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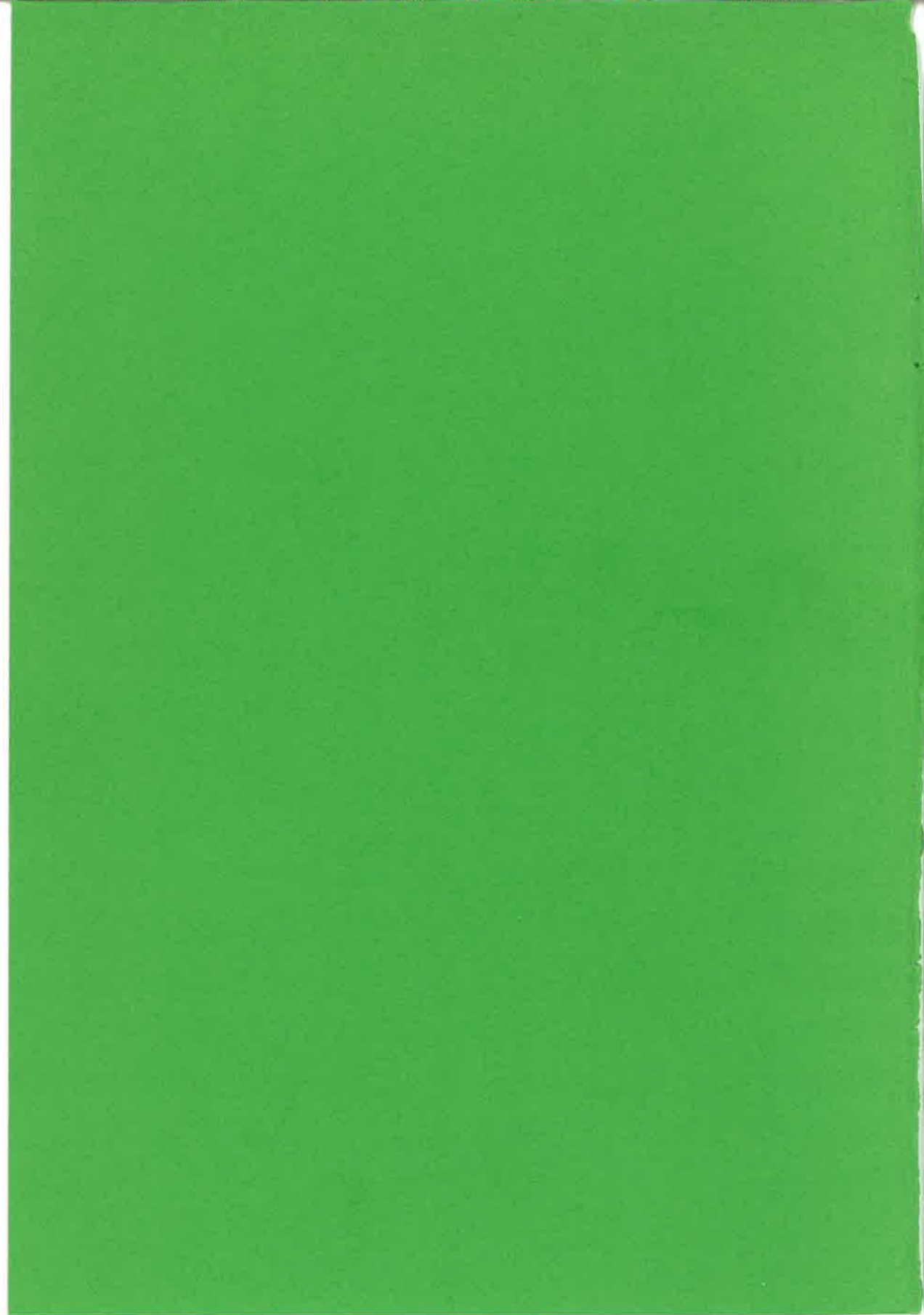
ANNUAL REPORT

1991-1992

TARFALA RESEARCH STATION

STOCKHOLM 1993

STOU-NG 96





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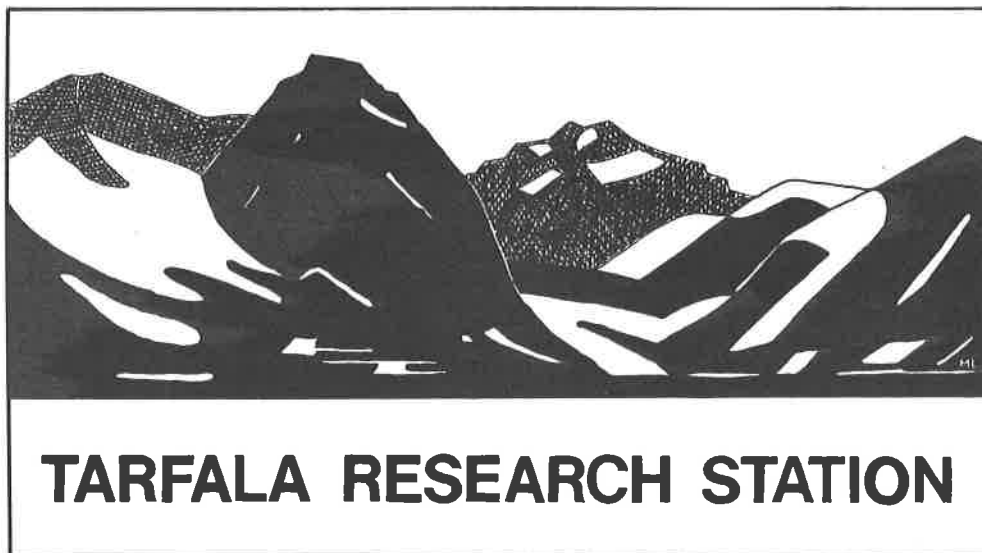
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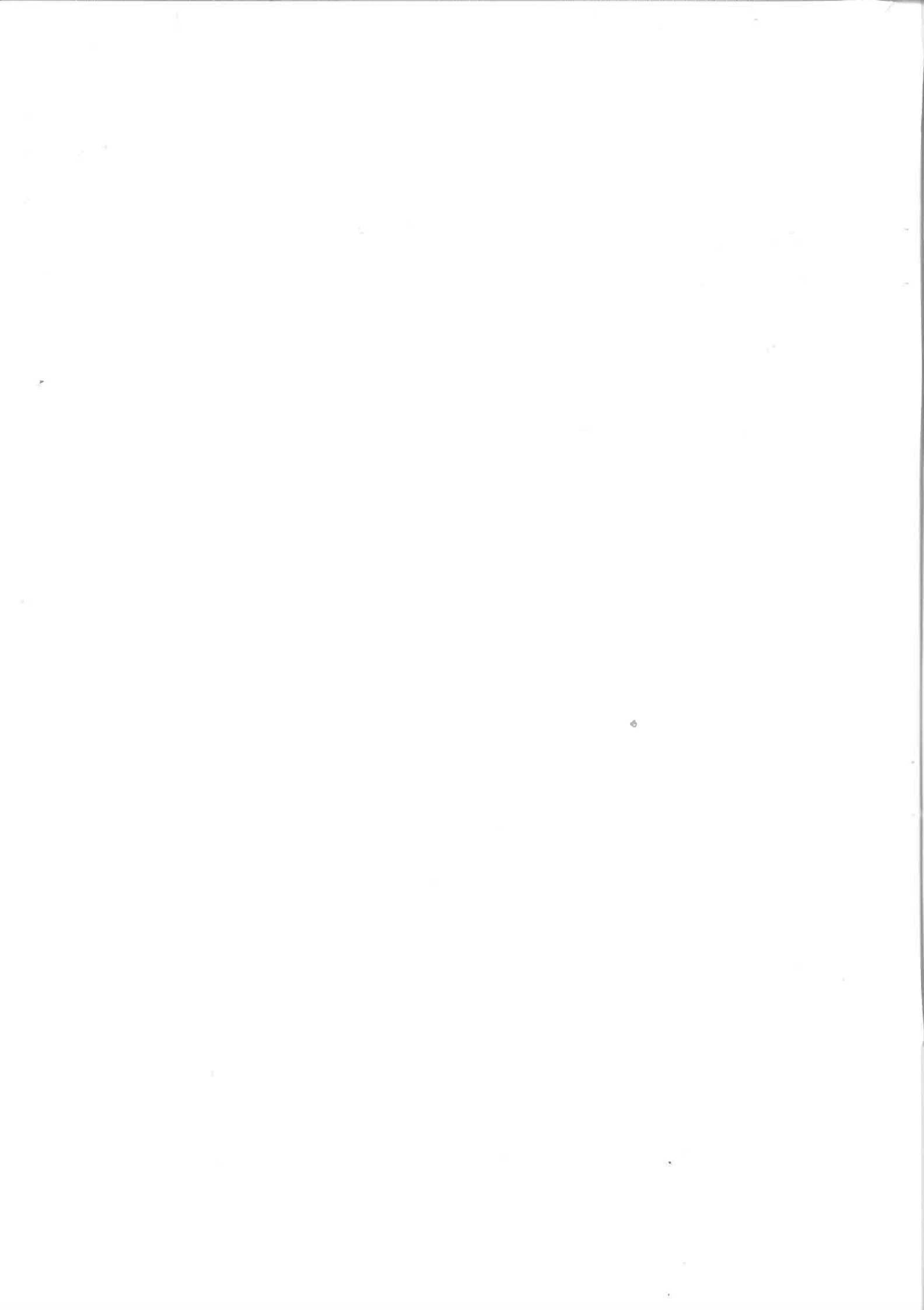
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INTRODUCTION

This "annual report" is, like previous reports, intended to give basic data concerning the mass balance of Storglaciären and the weather at Tarfala Research Station. In addition, a selection of short descriptions of field projects has been included. We have included a relatively large number of tables and figures which we believe may be useful for the reader.

The report includes a number of contributions written by people who have worked at the station. Different ways of presenting data have been chosen by the various authors. The authors are responsible for their method of presentation as well as the text.

I would like to use the opportunity to thank all the scientists and students whose combined efforts have made it possible to operate the research station and conduct research.

Stockholm in February 1993



Wibjörn Karlén
Professor

MASS BALANCE OF STORGLACIÄREN 1991/92

Axel Bodin and Håkan Grudd

SUMMARY

The winter balance of Storglaciären was measured 21-23 May at 311 probing points. The density was measured at five stakes and as there were no systematic differences with height, the average value $0,51 \text{ g/cm}^3$ was used. When the probings were conducted, ablation had just started on the lower part of the glacier. As the first melting results in formation of superimposed ice, coring was conducted at approximately 10 points on the glacier tongue. The average thickness of superimposed ice was 10 cm, which was added to the winter balance. The total winter balance was calculated to 2,24 m water equivalent (w e).

The stake net used for ablation measurements contained 49 stakes. At the end of the season snow density was measured at stake 29, giving an average of $0,61 \text{ g/cm}^3$. Ablation occurred below the equilibrium line between mid September, when the station was closed, and early November when additional measurements were made. This late autumn melting was found to be 19 cm w e in average over the entire tongue, or 9 cm w e in average over the whole glacier. The total ablation was 1,36 m water equivalent, a very low value. Thus, the net balance was 0,88 m water equivalent.

STORGLACIÄRENS MASSBALANS 1991/92

Vinterbalansen bestämdes genom sonderingar i 311 punkter den 21-23 maj, en tidpunkt mycket nära gränsperioden för ackumulation och ablation. Smältningen hade delvis börjat på glaciärens nedre delar varför isborrningar gjordes för att bestämma mängden pålagrad is. Där snötäcket var tunt hade 10-15 cm pålagrad is bildats och medelvärde över hela ablationsområdet var 10 cm. Nedströms profil 22 har därför 9 cm vattenekvivalent (v e) adderats till snösonderingarna. Densiteten bestämdes vid fem stakar (tabell 1) och medelvärdet var $0,51 \text{ g/cm}^3$. Ingen skillnad i densitet noterades mellan glaciärens olika delar. Den totala ackumulationen beräknades till 2,24 m v e.

Ablationen mättes på 49 stakar under sommaren (se stakkarta, fig 5). Sommaren var kallare än normalt vilket resulterade i att ablationen vid de översta stakarna var mycket låg. Redan i början av augusti föll snö i de övre delarna. Denna sommarackumulation är inte mätt separat men kommer med i beräkningarna såsom minskad ablation. Ablationens avtagande med höjden och därmed nettobalansgradienten är således mycket hög för budgetåret, hela 1,41

m/100m. Den 3:e September bestämdes sommarbalansen till 1,27 m v e. Densiteten var då $0,61 \text{ g/cm}^3$ vid stake 29. I början av november konstaterades genom stakavläsningar att ytterligare ablation ägt rum under hösten. I medeltal 21 cm is hade smält nedströms jämviktslinjen. Nedströms 1420 möh har ett påslag beräknats som uppgår till 19 cm v e vilket motsvarar 9 cm v e över hela glaciären. Den totala ablationen är således 1,36 m v e.

Table 1. Snow density measurements on Storglaciären 1991/92.

Date	Location (stake)	Average density
22/2	6	0,35
22/2	14	0,38
22/2	29	0,43
22/5	3	0,51
22/5	12n3	0,53
22/5	16	0,49
22/5	29	0,52
22/5	31n7	0,50
3/9	29	0,61

Stakarna på Storglaciären mättes i år in med GPS (Global Positioning System), ett satellitbaserat mätsystem som installerats i Tarfala under sommaren. Noggrannheten i de mätningar som utförts i sommar är av storleksordningen ± 2 m (se vidare avsnittet "GPS measurements of glaciers in Swedish Lapland 1992" i denna rapport).

Nettobalansgradienten, G , är beräknad som kvoten mellan intervallen 1640-1660 möh och 1320-1340 möh:

$$G = (3.61 - (-0.91)) / (1660 - 1340)$$

Jämviktslinjens h ö h , ELA, är beräknad linjärt mellan 1380 möh och 1420 möh:

$$ELA = ((1410 - 1390) * 0.11 / 0.65) + 1390$$

Akkumulationsområdets storlek i procent av totala arean, AAR, beräknas med ledning av jämviktslinjens höjd enligt ovan till 58%.

Sonderingsprotokoll från snödjupsmätningarna den 21-23/5 är liksom statistik över alla massbalansmätningar sedan 1945/46 redovisad i appendix 6.

Storglaciären 1991/92

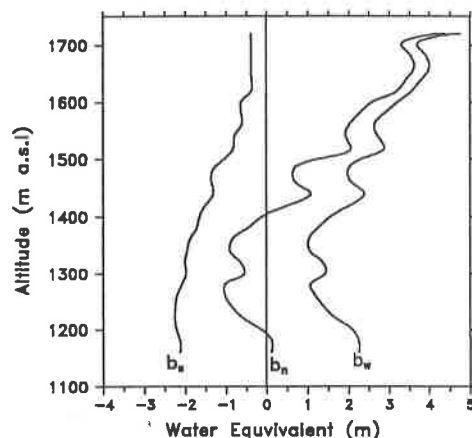


Figure 2. Winter-, summer-, and net balance as a function of height.

Storglaciären

Nettobalans 1991/92

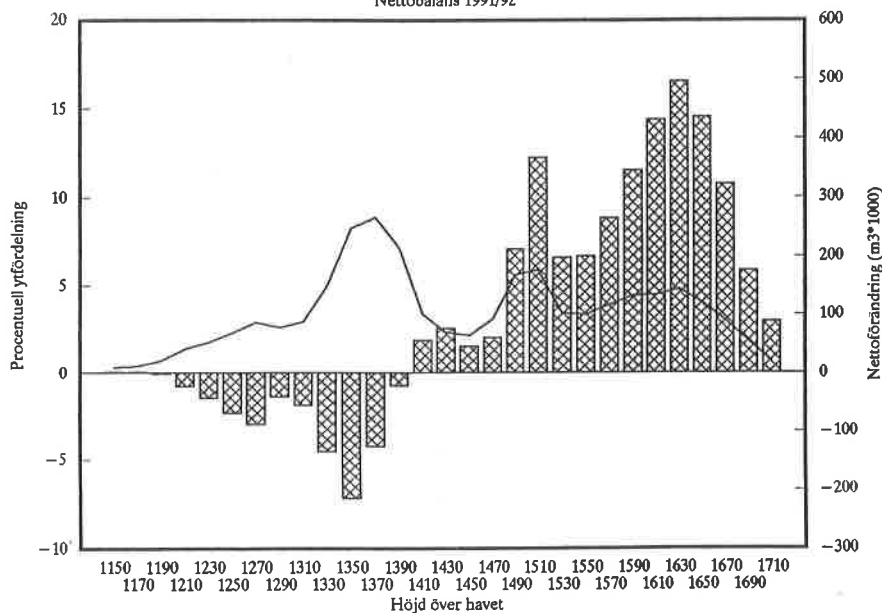


Figure 1. Net balance and area distribution (%) as a function of height.

Table 2. Mass balance of Storglaciären 1991/92.

Height	Area	Ackumulation		Ablation		Net balance	
m a sl	10 ³ m ²	10 ³ m ³	m w e	10 ³ m ³	m w e	10 ³ m ³	m w e
-1160	8.8	19.8	2.25	18.7	2.13	1.1	0.12
1160-1180	11.2	25.2	2.25	23.8	2.13	1.4	0.13
1180-1200	20.7	43.1	2.08	46.0	2.22	-2.9	-0.14
1200-1220	40.3	67.5	1.67	91.1	2.26	-23.6	-0.59
1220-1240	52.1	72.2	1.39	117.1	2.25	-44.9	-0.86
1240-1260	68.5	81.4	1.19	151.7	2.21	-70.3	-1.03
1260-1280	86.1	90.9	1.06	180.1	2.09	-89.2	-1.04
1280-1300	77.6	111.0	1.43	153.3	1.98	-42.3	-0.55
1300-1320	87.2	118.6	1.36	175.1	2.01	-56.5	-0.65
1320-1340	149.0	156.3	1.05	292.5	1.96	-136.2	-0.91
1340-1360	251.0	257.2	1.02	473.5	1.89	-216.3	-0.86
1360-1380	269.0	334.9	1.24	461.6	1.72	-126.7	-0.47
1380-1400	216.7	335.5	1.55	358.4	1.65	-22.9	-0.11
1400-1420	101.7	208.1	2.05	152.7	1.50	55.4	0.54
1420-1440	69.6	166.4	2.39	91.5	1.31	74.9	1.08
1440-1460	63.5	131.1	2.06	86.6	1.36	44.5	0.70
1460-1480	92.1	181.5	1.97	122.4	1.33	59.1	0.64
1480-1500	168.4	389.2	2.31	176.6	1.05	212.6	1.26
1500-1520	178.1	513.5	2.88	146.1	0.82	367.4	2.06
1520-1540	102.5	279.0	2.72	81.9	0.80	197.1	1.92
1540-1560	99.6	262.4	2.63	62.2	0.62	200.2	2.01
1560-1580	117.4	338.6	2.88	73.4	0.63	265.2	2.26
1580-1600	133.4	428.6	3.21	83.4	0.63	345.2	2.59
1600-1620	134.5	480.6	3.57	50.4	0.37	430.2	3.20
1620-1640	144.9	549.7	3.79	54.3	0.37	495.4	3.42
1640-1660	120.2	479.6	3.99	45.1	0.38	434.5	3.61
1660-1680	90.8	355.7	3.92	34.1	0.38	321.6	3.54
1680-1700	52.8	194.2	3.68	19.8	0.38	174.4	3.30
1700-1720	20.2	96.0	4.75	7.6	0.38	88.4	4.38
	3027.9	6767.8	2.24	3831.0	1.27	2936.8	0.97
Sep-nov:				273.6	0.09		
Total:	3027.9	6767.8	2.24	4104.6	1.36	2663.2	0.88

ELA = 1393 möh
 Net balance gradient, $G = 1.41 \text{ m}/100\text{m}$
 AAR = 58 %

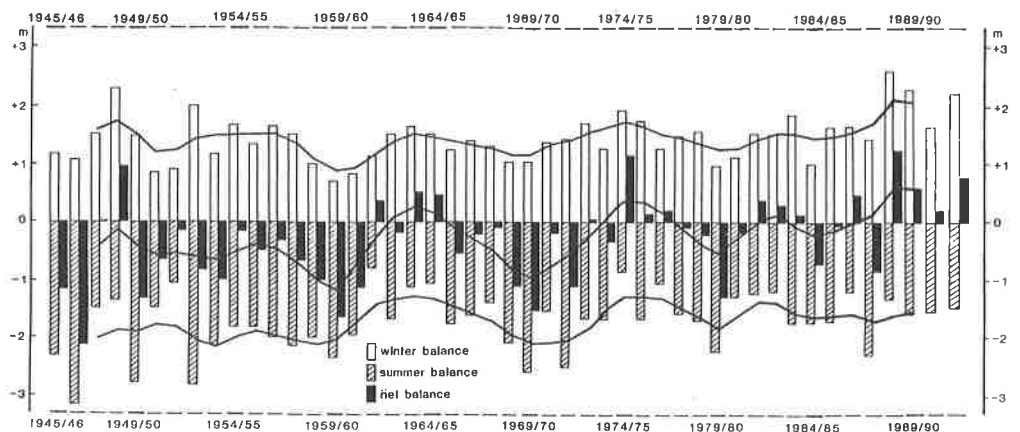


Figure 3. The mass balance record for Storglaciären.

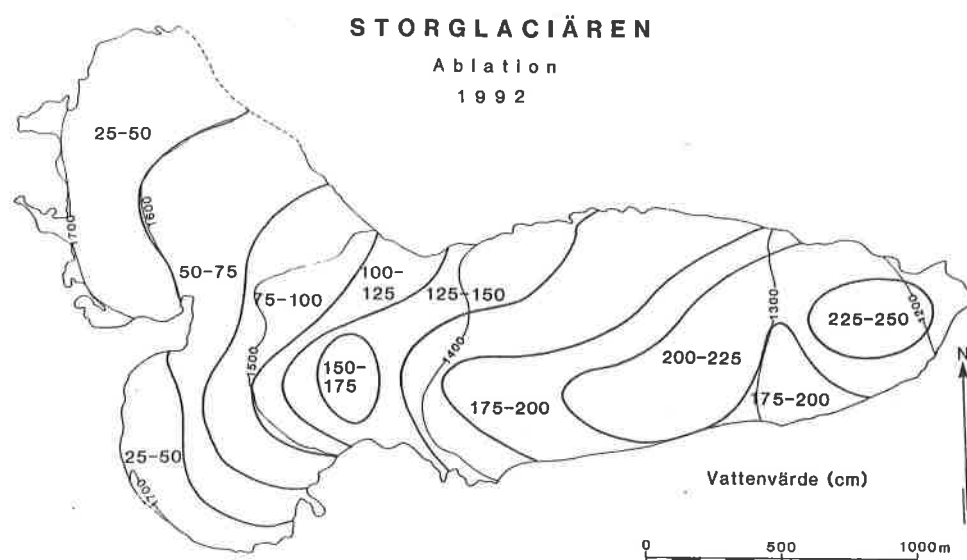
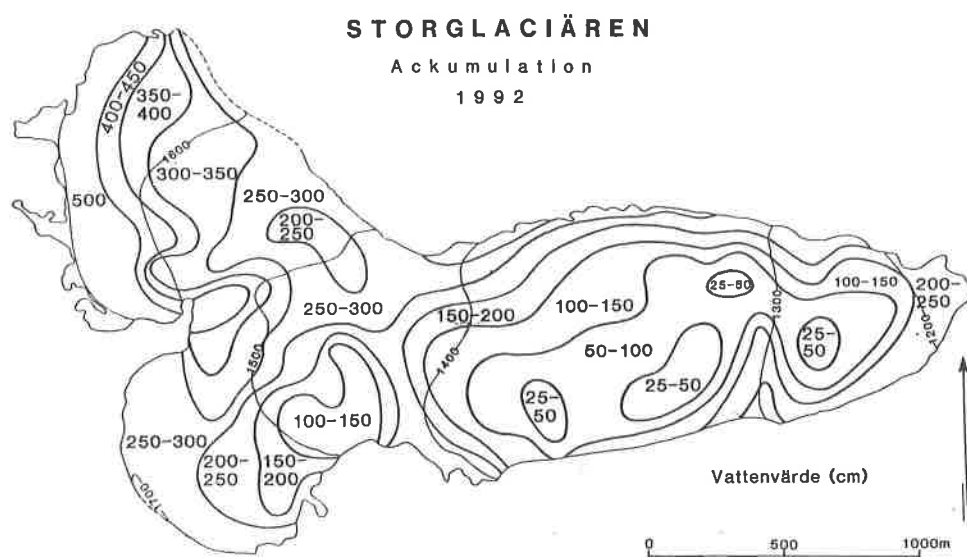


Figure 4. Accumulation (21-23 May) and ablation (-3/9) on Storglaciären.

STORGLACIÄREN Stakpositioner 1992

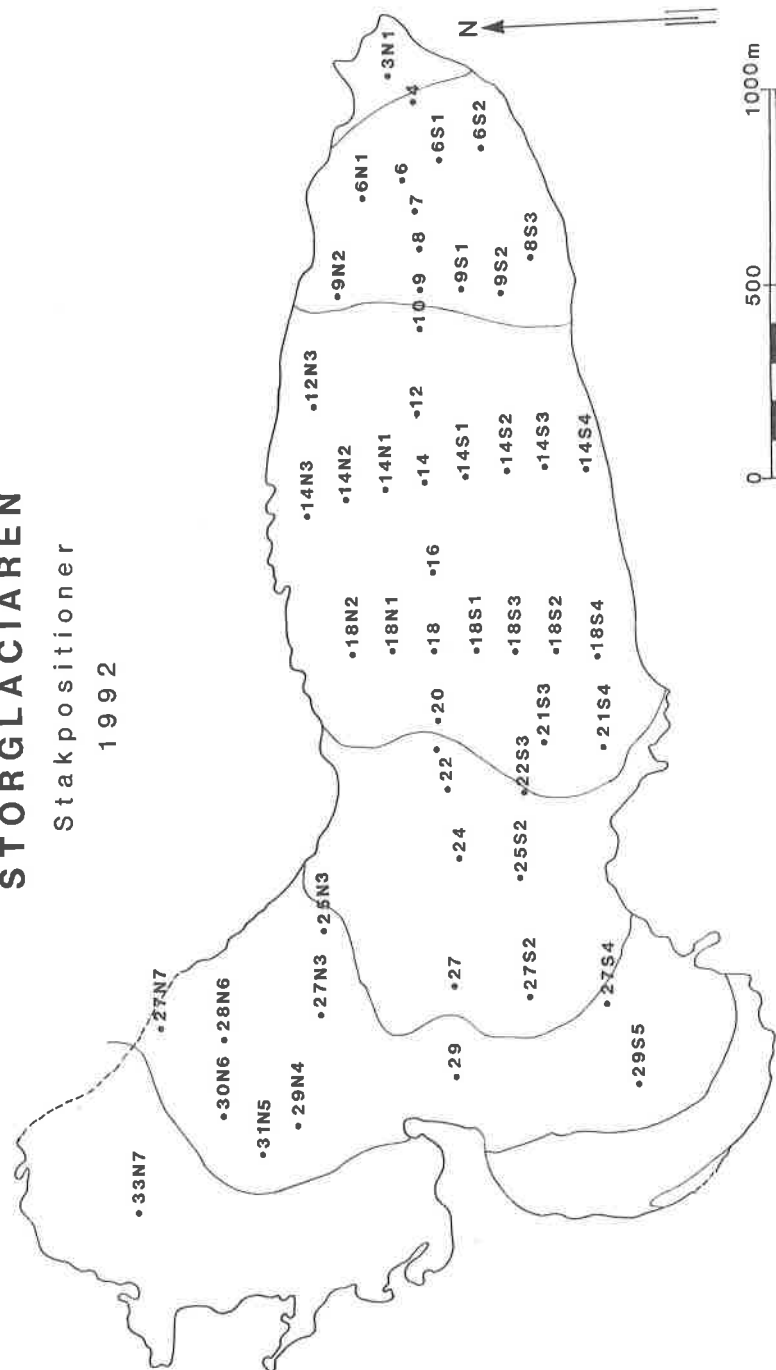


Figure 5. Stake positions on Storglaciären in early September 1992. All stakes were measured using GPS and are related to the fix points 16A, 18A, P40 and Hyllan.

METEOROLOGICAL OBSERVATIONS IN TARFALA 1991/92

Håkan Grudd

INTRODUCTION

Meteorological records in Tarfala extend back to 1946. The first years' observations were made manually during the periods when the station was operated. Later, chart recorders were installed, but it was not possible to get continuous yearly records until the early 60s when the station received electric power. Since 1965 there has been a good annual temperature record. In 1987 a new meteorological station was set up a couple of metres from the old one. This station is monitored by a datalogger and is connected to a computer inside one of the buildings via short-haul modem. In wintertime it is possible to transfer the data directly to a computer in Stockholm via the telephone line. The datalogger monitors the meteorological sensors every ten seconds, storing hourly mean values during the summer and three-hour mean values during the winter. The logger also computes minimum and maximum values as well as daily averages. Some of the meteorological data are presented in the annual reports from Tarfala (e.g. Grudd 1992). In appendix 3 the most important data for 1992 are presented.

THE METEOROLOGICAL YEAR 1992

summer. The mean summer temperature was 5,2 °C, which is only 0,4 °C colder than normal.

Table 1. Monthly mean values, Jan-Oct.

MONTH	MEAN TEMP [°C]	MEAN HUMID [%]	MEAN MAXTEMP [°C]	MAXTEMP [°C]	MEAN MINTEMP [°C]	MINTEMP [°C]	MEAN VIND [m/s]	MAXVIND [m/s]	PRECIP [mm]
1	-7.0	62	-3.2	4.0	-11.1	-21.3	7.4	63.6	20
2	-7.5	64	-3.8	2.7	-12.0	-20.0	4.5	59.2	4
3	-7.2	66	-3.8	7.0	-12.1	-21.7	3.9	32.9	13
4	-8.8	70	-3.3	3.9	-13.4	-22.1	2.9	21.8	38
5	0.8	60	5.4	13.6	-3.8	-11.8	3.7	26.4	34
6	5.7	48	9.5	16.5	1.3	-4.3	3.7	28.7	48
7	5.6	69	8.5	11.5	2.9	-0.8	3.4	27.8	220
8	4.2	84	6.5	10.0	2.2	-2.3	2.3	24.5	125
9	2.6	82	5.1	13.1	0.1	-4.4	2.3	16.0	152
10	-9.2	64	-6.2	6.1	-13.5	-21.1	3.0	31.5	27

The most striking feature of the temperature climate in Tarfala during the last year was the unusually warm winter (Figures 1 and 2). The mean temperature for the winter (here defined as October to April) was -6,5 °C (Table 1). This was the warmest winter yet since records of the winter temperature were begun in 1965. The coldest winter month was in fact April.

The warmest summer month was June; especially the first half of June was warmer than normal (Fig. 2). The maximum summer temperature, 16,5 °C, occurred on June 11. This was a period when the whole country had unusually warm weather. Both July and August were colder than normal (Fig. 1). Snow fell on the glaciers on several occasions throughout the

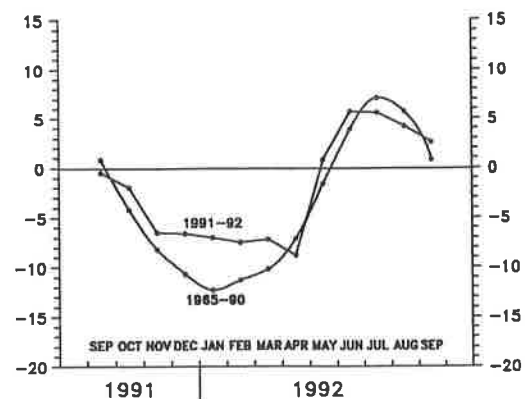


Figure 1. Difference between the temperatures during the mass balance year 1991-92 and the temperatures from 1965-90, which are considered to be "normal" and are the reference.

DAILY MEAN TEMPERATURES AT TARFALA 1991-92

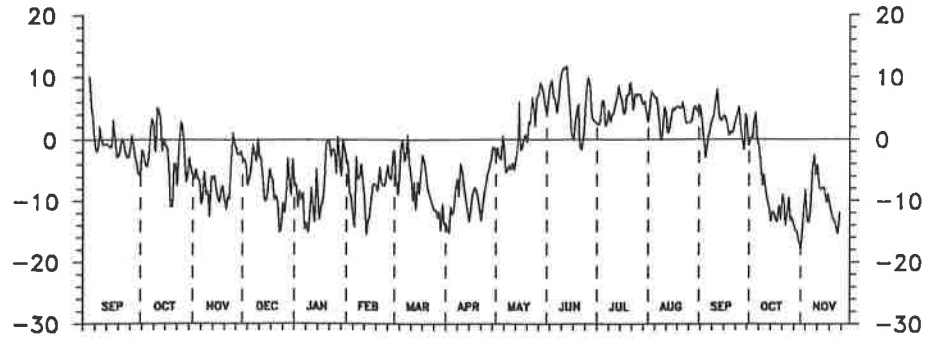


Figure 2. The winter 1991-92 was the fourth mildest winter in a row with daily mean temperatures around zero degrees at several occasions. The coldest temperature of the winter, -22,1 °C, was recorded on 22 April (Appendix 3).

The mean temperature of the mass balance year 1991/92 was -2,2 °C, which is one of the highest annual temperatures recorded since 1965. The normal annual mean temperature (1965-90) is -4,0.

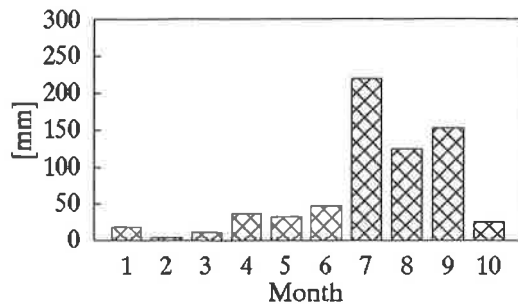


Figure 3. Monthly precipitation as registered by the datalogger.

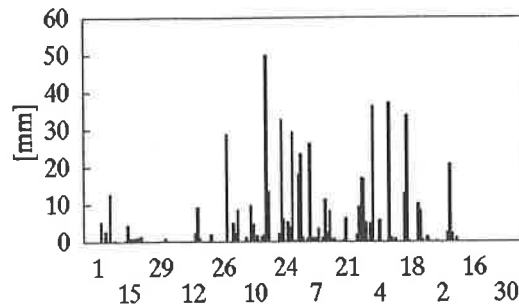


Figure 4. Daily precipitation from May 1 to October 31.

June was exceptionally dry with only 48 mm of precipitation, of which about 30 mm fell during one single rainstorm. The wettest month during 1992 was July, with 220 mm of precipitation (Fig. 3).

As reported in the 1990-91 Annual Report, December 1991 was an extremely windy month, with the highest wind speed ever recorded in Tarfala, 69 m/s (Grudd 1992, Karlén 1992). However, January 1992 was even more extreme. The average wind speed for the month was 7,4 m/s. During 17 days the daily maximum wind speed exceeded 30 m/s and two of those days experienced winds over 60 m/s (Appendix 3).

REFERENCES

- Grudd, H., 1992: Meteorologiska observationer i Tarfala 1991. In Annual Report 1990-1991. Grudd, H., ed., Dept. of Physical Geography, Stockholm University, Forskningsrapport 92: 14-19.
- Karlén, W., 1992: Blåsiget i fjällen. Väder och Vatten, Mars 1992, SMHI: 17.

MASS BALANCE OF RABOTS GLACIÄR 1991/92

Axel Bodin

SUMMMARY

The mass balance was measured on Rabots glaciär in the spring and in late August. Probing in 98 points on the 13th and 14th of May resulted in the calculation of a winter balance of 1,65 m water equivalent (w e). Four stakes were drilled down and one old stake proved to be useful for ablation measurements. The summer balance is based on measurements of these 5 stakes and mapping of the transient snow line on the 19th of August. As ablation continued long after the glacier was visited, an extra 20 cm w e is added to the ablation, an estimate based on measurements on Storglaciären. This gives a total of 1,54 m w e ablation and thus the net balance is 0,11 m w e.

MASSBALANSMÄTNINGAR 1992

Rabots glaciär besöktes den 13:e och 14:e maj varvid vinterbalansen bestämdes genom snödjupssonderingar i 98 punkter. Medeldensiteten var $0,47 \text{ g/cm}^3$ vid "Svarta väggen". Fyra nya stakar borrades i och en gammal stake påträffades och mättes. Den totala ackumulationen var 1,65 m vattenekvivalent (v e).

Avläsningar av fem stakar utgör jämte kartering av den temporära snögränsen den 19/8 underlag för beräkning av sommarbalansen. Eftersom smältningen fortgick långt in i september har ett påslag av 20 cm ablation gjorts utifrån mätningar på Storglaciären under denna tid. Den totala ablationen är därmed 1,54 m v e vilket gör att nettobalansen är 0,11 m v e.

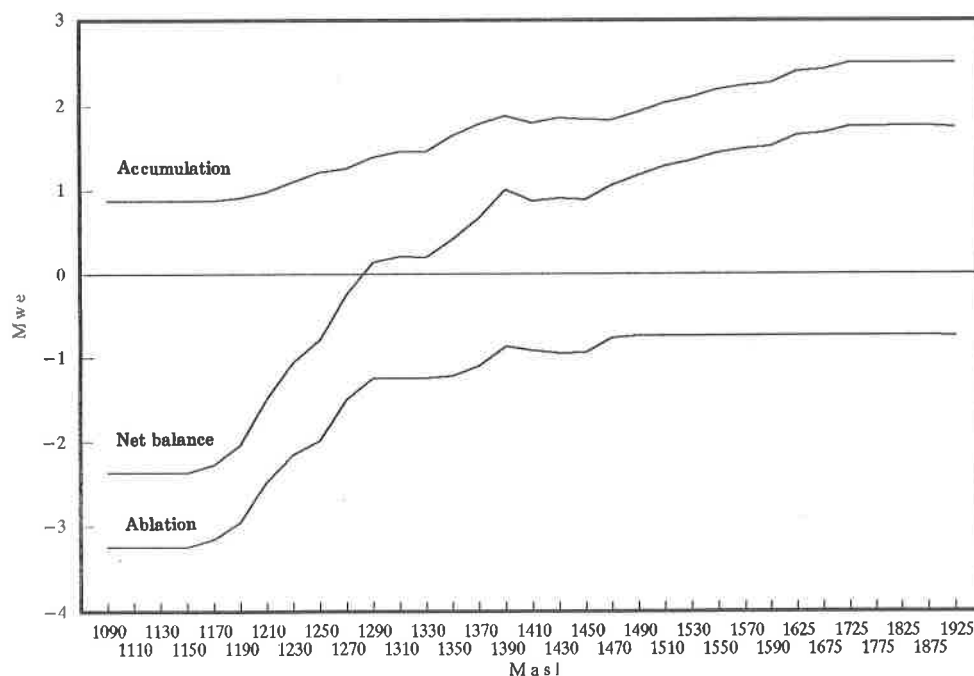


Figure 1. Accumulation, ablation and net balance as a function of height.

Table 1. Mass balance of Rabots glacier 1991/92.

Height	Area	Accumulation		Ablation		Net balance	
m a sl	10 ³ m ²	10 ³ m ³	m w e	10 ³ m ³	m w e	10 ³ m ³	m w e
-1100	17.8	15.6	0.88	57.8	3.25	-42.2	-2.37
1100-1120	36.7	32.1	0.87	119.3	3.25	-87.2	-2.38
1120-1140	47.2	41.3	0.88	153.4	3.25	-112.1	-2.37
1140-1160	65.3	57.1	0.87	212.2	3.25	-155.1	-2.38
1160-1180	89.7	78.5	0.88	283.5	3.16	-205.0	-2.29
1180-1200	89.5	81.8	0.91	264.9	2.96	-183.1	-2.05
1200-1220	128.4	126.0	0.98	319.4	2.49	-193.4	-1.51
1220-1240	169.8	186.0	1.10	367.1	2.16	-181.1	-1.07
1240-1260	196.3	237.8	1.21	392.4	2.00	-154.6	-0.79
1260-1280	222.5	279.7	1.26	336.1	1.51	-56.4	-0.25
1280-1300	213.0	296.4	1.39	266.3	1.25	30.1	0.14
1300-1320	135.1	197.0	1.46	168.9	1.25	28.1	0.21
1320-1340	137.9	200.7	1.46	172.4	1.25	28.3	0.21
1340-1360	235.4	386.3	1.64	289.8	1.23	96.5	0.41
1360-1380	270.3	480.5	1.78	300.2	1.11	180.3	0.67
1380-1400	216.1	406.7	1.88	189.6	0.88	217.1	1.00
1400-1420	103.0	184.6	1.79	95.3	0.93	89.3	0.87
1420-1440	109.2	202.6	1.86	104.4	0.96	98.2	0.90
1440-1460	126.3	231.8	1.84	120.2	0.95	111.6	0.88
1460-1480	147.8	270.9	1.83	114.9	0.78	156.0	1.06
1480-1500	180.8	347.5	1.92	135.6	0.75	211.9	1.17
1500-1520	211.4	429.1	2.03	158.6	0.75	270.5	1.28
1520-1540	161.5	339.2	2.10	121.1	0.75	218.1	1.35
1540-1560	98.8	216.8	2.19	74.1	0.75	142.7	1.44
1560-1580	83.3	186.6	2.24	62.5	0.75	124.1	1.49
1580-1600	64.7	146.7	2.27	48.5	0.75	98.2	1.52
1600-1650	111.6	267.8	2.40	83.7	0.75	184.1	1.65
1650-1700	65.2	158.3	2.43	48.9	0.75	109.4	1.68
1700-1750	50.5	126.3	2.50	37.9	0.75	88.4	1.75
1750-1800	13.5	33.8	2.50	10.1	0.75	23.7	1.76
1800-1850	10.3	25.8	2.50	7.7	0.75	18.1	1.76
1850-1900	10.3	25.8	2.50	7.7	0.75	18.1	1.76
1900-1950	4.9	12.3	2.50	3.7	0.76	8.6	1.74
Aug	3824.1	6309.4	1.65	5128.2	1.34	1181.2	0.31
Aug-sep:				764.8	0.20		
Total:	3824.1	6309.4	1.65	5893.0	1.54	416.4	0.11

ELA = 1283 möh

Net balance gradient, $G = 0.75 \text{ m/100m (d1700/1200)}$

AAR = 71 %

G is calculated as the quotient between the intervals 1650-1700 masl and 1180-1200 masl:

$$G = (1.68 - (-2.05)) / (1700 - 1200)$$

ELA is calculated lineary between 1260 masl and 1300 masl, which also gives AAR:

$$\text{ELA} = ((1290 - 1270) * 0.25 / 0.39) + 1270$$

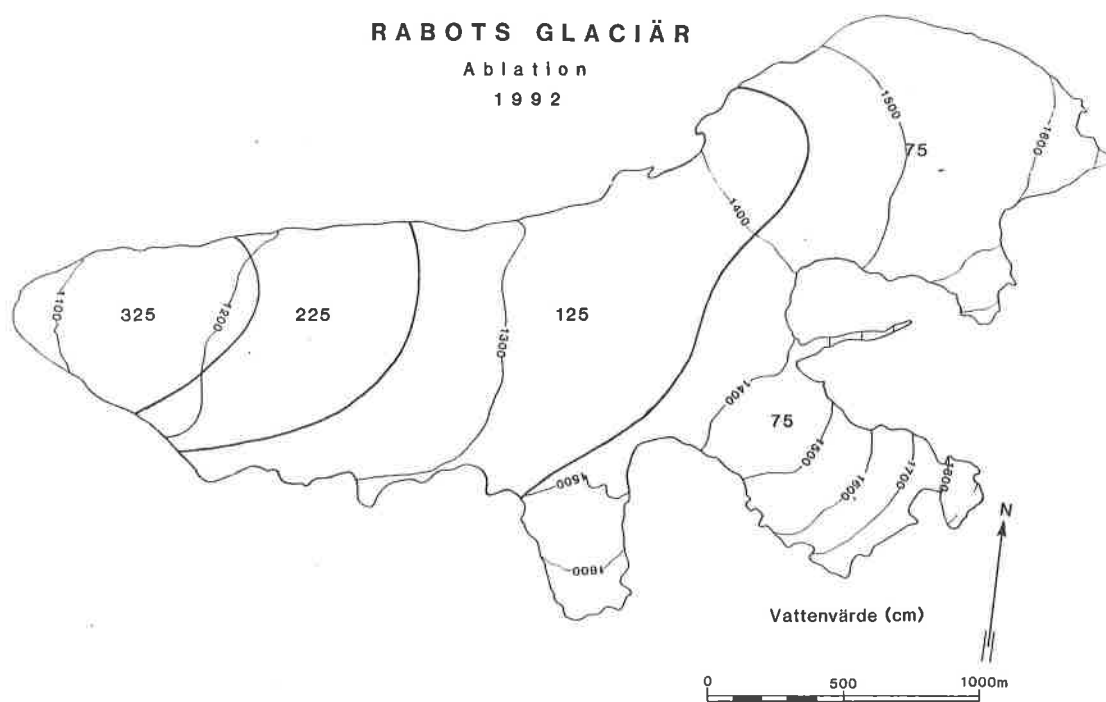
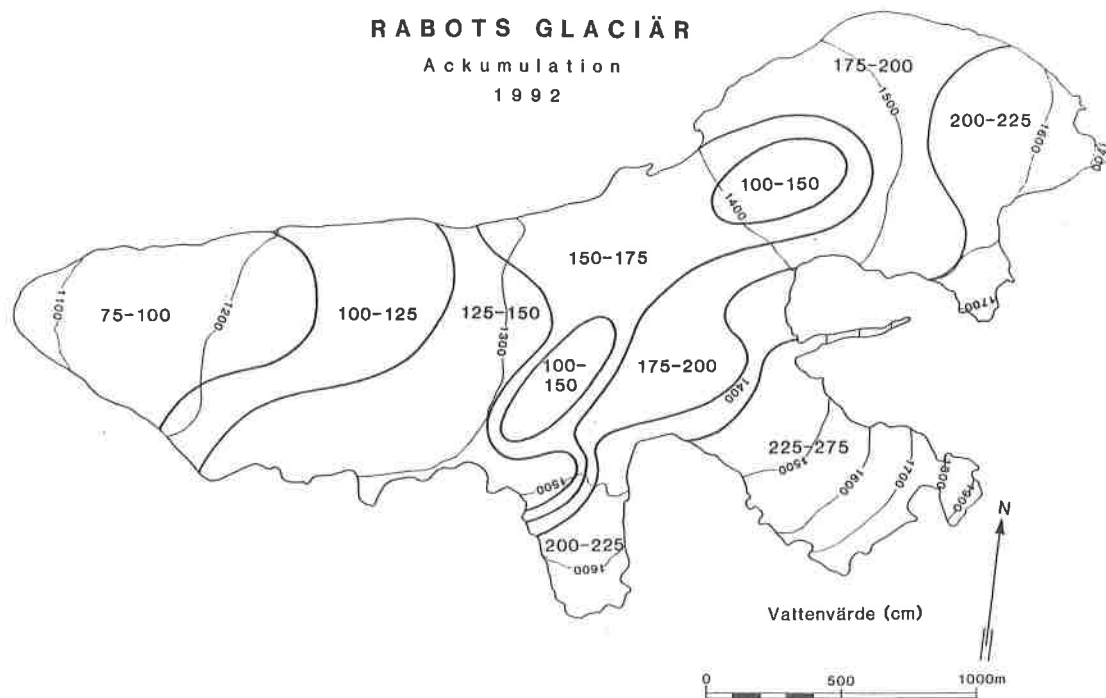


Figure 2. Accumulation and ablation on Rabots glacier 1991/92.

A THREE YEAR STUDY OF THE MASS BALANCE OF MÅRMAGLACIÄREN

Axel Bodin

ABSTRACT

Mårmaglaciären is located about 30 km north of Tarfala in the Mårma massif. For the last three years mass balance surveys have been conducted there. The results are significantly different compared with those from Storglaciären. The net balance has been almost constant from year to year. During the three years of study the accumulation varied between 1,15-1,30 m water equivalent (w e) and the ablation varied between 1,20-1,40 m w e. Consequently, the net balance is close to zero or slightly negative for the three year period. The net balance gradient is low (0,5 m/100 m), and so is the accumulation, indicating a far more continental climate in the Mårma massif than in the Kebnekaise massif.

MÅRMAGLACIÄRENS MASSBALANS 1991/92

Mårmaglaciären besöktes den 16/4 varvid vinterbalansen bestämdes. Snösonderingar gjordes i 113 punkter och densiteten bestämdes vid den översta av de tre stakar som borrades ned. Medeldensiteten var 0,45 g/cm³. En gammal stake återfanns också och mättes in. Ackumulationen bestämdes till 1,21 m vatten-ekvivalent (v e). Med ledning av mätningar på Storglaciären har totalt 10 cm v e adderats till ackumulationen för perioden april-maj. Den totala vinterbalansen var således 1,31 m v e.

Den 2/9 besöktes Mårmaglaciären åter varvid stakarna lästes av och den temporära snögränsen karterades. Den totala sommarbalansen beräknades uppgå till 1,22 m v e och nettobalansen var således 0,09 m v e.

MÅRMAGLACIÄREN 1990-92

Tre års mätningar på Mårmaglaciären har visat en förbluffande likhet i såväl ackumulation som ablation. Ackumulationen tycks vara ca en meter v e lägre än på Storglaciären och ablationen mellan 1,2 och 1,4 m v e, ca 0,25 m v e lägre än på Storglaciären. Skillnaden i massbalans mellan de tre åren är påfallande liten och totalt har Mårmaglaciärens massa *minskat* med motsvarande 9 cm v e/år, att jämföra med

Storglaciären vars massa *ökat* med motsvarande 55 cm v e/år!

Mårmaglaciärens nettobalansgradient är mycket låg, endast ca 0,5 m/100 m. Detta, jämte den låga massomsättningen, tyder på att klimatet i Mårmamassivet är betydligt mera kontinentalt än i Kebnekaisemassivet.

Table 1. The mass balance of Mårmaglaciären during the last three years.

Year	Winter balance mwe	Summer balance mwe	Net balance mwe	ELA masl	Net balance gradient m/100m
89/90	1,29	1,40	-0,11	1624	0,41
90/91	1,15	1,39	-0,24	1624	0,47
91/92	1,31	1,22	0,09	1539	0,54

Den låga ablationen massbalansåret 91/92 resulterade i en dramatisk sänkning av jämviktslinjen och en motsvarande ökning av ackumulationsområdets teoretiska storlek i förhållande till den totala arean (AAR). AAR var endast 21 % åren 89/90 och 90/91 men hela 51 % innevarande år. Detta påverkar dock nettobalansen mycket lite, vilket tydligt framgår då nettobalansen betraktas som funktion av höjden (fig 1). Massbalanstabeller för samtliga tre år återfinns i appendix 4.

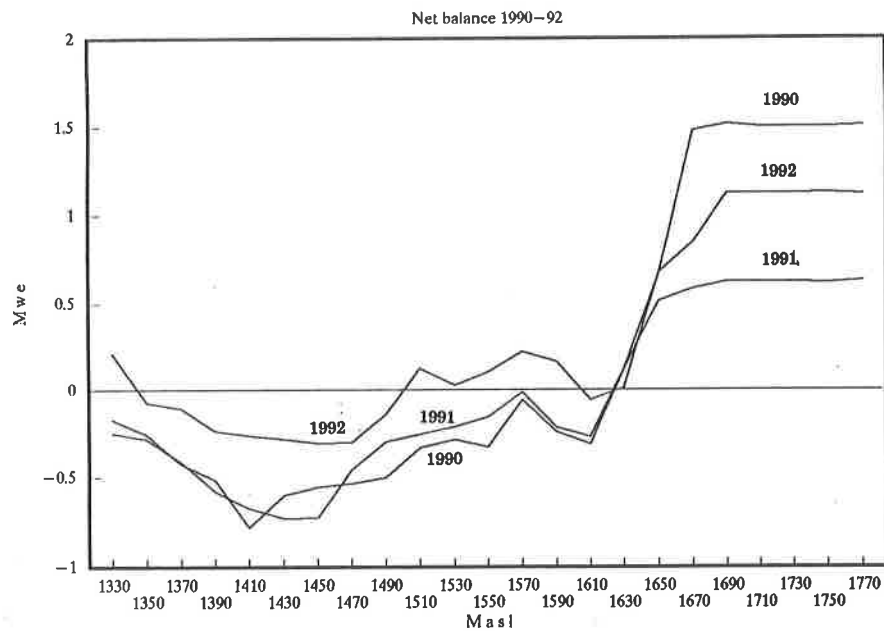


Figure 1. Net balance of Mårmagläciären the three years of measurements, 1990-92.

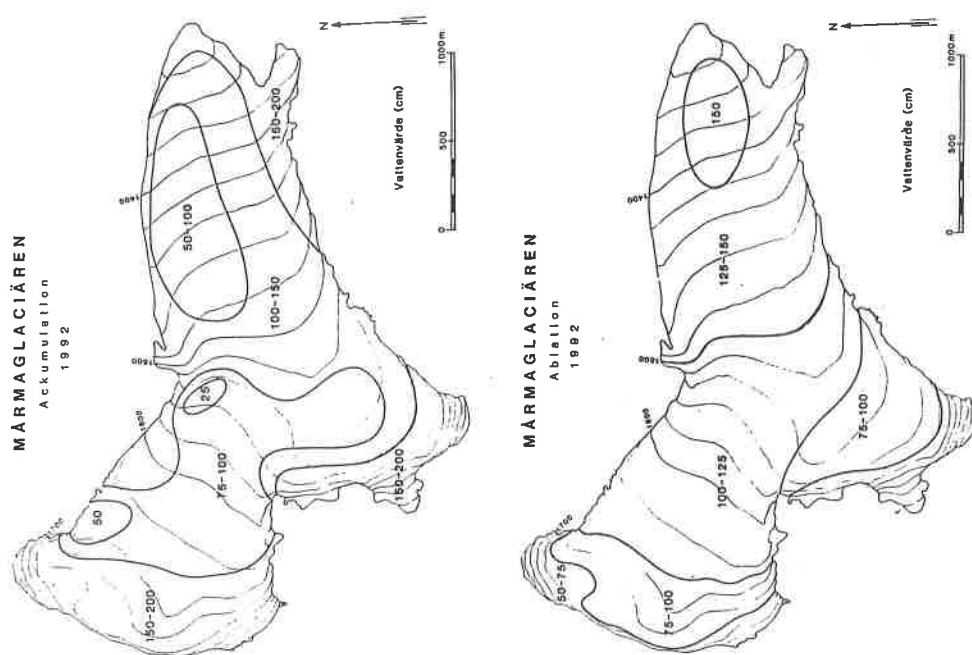


Figure 2. Accumulation and ablation of Mårmagläciären 1991/92.

A THREE YEAR STUDY OF THE MASS BALANCE OF KÅRSAGLACIÄREN

Axel Bodin

ABSTRACT

Mass balance measurements, one of a number of measurements made of Kårsaglaciären, have been carried out for the last three years. Even though the general trend (i.e. net balance) is comparable with Storglaciären, Kårsaglaciären has a quite unusual distribution of accumulation and ablation, resulting in an extremely low net balance gradient. The net balance has been positive for the last three years, giving a total net income of 1,12 m water equivalent. Slightly positive net balances were recorded for the 1989/90 and 1990/91 budget years, while the last glaciological year, 1991/92, showed a gain of 0,87 m water equivalent. This means that almost the entire glacier was snow-covered by the end of the ablation season 1992.

The net balance gradient ranges between 0,4 and 0,5 m/100 m, which is approximately the same value as that calculated for the years between 1942 and 1948 (Wallén, 1948). A major study concerning the reaction of Kårsaglaciären to the 20th century climate is in preparation. This work is based on ice velocity measurements, radio-echo soundings, field measurements and aerial photographs, as well as on lake sediment corings and the mass balance measurements presented here.

KÅRSAGLACIÄRENS MASSBALANS 1991/92

Vinterbalansen bestämdes efter två besök under våren -92. Sonderingar i 79 punkter gjordes redan i slutet av mars. Densiteten var då 0,46 g/cm³. En kompletterande sondering i 35 punkter jämte stakavläsningar (8 stakar borrades ned i mars) gjordes den 10 maj. Som densitetsökning antogs värden från Storglaciären för samma tidsintervall. Den totala ackumulationen är beräknad till 2,26 m ekvivalent vattenmängd (v.e.).

Ablationen baseras på stakavläsningar den 10 augusti och den 15 september. Dessutom fotograferades glaciären vid en förbi-flygning den 2 september. Nästan hela glaciären var snötäckt fram till september. Totalt var ablationen 1,39 m v.e. och nettobalansen således 0,87 m v.e. Jämviktslinjen beräknades till 1088 m ö.h. och nettobalansgradienten var 0,40 m/100 m. I sin helhet presenteras massbalansmätningarna 1991/92 tillsammans med de båda föregående årens mätningar i Appendix 5.

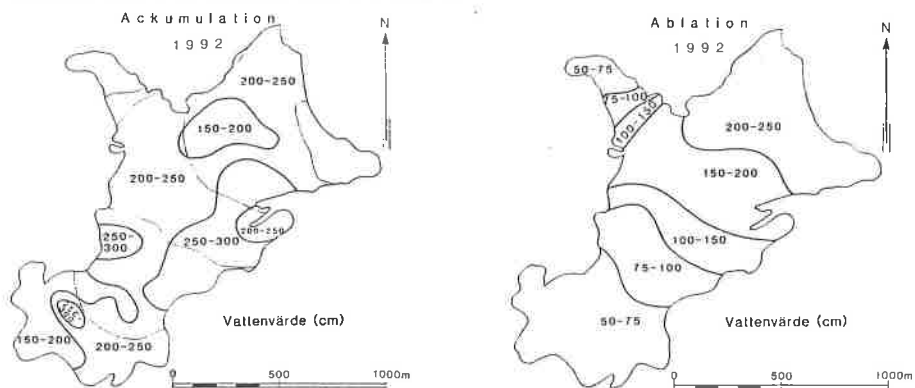


Figure 1. Accumulation (left) and ablation (right) on Kårsaglaciären 1991-92.

DISKUSSION

Table 1. The mass balance of Kårsaglaciären during the last three years.

Year	Winter balance mwe	Summer balance mwe	Net balance mwe	ELA balance masl	Net balance gradient m/100m
89/90	2,11	1,93	0,18	1088	0,49
90/91	1,86	1,79	0,07	1144	0,39
91/92	2,26	1,39	0,87	1012	0,40

Sommarbalansen är väl korrelerad med sommar-medeltemperaturen vid den närliggande meteorologiska stationen i Katterjåkk (Wallén 1948, Bodin 1991). Nederbörden under vinterhalvåret går dock inte att korrelera på motsvarande sätt, varför nettobalansen inte med någon större säkerhet kan utläsas ur klimatdata från SMHI. Däremot tycks ackumulationen samvariera med motsvarande mätningar på Storglaciären, dvs att hög ackumulation på Storglaciären har en motsvarighet i hög ackumulation på Kårsaglaciären och vice versa. De tre år som studerats är dock inte ett tillräckligt underlag för en sådan slutsats. Det är således befogat att ytterligare i några år mäta massbalansen på Kårsaglaciären.

Med en längre sammanhängande massbalans-serie kan ett eventuellt samband mellan Storglaciären och Kårsaglaciären bekräftas. Detta skulle vara till stor hjälp för pågående modellerings-försök av Kårsaglaciären (Bodin, in prep).

REFERENSER

Bodin, A., 1991: Kårsaglaciärens reträtt under 1900-talet. Examensarbete, Naturgeografiska institutionen, Stockholms universitet. 34 p.

Wallén, C. C., 1948: Glacial-meteorological investigations on the Kårsa glacier in Swedish Lapland 1942-1948. *Geografiska Annaler* 30 (1-2): 451-672.

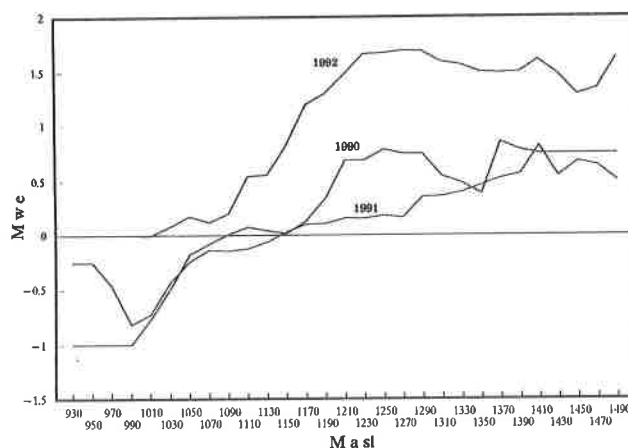


Figure 2. Net balance of Kårsaglaciären 1990-92.

MASS BALANCE OF TARFALAGLACIÄREN 1990-92

Håkan Grudd

INTRODUCTION

Tarfalaglaciären is a relatively small and steep glacier on the eastern slope of the ridge between Tarfalapakte and Tarfalatjåkka, two summits east of Tarfala valley. The glacier is located between 1390 and 1730 m a.s.l. and covers an area of 0,86 km² (Holmlund 1987). Its average slope inclination is 20 degrees. There are no cirque walls surrounding the glacier but although it is small in size, it has some impressive ice-cored moraines (Östrem 1962). The glacier is believed to be to a great extent frozen to its bed (Grudd 1990). The mass balance of Tarfalaglaciären has been measured since 1985.

1989/90

The winter balance was measured on May 31. Snow depths were measured at 35 points and the snow density at one site. A PICO auger was used during the density measurements. The mean snow density was 0,50 g/cm³ and this was considered to be representative for the whole glacier. The winter balance (B_w) was calculated to be 1,795 10⁶ m³ w.eq. (water equivalent) or 2,09 m w.eq. as an average value for the glacier surface (b_w).

The summer balance was calculated by measuring ablation at five points on the glacier. Three stakes were drilled down into the ice on May 31 and, in addition to this, two points at a known distance from the stakes were used. The ablation and the density of the remaining snow were measured on September 9. The density was 0,58 g/cm³. A linear relation was assumed between ablation and altitude (Schytt 1967). With a simple linear regression analysis of the ablation data, the ablation gradient was calculated to be 0,47*10⁻² m/m (Fig. 1). The summer balance was 2,09 m w.eq. (Tab. 1).

Tarfalaglaciären had no net change of mass during the balance year 1989/90. The net balance calculated as the difference between winter balance (B_w) and summer balance (B_s) was -2100 cubic metres w.eq. (Tab. 1). This is well within the limits of the errors and is considered to be zero. The equilibrium line altitude was 1510 m.

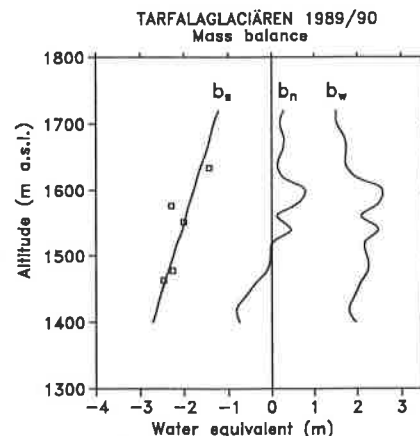


Figure 1. b_s = summer balance, b_w = winter balance and b_n = net balance as a function of altitude. Squares represent the ablation at different points (stakes).

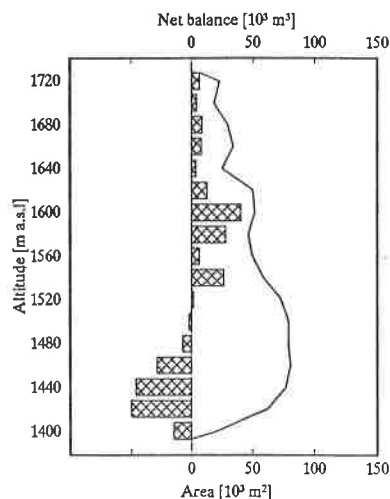


Figure 2. Net balance (B_n) and area as a function of altitude.

Table 1. 1989/90

Altitude interval [m a.s.l.]	Area [10 ³ m ²]	Winter balance		Summer balance		Net balance	
		Bw [10 ³ m ³]	bw [m]	Bs [10 ³ m ³]	bs [m]	Bn [10 ³ m ³]	bn [m]
1710 - 1730	23.0	34.8	1.51	28.1	-1.22	6.6	0.29
1690 - 1710	19.0	29.2	1.53	25.4	-1.33	3.8	0.20
1670 - 1690	30.0	51.0	1.70	42.3	-1.41	8.7	0.29
1650 - 1670	34.0	59.3	1.74	50.8	-1.49	8.4	0.25
1630 - 1650	25.0	43.4	1.73	40.0	-1.60	3.4	0.14
1610 - 1630	50.0	98.3	1.97	85.0	-1.70	13.3	0.27
1590 - 1610	51.5	132.1	2.57	91.6	-1.78	40.5	0.79
1570 - 1590	46.5	115.5	2.48	87.2	-1.88	28.3	0.61
1550 - 1570	50.0	104.5	2.09	97.9	-1.96	6.6	0.13
1530 - 1550	59.0	146.5	2.48	119.9	-2.03	26.6	0.45
1510 - 1530	73.5	159.1	2.17	157.9	-2.15	1.3	0.02
1490 - 1510	79.0	175.1	2.22	177.2	-2.24	-2.1	-0.03
1470 - 1490	79.0	177.5	2.25	184.9	-2.34	-7.4	-0.09
1450 - 1470	80.5	167.8	2.08	196.7	-2.44	-28.9	-0.36
1430 - 1450	77.0	149.5	1.94	195.6	-2.54	-46.1	-0.60
1410 - 1430	62.0	112.5	1.81	162.5	-2.62	-50.0	-0.81
1390 - 1410	20.0	39.3	1.96	54.1	-2.71	-14.9	-0.74
1390 - 1730	859.0	1795.0	2.09	1797.2	-2.09	-2.1	-0.00

Table 2. 1990/91

Altitude interval [m a.s.l.]	Area [10 ³ m ²]	Winter balance		Summer balance		Net balance	
		Bw [10 ³ m ³]	bw [m]	Bs [10 ³ m ³]	bs [m]	Bn [10 ³ m ³]	bn [m]
1710 - 1730	23.0	28.5	1.24	33.2	-1.44	-4.7	-0.21
1690 - 1710	19.0	24.9	1.31	28.3	-1.49	-3.3	-0.17
1670 - 1690	30.0	43.0	1.43	45.5	-1.52	-2.5	-0.08
1650 - 1670	34.0	60.1	1.77	52.8	-1.55	7.3	0.21
1630 - 1650	25.0	41.4	1.66	39.9	-1.59	1.5	0.06
1610 - 1630	50.0	91.1	1.82	81.8	-1.64	9.3	0.19
1590 - 1610	51.5	110.2	2.14	85.9	-1.67	24.3	0.47
1570 - 1590	46.5	102.8	2.21	79.4	-1.71	23.5	0.50
1550 - 1570	50.0	106.9	2.14	87.0	-1.74	19.8	0.40
1530 - 1550	59.0	137.5	2.33	104.5	-1.77	33.1	0.56
1510 - 1530	73.5	163.3	2.22	133.6	-1.82	29.7	0.40
1490 - 1510	79.0	165.9	2.10	146.7	-1.86	19.3	0.24
1470 - 1490	79.0	157.1	1.99	149.8	-1.90	7.3	0.09
1450 - 1470	80.5	162.2	2.01	156.0	-1.94	6.2	0.08
1430 - 1450	77.0	139.2	1.81	152.2	-1.98	-13.1	-0.17
1410 - 1430	62.0	107.8	1.74	124.6	-2.01	-16.8	-0.27
1390 - 1410	20.0	34.9	1.75	40.9	-2.04	-6.0	-0.30
1390 - 1730	859.0	1676.8	1.95	1541.9	-1.79	134.9	0.16

Table 3. 1991/92

Altitude interval [m a.s.l.]	Area [10 ³ m ²]	Winter balance		Summer balance		Net balance	
		Bw [10 ³ m ³]	bw [m]	Bs [10 ³ m ³]	bs [m]	Bn [10 ³ m ³]	bn [m]
1710 - 1730	23.0	42.0	1.82	18.2	-0.79	23.7	1.03
1690 - 1710	19.0	35.2	1.85	15.8	-0.83	19.4	1.02
1670 - 1690	30.0	52.5	1.75	25.8	-0.86	26.7	0.89
1650 - 1670	34.0	75.6	2.22	30.3	-0.89	45.3	1.33
1630 - 1650	25.0	58.2	2.33	23.2	-0.93	35.0	1.40
1610 - 1630	50.0	121.8	2.44	48.2	-0.96	73.6	1.47
1590 - 1610	51.5	144.8	2.81	51.2	-0.99	93.7	1.82
1570 - 1590	46.5	130.9	2.82	47.8	-1.03	83.1	1.79
1550 - 1570	50.0	131.4	2.63	52.9	-1.06	78.5	1.57
1530 - 1550	59.0	169.0	2.86	64.0	-1.08	105.0	1.78
1510 - 1530	73.5	198.1	2.70	82.8	-1.13	115.3	1.57
1490 - 1510	79.0	211.2	2.67	91.7	-1.16	119.5	1.51
1470 - 1490	79.0	202.2	2.56	94.5	-1.20	107.7	1.36
1450 - 1470	80.5	194.3	2.41	99.3	-1.23	95.0	1.18
1430 - 1450	77.0	164.9	2.14	97.7	-1.27	67.3	0.87
1410 - 1430	62.0	140.6	2.27	80.5	-1.30	60.2	0.97
1390 - 1410	20.0	49.4	2.47	26.6	-1.33	22.8	1.14
1390 - 1730	859.0	2122.2	2.47	950.5	-1.11	1171.7	1.36

1990/91

The thickness of the snow cover was determined at 92 points on May 17-19 and the density was measured to $0,48 \text{ g/cm}^3$ at one point. The winter balance was calculated to $1,95 \text{ m w.eq.}$ (Tab. 2).

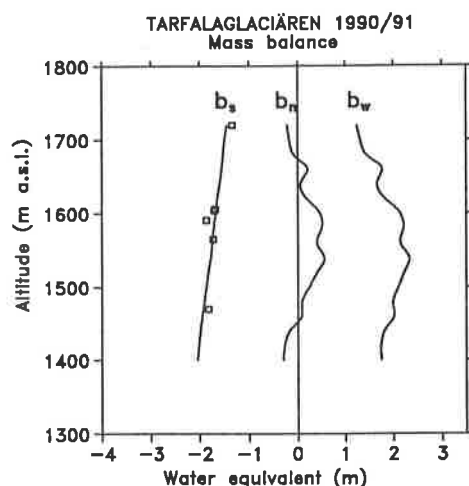


Figure 3. b_s = summer balance, b_w = winter balance and b_n = net balance as a function of altitude. Squares represent the ablation at different points (stakes).

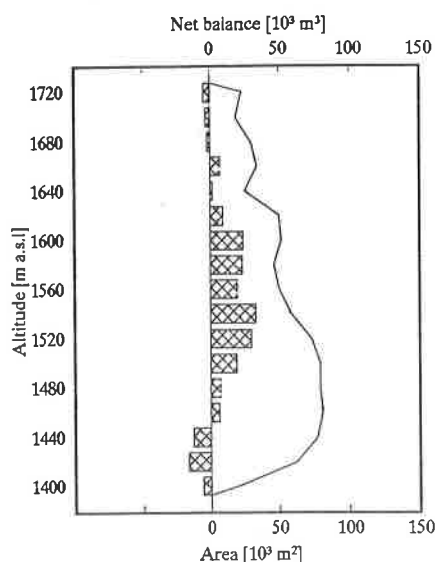


Figure 4. Net balance (B_n) and area as a function of altitude.

Six stakes were used for ablation measurements made between May 19 and September 14. The density of the remaining snow was $0,60 \text{ g/cm}^3$. A linear regression gave an ablation gradient of $0,19 \cdot 10^{-2} \text{ m/m}$ (Fig. 3). From these data the summer balance was calculated to $1,79 \text{ m w.eq.}$

The net balance was $+0,16 \text{ m w.eq.}$ and the equilibrium line altitude was 1450 m . Although the change in net balance since the year before was minor, there was a considerable drop in the ELA, leaving only a small area of the glacier with a negative net balance (Fig. 4).

1991/92

A snow-thickness survey of 60 points was carried out on May 25. The snow density was determined to $0,52 \text{ g/cm}^3$ at one point. The winter balance was calculated to $2,47 \text{ m w.eq.}$

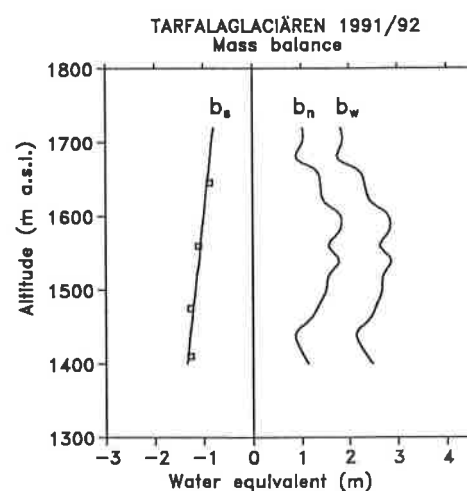


Figure 5. b_s = summer balance, b_w = winter balance and b_n = net balance as a function of altitude. Squares represent the ablation at different points (stakes).

The summer balance was calculated using the data from four ablation stakes drilled into the ice in May. The stakes were remeasured on September 9. At that time the snow had started to accumulate again. This new snow has not been

considered in the mass balance calculations for 1991/92. The ablation gradient for 1992 was $0,17 \cdot 10^{-2}$ m/m (Fig. 5) and the snow density was estimated to $0,65 \text{ g/cm}^3$. The summer balance was $1,11 \text{ m w.eq.}$ (Tab. 3)

The net balance was positive: $+1,36 \text{ m w.eq.}$ This is the highest value obtained since mass balance measurements were begun on Tarfalaglaciären.

Tarfalaglaciären is a glacier with typically low net balance gradients (Figures 1, 3 and 5). This has some very interesting implications when the net balance gradient is considered, i.e. a small change in net balance results in a large shift in the position of the equilibrium line. This is demonstrated in figures 2 and 4. An extreme case occurred in 1991/92, when the whole glacier surface turned into an area with positive net balance (Fig. 6). This was also the case in 1988/89 (Grudd 1991). The other extreme occurred in 1987/88, when the whole glacier surface had a net loss of mass (Grudd 1989).

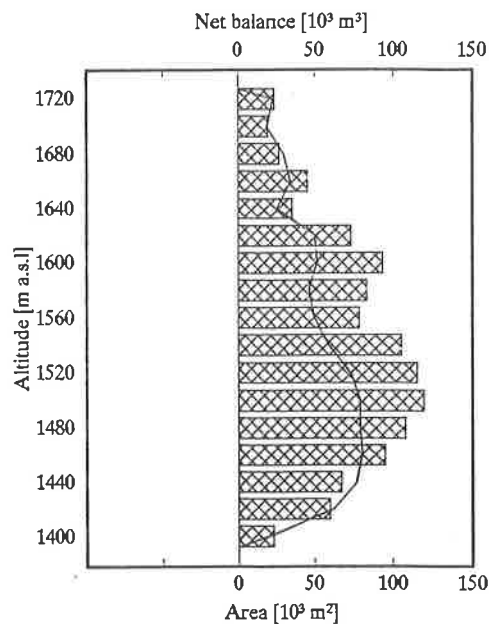


Figure 6. Net balance (B_n) and area as a function of altitude.

References

- Grudd, H., 1989: Tarfalaglaciären 1987-1988. In: Stroeven, A. P. (ed): Annual Report 1988, Tarfala Research Station (83 p): 25-27. Dept. of Physical Geography, Stockholm University.
- 1990: Small glaciers as sensitive indicators of climatic fluctuations. *Geogr. Ann.* 72A (1): 119-123.
- 1991: Tarfalaglaciären 1988/89. In: Grudd, H. and Bodin, A. (eds): Annual Report 1991, Tarfala Research Station (96 p): 12-13. Dept. of Physical Geography, Stockholm University.
- Holmlund, P., 1987: Mass balance of Storglaciären during the 20th century. *Geogr. Ann.* 69A (3-4): 439-447.
- Schytt, V., 1967: A study of "ablation gradient". *Geogr. Ann.* 49A (2-4): 327-332.
- Östrem, G., 1962: Ice-cored moraines in the Kebnekajse area. *Biuletyn Peryglacjalny*. N:o 11: 271-278.

STUDIES OF WATER IN THE FIRN AREA OF STORGLACIÄREN

Thomas Schneider

ABSTRACT

During the summer 1992 an investigation was carried out to study water in the firn area of Storglaciären. The firn layer was examined by making a pumping test, a dye-tracer test, radio echo soundings and core drillings. The border between firn and ice was found at a depth of about 20 m. The velocity of water seeping through the firn layer was 4 meters per day. The core drillings revealed that the firn was interspersed with quite a few ice lenses. The radio echo soundings roughly showed the stratification of the firn.

INTRODUCTION

Firn is an intermediate stage in the metamorphosis of snow to ice. Snow transforms into grains of firn due to repeated thawing and refreezing. The space between these grains gets smaller with increasing depth because of the pressure of the overlying snow and firn. These spaces are filled with air, or on temperate glaciers during summer, with water. A firn layer is therefore comparable to a porous groundwater aquifer. The amount of stored water in the firn area of a glacier is still uncertain in glacier hydrology. In summer 1992 an intensive measuring program was performed in the accumulation area of Storglaciären. About 15 holes were drilled to register the fluctuations of the waterlevel in the firn. A pumping test and a dye-tracer test were carried out to determine the hydraulic parameters of the firn aquifer. Two holes were drilled to examine the stratification and density of the firn layer. Several radio-echo soundings were carried out to test whether it was possible to detect the firn stratification or the water saturated zone.

MATERIAL AND METHODS

Investigation area and drillings

The centre of the investigation area (BH 0) was located in the accumulation area about 60 m NE of stake 29, near Svarta Väggen (Fig 1). This part of the glacier slopes only slightly and therefore the horizontal flow rate of the water is small. In addition, this area is relatively little crevassed, so

the possibility of water draining through englacial or subglacial channels was small. About 15 holes were drilled with an electrical melt drill having a diameter of about 4 cm. The depth of the holes ranged between 21 m and 30 m. These holes were used as piezometers for daily waterlevel measurements. They were located in the shape of a cross with a diameter of 30 m (Fig 1). The drilling velocity is a function of the density of the firn. Thus, the change in the drilling velocity with depth was assumed to reveal the border between firn and ice.

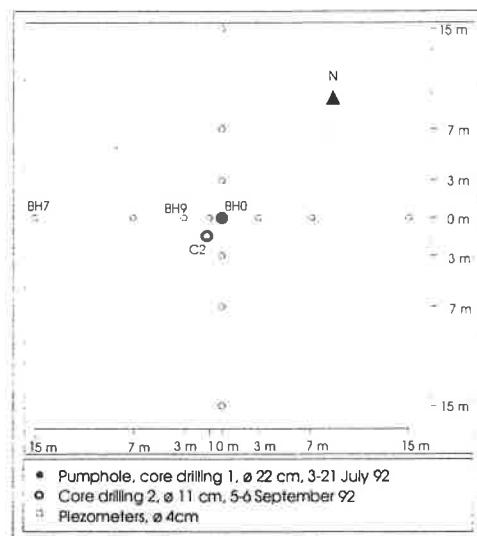


Figure 1. The investigation area on Storglaciären.

To determine the density of the snow and the firn and to gain knowledge about the stratification of the firn layer, two core drillings were performed. The first core was drilled in July, with an electrical melt drill designed by Veijo

Pohjola. The hole and the core were 20 cm and 14 cm in diameter, respectively. A depth of almost 23 m was reached. The second core drilling (5-6 September) was carried out with a PICO auger, obtaining a core of 7,5 cm and a hole of 11 cm in diameter, reaching a depth of about 17 m.

Monitoring the water level in the firn

The smaller holes (4 cm in diameter) were used to determine the water level in the firn. The goal was to measure the water level every day but because of refreezing or blocked boreholes this was not always possible. In three of the holes pressure transducers were installed measuring the water level every minute, with an accuracy of ± 1 cm. A Campbell CR 10 datalogger stored hourly mean values.

Pumping and dye-tracer tests

During the pumping tests a pump was lowered down to the bottom of the central bore hole (BH 0) and the water was pumped 80 m away from the investigation area. The first test was carried out with similar pumping rates as those used by Schommer (1978) and Oerter (1981) on glaciers in the Alps. It was found that these rates were far too high, so a more suitable pumping rate had to be found. The test on July 30 has been analysed. The pumping time was 200 minutes and the mean pumping rate amounted to 0,243 liter per second. The waterlevel in four piezometers and in the pumping hole was measured every minute with pressure transducers and a data logger. During another test, Fluoresceine and Rhodamine B were injected into two piezometers, located 3 m and 7 m away from the central hole. Samples were taken at the tube during the following pumping tests.

Radio-echo measurements

An attempt was made to detect the stratification of the firn by using the radio-echo technique

described by Holmlund & Eriksson (1989). On several occasions radio echo soundings were carried out. The first two profiles of every measuring procedure were situated along the borehole lines of the pumping test area. The third profile was a straight line between stake 29 and stake 27. A total of 8 radio-echo soundings per profile could be carried out in August and in the beginning of September. Seven radio-echo soundings were performed with a centre frequency of 895 MHz and a bandwidth of 250 MHz. One sounding was carried out with a frequency of 1500 MHz and a bandwidth of 200 MHz. The soundings will be calibrated using the results from stratification studies of firn cores and the water level measurements already described.

RESULTS

Drilling velocity of the electrical melt drill

The drilling velocity plotted against depth (Figure 2) showed a relatively constant velocity between 5 m and about 15 m and between 20 m and 30 m. The firn-ice border was assumed to be located between 18 m and 20 m. The core drilling confirmed this assumption.

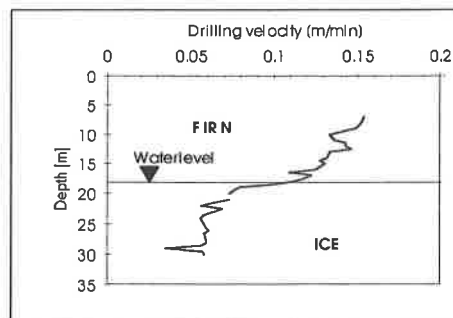


Figure 2. Drilling velocity at BH 9, July 11.

Core drillings

The core drilling 5-6 September (C2) revealed many ice lenses in the firn layer (Figure 3). In the core from C2, three debris layers were detected. Together with the debris layers from the core at

BH0 a total of five summer layers (1991-1987) were detected. The difference between the summer layers at C2 and BH0 was probably caused by ablation or compaction processes during the time between the two core drillings. The core drilling at BH0 was carried out between July 3 and July 20. The constant density below 16 m was probably caused by water saturation of the firn. Below 20 m in BH0, blue ice dominated, but thin firn layers were found.

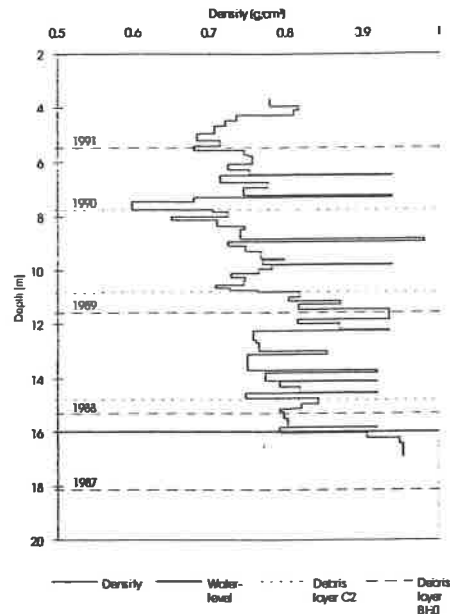


Figure 3. Core drilling C2. Density and summer layers.

Monitoring the water level in the firn

The water level in the firn was at the beginning of the measuring campaign between 17.5 m and 19 m below the glacier surface. This corresponded to an aquifer thickness of 2.5 and 1 m, respectively. The maximal thickness in the beginning of September was 4-5 m (Figure 4).

Radio-echo measurements

Some of the radio-echo measurements showed clear stratifications in the firn layer. It is not obvious what this stratification represents. Perhaps it will be possible to determine the depth of the firn-ice interface and the thickness of the aquifer. This would be a method to determine the amount of stored water in the firn in a glacier quite exactly.

Pumping test

The pumping test on July 30 yielded a transmissivity of $2.56 \cdot 10^{-4} \text{ m}^2/\text{s}$. With an aquifer thickness of 3.9 m the coefficient of hydraulic conductivity was calculated to $6.56 \cdot 10^{-5} \text{ m/s}$. The storage coefficient was $3.49 \cdot 10^{-4}$.

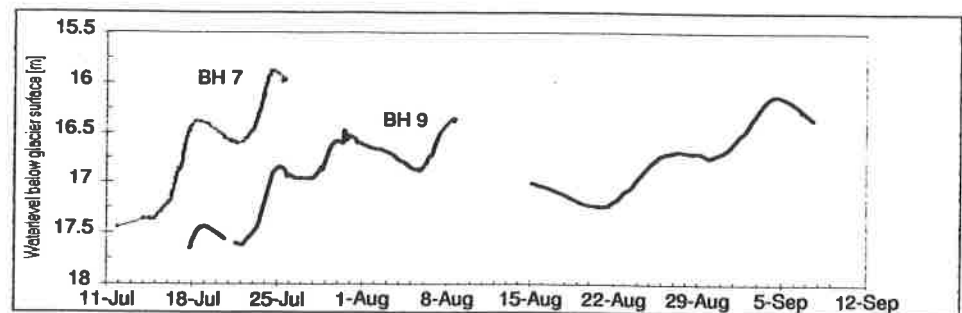


Figure 4. Water level in the firn on Storglaciären near stake 29.

CONCLUSIONS

It was shown that the drilling velocity obtained by an electrical melt drill can be used as a method to roughly locate the transition between firn and ice. To examine the stratification of the firn layer, core drillings must be applied. The stratification of the firn was quite surprising. The amount of ice lenses in the firn layer was much higher than expected. The velocity of the vertical percolation of water through the firn can be estimated by studying the response to precipitation events. In the beginning of July the water level began to rise 4 days after a rainstorm. Assuming a constant dynamic, the velocity was equivalent to about 4 m per day. The coefficient of conductivity calculated from the pumping tests agreed with the results of Schommer (1978) and Oerter (1981) on alpine glaciers. The dye-tracer experiment has not been analysed yet.

REFERENCES

- Holmlund, P., Eriksson, M., 1989: The cold surface layer on Storglaciären. *Geografiska Annaler* 71A (3-4): 241-244.
- Oerter, H., 1981: Untersuchungen über den Abfluss aus dem Vernagtferner unter besonderer Berücksichtigung des Schmelzwasserabflusses im Firnkörper. GSF-Bericht R 267, *Gesellschaft für Strahlen- und Umweltforschung*, München: 133 p.
- Schommer, P., 1978: Rechnerische Nachbildung von Wasserspiegelganglinien im Firn und Vergleich mit Feldmessungen im Ewigschneefeld (Schweizer Alpen). *Z. Gletscherkunde*. 14: 173-190.

SURFACE VELOCITY, HYDROLOGY, AND DIRECT MEASUREMENT OF SUBGLACIAL TILL STRENGTH AND DEFORMATION AT SITE S3, STORGLACIÄREN

Brian Hanson, Roger LeB. Hooke, Neal R. Iverson, Peter Jansson, and Hjalmar Laudon

INTRODUCTION

During the 1992 field season we concentrated our studies at a site in the lower part of the ablation area of Storglaciären, about 600 m from the glacier terminus and above the exit from a small overdeepening in the bed of this part of the glacier. We continued our efforts to obtain continuous velocity measurements, to sample the subglacial till and probe its thickness, to implant instruments in this till, and to make observations relevant to the hydrology of this part of the glacier.

TILL RHEOLOGY

Deformation of subglacial till under low effective stresses has recently gained widespread recognition as a possible mechanism for rapid sliding of modern and former ice masses (Boulton and Hindmarsh, 1987; Brown and others, 1987; Alley and others, 1987; Alley, 1989, 1991; Kamb, 1991; MacAyeal, 1987; 1992). Central to this problem is the need for a general constitutive law for till that will define the fundamental linkage between shear stress, effective pressure, and shear strain rate. Several widely divergent constitutive relations have been proposed (Boulton and Hindmarsh, 1987; Clarke, 1987; Kamb, 1991). None has gained widespread acceptance due to a paucity of reliable field measurements and directly applicable laboratory results.

Previous work on Storglaciären has shown that the glacier is underlain by a thin layer of till. Measurements with small, dual-axis tiltmeters demonstrated that till beneath the upper part of the ablation area was deforming at a rate that accounted for about 60% of the glacier surface velocity. However, to constrain the constitutive relation, shear stress must also be measured. This is far more difficult. Estimates based on glacier geometry yield only average values that may deviate greatly from the local shear stress at the point where deformation is being measured. Furthermore, estimates based on glacier geometry yield no information on short-term

variations that may result from changes in the local coupling between the till and the glacier sole. Thus, during the past summer we extended our measurements of till deformation to the lower part of the ablation area and also measured shear stress directly with a new instrument, a "dragometer".

INSTRUMENTATION

The dragometer was designed to measure shear stress in till at the bottom of a borehole (Fig. 1). A cylinder with conical ends, the "fish", was dragged through the till by a thin cable that ran horizontally through the till and then upward through a pipe to a load cell. The sides of the cylindrical part of the fish were roughened by cementing till to them. The tangential force supported by the roughened surface divided by the surface area is roughly equal to the shear strength of the till. Additional force, however, results from form drag, which depends on the till rheology and scales with the cross-sectional area of the fish. To determine the partitioning between the frictional drag on the cylinder sides and the form drag, another fish, consisting of base-to-base cones, was constructed. In laboratory experiments, both types of fish were then dragged through till collected from beneath the glacier. Experiments to date conducted over a range of effective pressure from 1.0 to 12 kPa suggest that about 30% of the drag results from friction on the fish sides. Thus, from the total force on the fish, it

is possible to extract the component of the force due to shear stress on the sides, and thereby, estimate the till strength.

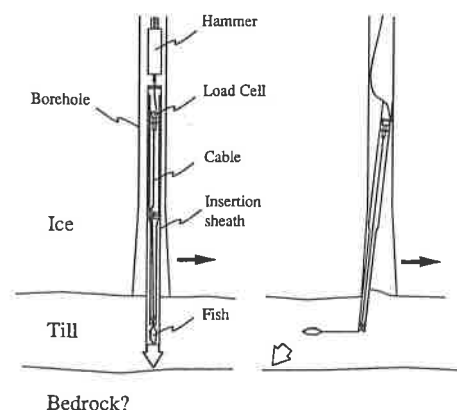


Figure 1. Sketch of the apparatus for in situ measurement of the till shear strength immediately after insertion (left) and after several days (right). An insertion sheath that contains the instrument is driven into the till and then withdrawn. The exposed pipe ploughs through the till as the glacier moves, dragging the fish behind it. The lower half of the pipe is about 19 mm in diameter.

The tiltmeters we used are similar to those deployed by Blake and others (in press). Each contains two flexible metal strips that are orthogonally positioned and suspended from the tiltmeter lid. The strips are weighted on their ends so that they bend significantly in response to tilting of the lid and housing. The bending is measured with strain gages cemented to the metal strips. The tiltmeters are inexpensive to build and are capable of $\pm 1.0^\circ$ accuracy. Those used in 1992 were 25 mm in diameter and 85 mm long.

"Continuous" measurements of surface velocity were made by determining the distance between a point on stable material off the glacier and a prism mounted on a stake at Site S3 (Fig. 2). Measurements were made at ten-minute intervals. A computer-controlled electronic distance meter (EDM) was used for the

measurements. A second such EDM, located at site S2 just downglacier from the riegel, obtained similar measurements of the change in distance between S2 and S3 (Fig. 2). Based on these two measurements, the speed of site S2 was calculated (Fig. 2).

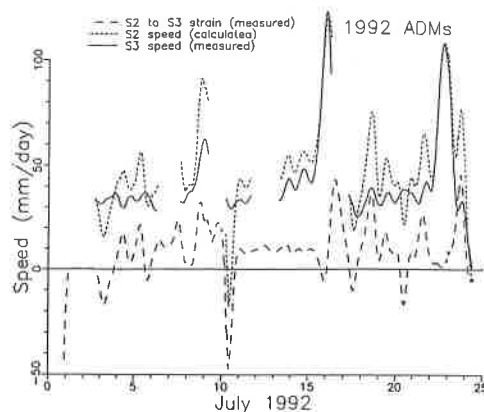


Figure 2. Speeds at stake S2 and S3 in 1992, and strain rate between the two stakes.

IMPLEMENTATION

During the 1992 field season, 14 boreholes were drilled at Site 3. All holes were probed to determine the till thickness, and thus also assess their suitability for inserting instruments. The till-thickness measurements were made by pounding a slender "penetrometer" into the till. The pounding technique used involved repeatedly raising and dropping a weight on the instrument. Two penetrometers were lost due to failure of materials used in their construction.

During some penetrometer tests, the relative stiffness of the till was determined while probing. This was accomplished by recording the depth of penetration for a given number of blows, usually 25 or 50 (Fig. 3). The results from two holes probed in this manner suggest that three distinct layers may be present: a readily-penetrated upper layer, a distinctly more compact middle layer, and an even harder basal layer. The upper layer can be explained in one of four ways. It is either a layer disturbed by the drilling

operation, a layer that has become dilated during till deformation, till squeezed up into the hole, or till plowed up into the hole as the ice moves across the bed.

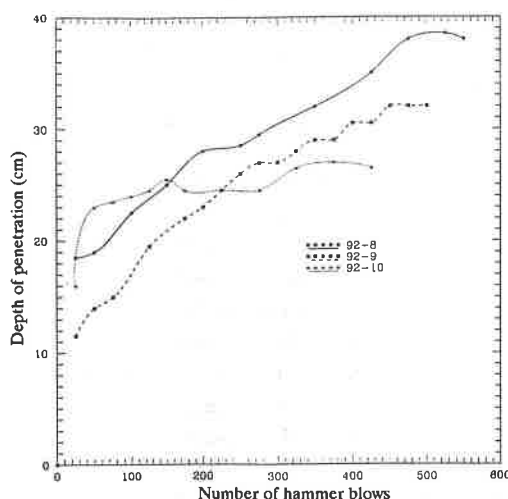


Figure 3. Till penetration curves for three boreholes at site 3.

The tiltmeters and dragometers were inserted with a different hammer than that used for the penetrometer experiment. The cable attached to the hammer was heavier than that used previously in order to minimize twisting of the hammer and instrument cables. The new cable proved to be superior to the old one in this respect, as no observable twisting occurred during the insertion of the dragometers. During tiltmeter insertion, however, there was some twisting, presumably because the instrument cable for the tiltmeters was lighter and more flexible than that for the dragometers. Once this was recognized, the problem was mitigated by carefully monitoring both cables and untwisting them as necessary.

All instruments were logged on a Campbell Scientific CR-10 datalogger, using a multiplexer unit to expand the number of input channels on the logger.

RESULTS

The velocity measurements revealed three major peaks in speed associated with rain storms (Fig 2). Speeds are out of phase prior to the July 8/9 storm and approximately in phase after that time. This curious behavior is not understood. These velocity measurements will provide a foundation for interpreting time series of the till shear strength and deformation rate, although such efforts are still in their early stages.

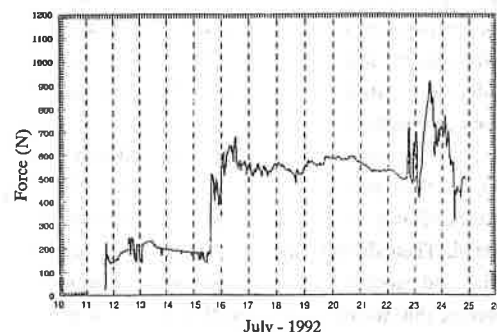


Figure 4. Force on the "dragometer" in July 1992. The force is proportional to the shear strength of the till after the sharp increase in force on July 15.

The record from the dragometer is shown in Figure 4. The sharp increase in force at about noon on July 15 is inferred to be when the instrument first began to measure the till strength. Major storms with associated peaks in surface velocity (Fig 2) occurred on July 15/16 and July 22/23. During both storms, as surface velocity increased, the force on the instrument decreased. This presumably reflects a reduction in shear strength of the till, in both cases of ≈ 0.15 bars. As surface velocity decreased after these storms, till strength appeared to increase. The increases were ≈ 0.30 bars on July 16 and 0.55 bars on July 23. Presumably increases in subglacial water pressure associated with the increase in water input to the glacier during the storms decreased the effective pressure in the till. This would reduce intergranular stresses and weaken

the till, and would thus be at least partially responsible for the accelerations recorded at the glacier surface.

The relatively steady force on the instrument between July 17 and 22 corresponds to a shear strength of ≈ 0.4 bars. This is consistent with the value required to balance the applied basal shear stress in this region, which probably lies between 0.25 and 0.6 bars, based on a range of possible shape factors for the valley cross-section. The value is also consistent with the yield strength of the till estimated using the till's geotechnical properties (determined in laboratory direct-shear tests) and the effective pressure inferred from subglacial water-pressure measurements in the region.

The record from one tiltmeter is shown in Figure 5. Averaged over the period prior to the storm of July 15/16, strain rates in the till were small. Then during the storm, strain rates were high and variable. The high-amplitude oscillations during this storm result from fluctuations in the output from only one of the tiltmeter axes, however, and thus may not represent actual fluctuations in strain rate. Following the storm, strain rates declined and then began to increase steadily, although there was not a general increase in surface velocity at this time (Fig 2). This suggests that an increased fraction of the glacier's basal motion may have been by till deformation rather than by sliding at this time. This would imply weakening of the till layer.

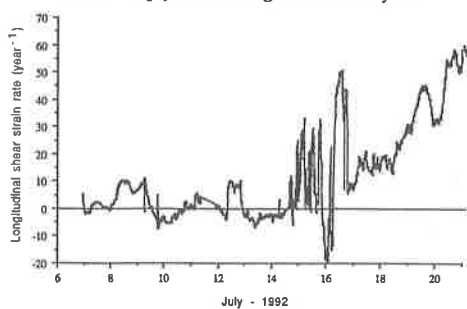


Figure 5. Rate of shear strain in till beneath lower part of the ablation area, as recorded by a tiltmeter inserted in 0.34 m of till beneath 96 m of ice in 1992.

Hydrological observations documented significant changes in the basal hydraulic system during these experiments. Most of the holes at Site S3 did not drain initially, indicating that basal water pressures exceeded the overburden pressure at least locally. In those holes that did drain, water levels remained high. This is consistent with observations in the large overdeepening beneath the upper part of the ablation area, but quite different from our previous experience in the lower part. Then on July 20, dirty water began to emerge from one hole, and murky water was at the top of a second. Frazil ice collected at the tops of these holes. On July 21 a third hole was overflowing; the discharge from it was estimated to be ≈ 1.6 l/s. Apparently an hydraulic connection had become established with the drainage system further upglacier where the ice is thicker, perhaps on the other side of the small overdeepening, and the resulting hydraulic head was sufficient to force basal water to the surface at S3. Such overflow continued through July 22, and then on July 23 all holes that were open had drained, and water was flowing rapidly into one of them. We suppose that the developing subglacial conduit system had propagated further downglacier and a connection to the terminus had become established. These events may represent a regular stage in the annual evolution of the conduit system to its late-season configuration.

FUTURE ANALYSIS

Because changes in the velocity of the dragometer fish should induce proportional changes in shear strain rate in the adjacent till, estimates of the fish velocity as function of time, together with the variation in till shear strength with time, will be used to evaluate this rate dependence in the constitutive relation. Changes in velocity of the fish can be estimated from diurnal surface velocity variations which, during the melt season, primarily reflect variations in ice velocity at the bed. The velocity of the fish relative to the adjacent till also depends on the

rate of deformation across the thickness of the till layer. If we assume there is no till deformation (an end-member case), then the relative velocity of the fish is approximately equal to the sliding velocity. If it assumed that all basal motion is by till deformation and that this deformation is distributed linearly across the till thickness, the relative velocity of the fish can be calculated from the depth of fish in the till. Therefore, using a time series of the surface velocity, upper and lower limits can be placed on the velocity fluctuations of the fish as a function of time. The resultant relationship between the fish velocity and the shear strength of the till should allow us to approximate the rate dependence in the constitutive relation, just as Kamb (1991) estimated it from shearing velocities and shear strengths in laboratory tests.

REFERENCES

- Alley, R.B., 1989: Water-pressure coupling of sliding and bed deformation: II Velocity depth profiles. *J. Glaciology* 35 (119): p. 119-129.
- Alley, R.B., 1991: Deforming-bed origin for southern Laurentide till sheets? *J. Glaciology* 125 (37): 67-76.
- Alley, R.B., Blankenship, D.D., Rooney, S.T. and Bentley, C.R., 1987: Till beneath Ice Stream B. 3. Till deformation: evidence and implications. *J. Geophysical Research* 92 (B9): 8921-8929.
- Blake, E., Clarke, G.K.C. and Gerin, M.C., in press: Tools for examining subglacial bed deformation. *J. Glaciology*.
- Boulton, G.F., Hindmarsh, R.C.A., 1987: Sediment deformation beneath glaciers: rheology and geologic consequences. *J. Geophysical Research* 92: 9059-9082.
- Brown, N.E., Hallet, B., Booth, D.B., 1987: Rapid sliding of the Puget glacial lobe. *J. Geophysical Research* 92 (B9): 8985-8997.
- Clarke, G.K.C., 1987: Subglacial till: A physical framework for its properties and processes. *J. Geophysical Research* 92 (B9): 9023-9036.
- Kamb, B., 1991: Rheological nonlinearity and flow instability in the deforming bed mechanism of ice stream motion. *J. Geophysical Research* 96 (B10): 16585-16595.
- MacAyeal, D.R., 1987: Large-scale ice flow over a viscous basal sediment: theory and application to ice stream B, Antarctica. *J. Geophysical Research* 92: 4071-4087.
- MacAyeal, D.R., 1992: Irregular oscillations of the West Antarctic ice sheet. *Nature* 359: 29-32.

MEASUREMENT AND MODELLING OF ABLATION ON STORGLACIÄREN

Paul Cutler

INTRODUCTION

A meltwater input model for Storglaciären is currently being constructed. This will be used to drive a second model simulating the seasonal development of the internal drainage network. The ultimate goal is to predict temporal variation of basal water pressures. The melt model is based on standard energy balance equations as follows:

$$Q_m = Q^* + Q_h + Q_e + Q_p$$

All terms are in Wm^{-2} . Q_m is energy available for melt, Q^* is net radiation, Q_h and Q_e are the sensible and latent heat energy, respectively, and Q_p is the thermal energy released by precipitation.

METHODOLOGY

The first stage of model development is validation against measured ablation at a point. At stake 16, in the centre of the ablation area, a 60 day continuous record of net radiation, air temperature, relative humidity and wind speed was collected. These data can be used to calculate ablation. During this period (July 1 - September 2) ablation was measured using three techniques: i) single stake, ii) ablatometer, iii) distance from a horizontal pole to the surface at 17 points spaced 10 cm apart. The single stake and 17 point average were measured daily whilst the ablatometer, linked to a Campbell 21X datalogger, recorded values at 15 minute intervals. The ablatometer was designed to measure ice melt, therefore the unusual occurrence of 7 periods of summer snowfall on the ablation area prevented a continuous data set from this instrument. However, it performed well on ice.

Two additional weather stations were employed to investigate longitudinal and lateral meteorological gradients over the whole glacier. This information is important in establishing a spatially reliable melt model. One of the stations was located in the centre of the accumulation area, and the other was positioned close to the terminus. This

configuration provides about 40 days of longitudinal gradient information, and 7 days of data were obtained for a lateral transect level with stake 16.

The input model will be of 100 m grid square resolution, and values of surface roughness and albedo are required for each square. The latter was systematically obtained close to each ablation stake in the ablation area during a single 4 hour period, whilst the former was measured regularly at stake 16 as the snowline passed through.

Weekly dye traces were performed using the same moulin each time (near stake 14) in order to demonstrate the seasonal development of the drainage system. In conjunction with these tests, discharge at Sydjåkk and Nordjåkk was obtained using stage recorders. Continuous data were collected from July 3 until September 3.

RESULTS

Typically on temperate glaciers, solar radiation provides the main source of melt energy. Figure 1 shows that on Storglaciären this is not a reliable conclusion. On Julian Day (JD) 242 (August 30) there are equal contributions from all three major energy sources (radiation, thermal and latent heat), whilst on JD 243,

following the passage of a cold front, radiation does indeed dominate as a source of melt. Energy released by precipitation is apparently minor. Standard equations only consider thermal energy, so the contribution of kinetic energy release will also be looked at in this project.

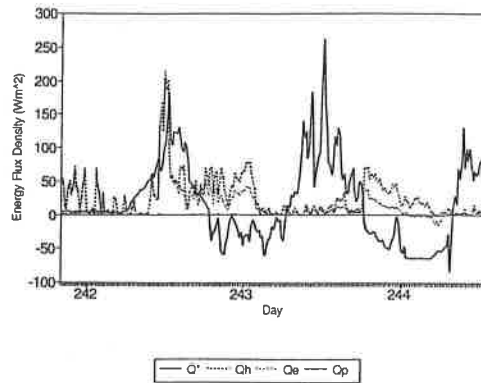


Figure 1. The relative contributions of net radiation (Q^*), sensible heat (Q_h), latent heat (Q_e) and thermal energy from precipitation (Q_p), to the energy balance at stake 16.

The performance of the ablatometer is demonstrated in Figure 2. The temporal variations of both calculated and measured melt are in reasonable agreement. Divergence between the two plots is probably associated with local variations in the thickness of the weathering crust (formed by internal melting in the ice). The most encouraging part of Figure 2 is the similarity of cumulative melt values between the calculated amount, the ablatometer, and the 17 point mean.

Further confirmation of the reliability of standard melt equations comes from calculated melt during a 30 day period between JD 207 and JD236. The measured value at stake 16 was 520 mm, compared with 552 mm predicted by the model. This period contained 3 snowfall events and prolonged periods of overcast cool weather, which accounts for the small total melt.

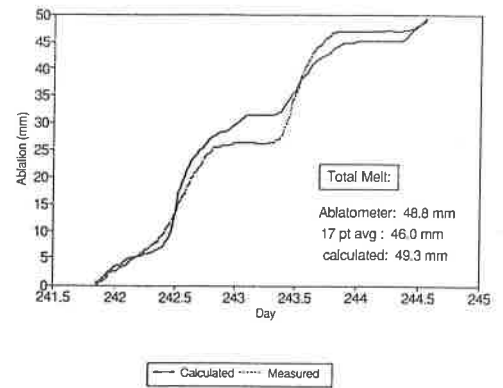


Figure 2. Comparison of ablation measured with the ablatometer with calculated values for the same point (stake 16).

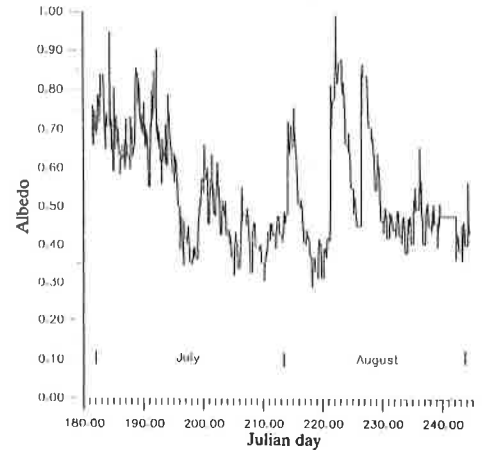


Figure 3. Variation of albedo measured at stake 16.

Temperature gradients over the entire glacier have not yet been evaluated. However, the difference between stake 16 and stake 29 was often 2 K (vertical difference = 130 m). Figure 3 illustrates the type of albedo data set which will be applied to each grid square (with modifications for locally-measured absolute values). The plot is surprisingly variable. Initial values are for metamorphosed snow, and this was underlain by an abnormally thick layer of superimposed ice (30 cm at stake 16) which became exposed on JD 195. Initially this layer was saturated, but by JD 200 all that remained were granular white crystals, and these

elevated the albedo until JD 205. Glacier ice was exposed on JD 205, and the range of values (0.35 - 0.45) is quite high compared to many other temperate glaciers. This causes the reduced importance of radiative melt energy. Three late summer snowfall events are evident on Figure 3. The latest 2 effectively shut off melt on the glacier for 3-4 days each.

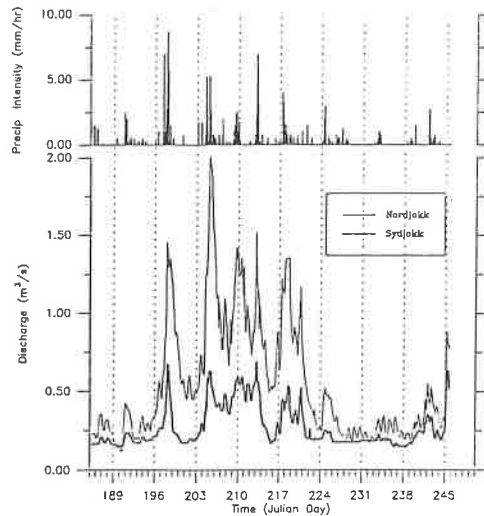


Figure 4. Relationship between precipitation and discharge from Sydjákk and Nordjákk during 1992

Figure 4 contains discharges from Sydjákk and Nordjákk, as well as precipitation measured by a tipping bucket rain gauge at stake 16 (one of a network of gauges on the glacier during 1992). The obvious relationship between rainfall inputs and discharge in both streams underlines the importance of considering this parameter in any drainage system development model. Results of two dye traces spaced 16 days apart are displayed in Figure 5. These data illustrate the increasing efficiency of the system as the melt season progressed. Time to peak shortens from 180 minutes to 120 minutes, and the spread of the peak is greatly reduced. Trace S2 continued to show for 24 hours in a gradually declining

trend, however only the first 7 hours are displayed here. These data were collected from Sydjákk, and additional data from Centrumjákk displayed identical return curves, suggesting a division of the streams very close to the terminus.

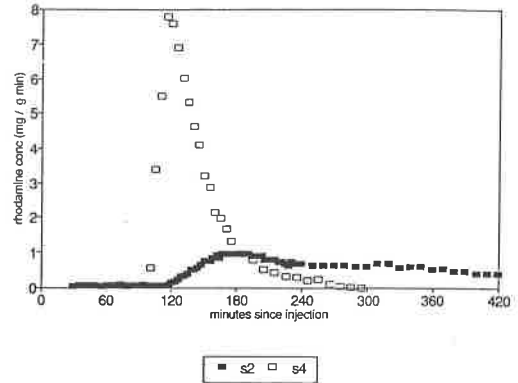


Figure 5. Comparison of dye return curves collected from Sydjákk on JD 191 (S2) and JD 207 (S4). The y-axis is normalized to mass of dye injected and discharge.

CONCLUSIONS

Standard melt equations have been successfully applied to predict melt on Storglaciären. A water input model for the entire glacier will now be constructed. 60 days of continuous meteorological data from three weather stations collected during the 1992 melt season will be used to establish lateral and longitudinal gradients, and these will drive the model. The importance of precipitation as an input cannot be overemphasized. This parameter will be intensively examined in 1993.

A weather station at stake 16 was left recording at 3 hour intervals from September 2. This will provide data for the remainder of the 1992 melt season, and hopefully for the initiation of melt in 1993, prior to our next intensive effort.

MEASUREMENTS OF pH VARIATIONS IN FRONT OF GLACIERS IN THE ABISKO REGION

K. Anton, A. Bodin, L. Eckstein

ABSTRACT

Retreating glaciers leave behind large areas of bare ground which is vulnerable to weathering as soon as it becomes exposed. Soil properties (e.g. pH) which change in time because of the complex influences of weathering, could be used as indicators for measuring the ice recession. In the investigations of Stork (1963) and Anton & Eckstein (1991), a rapid decrease of pH during the first decades of exposure of the soil could be detected. The aim of the present study was to investigate an area in front of the Kårsa glacier and some adjacent small snowfields (former glaciers) to determine whether pH estimations of the upper soil could be used for dating glacier recession during the last century.

For the "calibration" of the method, pH-measurements were conducted along a transect in front of Kårsaglaciären where the ice recession is very well known (Bodin 1991). With the help of the data gained in this investigation another transect in front of Kårsaglaciären, and two transects in front of Vuottasritaglaciären and Kärkereppejökeln, will be dated.

INTRODUCTION

Kårsaglaciären is the only well known and well documented glacier in the Abisko region. The records covering front position data and other measurements extend back to the beginning of the century. Kårsaglaciären reacts fast to climatic events, which is at least partly due to its topography. Centered around the Vuottasrita massif are a few small cirque glaciers that might indicate how representative Kårsaglaciären is in a climatic context.

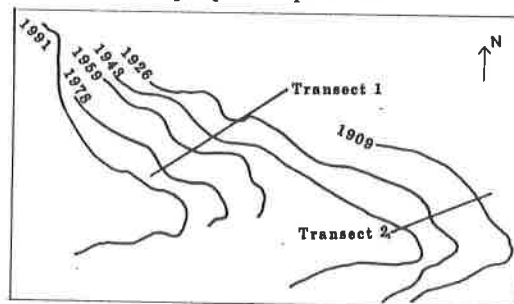


Figure 1. Map showing the investigation area (upper) and sampling sites in front of Kårsaglaciären, with front positions (right).

The recession of these small glaciers may be estimated through studies of air photographs from 1943, 1959, 1978 and 1991. However, the maximum extent of the glaciers at the beginning of the century is not covered by any maps or known photographs. Therefore, the technique described here was tested on a field trip in August 1992.

METHODS

Samples of the upper soil were taken irregularly along the transects at plots which seemed to be comparable and not too badly disturbed. Two profiles perpendicular to the well known former frontal positions of Kårsaglaciären was chosen. Three or five replicates were taken and stored in plastic bags. In the laboratory of the Abisko Scientific Station the $\text{pH}(\text{H}_2\text{O})$ was estimated using a HANNA pHep+ -field pH-meter.



RESULTS AND DISCUSSION

The results of the pH-measurements of transect 1 are listed in table 1. Two plots had to be rejected because of their irregularity.

Table 1. pH-data of transect 1 and the presumed age of the soil.

plot	pH	SE	n	age of soil
K1 a	6.0	0.13	4	c. 200 years
K1 b	7.6*	0.04	5	c. 66 years
K1 c	6.7	0.06	5	c. 55 years
K1 d	7.0	0.06	5	c. 47 years
K1 e	6.4*	0.04	5	c. 25 years
K1 f	7.0	0.04	5	c. 18 years
K1 g	7.5	0.05	5	c. 5 years

* these figures were rejected because of their irregularity.

When the pH-data are plotted as x-variables against the presumed age of the soils, plotted as y-variables, we can draw a quite reasonable regression line through the points that follow the formula $y = 979,26 - 133,663x$. It should nevertheless be noted that the regression-coefficient of this line differs from that of a possible regression line drawn on the basis of data from samples collected in 1990, during which moraines Kårsaglaciären were investigated (Anton & Eckstein, 1991).

The area investigated during the recent study seems to be much more heterogenous and disturbed. Indeed, the meltwater running perpendicular to the transects made difficulties in finding good sampling sites and probably caused an equalization of the pH-values along the transects.

The results of the pH-measurements of transect 2 are given in table 2. With the help of the regression formula above, the age of the soil in transect 2 can easily be calculated.

Table 2. pH-data of transect 2 and the calculated age of the soil.

plot	pH	SE	n	age of soil
K2 a	5.9	0.22	3	c. 191 years
K2 b	5.8	0.07	3	c. 204 years
K2 c	6.3	0.09	3	c. 137 years
K2 d	7.3	0.15	3	c. 4 years

The data does not seem to be reliable, as the ages of the first plots (K2 a, K2 b), which lie at the 1909 ice front position and further towards the glacier, are overestimated, while the age of plot K2 d, which lies far away from the recent ice front, seems to be underestimated. Again, the disturbing and equalizing influence of water running over the plots - even if only seasonally - is too great to get accurate results under these conditions.

Other difficulties are the deviations of the replicate measurements. A standard error of $\pm 0,1$ pH-units corresponds to a calculated age-range of c. 26 years, which is quite a lot, when the range of only a few decades is investigated. Concerning the results of the two other glaciers (Vuotasrita-glaciären and Kärkerpejökeln), a calculation of the ice recession is rejected because even the data on the transects in front of Kårsaglaciären do not seem to be comparable. In front of Vuotasrita-glaciären, the pH-figures are as a rule one pH-unit below those of Kårsaglaciären, which can only be explained by different geological and/or climatical conditions or a different genesis of the sites.

CONCLUSIONS

Accurate and valid estimations of pH as a measure of ice recession are dependent on two main prerequisites:

1. Homogenous, undisturbed sampling sites. This means either a large, more or less even forefield or well developed moraines. Especially the disturbing influence of large amounts of water running over the soil should be minimized. Also, unequally distributed meltwater causes irregularly changing pH-figures along the transect and makes it impossible to decide which of the estimated figures is "right" and which is "wrong".
2. Identical geological/climatological conditions and developmental history of the sampling sites.

Under these conditions pH-measurements can provide good data complementary to the "traditional" lichenometric datings. The pH-data has to be calibrated against the age of the soils, at least in front of a new glacier with different geological/climatological conditions. Thus, pH-measurements can never be used as the only method for dating the ice recession, nor replace lichenometry.

REFERENCES

- Anton, K., Eckstein, L., 1991: Accumulation of nitrogen and carbon on moraines of different age in front of the Kårsaglacier; Swedish Lapland. Examination paper at Carl von Ossietzky Universität, Oldenburg, Germany. 28 p.
- Bodin, A., 1991: Kårsagläciärens reträtt under 1900-talet. Examensarbete, Stockholms Universitet.
- Stork, A., 1963: Plant immigration in front of retreating glaciers, with examples from the Kebnekaise area, Northern Sweden. *Geografiska Annaler* 45, 1-22.

STUDIES OF LOCAL CLIMATE IN EMPTY GLACIER CIRQUES LOCATED JUST BELOW THE GLACIATION LIMIT

Stig Jonsson and Peter Jansson

INTRODUCTION

The Swedish mountains contain a large number of empty cirques that lack signs of Holocene glaciation. The effects of glacial erosion during the Holocene in such cirques have been seriously questioned, even though small terminal moraines may be found in some examples. The origin of these cirques is instead believed to be due to mountain glaciation during the initiation or the termination of an ice age or both. These are thus considered to be a result of several glaciations (see discussions in Bergström (1973), Vilborg (1977), and Hoppe (1983)). Lately the idea that glacial cirque-forms are produced by subglacial erosion (Holmlund, 1991) has gained acceptance. These studies have focused primarily on small cirque forms that are not over-deepened and that lie outside of mountainous regions.

Many of the empty cirque forms in the Swedish mountains contain semi-perennial snow patches. These might, of course, develop into cirque glaciers if there were an increase in winter precipitation or a decrease in summer temperature or both. In order to assess the likelihood of initiating a glacier in an empty cirque, the local climatic conditions at present must be known. It is thus important to know how much snow is accumulating in the cirque during the winter and how this snow is distributed. This local data must be accompanied by knowledge of the larger scale weather patterns during the winter which produce the measured accumulation. It may then be possible to correlate the large-scale winter circulation in the atmosphere with the snow accumulation in the cirque. The amount of melt taking place in these empty cirques is obviously large enough to prevent glaciers from forming. The current climatic conditions thus provide a limit on the climate favouring glacier growth. By

quantifying the current climate and by investigating how quickly winter snow fall disappears, a model of the mass balance of the cirque can be constructed.

The climatic conditions that caused the cirques to form are not known to us today. However, it is plausible that a study of local climate in empty cirques just below the present glaciation level could contribute to our understanding of their origin. This would be particularly true if the study was reinforced with numerical modelling experiments. In order to achieve this, climatic data must be gathered in a suitable cirque. The winter conditions are easily determined by measuring the accumulated snow in the cirque at the end of the winter season and by monitoring the regional weather situation during the winter. The important parameters for the summer, and for melting in particular, are: temperature, incoming and net radiation, wind speed and direction. These parameters are easily obtained by means of an automatic weather station and by obtaining data from the Swedish Meteorological and Hydrological Institute (SMHI). Establishing a digital terrain model of the cirque will facilitate the modelling.

FIELD INVESTIGATIONS IN AUGUST 1992

In August 1992 a study of the local climate in an empty cirque was initiated through a grant from the Mannerfelt fund. The cirque is located in the centre of the Rassepautasjtjåkka massif (68°05', 18°50') approximately 70 km NE of Tarfala Research Station. The highest peak in the massif is 1750 m a s l. The highest peak in the vicinity of the smallest glacier of the nearby Mårma massif is 1888 m a s l, which indicates that the glaciation level in this area is higher than 1750 m a s l. There are several cirque

forms in the Rassepautasj massif, some very distinct. The floors of these cirques are all located between 1200 and 1300 m a s l.

Our primary objective was to establish a site for an Aanderaa 2700 automatic weather station. This station records barometric pressure, humidity, incoming radiation, net radiation (incoming radiation minus outgoing radiation), average wind speed, maximum wind speed (in gusts), wind direction and temperature (air temperature at 2 m above the ground and soil temperature 0.5 m into the ground). The station was erected on a ridge in the central portion of the cirque (Figure 1). The station records all parameters every three hours, according to standard meteorological practise. Data are currently being logged and will be collected during the spring of 1993, when a snow inventory of the cirques in the area is planned.

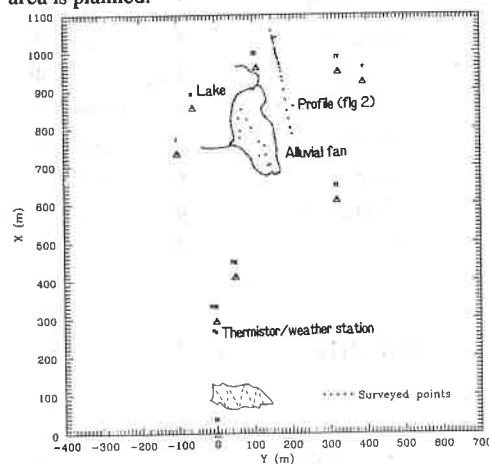


Figure 1. Map showing surveyed fixed points (triangles numbered I-IX), and other surveyed objects and profiles in the central cirque of the Rassepautasj massif. North is approximately parallel to the x-axis.

In order to produce a geodetic basis for a digital terrain model, a network of fixed points was established by surveying. The surveying was done

using a Geotronics 440 geodimeter. 9 fix points referred to by Roman capital numerals, I-IX, were established and surveyed (Figure 1). Eight of the points, I-VIII, were located on large boulders on the floor of the cirque. This was necessary because no bedrock outcrops were to be found in these parts of the valley. Fix point IX, however, was established on bedrock on the valley side. Fix points VIII and IX establish the base line for the local coordinate system used in the cirque. Fix point IX is the origin of the coordinate system. Since the local coordinate system is not yet connected to the general net used in Sweden, Rikets Nät, its absolute elevation and orientation are not known. An approximate elevation was obtained by assuming that the water level in the lake within the central cirque, 1247 m a s l, was provided accurately by the topographic map.

The central cirque and the cirque forms located around the Rassepautasj massif were also visited and photographed, partly through reconnaissance by foot but also by aerial photography from a helicopter. Thus, the distribution of snow patches in the different cirques were established. A small snow patch located in the central cirque was also mapped and studied by means of snow depth probing and snow density measurements in a pit.

The central cirque form contains several landforms that are of interest. An inactive alluvial fan is located on the northern side of the lake (Figure 1). Several surface profiles were surveyed on this fan. A ridge consisting of ice and rock avalanche debris is located in the inner part of the cirque (Figure 2). The ridge contained large blocks of dirty ice and may have a core consisting of a mixture of ice and rock debris. The ice is likely to be older than that from the previous winter. A large ridge, on which the weather station was established, cuts across the cirque down stream of the lake. This ridge was interpreted as a terminal moraine from aerial photographs, although its origin proved to be more complex and is not yet

understood. The upper surface of the ridge has a 20-50 cm thick layer of silty or sandy material. A sample was collected for further analysis which is now in progress. It is, however, clear from field inspection that the material has a very low clay content. Boulders and pebbles are dispersed on the surface and throughout the silty/sandy matrix. This is not typical of other tills in the area, although the rest of the ridge seems to have a grain size distribution similar to such tills. Several linear depressions run across this surface. These depressions have a larger concentration of boulders and intersect at triple junctions in a few locations. These forms are not well understood either, although they resemble frost wedge patterns. On the flank of the ridge lies a large boulder exhibiting severe weathering. The boulder has several weathering pits on its upper surface, one of which is approximately 10 cm in diameter and 3-5 cm deep. In spite of an effort to find similar rocks in the valley, no other specimen was found. Therefore, it is concluded that the rock may have been transported from some bedrock window in the Caledonides farther inland. Samples taken from the rock have been identified as ultramafic intrusive, containing a large percentage of pyroxene (J. Stout, personal communication). The rock resembles dunnite and is expected to weather rapidly. There is, however, some question whether the weathering phenomena on this boulder can be used to determine its approximate length of exposure, and thereby provide an estimate of the time since it was deposited by a glacier.

This study will be continued during 1993. A snow inventory of the cirques in the area is planned for April/May. Further visits to the area for mapping and snow melt measurements are planned for the following summer.

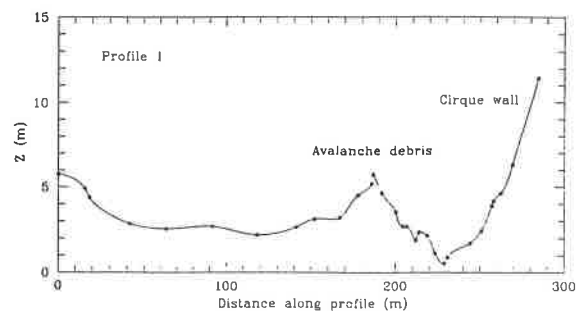


Figure 2. Surface profile through a ridge consisting of ice and rock avalanche debris (ice blocks and rock fragments) in the inner part of the central cirque of the Rassepautasj massif.

REFERENCES

- Bergström, E., 1973: Den prerecenta lokalglaciationens utbredningshistoria inom Skanderna. Naturgeografiska Institutionen, Stockholms universitet. *Forskningsrapport*. NGSU-16.
- Holmlund, P., 1991: Cirques at low altitudes need not necessarily have been cut by small glaciers. *Geografiska Annaler* 73A: 9-16.
- Hoppe, G., 1983: Fjällens Terrängformer. Solna: Statens naturvårdsverk.
- Vilborg, L., 1977: The cirque forms of Swedish Lapland. *Geografiska Annaler* 59A: 89-150.

GLACIER FRONT OBSERVATIONS 1992

Per Holmlund

ABSTRACT

Eighteen glacier fronts were observed during the summer 1992. Seven of these were covered by snow and could not be surveyed. Two glaciers, Isfallsglaciären and S.Ö. Kaskasatjåkkaglaciären, showed advanced front positions compared with last years survey. At S.Ö. Kaskasatjåkkaglaciären, only the western part was not covered by snow. The fronts of Kårsaglaciären and Vartasglaciären was partially snow free, and the exposed parts showed no sign of recession.

Dead-ice recession occurs at the front of Pårteglaciären because of its thin tongue and the undulating bed topography. A similar situation will soon occur at the front of Vartasglaciären, as small nunataks are exposed close to the terminus of the glacier.

INMÄTNINGAR 1992

Norra Kebnekaise

Kårsaglaciären besöktes av Axel Bodin den 2 september. Glaciären var fortfarande nästan helt snötäckt med undantag för några små ytor på tungan samt i nedre delen av ackumulationsområdet. Fronten var synlig helt nära jökelporten. Frontpositionen antas därför vara oförändrad sedan föregående år. Glaciären fotograferades från luften 1992-09-02.

Kåtotjåkkaglaciären besöktes inte under 1992, men den fotograferades från luften den 2 september. Dess front var framsmält.

Mårmaglaciären besöktes och fotograferades 1992-09-02 av Axel Bodin i samband med att stakarna avlästes. Tungan var till största delen framsmält, medan fronten var täckt av en smal sträng med snö.

Riukojietna besöktes och fotograferades (från öster) den 1 september. Nedersta delen av tungan var framsmält, men fronten var ännu täckt av snö.

Påssusglaciärerna överflögs den 16 augusti. Östra Påssusglaciären var då helt snötäckt, medan den Västra Påssusglaciären hade ett framsmält parti nära fronten. Isfronten var inte synlig. Den 1 september var den östra glaciären fortfarande snötäckt, medan fronten av den västra hade smält fram. Glaciärerna mättes inte in detta år.

Räitaglaciärerna besöktes den 17 och 18 augusti av Karin Andersson, Karen Marvig och Cecilia Richardsson. Unna Räitaglaciärens front var helt snötäckt medan Stour Räitaglaciären var framsmält. Mätningarna visar dock ingen reträtt sedan 1991.

Centrala Kebnekaiseområdet

Fronterna på Stor-, Kebnepakte- och Tarfalaglaciärerna smälte inte fram denna sommar. De observerades fram till den 15 september då Tarfalastationen stängdes.

Isfallsglaciärens front karterades den 1 september från punkten Isfalls utlopp. Mätningen utfördes av K. Andersson, C. Richardsson och F. Burstedt. I den sydligaste och högst belägna delen har fronten skjutit fram 20-25 meter sedan förra året. I den centrala delen, som ligger lägst och saknar rörelse har fronten retirerat 4-5 meter. Ovanpå den forna nunatakken visar fronten en svag framryckning på i medeltal en meter. Medelförändringen för fronten blir +5 meter.

Rabots glaciär mättes in den 19 augusti av K. Andersson, K. Marvig och C. Richardsson. Fronten visade en reträtt på 14 meter sedan augusti 1991.

Sydöstra Kaskasatjåkkaglaciären mättes in den 9 september av P. Holmlund, A. Bodin, K. Andersson och C. Richardsson. Den östra, inaktiva delen av fronten var snötäckt under hela smältsäsongen. Den västra delen av fronten

Norra Sarek

Norra Sarek besöktes den 30 augusti. Instrumenteringen utgjordes av teodolit och geodimeter samt GPS-utrustning. Mätlaget bestod av P. Holmlund, A. Bodin, K. Andersson, C. Richardsson och L. Lidström.

Vartasglaciärens front var framsmält i sin västra del. Ett klipparti hade smält fram vilket inte har varit synligt tidigare. Fronten har varit snötäckt under somrarna 1989-1991. Senast den mättes in var 1984. Resultaten från i år visar en total reträtt på ca 15 meter. Det är svårt att fastställa en bra siffra då det dels har skett viss dödisavsmältning i frontens centrala och västra del, dels var östra delen fortfarande snötäckt vid besöket. Merparten av den uppmätta reträtten har sannolikt ägt rum somrarna 1985 och 1988. Förändringen sedan i fjol antas vara lika med noll.

Suottasglaciärens front var ännu snötäckt, varför glaciären fotograferades från luften. Dessa bilder antyder att nunatakken i isfallet har blivit något större än den var 1990, då den senast fotograferades. Det är ispartiet nedströms nunatakken som sjunkit ned. Snötäckningen i övrigt på denna glaciär var betydligt större i år än den var 1990 och av bilder att döma även 1989, som ju i övrigt var ett rekordår vad snötäckning beträffar.

Ruotesglaciären karterades från en punkt nära II-77. Fronten visade en reträtt på 21 meter sedan 1989. Förändringen sedan den måttbandsmättes 1991 var ca 7 meter.

Mikkagglaciären karterades från en punkt mellan II-75 och I-90. Gamla punkter karterades med GPS, medan fronten karterades med teodolit. Reträtten sedan i fjol var 10 meter.

Ruopsokglaciären karterades från en punkt mellan I-89 och II-77. Avloppstunneln från issjötappningen 1985 har nu rasat samman. En ny punkt (I-92) las ut på tungans östra sida. Reträtten sedan 1989 är 7 meter.

Hyllglaciären fotograferades i samband med dessa inmätningar. Dess front var snötäckt.

Pårte

Pårteglaciärens front karterades av M. Nyman och A. Norling den 10 september i samband med isdjups- och massbalansmätningar. Förändringen i frontläget sedan i fjol är svårtolkad, dels pga att dess södra sida var snötäckt under hela smältperioden 1992, dels för att dödisavsmältning har skett vid den tidigare frontsjön samt strax söder om glaciärporten. Vid det förhållandesvis lågt liggande, sandurtäckta partiet intill glaciärporten var medelreträtten 8,5 meter. Längs norra sidan var reträtten avtagande med avståndet från glaciärporten. En medelreträtt för hela fronten under perioden augusti 1991 till september 1992 uppskattades till 4 meter.

Sulitelma

Salajekna besöktes den 30 augusti av P. Holmlund, A. Bodin, K. Andersson, C. Richardsson och L. Lidström. Fronten karterades från punkt IV-65. Nya punkter I-IV-92 lades ut med numrering från öst mot väst. I-92 ligger intill jökelporten. Inmätningen visade att fronten har retirerat 10 meter sedan 1990. Fronten flygfotograferades (snedbild) från söder.

Tabell 1. Årliga frontförändringar 1965-1992, uttryckt i meter.

Glaciär	1965-1992	1989-1992	1991-1992
Storglaciären	-4	0	0
Isfallsglaciären	-6	+3	+5
Kårsaglaciären	-7	-1	0
Mikkaglaciären	-15	-11	-10
Rabots glaciär	-11	-12	-14
Salajekna	-10	-5	-5
Riukojietna	-9	0	0
Suottasjekna	-7	0	0
S.Ö Kaskasatj.gl.	-6		+3
Unna Räitaglac.	-3	0	0
Pårteglaciären	-13	-6	-4
Ruotesglaciären	-13	-7	-6
Vartasjekna	-4	0	0
Ruopsokjekna	-6	-2	(*)
Stour Räitagl.	-6	0	0
Västra Påssusjietna	-12	0	(-)
Östra Påssusjietna	-6	0	0
Hyllglaciären	-4	0	0

(*) Ruopsokglaciärens front mättes inte in somrarna 1990 och 1991. Sommaren 1990 var fronten helt snöfri den 11 augusti då den observerades från en helikopter.

(-) Västra Påssusglaciärens front hade ett smalt snöbräm framför tungan den 17 augusti. Den 1 september var tungan helt snöfri. En viss reträtt har troligtvis ägt rum under slutet av sommaren.

AERIAL PHOTOGRAPHY 1990-1992

Per Holmlund

Under åren 1990-1992 har ett flertal glaciärer och fjällområden flygfotograferats av Lantmäteriverket (LMV) för Naturgeografiska institutionens räkning. 1990 fotograferades Tarfalaområdet och Sarekmassivet. 1991 utfördes fotograferingar i norra Kebnekaise och 1992 i södra Sarek samt i Sulitelma.

Flygbildsmaterialet har samlats in av två skäl. Det ena skälet är att dokumentera den nuvarande situationen. Detta är mycket viktigt då de senaste årens höga ackumulationsvärden har givit stora massöverskott på glaciärerna, vilket har fått många glaciärer att sluta retirera och i vissa fall skjuta fram sina fronter. Situationen idag kan därför komma att utgöra en minimiutbredning för våra glaciärer under 1900-talet, förutsatt att klimatet fortsätter att vara gynnsamt för glaciärtillväxt.

Det andra skälet till att flygfotograferingarna har utförts är behovet av aktuella arbetskartor för de glaciärer vi arbetar vid. Kartmaterialet kommer även utnyttjas för beräkningar av glaciärernas volymförändringar. Ur dessa beräkningar kan man sedan räkna fram ett medelvärde på den årliga massbalansen för en specifik period.

Projektet har finansierats av NFR och kommer slutföras under 1993 eller 1994. De återstående fjällmassiven är Äpar, Ruotes och Akka i Sarek och Räita och Kåtoktjåkka i Kebnekaise. I tabell 1 ges information om de hittills utförda fotograferingarna.

Table 1. Aerial photograph missions carried out 1990-92 by the Swedish Authority of Land Survey (LMV) requested by the Department of Physical Geography in Stockholm.

motiv	riktning	skala	datum	beteckning	ant.	film
Kebnekaise	W-E	1:30000	1990-09-02	90 812 11	7	Sv
Kebnekaise	W-E	1:30000	1990-09-04	90 812 11 1	6	IR
Tarfala	S-N	1:10000	1990-09-02	90 812 01	9	Sv
Tarfala	S-N	1:10000	1990-09-04	90 812 01 1	9	Sv
Tarfala	S-N	1:10000	1990-09-04	90 812 01 2	8	IR
Sarek	W-E	1:30000	1990-09-04	90 811 01 1	8	Sv
Sarek	W-E	1:30000	1990-09-04	90 811 01	7	IR
Riukojietna	W-E	1:30000	1991-07-31	90 811 01	3	Sv
Påssus	W-E	1:30000	1991-07-31	90 811 02	5	Sv
Mårma	W-E	1:30000	1991-07-31	90 811 03	5	Sv
Kårsområdet	N-S	1:30000	1991-07-31	91 811 04	5	Sv
Pårte	W-E	1:30000	1992-09-12	92 826 01	5	Sv
Sulitelma	S-N	1:60000	1992-09-12	92 826 11	3	Sv

GPS MEASUREMENTS OF GLACIERS IN SWEDISH LAPPLAND 1992

Axel Bodin

SUMMARY

During the summer of 1992 a GPS receiver was installed at the Tarfala station. Together with this permanently installed base station (Trimble 4000 SD) two portable receivers have been used (Trimble Pathfinder series). Simultaneous measurements, using the base station and one mobile station, give an accuracy of approximately ± 2 m in the horizontal plane for a fixed position related to the position of the base station which covers an area with a radius of approximately 500 km. A much higher accuracy, ca 2-5 cm in the horizontal plane, is achieved when using the 4000 ST station, but this is a heavier system that was not used in Tarfala this season. The portable Pathfinder receivers used here are adequate when mapping stakes, snow lines and glacier fronts, for example. Differential corrections between the receivers and transformation from the Ellipsoid (WGS 84) used here, to UTM are performed on an ordinary personal computer with software available from Trimble (PFINDER version 1.44 and PFINDER Basic version 1.0). Thereafter a plot may be written on any HP-plotter and put on a map. A program converting UTM coordinates to the local net used in Tarfala (Helmert transformation) is being written. A plotter may be installed, giving us the opportunity of making maps immediately after a field survey.

Measurements conducted during the summer 1992 included the fix points, stakes and the transient snow line on Storglaciären. Although far from all the data have been plotted, the stake map over Storglaciären has been completed. GPS measurements of fix points and glacier fronts were conducted in Sarek (Mikkaglaciären, Ruopsokjietna, Ruotesglaciären, Vartasglaciären and Salajekna) and on Kårsaglaciären in the Abisko region (only fix points). In addition, the mobile systems have been used for a number of measurements, without the option of measuring at the base station simultaneously. One receiver alone gives an accuracy of about 10-20 meters, which in some cases, for example positioning of a snow probing profile or radio echo soundings, may be fully acceptable.

RADIO ECHO SOUNDINGS AT UNNA RÄITAGLACIÄREN AND STOUR RÄITAGLACIÄREN

Sven Lagerberg och Lotta Liljedahl

INLEDNING

Inom ramen för fältkursen i glaciologi (5p) radioekosonderades botten av Unna och Stour Räitaglaciärerna ($67^{\circ}59'N$, $18^{\circ}26'E$). Det största djupet på Unna Räitaglaciären, 130 m, uppmättes i en överfördjupning i ackumulationsområdet. Stour Räitaglaciären var som djupast ca 90 m vid jämviktslinjen.

OMRÅDESBESKRIVNING

Unna och Stour Räitaglaciärerna ligger i Vaktpostenmassivet ca 8 km norr om Kebnekaise. Unna Räitaglaciären rinner ned åt nordost i Unna Räitavagge. Glaciären avgränsas åt sydost av Knivkammen. Stour Räitaglaciären avgränsas åt söder av Tjåktjahjälmen och rinner ned åt väst i Stour Räitavagge. Glaciären har två nischer som ligger på Tjåktjahjälmens nordsida. Både Tjåktjahjälmen och knivkammen har mycket branta nordsidor.

RESULTAT

Två längsprofiler och en tvärprofil (Unna Räitaglaciären) uppmättes (fig 1). Unna Räitaglaciären uppvisade en medeltjocklek på 75 m med ett maxdjup av 130 m (längdprofil). Flera överfördjupningar visade sig på profilen och åtminstone en är klart djupare än de andra. På Stour Räitaglaciären uppmättes ett maxdjup på 90 m och medeldjupet visade sig vara 50 m. Här urskiljdes två tydliga överfördjupningar.

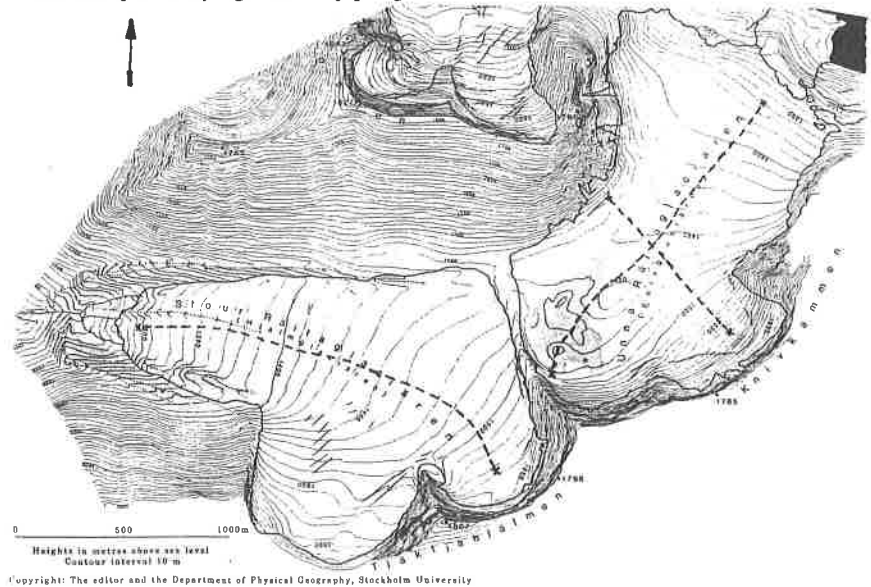


Figure 1. Map of the Unna Raitaglaciar and the Stour Raitaglaciar. The drawn line on the map shows where the profiles are taken.

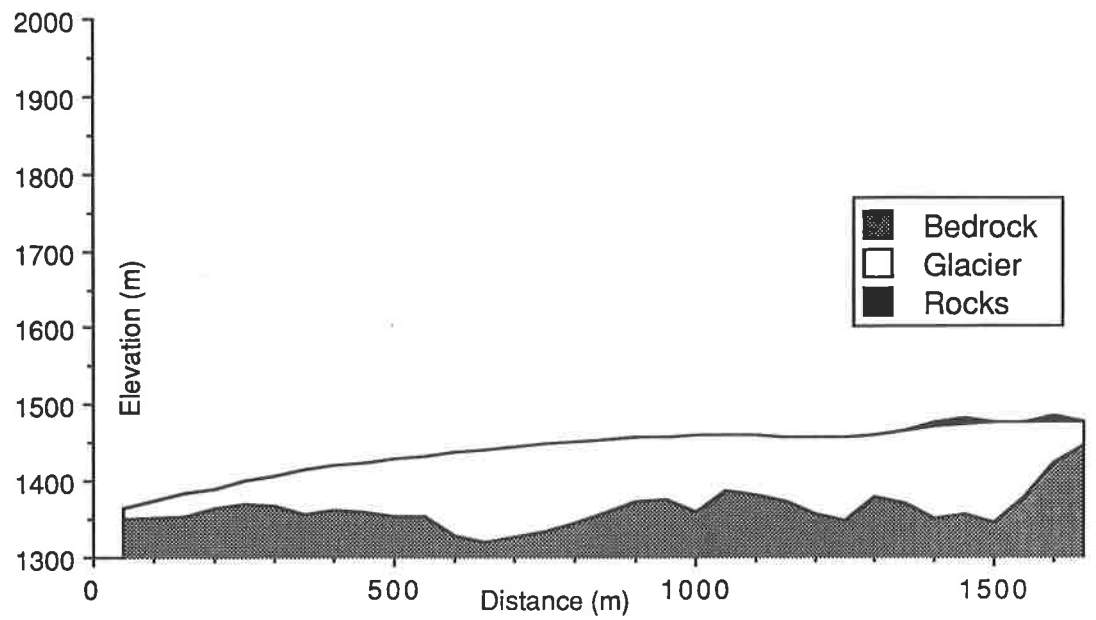


Figure 2. Longitudinal profile of the Unna Rättaglacier.

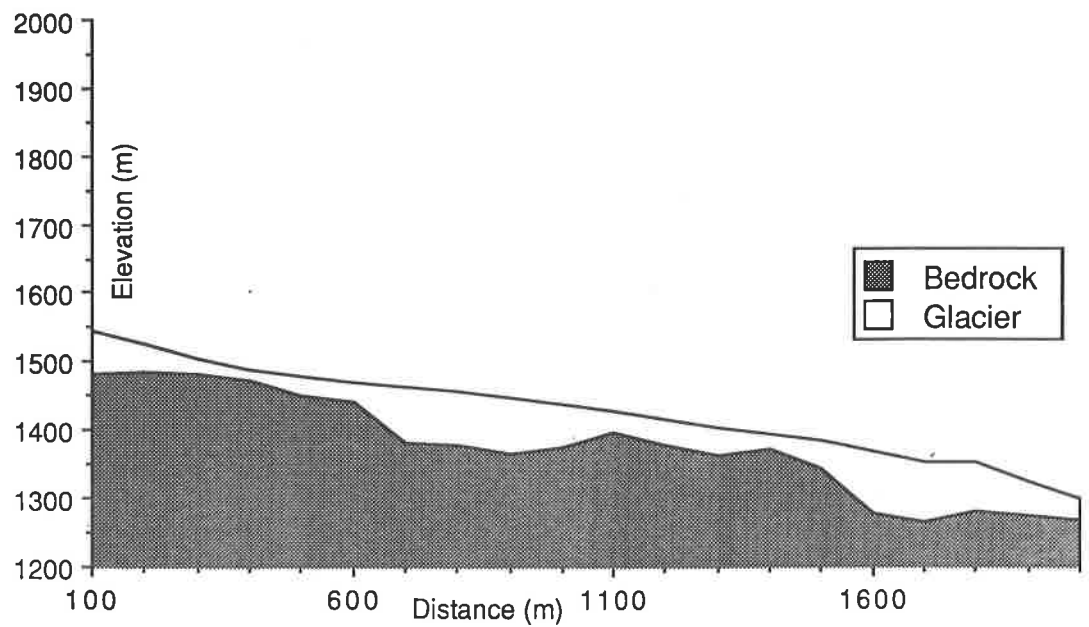


Figure 3. Longitudinal profile of the Stour Rättaglacier.

RADIO ECHO SOUNDINGS AT PÅRTEGLACIÄREN

Mart Nyman

ABSTRACT

During a few weeks in May and September 1992, several attempts to measure the depth of Påtejekna were made. Reliable results give a good picture of the central part of the glacier, in other words the midsection, including the tongue, plateau and central cirque.

In May only a few points at the tongue were successfully measured, but in September a better result was obtained. The information from the lower part of the glacier showed no discrepancies with the results obtained in the spring. The average depth of the main profile was 89 metres, resulting in a basal shear stress of 1,29 bar. It would probably be appropriate to increase this figure to compensate the less representative position of the profile, at some points.

INLEDNING

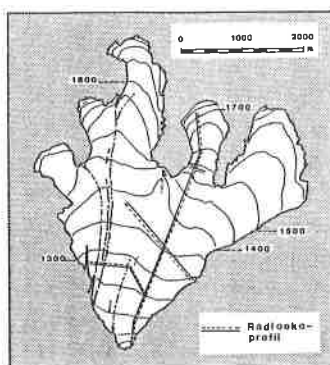


Figure 1. Map of Påteglaciären in Sarek and the position of profiles made by radio echo sounding.

Sommaren 1991 inleddes ett projekt inom ramen för ett examensarbete på geovetarlinjen med målsättning att ge en fysikalisk beskrivning av Påteglaciären. En längdprofil mättes sommaren

1991 som underlag för radioekosonderingarna följande vår. Eftersom resultaten från vårens mätningar inte var tillfredsställande, kompletterades dessa med ytterligare isdjups-mätningar i september. Syftet med dessa mätningar var, förutom att få underlag för en isdjupskarta, att beräkna den basala skjuvspänningen som ett mått på Påteglaciärens grad av kontinentalitet.

RESULTAT

En längdprofil av glaciären har konstruerats (fig 2) vilken följer en linje från fronten upp till överändan av den centrala nischen. Dessutom har en tvärprofil bestämts för glaciärens nedre hälft (fig 3). En mycket kort tvärprofil mättes tvärs över nischens mynning (fig 4). Tyvärr kunde den inte dras hela vägen ut till berget p g a sprickor.

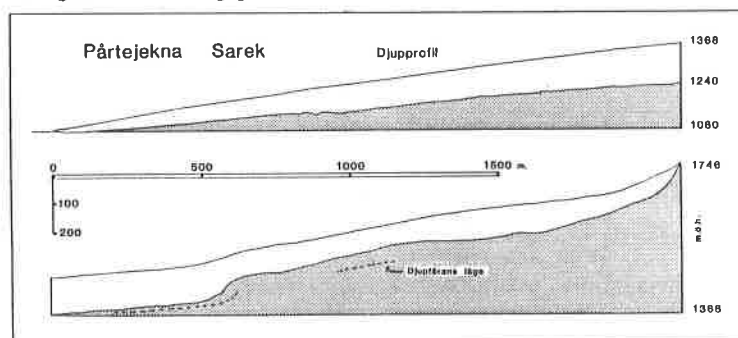


Figure 2. Longitudinal profile of the tongue and the central cirque of Påteglaciären.

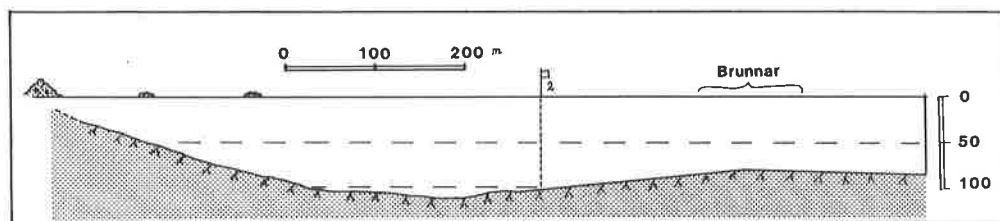


Figure 3. The lower cross section (new direction from stake 2).

Tvärprofilerna visar att glaciärens djupaste delar är belägna vid sidan av längdprofilen. Att maxdjupet vid nischen låg norr om längdprofilen var väntat. Sträckningen av profilen var till vissa delar en kompromiss till följd av det sprickiga underlaget.

Den nedre tvärprofilen visar ett tilltagande isdjup mot den södra sidan av glaciären. Ett maximalt isdjup om drygt 110 m uppmättes mitt i isflödet från den södra nischen. Tyvärr erhöles inte några användbara mätningar längre uppströms vilka kunnat visa om denna del av glaciären generellt är djupare än det centrala stråket. Några punktmätningar från våren pekar mot ett möjligt djup av 140 m nedanför södra nischen, men mätningen kunde inte positionsbestämmas med önskvärd noggrannhet. Merparten av den del av fronten, där frontinmätningar görs, har sitt tillflöde från det södra stråket.

Tvärprofilen passerar över Pärteglaciärens huvudsakliga brunnnsområde där isdjupet är cirka 80 m. Nedströms, något vid sidan av brunnarna, finns den enda, i maj uppmätta ojämnheten i underlaget vid denna mycket släta del av glaciären.

Längdprofilen har ett tillfredsställande dataunderlag, om än av varierande täthet. De största djupen återfinns under den markanta brant som kan skönjas nedanför nischmyningen. Här finns profilens maxdjup, 134 m. Detta får betraktas som ett påfallande grunt värde för en glaciär av Pärtes storlek. Troligen finns det djupare delar på sydsidan. Det beräknade medeldjupet för längdprofilen är 89 m. Detta ger en basal skjuvspänning på 1,29 bar.

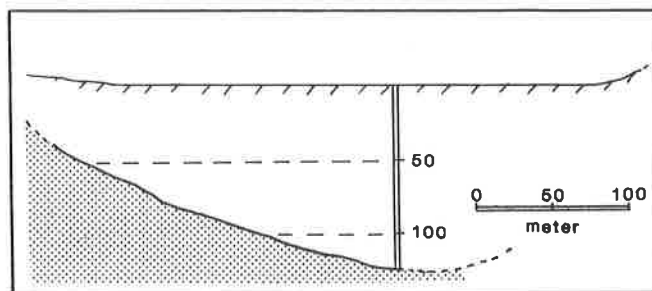


Figure 4. The upper cross section in the opening to the central cirque.

APPENDIX 1. Published papers 1988-1992.

Andreasson, P.-G. and Gee, D.G., 1989: Bedrock geology and morphology of the Tarfala area, Kebnekaise Mts., Swedish Caledonides. *Geografiska Annaler* 71A (3-4): 235-239.

Eriksson, M.G., Björnsson, H., Herzfeld, U.C. and Holmlund, P., 1992: The bottom topography of Storglaciären. A new map based on old and new ice depth measurements, analyzed with geostatistical methods. *Forskningsrapportserien STOU-NG* 95, 48 p.

Fleetwood, Å. and Thomas, J., 1990: Weathering and ion flow in Tarfala drainage basin, Lapland, N. Sweden. *Geografiska Annaler* 72A (1): 125-127.

Grudd, H., 1990: Small glaciers as sensitive indicators of climatic fluctuations. *Geografiska Annaler* 72 A (1): 119-123.

Holmlund, P., 1988: An application of two theoretical melt water drainage models on Storglaciären and Mikkaglaciären, Northern Sweden. *Geografiska Annaler* 70A (1-2): 1-7.

-1988: Is the longitudinal profile of Storglaciären in balance with the present climate? *Journal of Glaciology* 34 (118): 269-273.

-1988: Internal geometry and evolution of moulins, Storglaciären, Sweden. *Journal of Glaciology* 34 (117): 242-248.

-1991: Cirques at low altitudes need not necessarily have been cut by small glaciers. *Geografiska Annaler* 73A (1): 9-16.

-1992: Climatic influence on the size of glaciers in Northern Sweden during the last two centuries. *Quaternary Science Reviews*, In press.

Holmlund, P. and Eriksson, M., 1989: The cold surface layer on Storglaciären. *Geografiska Annaler* 71 A (3-4): 241-244.

Hooke, R.LeB., 1991: Positive feedbacks associated with erosion of glacial cirques and overdeepenings. *Geological Society of America Bulletin*, 103: 1104-1108.

Hooke, R. LeB., Calla, P., Holmlund, P., Nilsson, M., Stroeven, A., 1989: A 3 year record of seasonal variations in surface velocity, Storglaciären, Sweden. *Journal of Glaciology* 35 (120): 235-247.

Hooke, R.LeB., Miller, S.B. and Kohler, J., 1988: Character of the englacial and subglacial drainage system in the upper part of the ablation area of Storglaciären. *Journal of Glaciology* 34 (117): 228-231.

Hooke, R.LeB., Pohjola, V.A., Jansson, P., Kohler, J., 1992: Intra-seasonal changes in deformation profiles revealed by borehole studies, Storglaciären, Sweden. *Journal of Glaciology* 38 (130): 348-358.

Jahn, A., 1991: Slow soil movement in Tarfala valley, Kebnekaise mountains, Swedish Lapland. *Geografiska Annaler* 73A(2): 93-107.

Jansson, P.E., 1992: Interpretation of short-term variations in ice dynamics, Storglaciären, Kebnekaise, Northern Sweden. *Forskningsrapportserien STOU-NG* 89, 83 p.

Jansson, P. and Hooke, R.LeB., 1989: Short-term variations in strain and surface tilt on Storglaciären, Kebnekaise, northern Sweden. *Journal of Glaciology* 35 (120): 201-208.

Lück, A., 1991: Untersuchung zur Permafrosthydrologie, in einem subarktischen Hochgebirgseinzugsgebiet. Permafrosthydrological Dynamics of a Subarctic High Mountain Catchment Area. University of Bonn, 97 p.

Rosqvist, G. and Ostrem, G., 1989: The sensitivity of a small icecap to climatic fluctuations. *Geografiska Annaler* 71 A (1-2): 99-104.

Schneider, T. and Bronge, C., 1992: Suspended sediment transport and discharge of Tarfalajåkk, the proglacial stream of Storglaciären, Northern Sweden, 1980-1990. *Forskningsrapportserien STOU-NG*, 92, 28 p.

Seaberg, Z., Seaberg, J.Z., Hooke, R.L. and Wiberg, D.W., 1988: Character of the englacial and subglacial drainage system in the lower part of the ablation area of Storglaciären, Sweden, as revealed by dye-tracer studies. *Journal of Glaciology* 34 (117): 217-227.

Seppälä, M., (et al), 1989: Glaciological course in Tarfala. *Terra* 101 (3): 252-274.

Stroeven, A.P. and van de Wal, R.S.W., 1990: A comparison of the mass balances and flows of Rabots glaciär and Storglaciären, Kebnekaise, northern Sweden. *Geografiska Annaler* 72 A (1): 113-118.

Walford, M.E.R. and Kennett, M.I., 1989: A synthetic-aperture radio-echo experiment at Storglaciären, Sweden. *Journal of Glaciology* 35 (119): 43-47.

Filosofie doktorsexamen

Bronge, C., 1989: Climatic Aspects of Hydrology and Lake Sediments with Examples from Northern Scandinavia and Antarctica. *Naturgeografiska institutionen vid Stockholms universitet. Meddelande nr A 241 (ISBN 91-7146-785-8)*, 166 p.

Brugger, K., 1992: A Comparative study of the response of Rabots glacier and Storglaciären to recent climatic change, Department of geology and geophysics, University of Minnesota, 287 p.

Holmlund, P., 1988: Studies of the drainage and the response to climatic change of Mikkaglaciären and Storglaciären. *Naturgeografiska institutionen vid Stockholms universitet. Meddelande nr A 220 (ISBN 91-7146-590-1)*, 75 p.

Kennett, M., 1987: An analysis of the scattering of radio waves within a temperate glacier. Department of Physics, University of Bristol. 176 p.

Kohler, J.C., 1992: Glacial hydrology of Storglaciären, Northern Sweden. Department of geology and geophysics, University of Minnesota, 147 p.

Filosofie Licentiat- eller motsvarande examen

Jansson, P.E., 1992: Interpretation of short-term variations in ice dynamics, Storglaciären, Kebnekaise, Northern Sweden. *Naturgeografiska institutionen, Stockholms universitet. Forskningsrapportserien STOU-NG* 89, 83 p.

Rosqvist, G., 1989: Studies of glacier fluctuations and climatic change. *Naturgeografiska institutionen vid Stockholms universitet*.

APPENDIX 2. Personnel and guests 1992.

Stationspersonal

dygn

Bodin, Axel (amanuens)	99
Grudd, Håkan (intendent)	109
Holmlund, Per (forskarassistent)	41
Karlén, Wibjörn (professor, stationsföreståndare)	9

Hantlangare, extrapersonal

Andersson, Karin	43
Blom, Anders	41
Bondesson, Sören	5
Burstedt, Fredrik	11
Eklund, Jenni	5
Eriksson, Mats	34
Knutsson, Jesper	41
Laudon, Hjalmar	30
Marvig, Karen	37
Nyman, Mart	24
Obrovac, Julia	40
Persson, Eva	3
Pettersson, Anna	38
Richardsson, Cecilia	48
Ulfstedt, Kai	16

Projektansvariga, gästforskare

Andreasson, Per-Gunnar	5
Geologiska inst., Lunds universitet.	
Aravena, Juan Carlos	4
Departemento de Biología, Universidad de Chile, Santiago, Chile	
Bronge, Christian	3
Naturgeografiska inst., Stockholms universitet	
Bylund, Göran	7
Geologiska inst., Lunds universitet	
Criado, Constantino	10
Departemento de geografía, Teneriffa, Spain	
Cutler, Paul	47
Dept of geology, University of Minnesota, USA	
Goerke, Ute	7
Geologisches inst., Heidelberg, Germany	
Hall, Brenda	13
University of Maine, USA	

Hanson, Brian	30
Dept. of geography, University of Delaware, USA	
Hooke, Roger	30
Dept of geology, University of Minnesota, USA	
Naturgeografiska inst., Stockholms universitet	
Jansson, Peter	40
Dept of geology, University of Minnesota, USA	
Naturgeografiska inst., Stockholms universitet	
Jonsson, Stig	3
Naturgeografiska inst., Stockholms universitet	
Näslund, Jens-Ove	6
Naturgeografiska inst., Stockholms universitet	
Palacios, David	5
Dept. of geografía física, Madrid, Spain	
Pohjola, Veijo	25
Naturgeografiska inst., Uppsala universitet	
Rackowska, Zofia	11
Inst. of geography, Polish academy of science, Poland	
Rosqvist, Nini	3
Naturgeografiska inst., Stockholms universitet	
Schneider, Tomas	58
Naturgeografiska inst., Uppsala universitet	
Stroeven, Arjen	3
Naturgeografiska inst., Stockholms universitet	
Vrba, Elisabeth	2
Dept. of geology and geophysics, Yale university, USA	
Walde, Carl-Henrik	7
FMV:Elektro, Stockholm	
Wollesen, Dirk	31
Geographisches inst., Justus-Liebig-Univ., Giessen, Germany	
Kurser	
Estländarkurs	150
Fjälljägarskolan, Kiruna	63
Forskarkurs, Naturgeografiska inst., Stockholms univ.	99
Glaciologi 5p., Stockholms universitet.	180
Högskolan i Luleå, avd för byggt teknik	18
Kebnekaise fjällstation, STF, 10 kurser	219
Tärendö centralskola	51
Gäster, Totalt	165
Totalt:	1969

APPENDIX 3. Meteorological data 1992.

JANUARY

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-6.8	-0.7	-10.8	19.6	3.0	0
2	-7.5	-4.3	-11.4	18.9	7.4	0
3	-10.9	-5.6	-14.8	6.2	2.0	0
4	-8.3	-6.3	-11.9	21.0	5.3	0
5	-9.7	-6.3	-15.7	15.8	5.0	0
6	-8.6	-6.2	-16.6	18.0	7.3	0
7	-14.6	-9.5	-19.5	4.6	2.0	0
8	-13.5	-8.9	-19.9	5.4	1.7	0
9	-15.1	-11.3	-21.3	5.9	1.8	0
10	-12.4	-3.0	-20.6	16.5	2.2	0
11	-7.7	-3.2		47.4	7.1	0
12	-10.7	-5.1		43.3	8.8	1
13	-13.3	-11.3	-16.3	10.1	1.8	0
14	-4.7	-1.3	-13.1	39.6	6.8	0
15	-8.8			60.5	10.1	4
16	-12.9	-11.6	-14.5	44.8	9.9	0
17	-10.6			31.9	8.2	0
18	-9.8	-7.0	-14.3	14.3	3.3	0
19	-7.0	1.0	-15.2	19.8	3.1	0
20	-0.6	4.0	-3.8	63.6	14.3	1
21	0.1	3.7	-3.3	29.5	14.4	1
22	-0.7	2.0	-4.2	31.1	9.3	1
23	-2.6	-0.1	-6.1	44.2	9.0	1
24	-1.5	0.8	-4.4	31.0	9.8	1
25	-1.8	0.5	-5.8	30.7	7.3	0
26	-5.4		-8.5	51.1	11.3	0
27	0.5		-2.7	44.3	9.6	6
28	-3.7	1.9	-9.0	35.7	8.7	2
29	-5.8	2.8	-9.8	47.0	13.8	0
30	0.2	2.6	-2.2	39.5	13.0	2
31	-1.3		-5.2	48.7	12.4	1

FEBRUARY

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-3.2	-1.1	-6.2	20.1	4.7	0
2	-4.0	-1.2	-6.6	21.6	5.7	0
3	-8.6	-4.9	-13.1	10.1	2.3	0
4	-9.1	-5.8	-13.8	12.4	3.2	0
5	-12.7	-9.2	-17.4	31.6	5.0	0
6	-14.2	-5.5	-18.1	19.9	3.2	0
7	-2.7	1.4	-14.1	28.7	8.2	0
8	-6.4	-0.6			9.1	3
9	-5.9	2.7	-12.0	13.4	2.0	0
10	-4.0	1.4	-8.2	8.7	1.8	0
11	-6.6	-3.7	-8.9	11.5	1.3	0
12	-9.2	-4.0	-15.3	14.6	4.4	0
13	-15.5	-12.8	-20.0	8.5	1.9	0
14	-13.3	-11.2	-19.1	15.5	4.3	0
15	-12.5	-10.0	-15.8	9.4	2.8	0
16	-10.0	-3.7	-18.7	14.0	4.7	0
17	-7.1	-5.6	-9.8	20.0	6.5	0
18	-7.2	-4.9	-10.3	18.2	2.9	0
19	-7.5	-4.8	-11.8	15.0	4.4	0
20	-8.3	-0.5	-14.2	11.1	2.1	0
21	-4.4	-0.6	-8.0	35.7	4.2	0
22	-6.8	-3.4	-8.9	18.5	4.4	0
23	-7.4	-5.3	-9.1	42.3	8.4	0
24	-7.5	-4.6		42.0	5.4	0
25	-5.6	-3.1	-7.5	22.0	6.5	0
26	-4.1		-9.4	59.2	5.9	0
27	-6.1	-2.3	-12.2	28.8	7.3	0
28	-6.4	-3.1	-9.0	20.2	3.4	0
29	-2.0	1.2	-6.4	17.8	4.5	0

MARCH

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-1.7	0.8		22.1	6.8	0
2	-6.5	-3.5	-10.3	9.9	1.8	0
3	-8.9	-6.7	-12.5	2.7	0.9	0
4	-5.9	-2.4	-13.7	10.1	2.4	1
5	-0.8	2.2	-11.0	15.1	4.1	6
6	-0.0	3.1	-2.4	20.2	3.6	3
7	-3.4	-0.2	-5.6	32.9	7.2	0
8	-2.6	3.7	-7.9	20.9	6.9	0
9	0.8	7.0	-2.9	20.6	4.4	0
10	-3.6	-0.8	-7.3	22.5	3.2	0
11	-6.0	-2.0	-9.9	18.5	3.6	0
12	-10.0	-7.7	-12.9	14.7	4.3	0
13	-7.0	-6.2	-7.9	10.8	5.3	0
14	-11.3	-7.3	-15.9	4.8	1.9	0
15	-6.9	-4.7	-13.3	21.9	5.5	0
16	-8.7	-5.1	-13.2	18.8	6.3	0
17	-5.4	-0.8	-11.5	15.1	3.6	0
18	-2.5	-0.5	-5.0	23.2	5.7	0
19	-3.6	-1.5	-5.4	21.4	2.9	2
20	-5.5	-3.7	-7.4	14.9	5.8	0
21	-7.7	-4.7	-15.7	13.1	4.8	0
22	-9.1	-5.3	-15.0	4.6	1.4	0
23	-9.8	-6.5	-15.0	11.4	3.2	0
24	-10.7	-7.7	-14.7	12.2	3.0	0
25	-11.5	-8.0	-17.9	17.1	4.8	0
26	-11.5	-5.1	-18.1	4.1	1.4	0
27	-12.7	-7.3	-18.4	7.1	1.8	0
28	-11.7	-6.6	-17.6	10.4	3.3	0
29	-14.8	-10.0	-21.7	5.3	1.7	0
30	-10.5	-8.8	-18.1	17.4	5.1	0
31	-13.9	-12.1	-14.8	29.5	4.8	0

APRIL

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-13.6	-12.3	-14.7	17.4	4.2	0
2	-14.2	-9.5	-19.2	10.5	2.0	0
3	-15.2	-7.1	-19.6	3.6	1.2	0
4	-11.0	-4.8	-20.7	3.9	1.2	0
5	-12.1	-5.6	-17.5	3.4	1.0	0
6	-11.5	-2.8	-17.5	3.4	1.0	0
7	-7.6	-1.4	-12.1	17.6	4.1	0
8	-6.3	0.2	-15.0	19.8	5.4	0
9	-9.1	-3.0	-15.2	3.5	1.4	0
10	-3.9	3.9	-8.3	4.0	1.3	0
11	-5.4	-1.3	-11.1	15.3	3.8	0
12	-7.7	-0.9	-11.3	9.9	2.1	0
13	-9.4	-5.3	-14.9	16.9	4.0	1
14	-11.2	-6.7	-15.5	17.6	3.5	0
15	-13.3	-3.0	-19.5	7.4	2.1	0
16	-11.5	-4.4	-19.1	9.1	2.1	0
17	-9.1	-6.8	-11.1	19.3	4.8	0
18	-7.8	-3.1	-9.7	18.1	4.2	0
19	-8.0	-1.1	-13.5	3.9	1.1	7
20	-9.0	2.7	-14.5	4.3	1.6	0
21	-10.5	-2.3	-18.5	3.6	1.1	0
22	-13.2	-7.2	-22.1	13.6	3.2	0
23	-11.0	-8.4	-12.4	19.8	4.5	0
24	-8.9	-3.6	-16.0	13.8	2.4	0
25	-7.3	-5.5	-9.2	10.8	4.8	0
26	-5.5	0.9	-7.0	9.2	1.8	4
27	-4.5	-0.9	-6.6	11.6	4.3	3
28	-3.4	-2.0	-5.4	11.1	5.4	0
29	-1.4	0.2	-2.2	6.7	3.3	7
30	-1.2	1.8	-2.5	21.8	3.5	14

MAY						
DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-2.7	2.3	-6.3	22.4	5.4	0
2	-1.4	2.1	-3.5	5.9	0.9	5
3	-2.9	0.7	-6.6	19.0	7.7	0
4	-3.2	4.0	-7.4	8.8	1.6	3
5	0.7	5.2	-2.8	15.6	3.5	0
6	-1.1	3.9	-4.9	11.0	2.1	13
7	-5.3	-3.2	-8.3	15.7	4.9	0
8	-4.7	4.2	-9.8	11.8	2.9	0
9	-4.1	1.3	-8.7	6.1	1.2	0
10	-4.8	4.7	-11.9	7.2	1.5	0
11	-3.8	1.0	-7.2	10.5	3.4	0
12	-4.9	2.3	-9.2	8.1	2.0	0
13	-3.3	1.6	-11.0	14.0	3.0	0
14	-1.7	5.8	-9.1	20.2	3.4	4
15	6.0	9.4	0.5	26.4	6.4	1
16	-1.6	1.8	-5.5	22.6	4.8	1
17	-1.3	2.2	-5.8	22.6	5.7	1
18	0.2	2.2	-1.9	19.0	5.0	1
19	0.8	3.4	-4.5	25.0	8.6	1
20	-0.4	4.2	-6.0	20.4	3.0	1
21	2.9	5.9	-0.7	14.2	4.1	0
22	2.5	9.4	-2.6	4.2	1.1	0
23	6.9	10.7	0.8	13.8	2.9	0
24	5.0	8.0	0.2	15.5	5.1	0
25	2.1	8.9	-4.0	8.8	1.4	0
26	6.8	11.3	1.3	11.5	2.9	0
27	7.2	10.8	2.1	7.1	1.9	0
28	9.1	12.0	4.1	10.3	3.5	0
29	8.7	13.6	3.4	9.4	3.0	0
30	7.7	10.7	5.4	17.8	4.9	0
31	5.4	7.7	3.3	18.7	7.4	1

JUNE						
DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	4.2	7.5	-0.7	13.9	2.3	0
2	6.3	11.7	0.1	4.6	2.2	0
3	8.6	12.3	1.4	4.7	2.3	0
4	9.5	13.9	3.1	16.5	3.2	0
5	6.8	11.4	3.6	24.6	6.2	0
6	6.5	9.3	3.7	28.7	10.0	0
7	4.3	8.5	0.6	27.5	6.2	0
8	6.2	10.9	-1.4	4.5	2.1	0
9	9.3	13.8	2.4	5.2	2.6	0
10	10.7	14.5	5.4	5.5	3.0	0
11	11.6	16.5	6.3	6.9	2.5	0
12	11.3	15.9	5.6	7.5	2.5	0
13	11.8	15.8	6.3	9.7	2.4	2
14	8.6	12.3	3.9	16.7	4.3	9
15	4.1	5.9	2.9	16.2	3.7	1
16	0.7	4.7	-2.0	22.7	9.2	0
17	-0.1	2.2	-2.4	21.7	4.6	0
18	2.3	5.4	-0.2	8.2	1.9	0
19	4.7	9.0	-0.5	12.5	2.5	0
20	5.6	8.7	0.8	20.3	3.8	2
21	-1.1	1.3	-3.8	16.5	6.7	0
22	-1.6	1.8	-4.3	14.5	5.5	0
23	0.7	3.5	-1.8	11.4	4.4	0
24	4.5	9.9	-1.8	5.2	1.5	0
25	8.4	14.0	1.7	4.7	1.9	0
26	9.9	14.4	3.6	6.0	2.0	0
27	8.4	11.1	4.8	13.6	2.4	29
28	3.7	5.5	1.7	13.5	4.9	0
29	3.1	6.0	0.6	10.6	3.3	0
30	2.9	6.6	0.5	5.9	1.9	5

JULY						
DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	2.5	6.0	-0.0	7.6	2.1	2
2	2.4	6.4	-0.2	7.3	1.9	9
3	2.8	5.5	-0.5	17.7	4.2	0
4	6.2	9.1	3.2	16.4	5.5	0
5	6.2	11.0	1.1	10.4	2.7	0
6	2.1	4.5	0.8	11.9	3.9	1
7	2.7	5.4	0.5	14.5	5.4	0
8	4.6	7.9	1.0	17.0	5.0	10
9	2.9	4.9	1.6	22.2	5.0	5
10	4.0	7.7	1.5	13.2	3.4	0
11	4.1	7.4	1.5	14.5	3.7	2
12	5.8	10.1	1.1	13.6	4.0	0
13	6.9	10.2	4.6	8.9	2.3	1
14	8.6	11.5	5.7	7.8	2.2	2
15	7.2	8.8	5.3	10.8	2.2	50
16	6.1	8.5	3.6	8.8	2.6	14
17	4.1	6.9	0.7	10.7	3.5	0
18	4.4	9.7	-0.8	5.7	1.7	0
19	7.1	10.9	4.6	7.0	2.0	0
20	7.1	9.7	4.3	3.2	1.1	0
21	9.1	11.4	6.3	6.3	2.1	2
22	7.9	10.6	5.8	22.7	3.8	33
23	4.8	6.4	3.7	27.8	10.4	6
24	7.3	10.3	3.4	19.0	3.2	0
25	6.9	10.1	5.0	10.6	2.5	5
26	7.3	10.4	4.0	8.8	2.0	4
27	7.2	8.4	5.6	6.3	1.9	29
28	6.3	8.9	4.9	12.7	3.9	0
29	5.6	7.4	4.3	10.1	3.3	0
30	6.1	8.7	3.5	9.0	2.4	18
31	3.9	5.6	1.9	16.8	6.0	24

AUGUST						
DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	2.9	4.6	1.3	22.6	9.2	1
2	5.0	9.5	0.1	9.6	1.6	0
3	7.6	10.0	5.6	7.7	1.8	1
4	7.2	8.4	5.9	10.4	1.6	26
5	6.7	8.3	5.0	17.8	6.1	1
6	6.7	9.7	4.3	8.4	1.8	1
7	5.4	7.9	2.7	15.6	4.9	1
8	1.6	4.3	-1.1	21.5	5.4	4
9	-0.1	2.2	-1.9	24.5	6.3	0
10	2.2	5.2	-2.3	5.9	1.4	1
11	5.2	9.6	2.8	5.9	1.1	12
12	4.1	6.0	0.6	8.9	2.4	3
13	1.1	2.5	-0.1	5.5	2.7	8
14	1.7	2.8	0.7	5.1	1.6	1
15	3.3	6.6	1.5	4.4	1.1	1
16	5.0	10.0	1.3	4.1	1.6	0
17	4.7	6.0	3.4	3.0	1.1	0
18	5.1	7.3	3.4	4.2	1.3	0
19	5.4	7.1	3.7	3.0	0.9	1
20	5.0	5.8	3.8	3.5	1.1	6
21	5.0	8.0	2.3	3.5	1.1	0
22	6.0	9.7	2.1	3.2	1.4	0
23	4.4	7.2	1.5	6.9	2.1	0
24	2.6	3.9	1.6	3.5	1.3	0
25	2.7	4.0	1.8	5.5	2.0	2
26	2.7	4.4	1.6	6.9	2.2	9
27	2.8	3.9	1.8	6.2	2.4	17
28	3.6	4.6	2.5	6.7	2.3	17
29	5.2	7.4	3.7	10.1	2.1	5
30	5.4	8.8	2.8	6.5	1.7	0
31	4.4	6.7	1.8	7.1	2.6	5

SEPTEMBER

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	5.5	8.4	3.3	6.9	2.1	36
2	5.2	8.3	2.9	8.5	2.3	0
3	3.1	4.6	1.0	12.3	3.8	0
4	-0.2	1.7	-2.5	5.5	2.0	6
5	-2.8	-1.6	-3.8	8.3	2.5	0
6	-1.1	0.7	-3.3	6.9	1.7	0
7	0.8	5.4	-3.0	5.1	1.4	0
8	2.2	4.6	-1.8	11.4	3.1	37
9	3.1	5.7	1.5	8.1	2.0	1
10	3.9	7.2	0.0	16.0	2.5	0
11	5.9	8.2	3.1	12.4	3.0	1
12	8.0	13.1	3.0	3.9	1.4	0
13	4.5	8.0	1.8	4.9	1.3	0
14	3.0	5.7	0.3	5.8	1.7	0
15	3.1	4.4	-0.2	8.2	2.2	13
16	3.9	4.6	3.0	10.1	2.3	34
17	3.6	5.7	2.1	9.2	2.4	0
18	2.5	4.4	0.1	10.0	3.8	0
19	0.7	2.2	-0.8	4.2	1.4	0
20	1.3	3.2	0.5	5.4	1.8	0
21	1.1	2.0	-0.2	9.4	3.0	10
22	1.7	4.0	-0.2	8.7	2.7	8
23	3.3	5.8	2.3	6.9	1.3	1
24	4.1	6.2	2.6	9.8	1.4	0
25	5.3	7.4	3.1	14.9	5.7	1
26	2.9	5.5	-0.2	11.0	2.4	0
27	-0.2	2.8	-1.6	3.7	1.4	0
28	-1.6	2.6	-4.4	3.2	0.9	0
29	4.0	8.8	-2.4	9.4	1.8	0
30	3.1	7.0	-0.4	11.9	2.5	0

OCTOBER

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-0.9	1.9	-3.7	11.2	1.4	0
2	0.4	4.4	-4.2	12.7	2.5	0
3	0.1	3.2	-1.9	4.9	1.0	0
4	2.6	4.9	-1.3	19.3	6.0	3
5	4.4	6.1	2.5	26.1	8.4	21
6	-0.1	2.9	-3.3	31.5	6.7	2
7	-1.0	0.9	-3.0	17.1	5.8	0
8	-3.2	-0.6	-7.0	21.1	3.5	1
9	-7.5	-3.4	-12.0	13.4	3.4	0
10	-5.6	-3.0	-7.9	14.3	2.5	0
11	-8.0	-6.1	-10.7	14.2	4.7	0
12	-10.0	-5.3	-14.4	9.3	3.1	0
13	-11.0	-10.0	-15.3	7.7	3.0	0
14	-13.3	-9.6	-19.8	7.8	2.2	0
15	-11.7	-5.9	-18.7	5.7	2.0	0
16	-12.0	-8.8	-18.3	3.9	1.8	0
17	-13.1	-9.7	-18.2	3.9	1.7	0
18	-13.4	-8.0	-19.7	9.6	2.2	0
19	-10.7	-7.5	-16.2	9.8	3.3	0
20	-13.0	-10.4	-17.1	4.0	1.8	0
21	-8.8	-6.7	-12.8	10.9	3.4	0
22	-9.6	-7.1	-15.0	10.4	2.6	0
23	-14.0	-9.7	-19.6	4.1	1.4	0
24	-11.8	-6.1	-16.2	12.9	1.8	0
25	-9.4	-6.3	-14.8	6.1	1.4	0
26	-13.1	-10.5	-17.0	4.8	2.0	0
27	-12.7	-10.0	-16.3	3.8	2.0	0
28	-14.0	-11.0	-19.8	4.4	1.6	0
29	-15.0	-13.0	-21.1	10.0	1.9	0
30	-15.0	-13.6	-17.7	8.2	2.9	0
31	-16.5	-15.6	-19.1	5.0	1.5	0

NOVEMBER

DATE	MEAN TEMP	MAX TEMP	MIN TEMP	MAX WIND	MEAN WIND	PRECIP
	[°C]	[°C]	[°C]	[m/s]	[m/s]	[mm]
1	-17.9	-16.8	-21.4	4.5	1.3	0
2	-15.3	-8.4	-19.3	4.9	1.2	0
3	-11.2	-8.2	-15.5	4.5	1.0	0
4	-8.1	-5.4	-13.1	14.1	2.4	0
5	-13.3	-9.2	-18.5	4.7	1.9	0
6	-13.5	-10.3	-19.1	4.5	1.5	0
7	-11.5	-5.8	-20.1	15.0	3.4	0
8	-4.2	-2.2	-6.7	22.1	8.1	0
9	-2.5	1.4	-6.6	19.7	4.0	0
10	-5.7	-0.4	-10.2	4.9	1.6	0
11	-4.1	-1.3	-6.0	21.2	5.4	0
12	-7.9	-3.8	-13.8	12.2	2.2	0
13	-8.1	-6.0	-11.0	7.4	2.0	0
14	-7.8	-6.3	-14.1	5.3	1.3	0
15	-7.8	-4.0	-13.2	5.5	2.0	0
16	-10.3	-7.4	-16.2	3.5	1.2	0
17	-8.9	-6.0	-11.8	10.9	2.4	0
18	-10.5	-6.0	-14.3	12.5	2.3	0
19	-11.6	-9.5	-15.1	9.0	1.7	0
20	-13.0	-9.1	-15.4	7.4	2.0	0
21	-13.3	-11.3	-15.7	11.8	2.5	0
22	-14.6	-13.4	-17.1	6.7	1.5	0
23	-15.3	-9.9	-23.6	4.6	2.0	0
24	-11.9	-0.3	-19.8	23.6	3.3	0

APPENDIX 4. Mass balance 1989/90 - 1991/92 of Mårmaglacière.

Mårmaglacièrens massbalans under budgetåret 1989/90.

Nivå	Yta Vinterbalans			Sommarbalans		Nettobalans	
m ö h	10^3m^2	10^3m^3	m v e	10^3m^3	m v e	10^3m^3	m v e
-1340	55.0	96.3	1.75	105.9	1.93	-9.6	-0.17
1340-1360	96.5	163.1	1.69	187.9	1.95	-24.8	-0.26
1360-1380	148.0	223.3	1.51	286.5	1.94	-63.2	-0.43
1380-1400	150.5	202.1	1.34	280.2	1.86	-78.1	-0.52
1400-1420	156.0	166.1	1.06	288.6	1.85	-122.5	-0.79
1420-1440	161.0	196.3	1.22	292.6	1.82	-96.3	-0.60
1440-1460	218.5	247.4	1.13	368.8	1.69	-121.4	-0.56
1460-1480	253.0	266.9	1.05	402.5	1.59	-135.6	-0.54
1480-1500	199.5	214.1	1.07	314.5	1.58	-100.4	-0.50
1500-1520	188.5	231.1	1.23	293.7	1.56	-62.6	-0.33
1520-1540	365.0	423.9	1.16	528.8	1.45	-104.9	-0.29
1540-1560	352.5	333.1	0.94	449.1	1.27	-116.0	-0.33
1560-1580	232.0	227.4	0.98	241.5	1.04	-14.1	-0.06
1580-1600	196.5	185.6	0.94	233.9	1.19	-48.3	-0.25
1600-1620	311.0	291.3	0.94	388.9	1.25	-97.6	-0.31
1620-1640	332.5	399.5	1.20	360.9	1.09	38.6	0.12
1640-1660	200.0	330.8	1.65	198.0	0.99	132.8	0.66
1660-1680	203.0	500.0	2.46	200.5	0.99	299.5	1.48
1680-1700	103.0	257.5	2.50	101.8	0.99	155.7	1.51
1700-1720	40.0	100.0	2.50	40.0	1.00	60.0	1.50
1720-1740	33.0	82.5	2.50	33.0	1.00	49.5	1.50
1740-1760	10.0	25.0	2.50	10.0	1.00	15.0	1.50
1760-1780	6.5	16.3	2.51	6.5	1.00	9.8	1.51
	4011.5	5179.6	1.29	5614.1	1.40	-434.5	-0.11

ELA = 1624 m

Nettobalansgradienten, $G = 0.41 \text{ m}/100\text{m}$

AAR = 21 %

G är beräknad som kvoten mellan intervallen 1620-1640 möh och 1400-1420 möh:

$$G = (0.12 - (-0.79)) / (1640 - 1420)$$

ELA är beräknad linjärt i intervallen mellan 1600 möh och 1640 möh, vilket även ger AAR:

$$ELA = ((1630 - 1610) * 0.31 / 0.43) + 1610$$

Mårmaglaciaciärens massbalans under budgetåret 1990/91

Nivå	Yta Vinterbalans			Sommarbalans			Nettobalans		
m ö h	10^3m^2	10^3m^3	m v e	10^3m^3	m v e	10^3m^3	m v e		
-1340	55.0	75.6	1.37	89.4	1.63	-13.8	-0.25		
1340-1360	96.5	129.4	1.34	156.8	1.62	-27.4	-0.28		
1360-1380	148.0	179.2	1.21	240.5	1.63	-61.3	-0.41		
1380-1400	150.5	157.3	1.05	244.6	1.63	-87.3	-0.58		
1400-1420	156.0	148.1	0.95	253.5	1.63	-105.4	-0.68		
1420-1440	161.0	143.5	0.89	261.6	1.62	-118.1	-0.73		
1440-1460	218.5	196.4	0.90	355.1	1.63	-158.7	-0.73		
1460-1480	253.0	232.4	0.92	347.9	1.38	-115.5	-0.46		
1480-1500	199.5	214.5	1.08	274.3	1.37	-59.8	-0.30		
1500-1520	188.5	210.4	1.12	259.2	1.38	-48.8	-0.26		
1520-1540	365.0	331.2	0.91	410.6	1.12	-79.4	-0.22		
1540-1560	352.5	323.9	0.92	380.2	1.08	-56.3	-0.16		
1560-1580	232.0	231.9	1.00	235.8	1.02	-3.9	-0.02		
1580-1600	196.5	164.8	0.84	208.1	1.06	-43.3	-0.22		
1600-1620	311.0	248.9	0.80	333.0	1.07	-84.1	-0.27		
1620-1640	332.5	350.6	1.05	312.4	0.94	38.2	0.11		
1640-1660	200.0	279.0	1.40	176.9	0.88	102.1	0.51		
1660-1680	203.0	296.8	1.46	178.1	0.88	118.7	0.58		
1680-1700	103.0	154.5	1.50	90.1	0.87	64.4	0.63		
1700-1720	40.0	60.0	1.50	35.0	0.88	25.0	0.63		
1720-1740	33.0	49.5	1.50	28.9	0.88	20.6	0.62		
1740-1760	10.0	15.0	1.50	8.8	0.88	6.2	0.62		
1760-1780	6.5	9.8	1.51	5.7	0.88	4.1	0.63		
	4011.5	4202.7	1.05	4886.5	1.22	-683.8	-0.17		
Apr-Maj + 10%		4623.0	1.15	5306.8	1.32	-683.8	-0.17		
Aug-Sep	1438.0			287.6	0.20				
Totalt	4011.5	4623.0	1.15	5594.4	1.39	-971.4	-0.24		

ELA = 1624 möh

Nettobalansgradienten, $G = 0.47 \text{ m}/100\text{m}$

AAR = 21 %

G är beräknad som kvoten mellan intervallen 1620-1640 möh och 1440-1460 möh:

$$G = (0.11 - (-0.73)) / (1640 - 1460)$$

ELA är beräknad linjärt mellan 1600 möh och 1640 möh, vilket även ger AAR:

$$ELA = ((1630 - 1610) * 0.27 / 0.38) + 1610$$

Mårmaglacièrens massbalans under budgetåret 1991/92

Nivå	Yta Vinterbalans			Sommarbalans		Nettobalans	
m ö h	10^3 m^2	10^3 m^3	m v e	10^3 m^3	m v e	10^3 m^3	m v e
-1340	55.0	87.2	1.59	75.9	1.38	11.3	0.21
1340-1360	96.5	131.6	1.36	138.9	1.44	-7.3	-0.08
1360-1380	148.0	194.5	1.31	210.8	1.42	-16.3	-0.11
1380-1400	150.5	178.1	1.18	214.2	1.42	-36.1	-0.24
1400-1420	156.0	178.0	1.14	219.4	1.41	-41.4	-0.27
1420-1440	161.0	175.8	1.09	221.4	1.38	-45.6	-0.28
1440-1460	218.5	233.6	1.07	300.4	1.37	-66.8	-0.31
1460-1480	253.0	271.2	1.07	347.9	1.38	-76.7	-0.30
1480-1500	199.5	245.4	1.23	274.3	1.37	-28.9	-0.14
1500-1520	188.5	235.6	1.25	212.1	1.13	23.5	0.12
1520-1540	365.0	383.3	1.05	374.1	1.02	9.2	0.03
1540-1560	352.5	381.0	1.08	345.7	0.98	35.3	0.10
1560-1580	232.0	284.8	1.23	234.0	1.01	50.8	0.22
1580-1600	196.5	226.3	1.15	194.6	0.99	31.7	0.16
1600-1620	311.0	316.2	1.02	335.6	1.08	-19.4	-0.06
1620-1640	332.5	349.5	1.05	345.7	1.04	3.8	0.01
1640-1660	200.0	304.6	1.52	170.0	0.85	134.6	0.67
1660-1680	203.0	343.2	1.69	171.4	0.84	171.8	0.85
1680-1700	103.0	180.2	1.75	64.4	0.63	115.8	1.12
1700-1720	40.0	70.0	1.75	25.0	0.63	45.0	1.13
1720-1740	33.0	57.8	1.75	20.6	0.62	37.2	1.13
1740-1760	10.0	17.5	1.75	6.2	0.62	11.3	1.13
1760-1780	6.5	11.4	1.75	4.1	0.63	7.3	1.12
	4011.5	4856.8	1.21	4506.7	1.12	350.1	0.09
Apr-maj +10 cm			1.31		1.22		0.09

ELA = 1539 m

Nettobalansgradienten, $G = 0.54 \text{ m}/100\text{m}$

AAR = 51 %

G är beräknad som kvoten mellan intervallen 1640-1660 möh och 1460-1480 möh:

$$G = (0.67 - (-0.30)) / (1660 - 1480)$$

ELA är beräknad linjärt mellan 1660 möh och 1480 möh, vilket även ger AAR:

$$ELA = ((1650 - 1490) * 0.30 / 0.97) + 1490$$

APPENDIX 5. Mass balance 1989/90 - 1991/92 of Kårsaglaciären.

Kårsaglaciärens massbalans under budgetåret 1989/90

Nivå	Yta Vinterbalans			Sommarbalans		Nettobalans	
m ö h	$10^3 m^2$	$10^3 m^3$	m v e	$10^3 m^3$	m v e	$10^3 m^3$	m v e
- 940	4	6.0	1.50	10.0	2.50	-4.0	-1.00
940- 960	12	18.0	1.50	30.0	2.50	-12.0	-1.00
960- 980	13	19.5	1.50	32.5	2.50	-13.0	-1.00
980-1000	37	55.5	1.50	92.5	2.50	-37.0	-1.00
1000-1020	76	131.5	1.73	190.0	2.50	-58.5	-0.77
1020-1040	67	128.8	1.92	161.7	2.41	-32.9	-0.49
1040-1060	60	131.7	2.20	142.1	2.37	-10.4	-0.17
1060-1080	67	154.7	2.31	160.0	2.39	-5.3	-0.08
1080-1100	75	171.5	2.29	170.8	2.28	0.7	0.01
1100-1120	61	132.6	2.17	127.9	2.10	4.7	0.08
1120-1140	75	159.8	2.13	156.8	2.09	3.0	0.04
1140-1160	68	142.5	2.10	141.3	2.08	1.2	0.02
1160-1180	58	125.5	2.16	118.0	2.03	7.5	0.13
1180-1200	52	117.8	2.27	100.4	1.93	17.4	0.33
1200-1220	43	105.0	2.44	75.3	1.75	29.7	0.69
1220-1240	33	80.6	2.44	57.8	1.75	22.8	0.69
1240-1260	27	68.5	2.54	47.3	1.75	21.2	0.79
1260-1280	22	55.0	2.50	38.5	1.75	16.5	0.75
1280-1300	19	47.5	2.50	33.3	1.75	14.2	0.75
1300-1320	23	52.8	2.30	40.3	1.75	12.5	0.54
1320-1340	23	51.3	2.23	40.3	1.75	11.0	0.48
1340-1360	23	49.0	2.13	40.3	1.75	8.7	0.38
1360-1380	32	67.3	2.10	40.0	1.25	27.3	0.85
1380-1400	31	63.0	2.03	38.8	1.25	24.2	0.78
1400-1420	53	106.0	2.00	66.3	1.25	39.7	0.75
1420-1440	87	174.0	2.00	108.8	1.25	65.2	0.75
1440-1460	66	132.0	2.00	82.5	1.25	49.5	0.75
1460-1480	21	42.0	2.00	26.3	1.25	15.7	0.75
1480-1500	6	12.0	2.00	7.5	1.25	4.5	0.75
	1234	2601.4	2.11	2377.3	1.93	224.1	0.18

ELA = 1088 möh

Nettobalansgradienten, $G = 0.49 \text{ m}/100 \text{ m}$

AAR = 70 %

G är beräknad som kvoten mellan intervallen 1360-1380 möh och 980-1000 möh:

$$G = (0.85 - (-1.00)) / (1380 - 1000)$$

ELA är beräknad linjärt i intervallen mellan 1060 möh och 1100 möh, vilket även ger AAR:

$$ELA = ((1090 - 1070) * 0.08 / 0.09) + 1070$$

Kårsaglaciärens massbalans under budgetåret 1990/91

Nivå	Yta Vinterbalans			Sommarbalans		Nettobalans	
m ö h	10^3m^2	10^3m^3	m v e	10^3m^3	m v e	10^3m^3	m v e
- 940	4	7.5	1.88	8.5	2.13	-1.0	-0.25
940- 960	12	22.5	1.88	25.5	2.13	-3.0	-0.25
960- 980	13	21.6	1.66	27.6	2.13	-6.0	-0.46
980-1000	37	48.4	1.31	78.6	2.13	-30.2	-0.82
1000-1020	76	106.3	1.40	161.5	2.13	-55.2	-0.73
1020-1040	67	113.9	1.70	142.4	2.13	-28.5	-0.43
1040-1060	60	113.0	1.88	127.5	2.13	-14.5	-0.24
1060-1080	67	133.4	1.99	142.4	2.13	-9.0	-0.13
1080-1100	75	147.9	1.97	158.6	2.11	-10.7	-0.14
1100-1120	61	115.4	1.89	122.8	2.01	-7.4	-0.12
1120-1140	75	141.4	1.89	146.3	1.95	-4.9	-0.07
1140-1160	68	132.0	1.94	130.1	1.91	1.9	0.03
1160-1180	58	115.1	1.98	109.3	1.88	5.8	0.10
1180-1200	52	104.3	2.01	98.8	1.90	5.5	0.11
1200-1220	43	88.1	2.05	81.4	1.89	6.7	0.16
1220-1240	33	65.5	1.98	60.5	1.83	5.0	0.15
1240-1260	27	53.5	1.98	48.8	1.81	4.7	0.17
1260-1280	22	43.0	1.95	39.5	1.80	3.5	0.16
1280-1300	19	37.5	1.97	30.9	1.63	6.6	0.35
1300-1320	23	44.5	1.93	36.3	1.58	8.2	0.36
1320-1340	23	45.4	1.97	36.3	1.58	9.1	0.40
1340-1360	23	44.4	1.93	33.9	1.47	10.5	0.46
1360-1380	32	62.3	1.95	45.6	1.43	16.7	0.52
1380-1400	31	59.1	1.91	41.6	1.34	17.5	0.56
1400-1420	53	99.4	1.88	55.9	1.05	43.5	0.82
1420-1440	87	157.5	1.81	110.2	1.27	47.3	0.54
1440-1460	66	123.8	1.88	79.0	1.20	44.8	0.68
1460-1480	21	39.4	1.88	26.0	1.24	13.4	0.64
1480-1500	6	11.3	1.88	8.3	1.38	3.0	0.50
	1234	2297.4	1.86	2214.1	1.79	83.3	0.07

ELA = 1144 möh

Nettobalansgradienten, $G = 0.39 \text{ m}/100 \text{ m}$

AAR = 55 %

G är beräknad som kvoten mellan intervallen 1400-1420 möh och 980-1000 möh:

$$G = (0.82 - (-0.82)) / (1420 - 1000)$$

ELA är beräknad linjärt i intervallen mellan 1120 möh och 1160 möh, vilket även ger AAR:

$$ELA = ((1150 - 1130) * 0.07 / 0.10) + 1130$$

Nivå	Yta Vinterbalans			Sommarbalans			Nettobalans	
m ö h	10 ³ m ²	10 ³ m ³	m v e	10 ³ m ³	m v e	10 ³ m ³	m v e	
- 940	4	9.0	2.25	9.0	2.25	0.0	0.00	
940- 960	12	27.0	2.25	27.0	2.25	0.0	0.00	
960- 980	13	29.3	2.25	29.3	2.25	0.0	0.00	
980-1000	37	83.3	2.25	83.3	2.25	0.0	0.00	
1000-1020	76	170.5	2.24	171.0	2.25	-0.5	-0.01	
1020-1040	67	146.8	2.19	141.4	2.11	5.4	0.08	
1040-1060	60	134.0	2.23	123.6	2.06	10.4	0.17	
1060-1080	67	147.3	2.20	139.4	2.08	7.9	0.12	
1080-1100	75	164.8	2.20	150.0	2.00	14.8	0.20	
1100-1120	61	139.8	2.29	106.8	1.75	33.0	0.54	
1120-1140	75	172.8	2.30	131.3	1.75	41.5	0.55	
1140-1160	68	159.5	2.35	103.4	1.52	56.1	0.83	
1160-1180	58	141.5	2.44	72.5	1.25	69.0	1.19	
1180-1200	52	128.0	2.46	60.8	1.17	67.2	1.29	
1200-1220	43	106.8	2.48	43.4	1.01	63.3	1.47	
1220-1240	33	83.8	2.54	28.9	0.88	54.9	1.66	
1240-1260	27	68.8	2.55	23.6	0.88	45.1	1.67	
1260-1280	22	56.5	2.57	19.3	0.88	37.3	1.69	
1280-1300	19	48.8	2.57	16.6	0.88	32.1	1.69	
1300-1320	23	56.8	2.47	20.1	0.88	36.6	1.59	
1320-1340	23	50.3	2.18	14.4	0.63	35.9	1.56	
1340-1360	23	48.8	2.12	14.4	0.63	34.4	1.49	
1360-1380	32	67.5	2.11	20.0	0.63	47.5	1.48	
1380-1400	31	65.8	2.12	19.4	0.63	46.4	1.50	
1400-1420	53	118.3	2.23	33.1	0.63	85.1	1.61	
1420-1440	87	182.8	2.10	54.4	0.63	128.4	1.48	
1440-1460	66	126.0	1.91	41.3	0.63	84.8	1.28	
1460-1480	21	41.3	1.96	13.1	0.63	28.1	1.34	
1480-1500	6	13.5	2.25	3.8	0.63	9.8	1.63	
	1234	2788.5	2.26	1714.2	1.39	1074.3	0.87	

AAR = 91 %

$$G = (1.61 - (-0.01)) / (1420 - 1020)$$
$$ELA = ((1030-1010)*0.01/0.09)+1010$$

APPENDIX 6. Storglaciären, mass balance 1946-92 and snow depths 1992.

År	Medeltemp År jun-aug	Ack (mve)	Abl (mve)	Netto (mve)	ELA (möh)
1946	7,1	1,13	2,26	-1,13	1480
1947	8,3	1,03	3,10	-2,06	1600
1948	5,7	1,45	1,45	0,00	1400
1949	4,0	2,23	1,32	0,90	1410
1950	7,5	1,42	2,71	-1,29	1550
1951	5,7	0,81	1,45	-0,65	1500
1952	5,1	0,87	1,03	-0,16	1450
1953	6,1	1,94	2,74	-0,81	1530
1954	7,0	1,13	2,10	-0,97	1540
1955	5,8	1,61	1,77	-0,16	1470
1956	6,3	1,29	1,77	-0,48	1500
1957	4,3	1,61	1,94	-0,32	1480
1958	5,9	1,45	2,10	-0,65	1510
1959	6,4	0,97	1,94	-0,97	1540
1960	7,0	0,68	2,29	-1,61	1620
1961	6,3	0,81	1,90	-1,10	1575
1962	3,9	1,10	0,77	0,32	1400
1963	5,2	1,45	1,65	-0,19	1425
1964	4,1	1,58	1,10	0,49	1400
1965	-4,5	4,7	1,47	0,43	1400
1966	-5,8	5,7	1,20	-0,53	1500
1967	-3,3	5,1	1,35	-0,23	1500
1968	-4,6	4,5	1,27	-0,10	1480
1969	-3,9	7,1	0,98	-1,04	1570
1970	-3,9	7,3	0,99	-1,52	1610
1971	-4,5	5,3	1,33	-0,19	1490
1972	-2,1	7,6	1,39	-1,05	1550
1973	-4,2	5,7	1,67	0,05	1490
1974	-2,8	6,0	1,31	-0,34	1480
1975	-3,6	3,3	1,98	1,17	1380
1976	-4,1	5,3	1,93	0,27	1440
1977	-4,6	4,6	1,23	0,20	1420
1978	-4,7	5,7	1,46	-0,08	1469
1979	-4,0	6,5	1,54	-0,21	1497
1980	-3,2	7,8	0,93	-1,24	1591
1981	-4,5	4,6	1,16	-0,20	1510
1982	-3,6	4,1	1,49	0,26	1385
1983	-3,7	4,2	1,47	0,28	1375
1984	-3,1	5,2	1,83	0,12	1460
1985	-4,7	6,0	0,99	-0,72	1570
1986	-3,7	5,8	1,62	-0,06	1465
1987	-5,2	4,2	1,69	0,48	1370
1988	-4,5	6,6	1,42	-0,84	1565
1989	-3,3	5,4	2,58	1,24	1374
1990	-2,7	6,0	2,26	0,59	1495
1991	-2,9	6,1	1,68	0,17	1460
46-90	5,7	1,40	1,72	-0,31	1480
65-90	-4,0	5,6	1,48	-0,13	1478
1992	5,2	2,24	1,36	0,88	1393

Snödjup

STOR-GLACIAREN

Snödjup

22 - 24 / 5 1992

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