

Tarfala Research Station Annual Report 1998–99

Per Klingbjør (Ed.)



Department of Physical Geography
Research Report No. 111



Tarfala Research Station Annual Report 1998–99

Per Klingbjør (Ed.)



Tarfala Research Station Annual Report, 1998-99

Per Klingbjer (ed.)

ISSN 1403-9788

© The editor and the Department of Physical Geography at Stockholm University

Cover figure. Debris covered ridges on Storglaciären, northern Sweden in September 1996 (Photo: Rickard Pettersson).

Printed in Sweden

Stockholm, 2000

Högskoletryckeriet, KTH

Mailing adress:
Department of Physical geography
Stockholm University
SE-106 91 Stockholm
SWEDEN

Visiting adress:
Svante Arrhenius väg 8
Internet:
www.geo.su.se/naturgeo/glaciologi

Telephone:
+46 (0)8 162000
Fax:
+46 (0)8 164818

Contents

Introduction	5
<i>Per Holmlund</i>	
Tarfala Research Station	6
Massbalance of Storglaciären 1998/99	7-10
<i>Peter Jansson</i>	
Mass balance of Mårmaglaciären 1998/99	11-13
<i>Rickard Pettersson</i>	
Mass balance of Riukojietna 1998/99	14-15
<i>Per Klingbjer</i>	
Mass balance of Pårteglaciären and Salajekna 1997/98 and 1998/99	16-19
<i>Per Klingbjer</i>	
Glacio-meteorological studies on Storglaciären in 1999	20-23
<i>Regine Hock, Jonathan L. Carrivick and Ulf Jonsell</i>	
Water content and temperature in the firn of Storglaciären	24-27
<i>Thomas Schneider</i>	
Chloroacetates and Trifluoroacetate in ice from Storglaciären and Mårmaglaciären	28-29
<i>Lena von Sydow</i>	
Measured and modelled melt and the surface energy balance on Storglaciären	30-35
<i>Jonathan L. Carrivick and Regine Hock</i>	
Geomorphological mapping in Tarfala, Swedish Lapland, August 1999	36-37
<i>Alexander Quirin</i>	
Digital elevation model covering Tarfala valley and its close surroundings	38-41
<i>Margareta Johansson, Johan Ekroth and Maria Johansson</i>	
Temporal and spatial variations in albedo on Storglaciären	42-43
<i>Ulf Jonsell</i>	
Climate conditions required for reglaciation of cirques in Rassepautasjtjåkká massif, northern Sweden	44-46
<i>Margareta Johansson and Regine Hock</i>	
Abstract from the Tarfala student course papers 1999	47-48
<i>Compiled and edited by Jens-Ove Näslund</i>	
Litterature concerning the Tarfala valley and its close surroundings	49-57
Boende på Tarfala forskningsstation under 1999	58-59
Appendix 1. Snow depht survey 1999 on Storglaciären	60
Appendix 2. Stake locations on Storglaciären 1999	60
Appendix 3. Winter balance map for Storglaciären 1998/99	61
Appendix 4. Summer balance map for Storglaciären 1998/99	61

Introduction

Introduction

The hydrological year 1998/99 was characterised by a cold and dry winter season and cold and wet summer. The mass balance was negative on all the 6 glaciers studied this year, basically because of the low winter balances. The initiation of the summer was warm and sunny, but from mid July to the end of the season temperatures were far below average.

The year 1999 was also characterised by changes in positions within the glaciology division and also changes of technical and administrative staff. I received the professorship in glaciology, with focus on climate, and Peter Jansson became associate professor in physical geography.

Our two technicians on external fundings, Mats Nilsson and Krister Jonsson left Tarfala and they were replaced by Lisette Lundström and Lars Lidstöm. In 1999 we extended our staff with a half time technical position specifically focussed on Tarfala research. This position was allocated to Mart Nyman. In May 1999 Månika Henkow became our new administrator.

We were successful in receiving research grants during 1999. This is encouraging as it reflects a current interest in polar research focussed on climate change issues. At Tarfala Research Station we have an enormous potential to execute high quality science, and the combination of good fundings and a solid organisation stimulates us to develop our scientific work for the future.

July 2000

Per Holmlund
Professor

Tarfala Research Station

Founded 1946

The Field Station

Location

The station is located in the Tarfala Valley, 67°55'N 18°36'E, at 1130ma.s.l. in the Kebnekaise mountains, Swedish Lappland. The valley is surrounded by glaciers and 2000m peaks. Tarfala can be reached by foot (25km hike) or by helicopter from the nearest village, Nikkaluokta. Public transportation is available to Nikkaluokta.

Environment

Arctic alpine environment. The tree line (birch) is at ~700ma.s.l. in the area. Several glaciers in the valley terminate below 1200ma.s.l. Mean annual temperature is –4°C, resulting in widespread permafrost conditions.

Field Station Management

Director

Professor Per Holmlund
Department of Physical Geography
Stockholm University
SE-106 91 Stockholm
Sweden
Tel. +46 (0)8 164811
Fax. +46 (0)8 164818
E-mail. per.holmlund@natgeo.su.se

Senior scientist

Associate Professor Peter Jansson
Department of Physical Geography
Stockholm University
SE-106 91 Stockholm
Sweden
Tel. +46 (0)8 164815
Fax. +46 (0)8 164818
E-mail. peter.jansson@natgeo.su.se

Administrator

Månika Henkow
Department of Physical Geography
Stockholm University
SE-106 91 Stockholm
Sweden
Tel. +46 (0)8 164777
Fax. +46 (0)8 164818
E-mail. manika.henkow@natgeo.su.se

Availability

The station is open during the summer season: June–September. Summer bookings must be made before May 1. Restricted availability during winter, contact the station director for details.

Station address (summer only)

Tarfala Research Station
c/o Kebnekaise Turiststation
SE-981 29 KirunaSweden
Tel. +46 (0)980 55039
Fax. +46 (0)980 55043
www.geo.su.se/naturgeo/glaciologi/Tarfala/Tarfala.htm

Logistics

Mart Nyman
Department of Physical Geography
Stockholm University
SE-106 91 Stockholm
Sweden
Tel. +46 (0)8 6747591
Fax. +46 (0)8 164818
E-mail. mart.nyman@natgeo.su.se

Lars Lidström
Lisette Lundström
Climate Impacts Research Centre (CIRC)
Björkplan 6a
SE-981 42 Kiruna
Sweden
Tel. +46 (0)980 826 80
Fax. +46 (0)980 826 28
e-mail. lars.lidstrom@natgeo.su.se
lisette.lundstrom@natgeo.su.se

Mass balance of Storglaciären 1998/99

Peter Jansson

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Summary

The winter balance was surveyed between April 30 and May 8, 1999 by Sara Frödin, Erik Huss, Mart Nyman, and the author. Snow depth was determined at 292 points by manual probing (Appendix 1). During the same period snow density was measured in four pits at standard locations by stake positions 5, 10, 15, and 20 (Appendix 2). A snow core was also extracted from the firn area at location 29. The density profiles from these measurements are seen in Figure 1–5. Table 1 shows average densities from all measurements. At the time of the snow density measurements, the snow temperature was well below freezing throughout the snow pack. These conditions prevailed throughout the measurement.

The conversion of snow depth, d_{snow} , into water equivalent values, $d_{\text{w.eq.}}$, was done by determining an empirical relationship between the two (Figure 6). Data from the density pits and core were plotted as cumulative water equivalent vs. cumulative snow depth. A second degree polynomial was fit to the

data, forcing a zero intercept, yielding $d_{\text{w.eq.}} = 0.0002 d_{\text{snow}}^2 + 0.3414 d_{\text{snow}}$, $R^2=1.0$. The snow depths recorded by probing was then converted using this relationship. The resulting grid of water equivalent values was then converted into a contour map (Appendix 3) through kriging interpolation using Golden Software Surfer. The total accumulation during the winter 1998/99 was 1.33 m w.eq. (Figure 7 & 8, Table 2).

During the spring, several new ablation stakes were established to improve on the existing ablation stake net. During the winter some stakes were lost due to accumulation. In September 1999 a total of 49 stakes (Appendix 2) were available for determining the summer balance of the glacier. The ablation measurements were mainly carried out by Mats Nilsson, Jonas Nässen, and Andrea Dellenbach during the summer. Ablation in areas with no stakes were extrapolated using the kriging routine in Golden Software Surfer. The ablation gradient calculated from values of ablation, b_s , and elevation, Z , of all stakes used in the final evaluation of the summer

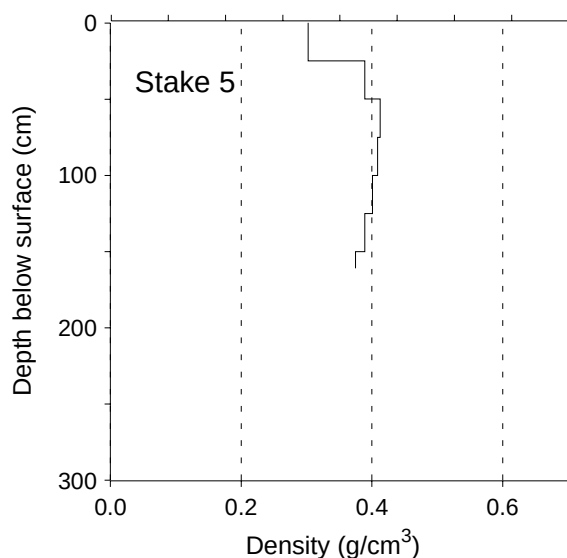


Figure 1. Snow density at stake location 5, Storglaciären, May 1999.

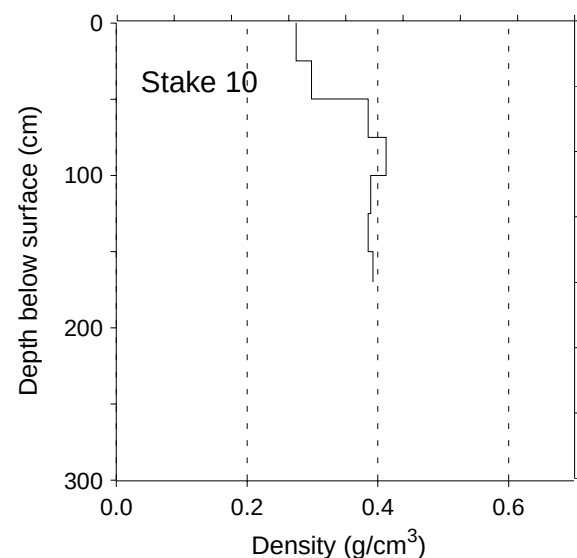


Figure 2. Snow density at stake location 10, Storglaciären, May 1999.

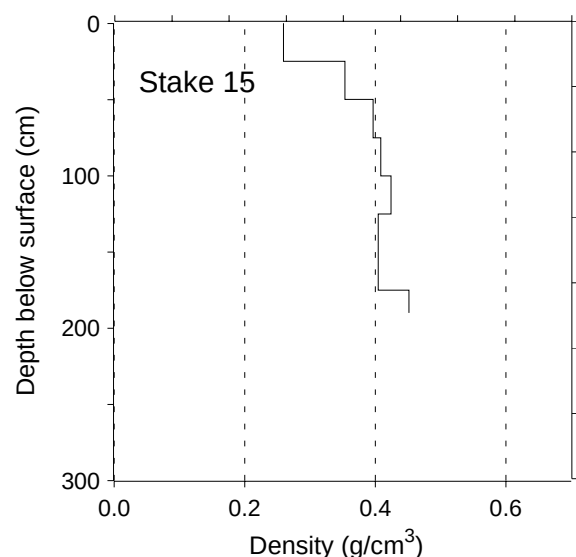


Figure 3. Snow density at stake location 15, Storglaciären, May 1999.

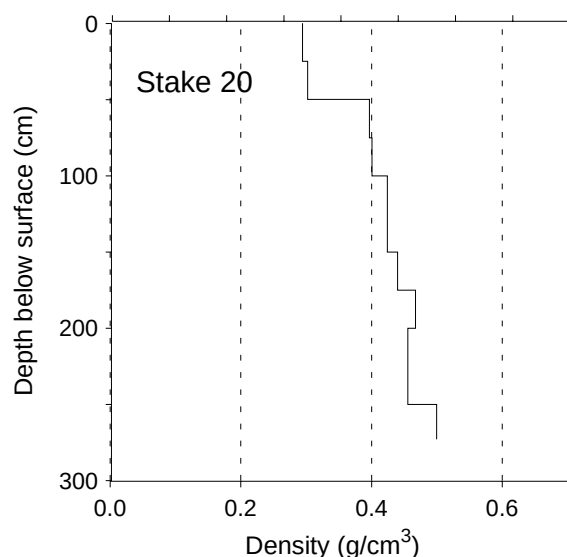


Figure 4. Snow density at stake location 20, Storglaciären, May 1999.

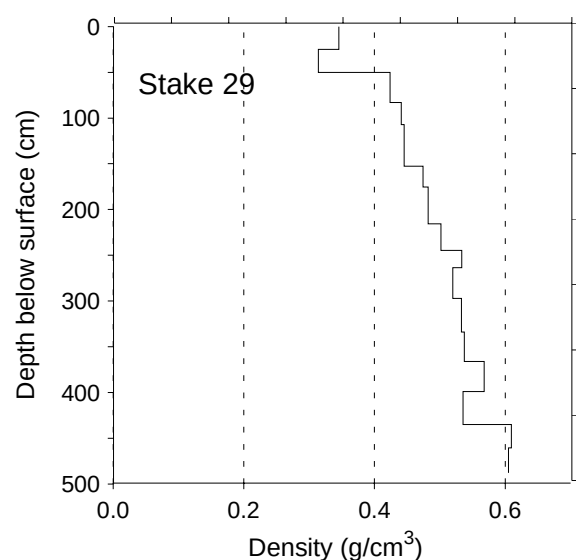


Figure 5. Snow density at stake location 29, Storglaciären, May 1999.

Table 1. Snow densities at the time of the accumulation survey, May 1999. Stake locations are given in Appendix 2.

Stake location	Snow depth (cm)	Density (g/cm ³)
5	161	0.38
10	170	0.36
15	190	0.38
20	273	0.41
29	488	0.44

balance yielded $b_s = -0.007Z + 11.9$ m w.eq., $R^2 = 0.90$ (Figure 9). Using the ablation gradient to establish the summer balance I arrive at 1.39 m

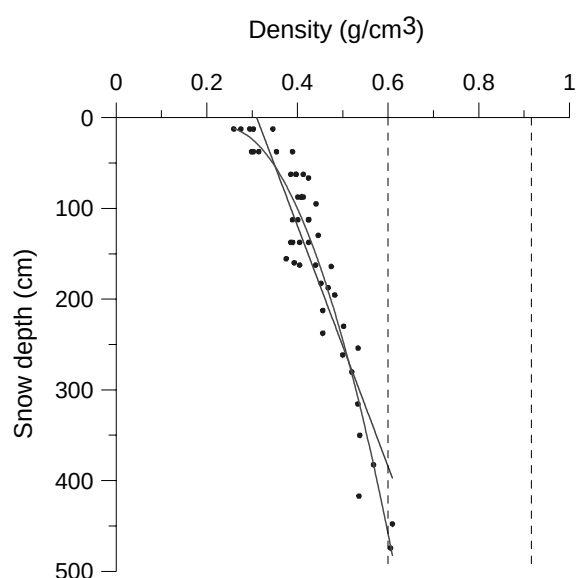


Figure 6. Water equivalent values as a function of snow depth based on density measurements in pits at stake locations 5, 10, 15, 20 and a core at stake location 29, May 1999. Curves correspond to polynomials fits of order 1 and 2.

w.eq. As can be seen in figure 9, the ablation gradient yield negative values at higher elevation explaining the lower values obtained by this method. The summer balance of 1999 was 1.51 m w.eq. (Figure 7 & 8, Table 2). The distribution of melt is shown in Appendix 4.

The winter and summer balance values yield a net balance volume of $-556 \times 10^3 \text{ m}^3$, equivalent to -0.18 m w.eq., on Storglaciären for the 1998/99 mass balance year (Figure 7, 8 & 10). This was the fourth consecutive year with negative mass balance. The trend seems to fit the longer-term cyclic variations in the mass balance record.

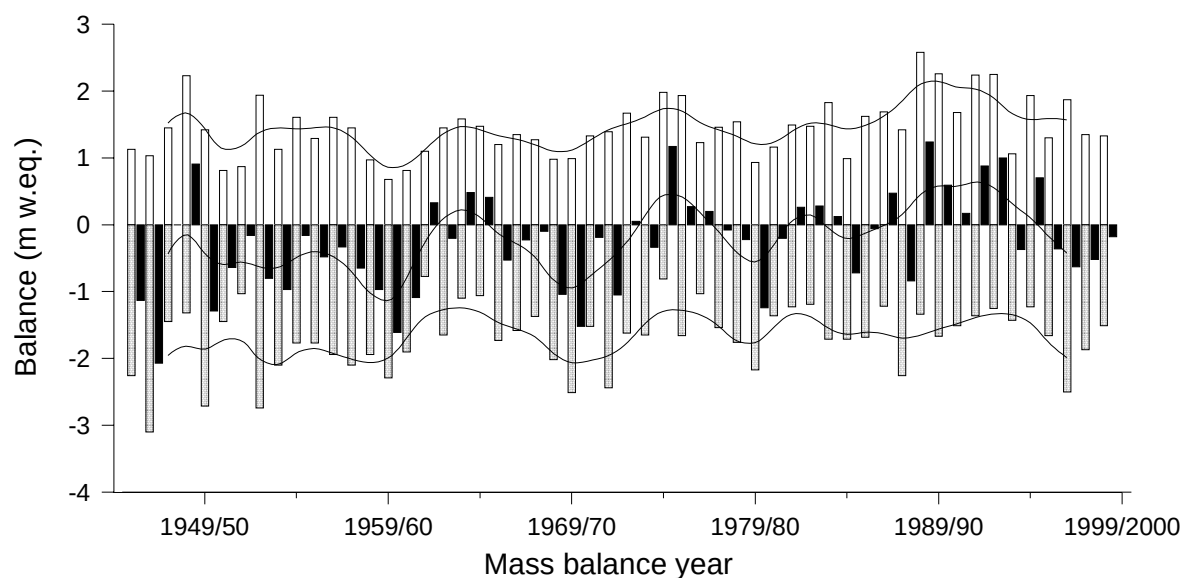


Figure 7. The 54-year mass balance record for Storglaciären.

Table 2. Mass balance of Storglaciären 1998/99.

Elevation m a.s.l.	Area m ²	Winter balance		Summer balance		Net balance	
		m ³	m w.eq.	m ³	m w.eq.	m ³	m w.eq.
1140-1160	3300	3805	1.15	11997	3.64	-8192	-2.48
1160-1180	7700	8441	1.10	28134	3.65	-19693	-2.56
1180-1200	17100	17961	1.05	61802	3.61	-43841	-2.56
1200-1220	35800	32536	0.91	125079	3.49	-92543	-2.58
1220-1240	53400	47295	0.89	180235	3.38	-132940	-2.49
1240-1260	63700	59336	0.93	202623	3.18	-143287	-2.25
1260-1280	83600	55860	0.67	240849	2.88	-184989	-2.21
1280-1300	80800	78867	0.98	213743	2.65	-134876	-1.67
1300-1320	95300	104550	1.10	233129	2.45	-128579	-1.35
1320-1340	149900	113019	0.75	320237	2.14	-207218	-1.38
1340-1360	271300	195511	0.72	531294	1.96	-335783	-1.24
1360-1380	320000	272649	0.85	597583	1.87	-324934	-1.02
1380-1400	254400	222840	0.88	464439	1.83	-241598	-0.95
1400-1420	118200	136379	1.15	193312	1.64	-56933	-0.48
1420-1440	78600	98051	1.25	113135	1.44	-15084	-0.19
1440-1460	66200	65987	1.00	83605	1.26	-17618	-0.27
1460-1480	82000	76612	0.93	99696	1.22	-23084	-0.28
1480-1500	149100	162328	1.09	176322	1.18	-13994	-0.09
1500-1520	228000	389051	1.71	230594	1.01	158457	0.69
1520-1540	107600	164916	1.53	109993	1.02	54923	0.51
1540-1560	103300	141705	1.37	104398	1.01	37307	0.36
1560-1580	101300	139963	1.38	92747	0.92	47216	0.47
1580-1600	141800	238550	1.68	109581	0.77	128969	0.91
1600-1620	134000	253144	1.89	81821	0.61	171323	1.28
1620-1640	162200	366236	2.26	75421	0.46	290815	1.79
1640-1660	128500	325323	2.53	60580	0.47	264743	2.06
1660-1680	87800	233972	2.66	45981	0.52	187991	2.14
1680-1700	61600	165324	2.68	35049	0.57	130275	2.11
1700-1720	53400	150684	2.82	54494	1.02	96190	1.80
1140-1720	3239900	4320894	1.33	4877874	1.51	-556980	-0.18

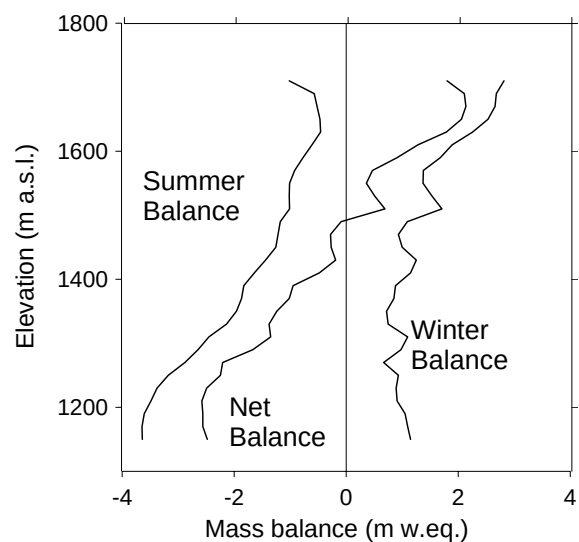


Figure 8. Winter, summer and net balance as a function of altitude, 1998/99.

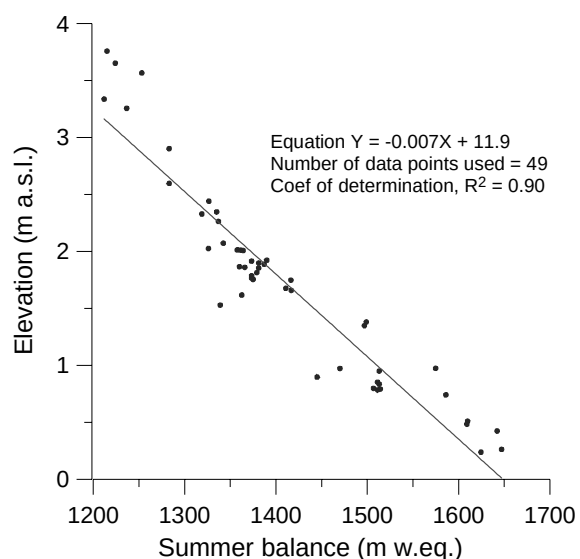


Figure 9. Ablation as a function of altitude (the ablation gradient) 1999.

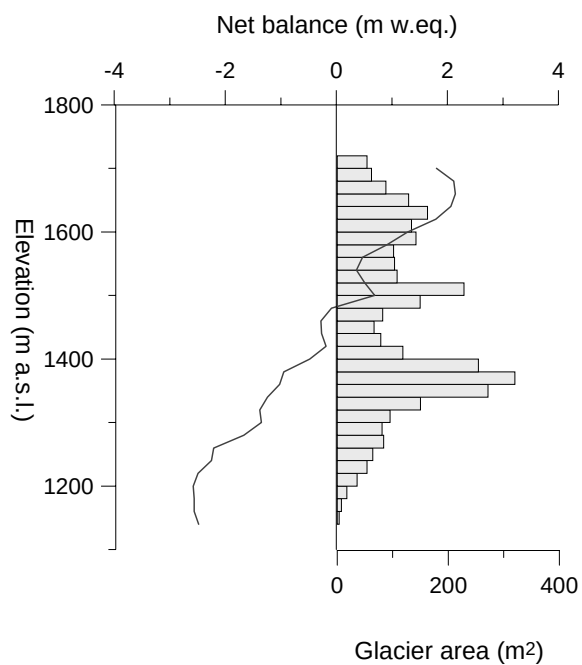


Figure 10. Net balance and area distribution (%) as a function of elevation, 1998/99.

Mass balance of Mårmaglaciacären 1998/99

Rickard Pettersson

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Summary

The winter accumulation was determined on April 23. Snow depths at 123 probings were performed and snow density was measured in two pits at the altitude of 1625m a.s.l and at 1540m a.s.l. The mean density was 0.40 g/cm³ and 0.38 g/cm³, respectively (figure 1 and 2). The relationship between snow depth and snow density was approximated with exponential regression (figure 3). The regression equation was used to calculate the mean snow density for each snow depth probing. The mean density was then used to convert snow depth measurements to water equivalents (w. eq.). From the water equivalent values the winter balance map was constructed. The winter mass balance (figure 4) of Mårmaglaciacären amounted to 1.10 m w.eq.

The summer balance (figure 5) was determined by means of two stakes on September 12 to the summer balance. The ablation gradient was calculated by means of linear regression to -0.35 cm/m (figure 6) and was used to construct the summer balance map (figure 5). The summer mass

balance amounted to -1.40 m w.eq. Thus the net mass balance for the glaciological year 98/99 amounted to -0.30 m w.eq (figure 7).

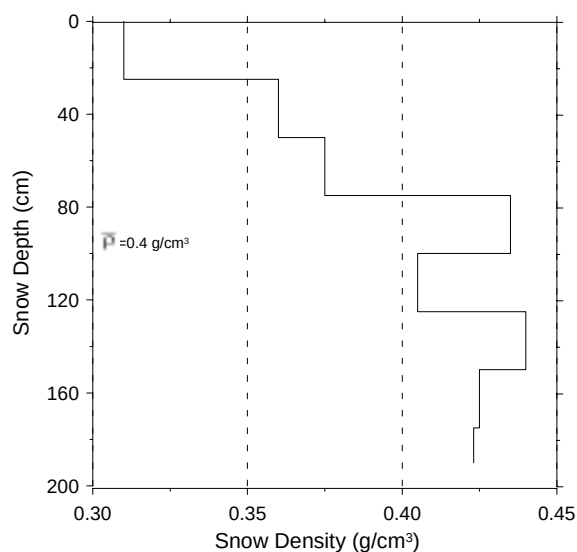


Figure 1. Snow density at 1625m a.s.l. Determined on April 23 in a pit.

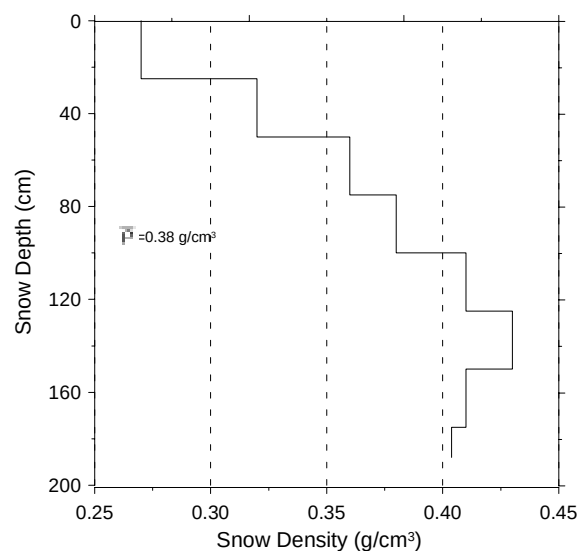


Figure 2. Snow density at 1540m a.s.l. Determined on April 23 in a pit.

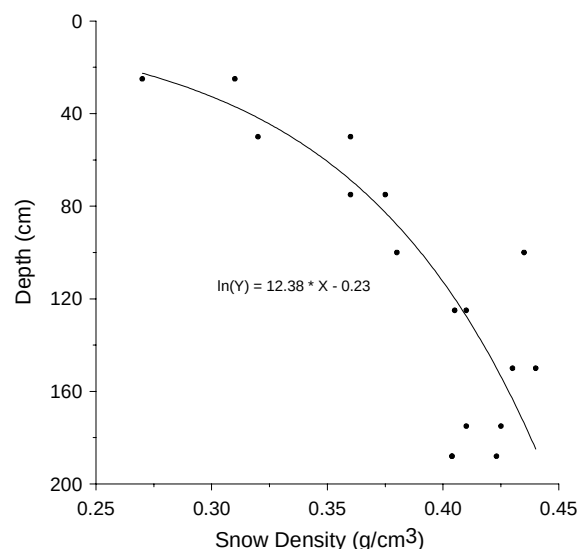


Figure 3. Mean density as a function of snow depth. The relationship was fitted with exponential regression.

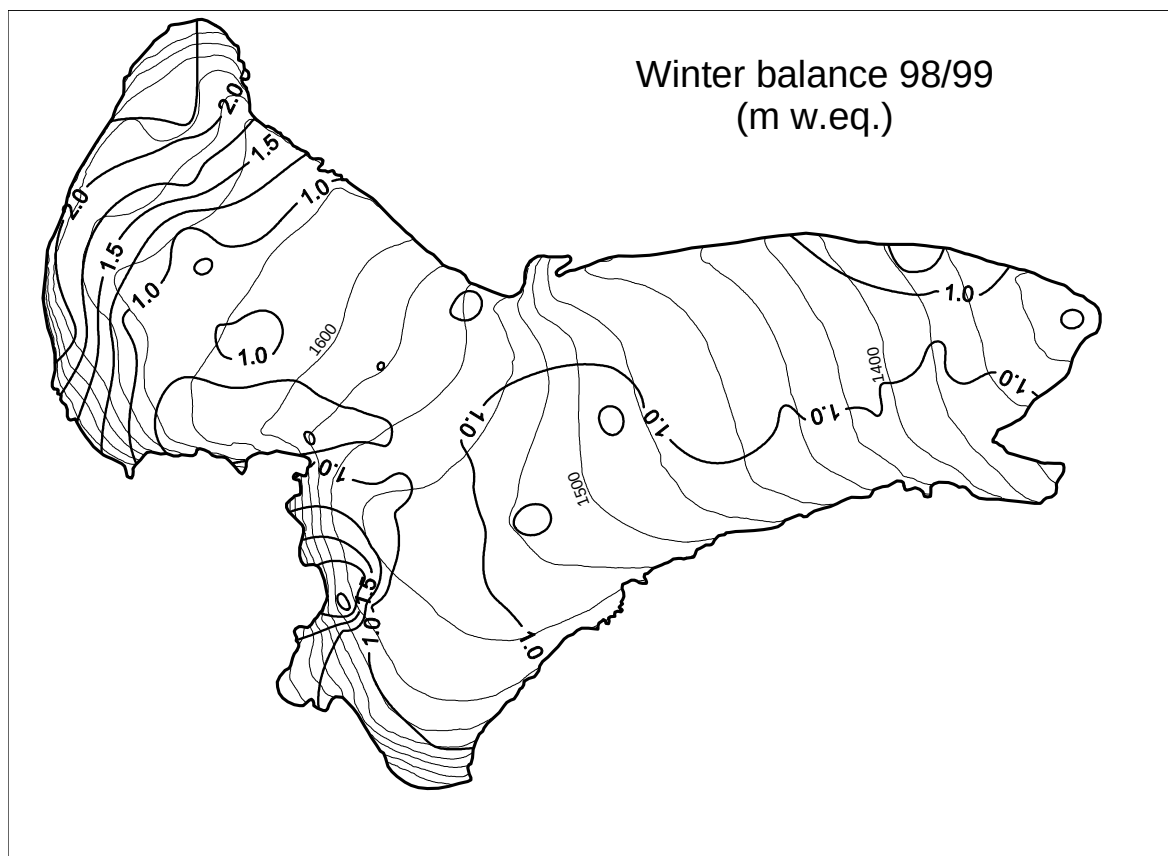


Figure 4. Winter mass balance map for Måraglaciären 98/99. Values in m w.eq.

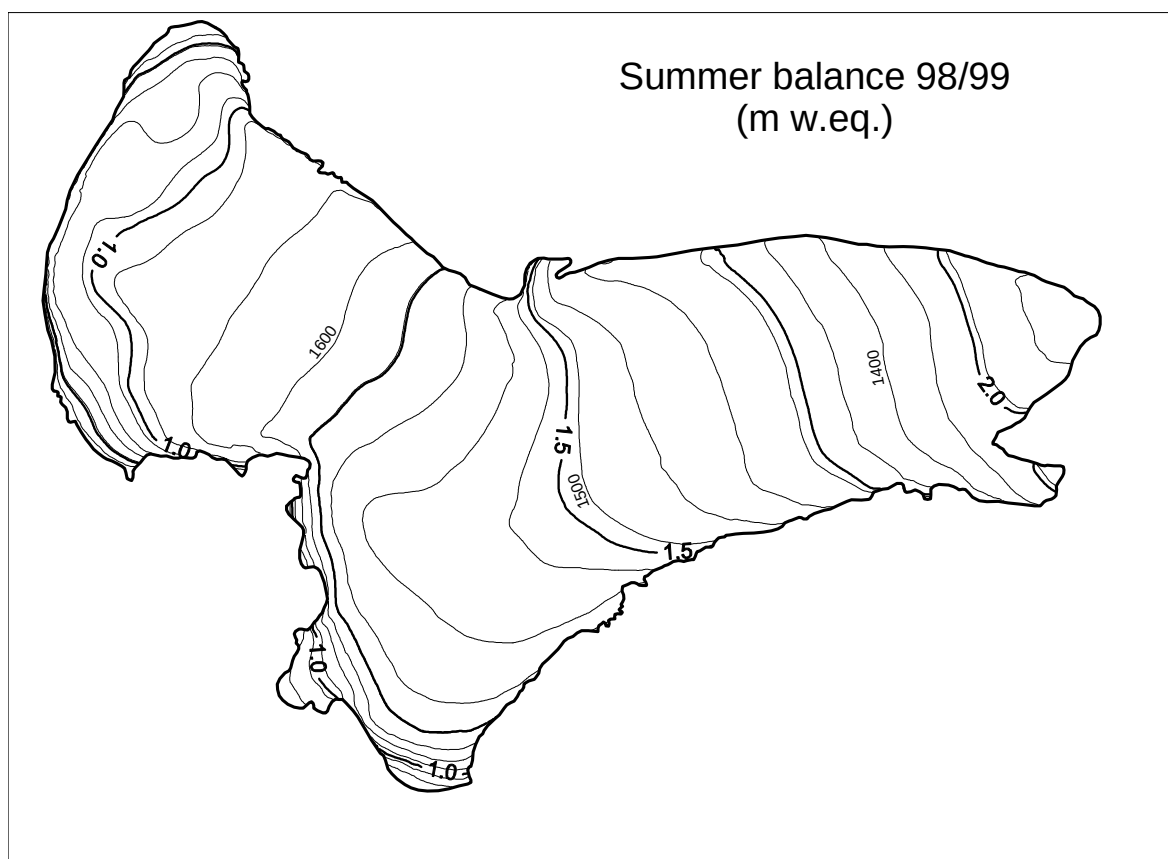


Figure 5. Summer mass balance map for Måraglaciären 98/99. Values in m w.eq.

The equilibrium line altitude (ELA) was calculated linearly between 1640 and 1660 m a.s.l. to 1644 m a.s.l. (table 1). The net balance gradient was determined for 1330 to 1790 m a.s.l. to 0.62

cm/m with linear regression. The ratio between accumulation area and total area (AAR) was calculated to 15 %.

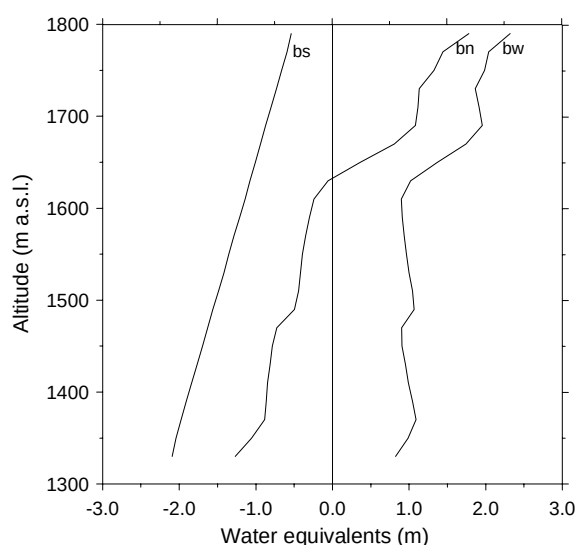


Figure 6. Winter (bw), Summer (bs) and net balance (bn) as a function of altitude for Mårmagläciären 1998.

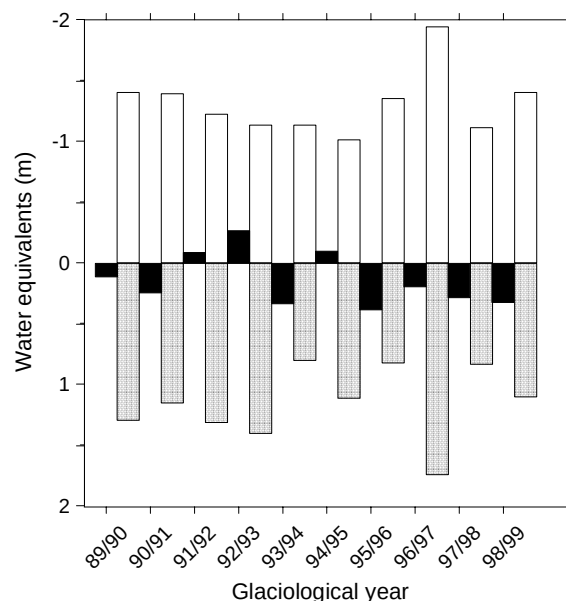


Figure 7. The mass balance record from Mårmagläciären 1989/90 to 1998/99.

Table 1. Mass balance of Mårmagläciären 1998/99.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance 10 ³ m ³ m w.eq.	Summer balance 10 ³ m ³ m w.eq.	Net balance 10 ³ m ³ m w.eq.
1320-1340	51,0	42,0 0,8	106,6 2,1	-6,5 -1,3
1340-1360	97,5	96,1 1,0	199,1 2,0	-10,3 -1,1
1360-1380	143,6	156,5 1,1	283,5 2,0	-12,7 -0,9
1380-1400	145,9	152,2 1,1	278,2 1,9	-12,6 -0,9
1400-1420	149,8	148,4 1,0	275,3 1,8	-12,7 -0,8
1420-1440	158,8	151,5 1,0	280,8 1,8	-12,9 -0,8
1440-1460	217,0	197,2 0,9	367,7 1,7	-17,1 -0,8
1460-1480	251,0	226,7 0,9	409,3 1,6	-18,3 -0,7
1480-1500	196,8	209,8 1,1	307,3 1,6	-9,8 -0,5
1500-1520	186,0	194,3 1,1	276,9 1,5	-8,3 -0,4
1520-1540	363,7	362,8 1,0	515,0 1,4	-15,2 -0,4
1540-1560	345,7	333,1 1,0	468,1 1,4	-13,5 -0,4
1560-1580	228,5	213,8 1,0	293,4 1,3	-8,0 -0,3
1580-1600	189,8	172,9 0,9	229,9 1,2	-5,7 -0,3
1600-1620	311,6	279,8 0,9	355,6 1,1	-7,6 -0,2
1620-1640	326,0	332,4 1,0	351,1 1,1	-1,9 -0,1
1640-1660	191,5	262,6 1,4	192,8 1,0	7,0 0,4
1660-1680	204,0	355,7 1,8	191,3 0,9	16,4 0,8
1680-1700	104,0	203,4 2,0	90,7 0,9	11,3 1,1
1700-1720	42,0	80,5 1,9	33,6 0,8	4,7 1,1
1720-1740	29,4	54,7 1,9	21,4 0,7	3,3 1,1
1740-1760	17,9	35,5 2,0	11,8 0,7	2,4 1,3
1760-1780	4,8	9,7 2,0	2,8 0,6	0,7 1,4
1780-1800	0,4	1,0 2,3	0,2 0,5	0,1 1,8
1320-1800	3956,8	4272,4 1,10	-5542,8 -1,40	-127,0 -0,30

Mass balance of Riukojietna 1998/99

Per Klingbjør

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Abstract

The mass balance of Riukojietna now comprises 14 years. The winter balance in 1998/99 was 0.94 m w.eq. The summer balance was -1.72 m w.eq, yielding a net balance of -0.78 m w.eq.

Summary

The mass balance record now comprises 14 years (Figure 1, Table 1).

The winter balance of 1998/99 was surveyed by Per Holmlund in 11/4 1998 in a total of 76 probings. The snow density was determined in one pit close to an ablation stake at 1240 m a.s.l. The snow density was calculated to 0.40 g/cm³. During this fieldwork three ablation stakes were drilled in to the glacier at 1454, 1410 and 1240 m a.s.l. Stake readings from 10/5 1998 show an additional accumulation of 0.02 m w.eq. which was added to to the winter balance, thus the winter balance amounted to 0.94 m w.eq. (Figure 1, Table 1 and 2).

The summer balance of 1998/99 was determined by means of three stakes on September 12. by Mart Nyman. The summer balance was calculated from the ablation gradient to 1.72 m w.eq. (Figure 1, Table 1 and 2).

The net balance for the glaciological year 1998/99 amounted to -0.78 m w.eq. (fig 1, table 2).

The estimated equilibrium line altitude (ELA) was >1460 m a.s.l and the accumulation-area ratio (AAR) was estimated from oblique photographs to 5%.

Table 1. Mass balance data for Riukojietna 1985/86 to 1998/99. bw = winter balance, bs = summer balance and bn = net mass balance.

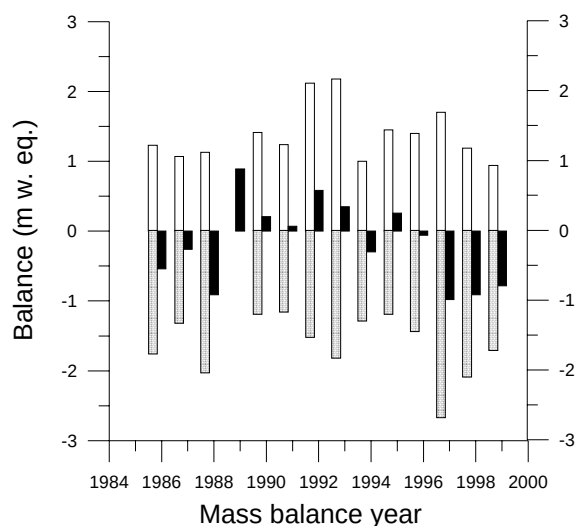


Figure 1. The mass balance record for Riukojietna 1985 - 1999.

Mass balance year	b _w (m w. eq.)	b _s (m w. eq.)	b _n (m w. eq.)
1985/86	1.23	-1.77	-0.54
1986/87	1.07	-1.33	-0.26
1987/88	1.13	-2.04	-0.91
1988/89			0.89
1989/90	1.41	-1.20	0.21
1990/91	1.24	-1.17	0.07
1991/92	2.12	-1.53	0.59
1992/93	2.18	-1.83	0.35
1993/94	1.00	-1.30	-0.30
1994/95	1.45	-1.20	0.26
1995/96	1.40	-1.45	-0.06
1996/97	1.70	-2.68	-0.98
1997/98	1.36	-2.10	-0.74
1998/99	0.94	-1.72	-0.78

Table 2. Mass balance of Riukojietna 1998/99.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance		Summer balance		Net balance	
		10 ³ m ³	m w.eq.	10 ³ m ³	m w.eq.	10 ³ m ³	m w.eq.
1140-1160	29	25	0.88	-99	-3.42	-74.1	-2.54
1160-1180	45	39	0.88	-146	-3.25	-107.5	-2.37
1180-1200	60	53	0.88	-186	-3.09	-132.5	-2.21
1200-1220	65	57	0.88	-190	-2.93	-133.4	-2.05
1220-1240	94	82	0.88	-260	-2.77	-178.0	-1.89
1240-1260	133	118	0.89	-346	-2.60	-228.3	-1.71
1260-1280	189	173	0.92	-461	-2.44	-288.3	-1.52
1280-1300	259	239	0.92	-590	-2.28	-351.0	-1.36
1300-1320	391	350	0.89	-827	-2.12	-477.0	-1.23
1320-1340	512	453	0.88	-1000	-1.95	-546.6	-1.07
1340-1360	428	399	0.93	-766	-1.79	-366.9	-0.86
1360-1380	444	426	0.96	-722	-1.63	-296.2	-0.67
1380-1400	420	411	0.98	-615	-1.46	-203.8	-0.48
1400-1420	387	374	0.97	-503	-1.30	-129.5	-0.33
1420-1440	676	611	0.90	-769	-1.14	-158.4	-0.24
1440-1460	516	452	0.88	-503	-0.98	-51.3	0.10
1140-1460	4648	4260	0.92	-7985	-1.72	-3724.8	-0.80
11 May 1999			0.02				
Total			0.94		-1.72		-0.78

Mass balance of Pårteglaciären and Salajekna 1997/98 and 1998/99

Per Klingbjör

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Pårteglaciären

The mass balance year 1997/98

The winter balance 1997/98 was surveyed between April 21–22 by Mats Nilsson and the author. Snow depth was measured in approx. 100 points by manual probing. The mean snowdensity was determined from one snowpit at 1340 m a.s.l. to 0.41 g/cm³. The total accumulation during the winter 1997/98 was 1.20 m w. eq. (table 1 and 2). During the same period, six new ablationstakes was established. One ablation stake from 1996/97 was found at 1405 m a.s.l. The stakes was drilled along profiles to establish an ablation gradient.

The ablation measurement was measured by the the author in August 30, and two weeks later by Krister Jonsson. The summer balance 1997/98 was determined by from six stake measurements and the ablation gradient was calculated by means of linear regression. The summer balance amounted to -1,68 m w. eq. (table 1 and 2).

The winter and summer balance yield a net balance 1997/98 of -0.48 m w. eq. The equilibrium line altitude (ELA) was calculated linearly between 1575 and 1625 m a.s.l. to 1578 m a.s.l. The ratio between accumulation area and total area (AAR) was estimated to 31 % from oblique photos taken from helicopter.

The mass balance year 1998/99

The winter balance 1998/99 was determined between April 24–25, by Krister Jonsson and the author. Snow depth was measured in approx. 100 points by manual probing. The mean snowdensity was determined from one snowpit at 1360 m a.s.l. to 0.39 g/cm³. The total accumulation during the winter 1998/99 was 1.17 m w. eq. (table 1 and 3). During the same period, five new ablationstakes was established. One ablation stake from 1997/98 was found at 1230 m a.s.l. The stakes was drilled along profiles to establish an ablation gradient.

The summer balance 1998/99 was determined by Thomas Claesson and the author in September 6, by means of six stakes and the ablation gradient was calculated by means of linear regression. The summer balance amounted to -1,56 m w. eq. (table 1 and 3).

The winter and summer balance yield a net balance 1998/99 of -0.39 m w. eq. The equilibrium line altitude (ELA) was calculated linearly between 1475 and 1525 m a.s.l. to 1509 m a.s.l. The ratio between accumulation area and total area (AAR) was estimated to 28 % from oblique photos taken from helicopter.

Table 1. Data on winter balance, bw (m w. eq), summer balance, bs (m w. eq) and net mass balance, bn (m w. eq), at Pårteglaciären and Salajekna 1997–1999.

Mass balance year	Pårteglaciären			Salajekna		
	b _w	b _s	b _n	b _w	b _s	b _n
1996/97	1.72	-2.59	-0.87	*	*	*
1997/98	1.20	-1.68	-0.48	1.95	-2.42	-0.47
1998/99	1.17	-1.56	-0.39	1.65	-2.02	-0.37

* not measured

Table 2. Mass balance of Pårteglaciären 1997/98.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance 10 ³ m ³ m w.eq.		Summer balance 10 ³ m ³ m w.eq.		Net balance 10 ³ m ³ m w.eq.	
1050-1100	13	9.8	0.75	37.1	2.86	-27.4	-2.11
1100-1150	128	114.0	0.89	345.1	2.70	-231.1	-1.81
1150-1200	307	334.3	1.09	778.5	2.54	-444.3	-1.45
1200-1250	499	552.3	1.11	1185.4	2.38	-633.1	-1.27
1250-1300	701	825.8	1.18	1552.8	2.22	-727.1	-1.04
1300-1350	945	1166.8	1.23	1941.7	2.05	-775.0	-0.82
1350-1400	1348	1673.0	1.24	2553.6	1.89	-880.6	-0.65
1400-1450	1256	1452.0	1.16	2177.8	1.73	-725.8	-0.58
1450-1500	1096	1257.0	1.15	1724.6	1.57	-467.6	-0.43
1500-1550	1357	1659.8	1.22	1917.7	1.41	-257.9	-0.19
1550-1600	931	1158.8	1.24	1166.3	1.25	-7.6	-0.01
1600-1650	707	907.3	1.28	772.3	1.09	134.9	0.19
1650-1700	420	507.5	1.21	391.4	0.93	116.1	0.28
1700-1750	146	209.5	1.43	112.7	0.77	96.8	0.66
1750-1800	54	84.5	1.56	33.0	0.61	51.5	0.95
1800-1850	5	8.8	1.75	2.3	0.45	6.5	1.30
1050-1850	9913	11920,8	1,20	16692,4	1,68	-4771,7	-0,48

Table 3. Mass balance of Pårteglaciären 1998/99.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance 10 ³ m ³ m w.eq.		Summer balance 10 ³ m ³ m w.eq.		Net balance 10 ³ m ³ m w.eq.	
1050-1100	13	16.3	1.25	38.6	2.97	-22.3	-1.72
1100-1150	128	146.0	1.14	355.4	2.78	-209.4	-1.64
1150-1200	307	292.3	0.95	793.4	2.58	-501.2	-1.63
1200-1250	499	446.3	0.89	1193.7	2.39	-747.5	-1.50
1250-1300	701	625.8	0.89	1542.1	2.20	-916.4	-1.31
1300-1350	945	940.8	1.00	1897.2	2.01	-956.4	-1.01
1350-1400	1348	1461.0	1.08	2447.0	1.82	-986.0	-0.73
1400-1450	1256	1438.0	1.14	2038.5	1.62	-600.5	-0.48
1450-1500	1096	1428.0	1.30	1568.1	1.43	-140.1	-0.13
1500-1550	1357	1758.3	1.30	1680.5	1.24	77.7	0.06
1550-1600	931	1157.8	1.24	973.9	1.05	183.8	0.20
1600-1650	707	1000.8	1.42	603.7	0.85	397.1	0.56
1650-1700	420	560.0	1.33	277.8	0.66	282.2	0.67
1700-1750	146	221.5	1.52	68.5	0.47	153.0	1.05
1750-1800	54	82.0	1.52	15.0	0.28	67.0	1.24
1800-1850	5	8.8	1.75	0.4	0.08	8.3	1.67
1050-1850	9913	11583.3	1.17	15494.0	1.56	-3910.7	-0.39

Salajekna

The mass balance of Salajekna was determined on the main part of the glacier. The main part of the glacier covers 21 km² and extends from 900 to 1650 m a.s.l. The main unit of the accumulation area is located in Norway and the glacier flows towards the southeast into Sweden where it turns south.

The mass balance year 1997/98

The winter balance 1997/98 was surveyed between April 23–24 by Mats Nilsson and the author. Snow depth was measured in approx. 100 points by manual probing. The mean snowdensity was determined from one snowpit at 980 m a.s.l. to 0.45 g/cm³. The total accumulation during the winter 1997/98 was 1.95 m w. eq. (table 1 and 2). During the same period, five ablationstakes was established. The stakes was drilled along profiles to establish an ablation gradient.

The summer balance 1997/98 was determined by the author in August 30, from four stake measurements and the ablation gradient was calculated by means of linear regression. The summer balance amounted to -2.42 m w. eq. (table 1 and 2).

The winter and summer balance yield a net balance 1997/98 of -0.47 m w. eq. The equilibrium

line altitude (ELA) was calculated linearly between 1325 and 1375 m a.s.l. to 1359 m a.s.l. The ratio between accumulation area and total area (AAR) was estimated to 57 % from oblique photos taken from helicopter.

The mass balance year 1997/98

The mass balance for 1998/99 is based on three stakes drilled in May 11, by Per Holmlund. The snow depth was measured when three ablations stakes was drilled. The mean snowdensity was assumed to be 0.45 g/cm³ (the same value as the density during the mass balance year 1997/98 for Salajekna). The distribution of the snow was assumed to be similar to the previous year. The total accumulation during the winter 1997/98 was then estimated to 1.65 m w. eq. (table 1 and 2).

The summer balance 1997/98 was determined by Thomas Claesson and the author in Sept. 6, from two stake readings. The summer balance amounted to -2.02 m w. eq. (table 1 and 2).

The winter and summer balance yield a net balance 1997/98 of -0.37 m w. eq. The equilibrium line altitude (ELA) was calculated linearly between 1325 and 1375 m a.s.l. to 1331 m a.s.l. The ratio between accumulation area and total area (AAR) was estimated to 51 % from oblique photos taken from helicopter.

Table 4. Mass balance of Salajekna 1997/98.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance 10 ³ m ³ m w.eq.		Summer balance 10 ³ m ³ m w.eq.		Net balance 10 ³ m ³ m w.eq.	
900-950	810	1417.5	1.75	2974.2	3.67	-1556.7	-1.92
950-1000	714	1249.5	1.75	2486.7	3.48	-1237.2	-1.73
1000-1050	1400	2450.0	1.75	4611.1	3.29	-2161.1	-1.54
1050-1100	1304	2282.0	1.75	4048.3	3.10	-1766.3	-1.35
1100-1150	1654	2894.5	1.75	4822.1	2.92	-1927.6	-1.17
1150-1200	2068	3789.0	1.83	5638.0	2.73	-1849.0	-0.89
1200-1250	1620	2783.0	1.72	4110.3	2.54	-1327.3	-0.82
1250-1300	2040	4030.0	1.98	4790.1	2.35	-760.1	-0.37
1300-1350	3080	5772.0	1.87	6649.7	2.16	-877.7	-0.28
1350-1400	7328	15410.0	2.10	14435.3	1.97	974.7	0.13
1400-1450	1137	2401.8	2.11	2024.7	1.78	377.0	0.33
1450-1500	276	559.0	2.03	439.3	1.59	119.7	0.43
1500-1550	223	466.3	2.09	312.8	1.40	153.5	0.69
1550-1600	112	252.0	2.25	135.9	1.21	116.1	1.04
1600-1650	44	99.0	2.25	45.1	1.02	53.9	1.23
900-1650	20886	40738.5	1.95	57523.6	2.42	-16785.1	-0.47

Table 5. Mass balance of Salajekna 1998/99.

Elevation m a.s.l.	Area 10 ³ m ²	Winter balance 10 ³ m ³ m w.eq.		Summer balance 10 ³ m ³ m w.eq.		Net balance 10 ³ m ³ m w.eq.	
900-950	810	1174.5	1.45	3161.8	3.90	-1987.3	-2.45
950-1000	714	1035.3	1.45	2584.8	3.62	-1549.5	-2.17
1000-1050	1400	2030.0	1.45	4671.6	3.34	-2641.6	-1.89
1050-1100	1304	1890.8	1.45	3981.9	3.05	-2091.1	-1.60
1100-1150	1654	2398.3	1.45	4582.1	2.77	-2183.8	-1.32
1150-1200	2068	3168.6	1.53	5143.1	2.49	-1974.5	-0.95
1200-1250	1620	2297.0	1.42	3570.0	2.20	-1273.0	-0.79
1250-1300	2040	3418.0	1.68	3917.7	1.92	-499.7	-0.24
1300-1350	3080	4848.0	1.57	5042.4	1.64	-194.4	-0.06
1350-1400	7328	13211.6	1.80	9921.1	1.35	3290.5	0.45
1400-1450	1137	2060.7	1.81	1217.2	1.07	843.4	0.74
1450-1500	276	476.2	1.73	217.3	0.79	258.9	0.94
1500-1550	223	399.4	1.79	112.4	0.50	287.0	1.29
1550-1600	112	218.4	1.95	24.7	0.22	193.7	1.73
1600-1650	44	85.8	1.95	-2.8	-0.06	88.6	2.01
900-1650	20886	34472.7	1.65	-48145.4	-2.02	-13672.7	-0.37

Glacio-meteorological studies on Storglaciären in 1999

Regine Hock¹, Jonathan L. Carrivick² and Ulf Jonsell³

¹*Department of Physical Geography, Stockholm University, SE-10691 Stockholm, Sweden*

²*Cranfield University at Silsoe, Bedfordshire, MK45 4DT, England*

³*Department of Earth Sciences, Uppsala University, Villav. 16, SE-752 36 Uppsala, Sweden*

Abstract

An automatic weather station was run on Storglaciären during the melt season 1999, collecting half-hourly data on air temperature, humidity, wind speed, radiation components and precipitation. The data are used for studies on surface energy balance, glacio-meteorology and melt modelling.

Methodology

An automatic weather station was operated close to the equilibrium line altitude in the upper ablation area of Storglaciären (ca. 1380 m a.s.l.) from 8 May to 15 September 1999 (Figure 1). An overview of the measurements and the instrumentation is given in Table 1. In addition, cloud observations (cloud cover and type) were recorded throughout most of the period. The data are used for energy balance studies (Carrivick *et al.*, 2000), glacio-meteorological investigations and glacier melt simulations.

The temperature/humidity sensors and most radiation instruments were artificially ventilated. The Eppley pyrgeometers were calibrated and priorly modified at the World Radiation Center (WRC) in Davos, Switzerland, according to the “Swiss modification” (Philipona *et al.*, 1995) containing three dome thermistors at 45° instead of just one dome thermistor, thus reducing the instrumental error. Measurements were taken every 60 seconds (wind speed every 10 seconds) and half-hourly averages were stored on a Campbell CR10X datalogger. Four car batteries and a 55 W solar

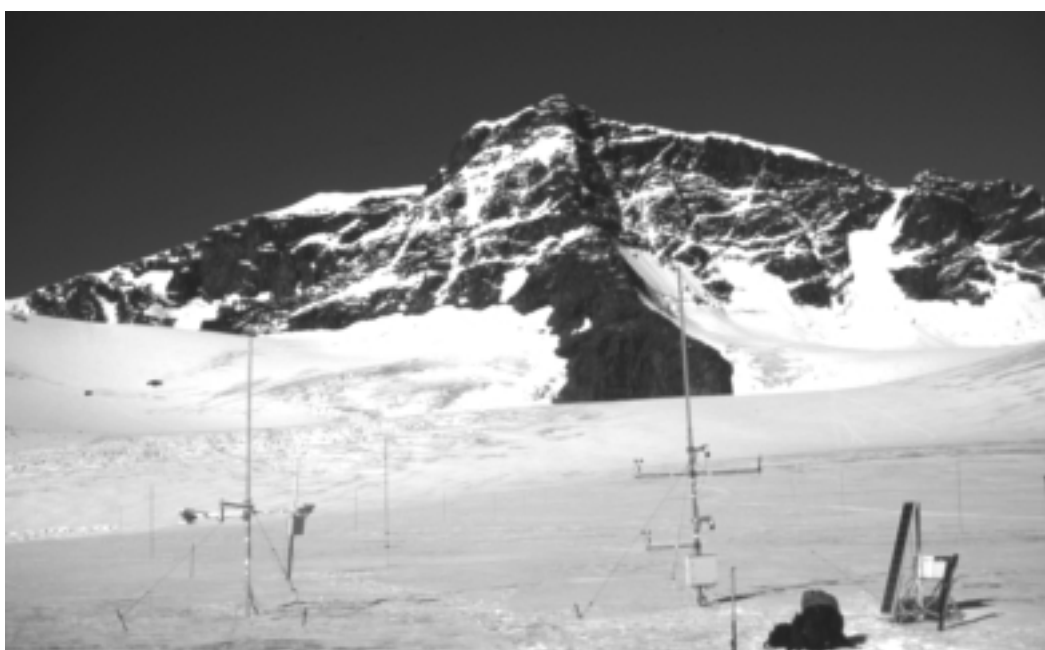


Figure 1. Weather station on Storglaciären on 14 August 1999. Radiation mast to the left and temperature/humidity/wind speed mast to the right. Photograph by Margareta Johansson.

Table 1. Instrumentation of the automatic weather station on Storglaciären, 1999.

Measurement	Instrument	Instrument height	Comment
Air temperature	Vaisala HMP45D	1 and 2 m	Ventilated
Air humidity	Vaisala HMP45D	1 and 2 m	Ventilated
Wind speed	Aanderaa 2740S	1 and 2 m	
Wind direction	Young	2 m	
Global radiation	Kipp & Zonen CM 11	ca. 1.2–1.4 m	Ventilated
Reflected shortwave radiation	Kipp & Zonen CM 11	ca. 1.2–1.4 m	Ventilated
Longwave incoming radiation	Eppley Model PIR	ca. 1.2–1.4 m	Ventilated
Longwave outgoing radiation	Eppley Model PIR	ca. 1.2–1.4 m	
Precipitation	Tipping bucket	ca. 1.2–1.5 m	Unheated
Ablation	Campbell SR50	ca. 1.0–1.2 m	

panel supplied power for the station. The instruments were mounted onto two separate masts to avoid interference from other instruments. For additional support against strong winds, three guy-cables secured to stakes drilled into the ice were added to the masts. Each mast consisted of a 4 cm width aluminium profile drilled several meters into the ice and a 1.5 to 2 m long outer sleeve (5 cm width aluminium profile), which could easily be moved vertically by adjusting screw-clamps. The instruments were mounted on horizontal bars fastened onto the outer sleeve. This construction allowed easy height alterations of all instruments of one mast simultaneously. For general maintenance, including adjustments of instrument heights to reposition sensors to the heights given in Table 1 and re-levelling the radiation instruments, the weather station was visited at least twice a week except for most of June, when the Tarfala Research Station was closed.

A 1 ½ day data gap between 4 and 6 August due to power failure was interpolated based on the data collected at a less-equipped climate station approximately 1 km west in the accumulation area. As not available at this station, radiation data were copied from days with similar weather conditions close to the dates of the gap. Radiation data are only available until September 2, when the mast with the radiation instruments fell over in a severe storm.

Results

The data are presented in Figure 2 and Table 2. The prevailing wind direction was west, i.e. down-glacier, due to the dominant free atmosphere west wind direction and topographic channeling along

the west-east oriented glacier valley and also due to katabatic flow, as the glacier flows to the west. The maximum wind speed (10 sec means) during the measurement period was 26.6 m s^{-1} . A pronounced rise in air temperature was observed on the 9th of June. From then onwards, a continuously melting surface is indicated by an approximately constant value for longwave outgoing radiation of 316 Wm^{-2} . From the end of July to the end of August, relatively cold air temperatures around the freezing

Table 2. Means of air temperature, T ($^{\circ}\text{C}$) at 2 m, relative humidity, RH (%), wind speed, u (m s^{-1}) at 2 m, global radiation, G (Wm^{-2}), albedo, a , longwave incoming radiation, $L\uparrow$ (Wm^{-2}), longwave outgoing radiation, $L\downarrow$ (Wm^{-2}), netradiation, Net (Wm^{-2}), precipitation, P (mm) from Storglaciären during the melt season 1999.

Data	June	July	August	9 May–2 Sep
T	4.5	4.7	2.3	2.7
RH	79.8	86.2	82.8	82.6
u	3.4	3.7	3.0	3.2
G	223	142	132	180
a	0.75	0.58	0.57	0.69
$L\uparrow$	293	313	291	290
$L\downarrow$	313	317	312	310
Net	35	55	36	35
P	567.0*	387.5	84.5	1135.7*

*includes a half-hourly value of 169.5 mm/30min on June 14. Although a heavy rain storm is indicated by surrounding precipitation gauges this value is considered questionable.

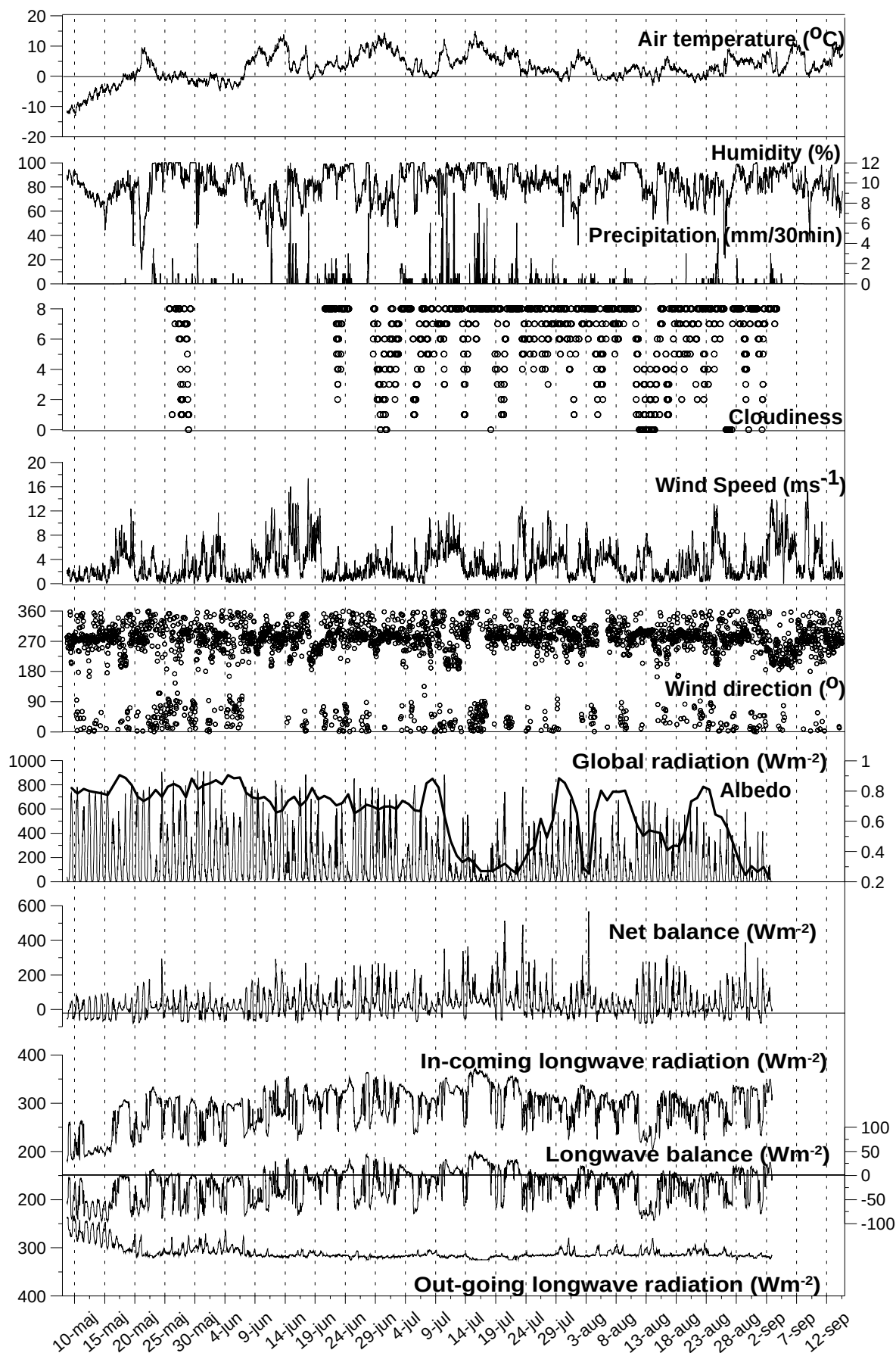


Figure 2. Half-hourly data from the automatic weather station on Storglaciären, 8 May – 15 September, 1999. Albedo data are daily means. Note: precipitation gauge was not heated and frequent snow falls occurred in July and August.

point were dominant and frequent snow falls are indicated by a marked increase in albedo and maintained high albedo values throughout this period.

Acknowledgements

Thomas Persson from the SMHI in Norrköping is gratefully acknowledged for providing the ventilation system for the radiation instruments.

References

- Carrivick, J. L. and Hock, R., 2000: Measured and modelled melt and the surface energy balance on Storglaciären. In: Klingbjer, P. (ed.): *Tarfala Research Station Annual Report, 1998-1999*. Department of Physical Geography, Stockholm University, Research Report 111: 28-33.
- Philipona, R., Fröhlich, C. and Betz, Ch., 1995: Characterization of pyrgeometers and the accuracy of atmospheric longwave radiation measurements. *Appl. Optics* 34, 1598-1605.

Water content and temperature in the firn of Storglaciären

Thomas Schneider

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Abstract

A 21-m long firn core in the accumulation area of Storglaciären was analysed on stratification, density and water content. Temperature was measured in boreholes and the 0°C-isotherm was found at depths between 11 and 13 m below snow surface. Water content was found to range between 0.02 and 0.04 with a mean value of 0.03. The mean thickness of the active layer of internal accumulation due to refreezing of capillary water was 4.25 m. The volume of refreezing water corresponded to 0.12 m water equivalent which is 5.5% of snow accumulation at the same site.

Introduction

Water content and temperature in firn is an important parameter for calculating internal accumulation of subpolar glaciers. There are two components of internal accumulation: (1) water which percolates into cold snow and firn and freezes immediately and (2) water which is retained in pores by capillary forces in the end of summer and freezes during winter (Trabant and Mayo, 1985). This investigation is focused on refreezing of capillary water in the firn of Storglaciären. I will present preliminary results from the field season 1999.

Methods

Firn core

In May 1999, a firn core was drilled at location 29 in the accumulation area of Storglaciären (Figure 1). A mechanical ice drill was used yielding a 21 m long core with a diameter of 7.5 cm. The core was weighed immediately after drilling with a digital scale to determine density. Porosity and dry density were calculated from wet density and water content, according to Schneider (in press).

Irreducible water content

In the beginning of the winter, water input into the firn layer ceases. All liquid water drains from the firn layer except of the water retained in small pores and veins by capillary and adhesive forces. Thus, water content (water volume divided by total volume) decreases until irreducible water content is reached. Water content measured in the end of the winter should therefore be close to irreducible water content.

Water saturation (volume of water divided by pore volume) and porosity (pore volume divided by total volume) control most of the important material properties of wet snow and firn, but measuring these parameters is difficult (Colbeck, 1978). In this investigation, we used a dilution method. An aqueous salt solution is diluted when mixed with wet snow or firn. The change in concentration is the base for the measurements. For detailed description of the method, see Davis and others (1985). To minimise melting of ice or freezing of free water the analyses had to be carried out immediately after drilling. Analyses were carried out in a tent in which temperature was approximately 0° C.

Firn temperature

Firn temperature was measured continuously at location 29 (Figure 1) at one-meter intervals. Thermocouples were connected to a Campbell Scientific CR10 datalogger and temperature was recorded every hour. In addition to the continuous measurement, temperature was measured at several locations 29, A, B and 28S3 (Figure 1) in the end of the winter season to determine the depth of the 0°C-isotherm over a larger area. These measurements will later be used to calibrate radar images of the firn layer to obtain a map of the depth of the 0°C-isotherm.

Results and discussion

Density and stratification and porosity

Wet firn density decreased continuously from 700 kg m⁻³ at 10 m to 900 kg m⁻³ at ~16 m. At this

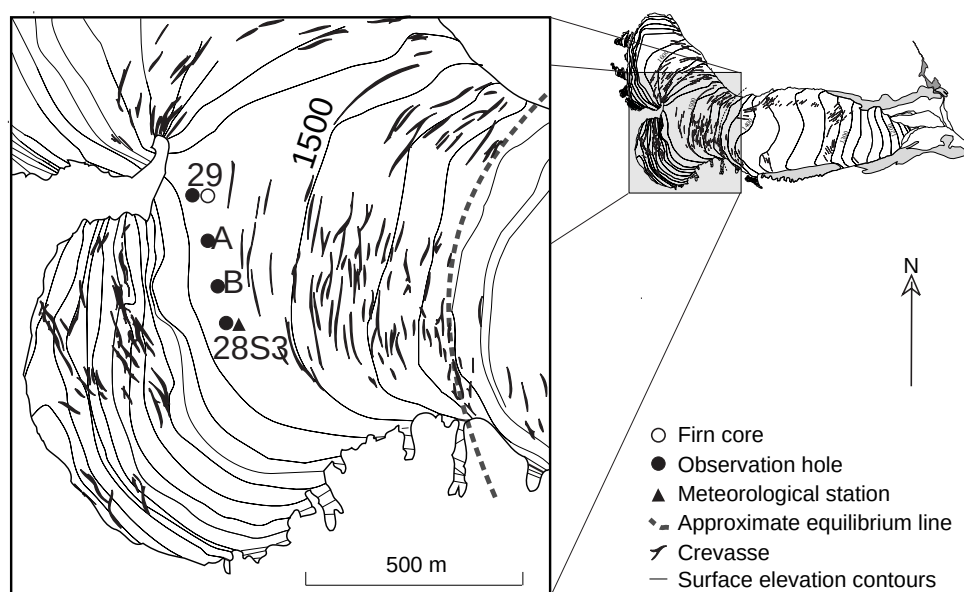


Figure 1. Location map of the accumulation area of Storglaciären, May 1999.

depth ice lenses became more frequent and a 20 cm thick ice lens bounded the upper part of the firn layer. Firn density decreased abruptly below this layer to 750 kg m^{-3} and started increasing again down to the firn water table. Between the ice lens at 16 m and the firn water table at 18.9 m, firn structure was homogenous without any significant layering or ice lenses. Dry density at the depth of the firn-water table reaches values of 830 kg m^{-3} . At this density, pores are closed off and firn becomes impermeable (Paterson, 1994). Even the location of the firn-water table indicates at which depth firn becomes impermeable. If the firn had been permeable below the firn-water table, water would have drained during winter. However, density increased a bit more and became constant around 910 kg m^{-3} at 19.7 m.

As porosity is calculated from density and water content, it follows the variations of these parameters. Porosity was 0.3 at 10 m depth and decreased to 0.1 just above the ice layer at 16 m. Below this depth it was 0.2 to a depth of 17 m and decreased again to 0.1 at the firn-water table. Thus, in the depth where a firn aquifer was formed during summer (above the firn water table in May) mean porosity was ~ 0.15 , which agrees with several investigations from other temperate glaciers (cf Schneider, 1999; Schneider, in press).

Water content and water saturation

Volumetric water content was relatively constant over the entire unsaturated part of the firn core (0.02–0.04). In the saturated firn, water content reached its maximum of 0.05 but decreased rapidly with depth to 0.02. Water saturation was below 0.2 down to 17 m, instead of a zone of higher

saturation (0.5) just above the ice layer at 16 m. In the upper part of the saturated firn, water saturation was 0.6, a result similar to that of Fountain (1989). This means, that in saturated firn only 60 % of the pore space is filled by water whereas 40 % are isolated air bubbles.

Firn temperature

Figure 2 shows temperature profiles at 29, A, B and 28S3 in May 99. The penetration depth of the cold wave ranged between 11 and 13 m (Figure 3 and 4) and was not significantly dependent upon snow depth (Figure 4).

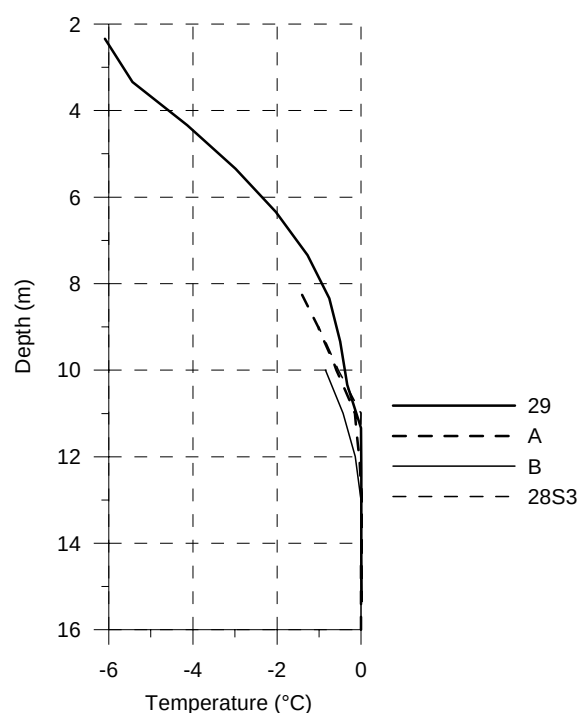


Figure 2. Temperature profiles in boreholes in the accumulation area of Storglaciären, May 1999.

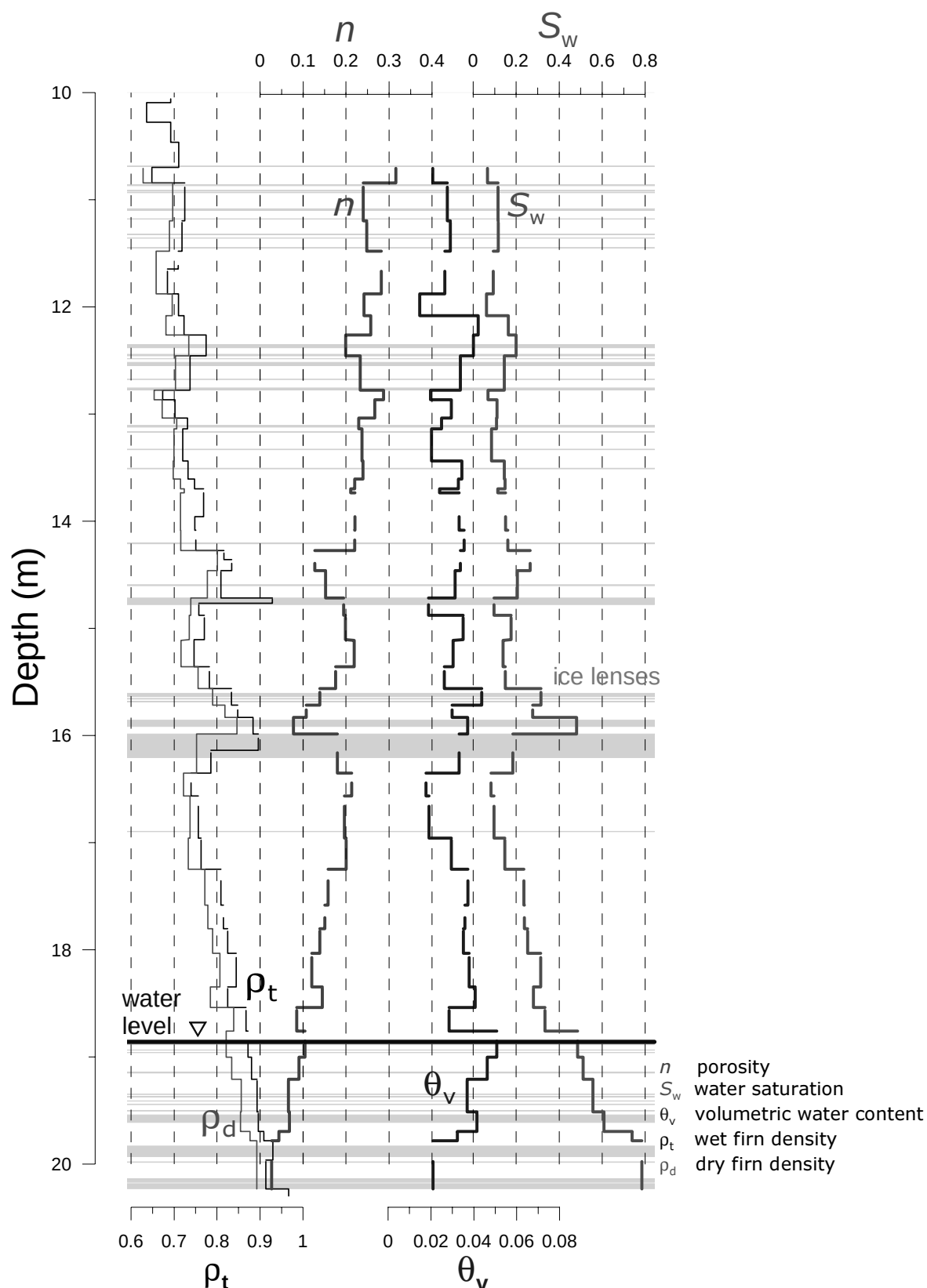
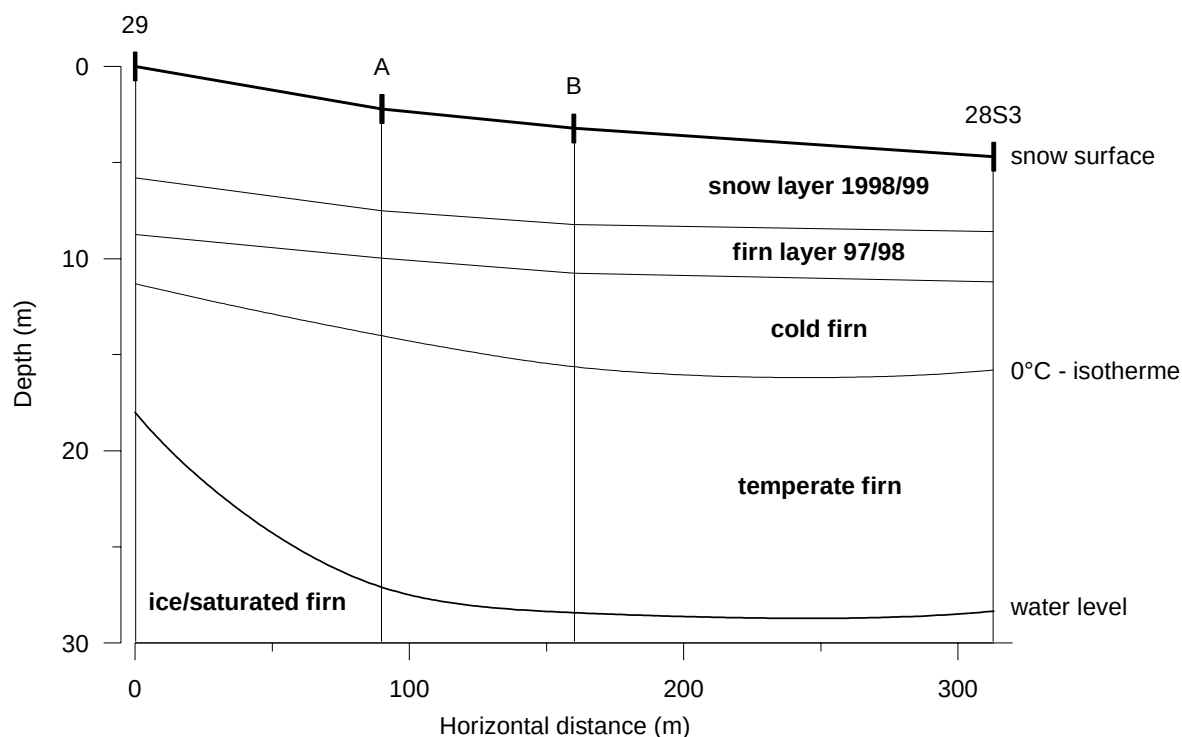


Figure 3. Density, porosity, water content in a firn core from location 29 (Figure 1) on Storglaciären, May 1999.

Refreezing of capillary water

The volume of refrozen capillary water that contribute internally to the mass balance of the glacier was calculated from the depth of the cold

wave and the water content in the firn layer below the annual snow layer of 1997/98 (see Schneider, in press, for further discussion on internal accumulation). Figure 4 shows that snow depth decreases



from 29 to 28S3. As the depth of the cold wave was not correlated to snow depth the active layer of internal accumulation (“cold firn“ in Figure 4) increases with decreasing snow depth. The active layer had an average thickness of 4.25 m and with a water content of 0.03 (Figure 2) the volume of frozen capillary water was 0.13 m water equivalent (w.eq.). In 1999 snow accumulation in the investigation area was ~2.2 m w.eq. This implies that real accumulation in the investigated area is underestimated by ~5.5% if only snow accumulation is considered.

Conclusion

The cold wave in winter penetrated into the firn layer of Storglaciären down to a depth of between 11 and 13 m. This caused a freezing of capillary water which usually is not taken into account when measuring winter accumulation. Water content in the temperate part of the firn layer was found to vary around 0.03 and the active layer of internal accumulation was in average 4.25 m. This implies that 0.12 m w.eq. was internally accumulated during the winter of 1998/99. This accounts for 5.5% of snow accumulation during the same period.

Acknowledgements

Karin Grust and Sara Frödin and the staff at Tarfala Research Station are gratefully acknowledged for assisting in the field. The project was financially supported by H. W:son Ahlman's fund, the Göran Gustafsson Foundation, Axel Hamberg's fund and C. Mannerfelt's fund.

References

- Colbeck, S.C. 1978: The difficulties of measuring the water saturation and porosity of snow. *J. Glaciol.*, **20**(82), 189-201.
- Davis, R.E., J. Dozier, E.R. LaChappelle and R. Perla. 1985: Field and laboratory measurements of snow liquid water by dilution. *Wat. Resour. Res.*, **21**(9), 1415-1420.
- Fountain, A.G. 1989: The storage of water in, and hydraulic characteristics of, the firn of South Cascade Glacier, Washington State U.S.A. *Ann. Glaciol.*, **13**, 69-75.
- Paterson, W.S.B. 1994: The physics of glaciers. Pergamon Press, Oxford, 480 p.
- Schneider, T. 1999: Water movement in the firn of Storglaciären, Sweden. *J. Glaciol.*, **45**(150), 286-294.
- Schneider, T. in press. Hydrological processes in the wet-snow zone of glaciers - a review. *Zeitschrift für Gletscherkunde und Glazialgeologie*. 36(1). in press.
- Trabant, D.C. and L.R. Mayo. 1985: Estimation and effects of internal accumulation on five different glaciers in Alaska. *Ann. Glaciol.*, **6**, 113-117.

Chloroacetates and Trifluoroacetate in ice from Storglaciären and Mårmaglaciären

Lena von Sydow

*Department of Water and Environmental Studies, Linköping University,
SE-581 83 Linköping, Sweden.*

Introduction

Chloroacetates, i.e. mono-, di- and trichloroacetate (MCA, DCA and TCA) as well as trifluoroacetate (TFA) are among the most prevalent haloorganics in precipitation (von Sydow *et al.*, 1999; von Sydow *et al.* 2000b). However, there is no consensus regarding the sources of these compounds. It has been suggested that atmospheric degradation of chlorinated solvents and CFC replacements are responsible for the presence of haloacetates in precipitation in populous regions. Detailed examination of the possible pathways, however, has indicated that this explanation is unlikely (Franklin, 1994; Sidebottom and Franklin, 1996). Evidence presented by some authors have suggested that chloroacetates may occur naturally in precipitation. Chloroacetates have been found in 100-year-old glacier ice collected in the Alps (Haiber *et al.*, 1996) and there are also indications that chloroacetates are formed naturally in soil (Hoekstra *et al.*, 1995). A large study of haloacetates in snow, firn and glacier ice was undertaken to determine how widespread such compounds are in precipitation, and to elucidate the possible involvement of anthropogenic and natural sources (von Sydow *et al.*, 1999; von Sydow *et al.* 2000a; von Sydow *et al.*, 2000b). As part of this study, chemical analysis of glacier ice was performed on samples from two sub-polar glaciers in northern Sweden, Storglaciären and Mårmaglaciären.

Methods

Glacier ice was sampled at both glaciers where clearly visible annual growth layers enabled identification of sections of ice that had been formed at least 500 years ago (Holmlund, 1998). After removing about 1.5 m of snow and 20 cm of

the ice that was closest to the surface of the glacier, a chain saw was used to cut large blocks of solid ice (5–27 L) out of the glacier. To minimise the risk of *in situ* contamination through transport of chloroacetates from recent precipitation to older layers of ice, the samples of glacier ice were taken from permanently frozen ice layers with well-preserved primary structures and no visible crevasses (Holmlund *et al.*, 1996). All samples were transported and stored frozen (-20°C) pending analysis. In addition, the analysed sub-samples of the inner parts of the glacier ice blocks were obtained by using a handsaw to remove the outer 5 cm of ice. Chloroacetates and TFA in ice were analysed according to the analytical procedures described in von Sydow *et al.* (1999) and von Sydow *et al.* (2000b).

Results and discussion

The samples of several-hundred-year-old glacier ice from Storglaciären and Mårmaglaciären in northern Sweden were found to contain all three of the chloroacetates and TFA (see Table 1), and the amounts detected were comparable to those found in samples of fresh snow collected in remote areas (von Sydow, 1999; von Sydow *et al.* 2000a; von Sydow *et al.*, 2000b).

Contamination is often a serious problem in the analysis of trace organics, however, all possible precautionary measures were taken and the study produced convincing evidence that the analysed samples were not contaminated in the laboratory. Although the possibility of *in-situ* contamination from percolating water cannot be completely ruled out, more recent findings have confirmed that these compounds are also present in samples of 200 year old firn from the Antarctica where the temperature

Table 1. Observed concentrations in samples of old glacier ice from northern Sweden (von Sydow *et al.*, 1999; von Sydow *et al.* 2000b).

Sampling area	Sampling period	MCA (ng/L)	DCA (ng/L)	TCA (ng/L)	TFA (ng/L)
Storglaciären	Sept 1994	15	6	<5	–*
Mårmaglaciären	Dec 1994	32	12	13	5

* not measured

is too low to permit such transport (von Sydow *et al.* 2000a; von Sydow *et al.*, 2000b). In conclusion, the concentration of chloroacetates and TFA found in glacier ice in northern Sweden provide support to the growing body of evidence that unidentified natural sources play a key role in the distribution of these compounds in precipitation.

References

- Franklin, J., 1994: The atmospheric degradation and impact of perchloroethylene, *Toxicol. Environ. Chem.* **46**, 169–182.
- Haiber, G., Jacob, G., Niedan, V., Nkusi, G. and Schöler, H. F., 1996: The occurrence of trichloroacetic acid (TCAA) – indications of a natural production? *Chemosphere* **33**, 839–849.
- Hoekstra, E. J., Lassen, P., van Leeuwen, J. G. E., de Leer E. W. B. and Carlsen L., 1995: Formation of organic chlorine compounds of low molecular weight in the chloroperoxidase-mediated reaction between chloride and humic material. In: Grimvall, A. and de Leer, E. W. B. (eds.) *Naturally-Produced Organohalogenes*. Kluwer Academic Publishers, Dordrecht. 149–158.
- Holmlund, P., 1998: Glacier mass balance and ice-core records from northern Sweden, *Ambio* **27**, 266–269.
- Holmlund, P., Näslund J.-O. and Richardson C., 1996: Radar surveys on Scandinavian glaciers in search of useful climate archives, *Geogr. Ann.* **78 A**, 147–154.
- Sidebottom, H. and Franklin, J., 1996: The atmospheric fate and impact of hydrochlorofluorocarbons and chlorinated solvents, *Pure Appl. Chem.* **68**, 1757–1769.
- von Sydow L. M., Boren H. B. and Grimvall A. B., 1999: Chloroacetates in snow, firn and glacier ice, *Chemosphere* **39**, 2479–2488.
- von Sydow, L. M., Nielsen, A. T., Grimvall, A. B. and Boren, H. B., 2000a: Chloro- and bromoacetates in natural archives of firn from Antarctica, *Environ. Sci. Technol.* **34**, 239–24.
- von Sydow, L. M., Grimvall, A. B., Boren, H. B., Laniewski, K. and Nielsen A. T., 2000b: Natural background levels of trifluoroacetate in rain and snow, accepted for publication in *Environ. Sci. Technol.*

Geomorphological mapping in Tarfala, Swedish Lapland, August 1999

Alexander Quirin

*Department of Physical Geography, Justus Liebig University Giessen, 35390 Giessen,
Germany*

Introduction

In August 1999, I was mapping the geomorphological features in the Tarfala area in order to contribute with this data to the PACE-project (Permafrost and Climate in Europe). The focus of the project is naturally on permafrost related features and processes. The area mapped is bigger than the shown area in Figure 1 but the highest diversity and clearness in geomorphology was found in the vicinity of the Tarfala Research Station and the eastern neighborhood, Tjeurolako.

Predominant features and processes

The predominant features are patterned ground and stone-banked solifluktion. Patterned ground features change from sorted polygons into sorted circles (when less frequent) or into sorted stripes (when inclination rises), some of them are relict. They are widespread on gentle slopes as they occur in Tjeurolako and at Kebnetjakkaplatan.

On steeper slopes these features change into stone-banked solifluktion (also called steps or stone-banked terraces). They are still sorted and have a

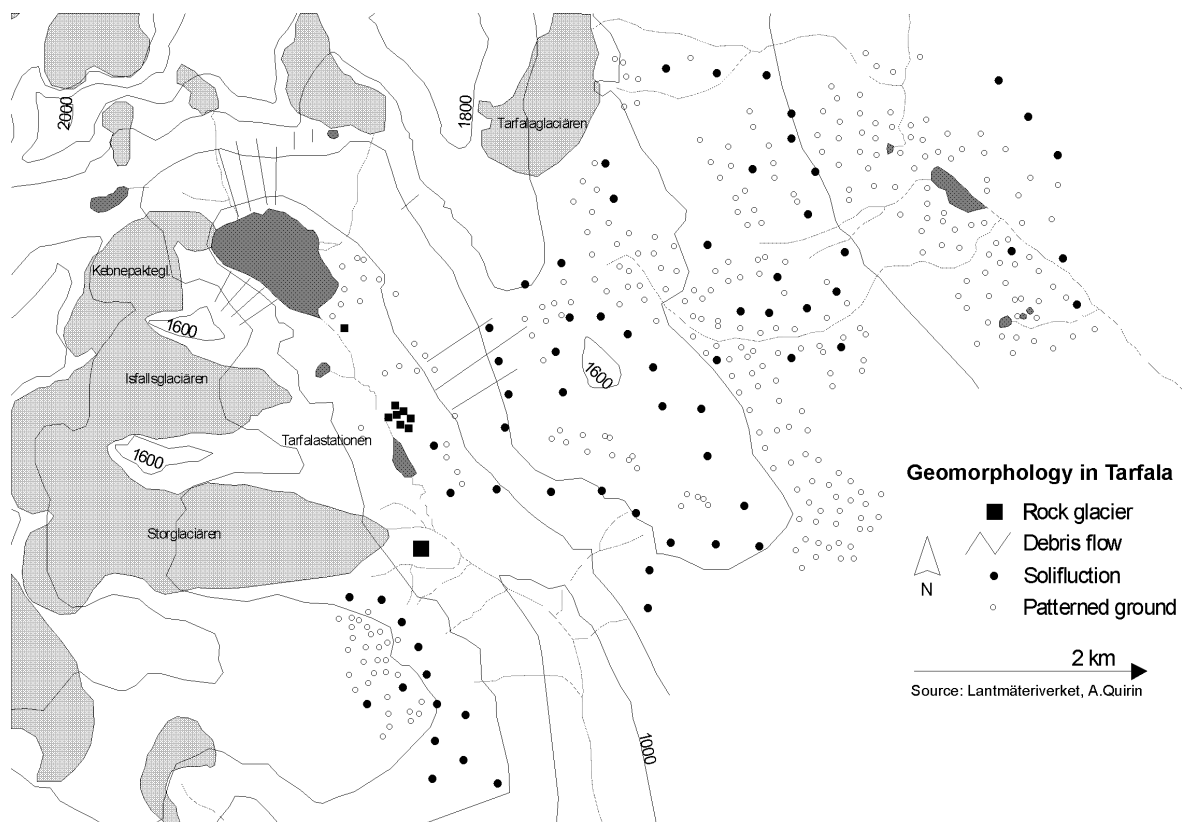


Figure 1. Geomorphology in Tarfala

lobate and downslope elongated shape with stone accumulation at their front and sides. Unsorted steps with more organic and other fine material are called turf-banked solifluction and occur on the west-faced slope of Tarfalavagge.

Since patterned ground and solifluction occurs as well below the assumed altitude for permafrost (King 1984) it is probable that the recent features develop due to yearly frozen ground. Embleton & King (1975) as well described that solifluction doesn't require permafrost conditions.

It is obvious that patterned ground and solifluction is well developed in places where water supply is sufficient for example from snow patches. Jahn (1991) mentioned that the moisture content is the predominant factor for horizontal movement besides inclination. These conditions occur on the east-faced slope of Tjeurolako at about 1400 m a.s.l.. Embleton & King (1975) think that moisture is even more decisive than inclination.

Another remarkable geomorphological process is debris flow esp. in Tarfalavagge. Very often the trigger is an exceptionally high precipitation during the snow-thawing period as it has been on July, 6th 1972 in Tarfalavagge (described by Rapp & Strömquist, 1976).

According to abundant publications many moraine ridges are ice-cored (Karlén, 1973; Östrem, 1971, 1963, 1964; Ackert, 1984). There is a great likelihood for a rock glacier which has its origin in the southern lateral moraine of Storglaciären. This moraine front is the only one steeper than 19° and is according to King (1984) not frozen to the ground.

Permafrost

According to King (1984) continuous and discontinuous permafrost occurs in Tarfalavagge with considerable thickness. The lower limit of permafrost on northern slopes is at about 920 m a.s.l. (-2.4°C, Mean Annual Air Temperature), on S-slopes at 1420 m a.s.l. (-5.0°C) and on ridges on valley bottoms at 1120 m a.s.l. (-3.4°C).

Due to mean annual ground temperatures of -4.0°C and lower at some sites the thickness of relic permafrost can be interpreted to be more than 100m there.

References

- Ackert, R.P., 1984: Ice-cored lateral moraines in the Tarfala Valley, Swedish Lapland. *Geografiska Annaler*. 66A (1-2): 79-88.
- Embleton E. & King C.A.M., 1975: *Periglacial Geomorphology*. London.
- Jahn, A., 1991: Slow soil movement in Tarfala Valley, Kebnekaise Mountains, Swedish Lapland. *Geografiska Annaler* 73A (2): 93-107.
- Karlén, W., 1973: Holocene Glaciers and Climate Variations, Kebnekaise Mountains, Swedish Lapland. *Geografiska Annaler* 55A (1): 29-63.
- King, L. , 1984: *Permafrost in Scandinavia*. Heidelberg.
- Östrem, G., 1971: Rock glaciers and ice-cored moraines, a reply to D. Barsch. *Geografiska Annaler* 53A (3-4): 207-213.
- Östrem, G. 1963: Comparative crystallographic studies on ice from ice-cored moraines, snow-ganks and glaciers. *Geografiska Annaler* XLV (4): 210-240.
- Östrem, G., 1964: Ice-cored moraines in Scandinavia. *Geografiska Annaler* XLVI (3): 282-373.
- Rapp, A. & Strömquist, L. 1976: Slope Erosion due to Extreme Rainfall in the Scandinavian Mountains. *Geografiska Annaler* 58A (3), 193-200.

Measured and modelled melt and the surface energy balance on Storglaciären

Jonathan L. Carrivick¹ and Regine Hock²

¹ *Cranfield University at Silsoe, Bedfordshire, MK45 4DT, England*

² *Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden*

Abstract.

The surface energy balance at a point within the upper ablation area on Storglaciären is calculated from half-hourly meteorological data collected on the glacier, for a 117-day period from May 9 to September 2, 1999. On average, net radiation and turbulent heat fluxes make a roughly equal contribution to the total melt energy. The total energy available for melt (-54 Wm^{-2}) is less than half of that determined in a previous study on Storglaciären (-122 Wm^{-2}). The main source of this is the decreased net radiation received in 1999 (41 Wm^{-2} compared to 73 Wm^{-2} in 1994). There is a 2.17 m depth of ablation calculated by the model, although only 1.64 m is actually measured in the ablatograph record. Part of this discrepancy is attributed to inaccuracies within the ablatograph record, arising from the frequently changing surface density, under snow-fall events.

Purpose

This study aims to analyse the relative contributions of the various energy fluxes towards the total energy available for melting, at a single point on Storglaciären. The modelled melt energy will be compared to that actually observed by an ablatograph located at the climate station and also from measurements taken at local ablation stakes. The main factors influencing the modelling accuracy with respect to specific prevailing meteorological conditions will be examined. Additionally, analyses from results in an earlier study on Storglaciären will provide a comparative and investigative synthesis.

Methodology

Temperature index models or energy balance models may be used to suggest the amount of melt from a glacier in a given time. Temperature Index models are based on an assumed relationship between ablation and air temperature (usually expressed as positive temperature sums). An energy balance model however more properly examines the complex processes concerning the energy fluxes directed towards and away from a glacier surface. The surface energy balance of a glacier indicates the degree to which energy may become available for ablation. In this study, energy balance modelling is used to determine melting at a single fixed point,

using data obtained at half-hourly intervals from a meteorological station in the upper ablation area of Storglaciären (Hock et al, 2000).

The total energy available for melt (Q_M) is given by the sum of the net radiation (Q_N), the sensible heat flux (Q_H), the latent heat flux (Q_L), the heat transfer into the ice (Q_G) and the heat supplied by rain (Q_R):

$$Q_M = Q_N + Q_H + Q_L + Q_G + Q_R$$

In this study the ice heat flux was not included. Hock and Holmgren (1996) report an average value of 3% for a 40-day period in 1994.

On Storglaciären the net radiation was obtained from the direct measurements of the incoming ($L\downarrow$) and emitted long-wave radiation ($L\uparrow$) and the incoming ($S\downarrow$) and reflected short wave radiation ($S\uparrow$).

$$Q_N = (L\downarrow - L\uparrow) + (S\downarrow - S\uparrow)$$

Also at the same climate station, air temperature, humidity and wind speed were measured directly and recorded as 30 minute means from one-minute interval observations. These measurements were taken to calculate the sensible and latent heat fluxes, using the bulk aerodynamic method. Since the surface of a melting snow or ice surface cannot exceed 0°C , the air immediately above the surface

can become very stratified, thus suppressing turbulence. Following Hock and Holmgren (1996) stability corrections were not applied to these calculations. A constant value of 2.7 mm was used as the surface roughness length of wind and 0.009 mm for the roughness length of temperature and vapour pressure. The energy available for melt was converted to a melt water equivalent (dividing by the latent heat of fusion constant) and daily mean values were produced.

In order to gather ablation data, an ablatograph was located at the same climate station (SR50 Sonic Ranging Sensor, accurate to 1 cm with a resolution of 0.1 mm). The sensor transmits an ultrasonic pulse and records the echoes from the target surface. A difference between successive values indicates a motion of the surface. The measurements are corrected for air temperature since the speed of sound in air varies with temperature. The raw data was stored as 30-minute means, taken from measurements every sixty seconds. The ablatograph raw data had a significant 'noise' component generally, especially under snowfall events (Figure 1). The surface lowering (ablatograph) measurements were converted to melt water equivalents, using densities of 0.9 for ice, 0.41 for snow and 0.2 for fresh snow.

Both the meteorological and ablatograph raw data sets required extensive work to remove errors and for correction. Mainly these were due to missing values or displacement of the data occurring from power failures. However protocols of visits to the station throughout the season were inval-

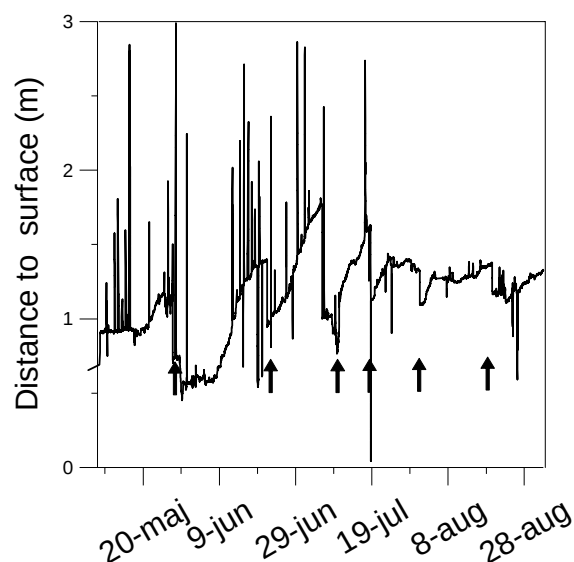


Figure 1. Ablatograph raw data. Arrows indicate an artificial mast lowering.

able in identifying the problem areas. Unrealistic values were removed from the ablatograph data and interpolated manually, including much of the 'noise' resulting from snow-fall events which required 'smoothing'.

Results

The daily averaged components of the energy balance are given in Figure 2. There is a negative energy balance throughout most of May. The low or even negative energy balances between the end of July and the end of August reflect the rather unusual weather conditions, characterised by frequent snow-fall events and cold temperatures,

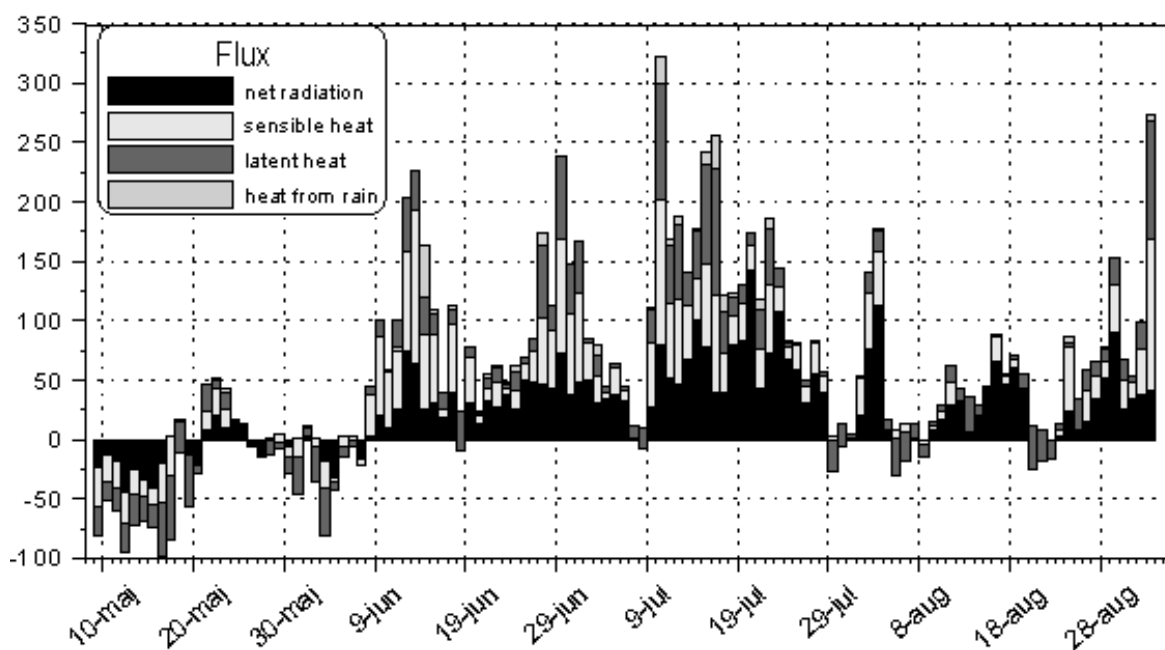


Figure 2. Daily surface energy balance (Wm^{-2}) components for Storglaciären 9 May – 2 Sept., 1999.

during this time. Over the entire study period in 1999 the total energy available for melt was -54 Wm^{-2} (Table 1). In a similar study on Storglaciären, the total energy available for melt amounted to -122 Wm^{-2} over a 40-day period, in 1994 (Hock and Holmgren, 1996). During the same period of time in 1999, the melt energy was less than half of that from 1994 (-54 Wm^{-2}). The main source of this is the decreased net radiation (due to the

unusual weather conditions mentioned above) received in 1999 (41 Wm^{-2} compared to 73 Wm^{-2} in 1994).

A high and a low energy 3-day period in July 1999 are compared to each other in Figures 3 and 4. The periods were selected not to include any negative fluxes. The mean meteorological conditions and energy balance components are listed in Table 2, indicating higher temperatures

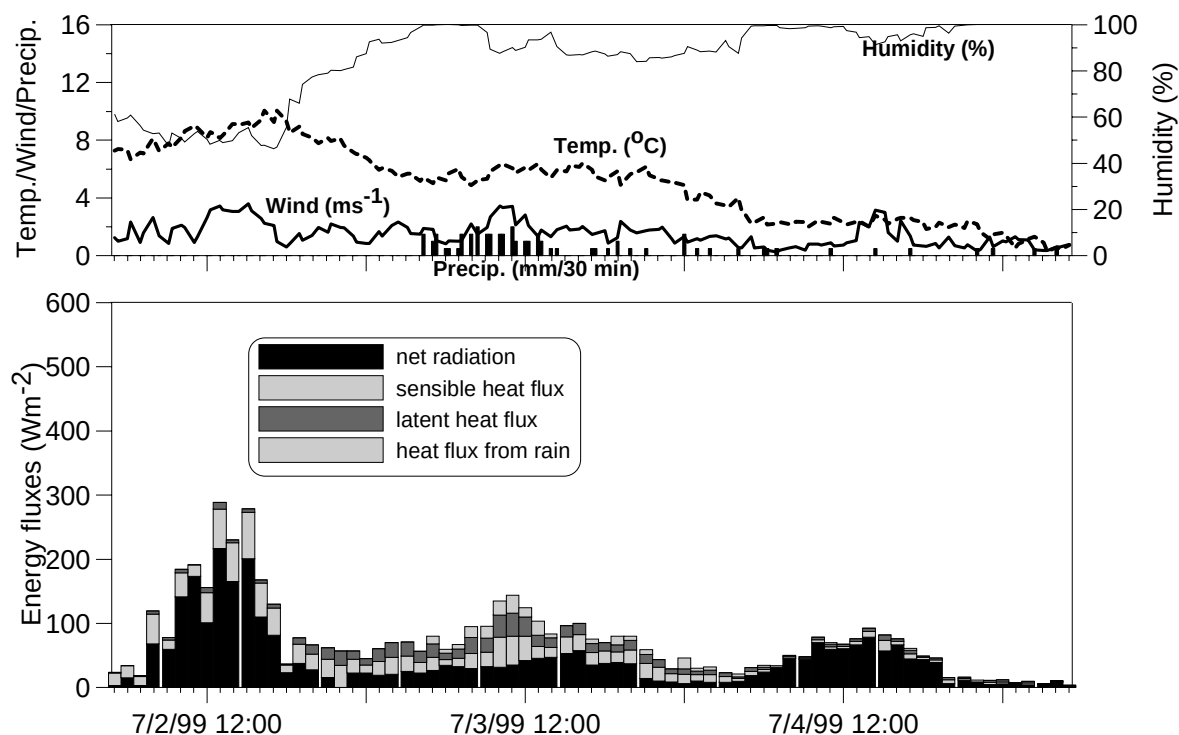


Figure 3. Half-hourly meteorological data and energy balance components for a 3-day period of low melt.

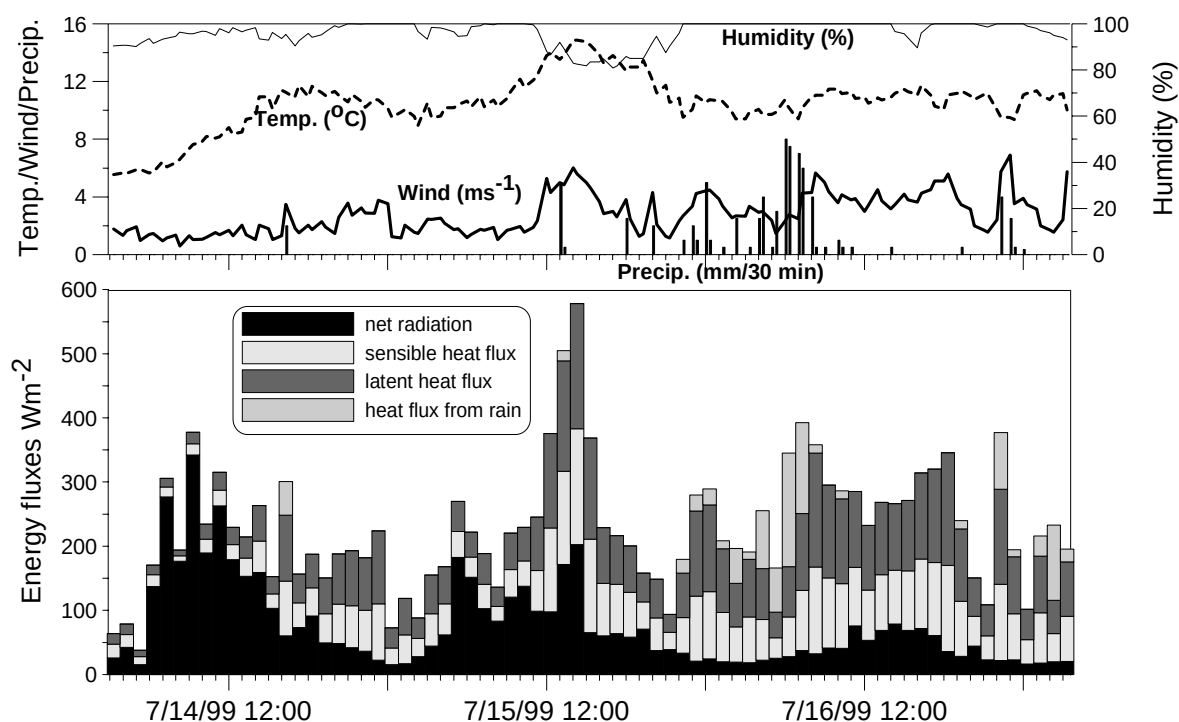


Figure 4. Half-hourly meteorological data and energy balance components for a 3-day period of high melt.

Table 1. Energy balance components for 1999 and comparison to results from Hock and Holmgren (1996).
“() ” refer to % of a source / sink of energy.

Balance Component	Symbol		Mean Flux (Wm^{-2}) 19/7-27/8 1994* (40 days)	Mean Flux (Wm^{-2}) 19/7-27/8 1999 (40 days)	Mean Flux (Wm^{-2}) 9/5-2/9 1999 (117 days)
Net radiation	Q_N	(source)	73 (66%)	41 (76%)	27 (56%)
Sensible heat flux	Q_H	(source)	33 (30%)	16 (30%)	21 (35%)
Latent heat flux	Q_L	(source/sink)	5 (5%)	-4 (-4%)	4 (6%)
Ice heat transfer	Q_G	(sink)	-3 (-3%)	-	-
Heat supplied by rainfall	Q_R	(source)	-	1 (2%)	2 (3%)
Total energy available for melt	Q_M	(sink)	-122 (-97%)	-54 (-93%)	-54 (-100%)

Table 2. Mean climate data and energy balance components from 3-day periods of high and low melt energy.
“() ” refer to % of a source / sink of energy.

	117-day entire study period (9 May- 2 Sept.)	3-day high energy period (14–16 July)	3-day low energy period (2–4 July)
<i>Climatic data</i>			
Air Temperature ($^{\circ}\text{C}$)	2.86	10.6	5.1
Wind Speed (ms^{-1})	3.35	2.8	7.3
Humidity (%)	82.7	96.3	84.9
Total Precipitation (mm)	1143	79.6	36.5
<i>Energy balance components</i>			
Q_N :Net radiation (Wm^{-2})	27 (56%)	75 (32%)	42 (58%)
Q_H :Sensible heat flux (Wm^{-2})	21 (35%)	64 (28%)	18 (25%)
Q_L :Latent heat flux (Wm^{-2})	4 (6%)	78 (34%)	9 (13%)
Q_G :Ice heat flux (Wm^{-2})	-	-	-
Q_R :Heat supplied by rainfall (Wm^{-2})	2 (3%)	15 (7%)	3 (4%)
Q_M :Total energy available for melt (Wm^{-2})	-54 (100%)	-232 (100%)	-70 (100%)
Total (WE) modelled melt (m)	1.64	0.33	0.034
Total (WE) measured melt (m)	2.17	0.28	0.002

and higher precipitation with lower wind speeds in the “high energy” period. During the high energy period net radiation accounts for 75% of the total energy available for melt, whilst in the low energy period it is just 42% (Table 2). During the period of high melt the turbulent heat fluxes are significantly more important for total melt energy than during the low energy period, when they can account for up to three quarters of the total melt energy in any one day. This indicates that high daily melt rates are caused by a combination of both, high net radiation and high turbulent energy fluxes.

Both high temporal resolution graphs (Figures 3 and 4) display a clear diurnal cycle within the energy available for melt, with the maximum occurring close to midday and the minimum soon after midnight.

Calculated (energy balance model) and measured (ablatograph) melt values per day can be seen in Figure 5. In general there is a good agreement between calculated and measured melt. However discrepancies occur later in the study period due to snow-fall events. The energy available for melt in total over the entire study period produced a

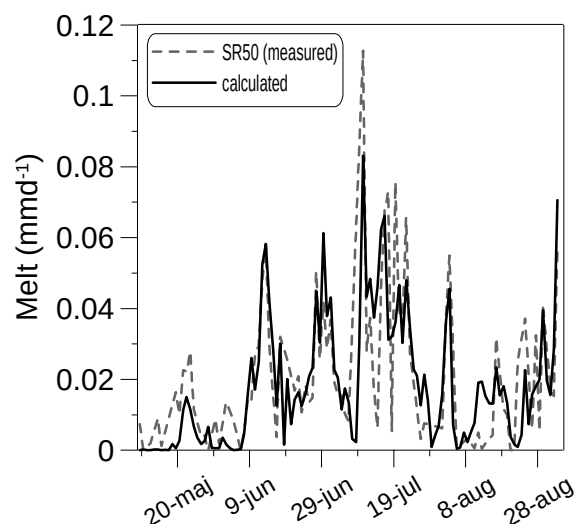


Figure 5. Calculated and measured daily melt, 9 May – 2 Sept., 1999.

total of 2.17 m melt, compared to 1.64 m obtained from the SR50 ablatograph (Figure 6).

Discussion

The complete composite energy balance (Figure 2) shows the effect that the snowfall events in July and August have in reducing the energy available for melt. On average there is a roughly equal contribution to the 'energy available for melt' by net radiation and the turbulent heat fluxes. The latent heat flux is mainly directed towards the surface providing energy for melt from condensation. Oc-

casionally, in periods when it is directed away from the surface, energy is consumed for evaporation.

A generally close agreement with calculated and measured melt in the early part of the study period indicates that the energy balance model is reliable under the typically cold and wet summer conditions encountered on Storglaciären. However late in the season there is an increasing discrepancy between the calculated and measured cumulative melt. There is a general over-estimation of melt by the energy balance model, when compared to the melt derived from the SR50 ablatograph (Figure 6). This is partly attributed to the fact that during July and August the ablatograph record became less representative of true melt. These periods coincide with frequent snow-fall events that cause two major problems. Firstly, energy is required to melt the new snow before the original surface can lower, which is not accounted for in the ablatograph curve (Figure 6). Secondly, inaccuracies arise as to the conversion of the ablatograph record to a water equivalent, as it is not always clear which density (snow or ice) should be applied at which time for the calculations. This is significant due to the large difference in density between ice and new snow. The actual density of the new snow is also unknown. An empirical density formula for the compaction of snow by gravity until the next snow-fall event needs to be developed and employed. Additionally snow can be wind-blown to and from

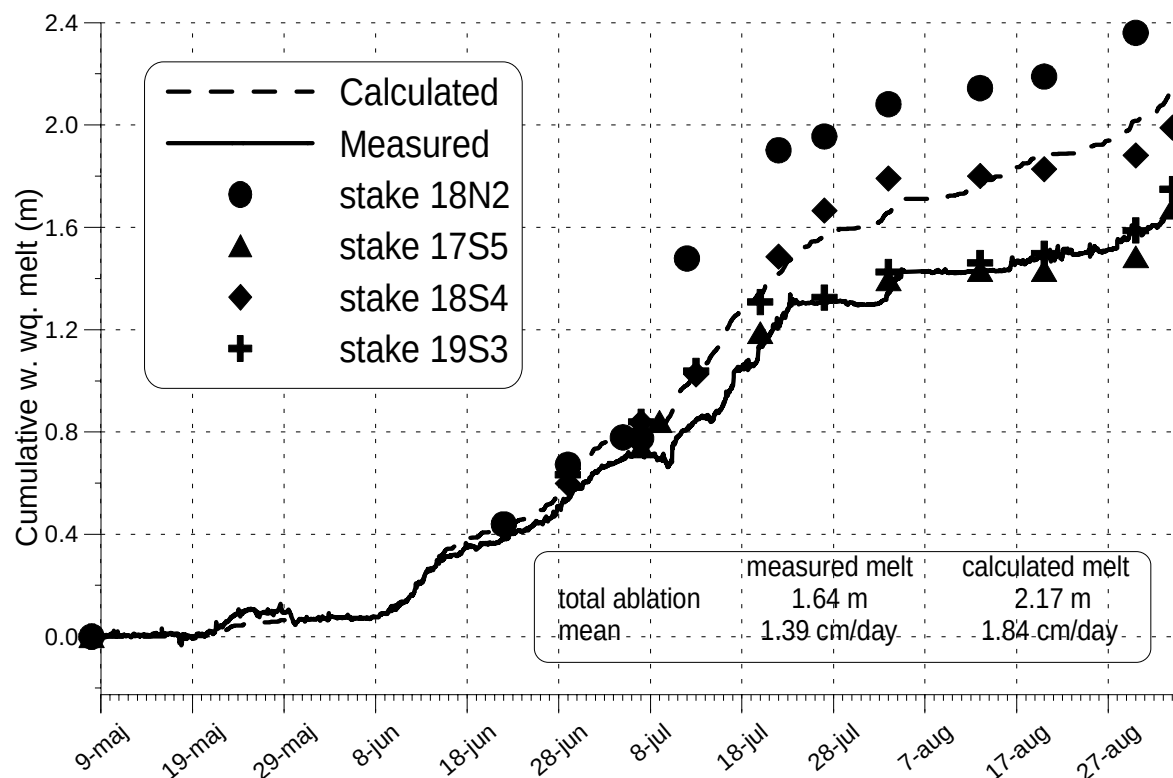


Figure 6. Measured and calculated cumulative melt.

an ice surface creating additional problems. Thus the measured 'surface lowering' does not accurately represent the water volume equivalent of melt. On a short-term (daily) time scale uncertainties also arise due to changes in ice density of the upper 'weathering crust', but over a period of time these errors will cancel out.

The over-estimation of melt by the energy balance calculations, may also be due to an over-estimation of the turbulent fluxes. This arises from the inability to accurately apply roughness lengths and stability functions that constantly change (depending on the duration of melt and ambient air conditions respectively) throughout the study period. Generally, it is clear that the assumptions of a homogenous, infinite and flat terrain and of a constant flux with height, do not hold on a glacier surface.

Generally there is a good correlation of 0.76 between calculated and measured melt (Figure 7) although the scatter is significant. Nevertheless, Fig. 8 clearly indicates the degree to which the model performs badly under precipitation. Up until mid-July the errors tend to cancel out over a period of a week or so, but once snow fall events interfere, there appears to be either a general over-estimation of melt by the energy balance model, or an under-measurement by the ablatograph. The errors between measured and calculated melt can be as great as +29% and –40%. In general there are clearly both systematic and random errors acting in both the energy balance calculations and the ablatograph measurements.

Conclusions

The glacier-atmosphere interactions are complex. The atmosphere acts upon the glacier surface supplying energy for melt, whilst the atmospheric conditions are modified by the presence of snow and ice, due to the specific properties of snow and ice and their high temporal variability.

Concerning the various component heat fluxes, over the entire 1999 study period, there is a roughly equal contribution to 'energy available for melt' by net radiation and the turbulent heat fluxes. On average, the latent heat flux is mainly directed towards the surface providing energy for melt from condensation. With a comparison to the 1994 study (over the same period) it is notable that the latent heat flux component is very similar in 1994 (5%) and 1999 (6%). On the other hand, the sensible heat flux is more important in 1999 (35%) than in 1994 (30%) due to the generally more cloudy and rainy conditions experienced in 1999.

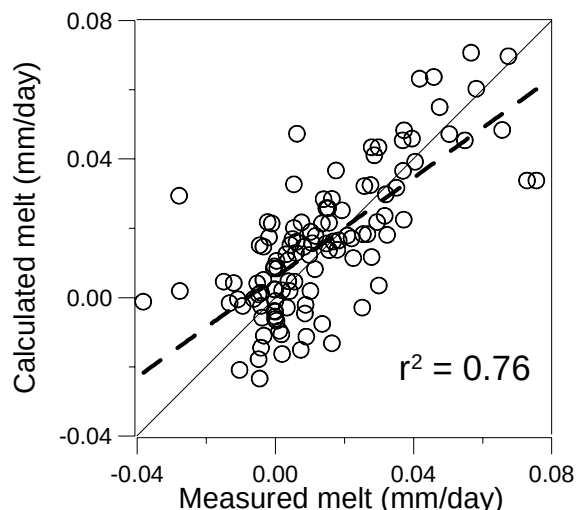


Figure 7. Calculated versus measured daily melt.

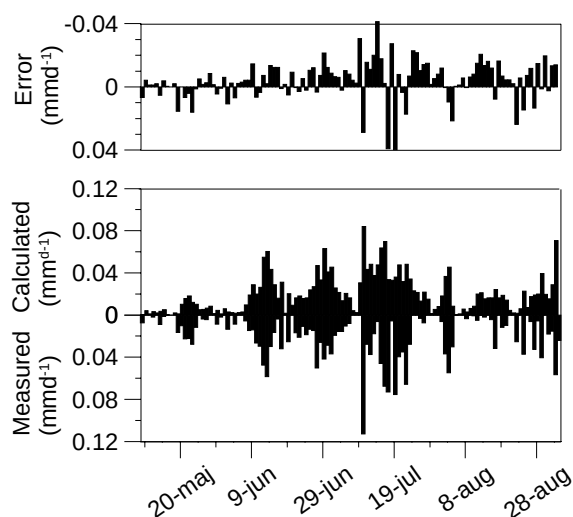


Figure 8. Daily error defined as calculated - measured melt.

The energy available for melt compared to measured melt shows generally good agreement early in the study period. Later the discrepancy can be accounted for by unusual new snow events in July and August that 'consume' melt energy. This is not accounted for in the 'ablatograph' record and thus leads to an over-estimation of calculated melt compared to measured melt.

References

- R. Hock, J. L. Carrivick and U. Jonsell, 2000: Glaciometeorological studies on Storglaciären, 1999. In: Klingbjer, P. (ed.): *Tarfala Research Station Annual Report, 1998-1999*. Department of Physical Geography, Stockholm University, Research Report 111: 18-21.
- R. Hock and B. Holmgren, 1996: Some Aspects of Energy Balance and Ablation on Storglaciären, northern Sweden. *Geografiska Annaler*. 78 A (2-3): 121-131.

Digital elevation model covering the Tarfala valley and its surroundings

Margareta Johansson¹, Johan Ekroth² and Maria Johansson²

¹*Department of Physical Geography, Lund University, SE-22362 Lund, Sweden*

²*Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden*

Introduction

The Tarfala valley has been a center for glaciological research for many years thus a digital elevation model (DEM) for the area has now been developed to facilitate future studies in the area. The DEM has been derived from three different parts. Two types of data have been used as input when deriving the DEM; a map and IR-aerial photos (Table 1).

The western part of the digital elevation model is based on the map; “Högfjällskartan Kebnekaise” (1:20 000), which covers the Tarfala valley, the Kebnekaise massif, Kuopervagge and parts of Ladtjovagge. The eastern part of the DEM is composed out of two DEM's both based on IR-aerial photos (1:60 000), taken on the 29th of July in 1980, covering the Tjeuralako plateau. The whole DEM is available in the Swedish National reference system RT 90 2.5gon V with a resolution

of 15 m. The western part of the DEM, the part derived from the map is also available in the Swedish National reference system RT 90 0gon since most of the GPS-measurements of the glaciers in the Tarfala valley are made using this reference system.

Generating a DEM from aerial photos

The aerial photos were scanned using an AGFA Scanner “Horizon Plus” at 800 dots per inch (dpi). Erdas Imagine, Orthomax 8.3 was used to derive the DEM from the scanned aerial photographs. In Orthomax the photographic details are used to construct the DEM and since orthophotos are the basis the geometric errors like relief displacement are avoided. The interior orientation of the images was calculated on the basis of the minutes of the camera. The fiducial marks in the four corners in both of the scanned photos were used to determine

Table 1. Specification of the input data of the constituting part of the derived DEM

	Western part	North Eastern part	South Eastern part
Input data	Map högfjällskartan, Kebnekaise	IR-aerial photos 296678: 15 and 16	IR-aerial photos 296678: 15 and 16
Scale	1:20000	1:60000	1:60000
Coverage*			
ULC	1608000/ 7542000	1618268/ 7542098	1619250/ 7542098
LRC	1619000/ 7532000	1626668/ 7537436	1626150/ 7530203
Resolution	15 m	15 m	7.5 m

*RT90, 2.5 gon V.

the interior orientation of the images. In the north-eastern part the RMS- error for the right image was 0.1 pixels (19 cm) and for the adjacent, left image the RMS-error was 0.4 pixels (76 cm). For the right image in the southeastern part the RMS-error was 0.1 pixels (19 cm) and for the left it was 0.7 pixels (133 cm).

The external orientation was determined from known points, i.e. six Ground Control Points (GCP's), three in each of the two images. The RMS-error that was introduced by identifying the counter point of the GCP's is estimated to 0.5 m.

The digital elevation model was generated using band 2, corresponding to the red wavelength in the IR-aerial photographs. Only 31% of the generated elevation data was interpolated, which is a good result since the calculations of the DEM was made over an area exceeding the area with stereo coverage. In some of the interpolated regions the interpolated z-values, did not correspond to the values in the map, due to low contrast in the aerial photos. The software cannot calculate the height parallax under these circumstances and thus it has to interpolate the elevation values. Areas in shadow usually suffer from this. In these areas the interpolated elevation data was edited manually according to the map. The RMS-error in z-axis was approximately 4.5 meter for both part derived from the IR-aerial photos.

The southern part of the DEM (Table 1) had an original resolution of 7.5 m thus it had to be generalized to a resolution of 15 m to be compatible with the northern part of the DEM. This generalization was made in IDRISI by reducing the number of rows and columns while simultaneously decreasing the pixel resolution. In this case four pixels constitute one new pixel and the average z-value of the four pixels constituted the new z-value, with a pixel resolution of 15 m.

Generating a DEM from a paper map

The map used was "Högfjällskartan, Kebnekaise", 1:20 000. Every tenth and, on the glaciers every fifth m contour line is represented in the map. Every 20 m contour line was digitized using ARCINFO, PCARC 3.5.1. ArcShellW. The RMS-error, which describe the accuracy of the tic registration, in x and y-direction was ranging from 0.006-0.008. The reference system used when digitizing was RT 90 Ogon (Jansson and Pettersson, 1997). Since the two parts of the DEM derived from the aerial photos were calculated in RT 90 2.5gon V and the western part, derived from the map was calculated in RT

90 Ogon a transformation of the digitized vector file was needed. This was done using the software SWETRANS, since this program could support ArcInfo format.

In order to generate a DEM out of the contour lines the area in between the lines needed to be interpolated. There are many problems connected with interpolation of digitized contour lines when converting the vector data into raster format. When estimating an unknown z-value for a location in a grid it involves finding a certain number of data points within a given search radius and then computing a weighted average. If all data points have the same z-value, this will generate narrow zones bordering each contour line and result in terraces in the output DEM (Burrough and McDonnell 1998). The terrace formation is a consequence of the unevenly distributed point data; many points along the line and few in between (Eklundh 2000). The errors become larger in areas with low relief, since the contour lines are further apart and there is a risk that the search algorithm only catches data from one contour line (Burrough and McDonnell, 1998). The error can be diminished by reducing the amount of data points along the contours, using for example Douglas-Peucker algorithm (Eklundh 2000). The classical Douglas-Peucker simplification algorithm selects a subset of polyline vertices and, from this subset of vertices it builds a new simplified polyline, which lies within a predefined distance of the original polyline (Figure 1) (Douglas and Peucker 1973). However by reducing the points, valuable information concerning the terrain might be lost (Eklundh, 2000).

Since the area of interest has high relief a large amount of important information would be lost if a simplification algorithm according to above was applied. A more accurate solution is therefore to use an interpolation method that is designed to deal with the kind of data yielded when digitizing contours (Burrough and McDonnell, 1998). Such an interpolation method suitable for contour line

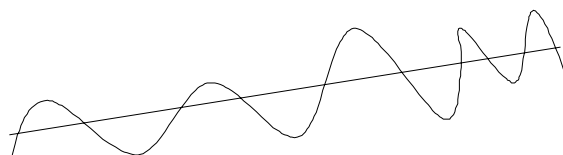


Figure 1. The simplification algorithm may locate a point on the wrong side of the contour line. (modified from Douglas and Peucker 1973)

data is GRDINT in PCI, which is used here. This algorithm interpolates the unknown values between the encoded contour lines and, calculates the grey-level value for each unknown pixel, based on the known vector data (Carrara, 1988). The input vector data used are the contour lines and the mountain peaks. The interpolation method used has three optional search algorithms:

- * Diagonal search, produces many artifacts
- * Smoothed diagonal search, fewer artifacts
- * Conic search, fewest artifacts.

When rasterizing the contour lines and the mountain peaks we used the conic search that searches along 22.5 degrees cones and the MDIP (Morphology Dependent Interpolation Procedure) since this search algorithm produced the best result (Carrara, 1988). Along the edges in the DEM derived from the map there are missing values due to a lack of input data in this regions.

Finalizing the DEM by putting all the constituting parts together

Finally all three digital elevation models were pasted together starting with the two parts derived from the aerial photos (Figure 2, Table 2 and 3). However when these two terrain models were derived they did not cover the exact same area along the x-axis and thus the x co-ordinates for the columns in one image did not match the x co-ordinates for the columns in the other image. Since the difference in x co-ordinates between the columns in the two DEM's was small the x-axis in the northeastern DEM was shifted two meters in the eastern direction. Since the resolution of the DEM is 15 m this has only minor effects on the elevation model. When the two elevation models had the same x-co-ordinates they were pasted together in a new raster-file. The same procedure was repeated when the third part, derived from the map was pasted together with the two parts derived from the aerial photos.

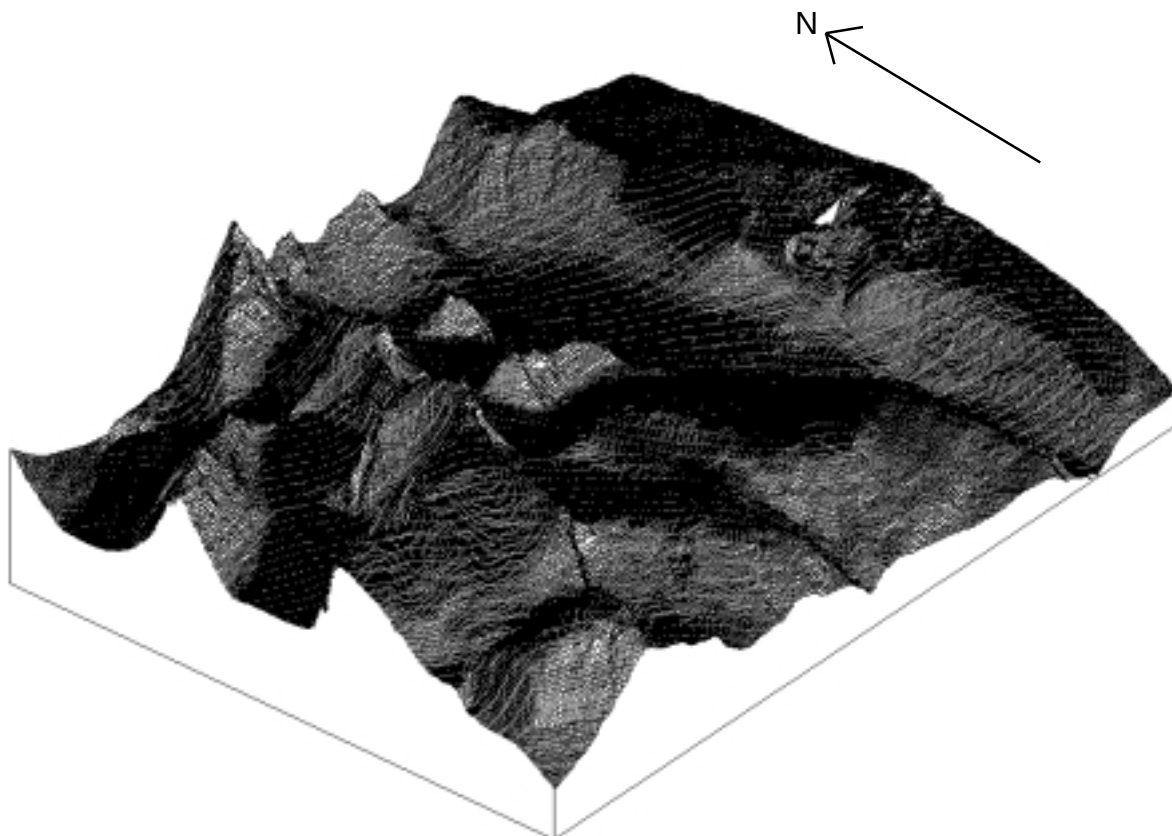


Figure 2. The central part of the digital elevation model

Table 2. Documentation of the DEM in RT 90 2.5 gon V.

DEM RT 90 2.5 gon V	
No. of columns	1206
No. of rows	748
Ref. system	Plane
Ref. unit	Meter
Min x-value	1608105
Max x-value	1626180
Min y-value	7530870
Max y-value	7542105
Min z-value	493 m
Max z-value	2114 m
Resolution	15 m
Missing value	-9999

Table 3. Documentation of the DEM in RT 90 0 gon.

DEM RT 90 0 gon	
No. of columns	841
No. of rows	724
Ref. system	Plane
Ref. unit	Meter
Min x-value	13785
Max x-value	26400
Min y-value	7528550
Max y-value	7539410
Min z-value	578m
Max z-value	2114 m
Resolution	15 m
Missing value	-9999

References

- Burrough, P. A and McDonnell, R. A., 1998: *Principles of Geographical Information systems*. Oxford University Press, New York. 333 pp.
- Carrara, A., 1988: *Drainage and divide networks derived from high-fidelity digital terrain models*. Proceedings of the NATO advanced study institute on statistical treatments for estimation of mineral and energy resources, II Ciocco (Lucca) Italy, June 22-July 4, 1986. D. Reidel Publishing Company, Dordrecht, Holland. 581- 597.
- Douglas, D. and Peucker, T., 1973: Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *The Canadian Cartographer* **10**, 112-122.
- Eklundh, L., 2000: *Geografisk informationsbehandling metoder och tillämpningar*. Centraltryckeriet, Borås. 175- 192.
- Jansson, P. and Pettersson, R., 1997: Fixed points and co-ordinate systems in the Tarfala valley. In: Klingbjer, P. (Ed.) *Tarfala Research Station Annual report 1995-96*. Research report 104. ISSN 0346-7406. Department of Physical geography, Stockholm University. 26-29.

Temporal and spatial variations in albedo on Storglaciären

Ulf Jonsell

Department of Earth Sciences, Uppsala University, Villav. 16, SE-752 36 Uppsala, Sweden

Abstract

Albedo is a key parameter controlling melt rates on glaciers. During the melt season 1999 extensive albedo measurements were carried out on Storglaciären to investigate both the temporal and the spatial distribution in albedo. Albedo varied from 0.06–0.95. A pronounced diurnal variation was found to be due to horizontal mounting of the albedometer. Considerable variations in albedo on even shorter temporal scale were due to changes in the diffuse variation of global radiation. Albedo altered as much as up to 19% due to these two factors, which stresses the importance to consider these effects when using albedo data in various models.

Introduction

Albedo is a key parameter controlling melt on glaciers and is a crucial factor to consider in studies on climate response. Small-scale studies on well-instrumented sites can help to understand the underlying mechanisms, which can be applied in large-scale modelling. Thus, a detailed knowledge of the factors controlling spatial and temporal distribution of albedo is essential.

This study assesses the variations of albedo on Storglaciären with data from the ablation season 1999, with the prior aim to act as a basis for improving albedo parameterisations in distributed glacier melt. In most models ice albedo has, because of its complexity been treated as a fixed value both spatial and temporal. Snow albedo has often been treated more in detail. This study is a multi-factor analysis of controls to albedo variations. Special attention is given to diurnal and even more short-term temporal variations, to assess albedo variations not related to the changes in surface properties.

Methods

During the melt season 1999 extensive fieldwork was conducted on Storglaciären in order to collect albedo data from the glacier. These were collected in three different ways (Figure 1): (1) At 17 selected sites, with different surface characteristics, spread over the ablation area several times during the season (18 July - 2 September). (2) Along a longi-

tudinal profile conducted on two different days. (3) At an automatic weather station (AWS), placed near the equilibrium line, recording data on air temperature, wind speed, precipitation, long and short wave radiation. Half-hourly averages were stored from readings every minute from 7 May to 2 September.

The purpose of the stake measurements was to show the spatial distribution of albedo at a certain time, and the temporal change between successive measurements. The AWS record shows temporal albedo changes for the specific site with high temporal resolution.

Results and conclusions

Albedo in the data sets varied considerably, from 0.06 to 0.95 (Figure 2). Snowfall contributed to the most pronounced changes. Sediment rich ice showed a long term decreasing trend over the season, which was not found on clean ice. Albedo for clean ice was significantly higher (0.40–0.60) then reported in other studies (see Cutler and Munro, 1996; Paterson, 1994). In general, the longitudinal albedo profiles showed an increase in albedo with altitude, with rather similar gradients. This holds, even though they were conducted at different surface conditions, one with a fresh snow cover and the other with melting ice in the ablation area. However, certain areas clearly deviated from the general trend. This was due to an area with superimposed ice close to the equilibrium line

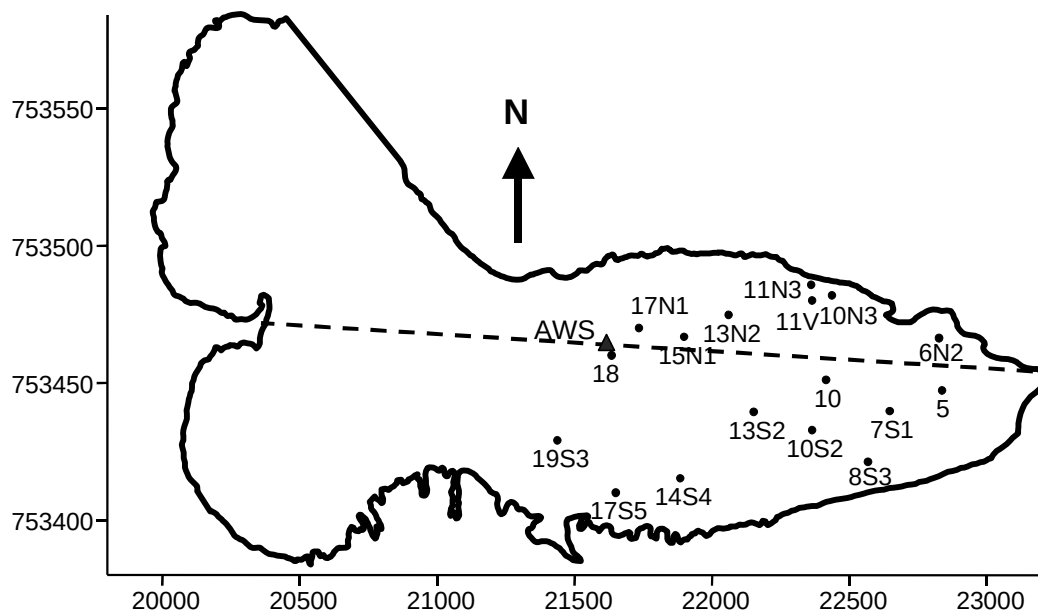


Figure 1. Location of measurement sites and the AWS. The dotted line indicates the longitudinal profile. Grid is in Swedish RT90 co-ordinate system in meters. Labels refer to the notation of ablation stakes.

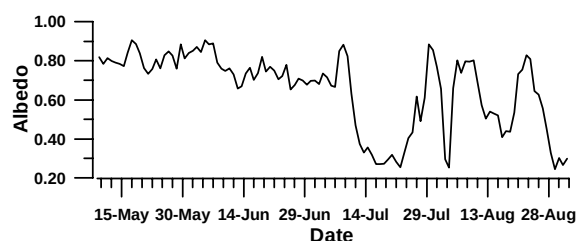


Figure 2. Daily mean albedo from the AWS record.

lowering albedo considerably as well as an area with very white clean ice in the middle of the ablation area, increasing albedo.

Albedo varied significantly on short time scales. A pronounced diurnal variation in albedo (up to 0.2) was partly due to the presence of melt water, but could mainly be explained as a pseudo-variation caused by the horizontal mounting of the pyrano-meters, although the surface underneath sloped roughly only 3° . The continuously decreasing albedo trend on clear-sky days disappeared after correcting the measurements for effects of slope (Figure 3). The correction method is presented in Jonsell, 2000. These large variations of albedo, not due to changes in the glacier surface, show that the slope factor is important even on gentle slopes and that albedo measurements must be conducted either with the instrument mounted parallel to the surface or horizontal required that the data will be corrected.

Because of shifts between clear and overcast sky, albedo changed up to 0.12 within one hour due to

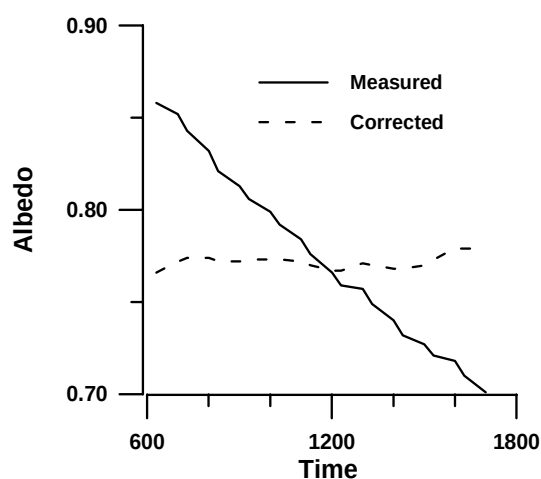


Figure 3. Measured and corrected albedo on 15 May at the AWS site.

variations in the diffuse proportion of global radiation. Surfaces with similar may deviate more than 15 % due to this factor making models based on data not considering this effect unreliable.

References

- Cutler, P. M. and Munro, D. S. 1996: Visible near infrared reflectivity during the ablation period on Peyto Glacier, Alberta, Canada. *Journal of Glaciology*, Vol. 42 No. 141. 333-340.
- Jonsell, U.Y. 2000: *Temporal and Spatial Variations in albedo on a valley glacier*. Master of science thesis. Department of Earth Sciences, Physical Geography. Uppsala University, Sweden.
- Paterson, W.S.B. 1994: *Physics of glaciers*. Pergamon Press. Ed. 3. 59-60.

Climate conditions required for re-glaciation of cirques in Rassepautasjtjåkka massif, northern Sweden

margareta Johansson¹ and regine Hock²

¹*Department of Physical Geography, Lund University, SE-223 62 Lund, Sweden*

²*Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden*

Introduction

Since the mid 1970s the general retreating trend for glaciers in Scandinavia has ceased and some glaciers have even started to advance. This is due to a more maritime influence on the climate, in particular an increase in winter precipitation and lower summer temperatures. A more maritime climate can be said to be favourable for glacier growth. Under such climate conditions, is it possible that new glaciers are forming?

This project is a continuation of a project that started in 1992 by Jonsson and Jansson (1993). The aim was to study the local climate in empty cirques to contribute to an understanding of their origin. This study aims to assess the climate conditions that are needed to initiate glaciers in empty cirques in the Rassepautasjtjåkka massif, northern Sweden, using a modelling approach. The study area is of

interest since the cirques are assumed to be located just below the glaciation limit. Since there are no moraines or other signs of glaciation in the area it is still uncertain when the cirques were formed.

Site description

Rassepautasjtjåkka (68°05' N, 18°50' E) is a small mountain massif located in the northern-most part of Sweden, approximately 25 km NE of the Kebnekaise massif and the Tarfala research station (Figure 1). The area covers roughly 40 km² and the elevation in the area ranges from 1080 to 1728 m a.s.l. The glaciation limit in the area is inferred to be at 1820 m a. s. l. (Østrem, 1964). In this area there are four well-developed cirques and some less developed ones. The distinct cirques are approximately 1 km wide. Two cirques are facing towards the southeast and one towards the northeast and the fourth is facing towards the southwest.

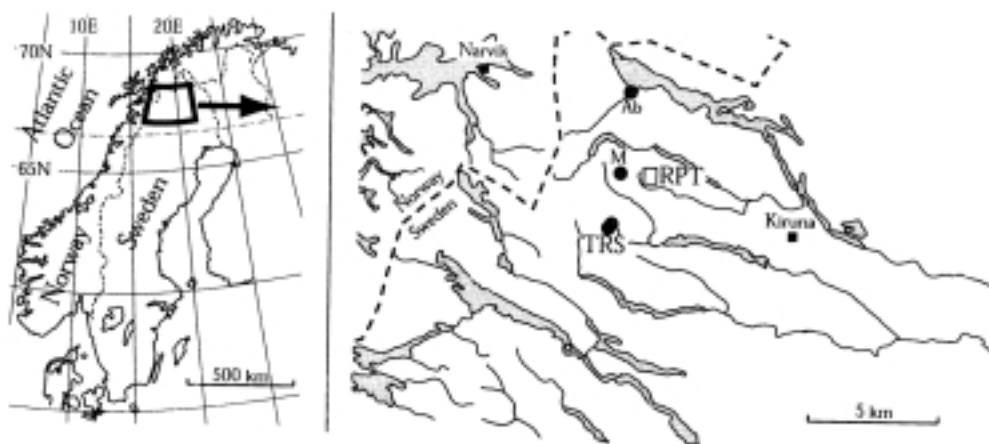


Figure 1. The location of the Rassepautasjtjåkka (RPT), Tarfala Research Station (TRS), the Mårmagläciären (M), and Abisko (Ab) (Jansson et al., 1999).

Model description

Progressive melt and the recession of the snow line during three melt seasons (1993, 1995 and 1999) were computed using a grid-based temperature index model (Hock, 1999). The calculations were done with a three-hourly time resolution and based on a 50 m resolution grid. Unlike ordinary degree-day models the model used in this study takes into account the topographic effects on melt by including potential direct solar radiation at the surface.

The model was initialised with maps of snow water equivalent derived from snow cover measurements in spring. The modelling procedure involved two steps: (1) Calibration of the model to current climate conditions (2) Variation of the winter precipitation, the measured air temperature record or both to quantitatively assess the conditions required for winter snow to survive the summer and thus to initiate a glacier.

The equation used to calculate the potential clear-sky direct solar radiation (I) is expressed as:

$$I = I_0 \left(\frac{R_m}{R} \right)^2 \psi \left(\frac{p}{p_0 \cos Z} \right) \cos Z$$

where I_0 is the solar constant (1368 W/m²) and $(R_m/R)^2$ is the eccentricity correction factor of the Earth orbit for the time considered with R the immediate and R_m the mean distance between the sun and Earth. ψ_a is the mean atmospheric clear-sky transmissivity, p the atmospheric pressure and p_0 the mean atmospheric pressure at sea level. Z is the local zenith angle (the angle between the solar beams and the normal) and $\cos \Phi$ is the angle of incidence based on the slope angle, zenith angle, solar azimuth and slope azimuth angle.

The calculated potential solar radiation is incorporated into the temperature index model that calculates the ablation (M):

$$M = \begin{cases} \frac{1}{n} MF + a_{\text{snow/ice}} I & T < 0 \\ 0 & T \leq 0 \end{cases}$$

where MF is the melt factor (mm h⁻¹ °C⁻¹), $a_{\text{snow/ice}}$ is the radiation coefficient different for snow and ice and I is the potential direct solar radiation at the ice or snow surface (Wm⁻²), T is the air temperature (°C) and n is the time steps in hours (here 3). The melt factor and the radiation factors for snow and ice are empirical coefficients. The radiation coefficient for ice exceeds the one for snow due to lower ice albedo. The melt during the summer was calculated and the snow that remained at the end of the melt season was what could constitute the ground to a new glacier.

Input data and calibration

The model requires air temperature, a digital elevation model (DEM) and derived digital terrain information as input data. Air temperature was taken from an automatic weather station located in one of the cirques recording three hourly values. The temperature index model needs to be calibrated for every new area in which it is applied since the factors that influence the melt may vary from one site to another. The parameters to be optimised are the melt factor MF , the radiation factor for snow a_{snow} and for ice a_{ice} . Only the two first parameters are of relevance in this study, as there are no glaciers in the area.

The model has been tested and calibrated on Storglaciären by Hock (1999). In that case the modelled ablation was compared to the measured ablation derived from ablation stakes and simulated glacial runoff compared to measured runoff. In the Rassepautasjtjåkka massif there are no observation or measurements of snow cover depletion. This is a disadvantage when calibrating the model, as there are no independent validation data available. Therefore, the model was calibrated by making certain assumptions based on comparisons between the snow line retreat in the Tarfala valley and Rassepautasjtjåkka and also between the mass balance record of Måmaglaciären and Rassepautasjtjåkka.

Result and discussion

Under present climate conditions all winter snow melts away by the end of the melt season. Some snow remains in the cirques only in certain years of high winter accumulation. In the model two climate variables can be changed to determine the climate conditions required to re-glaciate the cirques in the Rassepautasjtjåkka massif. These are winter precipitation (changing the amount of snow at the beginning of the melt season) and air temperature.

The summer mean temperature needs to be lowered between -2 °C and -3 °C from the current climate before snow will remain after a melt season. An increase in the initial snow cover of today by 100-150% (under otherwise equal conditions) will have the same effect. When increasing the initial snow cover with 50% and lower the summer mean temperature by 2 °C and also when increasing the initial snow cover by 100% and lowering the temperature by 1 °C, snow will be left in all four cirques after a melt season (Figure 2).

The climate conditions that are required for glaciation have not been met during the Holocene,

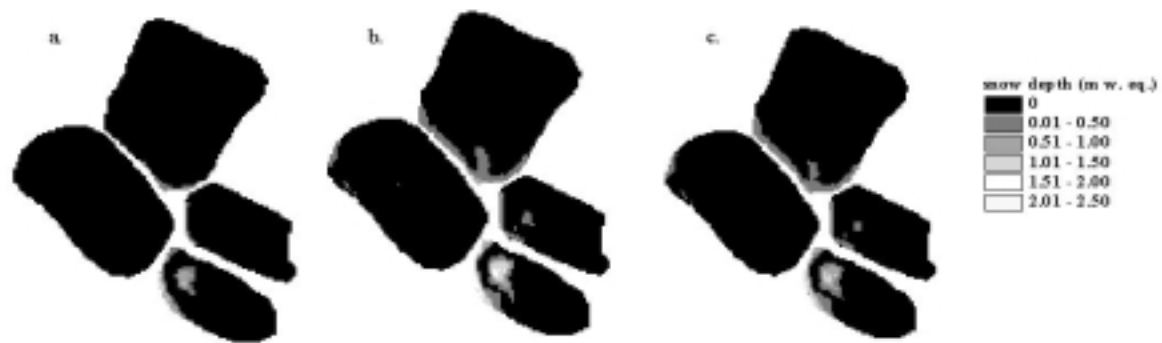


Figure 2. Remaining snow after a melt season in the four cirques: when decreasing the temperature by 1°C and increasing initial snow cover 50% (a), decreased temperature by 1 °C and increased snow cover by 100% (b), decreased temperature by 2°C and increased snow cover by 50% (c).

as evaluated from proxy-data derived from glacier advances, macrofossil and pollen analyses in northern Sweden. Since the optimal climate conditions for glaciation are not likely to have occurred during Holocene, the origin of the cirques in the Rassepautasjtjåkka massif can be concluded to extend further back in time than the Holocene. Even though the climate in Scandinavia can be said to have been favourable for glacier growth since the end of the 1980s, the climate scenarios that are predicted in the future by regional climate models make the likelihood of initiating a glacier in the near future unrealistic.

References

- Hock, R., 1999: A distributed temperature-index ice- and snow melt model including potential direct solar radiation. *Journal of Glaciology* 45, 101-111. 140 pp.
- Jansson, P., Richardsson, C. and Jonsson, S., 1999: Assessment of requirements for cirque formation in northern Sweden. *Annals of Glaciology* 28, 16-22.
- Jonsson, S. and Jansson, P., 1993: Studies of local climate in empty glacier cirques located just below the glaciation limit. *Forskningsrapport 96*. Bodin, A. Ed. Department of Physical Geography, University of Stockholm, 37-39.
- Østrem, G., 1964: Ice-cored moraines in Scandinavia. *Geografiska Annaler* 46, 282-337.

Abstracts from the Tarfala student course papers 1999

Abstracts compiled and edited by Jens-Ove Näslund

Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

Field courses in glaciology has been given at Tarfala research station since the late 1950's. Today about 10-15 undergraduate students are educated in glaciology and related subjects such as glacial geology, hydrology, periglacial morphology, and ice sheet modelling. The course is divided into a field period and a period for reading and writing. The field period includes lectures, excursions and a field project. Each year the individual reports of the various field projects are compiled in a final report. In 1999 there were 11 students participating in the course, which was lead by Per Holmlund, Jens-Ove Näslund, and Richard Pettersson. The abstracts of the 1999 field projects are found below.

Dye trace experiments for studies of the development of the subglacial drainage, Storglaciären, Sweden

Tomas Ahlberg

The subglacial drainage system below the ablation area of Storglaciären, northern Sweden, is assumed to change its geometry and capacity during the ablation season. Former studies inferred that the system changes from a braided system with many small channels to a system with a few larger more or less straight channels. This report aims at determining the extent of this development between august 1 and august 3 1999. Tracers were injected into moulins in the lower ablation area. Measurements of the response after the en- and subglacial transport of the tracer were undertaken in the two proglacial streams of Sydjåkk and Nordjåkk. However, the results of the tracer experiments are difficult to interpret, but it seems probable that the drainage system consists of a braided channel system with large sediment contact areas.

Ice velocity measurements on Storglaciären

Jonas Andersson & Annika Lundmark

The ice velocity in the ablation area of Storglaciären has increased since the mid 1980's. The increase is due to an increase in accumulation during the last decade, which has lead to a thickening of the glacier.

Detailed measurements of ice velocity were made over the entire glacier. The results showed that both the horizontal velocity and the emergence velocity were highest in an area close to the bedrock riegel. The ice movement was greater from the northern accumulation area than from the southern one, showing that the main ice flow comes from the northern cirque. Another important result of the study are improved co-ordinates for the fixed point A-96 (Norra morän). The new RT90 (0 gon) co-ordinates for A-96 are: 22586.906 E, 7534863.627 N, and the altitude is 1326.016 m a.s.l.

Comparison of measured ablation and energy balance calculations on Storglaciären, northern Sweden

Alexandra Björk & Jodi Di Mena

Measurements of glacier ablation are of interest for research on mass balance and global climate change. The melt-off from glaciers is also important for practical reasons such as hydroelectricity and water supplies. This report attempts to test the reliability of energy balance calculations based on climate data versus ablation measurements made on a stake network on Storglaciären, northern Sweden. An analysis of the spatial variations of ablation over the glacier surface is also made. The comparison between measured and calculated ablation was difficult due to short and irregular

measuring periods. It is shown that the spatial melt pattern can be determined only over an extended measuring period. Observed variations in melting from one stake to the adjacent stake illustrate that measurements of ablation at a single point provides inaccurate estimates of the ablation for larger regions of the glacier surface.

Radio-echo sounding of Norra Kaskasapakteglaciären

Elisabeth Däcker & Rickard Exner

A series of radio-echo sounding profiles were obtained over Norra Kaskasapakteglaciären, Kebnekaise, northern Sweden. The purpose of the study was to map the bed topography of the glacier and correlate the results to the geology of the massif. The results show that the glacier is a valley glacier with a glacially eroded bed. No over-deepening was found in the bed topography. The bedrock is eroded to a smooth valley with nearly vertical cirque walls. The bedrock in the areas was identified as amphibolite and dolerite, which can be assigned to the Kebne dyke complex.

Energy balance and meteorological parameters from a climate station on Storglaciären, Kebnekaise

Anna Grönlund

A study of the energy balance of Storglaciären and the variations of different meteorological parameters from a climate station was made during June–August 1999. Calculations of the melt-off from Storglaciären could be correlated with meteorological factors such as global radiation, reflected short wave radiation and air temperature above the glacier surface. The net radiation and the sensible heat flux had the greatest impact on the melting, contributing with c. 80% of the energy available for melt. A better knowledge on this matter would be of great importance for other climate studies. On a local scale water power plants

could use the information to better control the water level in dams by better knowing the expected amount of glacier melt-off.

The longitudinal profile of Storglaciären - present mass distribution and trend

Kristoffer Gunnarts & Sofia Åberg

As result of a temporal increase in precipitation an extensive mass surplus was registered at Storglaciären between 1989–1995. The mass increase has not yet lead to an advancement of the front, which has been the case for several smaller glaciers in the region. By measuring the ice surface elevation along three profiles at Storglaciären and comparing the results with previous profiles the present study aims at: 1) describe the present mass distribution of the 1989–1995 mass surplus, and 2) estimating the possibility for the mass surplus to cause a front advancement. Available profile data since 1996 seem to suggest that an advancement of the front now is unlikely to happen as a result of the 1989–1995 mass surplus.

Polygons and Rayleigh convection-movements within a tundra polygon in Tarfala valley, Kebnekaise

Lisa Öberg

The main issue for this geomorphological survey, which was initiated in 1984 and continued in 1993, was to study the movements within a polygon located in an area with discontinuous permafrost, and relate the results to a suggested genetic convection model. The Rayleigh convection model for patterned ground regularity was proved to be adequate for a specific polygon in the periglacial area of the Tarfala valley, Kebnekaise, Sweden. The convection model, with several convection cells, results in an uneven melting of the underlying ice front during thaw, with regularly spaced surface heights and troughs as result.

Literature concerning the Tarfala valley and its close surroundings

Revised version, January 10, 2000

New papers 1999

- Braithwaite, R. J. and Zhang, Y., 1999. Modelling changes in glacier mass balance that may occur as a result of climate changes. *Geografiska Annaler*. 81A (4): 489-496.
- Braithwaite, R. J. and Zhang, Y., 1999. Relationships between interannual variability of glacier mass balance and climate. *Journal of Glaciology*. 45 (151): 456-462.
- Dyurgerov, M. and Meier, M., 1999. Analysis of winter and summer glacier mass balances. *Geografiska Annaler*. 81A (4): 541-554.
- Fountain, A. G., Jansson, P., Kaser, G. and Dyurgerov, M., 1999. Summary of the workshop on methods of mass balance measurements and modelling, Tarfala, Sweden August 10-12, 1998. *Geografiska Annaler*. 81A (4): 461-465.
- Haeberli, W., Hoelzle, M. and Frauenfelder, R., (eds.) 1999: Glacier mass balance bulletin. A contribution to the global environment monitoring system (GEMS) and the international hydrological programme (IHP). IAHS (ICSU)-UNEP-UNESCO. Bulletin No.5 (1996-1997).
- Hock, R. 1999: A distributed temperature-index ice- and snowmelt model including potential direct solar radiation. *Journal of Glaciology*. 45(149). 101-111.
- Hock, R. and Jensen, H., 1999: Application of kriging interpolation for glacier massbalance computations. *Geografiska Annaler*. 81A (4): 611-619.
- Holmlund, P., 1999: Tarfalaverksamheten och Storglaciärens massbalans. *Storbreesymposiet, 50 år av massebalansmålningar* (eds. Andreassen, L.M., Östrem, G.), Norges vassdrags- og energidirektorat, Dokument 5 (ISSN 1501- 2840): 36-39.
- Holmlund, P. and Jansson, P., 1999. The Tarfala mass balance program. *Geografiska Annaler*. 81A (4): 621-631.
- Iversen, N. R., Baker, R. W., Hooke, R. LeB., Hansson, B., and Jansson, P., 1999. Coupling between a glacier and a soft bed: I. A relation between effective pressure and local shear stress determined from till elasticity. *Journal of Glaciology*. 45 (149): 31-40.
- Jansson, P., 1999. Effects of uncertainties in measured variables on the calculated mass balance of Storglaciären. *Geografiska Annaler*. 81A (4): 633-642.
- Jansson, P., Richardsson, C. and Jonsson, S., 1999. Assessment of requirements for cirque formation in northern Sweden. *Annals of Glaciology*. 28: 16-22.
- Klingbjer, P., (ed.) 1999: *Tarfala Research Station Annual report, 1997-98*. Forskningsrapport 110. (ISSN 1403-9788). Naturgeografiska institutionen. Stockholms Universitet. 50 p.

- Schneider, T., 1999. Water movement i the firn of Storglaciären, Sweden. *Journal of Glaciology*. 45 (150): 286-294.

Papers published after 1980

- Ackert, R., 1984. Ice-cored lateral moraines in Tarfala Valley, Swedish Lapland. *Geografiska Annaler*. 66A (1-2): 79-88.
- 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.
- Björnsson, H., 1981. Radio-echo sounding maps of Storglaciären, Isfallsglaciären and Rabots Glaciär, northern Sweden. *Geografiska Annaler*. 63A (3-4): 225-231.
- Bodin, A., 1993. *Physical properties of the Kårsa glacier, Swedish Lapland*. Naturgeografiska institutionen vid Stockholms universitet, Forskningsrapport nr .(ISSN 0346-7406), p.
- Brand, G., Pohjola, V., and Hooke, R. LeB., 1987. Evidence for a till layer beneath Storglaciären, Sweden, based on electrical resistivity measurements: *Journal of Glaciology*. 33 (115): 311-314.
- Braithwaite, R. J. and Zhang, Y., 1999. Modelling changes in glacier mass balance that may occur as a result of climate changes. *Geografiska Annaler*. 81A (4): 489-496.
- Braithwaite, R. J. and Zhang, Y., 1999. Relationships between interannual variability of glacier mass balance and climate. *Journal of Glaciology*. 45 (151): 456-462.
- Bronge, C., 1985. *Hydrologisk verksamhet i Tarfala, 1974-1982*. Dept. Physical Geography, University of Stockholm Forskningsrapport 62, (ISSN 0346-7406), 81 p.
- 1996. The excavation of the Storglaciären trough during Quaternary. *Geografiska Annaler* 78A (2-3): 163-170.
- Brzozowski, J., and Hooke, R. LeB., 1981. Seasonal variations in surface velocity of the lower part of Storglaciären, Kebnekaise, Sweden. *Geografiska Annaler*. 63A (3-4): 233-240.
- Clark, P. U., 1995. News and Views. Fast glacier over slow beds. *Science* 267 (5195): 43-44.
- Criado Hernández, C., 1995. La estacion cientifica del Valle de Tarfala (Laponia sueca). *Alisios, Canary Journal of Geography*. (3): 108-113.
- Cutler, P., 1998. Modelling the evolution of subglacial tunnels due to varying water input. *Journal of Glaciology*. 44 (148): 485-497.
- Dowdeswell, J. A., Hagen, J. O., Björnsson, H., Glazovsky, A. F., Harrison, W. D., Holmlund, P.,

- Jania, J., Koerner, R. M., Lefauconnier, B., Ommanney, C. S. L. and Thomas, R. H., 1997. The mass balance of circum-artic glaciers and recent climate change. *Quaternary Research*. 48: 1-14.
- Dyurgerov, M. and Meier, M., 1999. Analysis of winter and summer glacier mass balances. *Geografiska Annaler*. 81A (4): 541-554.
- Eriksson, M. G., Björnsson, H., Herzfeld, U. C., and Holmlund, P., 1993. *The bottom topography of Storglaciären. A new map based on old and new ice depth measurements, analyzed with geostatistical methods*. Forskningsrapportserien STOU-NG 95, (ISSN 0346-7406), 48p.
- Fischer, U. H., Iversson, N. R., Hanson, B., Hooke, R. LeB. and Jansson, P., 1998. Estimation of hydraulic properties of subglacial till from ploughmeter measurements. *Journal of Glaciology*. 44 (148): 517-522.
- Fleetwood, Å., and Thomas, J., 1990. Weathering and ion flow in Tarfala drainage basin, Lapland, N. Sweden. *Geografiska Annaler*. 72A (1): 125-127.
- Fountain, A. G. and Walder, J. S., 1998. Water flow through temperate glaciers. *Reviews of Geophysics*. 36, 3: 299-328.
- Fountain, A. G., Jansson, P. Kaser, G. and Dyurgerov, M., 1999. Summary of the workshop on methods of mass balance measurements and modelling, Tarfala, Sweden August 10-12, 1998. *Geografiska Annaler*. 81A (4): 461-465.
- Fuenzalida, H. and Holmlund, P., 1995. Anomalous responses to 20th century climatic changes in the Darwin Cordillera, southern Chile. *Journal of Glaciology*, 41 (139): 465-473.
- Grove, J.M., 1988. *The Little Ice Age*. 498 p, Methuen & Co, London.
- Grudd, H., 1990. Small glaciers as sensitive indicators of climatic fluctuations. *Geografiska Annaler*. 72A (1): 119-123.
- Grudd, H. and Schneider, T., 1996. Air temperature at Tarfala Research Station 1946-1995. *Geografiska Annaler*, 78A (2-3): 115-120.
- Günter, R., and Widlewski, D., 1986. Die korrelation verschiedener Klimatelemente mit dem Massenhaushalt alpiner und Skandinavischer Gletscher. *Zeitschrift für Gletscherkunde und Glazialgeologie* 22 (2): 125-147.
- Haeberli, W., 1985. *Fluctuation of Glaciers 1975-1980*. A compilation of national reports to "The Permanent Service on the Fluctuations of Glaciers of the IUGG - FAGS/ICSU", 265 p.
- 1987. *Fluctuation of Glaciers 1980-1985*. A compilation of national reports to "the Permanent Service on the Fluctuations of Glaciers of the IUGG - FAGS/ICSU", 322 p.
- 1993. *Fluctuation of Glaciers 1985-1990*. A compilation of national reports to "the Permanent Service on the Fluctuations of Glaciers of the IUGG - FAGS/ICSU", 322 p.
- 1997. *Fluctuation of Glaciers 1990-1995*. A compilation of national reports to "the Permanent Service on the Fluctuations of Glaciers of the IUGG - FAGS/ICSU", 296p.
- Haeberli, W., and Herren, E., 1991. *Glacier mass balance bulletin*. A contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme. IAHS(ICSU)-UNEP-UNESCO. Bulletin No. 1 (1988-1989), 70 p.
- 1993. *Glacier mass balance bulletin*. A contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme. IAHS(ICSU)-UNEP-UNESCO. Bulletin No. 2 (1990-1991), 74 p.
- Haeberli, W., Hoelzle, M. and Bösch, H., 1994: *Glacier mass balance bulletin*. A contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme. IAHS(ICSU)-UNEP-UNESCO. Bulletin No. 3 (1992-1993).
- 1997: *Glacier mass balance bulletin*. A contribution to the Global Environment Monitoring System (GEMS) and the International Hydrological Programme. IAHS(ICSU)-UNEP-UNESCO. Bulletin No. 4 (1994-1995).
- Haeberli, W., Hoelzle, M. and Frauenfelder, R., (eds.) 1999: *Glacier mass balance bulletin*. A contribution to the global environment monitoring system (GEMS) and the international hydrological programme (IHP). IAHS (ICSU)-UNEP-UNESCO. Bulletin No.5 (1996-1997).
- Hanson, B., 1995. A fully three-dimensional finite-element model applied to velocities on Storglaciären, Sweden. *Journal of Glaciology*. 41 (137): 91-102.
- Hanson, B., and Hooke, R. LeB., 1994. Short term velocity variations and basal coupling near a bergschrund, Storglaciären, Sweden. *Journal of Glaciology*, 40 (134): 67-74.
- Hanson, B., Hooke, R. LeB. and Grace, Jr, E. M., 1998. Short-term velocity and water-pressure variations down-glacier from a riegel, Storglaciären, Sweden. *Journal of Glaciology*. 44 (147): 359-367.
- Herzfeld, U. C., Eriksson, M. G. and Holmlund, P., 1993. On the Influence of Kriging Parameters on the Cartographic Output—A study in Mapping Subglacial Topography. *Mathematical Geology* 25 (7): 881-900.
- Hock, R. 1998. *Modelling of glacier melt and discharge 1998*, Züricher Geographische Schriften, Department of Geography, ETH Zürich. 140 pp.
- Hock, R. 1999: A distributed temperature-index ice- and snowmelt model including potential direct solar radiation. *Journal of Glaciology*. 45(149). 101-111.
- Hock, R. and Holmgren, B., 1996. Some aspects of energy balance and ablation of Storglaciären, northern Sweden. *Geografiska Annaler* 78A (2-3): 121-132.
- Hock, R. and Hooke, R. LeB., 1993. Evolution of the internal drainage system in the lower part of the ablation area of Storglaciären, Sweden. *Geological Survey of America Bulletin* 105 (4): 537-546.
- Hock, R. and Jensen, H., 1999: Application of kriging interpolation for glacier massbalance computations. *Geografiska Annaler*. 81A (4): 611-619.
- Hock, R. and Noetzli, C., 1997, Areal melt and discharge modelling of Storglaciären, Sweden. *Annals of Glaciology*. 24: 211-216.
- Holmlund, P., 1986. Mikaglaciären: Bed topography and response to 20th century climate change. *Geografiska Annaler*. 68A (4): 291-302.
- 1987. Mass balance of Storglaciären during the 20th century. *Geografiska Annaler*. 69A (3-4): 439-447.

- 1987. *Climatic influence on the shape of glaciers in northern Sweden, 1878–1986*. Dept. Physical Geography, Univ. of Stockholm. Forskningsrapport 65, (ISSN 0346-7406), 14 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. Internal geometry and evolution of moulins, Storglaciären, Sweden. *Journal of Glaciology*. 34 (117): 242–248.
- 1988. Is the longitudinal profile of Storglaciären in balance with the present climate? *Journal of Glaciology*. 34 (118): 269–273.
- 1991. Cirques at low altitudes need not necessarily have been cut by small glaciers. *Geografiska Annaler*. 73A (1): 9–16.
- 1993. Surveys of Post-Little Ice Age glacier fluctuations in northern Sweden. *Zeitschrift für Gletscherkunde und Glazialgeologie*, 29 (1): 1–13.
- 1995. Mass balance studies in northern Sweden. *Zeitschrift für Gletscherkunde und Glazialgeologie*. 31: 105–114.
- 1996. Radar measurements of annual snow accumulation rates. *Zeitschrift für Gletscherkunde und Glazialgeologie*. 32: 193–196.
- 1996. Maps of Storglaciären and their use in glacier monitoring studies. (incl. 2 maps of the glaciers in the Tarfala valley in the scale 1:10 000). *Geografiska Annaler*, 78 A (2–3): 193–196.
- 1997. Climatic influence on the size of glaciers in Northern Sweden during the last two centuries. In Frenzel, B., et al. (eds.) *Glacier fluctuations during the holocene*. ESF project, European paleoclimate and man 16. Paläoklimatforschung band 24, Zürich. 115–124.
- 1998. Glacier mass balance and ice-core records from northern Sweden. *Ambio*. 27(1): 266–269.
- 1999. Tarfalaverksamheten och Storglaciärens massbalans. *Storbreesymposiet, 50 år av massebalansmålinger* (eds. Andreassen, L.M., Östrem, G.), Norges vassdrags- og energidirektorat, Dokument 5 (ISSN 1501- 2840): 36–39.
- Holmlund, P. and Eriksson, M., 1989. The cold surface layer on Storglaciären. *Geografiska Annaler*. 71A (3–4): 241–244.
- Holmlund, P. and Hooke, R. LeB., 1983. High water-pressure events in moulins, Storglaciären, Sweden. *Geografiska Annaler*. 65A (1–2): 19–25.
- Holmlund, P. and Jansson P., 1999. The Tarfala mass balance program. *Geografiska Annaler*. 81A (4): 621–631.
- Holmlund, P. and Schneider, T., 1997. The effect of continentality on glacier response and mass balance. *Annals of Glaciology*. 24: 272–276.
- Holmlund, P., Burman, H. and Rost, T., 1996. Sediment-mass exchange between turbid meltwater streams and proglacial deposits of Storglaciären. *Annals of Glaciology*. 22: 63–67.
- Holmlund, P. Karlén, W. and Grudd, H., 1996. Fifty years of mass balance and glacier front observations at the Tarfala research station. *Geografiska Annaler* 78(2–3): 105–114.
- Holmlund, P., Näslund, J-O. and Richardson, C., 1996. Radar surveys on Scandinavian glaciers, in search for useful climate archives. *Geografiska Annaler* 78 (2–3): 147–154.
- Hooke, R. LeB., 1984. On the role of mechanical energy in maintaining subglacial water conduits at atmospheric pressure. *Journal of Glaciology*. 30 (105): 180–187.
- 1991. Positive feedbacks associated with erosion of glacial cirques and overdeepenings. *Geological Society of America Bulletin*, 103: 1104–1108.
- Hooke, R. LeB., Brzozowski, J., and Bronge, C., 1983. Seasonal variations in surface velocity, Storglaciären, Sweden. *Geografiska Annaler*. 65A (3–4): 263–277.
- Hooke, R. LeB., Calla, P., Holmlund, P., Nilsson, M., and Stroeve, A., 1989. A 3 year record of seasonal variations in surface velocity, Storglaciären, Sweden. *Journal of Glaciology*. 35 (120): 235–247.
- Hooke, R. LeB., Gould, J. E., and Brzozowski, J., 1983. Near-surface temperatures near and below the equilibrium line on polar and subpolar glaciers. *Zeitschrift für Gletscherkunde und Glazialgeologie*. 19 (1): 1–25.
- Hooke, R. LeB., Hansson, B., Iverson, N. R., Jansson, P. and Fischer, U. H., 1997. Rheology of till beneath Storglaciären, Sweden. *Journal of Glaciology*. 43 (143): 172–179.
- Hooke, R. LeB., Laumann, T., and Kohler, J., 1990. Subglacial water pressures and the shape of subglacial conduits. *Journal of Glaciology*. 36 (122): 67–74.
- Hooke, R. LeB., and Pohjola, V.A., 1994. Hydrology of a segment of a glacier situated in an over-deepening, Storglaciären, Sweden. *Journal of Glaciology*, 40 (130): 140–148..
- Hooke, R. LeB., Pohjola, V.A., Jansson, P., and Kohler, J., 1992. Intra-seasonal changes in deformation profiles revealed by borehole studies, Storglaciären, Sweden. *Journal of Glaciology*. 38 (130): 348–358.
- Hooke, R. LeB., and Iverson, N., 1985. Experimental study of ice flow around a bump, comparison with theory. *Geografiska Annaler*. 67A (3–4): 187–197.
- Hooke, R. LeB., Holmlund, P., and Iverson, N. R., 1987. Extrusion flow demonstrated by borehole deformation measurements over a riegel, Storglaciären, Sweden. *Journal of Glaciology*. 33 (113): 72–78.
- 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, Sweden. *Journal of Glaciology*. 34 (117): 228–231.
- Hoppe, G., 1983. *Fjällens terrängformer. Landforms of the Swedish mountain area. En översikt av den svenska fjällkedjan på grundval av geomorfologisk kartering och naturvärdering*. Statens naturvårdsverk (ISBN 91-38-08003-6), 59 p.
- 1987. Till minne av Valter Schytt (1919–1985). In, *Expeditionen Ymer-80 – en slutrapport*. Eds. Hoppe, G., Björn-Rassmusen, S. and Wiberg, M. Kungliga Vetenskapsakademien, Polarforskningskommittén, Stockholm (ISBN 91-7190-015-2), 16–18.
- 1988. The general and the specific view in geography. In, *Geographers of Norden*. Eds. Hägerstrand, T., and Buttner, A. *Lund Studies in Geography B* 52: 83–94.

- Huddleston, P. J., 1989. The association of folds and veins in shear zones. *Journal of Structural Geology*. 11 (8): 949-957.
- Iverson, N. R., Jansson, P., Hooke, R. LeB., and Hanson, B., 1992. Direct measurements of the shear strength and deformation of till beneath Storglaciären, N. Sweden (Abstract). *EOS, Transactions of the American Geophysical Union* 74 (47): 160.
- Iverson, N. R., Jansson, P., and Hooke, R. LeB., 1994. In-situ measurement of the strength of deforming subglacial till. *Journal of Glaciology*. 40 (136): 497–503.
- Iverson, N. R., Hanson, B., Hooke, R. LeB., and Jansson, P., 1995. Flow mechanism of glaciers on soft beds. *Science*. 267 (5195): 80–81.
- Iversen, N. R., Hooyer, T. S. and Baker, R. W., 1998. Ring-shear studies of till deformation: Coulumb-plastic behavior and distributed strain in glacier beds. *Journal of Glaciology*. 44 (148): 31-40.
- Iversen, N. R., Baker, R. W., Hooke, R. LeB., Hansson, B., and Jansson, P., 1999. Coupling between a glacier and a soft bed: I. A relation between effective pressure and local shear stress determined from till elasticity. *Journal of Glaciology*. 45 (149): 31-40.
- Jahn, A., 1984. Periglacial talus slopes. Geomorphological studies on Spitsbergen and in Northern Scandinavia. *Polar Geography and Geology*. 8 (3): 177–193.
- Jahn, A., 1991. Slow soil movement in Tarfala valley, Kebnekaise mountains, Swedish Lapland. *Geografiska Annaler*. 73A (2): 93–107.
- Jansson, E. P., 1992. *Interpretation of short-term variations in ice dynamics, Storglaciären, Kebnekaise, Northern Sweden*. Forkningsrapportserien STOU-NG 89, (ISSN 0346-7406), 83 p.
- 1995. Water pressure and basal sliding, Storglaciären, Sweden. *Journal of Glaciology*. 41 (138): 232–240.
- 1996. Dynamics and hydrology of a small polythermal valley glacier. *Geografiska Annaler*, 78A (2-3): 171–180.
- 1997. Longitudinal coupling effects in ice flow across a subglacial ridge. *Annals of Glaciology*. 24: 169–174.
- 1999. Effects of uncertainties in measured variables on the calculated mass balance of Storglaciären. *Geografiska Annaler*. 81A (4): 633–642.
- 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.
- Jansson, P., Richardsson, C. and Jonsson, S., 1999. Assessment of requirements for cirque formation in northern Sweden. *Annals of Glaciology*. 28: 16–22.
- Karlen, W., 1984. Dendrochronology, mass balance and glacier front fluctuations in northern Sweden. In: *Climatic Changes on a Yearly to Millennial Basis: 263–271. N.-A. Mörner and W Karlén (eds.). Reidel Publishing Company. Meddelande från Naturgeografiska institutionen vid Stockholms universitet*, No 169.
- 1998. Climate variations and the enhanced greenhouse effect. *AMBIO*. 27(4): 270–274.
- King, L., 1982. Qualitative and quantitative Erfassung von Permafrost in Tarfala (Swedish-Lappland) und Jotunheimen (Norwegen) mit Hilfe geoelektrischer Sondierungen. *Zeitschrift für Geomorphologie*. 43: 139–160.
- 1984. *Permafrost in Scandinavia. Permafrost in Skandinavien. Untersuchungsergebnisse aus Lappland, Jotunheimen und Dovre/Rondane*. Heidelberg 1984. 174 p.
- 1986. Zonation and ecology of high mountain permafrost in Scandinavia. *Geografiska Annaler*. 68A (3): 131–139.
- Kleman, J., 1992. The Palimpsest glacial landscape in northwestern Sweden. -Late Weichselian deglaciation landforms and traces of older west-centered ice sheets. *Geografiska Annaler*. 74A (4): 305–325.
- Kohler, J., 1995: Determining the extent of pressurized flow beneath Storglaciären, Sweden, using results of tracer experiments and measurements of input and output discharge. *Journal of Glaciology*. 41 (138): 217–231.
- Lück, A., 1991. *Untersuchung zur Permafrost-hydrologie, in einem subarktischen Hochgebirgseinzugsgebiet. Permafrosthydrological Dynamics of a Subarctic High Mountain Catchment Area*. University of Bonn, 97 p.
- Oerlemans, J., Anderson, B., Hubbard, A., Huybrechts, Ph., Johannesson, T., Knap, W. H., Schmeits, M., Stroeve, A. P., van de Wal, R. S. W., Wallinga, J. and Zou, Z., 1998. Modelling the response of glaciers to climate warming. *Climate Dynamics*. 14: 267–274.
- Pohjola, V. A., 1993. TV-video observations of bed and basal sliding on Storglaciären, Sweden. *Journal of Glaciology*, 39 (131): 111–118.
- 1994. TV-video observations of englacial voids in Storglaciären, Sweden. *Journal of Glaciology*. 40 (135): 231–240.
- 1996. Simulation of particle paths and deformation of ice structures along a flow-line on Storglaciären, Sweden. *Geografiska Annaler*, 78A (2-3): 181–192.
- Pohjola, V. A. and Rogers, J. C., 1997. Atmospheric circulation and variations in Scandinavian mass balance. *Quaternary Research*. 47(1): 29–36.
- Pohjola, V. A. and Rogers, J. C., 1997. Coupling between the atmospheric circulation and extremes of the mass balance of Storglaciären, northern Scandinavia. *Annals of Glaciology*. 24: 229–233.
- Radok, U., 1980. Climatic background to some glacier fluctuations. World Glacier Inventory. Proceedings of the Riederalp Workshop, September 1978. *IAHS-AISH Publ.* 126: 295–304.
- Rafstedt, T., 1983. *Vegetationskarta över de svenska fjällen. Kartblad nr 5 Kebnekaise (29 I)*. Naturgeog. inst. Stockholms univ.
- Raper, S.C.B., Briffa, K.R. and Wigley, T.M.L., 1996. Glacier change in northern Sweden from AD 500: a simple geometric model of Storglaciären. *Journal of Glaciology*. 42 (141): 341–351.
- Reynaud, L., Vallon, M., Martin, S., and Letreguilly, A., 1984. Spatio temporal distribution of the glacial mass balance in the Alpine, Scandinavian and Tien Shan areas. *Geografiska Annaler*. 66A (3): 239–247.
- Richardson, C. and Holmlund, P., 1996. Glacial cirque formation in northern Sweden. *Annals of Glaciology* 22: 102–106.

Rosqvist, G., and Östrem, G., 1989. The sensitivity of a small ice cap to climatic fluctuations. *Geografiska Annaler*. 71A (1–2): 99–104.

Schneider, T., 1994. Water movement and storage in the firn of Storglaciären, northern Sweden. *Förkningsrapportserien STOU-NG 99*, (ISSN 0346-7406), 89 p.

—1999. Water movement in the firn of Storglaciären, Sweden. *Journal of Glaciology*. 45 (150): 286–294.

Schneider, T., and Bronge, C., 1992. *Suspended sediment transport and discharge of Tarfalajåkk, the proglacial stream of Storglaciären, Northern Sweden, 1980–1990*. *Förkningsrapportserien STOU-NG 92*, (ISSN 0346-7406), 28 p.

—1996. Suspended sediment transport in the Storglaciären drainage basin. *Geografiska Annaler*, 78A (2–3): 155–162.

Schytt, V., 1981. The net mass balance of Storglaciären related to the height of the equilibrium line and to the height of the 500 mb surface. *Geografiska Annaler*. 63A (3–4): 219–223.

—1985. Glaciologi. *Kosmos* 62: 109–124.

—1993. Glaciers of Europe - Glaciers of Sweden. In, *Satellite image atlas of glaciers of the world* (eds. Williams, R.S. and Ferrigno, J.G.), U.S. Geological survey professional paper 1386-E, Washington, 1993. E-4: 111–125.

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

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

Skrivastava, H. B., Huddleston, P. and Earley, D., 1995. Strain and possible volume loss in a high-grade ductile shear zone. *Journal of Structural Geology*. 17 (9): 1217–1231.

Stroeve, A.P., 1996. The robustness of one-dimensional, time dependent, ice-flow models: A case study from Storglaciären, northern Sweden. *Geografiska Annaler* 78A (2–3): 133–146.

Stroeve, A.P., and van der Wal, R.S., 1987. *Mass balance and flow of Rabots glaciär; A comparison with Storglaciären*. Dept. Physical Geography, University of Stockholm. *Förkningsrapport* 64, (ISSN 0346-7406), 99 p.

—1990. A comparison of the mass balances and flows of Rabots glaciär and Storglaciären, Kebnekaise, northern Sweden. *Geografiska Annaler*. 72A (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.

Walford, M., Kennett, M. I., and Holmlund, P., 1986. Interpretation of radio echoes from Storglaciären, northern Sweden. *Journal of Glaciology*. 32 (110): 39–49.

Åmark, M., 1980. Glacial flutes at Isfallsglaciären, Tarfala, Swedish Lapland. *Geologiska Föreningens Förhandlingar (GFF)*. 102 (3): 251–259.

Östling, M., and Hooke, R. LeB., 1986. Water storage in Storglaciären, Kebnekaise, Sweden. *Geografiska Annaler*. 68A (4): 279–290.

Papers published before 1980

Ahlmann, H. W. son., 1948. *Glaciological Research on the North Atlantic Coasts*. The Royal Geographical Society Research series, 1: 83 p.

—1949. De glaciologiska undersökningarna i Kebnekajse 1946–49. *Svensk geografisk årsbok* 1949. 25: 106–127.

—1951. Scientific investigations in the Kebnekajse Massif, Swedish Lapland. I. General outline of the investigations in 1946–51. *Geografiska Annaler*. 33 (1–2): 90–94.

—1953. *Glacier Variations and Climatic Fluctuations*. Bowman Memorial Lectures, series three. The American Geographical Society, New York 1953, 51 p.

Ahlmann, H. W. son. and Droessler E. G., 1949. Glacier ice crystal measurements at Kebnekajse, Sweden. *Journal of Glaciology*. 1 (5): 268–274.

Bergström, E., 1955. Studies of the variations in size of Swedish glaciers in recent centuries. -*UGGI: IASH Assemblée Generale de Rome* 1954 (4): 356–366.

Cewe, T., and Norrbin, J., 1965. Tarfalajåkka; Ladtjojåkka och Ladtjojaure. Vattenföring, slamtransport och sedimentation. *Ymer* (1–2): 85–111.

Danfors, E., Fleetwood, Å., and Schytt, V., 1962. Application of the neutron scattering method for measuring snow density. *Geografiska Annaler*. 44 (3–4): 409–411.

Eckerbom, E. and Palosuo, E., 1963. A study of ice crystals at Storglaciären, Kebnekajse. in: *Kingery, W. D. (ed.): Ice and snow, properties, processes, and applications*. Proc. Conf. Mass. Inst. Tech., M.I.T. Press. 56–62.

Ekman, S.-R., 1961. Thermal Drilling in Isfallsglaciären, Kebnekajse. *Geografiska Annaler*. 43 (3–4): 422–423.

Grainger, M. E. and Lister, H., 1966: Wind speed, stability and eddy viscosity over melting ice surfaces. *Journal of Glaciology*. 6 (43): 101–127.

Hamberg, A., Rabot, C., and Mercanton, P. L., 1930. *Commission UGGI des glaciers: Rapport pour 1914–1928*. Venezia 1930. 1–53.

Herrmann E., 1931. Gletscherstudien im Kebnekaise-Gebiet (Schwed. Lapland). *Zeitschrift für Gletscherkunde*. 19: 263–284.

Hoinkes, H., 1967. Gletscherschwankungen und Wetter in den Alpen. In: *Karin Schrom and J. C. Thams (eds.): Veröffentlichungen der Schweizerischen Meteorologischen Zentralanstalt nr. 4. (Internationale tagung für alpine meteorologie. In Brig und Zermatt 14–17 sept 1966. City-druck AG, Zürich. 9–24.*

—1968. Glacier variation and weather. *Journal of Glaciology*. 7 (49): 3–19.

Hoppe, G., 1960. Glacial morphology and inland ice recession in Northern Sweden. *Geografiska Annaler*. 41: 193–212.

—1961. Naturgeografisk fältstation i Kebnekaise. *Svensk Geografisk Årsbok* 37: 224–225.

—1963. I den stora landisens spår: terrängformer i Lapland. *Natur i Lapland* 1: 130–144.

—1969. Norrlandsälvarnas naturvärden. Värdegraderad bedömning av Torne, kalix, Pite älvars samt Vindelälvens betydelse för forskning och turism. *Statens naturvårdsverk*. Del II av PU 20.11.1969: 3–27.

- Hoppe, G., and Ekman, S.-R., 1964. A note on the alluvial fans of Ladtjovagge, Swedish Lapland. *Geografiska Annaler*. 46 (3): 338–342.
- Hoppe, G., and Schytt, V., 1953. Some observations on fluted moraine surfaces. *Geografiska Annaler*. 35 (2): 105–115.
- Hoppe, G., Schytt, V., and Strömberg, B., 1965. Från fält och forskning Naturgeografi vid Stockholms Universitet. *Ymer* (3–4): 109–125
- Håkansson, T., 1955. Anteckningar om flora och vegetation i Kebnekajseområdet. *Botaniska notiser* 108 (2):
- Johansson, H. F., 1951. Scientific investigations in the Kebnekajse Massif, Swedish Lapland. II. The petrology and tectonics of the Kebnekajse region and their morphological importance. *Geografiska Annaler*. 33 (1–2): 95–120.
- Jonsson, S., 1970. Structural studies of subpolar glacier ice. *Geografiska Annaler*. 52A (2): 129–145.
- 1973. Registration of a sudden vertical displacement of the ice surface of Isfallsglaciären, Northern Sweden. *Geografiska Annaler*. 55A (1): 64–68.
- Karlen, W., 1973. Holocene glacier and climatic variations, Kebnekaise mountains, Swedish Lapland. *Geografiska Annaler*. 55A (1): 29–63.
- 1975. *Lichenometrisk datering i norra Skandinavien – metodens tillförlitlighet och regionala tillämpning*. Naturgeografiska institutionen, Stockholms univ. Forskningsrapport 22, (ISSN 0346-7406), 67 p.
- 1976. *Holocene climatic fluctuations indicated by glacier and tree-limit variations in northern Sweden*. Naturgeografiska institutionen, Stockholms univ. Forskningsrapport 23, 7p.
- Karlen, W., and Denton, G. H., 1975. Holocene glacial variations in Sarek National Park, northern Sweden. *Boreas* 5: 25–56.
- Kasser, P., 1967. *Fluctuations of glaciers 1959–1965*. A contribution to the International Hydrological Decade. IASH (ICSU) UNESCO, 52 p.
- 1973. *Fluctuation of Glaciers 1965–1970*. A compilation of national reports to “The Permanent Service on the Fluctuations of Glaciers of the IUGG – FAGS/ICSU”, 357 p.
- King, L., 1976. Permafrostuntersuchungen in Tarfala (Schwedisch Lapland) mit Hilfe der Hammerschlagseismik. *Zeitschrift für Gletscherkunde und Glazialgeologie* 12 (2): 187–204.
- Kulling, O., 1964. Översikt över norra Norrbottensfjällens kaledonberggrund. Sveriges geologiska undersökning (SGU), Ba 19: 166 p.
- Mannerfelt, C. M:son., 1939. *Geografiska bilder*. *Ymer* 59: 162–166.
- 1940. Storglaciärens tillbakagång i Kebnekaise. *Ymer* 60 (1): 60–61.
- Melander, O., 1975. *Geomorfologiska kartbladet*, 29 I Kebnekaise. *Beskrivning och naturvärdesbedömning*. SNV PM 540. 78 p.
- Müller, F., 1977. *Fluctuation of Glaciers 1970–1975*. A compilation of national reports to “The Permanent Service on the Fluctuations of Glaciers of the IUGG – FAGS/ICSU”, 269 p.
- Nilsson, J., and Sunblad, B., 1975. The internal drainage of Storglaciären and Isfallsglaciären described by an autoregressive model. *Geografiska Annaler*. 57A (1–2): 73–98.
- Nye, J. F., 1965. The frequency response of glaciers. *Journal of Glaciology*. 5 (41): 567–587.
- Nye, J. F., 1965. A numerical method of inferring the budget history of a glacier from its advance and retreat. *Journal of Glaciology*. 5 (41): 589–607
- Quensel, P., 1919. De kristallina sevebergarternas geologiska och petrografiska ställning inom Kebnekajseområdet. *Geologiska Föreningens i Stockholm Förhandlingar (GFF)* 41:
- Rapp, A., 1959. Avalanche Boulder Tongues in Lapland. *Geografiska Annaler*. 41 (1): 34–48.
- Schytt, V., 1947. Glaciologiska arbeten i Kebnekajse. *Ymer* 67 (1): 18–42.
- 1949. Re-freezing of meltwater on the surface of glacier ice. *Geografiska Annaler*. 31 (1–4): 222–227.
- 1959. The Glaciers of the Kebnekajse-Massif. *Geografiska Annaler*. 41 (4): 213–227.
- 1960. Regime studies on Storglaciären, Kebnekajse during 1960. *Geografiska Annaler*. 42 (1): 62–63.
- 1961. Notes on Glaciological activities in Kebnekajse, Sweden. Regime studies on Storglaciären, Kebnekajse, during 1961. *Geografiska Annaler*. 43 (3–4): 420–421
- 1962. Naturgeografisk fältstation i Kebnekajse. *Svensk Naturvetenskap*, 332–345.
- 1962. Mass balance studies in Kebnekajse. *Journal of Glaciology*. 4 (33): 281–286.
- 1962. Mass balance studies on Storglaciären during 1962. *Geografiska Annaler*. 44 (3–4): 407–409.
- 1962. A tunnel along the bottom of Isfallsglaciären. *Geografiska Annaler*. 44 (3–4): 411–412.
- 1963. Fluted moraine surfaces. *Journal of Glaciology*. 4 (36): 825–827.
- 1965. Notes on glaciological activities in Kebnekaise, Sweden during 1964. *Geografiska Annaler*. 47A (1): 65–71.
- 1966. Notes on glaciological activities in Kebnekaise, Sweden-1965. *Geografiska Annaler*. 48A (1): 43–50.
- 1967. A study of “Ablation Gradient”. *Geografiska Annaler*. 49A (2–4): 327–332.
- 1968. Notes on glaciological activities in Kebnekaise, Sweden during 1966 and 1967. *Geografiska Annaler*. 50A (2): 111–120.
- 1968. *Tarfalajåkkan vattenföring och slamtransport 1966–1967*. Naturgeografiska inst. Stockholms universitet. Forskningsrapportserien STOU-NG 3 (ISSN 0346-7406), 24 p.
- 1970. De svenska glaciärernas vittnesbörd. In: Ahlmann m fl Klimatologiska förändringar omkring Nordatlanten under gammal och nyare tid. *Ymer*. 90: 241–242.
- 1973. Snow densities on Storglaciären in Spring and summer. *Geografiska Annaler*. 54A (3–4): 155–158.
- 1973. *Tarfala och dess forskningsverksamhet*. Information 1, STOU-NG, Naturgeografiska inst. Stockholms universitet. 2:a uppl. 1975, 3:e uppl. 1978. 27 p.
- 1973. *Hydrologisk aktivitet inom undersökningsområdet Tarfala*, (ur Vannet i Norden nr 1, s 12–29). Information 2, STOU-NG, Naturgeogr. inst., Stockholms universitet. 18 p.
- 1979. *Tarfala and it's research activities*. Naturgeografiska institutionen Stockholms universitet. Forskningsrapportserien STOU-NG 34 (ISSN 0346-7406), 31 p.

- Schytt, V., Jonsson, S., and Cederstrand, P., 1963. Notes on glaciological activities in Kebnekaise, Sweden – 1963. *Geografiska Annaler*. 45 (4): 292–302.
- Smith, I. N. and Budd, W. F., 1979. The derivation of past climate changes from observed changes of glaciers. *Sea level, Ice, and Climatic Change (proceedings of the Canbverra Symposium, Dec. 1979)*. IAHS 131: 31–52.
- Stenborg, T., 1965. Problems concerning winter run-off from glaciers. *Geografiska Annaler*. 47A (3): 141–184.
- 1969. Studies of the internal drainage of glaciers. *Geografiska Annaler*. 51A (1–2): 13–41.
- 1973. Some viewpoints on the internal drainage of glaciers. *Symposium on the Hydrology of Glaciers. Cambridge, 7–13 September 1969, organized by the Glaciological society*. Publication no. 95. 1973, 117–130.
- Stork, A., 1963. Plant Immigration in front of Retreating Glaciers, with examples from the Kebnekajse Area, Northern Sweden. *Geografiska Annaler*. 45 (1): 1–22.
- 1963. Några bidrag till kännedomen om Kebnekajseområdet kryptogamflora. *Botaniska notiser* 116 (1): 11–15.
- Svenonius F., 1910. *Die gletscher Schwedens im Jahre 1908*. Sveriges Geologiska Undersökningar (SGU) serie Ca 5 part I: 1–54.
- Vilborg, L., 1977. The cirque forms of Swedish Lapland. *Geografiska Annaler*, 59A (3–4): 89–150.
- Woxnerud, E., 1951. Scientific investigations in the Kebnekajse Massif, Swedish Lapland. III. Kartografiska arbeten i Kebnekajse. IV. Det lokala triangelnätets i Kebnekajse anslutning till riksnätet. Syd- och nordtopparnas höjd över havet. *Geografiska Annaler*. 33 (3–4): 121–143.
- Östrem, G., 1959. Ice melting under a thin layer of moraine, and the existence of ice cores in moraine ridges. *Geografiska Annaler*. 41: 228–230.
- 1961. A new approach to end moraine chronology. *Geografiska Annaler*. 43 (3–4): 418–419.
- 1962. Nya metoder för åldersbestämning av ändmoräner. *Ymer* 82: 241–252.
- 1962. *Ice-cored moraines in Kebnekajse area*. Meddelande från Geografiska institutionen Stockholms univ. 154 p
- 1963. Comparative Crystallographic Studies on Ice from Ice-cored Moraines, Snow-banks and Glaciers. *Geografiska Annaler*. 45 (4): 210–242.
- 1964. Ice-cored Moraines in Scandinavia. *Geografiska Annaler*. 46 (3): 282–337.
- 1965. Problems of dating ice-cored moraines. *Geografiska Annaler*. 47A (2): 1–38.
- Östrem, G., Haakensen, N., and Melander, O., 1973. *Atlas over breer i Nord-Skandinavia*. Meddelande nr 46 från Naturgeografiska inst. Stockholms univ. 315 p.
- Brugger, K., 1992. *A comparative study of the response of Rabots Glaciär and Storglaciären to recent climate change in Sweden*, PhD dissertation, Department of Geology and Geophysics, University of Minnesota, 287 p.
- Cutler, P. M., 1996. *Water input and subglacial tunnel evolution at Storglaciären, northern Sweden*. PhD dissertation, Department of Geology and Geophysics, University of Minnesota, xx pp.
- Hock, R., 1998. *Modelling of glacier melt and discharge*. PhD dissertation, no 12430, Department of Geography, ETH Zurich, 126 pp.
- Holmlund, P., 1988. *Studies of the drainage and the response to climatic change of Mikagglaciären and Storglaciären*. Naturgeografiska institutionen vid Stockholms universitet. Meddelande nr A 220 (ISBN 91-7146-590-1), 75 p.
- Jansson, P., 1993. *Interpretation of short-term variations in ice dynamics, Storglaciären, Kebnekaise, Northern Sweden*. PhD dissertation, Department of Geology and Geophysics University of Minnesota, USA,
- Jansson, P., 1994. *Studies of short-term variations in ice dynamics, Storglaciären, northern Sweden*. Naturgeografiska institutionen, Stockholms universitet, Avhandlingsserie (ISSN 1104-7208), Dissertation no.1 (ISBN 91-7153-247-1).
- Jonsson, S., 1970. *Strukturstudier av subpolär glaciärs från Kebnekaiseområdet*. Naturgeografiska institutionen, Stockholms universitet, Forskningsrapportserien 8, (ISSN 0346-7406), 200p.
- Karlén, W., 1976. *Holocene climatic fluctuations indicated by glacier and tree-limit variations in northern Sweden*. Naturgeografisk institutionen, Stockholms universitet. Forskningsrapportserien 23, (ISSN 0346-7406).
- 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*. PhD dissertation, Department of Geology and Geophysics, University of Minnesota, USA, 147 p.
- Pohjola, V. A., 1993. *Ice Dynamical Studies on Storglaciären, Sweden. A study based on TV-video observations of englacial Structures and deformation measurements within boreholes*. Institutionen för geovetenskap vid Uppsala universitet. Acta universitatis Upsaliensis, Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science 470 (ISBN 91-554-3173-9).
- Rapp, A., 1961. *Studies of the postglacial development of mountain slopes*. Geografiska institutionen vid Uppsala universitet. meddelande nr 159.
- Östrem, G., 1965. *Studies of Ice-cored moraines*. Naturgeografiska institutionen, Stockholms universitet, Esselte AB, Stockholm 1965.

Doctor of Philosophy dissertations

- 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.

Filosofie licentiatexamen, Master of Science dissertations, or equivalent work, after 1980

- Bronge, C., 1985. *Hydrologisk verksamhet i Tarfala, 1974-1982. En analys av bearbetningsmetoder och resultat*. Naturgeografiska institutionen, Stockholms

- universitet. Forkningsrapportserien STOU-NG 62, (ISSN 0346-7406), 81 p
- Goerke, U., 1993. *Geologische untersuchungen im südlichen Kebnekaise-gebiet, Tarfala, in den Skandinavischen Kaledoniden, Nordschweden*. Diplomarbeit, Department of Geology/Paleontology, Ruprecht-Karls University, Heidelberg, Germany.
- Hock, R., 1991. *Aspects of the internal drainage system of Storglaciären, Sweden, as indicated by dye-trace studies*. Diplomarbeit at the Department of Physical Geography, University of Freiburg, Germany.
- Jansson, E. P., 1992. *Interpretation of short-term variations in ice-dynamics, Storglaciären, Kebnekaise, northern Sweden*. NGSU Research Report 89.
- Krüger, G., 1985. *Aktuelle Schneefleckenformung in den Skanden am beispiel des Kebnekaise (67°55'N, 10°32'E), Nord-Lappland*. Diplomarbeit im Fach Geographie der mathematisch-naturwissenschaftlichen Fachbereiche der Georg-August-Universität Göttingen. 55 p.
- Richardson, C., 1996. *Klimatinriktade georadarstudier på glaciärer i svenska fjällen och på den antarktiska inlandsisen*. Naturgeografiska institutionen vid Stockholms universitet.
- Rosquist, G., 1989. *Studies of glacier fluctuations and climatic change*. Naturgeografiska institutionen vid Stockholms universitet.
- Schneider, C., 1992. *GIS based modelling of the energy balance from Landsat-TM*. Diplomarbeit at the Department of Physical Geography, University of Freiburg, Germany. p.
- Schneider, T., 1994. *Water movement and storage in the firn of Storglaciären, northern Sweden*. Diplomarbeit at the Department of Physical Geography, University of Freiburg, Germany. 74 p.
- Schneider, T., 1998. *Hydrological processes in the firn of Storglaciären*. Naturgeografiska institutionen vid Stockholms Universitet.
- Shimko, K. A., 1987. *A study on structures in two valley glaciers in northern Sweden by observation and computer modelling*. MS diss., Department of Geology and Geophysics, University of Minnesota, USA.
- Zimmerer, S., 1987. *A study of the englacial and subglacial hydrology of Storglaciären, northern Sweden*. MS diss., Department of Geology and Geophysics, University of Minnesota, USA.
- Undergraduate papers (examensarbeten), after 1980**
- Bodin, A., 1991. *Kårsaglaciärens reträtt under 1900-talet*. Naturgeografiska institutionen, Stockholms universitet, Examensarbete på geovetarlinjen, 24 p.
- Bomark, M., och Lundberg, C., 1995. *GPS-mätning i Tarfala 1994. Stomnät, metodförsök, amnslutning till RR92*. Institutionen för Geodesi och Fotogrammetri, Kungliga Tekniska Högskolan, Stockholm. Examensarbete i Geodesi. 49 p.
- Burman, H., och Rost, T., 1991. *Uppmätning av erosion och sedimentation i Tarfaladalen med analytisk fotogrammetri*. Institutionen för fotogrammetri, Kungl Tekniska Högskolan, Stockholm. Examensarbete i fotogrammetri nr 95, 37 p.
- Calla, P., 1988. *Datering av snökärnor borrade på Grönlands inlandsis*. Naturgeografiska institutionen, Uppsala universitet. 24 p.
- Eriksson, M., 1990. *Storglaciärens bottentopografi uppmätt genom radioekosondering*. Naturgeografiska institutionen, Stockholms universitet. 28 p.
- Finnander, M.-L., 1989. *Vädrets betydelse för snöavsmältningen i Tarfaladalen*. Naturgeografiska institutionen, Lunds universitet. 41 p.
- Fredin, O., 1997. *Kortidsvariationer i isrörelse på Storglaciären*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete. 43 p.
- Frisk, A. and Ståhl, L., 1985. *Kalibrering av mätvärden i Tarfala*. Kungliga Tekniska Högskolan, 42 p.
- Hedin, M., 1984. *Tarfalavagge - former och deglaciation*. Naturgeografiska institutionen, Stockholms universitet. 31 p.
- Hieltala, M., 1989. *En utvärdering av areella nederbördsmetoder och mätarplaceringar i Tarfaladalen*. Naturgeografiska institutionen, Stockholms universitet. 41 p.
- Holmlund, P., 1982. *Glaciärbrunnars genes och morfologi*. Naturgeografiska institutionen, Stockholms universitet. 41 p.
- Huss, E., 1997. *Glaciärfrontsreträtter under 1900-talet - en detaljstudie av Rättaglaciärerna, norra Lappland*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete för filosofie kandidatexamen. 73 p.
- Jansson, P., 1986. *Variations in surface tilt on Storglaciären, Kebnekaise, Northern Sweden*. Naturgeografiska institutionen, Stockholms universitet. 16 p.
- Karlöf, L., 1997. *Densitetsutvecklingen i snö och firn på Storglaciären under ett massbalansår kopplat till vädrets förändringar*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete.
- Kjessel, R., 1986. *Blöta lössnölaviner och slasklaviner*. Naturgeografiska institutionen, Stockholms universitet. 56 p.
- Klingbjör, P., 1996. *Jökellopp vid Sälka*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete för filosofie magisterexamen. 56 p.
- Lind, L., 1982. *Studier av basal isrörelse på Isfallsglaciären, Kebnekaise, 1980-1981*. Naturgeografiska institutionen, Lunds universitet. 47 p.
- Lindstrand, O., 1986. *Sediment från Storglaciären, Kebnekaise. En kvalitativ bestämning*. Geologiska institutionen, Göteborgs universitet. 35 p.
- Moberg, A., 1984. *Massbalansundersökningar på Björlings glaciär, Kebnekaise, 1983*. Naturgeografiska institutionen, Stockholms universitet. 24 p.
- Neidhart, F., 1997. *Die kartierung des Pärteglaciären und die analyse seine veränderung von 1963 bis 1996*. Fachhochschule Stuttgart - Hochschule fürtechnik. Germany.
- Näslund, J.-O., 1989. *En studie av proglaciala lakustrina sediment från Valfojaure, norra Sverige*. Naturgeografiska institutionen, Stockholms universitet. 14 p.

- Pettersson, R., 1996: *Studier av isstrukturer och deras koppling till klimatet på två subpolära glaciärer i Kebnekaise*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete för filosofie magisterexamen. 47 p.
- Pohjola, V., 1986. *Mätningar av hastighetsfördelningar, längs en profil i Storglaciären, Kebnekaise, 1985*. Naturgeografiska institutionen, Uppsala universitet. 34 p.
- Richardson, C., 1993. *Nischbildningsprocesser – En fältstudie vid Passglaciären, Kebnekaise*. Naturgeografiska institutionen, Lunds universitet, Seminarieuppsats nr 30, 58 p.
- Schneider, T., 1992. *Suspended sediment transport in the proglacial stream of Storglaciären, northern Sweden, 1980–1990*. Avdelningen för hydrologi, Uppsala universitet, C-uppsats, 27 p.
- Strömberg, K., 1987. *Vattentillskott till Storglaciären från snösmältning på omgivande dalsidor*. Naturgeografiska institutionen, Göteborgs universitet.
- Troëng, S., 1993. *Glacialmorfologiska studier vid Pårtjekna, Sarek – en jämförelse mellan två frontområden*. Naturgeografiska institutionen, Stockholms universitet. Examensarbete vid geovetarinjen, 27 p.
- Wennberg, S., 1986. *Nederbörds-mätning i Tarfaladalen - extremvärden och nederbördsfördelning*. Naturgeografiska institutionen, Stockholms universitet. 38 p.
- Östling, M., 1986. *Vattenbalansen i Storglaciären*. Naturgeografiska institutionen, Stockholms universitet. 31 p.

Compilations of data from Tarfala, (Available at the department)

- Bergman, V., 1988. *Sommarnederbörd vid Tarfala-stationen och i dess omgivningar 1965–1984*. 39 p.
- Grudd, H., and Jansson, P., 1986. *The 1984/85 mass balance of Storglaciären, Kebnekaise, Swedish Lapland*. 13p.
- Årsrapport från Tarfala forskningsstation, 1986. Peter Jansson (ed.), 95 p.
- Årsrapport 1987. Tarfala research station. Gunhild Rosqvist (ed.), 103 p.
- Årsrapport 1988. Tarfala research station. Arjen Stroeve (ed.), 85 p.
- Årsrapport 1989. Tarfala research station. Arjen Stroeve and Mats Eriksson (eds). 76 p.
- Årsrapport 1990. Tarfala reserach station. Håkan Grudd and Axel Bodin (eds.), 96 p.
- Årsrapport 1990–1991. Tarfala research station. Håkan Grudd (ed.), Forskningsrapportserien STOU-NG 92 (ISSN 0346-7406), 73 p.
- Årsrapport 1991–1992. Tarfala research station. Axel Bodin (ed.), Forskningsrapportserien STOU-NG 96 (ISSN 0346-7406), 64 p.
- Tarfala Research Station Annual Report, 1992–93. Peter Jansson, (ed.), NGSU Forskningsrapport 100. (ISSN 0346-7406), 50 p.
- Tarfala Research Station Annual Report, 1993–94. Peter Jansson, (ed.), NGSU Forskningsrapport 102. (ISSN 0346-7406), 66 p.

- Tarfala Research Station Annual Report, 1994–95. Peter Jansson, (ed.), NGSU Forskningsrapport 103. (ISSN 0346-7406), 66 p.
- Tarfala Research Station Annual Report, 1995–96. Per Klingbjer, (ed.), NGSU Forskningsrapport 104. (ISSN 0346-7406), 76 p.
- Tarfala Research Station Annual Report, 1996–97. Per Klingbjer, (ed.), NGSU Forskningsrapport 105. (ISSN 0346-7406), 76 p.
- Tarfala Research Station Annual Report, 1997–98. Per Klingbjer, (ed.), NGSU Forskningsrapport 110. (ISSN 1403-9788), 50 p.
- Tarfala Research Station Annual Report, 1998–99. Per Klingbjer, (ed.), NGSU Forskningsrapport 111. (ISSN 1403-9788), 60 p.

Publications in popular science

- Ahlmann, H. W:son, 1952. Kebnekajse. Svenska turistföreningens årsskrift 1952: 265–288.
- Holmlund, P., 1986. Glaciärforskning i Tarfala. *Till Fjälls*, Svenska Fjällklubbens årsskrift, 58: 48–53.
- 1991. Valter Schytt och Tarfalastationen., *Till Fjälls*, Svenska Fjällklubbens årsskrift, 61-62: 48–53.
- 1992. Glaciärer och forskare i Tarfala under ett halvt sekel. *Geologklubben vid Stockholms universitet, Geologklubben 100 år*, 61–67.
- 1995. Mikkaglaciären – dess liv, leverne och framtid. *Till Fjälls*, Svenska Fjällklubbens årsskrift 65-66: 12–27.
- Holmlund, P., och Schytt, A., 1989. *Glaciärer—En kunskapsvandring på Storglaciären, Kebnekaise*. Småskrift nr. 1 (ISBN 91-87636-01-8) från Ajtte museum. Jokkmokk 1989. 32 sidor.
- 1995. Vi går mot en ny istid. *Populär vetenskap* 4: 34-39.
- 1995: Tarfala - Tarfalaverksamheten 50 år. En jubileumsskrift med anledning av Tarfalaverksamhetens 50-årsjubileum. Stockholms universitet (ISBN: 91-7540-112-6), 48 s.
- Lundqvist, G., 1944. *De svenska fjällens natur*. STF:s förlag, Stockholm 1944. 440pp.
- 1948. *De svenska fjällens natur (2:nd edition)*. STF:s förlag, Stockholm 1948. 502 pp.
- Karlén, W., och Holm, F., 1989. Glaciärerna smälter - istiden kommer ändå. *Forskning och framsteg* 1989 (4): 4–11.
- Mannerfelt, C. M:son., 1940. I Kebnekaise. En Naturhistorisk rundvandring. Svenska turistföreningens årsskrift 1940: 312–338.
- Rosquist, G. and Karlén, W., 1996. Värmeböljor och fimbulvintrar: klimatet de senaste 10 000 åren. Jordens klimat. *Naturvetenskapliga forskningsrådets årsbok* 1996, 97-105.
- Schytt, V., 1963. Glaciärernas liv. Svenska turistföreningens årsskrift 1963: 144–158.
- 1963. Lapplands glaciärer. *Natur i Lappland*. Uppsala., 158–171.
- 1973. Glaciologiska metoder i klimatforskningens tjänst. *Svensk Naturvetenskap* 1973. 14 p.
- 1981. Det föränderliga klimatet. *Här är vi hemma*. Rolf Edberg (ed.) Bra Böcker, 1982, 90–105.

Boende på Tarfala forskningsstation under 1999

Stationspersonal

Holmlund, Per	Professor, stationsföreståndare	43
Jansson, Peter	Docent, forskarassistent	35
Nyman, Mart	Amanuens	108
Nilsson, Mats	Tekniker	58
Jonsson, Krister	Tekniker	34
Lidström, Lars	Tekniker	39

Extrapersonal

Frödin, Sara	Hantlangare	21
Nässen, Jonas	Hantlangare	45
Ruth, Eleonor	Hantlangare	30
Ekman, Per	Hantlangare	32
Malmkvist, Erik	Hantlangare	34
Dellenbach, Andrea	Hantlangare	41
Huss, Erik	Amanuens	15
Norin, Johan	Kock	52
Lindberg, Anette	Kock	34
Larocque, Isabelle	Kock	23

Projektansvariga och gästforskare

Blomkvist, Sven		17
Institutionen för systemekologi, Stockholms universitet		
Brown, Ian		1
Climate Impact Research Centre, Kiruna		
Naturgeografiska institutionen, Stockholms universitet		
Foyer, Märta		4
Naturgeografiska institutionen, Stockholms universitet		
Grudd, Håkan		4
Climate Impact Research Centre, Kiruna		
Naturgeografiska institutionen, Stockholms universitet		
Grust, Karin		15
Department of Geography and Topographic Science, University of Glasgow, England		
Hock, Regine		60
Climate Impact Research Centre, Kiruna		
Naturgeografiska institutionen, Stockholms universitet		
Isaksen, Ketil		5
Geografiska institutionen, Oslo universitet, Norge		
Johansson, Margareta		21
Naturgeografiska institutionen, Lunds universitet		
Johansson, Maria		9
Climate Impact Research Centre, Kiruna		
Naturgeografiska institutionen, Stockholms universitet		
Jonsell, Ulf		57
Naturgeografiska institutionen, Uppsala universitet		

Klingbjer, Per	7
Naturgeografiska institutionen, Stockholms universitet	
Jan Lundkvist	3
Kvärtärgeologiska institutionen, Stockholms universitet	
Pettersson, Rickard	55
Naturgeografiska institutionen, Stockholms universitet	
Schneider, Thomas	16
Naturgeografiska institutionen, Stockholms universitet	
Näslund, Jens-Ove	20
Naturgeografiska institutionen, Stockholms universitet	
Näslund-Rickardsson, Cecilia	14
Naturgeografiska institutionen, Stockholms universitet	
Karlén, Wibjörn	3
Naturgeografiska institutionen, Stockholms universitet	
Quirin, Alexander	26
Institut für Geographie, Justus-Liebig Universität, Giessen, Tyskland	

Kurser och grupper

Akademiska hus, Luleå	10
Fältkurs, Arctic Centre, Rovaniemi, Finland	115
Anders Bergwall, guideverksamhet	9
BRW, Wigerbäcks bergentreprenad, Kiruna	4
Doktorandkurs, norrbottensexkursionen	15
Stockholms Universitets Forskarskola	12
Hj.Lundbomsskolan, Kiruna, praktikfallsarbetare	15
Konsthögskolan, Umeå	32
Lapplands jägarregemente, I22, Kiruna	100
Markstridsskolan	5
Personalbyrån, SU	14
Peter Mågård, guideverksamhet	7
Polarforskningsserietatiet, Logistik	4
Skandinature films	11
Statens Fastighetsverk, Uppsala	1
Studio Ljusspel	4
Svenska Turistföreningen STF AB, Kebnekaise fjällstation	321
Tarfalakursen, Naturgeografiska institutionen, Stockholms universitet	214
Tärendö centralskola	39
Universitetsstyrelsen	17
Vattenfall	15

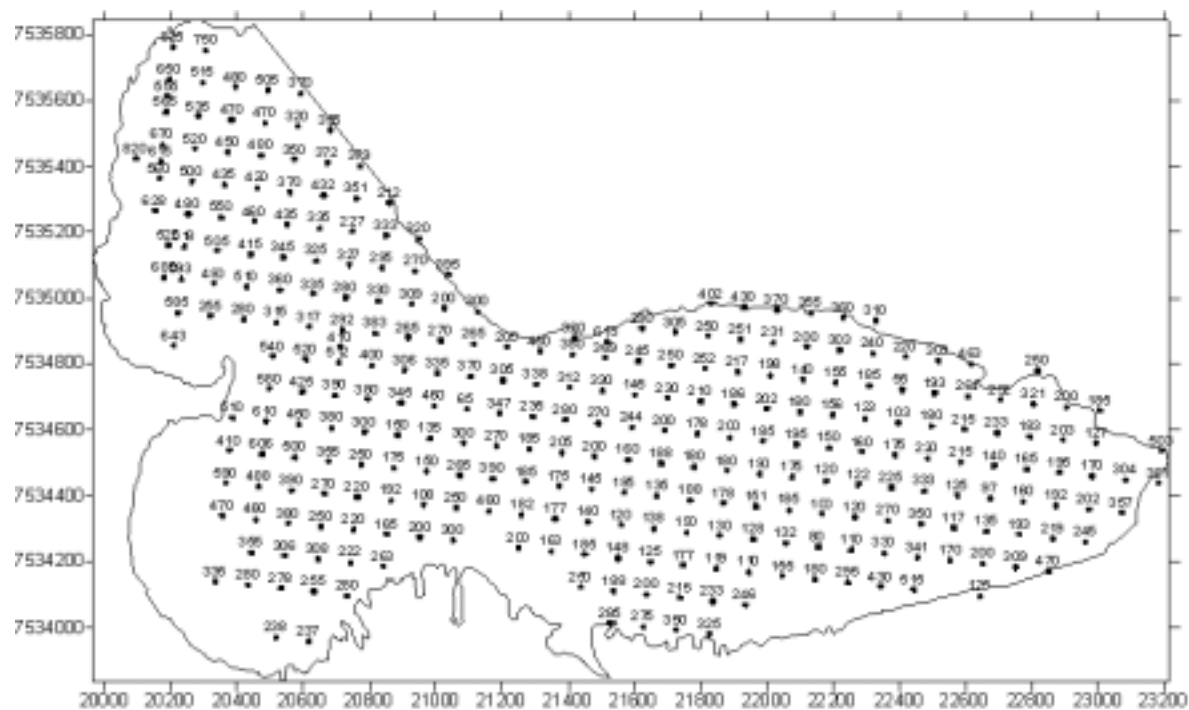
Övriga

Schytt, Anna	14
Johnson, Rita	2
Övriga gäster	80

Totalt 1999	2041
--------------------	-------------

Appendix 1

Snow depth survey 1999 on Storglaciären

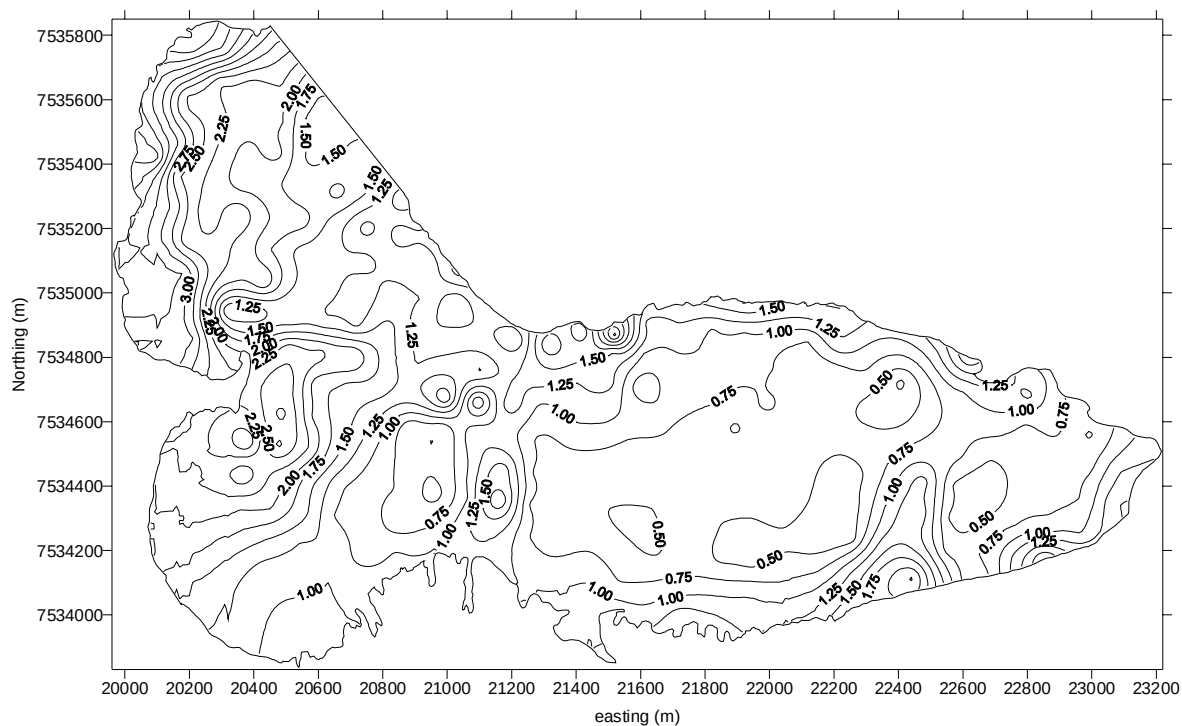


Appendix 2

Stake locations 1999 on Storglaciären

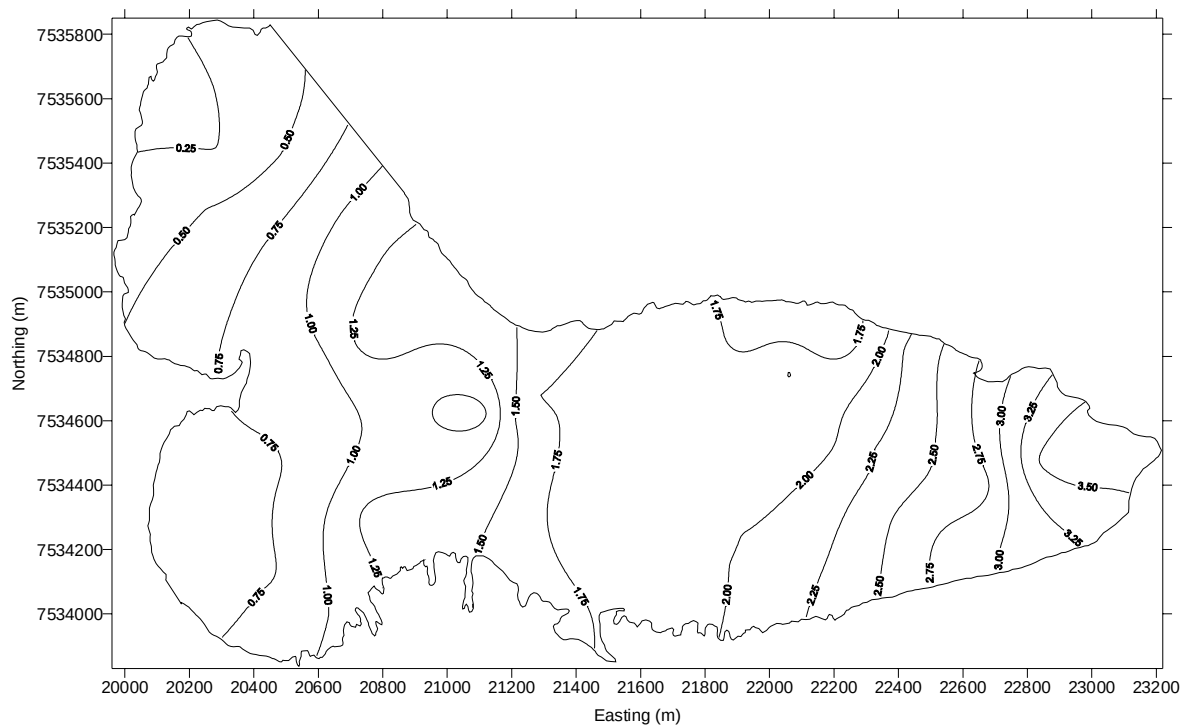
Appendix 3

Winter balance map for Storglaciären 1998/99



Appendix 4

Summer balance map for Storglaciären 1998/99



Department of Physical Geography, Stockholm University

Research Report Series

Series editor: Peter Jansson

111. Klingbjer, P. (Ed.) 2000: *Tarfala Research Station Annual Report 1998–99*. (61 p.)
110. Klingbjer, P. (Ed.) 1999: *Tarfala Research Station Annual Report 1997–98*. (50 p.)
109. Allard, A., Ihse, M., Nordberg, M.-L., 1998: Vegetationsförändringar i fjällen. (64 s.)
108. Löfvenhaft, K., Ihse, M., 1998: Biologisk mångfald och fysisk planering. (112 s.)
107. Eknert, B., 1998: Biotopernas betydelse för fågelfaunan i odlingslandskapet. (58 s.)
106. Moberg, A. (Ed.) 1998: *Modelling in Physical Geography. Projects Works 1998*. (89 p.)
105. Klingbjer, P. (Ed.) 1998: *Tarfala Research Station Annual Report 1996–97*. (76 p.)
104. Klingbjer, P. (Ed.) 1997: *Tarfala Research Station Annual Report 1995–96*. (76 p.)
103. Jansson, P. (Ed.) 1996: *Tarfala Research Station Annual Report 1994–95*. (66 p.)
102. Jansson, P. (Ed.) 1995: *Tarfala Research Station Annual Report 1993–94*. (66 p.)
101. Forsberg, P., 1995: *Geomorfologiska studier av kustplattformen utmed Gotlands nordvästra klintkust*. (74 p.)
100. Jansson, P. (Ed.) 1994: *Tarfala Research Station Annual Report 1992–93*. (50 p.)
99. Schneider, T., 1994: *Water movement and storage in the firn of Storglaciären, Northern Sweden*. (89 p.)
98. Näslund, J-O, Bodin, A., 1994: *Studies on ice dynamics, mass balance and paleoclimate in East Antarctica 1991–92*. (43 p.)
97. Bodin, A., 1993: *Physical properties of Kårsa Glacier in Swedish Lapland*. (24 p.)
96. Bodin, A. (red.), 1993: *Årsrapport, Tarfala Research Station*. (63 s.)
95. Eriksson, M.G., Björnsson, J., Herzfeld, U.C., Holmlund, P., 1993: *The bottom Topography of Storglaciären. A new map based on old and new ice depth measurements, analyzed with geostatistical methods*. (48 s.)
94. Schneider, T., Bronge, C., 1992: *Discharge and suspended sediment transport of the proglacial stream of Storglaciären, Northern Sweden, 1980–1990*. (44 s.)
93. Nordberg, M-L, 1992: *Mapping of local-scale thermal variations in Landsat images for risk assessment of forest regeneration failures*. (105 s.)
92. Grudd, H. (red.), 1992: *Årsrapport, Tarfala Research Station*. (73 s.)
91. Rosqvist, G., 1992: *Late Holocene glacial activity recorded in lacustrine sediments on El Altar, Ecuador*. (27 s.)
90. Rosqvist, G., 1992: *Late quaternary glacial and climatic history of the Ecuadorian Andes*. (11 s.)
89. Jansson, E.P., 1992: *Interpretation of short-term variations in ice dynamics, Storglaciären, Kebnekaise, Northern Sweden*. (83 s.)
88. Holmgren, K., 1992: *The late Quaternary climate in Botswana. A literature review*. (30 s.)
87. Isaksson, E., 1992: *Spatial and temporal patterns in snow accumulation and oxygen isotopes, Western Dronning Maud Land, Antarctica*. (86 s.)
86. Skånes, H., 1991: *Förändringar i odlingslandskapet och dess konsekvenser för gräsmarksfloran. En studie från södra Halland*. (70 s.)
85. Ihse, M., Löfgren, T., 1991: *Bestämning av biomassa på rikkärr i norra Finland med hjälp av spektral-mätning*. (58 s.)
84. Isaksson, P-O., 1991: *Vittringsstudier på Nordaustlandet*. (24 s.)
83. Näslund, J-O., Pohjola, V., Stroeven, A., 1991: *Glaciological surveys in Vestfjella and Heimefrontfjella, Dronning Maud Land, Antarctica, 1998/1990*. (71 s.)
82. Forsberg, P., 1991: *Lichenometrisk studier av laven *Aspicilia Calcaria* på norra Gotland*. (31 s.)
81. Runborg, S., 1990: *Tomteby – Vegetationsförändringar i ett ålderdomligt odlingslandskap i en öländsk by, studerade genom flygbildstolkning*. (61 s.)
80. Syrén, P., 1990: *Reflektans för fysiska modeller av skogsbestånd som funktion av belysningsgeometri*. (33 s.)
79. Granath, L., 1990: *Radarsynkron ekolodning - Ett nytt system för batymetrisk kartläggning och bottenmaterialundersökning*. (36 s.)
78. Granath, L., 1989: *Kartläggning av erosionskänsliga stränder längs Röd kobbsleden*. (30 s.)
77. Sadeghi-Nad, A., 1989: *Computer aided analysis of Landsat MSS data for mapping urban/suburban land use and land cover in Teheran area, IRAN*. (42 s.)
76. Bronge, C., 1989: *Holocene climatic fluctuations recorded from lake sediments in Nicholson Lake, Vestfold Hills, Antarctica*. (23 p.)
75. Kleman, J., & Alm, G., 1989: *Estimation of the atmospheric influence on a Landsat TM scene using low-altitude radiometer data*. (28 p.)
74. Bronge, C., 1989: *The hydrology of proglacial Chelnok Lake, Vestfold Hills, Antarctica*. (41 p.)
73. Holmlund, P., Isaksson, I., Karlén, W., 1989: *Massbalans, isrörelse och isdynamik – preliminära resultat från fältsäsongen 1988/89 i Vestfjella och heimefrontfjella, V. Dronning Maud Land, Antarktis*. (66 p.)
72. Bronge, C., Openshaw, A., 1989: *New instrument for measuring water discharge by the salt dilution method*. (12 p.)
71. Österholm, H., 1988: *The glacial history of Prins Oscars Land, Nordaustlandet, Svalbard*. (3 p.)
70. Österholm, H., 1988: *The glacial striation on Prins Oscars Land, Nordaustlandet, Svalbard*. (10 p.)