspicuous boulders are shown for both surveys for Gries glacier only; these details are missing to some extent on the other maps. The survey stations on the glacier margins are shown in black.

3. Mass balance results

From the maps, volume and mean elevation changes were determined for each 100 m altitude interval. Averaged over the whole glacier, the mean annual elevation change, which is identical to the change in thickness, can be compared to the mean annual mass change or annual mass balance of the same period. The mass balance was determined independently from the measurements made on the stake networks. A comparison of the values obtained from both the geodetic and the glaciological methods is given in Table 1, where the respective values are summarized as totals or annual means for the periods given for each glacier (values for mass change are specific annual means). Detailed data for 100 m altitude

intervals are given in Tables CCC and D of this volume (cf. also Tables 17 to 20 in PSFG Volume I (Kasser 1967) or tables in publications cited earlier).

The general tendency and variability of mass change during the time period between the two surveys are indicated in Table 2 in terms of mean, maximum and minimum values of the annual mass balance, equilibrium line altitude and accumulation area ratio. These values result from the glaciological measurements on the stake networks. Detailed data for each year are published in the glaciological yearbooks (Kasser et al. 1982, Siegenthaler 1983 and 1984).

Table 1: Changes in area, volume, thickness and mass of the mapped glaciers for the time period between the two surveys

Glacier	Time period	Area at start of period (km^2)	CHANGE IN AREA total (km^2)	AREA annual %	VOLUME total ($10^6 m^3$)	THICKNESS annual (cm)	MASS annual (mm)
Silvretta	1959/73	3.22	-0.07	-0.2	-4.60	-10	-81
Verstancla		1.04	-0.06	-0.4	-0.48	-3	-
Limmern	1947/77	2.72	-0.20	-0.2	-11.39	-14	-145
Plattalva		0.76	+0.10	+0.4	-4.82	-23	-171
Gries	961/79	6.69	-0.35	-0.3	-11.25	-10	-83

Table 2: Maximum, minimum and mean values of the annual mass balance of the mapped glaciers, with corresponding values of the equilibrium line altitude and accumulation area ratio (AAR)

Glacier	Time period	Annual mass balance	Year	Value (kg/m^2)	Equilibrium line altitude m a.s.l.	AAR
Silvretta	1959/73	Mean		-81	2767	0.52
		Maximum	1964/65	+1338	2490	0.97
		Minimum	1963/64	-1409	3019	0.04
Limmern	1947/77	Mean		-145	2729	0.48
		Maximum	1964/65	+1102	2325	0.94
		Minimum	1948/49	-1670	2945	0.11
Plattalva	1947/77	Mean		-171	ca.2770	ca.0.48
		Maximum	1964/65	+985	equilibrium line	1.00
		Minimum	1963/64	-1437	outside glacier	0.00
Gries	1961/79	Mean		-83	2842	0.53
		Maximum	1976/77	+1274	2530	0.97
		Miminum	1972/73	-1110	3135	0.10

4. Glossary

German	English
Gletschergrenzen	glacier boundary
Firnschneegrenze	limit of firn
Neuschneegrenze	limit of fresh snow
Einzugsgebietgrenze	limit of catchment basin
Grenze der (Oberflächen-)Moränan	(surface) moraine boundary
Seen	lakes
Unterschied zwischen den Gletscherständen der 1. und der 2. Aufnahme, dargestellt durch horizontale Schnittflächen:	Changes of the glacier's surface between 1st and 2nd surveys, represented by horizontal areas corresponding to the shift in contour lines:
(grün) Bei Zunahme der Gletscherdicke	(green) incr. in thickness
(gelb) Bei Abnahme der Gletscherdicke	(yellow) decr. in thickness
Vermessungsstationen:	survey stations:
Triangulationspunkt	triangulation point
Fixes Stativ	fixed theodolite mount
Permanente Signaltafel	permanent signal plates
Messpunkte auf dem Gletscher:	Measurement points on the glacier:
Pegel zur Messung des spezifischen Massenhaushalts $\overline{b}$ (kg/m^2.Jahr) und der Horizontalkomponente der Geschwindigkeit V_h (m/Jahr)	stake for measuring specific net balance $\overline{b}$ (kg/m^2.yr) and horizontal velocity V_h (m/yr)
Pegel mit alljährlich gleicher Ausgangslage	annually repositioned stake
Pegelbezeichnung	stake identification

5. Technical Details

The following government institutions and private civil surveying offices were involved with the aerial surveys and photogrammetric mappings:

Glacier	Aerial Survey		Photogrammetric Mapping by the Office of
	Date	Flight by	
Silvretta + Verstancla	31.8.59	Swiss Federal Office of Cadastral Surveying, Bern (V+D)	Joos & Co., Davos
+ Chamm	12.9.73	Swiss Federal Topographical Survey, Bern (L+T)	A. Flotron, Meiringen
Limmern + Plattalva	28+29.8.47	V+D	M. Zurbuchen, Bern
	15.9.77	L+T	A. Flotron, Meiringen
Gries	20.9.61	Swissair Photo AG, Zürich	H. Leupin, Bern
	15.8.79	V+D	H. Leupin, Bern

The editing and graphical design of the maps, as well as the preparation of the lettering and colour plates were the responsibility of the authors, assisted by other colleagues from the glaciology department of the VAW.

6. Acknowledgements

Special thanks go to the Swiss Federal Topographical Survey for printing the maps, and to the Glacier Commission of the Swiss Academy of Sciences for financial support.

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