Glaciological investigations in Norway in 2004

Bjarne Kjøllmoen (Ed.)

2
2004

REPORT

Glaciological investigations in Norway in 2004

The Norwegian Water Resources and Energy Directorate (NVE)
2005

Report No 2

Glaciological investigations in Norway in 2004

Published by: Norwegian Water Resources and Energy Directorate

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Print: Lobo Media
Number printed: 250
Frontpage photo: The end moraine and glacier snout of Flatbreen. On 8th May huge volumes of water broke through the moraine and gushed down to the valley Supphelledalen in Fjærland.
ISSN: 1502-3540
ISBN: 82-410-0540-7

Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2004 are presented in this report. The main part concerns mass balance investigations. Results from investigations of glacier monitoring are discussed in a separate chapter.
Subjects: Glaciology, Mass balance, Front position, Glacier velocity

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April 2005

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Preface

This report is a new volume in the series "Glaciological investigations in Norway" which has been published since 1963.

The report is based on a number of reports on investigations of Norwegian glaciers. Measurements of mass balance, front position change, glacier velocity, volume changes and other glaciological investigations are presented. Most of the investigations were ordered by private companies and have been published earlier as reports to the respective companies.

The report is published in English with a summary in Norwegian. The purpose of this report is to provide a joint presentation of the investigations and calculations made mainly by NVE's Section for Glaciers and Environmental Hydrology during 2004. The chapters are written by different authors with different objectives, but are presented in a uniform format. The individual authors hold the professional responsibility for the contents of each chapter. The fieldwork and the calculations are mainly the result of co-operative work amongst the personnel at the Section for Glaciers and Environmental Hydrology.

Bjarne Kjøllmoen was editor and Miriam Jackson made many corrections and improvements.

Oslo, April 2005

Morten Johnsrud
Director,
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Summary

Mass balance

Mass balance investigations were performed on fourteen glaciers in Norway in 2004. Ten of these glaciers are in southern Norway and four in northern Norway.

The winter balance was lower than average for all ten measured glaciers in southern Norway. The glaciers in Jotunheimen had the lowest relative winter balances with 59-70 % of their average. In northern Norway the winter balance was lower than average on Langfjordjøkelen and the same as average on Engabreen.

The summer balance was close to average for glaciers in southern Norway, lower than average in the Svartisen area and greater than average on Langfjordjøkelen.

Hence, the net balances in southern Norway were significantly negative at seven glaciers and about in balance at three glaciers. The greatest deficit was measured at Austdalsbreen (−1.0 m w.eqv.) and Breidablikkbrea (−0.9 m w.eqv.). In northern Norway, Engabreen had a surplus of 0.8 m w.eqv., while Langfjordjøkelen had a deficit of 1.9 m w.eqv.

Front position

Front position measurements were performed at 24 glaciers in southern Norway and two glaciers in northern Norway in 2004. Twenty two of the glacier outlets had a retreat in front position, while four outlets show minor changes (±4 m). Briksdalsbreen had a retreat of 96 m during the previous year, and the total recession since 1999 is 176 m. Buerbreen had a retreat of 90 m and the total retreat since 1998 is 164 m. Both measured glaciers in northern Norway, Engabreen and Langfjordjøkelen, had significant retreats.

Sammendrag

Massebalanse

I 2004 ble det utført massebalansemålinger på 14 breer I Norge – ti i Sør-Norge og fire i Nord-Norge.

Vinterbalansen ble mindre enn gjennomsnittet på alle 10 målte breer i Sør-Norge. Breene i Jotunheimen hadde relativt minst vinterbalanse med 59-70 % av gjennomsnittet. På breene i Nord-Norge ble vinterbalansen mindre enn gjennomsnittet på Langfjordjøkelen og omtrent det samme som gjennomsnittet på Engabreen.

Sommerbalansen ble omtrent som normalt på breene i Sør-Norge. I Nord-Norge ble sommerbalansen i Svartisen-området mindre enn gjennomsnittet, mens Langfjordjøkelen hadde betydelig større sommerbalanse enn gjennomsnittet.

I Sør-Norge ble det signifikant underskudd på sju breer, mens tre breer var omtrent i likevekt. Det største underskuddet ble målt på Austdalsbreen (−1,0 m vannekvivalenter) og Breidablikkbrea (−0,9 m vannekv.). I Nord-Norge fikk Engabreen et solid overskudd med 0,8 m vannekv., mens Langfjordjøkelen fikk et betydelig underskudd med 1,9 m vannekv.

Front posisjon

Frontmålinger ble utført på 24 breer i Sør-Norge og to breer i Nord-Norge i 2004. Tjueto av breutløperne hadde tilbakegang, mens fire utløpere viste små endringer (±4 m). Briksdalsbreen hadde en tilbakegang på 96 m det siste året, og har siden 1999 gått tilbake 176 m. Buerbreen gikk tilbake 90 m og har hatt en samlet tilbakegang på 164 m siden 1998. Begge de målte breene i Nord-Norge, Engabreen og Langfjordjøkelen, hadde signifikant tilbakegang.

1. Glacier investigations in Norway in 2004

1.1 Mass balance

Studies of mass balance include measurements of accumulated snow (winter balance) during the winter season, and measurements of snow and ice removed by melting (summer balance) during the summer season. The difference between these two parameters gives the net balance. If the winter balance is greater than the summer balance, the net balance is positive and the glacier increases in volume. Alternatively, if the melting of snow and ice during the summer is larger than the winter balance, the net balance is negative and the ice volume decreases.

Method

The method used to measure mass balance is the same as used in previous years. With the experience gained from many years of measurements, the measurement network was simplified on individual glaciers at the beginning of the 1990s, without affecting the accuracy of the resulting balance calculations or the final results.

Winter balance

The winter balance is normally measured in April or May by probing to the previous year's summer surface along approximately the same profile each year. Stake readings are used to verify the probings where possible. Since the stakes can disappear during particularly snow-rich winters, and since it is often difficult to distinguish the summer surface (S.S.) by probing alone, snow coring is also used to confirm the probing results. Snow density is measured in pits at one or two locations at different elevations on each glacier (Fig. 1-1).

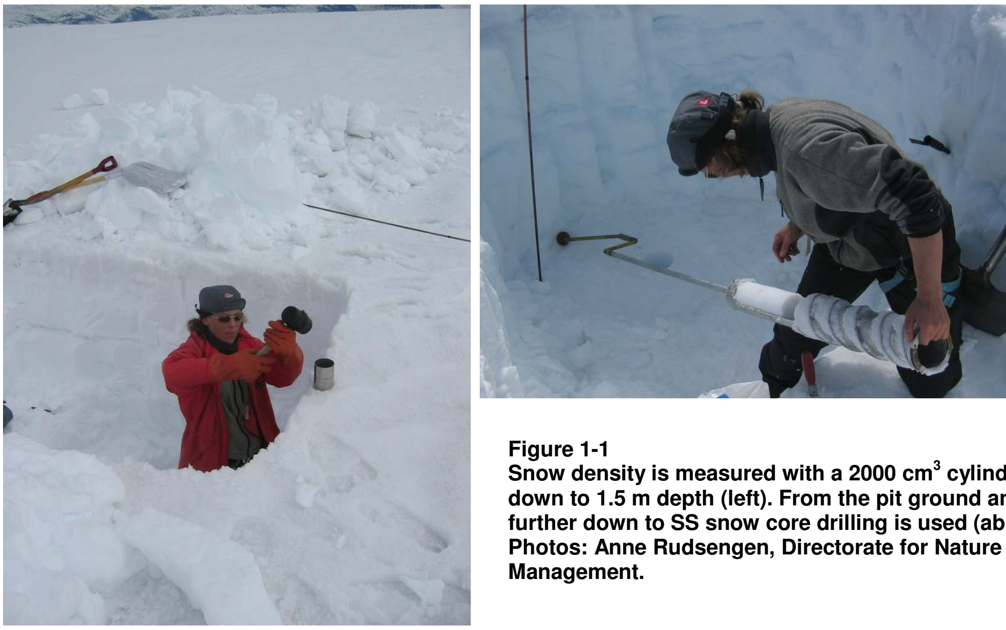


Figure 1-1
Snow density is measured with a 2000 cm^3 cylinder down to 1.5 m depth (left). From the pit ground and further down to SS snow core drilling is used (above). Photos: Anne Rudsengen, Directorate for Nature Management.

Summer and net balance

Summer and net balances are obtained from stake measurements, usually performed in September or October (Fig. 1-2). Below the glacier's equilibrium line the net balance is negative, meaning that more snow and ice melts during a given summer than accumulates during the winter. Above the equilibrium line, in the accumulation area, the net balance is positive. Based on past experience, snow density of the remaining snow in the accumulation area is typically assumed to be 0.60 g/cm^3. After especially cold summers, or if there is more snow than usual remaining at the end of the summer, snow density is either measured using snow-cores or is assumed to be 0.65 g/cm^3. The density of melted firn is, depending on the age, assumed to be between 0.65 and 0.80 g/cm^3. The density of melted ice is taken as 0.90 g/cm^3.

Figure 1-2
Summer and net balances can be calculated based on stake readings in September or October. Photo: Liss M. Andreassen.

Stratigraphic method

The mass balance is usually calculated using the traditional stratigraphic method (Østrem and Brugman 1991), which means the balance between two successive "summer surfaces" (i.e. surface minima). Consequently, the measurements describe the state of the glacier *after* the end of melting and *before* fresh snow has fallen. In some occasions ablation *after* the final measurements in September/October can occur. Strictly speaking, this ablation should be included in this year's summer balance. However, measuring and calculating this additional ablation cannot be done until the following winter or spring. Thus, it is counted as a negative contribution to the next year's winter balance.

Accuracy

The accuracy of the mass balance measurements depends on several factors. The accuracy of the winter balance is influenced mainly by the accuracy of the point measurements (soundings, core drillings, stakes, towers and density pit) and how representative they are. The smoothness of the snow layer is also of importance. The accuracy of soundings and core drillings depends on the number of point measurements, the certainty of identifying the summer surface and the implementation of the measurements (e.g. if the probe penetrates vertically through the snow pack). Overall, the accuracy of winter balance decreases with increasing snow depth.

The accuracy of summer balance is dependent on the number of ablation stakes, the height distribution, how representative they are, and on the state of the stakes. Sources of error can be stakes sinking or tilting to one side.

The accuracy of the net balance is dependent on all the factors mentioned above.

As the mass balance is measured and calculated, it is very difficult to estimate the accuracy mathematically because it is difficult to quantify the accuracy of the individual factors. The determined values of accuracy are therefore based on a subjective estimate.

Mass balance program

In 2004 mass balance measurements were performed on 14 glaciers in Norway - 10 in southern Norway and 4 in northern Norway. In southern Norway, 6 of the glaciers have been measured for 42 consecutive years or more. They constitute a west-east profile extending from the maritime Ålfotbreen glacier with an average winter balance of 3.7 m water equivalent to the continental Gråsubreen with an average winter balance of 0.8 m w.eqv. Storbreen in Jotunheimen has the longest series of all glaciers in Norway with 56 years of measurements, while Engabreen at Svartisen has the longest series (35 years) in northern Norway. The location of the glaciers investigated is shown in Figure 1-3. A comprehensive review of the glacier mass balance and length measurements in Norway is given in Andreassen et al. (2005).

In the following chapters mass balance studies performed on Norwegian glaciers in 2004 are reported. The numbers from the World Glacier Monitoring Service (WGMS) are given for each glacier in Table 1-1.

The mass balance (winter, summer and net balance) is given both in volume (m^3 water) and specific water equivalent for each 50 or 100 m height interval. The results are shown in both tables and diagrams. All diagrams have the same ratio between units on the *x*- and *y*-axes in order to make comparison straightforward. Finally, histograms showing the complete mass balance results for each glacier are presented.

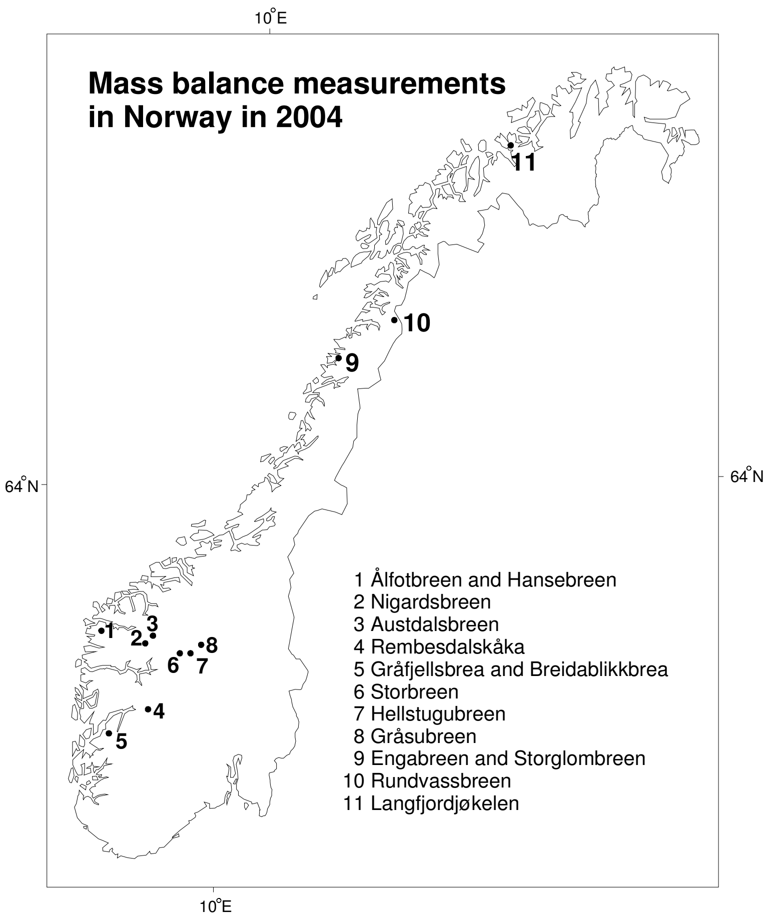


Figure 1-3
Location of the glaciers at which mass balance studies were performed in 2004.

Weather conditions and mass balance results

Wintry weather

October and November 2003 were dry over most of the country. However, in December there were several storms and lots of snow. The counties north of Sognefjorden and Jotunheimen particularly had a lot of precipitation in December – up to 2-3 times normal values.

The period January-April 2004 was variable. January was very dry in western, central and northern Norway, while eastern and southern Norway had considerably more precipitation than normal. In February, however, there was much precipitation in the counties north of Sognefjorden and most parts of northern Norway, but it was dry in eastern and southern Norway. March was dry over the whole country, and April was dry in the far north, snow rich in the central mountain regions in southern Norway and roughly normal everywhere else. The total winter season 2003/2004 was drier than normal in most of the country.

Snow accumulation and winter balance

In southern Norway winter balance was lower than average at all ten measured glaciers. The glaciers in Jotunheimen had the lowest relative balance with 59-70 % of average. The glaciers in western Norway had between 71 and 89 % of average. In northern Norway winter balance was less than average on Langfjordjøkelen and about average or a little more in the Svartisen region.

Summer weather

Summer 2004 began with extremely high temperatures in the first week of May. However, this was succeeded by considerably lower temperatures and snowfall. It continued with rather cool weather in June, particularly in southern Norway. July was cooler than usual in southern Norway, approximately as normal in central Norway, and in parts of northern Norway it was considerably warmer than usual. August was warmer than usual over the whole country. The total summer season 2004 was warmer than normal in northern Norway and approximately normal in southern Norway.

Ablation and summer balance

In southern Norway summer balance was approximately as average or slightly below. The lowest relative balance was measured on Hansebreen with 88 % of average. Austdalsbreen (102 %), Nigardsbreen (106 %) and Hellstugubreen (104 %) had the greatest relative summer balances. In northern Norway, Langfjordjøkelen had as much as 121 % of average, while Engabreen (91 %) and Storglombreen (76 %) at Svartisen, had less than average.

Net balance

In southern Norway net balance was negative for seven measured glaciers, while three glaciers were approximately in balance. The greatest deficit was measured at Austdalsbreen (−1.0 m w.eqv.) and Breidablikkbrea (−0.9 m w.eqv.). In northern Norway, Engabreen had a surplus of 0.8 m w.eqv., while Langfjordjøkelen was negative with −1.9 m w.eqv. This is the second largest deficit measured on Langfjordjøkelen since measurements began in 1989, the largest being measured in 2001 (−2.3 m w.eqv.).

The results from the mass balance measurements in Norway in 2004 are shown in Table 1-1. Winter (**b_w**,), summer (**b_s**) and net balance (**b_n**) are given in metres water equivalent (m w.eqv.) smoothly distributed over the entire glacier surface. The figures in the **% of average** column show the current results in percent of the average for the previous years (minimum eight years of measurements). The net balance results are compared with the mean net balance in the same way. **ELA** is the equilibrium line altitude (m a.s.l.) and **AAR** is the accumulation area ratio (%).

Table 1-1
Review of the results from mass balance measurements performed in Norway in 2004. The glaciers in southern Norway are listed from west to east. Each glacier is reported in the number system of World Glacier Monitoring Service (WGMS). All ID's begin with N4A000, so only the last five characters are shown here.

Glacier	*WGMS No.*	*Period*	*Area (km^2)*	*Altitude (m a.s.l.)*	*b_w (m)*	*% of average*	*b_s (m)*	*% of average*	*b_n (m)*	*b_n middle*	*ELA*	*AAR %*
Ålfotbreen	*BL004*	1963-04	4.5	903-1382	3.32	89	–3.42	98	–0.10	0.22	1225	53
Hansebreen	*BO002*	1986-04	3.1	930-1327	2.87	83	–3.38	88	–0.51	–0.39	1220	31
Breidablikkbrea	*AJ001*	1963-68	3.9	1219-1660						–0.19		
		2003-04	3.6	1236-1659	2.21	-	–3.16	-	–0.95	-	1605	17
Gråfjellsbrea	*AK007*	1964-68 1974-75	9.4	1039-1660						0.20		
		2003-04	8.9	1051-1659	2.04	-	–2.85	-	–0.81	-	1565	24
Nigardsbreen	*A4014*	1962-04	47.8	320-1960	1.97	83	–2.01	102	–0.04	0.41	1530	70
Austdalsbreen	*A4023*	1988-04	11.8	1200-1757	1.60	71	[1]–2.56	106	–0.96	–0.19	1495	48
Rembesdalsskåka	*AO001*	1963-04	17.1	1020-1865	1.89	90	–1.81	91	0.08	0.12	1670	75
Storbreen	*AD041*	1949-04	5.4	1390-2100	1.01	70	–1.59	94	–0.58	–0.26	1855	22
Hellstugubreen	*AD011*	1962-04	3.0	1465-2200	0.65	59	–1.49	104	–0.84	–0.32	1980	23
Gråsubreen	*AB047*	1962-04	2.3	1830-2290	0.48	62	–0.97	90	–0.49	–0.30	2210	7
Storglombreen	*C7013/*	1985-88	59.0	520-1580						–0.75		
	C7014	2000-04	62.4		2.26	[2]109	[3]–2.14	[2]76	0.12	[2]–0.75	1075	78
Engabreen	*C4011*	1970-04	39.6	10-1575	2.92	100	–2.10	91	0.82	0.63	1040	83
Rundvassbreen	[4]	2002-04	11.6	788-1537	1.95	-	–2.16	-	–0.21	[5]–0.07	1260	51
Langfjordjøkelen	*ET008*	1989-93	3.7	280-1050						–0.10		
		1996-04			1.69	[6]75	–3.61	[6]121	–1.92	[6]–0.74	>1050	0

[1] Contribution from calving amounts to 0.23 m for b_s
[2] Calculated for the measured periods 1985-88 and 2000-2003
[3] Contribution from calving amounts to 0.12 m for b_s
[4] WGMS number DI021 and DI022
[5] Mean value for the period 1961-98 estimated by map comparison
[6] Calculated for the measured periods 1989-93 and 1996-2003

Figure 1-4 gives a graphical presentation of the mass balance results in southern Norway for 2004. The west-east gradient is evident for both winter and summer balances. Seven glaciers have a distinct negative net balance and three glaciers are approximately in balance.

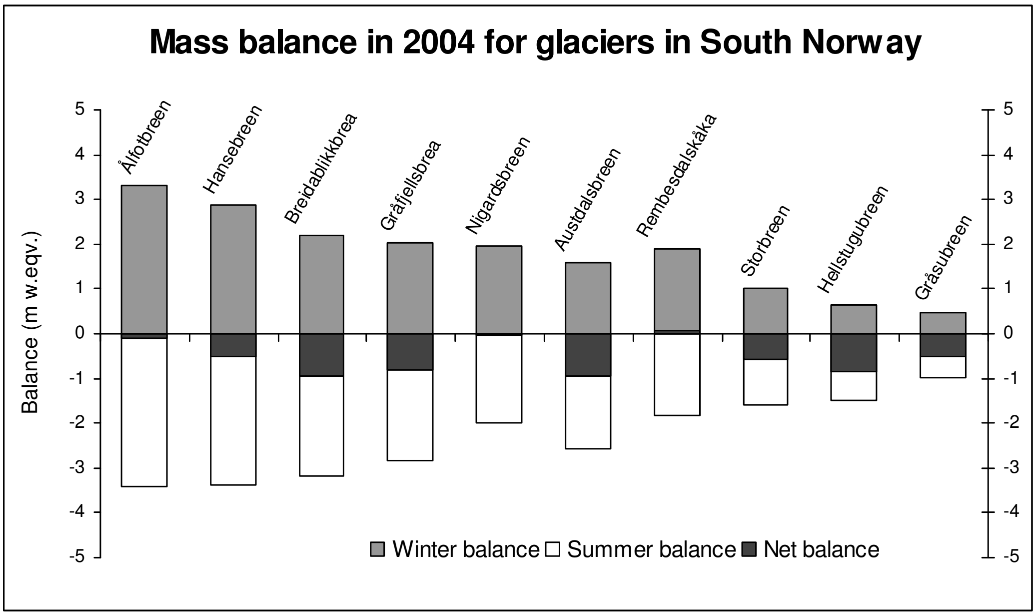


Figure 1-4
Mass balance 2004 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-time series during the period 1963-2004 is shown in Figure 1-5. The maritime glaciers – Ålfotbreen, Nigardsbreen and Rembesdalsskåka had a marked increase in volume during the period 1989-95. The surplus was mainly a result of several winters with heavy snowfall. However, over the last four years (2001-04) the net balance has become negative or in balance for these three glaciers. This volume decrease is due to a combination of low winter precipitation and warm summers. The continental glaciers in Jotunheimen – Storbreen and Gråsubreen show a distinct decrease in net balance over the whole period.

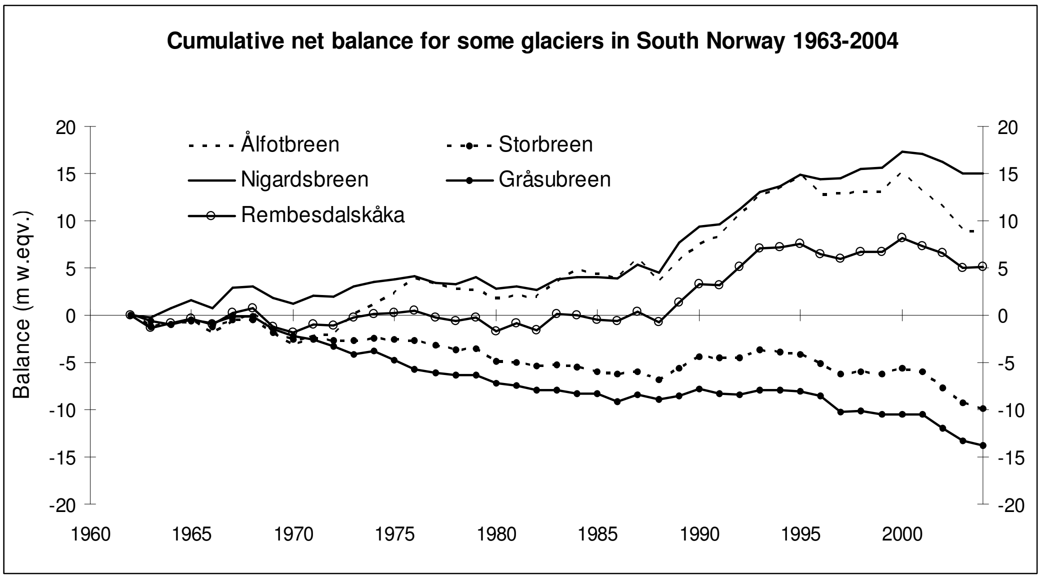


Figure 1-5
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka, Storbreen and Gråsubreen during the period 1963-2004.

1.2 Other investigations

Front position measurements were performed at 26 glaciers in Norway in 2004. Some of these have measurements going back to about 1900. The front position changes are described in a separate chapter (chap. 14).

Glacier velocity has been studied at Austdalsbreen since 1987 (chap. 5).

Meteorological observations have been performed at Storbreen (chap. 7) and Engabreen (chap. 10).

Svartisen Subglacial Laboratory was initiated in 1992 and has since been used by researchers from several different countries (Jackson 2000). An overview of activities in the laboratory is given in chapter 10.

Due to avalanche risk Baklibreen is the subject of a monitoring program which continued in 2004 (chap. 14).

Based on regression analyses the net balances for 2004 are modelled for Tunsbergdalsbreen (chap. 4) and Svartisheibreen (chap. 10).

2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45'N, 5°40'E) is 17 km^2, and is both the westernmost and the most maritime glacier in Norway. Mass balance studies have been carried out on two adjacent north-facing outlet glaciers - Ålfotbreen (4.5 km^2) and Hansebreen (3.1 km^2). The westernmost of these two has been the subject of mass balance investigations since 1963, and has always been reported as Ålfotbreen. On Hansebreen the investigations started in 1986. None of the outlet glaciers from the icecap are given names on the official maps. To distinguish the two different glaciers the last one has been given the name Hansebreen. Ålfotbreen, including its component parts and surroundings, is shown in Figure 2-1.

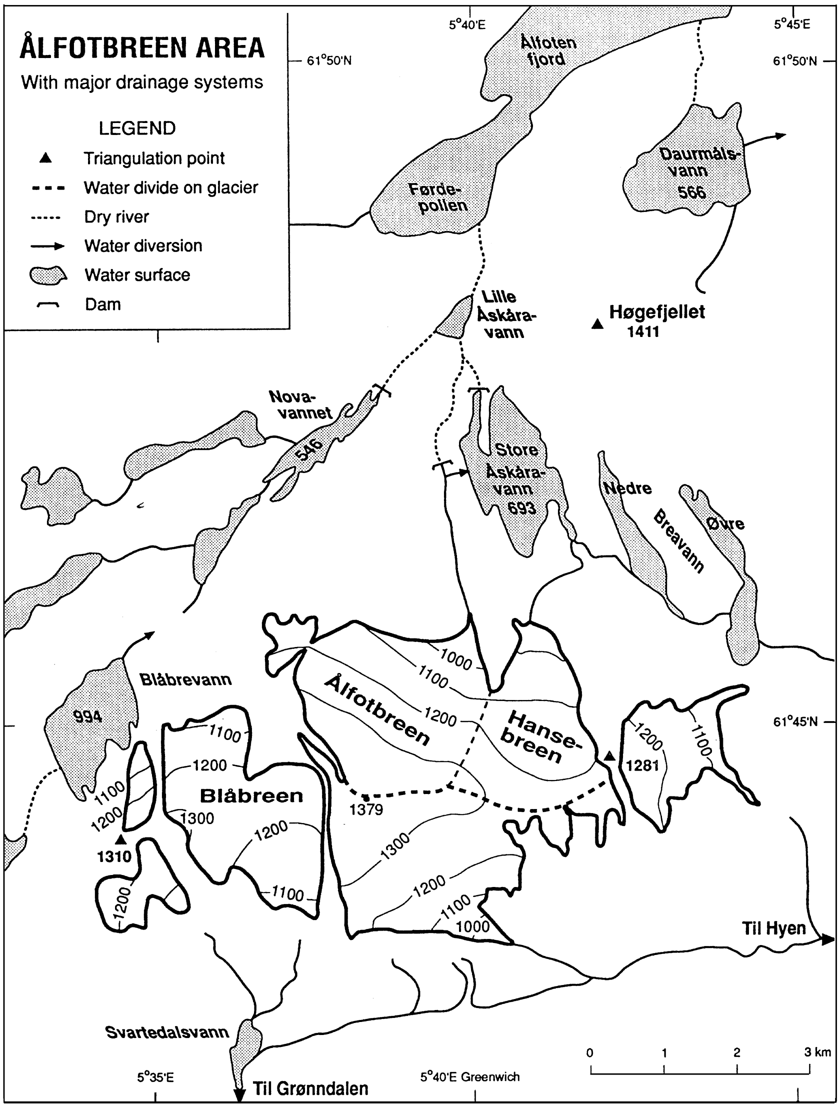


Figure 2-1
Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

2.1 Mass balance 2004

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 12th and 13th of May. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Uninterrupted measurements at tower T49 (1380 m a.s.l.). Measurements of stake replacements and older stakes that appeared during the melt season at positions 13 (1090 m a.s.l.), 45 (1185 m a.s.l.) and 37 (1225 m a.s.l.) on Ålfotbreen. Measurements of stake replacements and older stakes in positions 50 (1025 m a.s.l.), 60 (1070 m a.s.l.), 85 (1195 m a.s.l.) and 90 (1305 m a.s.l.) on Hansebreen.
- 62 snow depth soundings along a total of about 13 km of profiles on Ålfotbreen, and 40 snow depth soundings along about 8 km of profiles on Hansebreen. The snow depth at Ålfotbreen was between 6 and 7 m above 1250 m a.s.l. and between 5 and 6 m below 1250 m elevation. At Hansebreen the snow depth was 5-6 m in the areas above 1150 m a.s.l. and 4-5 m below 1150 m elevation. The summer surface (SS) could easily be identified over the entire glacier.
- Snow density was measured down to the SS (5.0 m) at stake position 37.

The location of tower, stakes, density pit and sounding profiles are shown in Figure 2-2.

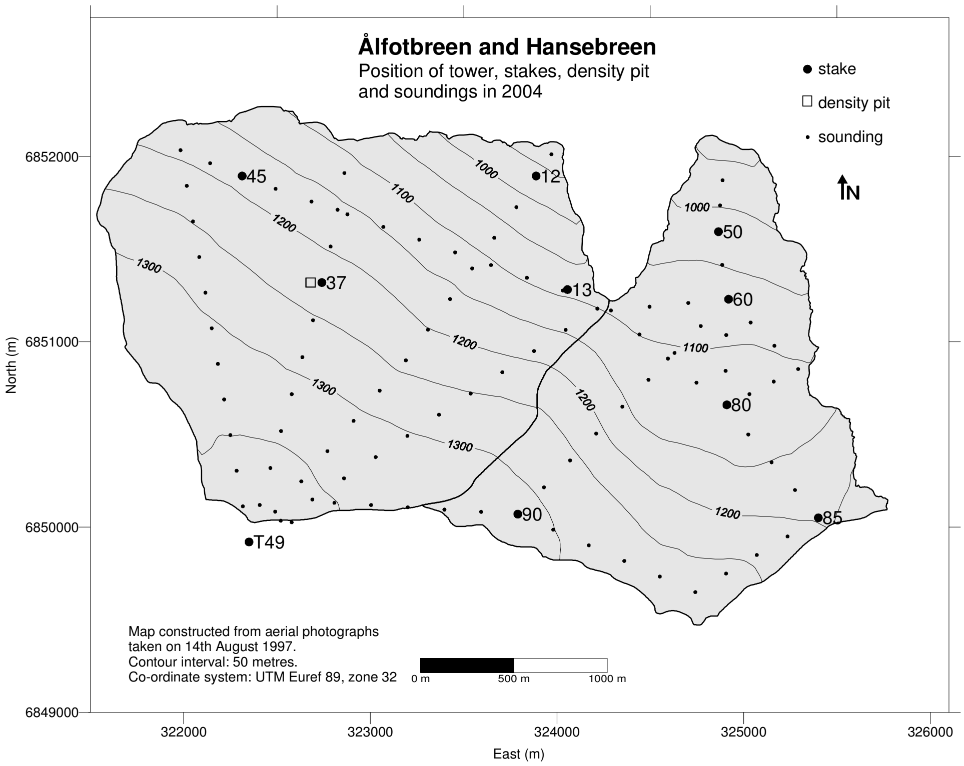


Figure 2-2
Location of stakes, soundings and density pit at Ålfotbreen and Hansebreen in 2004.

Ablation measurements

Ablation was measured on 12th and 13th of October. The net balance was directly measured on stakes in five different positions on both glaciers. There was 2 m of snow remaining at the top of Ålfotbreen (1380 m a.s.l.) and approximately 0.5 m at the top of Hansebreen. At the lowest stake positions as well as all the snow having melted, about 3 m of ice had melted at Ålfotbreen (965 m a.s.l.) and almost 2 m of ice at Hansebreen (1025 m a.s.l.). At the time of the ablation measurements up to 75 cm of fresh snow had fallen in the upper areas, while both glacier tongues were free of snow. Due to the fresh snow it was impossible to determine the boundary between old firn and ice.

Results

The calculations are based on a glacier map from 1997.

Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes, tower and probings) and on measurement of snow density in one location. There was no melting after the final measurements in October 2003.

A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 5.0 m snow was 0.545 g/cm^3. The density model was assumed to be representative for both Ålfotbreen and Hansebreen, and all snow depths were converted to water equivalents using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalents) in a diagram. A curve was drawn based on a visual evaluation (Fig. 2-4), and a mean value for each 50 m height interval was estimated (Tab. 2-1).

Winter balance at Ålfotbreen in 2004 was 3.3 ±0.2 m w.eqv., corresponding to a volume of 15 ±1 mill. m^3 of water. The result is 89 % of the mean winter balance for 1963-2003, and 83 % of the mean for 1986-2003 (same period as Hansebreen).

The winter balance at Hansebreen was 2.9 ±0,2 m w.eqv., corresponding to a volume of 9 ±1 mill. m^3 of water. The result is 83 % of the mean value for the period of investigation.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 2-3). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. Using this method, which is a control of the traditional method, gave the same result - 3.3 m at Ålfotbreen and 2.9 m w.eqv. at Hansebreen.

Summer balance

The density of remaining snow was estimated as 0.60 g/cm^3, while the density of melted ice was estimated as 0.90 g/cm^3.

The summer balance at Ålfotbreen was measured and calculated directly at five stakes. The summer balance varied from −2.7 m w.eqv. at 1380 m elevation to −5.0 m at 965 m elevation. Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −3.4 ±0.3 m w.eqv., corresponding to −15 ±1 mill. m^3 of water. The result is 98 % of the mean value for 1963-2003, and 92 % of the mean value for 1986-2003.

The summer balance for Hansebreen was measured and calculated at four stakes and increased from −2.9 m w.eqv. at 1305 m elevation to −4.3 m at 1025 m elevation. Based on the four stakes and the estimated density, the summer balance was calculated as −3.4 ±0.3 m w.eqv. or −10 ±1 mill. m^3 of water. The result is 88 % of the mean value.

The summer balance results for 2004 are the lowest measured during the last ten years for both Ålfotbreen and Hansebreen.

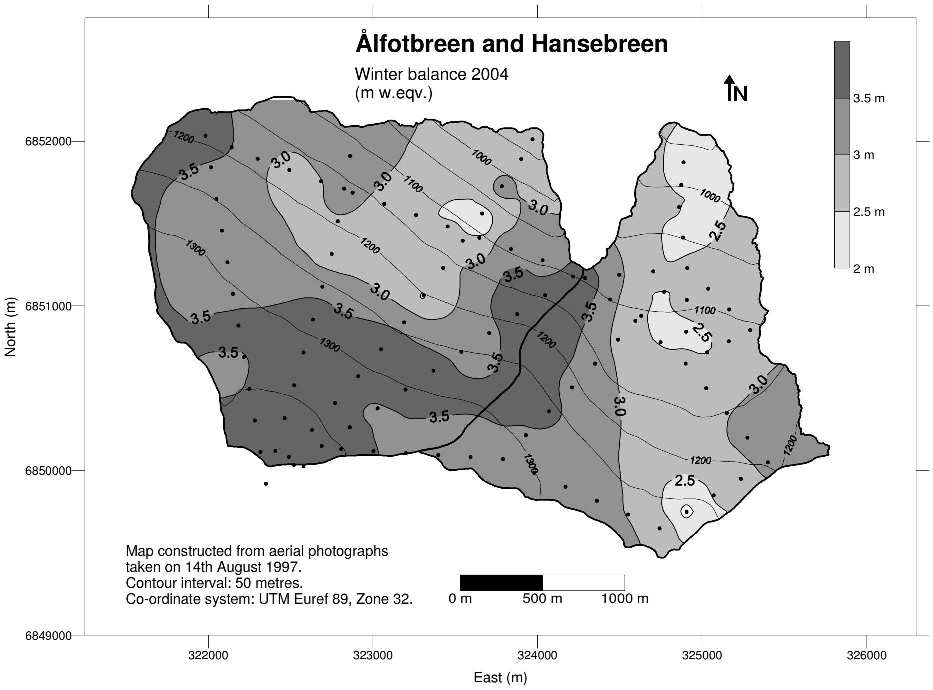


Figure 2-3
Winter balance at Ålfotbreen and Hansebreen in 2004 interpolated from 102 snow depth measurements (•).

Net balance

The net balance at Ålfotbreen for 2004 was calculated as −0.1 ±0.4 m w.eqv., or a volume loss of 0.4 ±2 mill. m^3 of water. The mean net balance between 1963 and 2003 is +0.22 m w.eqv., and +0.26 m during 1986-2003 (same period as Hansebreen).

The net balance at Hansebreen was calculated as −0.5 ±0.4 m w.eqv., or a deficit of 2 ±1 mill. m^3 of water. The mean value for the period 1986-2003 is −0.39 m w.eqv.

According to figure 2-4 the equilibrium line altitude (ELA) is 1225 m a.s.l. on Ålfotbreen and 1220 m a.s.l. on Hansebreen. Consequently, the AAR is 53 % and 31 % respectively.

The mass balance results are shown in Table 2-1. The corresponding curves for specific and volume balance are shown in Figure 2-4. The historical mass balance results are presented in Figure 2-5.

The balance year 2003/2004 is the fourth successive year with negative net balance at both Ålfotbreen and Hansebreen. However, last year's deficit at Ålfotbreen (−0.1 m) is not significant. Since 1996 the cumulative net balance is −5.9 m w.eqv. at Ålfotbreen and −9.3 m w.eqv. at Hansebreen. During the period 1996-2004 only one year (2000) shows a significant positive net balance. Consequently, the last nine years differ from the seven-year period 1989-95 when the cumulative net balance was +11.2 m w.eqv. at Ålfotbreen and +4.0 m eqv. at Hansebreen.

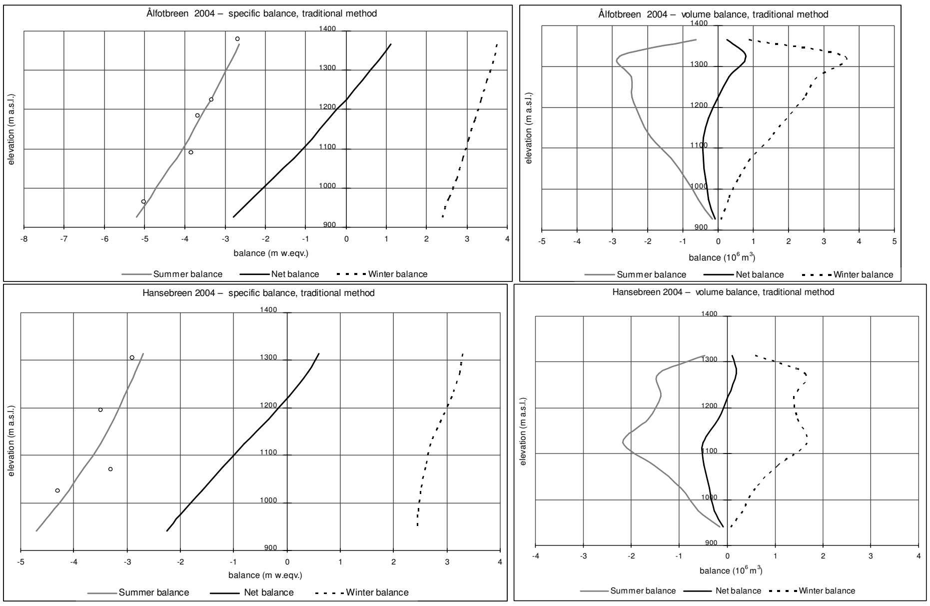


Figure 2-4
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2004 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (o).

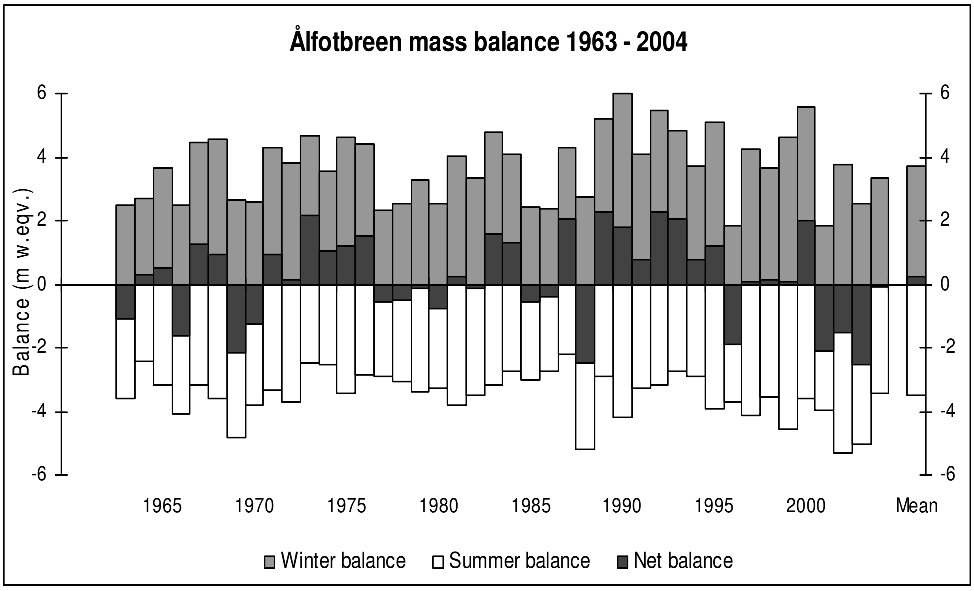
Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2004. The mean values for Ålfotbreen during the period 1963-2003 are 3.71 m (bw), −3.49 m (bs) and +0.22 m w.eqv. (bn). The corresponding values for Hansebreen during the period 1986-2003 are 3.46 m, −3.85 m and −0.39 m w.eqv.

Mass balance Ålfotbreen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 12th May 2004		Measured 13th Oct 2004		Summer surfaces 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1350 - 1382	0.23	3.75	0.9	-2.65	-0.6	1.10	0.3
1300 - 1350	0.98	3.65	3.6	-2.85	-2.8	0.80	0.8
1250 - 1300	0.80	3.50	2.8	-3.10	-2.5	0.40	0.3
1200 - 1250	0.73	3.35	2.4	-3.35	-2.4	0.00	0.0
1150 - 1200	0.61	3.20	1.9	-3.65	-2.2	-0.45	-0.3
1100 - 1150	0.49	3.05	1.5	-3.90	-1.9	-0.85	-0.4
1050 - 1100	0.32	2.90	0.9	-4.20	-1.3	-1.30	-0.4
1000 - 1050	0.20	2.75	0.6	-4.55	-0.9	-1.80	-0.4
950 - 1000	0.11	2.55	0.3	-4.85	-0.6	-2.30	-0.3
903 - 950	0.03	2.40	0.1	-5.20	-0.2	-2.80	-0.1
903 - 1382	**4.50**	**3.32**	**15.0**	**-3.42**	**-15.4**	**-0.10**	**-0.4**

Mass balance Hansebreen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 12th May 2004		Measured 13th Oct 2004		Summer surface 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1300 - 1327	0.18	3.30	0.58	-2.70	-0.48	0.60	0.11
1250 - 1300	0.50	3.25	1.63	-2.85	-1.43	0.40	0.20
1200 - 1250	0.45	3.10	1.40	-3.05	-1.38	0.05	0.02
1150 - 1200	0.51	2.90	1.47	-3.25	-1.65	-0.35	-0.18
1100 - 1150	0.62	2.70	1.68	-3.50	-2.17	-0.80	-0.50
1050 - 1100	0.40	2.60	1.05	-3.80	-1.53	-1.20	-0.48
1000 - 1050	0.23	2.50	0.58	-4.10	-0.96	-1.60	-0.37
950 - 1000	0.13	2.45	0.33	-4.45	-0.59	-2.00	-0.27
930 - 950	0.03	2.45	0.08	-4.70	-0.15	-2.25	-0.07
930 - 1327	**3.06**	**2.87**	**8.8**	**-3.38**	**-10.3**	**-0.50**	**-1.5**



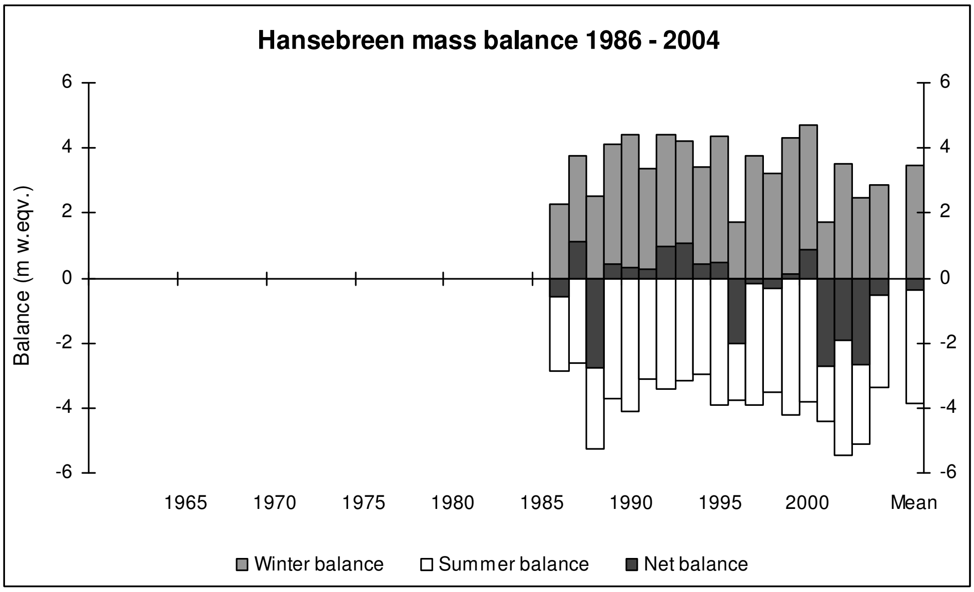


Figure 2-5
Mass balance at Ålfotbreen (upper) during the period 1963-2004 and Hansebreen (lower) during the period 1986-2004.

3. Folgefonna (Bjarne Kjøllmoen)

Folgefonna is situated in the south-western part of Norway between Hardangerfjorden to the west and the mountain plateau Hardangervidda to the east. It is divided into three separate ice caps - Northern, Middle and Southern Folgefonna. In 2003 mass balance measurements began on two adjacent westward-facing outlet glaciers of Southern Folgefonna (60°4'N, 6°24'E) – Breidablikkbrea (3.6 km^2) and Gråfjellsbrea (8.9 km^2). Southern Folgefonna is the third largest (168 km^2 in 1981) ice cap in Norway.

Mass balance measurements were carried out at Breidablikkbrea during 1963-68 (Pytte, 1969) and at Gråfjellsbrea during the periods 1964-68 and 1974-75 (Wold and Hagen, 1977). The historical results are presented in Figure 3-1.

3.1 Mass balance 2004

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 27th May. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-x):

- Uninterrupted measurements of stakes in four positions on each of the glaciers. Measurements of stake replacements and older stakes that appeared during the melt season at one position at Breidablikkbrea and two positions at Gråfjellsbrea. One stake position (60) is located on the boundary between the two glaciers and is included in the calculations for both glaciers.
- 49 snow depth soundings along a total of about 9 km of profiles at Breidablikkbrea, and 77 snow depth soundings along about 15 km of profiles at Gråfjellsbrea. The summer surface (SS) could be identified over the entire glacier area. However, the snow depths at Breidablikkbrea varied significantly and twelve soundings were rejected due to uncertainty. At Breidablikkbrea snow depth varied between 3 and 5 m. At Gråfjellsbrea snow depth was 1-1½ m in the lower parts (1100-1200 m a.s.l.). In the areas above 1300 m altitude snow depth varied between 2½ and 5½ m. However most soundings (70 %) showed depths between 4 and 5 m.
- Snow density was measured down to the SS (3.8 m) at stake position 25 (1485 m a.s.l.) at Gråfjellsbrea.

The location of stakes, density pit and sounding profiles are shown in Figure 3-1.

Ablation measurements

Ablation was measured on 29th September. The net balance was measured at stakes in five different positions on Breidablikkbrea and six positions on Gråfjellsbrea. In areas above 1500 m altitude there was up to 0.5 m of snow remaining on the glacier surface. At the time of the ablation measurements between 10 and 80 cm of fresh snow had fallen.

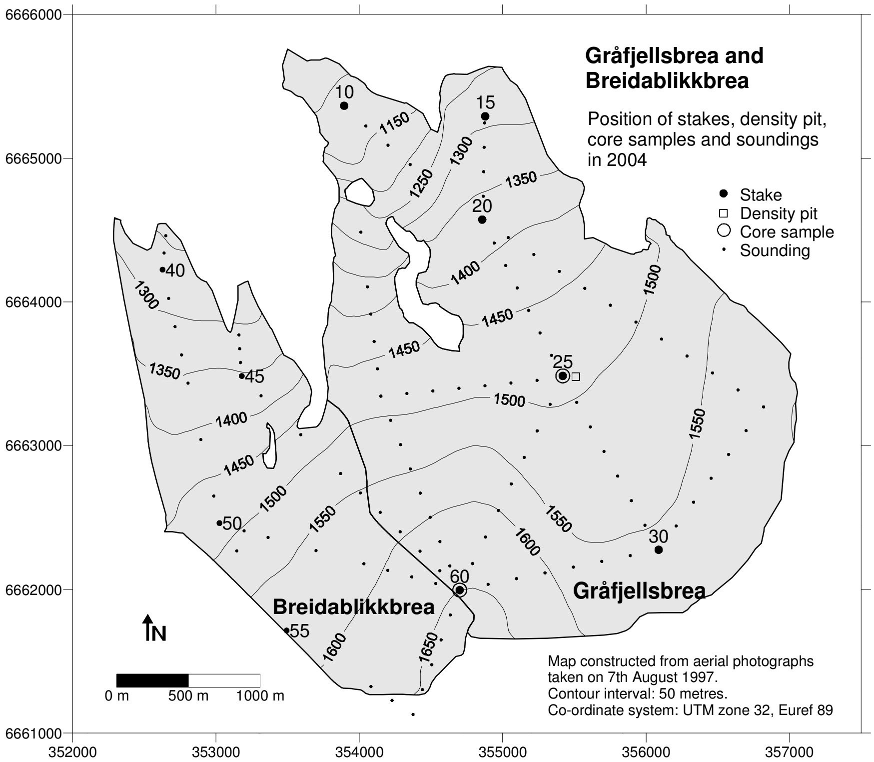


Figure 3-1
Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2004.

Results

The calculations are based on a glacier map from 1997.

Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes and soundings) and on measurement of snow density in one representative location. There was no melting after the final measurements in September 2003.

A density profile was modelled from the snow density measured at 1485 m a.s.l. The mean snow density of 3.8 m snow was 0.526 g/cm^3. The density model was assumed to be representative for both Breidablikkbrea and Gråfjellsbrea, and all snow depths were converted to water equivalent using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 3-3) and a mean value for each 50 m height interval was estimated (Tab. 3-1).

Winter balance at Breidablikkbrea in 2004 was 2.21 ±0.3 m w.eqv., corresponding to a volume of 8 ±1 mill. m^3 of water. The result is 100 % of the average for the study period 1963-68. The winter balance for 2003 was 2.1 m w.eqv.

The winter balance at Gråfjellsbrea was 2.0 ±0.2 m w.eqv., corresponding to a volume of 18 ±1 mill. m^3 of water. The result is 82 % of the average for 1964-68. The result for 2003 was 1.9 m w.eqv.

Usually there is a correlation between snow depth and elevation – increasing snow depth with increasing elevation. The soundings from Breidablikkbrea show huge local variation in snow depth. Nor is there any distinct trend of increasing snow depth with increasing elevation. Conversely, Gråfjellsbrea shows homogeneous soundings and increasing snow depth with increasing elevation. Due to this disparity in data quality the accuracy of winter balance for Breidablikkbrea (±0.3 m) is poor compared with Gråfjellsbrea (±0.2 m).

As verification, the winter balance was also calculated using three different gridding methods based on the aerial distribution of the snow depth measurements (Fig. 3-xx). For Breidablikkbrea twelve extra points estimated from nearest measurements were included to support the interpolation routine. Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. This method gave 2.3 m w.eqv. for Breidablikkbrea and 2.1 m w.eqv. for Gråfjellsbrea.

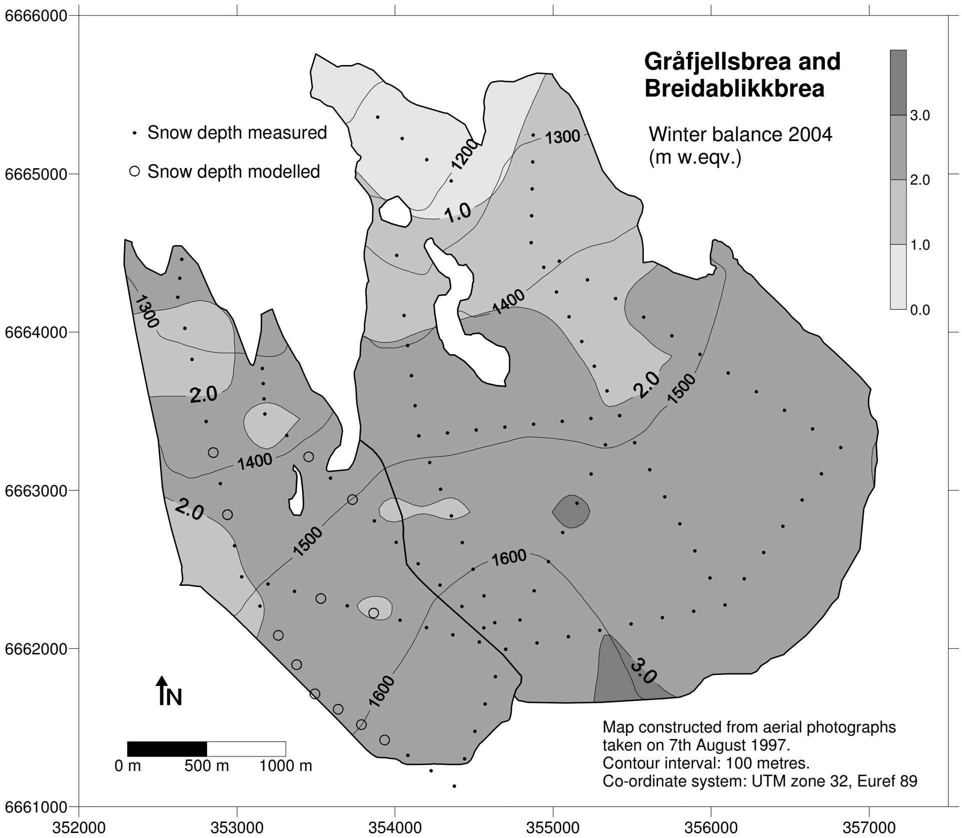


Figure 3-2
Winter balance at Breidablikkbrea and Gråfjellsbrea in 2004 interpolated from 111 snow depth measurements (•) and 12 estimated points (○).

Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 0.60 g/cm^3. The density of melted old firn was estimated as 0.80 g/cm^3, and the density of melted ice was determined as 0.90 g/cm^3.

The summer balance at Breidablikkbrea was measured and calculated at five stakes, and increased from −2.3 m w.eqv. at 1645 m altitude to −4.1 m at 1340 m altitude. Based on estimated density and stake measurements the summer balance was calculated as −3.2 ±0.3 m w.eqv., corresponding to −11 ±1 mill. m^3 of water. The result is 132 % of the mean value for 1963-68. The result for 2003 was −4.3 m w.eqv.

The summer balance for Gråfjellsbrea was measured and calculated at six stakes and increased from −2.3 m w.eqv. at 1645 m altitude to −5.1 m at 1095 m altitude. Based on the six stakes and the estimated density the summer balance was calculated as −2.9 ±0.3 m w.eqv. or −25 ±1 mill. m^3 of water. The result is 121 % of the mean value for 1964-68. The result for 2003 was −4.1 m w.eqv.

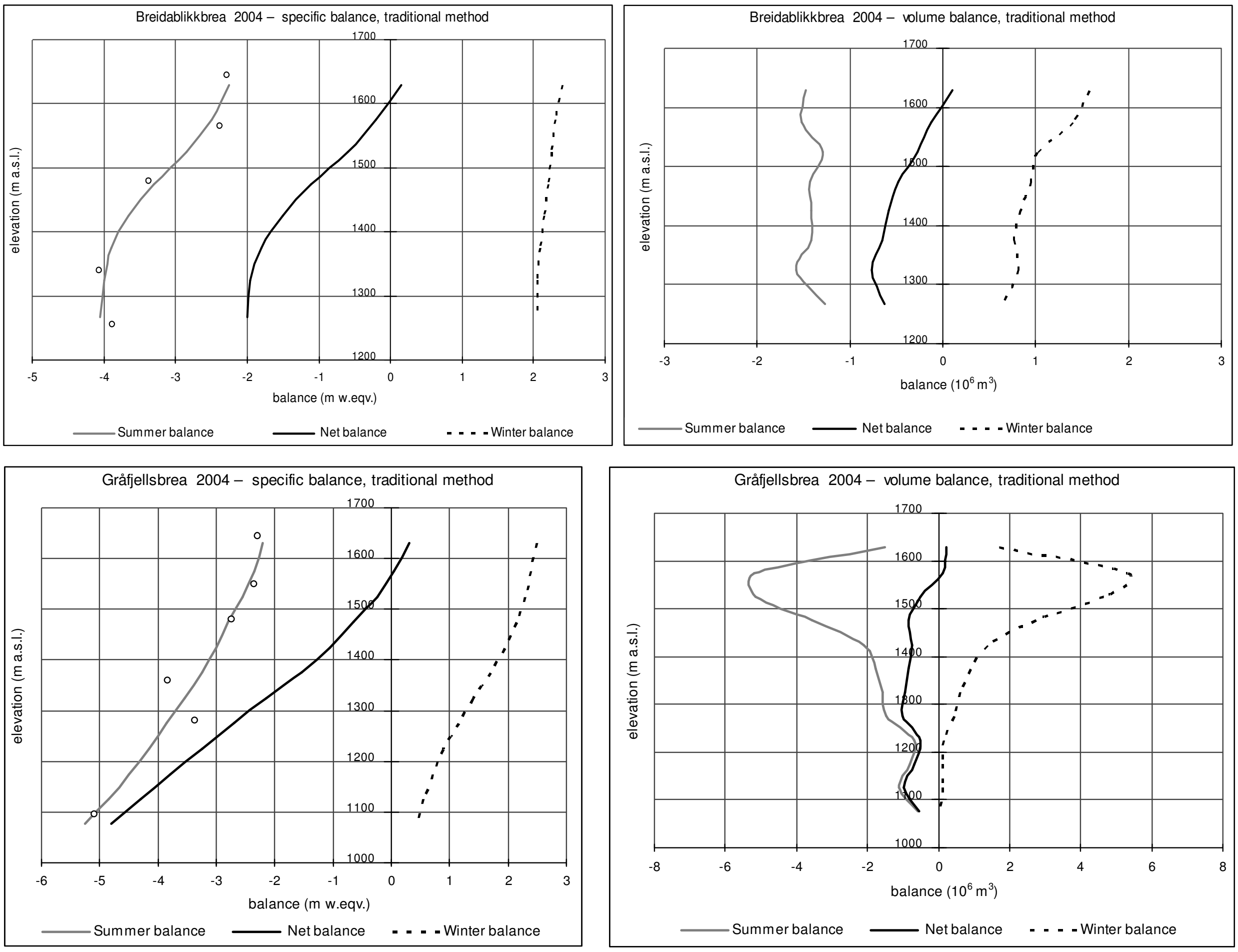


Figure 3-3
Mass balance diagram for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2004 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (o).

Net balance

The net balance at Breidablikkbrea for 2004 was calculated as −0.9 ±0.4 m w.eqv., or a volume loss of 3 ±1 mill. m^3 of water. The mean net balance for 1963-68 was −0.19 m w.eqv. In 2003 the net balance was −2.3 m w.eqv.

The net balance at Gråfjellsbrea was calculated as −0.8 ±0.4 m w.eqv., or a deficit of 7 ±4 mill. m^3 of water. The mean value for the period 1964-68 was +0.12 m w.eqv. and the result for 2003 was −2.2 m w.eqv.

Based on Figure 3-3 the equilibrium line altitude (ELA) lies at 1605 m a.s.l. on Breidablikkbrea and 1565 m a.s.l. on Gråfjellsbrea. Consequently, the Accumulation Area Ratios (AAR) are 17 % and 24 %, respectively.

The mass balance results are shown in Table 3-1. The corresponding curves for specific and volume balance are shown in Figure 3-3. The historical mass balance results are presented in Figure 3-4.

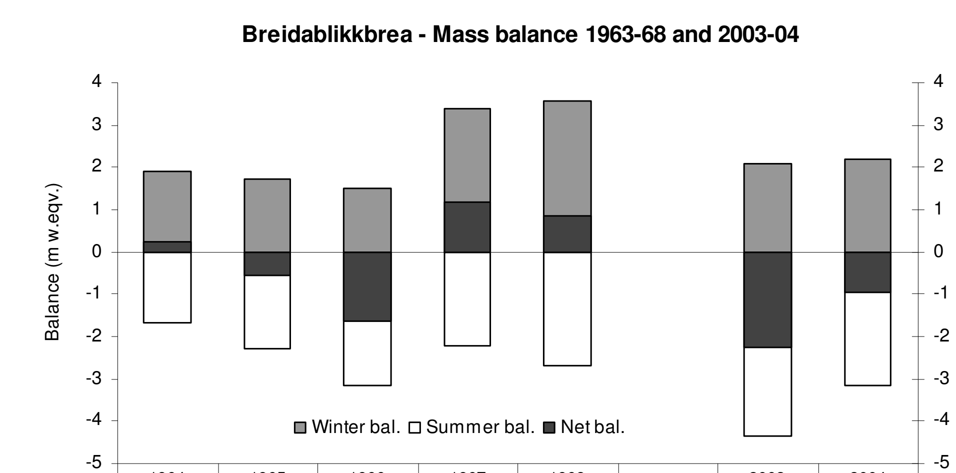
Table 3-1
Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2004.

Mass balance Breidablikkbrea 2003/04 – traditional method

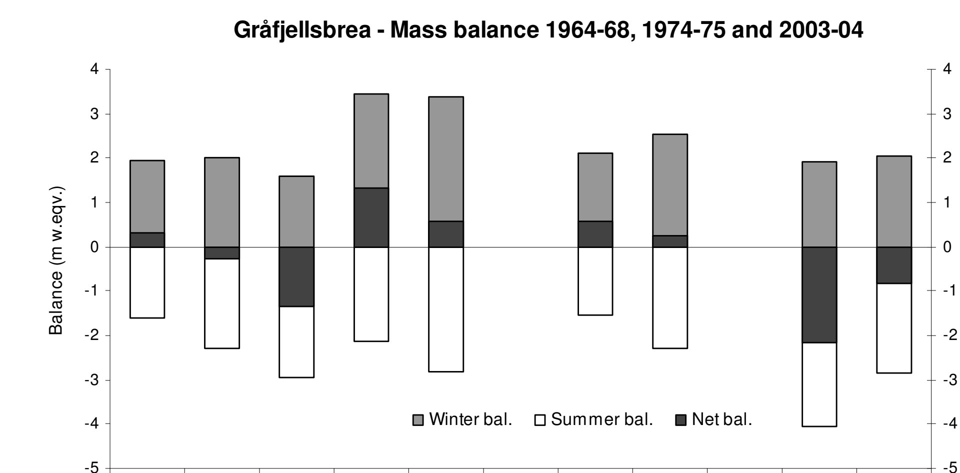
Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 27th May 2004: Specific (m w.eq.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 29th Sep 2004: Specific (m w.eq.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surfaces 2003 - 2004: Specific (m w.eq.)	Net balance: Volume (10^6 m^3)
1600 - 1659	0.66	2.40	1.6	-2.25	-1.5	0.15	0.1
1550 - 1600	0.61	2.30	1.4	-2.50	-1.5	-0.20	-0.1
1500 - 1550	0.45	2.25	1.0	-2.85	-1.3	-0.60	-0.3
1450 - 1500	0.43	2.20	1.0	-3.30	-1.4	-1.10	-0.5
1400 - 1450	0.39	2.15	0.8	-3.65	-1.4	-1.50	-0.6
1350 - 1400	0.36	2.10	0.8	-3.90	-1.4	-1.80	-0.7
1300 - 1350	0.40	2.05	0.8	-4.00	-1.6	-1.95	-0.8
1236 - 1300	0.31	2.05	0.6	-4.05	-1.3	-2.00	-0.6
1236 - 1659	**3.61**	**2.21**	**8.0**	**-3.16**	**-11.4**	**-0.94**	**-3.4**

Mass balance Gråfjellsbrea 2003/04 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 27th May 2004: Specific (m w.eq.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 29th Sep 2004: Specific (m w.eq.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surfaces 2003 - 2004: Specific (m w.eq.)	Net balance: Volume (10^6 m^3)
1600 - 1659	0.68	2.50	1.7	-2.20	-1.5	0.30	0.2
1550 - 1600	2.21	2.40	5.3	-2.35	-5.2	0.05	0.1
1500 - 1550	2.03	2.30	4.7	-2.55	-5.2	-0.25	-0.5
1450 - 1500	1.28	2.15	2.7	-2.80	-3.6	-0.65	-0.8
1400 - 1450	0.70	1.95	1.4	-3.00	-2.1	-1.05	-0.7
1350 - 1400	0.54	1.70	0.9	-3.25	-1.8	-1.55	-0.8
1300 - 1350	0.44	1.40	0.6	-3.55	-1.6	-2.15	-0.9
1250 - 1300	0.38	1.15	0.4	-3.85	-1.5	-2.70	-1.0
1200 - 1250	0.16	0.90	0.1	-4.15	-0.7	-3.25	-0.5
1150 - 1200	0.18	0.70	0.1	-4.50	-0.8	-3.80	-0.7
1100 - 1150	0.23	0.55	0.1	-4.85	-1.1	-4.30	-1.0
1051 - 1100	0.11	0.45	0.1	-5.25	-0.6	-4.80	-0.5
1051 - 1659	**8.94**	**2.04**	**18.2**	**-2.85**	**-25.5**	**-0.82**	**-7.3**



	1964	1965	1966	1967	1968		2003	2004
Winter bal.	1.92	1.72	1.52	3.40	3.55		2.08	2.21
Summer bal.	-1.68	-2.28	-3.17	-2.23	-2.68		-4.35	-3.16
Net bal.	0.24	-0.56	-1.65	1.17	0.87		-2.27	-0.95



	1964	1965	1966	1967	1968		1974	1975		2003	2004
Winter bal.	1.94	2.01	1.58	3.46	3.39		2.11	2.53		1.90	2.04
Summer bal.	-1.62	-2.29	-2.93	-2.14	-2.82		-1.53	-2.28		-4.07	-2.85
Net bal.	0.32	-0.28	-1.35	1.32	0.57		0.58	0.25		-2.17	-0.81

Figure 3-4
Winter, summer and net balance at Breidablikkbrea over the period 1963-68 and 2003-04 (upper figure), and at Gråfjellsbrea during the periods 1964-68, 1974-75 and 2003-04 (lower figure).

4. Nigardsbreen (Bjarne Kjøllmoen)

Nigardsbreen (61°42'N, 7°08'E) is one of the largest and best-known outlet glaciers from Jostedalsbreen. It has an area of 47.8 km^2 (measured in 1984) and flows south-east from the centre of the ice cap. Nigardsbreen accounts for approximately 10 % of the total area of Jostedalsbreen, and extends from 1960 m a.s.l. down to approximately 320 m a.s.l.

Glaciological investigations in 2004 include mass balance and front position change. Some observations of the ice-dammed lake Brimkjelen at Tunsbergdalsbreen have also been performed. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The glacier snout of Nigardsbreen and lake Nigardsvatnet photographed on 3rd August 2004. Photo: Hallgeir Elvehøy.

4.1 Mass balance 2004

Fieldwork

Snow accumulation measurements

Snow accumulation measurements on the plateau were performed on 11th and 12th of May and supplemented on 27th May at the glacier tongue. The calculation of winter balance (Fig. 4-2) is based on:

- Uninterrupted measurements of both towers (T56 and T95) and stakes in three different positions (50, 1000 and 600). It was also possible to make use of measurements of substitute stakes drilled in May 2004 and older stakes that appeared during the melt season in four more positions (96, 94, 54 and 53). The stake measurements on the plateau showed snow depth between 3.0 and 4.9 m. The supplementary measurements in late May showed 1.1 m snow at 1000 m altitude, while areas below 600 m altitude were free of snow. Stake readings did not show any indications of melting after the final measurements in September 2003.

- Core samples at positions 57, 96, 94 and 54 showing snow depth between 3.2 and 4.2 m.
- 199 snow depth soundings along approximately 30 km of profiles between 1320 and 1960 m a.s.l. Identifying the summer surface (SS) was fairly simple over most of the glacier, but somewhat difficult in the uppermost areas. The snow depth soundings gave snow thickness between 3 and 5 m.
- Snow density was measured at positions 57 (1960 m a.s.l.) and 54 (1610 m a.s.l.).

Location of stakes, towers, density pits, core samples and sounding profiles are shown in Figure 4-2.

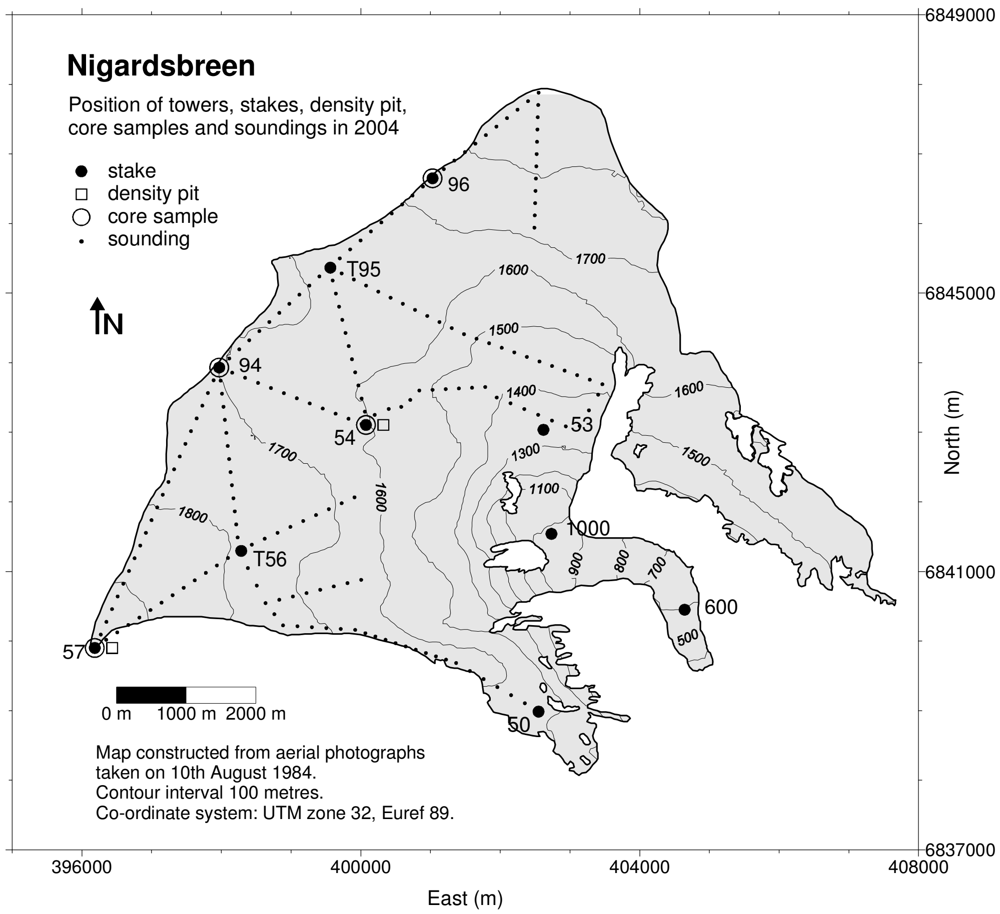


Figure 4-2
Location of towers and stakes, density pits, core samples and sounding profiles on Nigardsbreen in 2004.

Ablation measurements

The final ablation measurements were carried out on 29th and 30th September. Measurements were made at twelve stakes and two towers in ten different positions. Since snow measurements in May the stakes on the plateau had increased in length between 1.7 and 3.0 m. Hence, there was between 1.5 and 2.0 m of snow remaining from winter 2004. At the time of measurements 0.6-1.1 m of fresh snow had fallen in areas above 1600 m elevation.

Results

The calculations are based on a glacier map from 1984.

Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes and towers, probings and core drillings) and on measurement of snow density at two representative locations.

There was no melting after the final measurements in September 2003. Consequently, winter *accumulation* and winter *balance* are equal. Snow accumulation measurements on the plateau were performed on 11th and 12th May. Corresponding measurements at the tongue were carried out on 27th May. It is assumed that the snow accumulation was approximately unchanged below 1000 m altitude in the intervening period.

Density profiles were modelled from the snow density measured at 1960 m altitude (3.2 m depth) and 1610 m altitude (3.5 m). Using these models gave a snow density of 0.473 g/cm^3 (1960 m a.s.l.) and 0.538 g/cm^3 (1610 m a.s.l.). The model from 1960 m altitude was used for snow depth measurements carried out *above* 1750 m a.s.l., whereas the model from 1610 m altitude was used for elevations *below* 1750 m a.s.l.

The winter balance calculation was performed by plotting measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 4-3), and a mean value for each 100 m height interval estimated (Tab. 4-1). The elevations above 1320 m a.s.l. were well represented with point measurements. Below this altitude the curve pattern was based on stake measurements at 985 m and 615 m altitude.

This gives a winter balance of 2.0 ±0.2 m w.eqv., corresponding to a water volume of 94 ±10 mill. m^3. The result is 83 % of the average for 1962-2003.

The winter balance was also calculated using different gridding methods based on the aerial distribution of the snow depth measurements (Fig. 4-3). In areas with insufficient measurements some (nine) simulated points were extracted. These point values were modelled based on measurements from the period 1975-81, years with extensive measurements. Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. The calculations are performed using three different gridding methods. The results varied from 1.8 m to 2.0 m w.eqv.

Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 0.60 g/cm^3. The density of 1 year old ablated firn was estimated as 0.65 g/cm^3, and, the density of melted ice was taken as 0.90 g/cm^3.

The summer balance was calculated at ten stakes and towers, and increased from −0.6 m w.eqv. at the glacier summit (1960 m a.s.l.) to −8.4 m down on the tongue (615 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −2.0 ±0.3 m w.eqv., which is −96 ±15 mill. m^3 of water. The result is 102 % of the average for 1962-2003.

Net balance

The net balance was calculated at stakes and towers in ten positions. At stake 1000 (985 m a.s.l.) the measurements were supplemented with estimated values based on interpolation between stakes 600 (615 m a.s.l.) and 53 (1320 m a.s.l.).

The net balance for 2004 was calculated as −0.04 m ±0.3 m w.eqv., which is a deficit of −2 ±15 mill.m^3 water. The mean value for the period 1962-2003 is +0.41 m w.eqv. (Fig. 4-5), while the average for 1996-2003 is +0.03 m w.eqv.

Based on Figure 4-4, the Equilibrium Line Altitude (ELA) was 1530 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 70 %.

The mass balance in 2004 for Nigardsbreen is shown in Table 4-1 and the corresponding curves are shown in Figure 4-4. The historical mass balance results are presented in Figure 4-5.

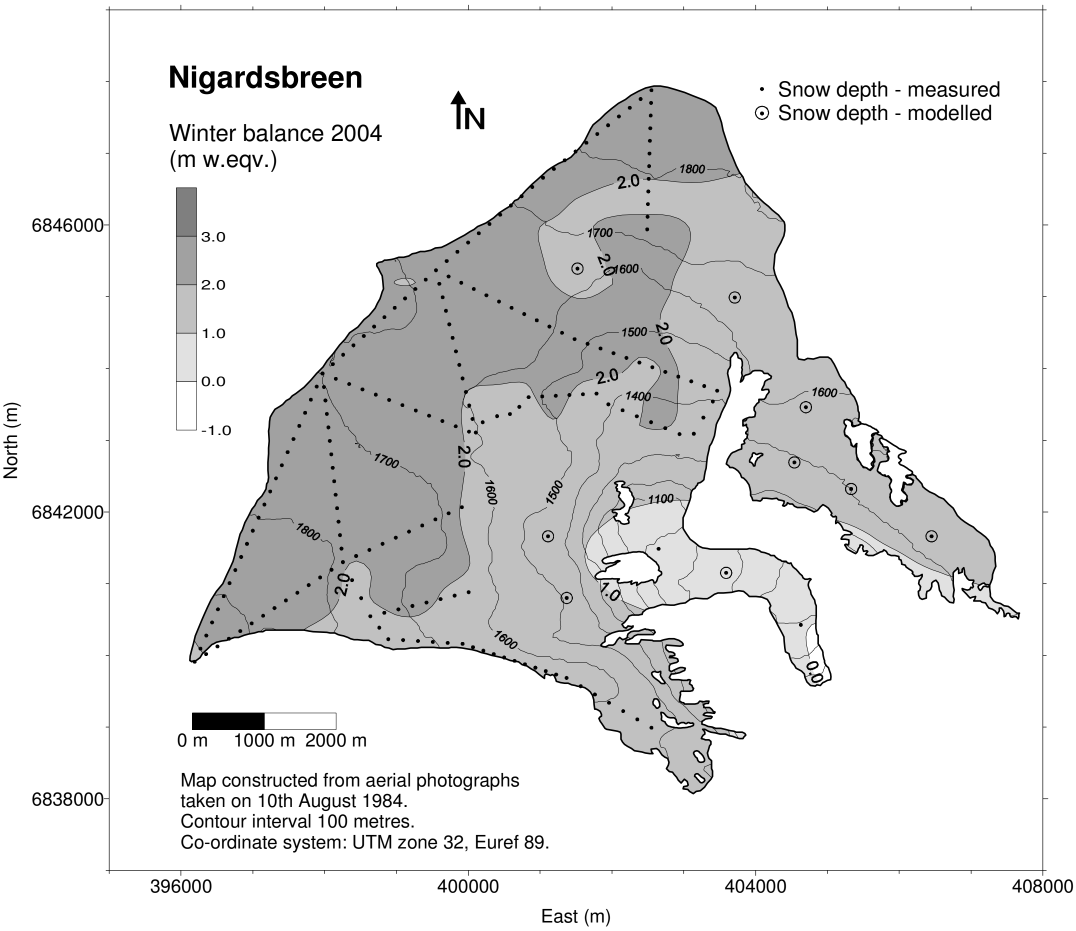


Figure 4-3
Winter balance at Nigardsbreen in 2004 interpolated from 201 measurements (•) of snow depth. In areas with few or no measurements nine extrapolated points (⊙) are added.

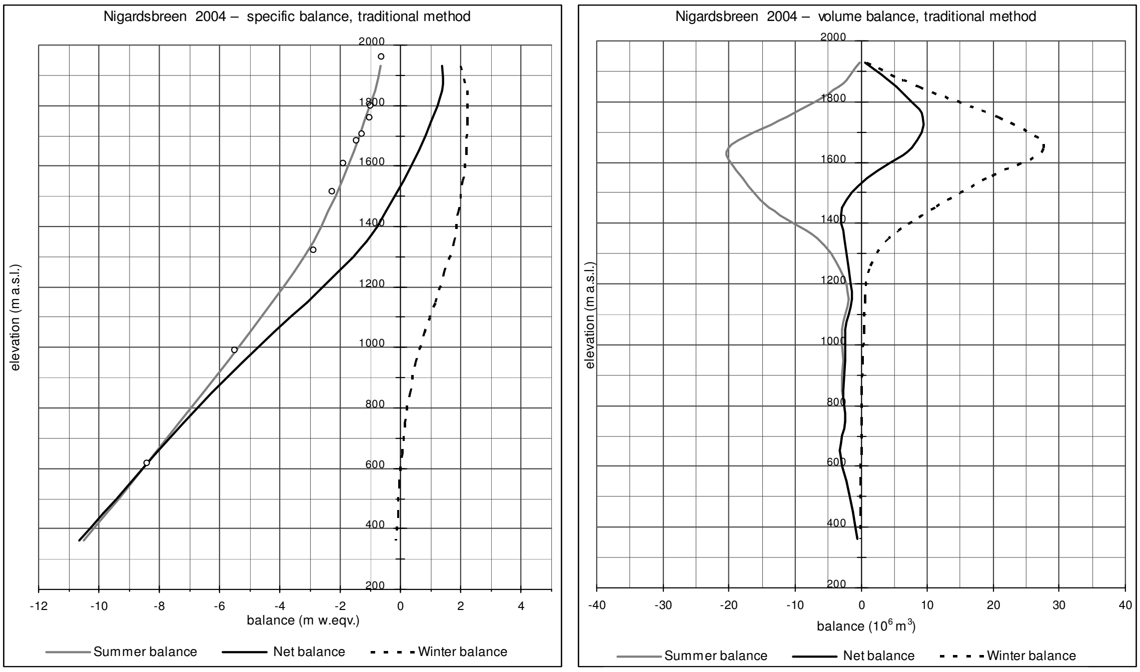


Figure 4-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2004. Specific summer balance at ten stakes are shown as dots (o). The net balance curve intersects the y-axis and defines the ELA as 1530 m a.s.l. Thus, the AAR was 70 %.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2004. Mean values for the period 1962-2003 are 2.38 (b_s), –1.97 m (b_s) and +0.41 m (b_n) water equivalent.

Mass balance Nigardsbreen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 11th May 2004		Measured 30th Sep 2004		Summer surface 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1900 - 1960	0.38	2.00	0.8	-0.65	-0.2	1.35	0.5
1800 - 1900	3.92	2.20	8.6	-0.85	-3.3	1.35	5.3
1700 - 1800	9.39	2.20	20.7	-1.20	-11.3	1.00	9.4
1600 - 1700	12.88	2.15	27.7	-1.55	-20.0	0.60	7.7
1500 - 1600	9.18	2.05	18.8	-1.95	-17.9	0.10	0.9
1400 - 1500	5.82	1.90	11.1	-2.40	-14.0	-0.50	-2.9
1300 - 1400	2.28	1.75	4.0	-2.90	-6.6	-1.15	-2.6
1200 - 1300	0.90	1.45	1.3	-3.55	-3.2	-2.10	-1.9
1100 - 1200	0.45	1.15	0.5	-4.25	-1.9	-3.10	-1.4
1000 - 1100	0.58	0.80	0.5	-5.00	-2.9	-4.20	-2.4
900 - 1000	0.47	0.50	0.2	-5.75	-2.7	-5.25	-2.5
800 - 900	0.44	0.30	0.1	-6.55	-2.9	-6.25	-2.8
700 - 800	0.33	0.15	0.0	-7.35	-2.4	-7.20	-2.4
600 - 700	0.39	0.05	0.0	-8.15	-3.2	-8.10	-3.2
500 - 600	0.24	-0.05	0.0	-8.95	-2.1	-9.00	-2.2
400 - 500	0.12	-0.10	0.0	-9.75	-1.2	-9.85	-1.2
320 - 400	0.05	-0.15	0.0	-10.50	-0.5	-10.65	-0.5
320 - 1960	**47.82**	**1.97**	**94.3**	**-2.01**	**-96.3**	**-0.04**	**-2.0**

The balance year 2003/2004 is the fourth successive year with negative net balance at Nigardsbreen. However, the slight deficit for 2003/04 is insignificant. During the 7-year period 1989-1995 the cumulative net balance was more than 10 m w.eqv. surplus. Over the last 9 years (1996-2004) the cumulative net balance is slightly positive with +0.2 m w.eqv. In this last period only two years show a significant positive net balance, 1998 and 2000. However, during the entire period of investigations (1962-2004) the cumulative net balance is more than 17 m w.eqv.

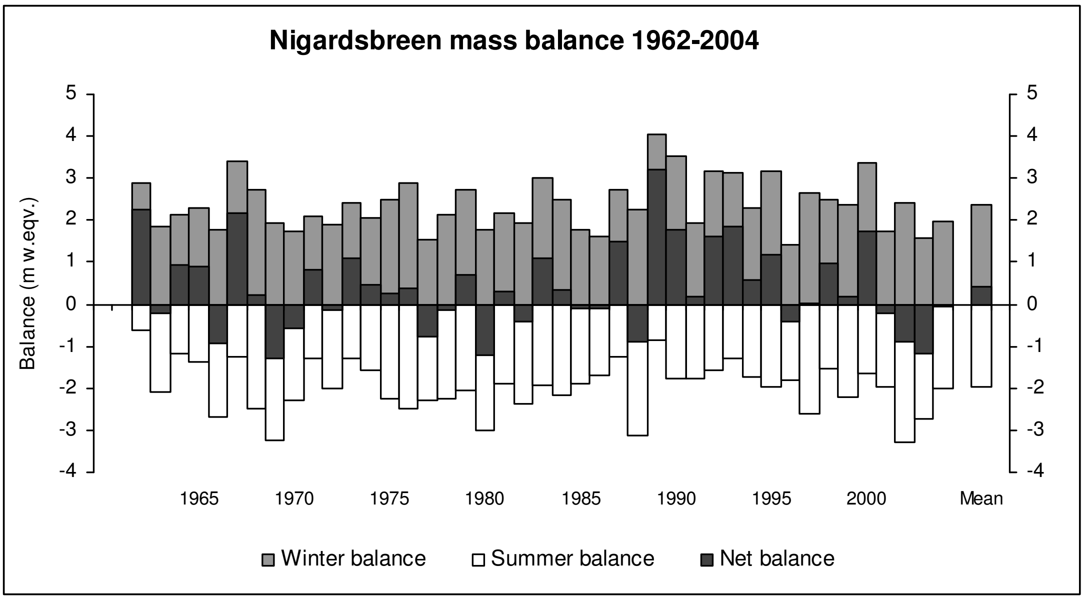


Figure 4-5
Annual mass balance at Nigardsbreen during the period 1962-2004.

4.2 Tunsbergdalsbreen

Mass balance

From 1966 to 1972 mass balance measurements were made simultaneously at both Tunsbergdalsbreen (ca. 50 km^2) and Nigardsbreen. A linear regression analysis of the results from these seven years gives an equation that can be used to calculate the annual net balance of Tunsbergdalsbreen.

$$bn_T = 0.987 \cdot bn_N - 0.283$$

bn_T = net balance at Tunsbergdalsbreen, and bn_N = net balance at Nigardsbreen.

For 2004 the net balance at Tunsbergdalsbreen was estimated as −0.32 ±0.45 m w.eqv., corresponding to a deficit of about 16 ±20 mill. m^3 of water. Since 1962 the estimated accumulated net balance is about +4.7 m w.eqv.

Based on measurements during 1966-72 a correlation between the equilibrium line altitude (ELA) for Nigardsbreen and Tunsbergdalsbreen was established. The analysis indicates that the ELA at Tunsbergdalsbreen in autumn 2004 was about 1400 m a.s.l.

Brimkjelen

About 3 km above the western side of the glacier snout lies an ice-dammed lake called Brimkjelen. Due to glacier recession during the last century, the area and volume of the lake has decreased considerably. The last estimate of the volume was about 2 million m^3 in 1982.

From 1984 to 1997 no systematic observations were made of the lake. Annual observations were resumed in autumn 1997 and continued in 2004 by photography on 27th May and 3rd August (Fig. 4-6). The lake was empty on both occasions. The observations from May, however, may indicate some water was present earlier in 2004.

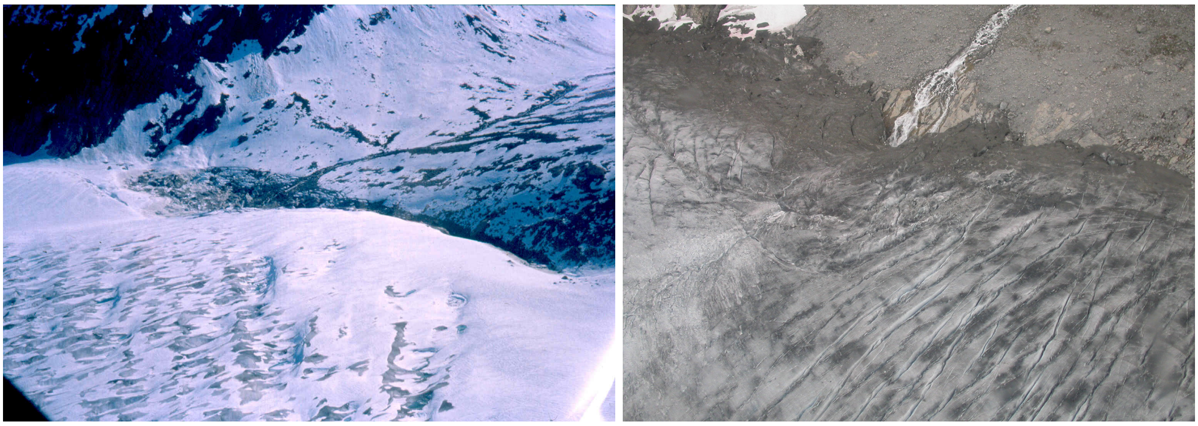


Figure 4-6
Brimkjelen photographed on 27th May 2004 (left) and on 3rd August 2004 (right). The glacier lake was empty on both occasions. Photo: Bjarne Kjøllmoen (left) and Hallgeir Elvehøy (right).

5. Austdalsbreen (Hallgeir Elvehøy)

Austdalsbreen (61°45'N, 7°20'E) is an eastern outlet of the northern part of Jostedalsbreen, ranging in altitude from 1200 to 1760 m a.s.l. Until 1988 the glacier terminated in Austdalsvatnet which is part of the hydro power reservoir Styggevatnet. Glaciological investigations started at Austdalsbreen in 1986 in connection with the construction of the hydro power reservoir.

The glaciological investigations in 2004 included mass balance, front position change and glacier velocity. Mass balance has been measured at Austdalsbreen since 1988.

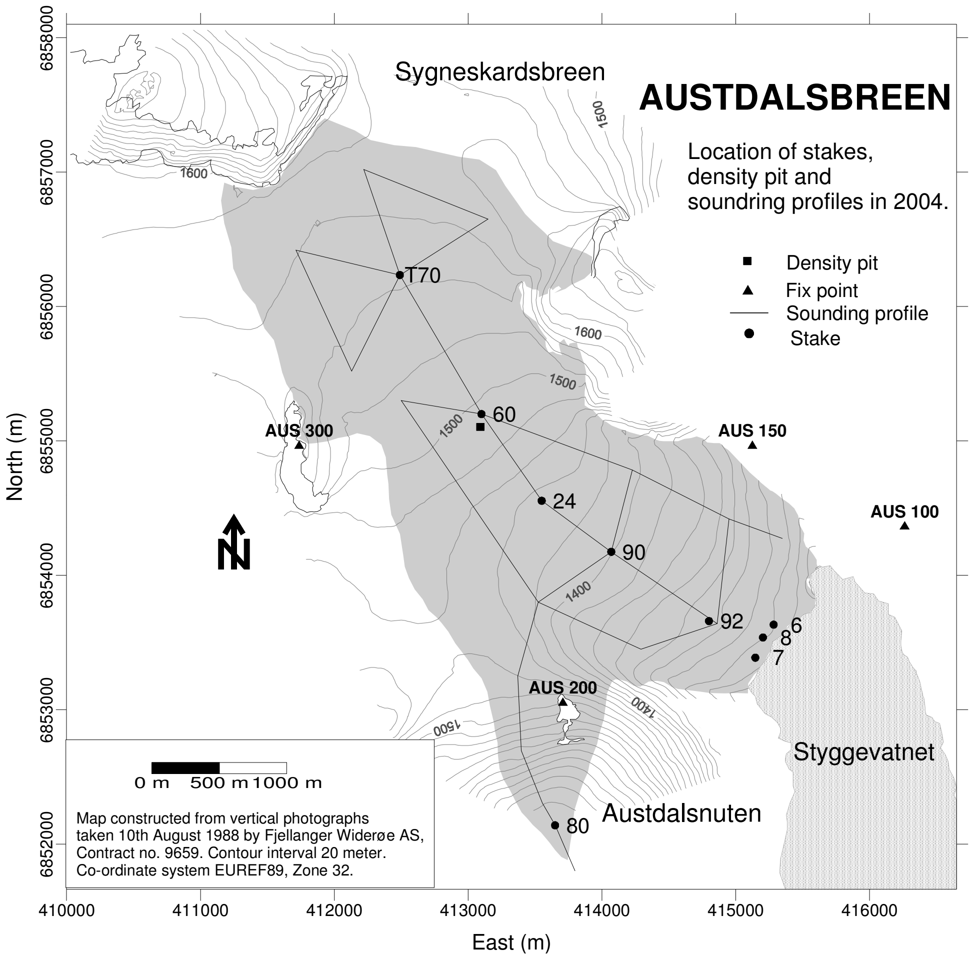


Figure 5-1
Location of stakes, density pit and sounding profiles at Austdalsbreen in 2004.

5.1 Mass balance 2004

Fieldwork

Winter balance was measured on 13th May. The calculation of winter balance was based on the following data (Fig. 5-1):

- Snow depth at stakes 6, 7, 8, 92-02, 90, 24, 60-95 and T70, which was 0.35, 0.00, 0.30, 0.45, 1.75 and 3.80 m, respectively. Stakes 6, 7 and 8 were measured on the 27th

May, but measurements at stake T70 indicate negligible melting between 13th and 27th May.

- Snow depth by coring at stakes 6-04, 7-04, 92-04, 24 and 80, which showed snow depth of 0.1, 0.6, 1.75, 3.15 and 2.55 meter.
- 86 snow depth measurements along 19 km of profiles. At Austdalsnuten above 1700 m a.s.l. the snow depth was 2 to 3 m. Between 1400 and 1600 m a.s.l. most of the soundings showed snow depth of 3 to 4 meter. Between 1300 and 1400 m a.s.l. the snow was 1.5 to 2.5 m deep. Below 1300 m a.s.l. the snow depth was less than 0.5 meter. The summer surface (SS) from 2003 was easy to detect in all areas.
- Snow density down to SS at 3.3 m depth at stake 60-04 (1495 m a.s.l.). Mean snow density was 0.53 g/cm^3.

Summer and net balance measurements were carried out on 30th September. The transient snow line altitude could not be detected due to new snow, but stake measurements indicate that the TSL was close to 1490 m a.s.l. At Austdalsnuten (stake 80), all the winter snow and 0.15 m of firn had melted. At stake T70, 0.55 m snow remained, and at stake 60-04 (1495 m a.s.l.) 0.1 m of snow remained, while other stakes at location 60 showed melting of 0.15 to 0.70 m of firn. The firn line altitude was 1440 m a.s.l. At stake 24, 3.00 m of snow and 0.75 m of ice melted. At stake 90, 1.75 m of snow and 2.50 m of ice melted, and at stake 92, 1.75 m of snow and 3.65 m of ice melted. At the stakes close to the terminus (6, 7, 8) 5 to 6 m of ice melted in addition to the winter snow cover.

Results

The mass balance was calculated according to the stratigraphic method (see chap.1). The calculations are based on a map from 10th August 1988 reduced for the areas below the highest regulated lake level (below 1200 m a.s.l., 0.11 km^2).

Winter balance

There are no observations indicating melting after the stake measurements on 20th September 2003.

The winter balance was calculated from snow depth and snow density measurements on 13th May. A function correlating snow depth with water equivalent was calculated based on snow density measurements at stake 60 (1495 m a.s.l.). The mean density of 4 m of snow in this profile was 0.53 g/cm^3. This function was then used to convert all snow depth measurements to water equivalent.

Snow depth water equivalent values were plotted against altitude. By averaging values in 50 m altitude intervals and visual evaluation, an altitudinal winter balance curve was drawn. From the winter balance curve a mean value for each 50 m altitude interval was determined. The winter balance was 1.6 ±0.2 m w.eqv., or 19 ±2 mill. m^3 water. This is the same result as in 2003, and 71 % of the 1988-2003 average (2.24 m w.eqv.).

The winter balance was also calculated using a gridding method based on the spatial distribution of the snow depth measurements (Fig. 5-2). Water equivalents for each cell in a 50 x 50 m grid were calculated and summarised. The result based on this method, which is a control of the traditional method, also showed a winter balance of 1.6 m w.eqv.

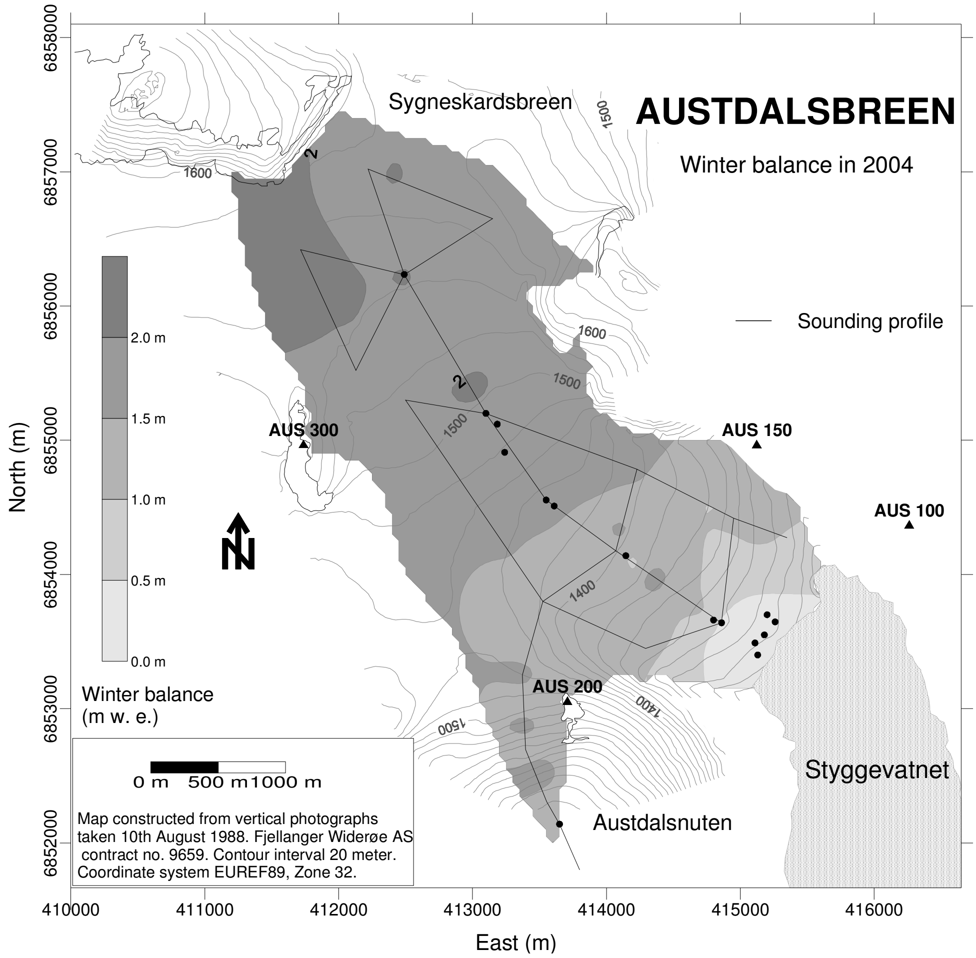


Figure 5-2
Winter balance at Austdalsbreen in 2004 from 96 water equivalent values calculated from snow depth soundings.

Summer balance

The summer balance was calculated directly at 13 stakes in seven stake positions between 1225 and 1730 m a.s.l. The density of firn was set to 0.7 g/cm^3. The density of ice at stake 24 close to the firn line is set to 0.8 g/cm^3 as this ice has not been exposed to high pressure. The summer balance curve was drawn from these values (Fig. 5-3).

Calving from the glacier terminus was calculated as the annual volume of ice (in water equivalent) transported through a cross section close to the terminus, and adjusted for the volume change related to the annual front position change. This volume is calculated as:

$$Q_k = \rho_{ice} * (u_{ice} - u_f) * W * H$$

where ρ_{ice} is 0.9 g/cm^3, u_{ice} is annual glacier velocity (60 ±10 m/a (chapter 5.3), u_f is front position change averaged across the terminus (−6 ±5 m/a, chapter 5.2), W is terminus width (1000 ±50 m), and H is mean ice thickness at the terminus (46 ±5 m) based on surface altitude surveyed September 2003 and September 2004, and a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989). The resulting calving volume was 2.7 ±0.5 mill. m^3 water or 0.23 ±0.04 m w.eqv. averaged across the glacier area (11.8 km^2).

The summer balance, including calving, was calculated as −2.6 ±0.3 m w.eqv., which corresponds to −30 ±3 mill. m^3 of water. The calving volume was 9 % of the summer balance. The result is 106 % of the 1988-2003 average (−2.43 m w.eqv.).

Net balance

The net balance at Austdalsbreen was calculated as −1.0 ±0.3 m w.eqv., corresponding to −11 ±3 mill. m^3 water. This is the fourth consecutive year with negative net balance at Austdalsbreen. The 1988-2003 average is −0.19 w.eqv. The equilibrium line altitude (ELA) is defined at 1495 m a.s.l. from the net balance curve. The negative mass balance at Austdalsnuten (stake 80) is neglected as the winter balance is locally reduced due to wind effects. Accumulation Area Ratio (AAR) was 48 % in 2004. The area above 1700 m a.s.l. is not included in the accumulation area. The altitudinal distribution of winter, summer and net balances are shown in Figure 5-3 and Table 5-1. Results from 1988-2004 are shown in Figure 5-4.

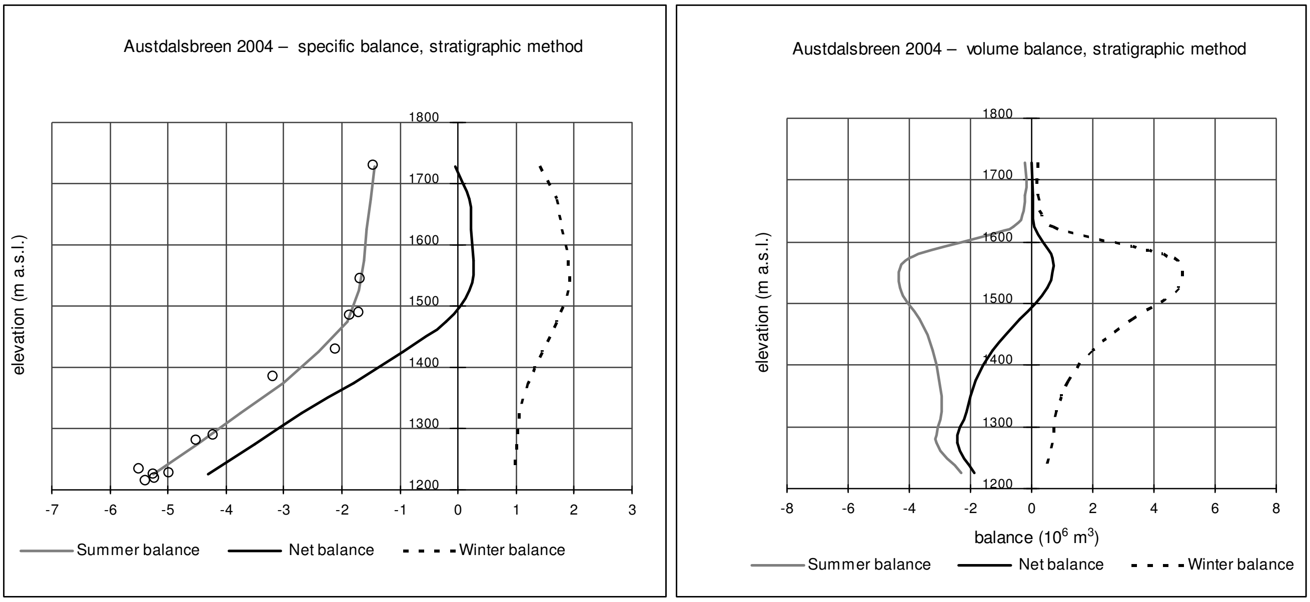


Figure 5-3
Altitudinal distribution of winter-, summer- and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2004. Specific summer balance at 13 stakes in nine locations is shown (o).

Table 5-1
Altitudinal distribution of winter, summer- and net balances at Austdalsbreen in 2004.

Mass balance Austdalsbreen 2003/04 – stratigraphic method

		Winter balance Measured 13th May 2004		Summer balance Measured 30th Sep 2004		Net balance Summer surface 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)
1700 - 1757	0,16	1,40	0,22	-1,45	-0,23	-0,05	-0,01
1650 - 1700	0,13	1,70	0,22	-1,50	-0,19	0,20	0,03
1600 - 1650	0,38	1,80	0,68	-1,57	-0,59	0,23	0,09
1550 - 1600	2,45	1,90	4,65	-1,63	-3,99	0,27	0,66
1500 - 1550	2,54	1,90	4,82	-1,70	-4,32	0,20	0,51
1450 - 1500	1,92	1,70	3,27	-1,90	-3,65	-0,20	-0,38
1400 - 1450	1,36	1,45	1,96	-2,40	-3,25	-0,95	-1,29
1350 - 1400	1,01	1,20	1,21	-3,00	-3,03	-1,80	-1,82
1300 - 1350	0,79	1,05	0,83	-3,75	-2,95	-2,70	-2,12
1250 - 1300	0,69	1,00	0,69	-4,50	-3,09	-3,50	-2,40
1200 - 1250	0,44	0,95	0,41	-5,25	-2,28	-4,30	-1,87
Calving					-2,7		-2,7
1200 - 1757	**11,84**	**1,60**	**19,0**	**-2,56**	**-30,3**	**-0,96**	**-11,3**

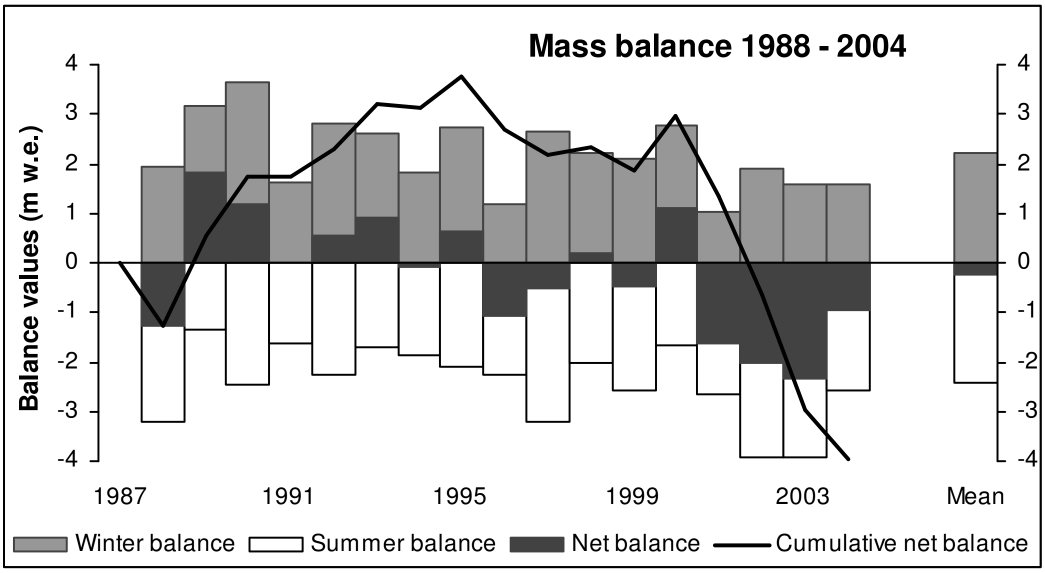


Figure 5-4
Winter, summer and net balances at Austdalsbreen during the period 1988-2004. Mean winter, summer and net balance is 2.20, –2.43 and –0.23 m w. eqv., respectively. Cumulative net balance in this period was –4 m w.eqv.

5.2 Front position change

Eighteen points along the terminus were surveyed on 30th September 2004. Between 20th September 2003 and 30th September 2004 the mean front position change was –6 ±5 m (Fig. 5-5). Since 1988 the glacier terminus has retreated 398 metres, while the glacier area is reduced by approximately 0.42 km^2. The lower part of Austdalsbreen is shown in Figure 5-5.

Due to large variations in calving, the variation in front position throughout the year is large compared with the net change from year to year. Figure 5-6 illustrates how the front position at a central flow line has varied over the last 16 years. As a consequence of lake regulation it was expected that the glacier terminus would retreat. Modelling resulted in a prediction for future front position change shown as a broken line in Figure 5-6. Mean annual net balance has been –0.23 m w.eqv., while the model input was –0.47 m w.eqv.

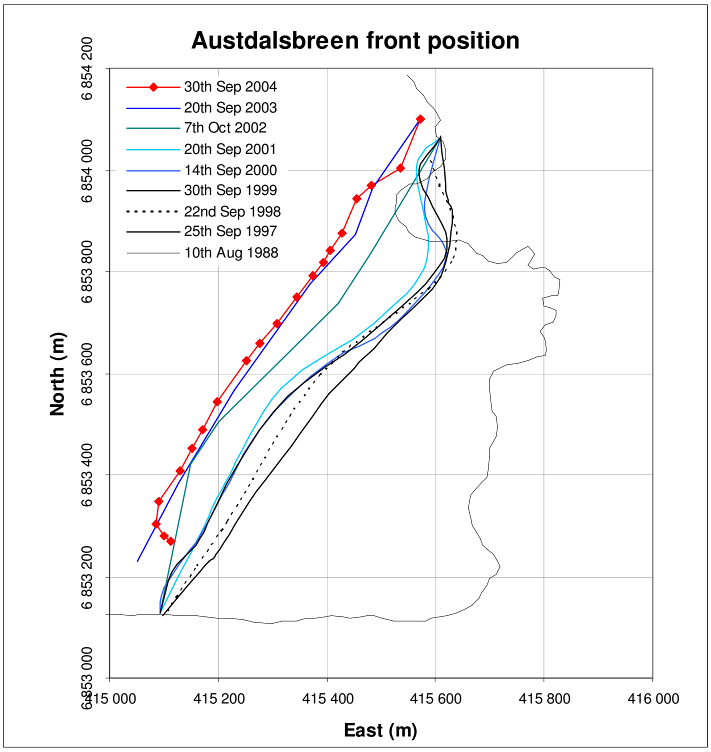


Figure 5-5
Surveyed front position of Austdalsbreen in 1988, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004. Mean front position retreat between 20th September 2003 and 30th September 2004 was –6 m.

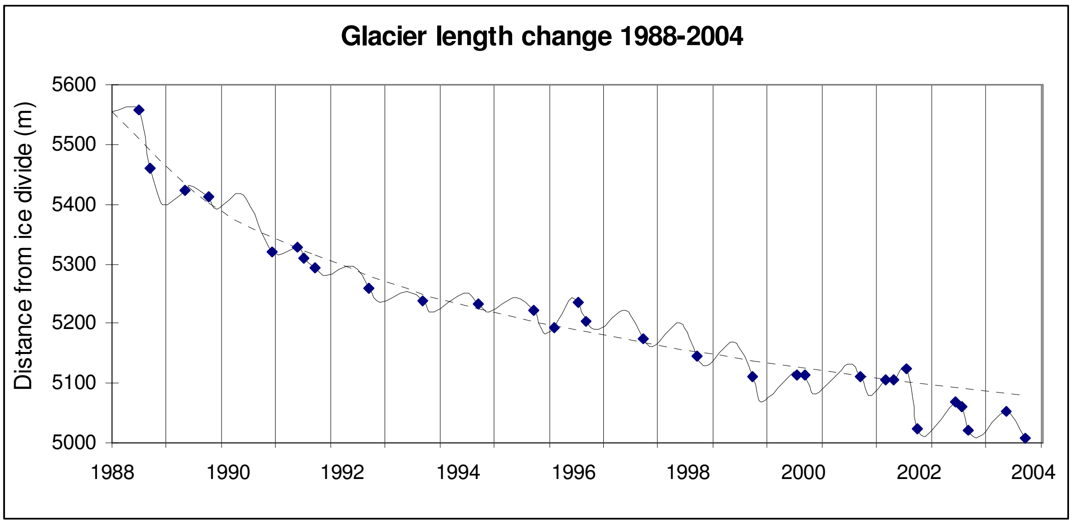


Figure 5-6
Surveyed glacier front position along a central flow line, shown as change in glacier length along this flow line (dots). The solid line indicates annual variation in front position. The glacier terminus advances from December to July while the lake is frozen, and retreats during July-December due to calving. In 1988 lake Austdalsvatnet /Styggevatnet was regulated as a reservoir for the first time. The broken line shows predicted glacier length change based on expected annual lake level variations due to regulation and an annual net balance of -0.47 m w.eqv. (Laumann & Wold, 1992).

5.3 Glacier velocity

Glacier velocities are calculated from repeated surveys of stakes on the lower part of the glacier. The stake network was surveyed on 20th September2003, and 27th May, 3rd August and 30th September 2004. Annual velocities were calculated for five stake locations (6, 7, 92, 90 and 24). Above 1300 m a.s.l. there were only small changes in velocities between 2003 and 2004. At the stakes close to the terminus the velocities increased from 60-70 m/a in 2003 to 90-100 m/a in 2004. The results are compared with results from 1988-2002 in Figure 5-7.

To calculate the calving volume (chapter 5.1), the glacier velocity averaged across the front width and thickness was estimated. The surface centre line velocity was calculated from measurements at stakes 6 and 7 (91 m/a and 80 m/a), distance from stake to terminus (September and September), and an average strain rate from previous years (0.01 a^{-1}). The cross-sectional averaged glacier velocity is estimated to be 70 % of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed. The resulting terminus cross-sectional averaged glacier velocity is 60 ±10 m/a.

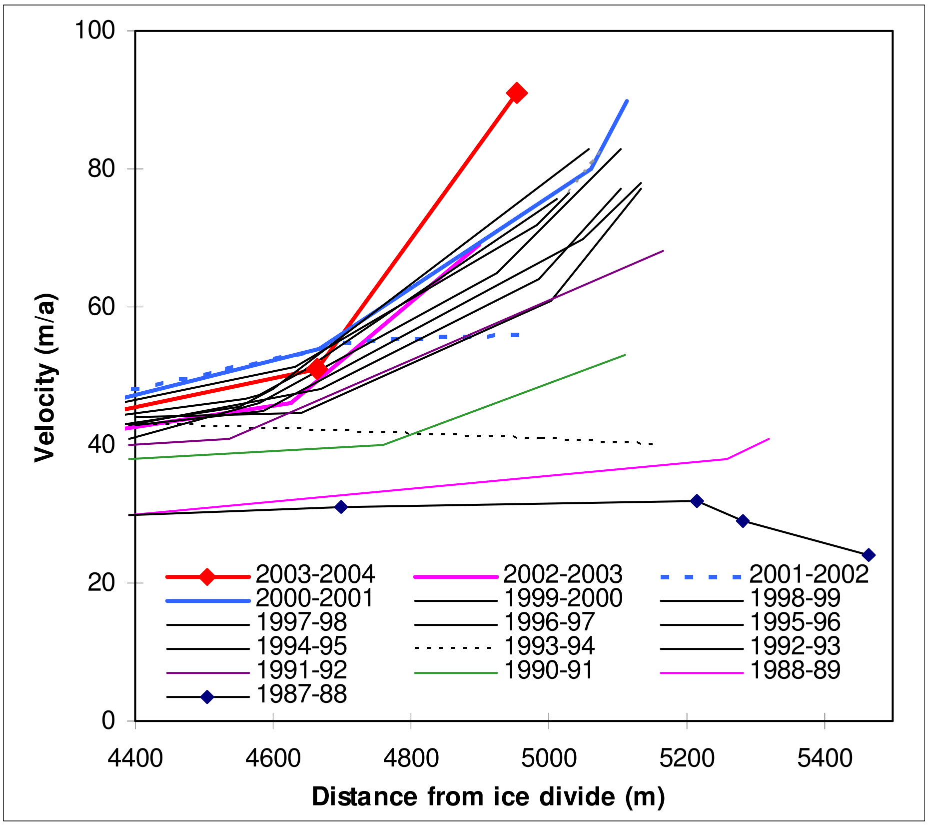


Figure 5-7
Glacier velocity (in m/a, measured each September) along a central flow line interpolated between averaged stake positions at the lower part of the glacier. Between the lowest stake and the terminus the velocity is extrapolated (broken line). The distance 4600 m from ice divide corresponds approximately to stake 92 (Fig. 5-1). Between 1988 and 2004 the terminus retreated approximately 500 metres along the flow line.

6. Hardangerjøkulen (Hallgeir Elvehøy)

Hardangerjøkulen (60°32'N, 7°22'E) is the sixth largest (73 km^2) glacier in Norway. The glacier is situated on the main water divide between Hardangerfjorden and Hallingdalen valley. In 1963 the Norwegian Polar Institute began mass balance measurements on the south-western outlet glacier Rembesdalsskåka (17 km^2), which drains towards Simadalen valley and Hardangerfjorden. This valley has been ravaged by jøkulhlaups (outburst floods) from the glacier dammed lake Demmevatnet, the most recent occurring in 1937 and 1938. Since 1985, the Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalsskåka. The investigated basin covers the altitudinal range between 1020 and 1865 m a.s.l.

At Rembesdalsskåka, glacier length observations have been conducted in several periods during the 20th century. Statkraft re-initiated the observations at Rembesdalsskåka in 1995. At Midtdalsbreen, glacier length observations were started by the University of Bergen in 1982. Glacier length observations are described in chapter 14.

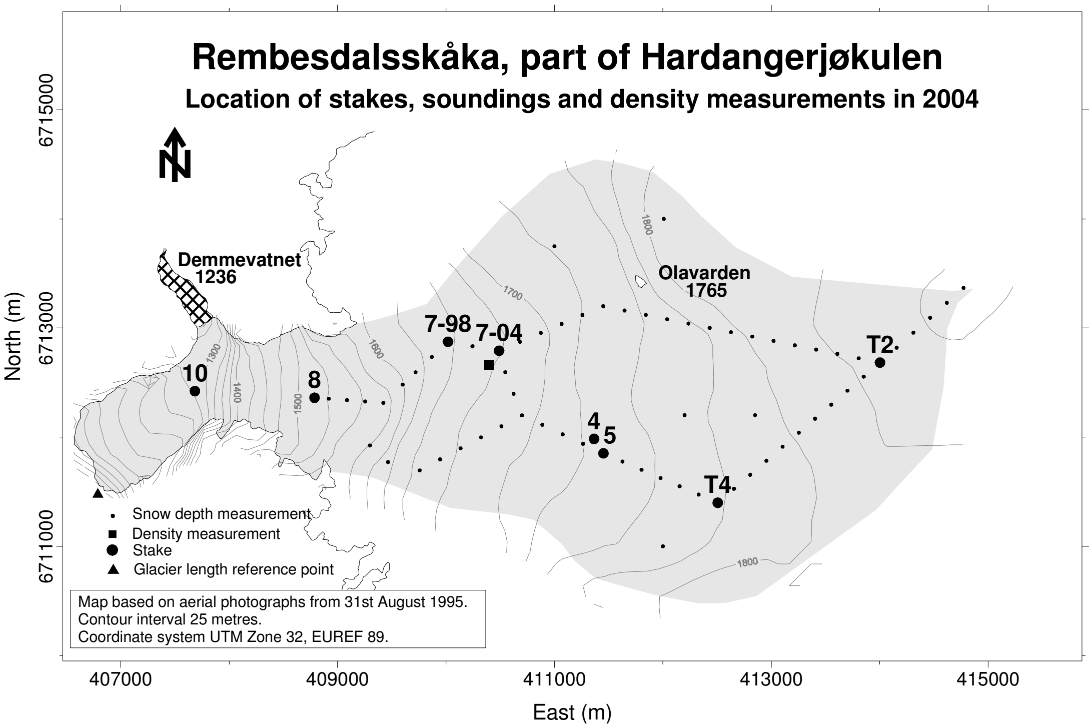


Figure 6-1
Location of sounding profiles, stakes and density pit at Rembesdalsskåka, the south western outlet of Hardangerjøkulen, in 2004. The reference point for glacier length observations is shown also.

6.1 Mass balance at Rembesdalsskåka in 2004

Fieldwork

The winter balance measurements were carried out on 26th May. The calculation of winter balance is based on the following data (Fig. 6-1):

- Snow depth measurements at stakes 10 (1270 m a.s.l.), 8 (1510 m a.s.l.), 7-98 (1635 m a.s.l.), 4 (1720 m a.s.l.), 5 (1725 m a.s.l.), T4 (1770 m a.s.l.) and T2 (1830 m a.s.l.) showing snow depths of 1.5, 0.8, 3.2, 4.4, 4.5, 4.6 and 4.6 m, respectively.
- Snow density down to 3.8 m depth at stake 7-04 (1660 m a.s.l.). Below the summer surface (SS) at 3.8 m depth there was firn.
- 62 snow depth soundings along 11 km of profiles on the glacier plateau above 1500 m a.s.l. between 1500 and 1700 m a.s.l. the snow depth was 3 to 4 m. Above 1700 m a.s.l. the snow depth was 4 to 5 m. The SS was easy to detect.

Summer and net balance was measured on 6th October. There was fresh snow on the glacier. Measurements at the stakes indicated up to 0.3 m of new snow. However, a comparison with observations at Folgefonna on the 29th September and evaluation of meteorological data suggest that the true snow depth was 0.6 to 0.8 m of new snow in the upper areas of Rembesdalsskåka. Consequently, the depth of new snow was increased by 0.4 m at locations T2, T4, 5 and 4, and by 0.3 m at location 7-04. At stakes T2 (1830 m a.s.l.), T4 (1775 m a.s.l.), 5 (1725 m a.s.l.), 4 (1720 m a.s.l.) and 7-04 (1660 m a.s.l.) the remaining snow depth was 1.7, 1.3, 1.4, 0.9 and 0.3 meter, respectively. At stakes 7-98 (1635 m a.s.l.), 8 (1510 m a.s.l.) and 10 (1270 m a.s.l.), 0.60, 2.85 and 4.35 m of ice, respectively, melted during the summer.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive "summer surfaces", excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The calculations are based on a map from 1995.

Winter balance

The winter balance was calculated from snow depth and snow density measurements taken on 26th May 2004.

A snow depth – water equivalent profile for 26th May 2004 was calculated based on snow density measurements in a pit at stake 7-04 (1660 m a.s.l.). The mean snow density of the snow pack (3.8 m) was 0.48 g/cm^3. Using the calculated profile, the mean density of 5 m of snow was 0.51 g/cm^3. The snow depth measurements were transformed to water equivalent values using this profile.

The calculated water equivalent values were plotted against altitude. From these points, an altitudinal winter balance curve was drawn (Fig. 6-2). Below 1510 m a.s.l. the only snow depth measurement was at stake 10, and the winter balance curve had to be extrapolated from the measurements at stakes 8 and 10. From the winter balance curve a mean value for each 50 m elevation interval was determined. The winter balance was 1.9 ±0.2 m w.eqv., or 32 ±3 mill. m^3 water. This is 90 % of the 1963 – 2003 average of 2.10 m w.eqv., and 97 % of the 1999-2003 average of 1.94 m w.eqv.

Summer balance

The summer balance was calculated at seven stake locations between 1270 and 1830 m a.s.l. The density of melted ice at stake 7-98 was set as 0.8 g/cm^3 because the stake is located close to the firn line where the surface ice has not been subjected to high pressure. The density of the ice at stakes 8 and 10 is set as 0.9 g/cm^3. From these seven point values the summer balance curve in Figure 6-2 was drawn.

The summer balance was calculated as −1.8 ±0.2 m w.eqv., corresponding to −31 ±3 mill. m^3 of water. This is 91 % of the 1963-2003 average, which is −1.98 m w.eqv., and 81 % of the 1999-2003 average of −2.23 m w.eqv.

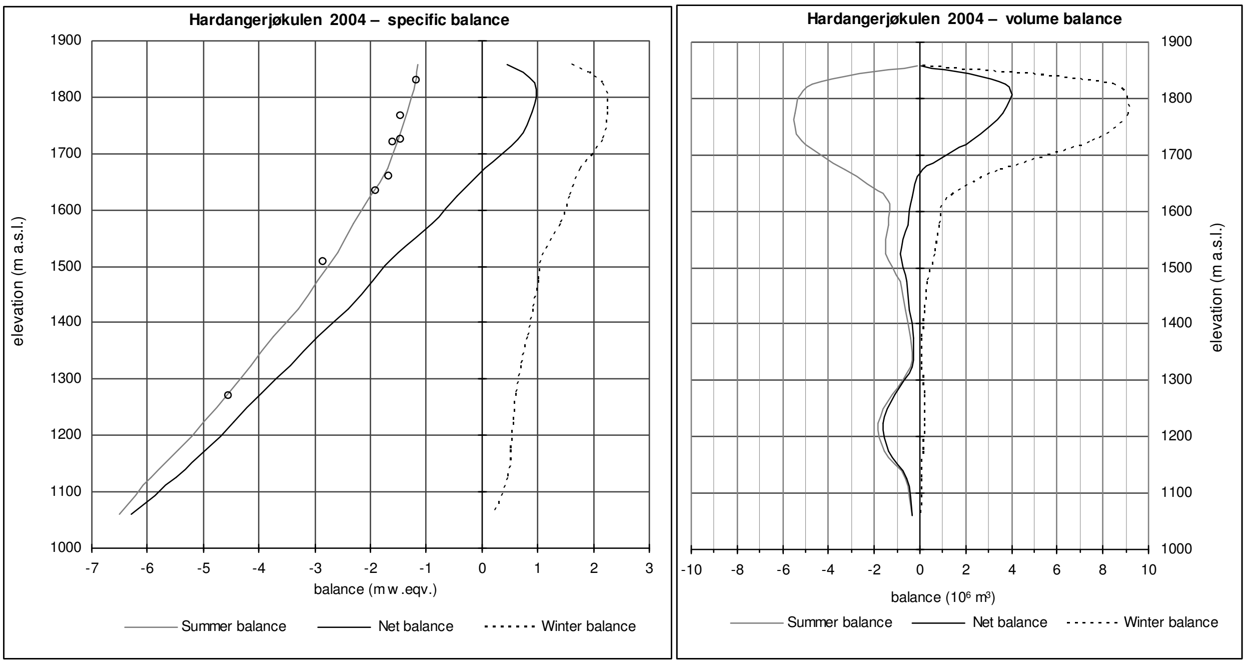


Figure 6-2
Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2004. Specific summer balance at seven locations is shown (o).

Net balance

The net balance at Rembesdalsskåka was calculated as +0.1 ±0.3 m w.eqv., or +7 ±5 mill. m^3 water. The 1963-2003 average is +0.12 m w.eqv., and the 1999-2003 average is –0.29 m. The altitudinal distribution of winter, summer and net balances are shown in Figure 6-2 and Table 6-1. The ELA is determined from the net balance curve as 1670 m a.s.l. The accumulation area ratio (AAR) was 75 %. Results from 1963-2004 are shown in Figure 6-3.

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka, Hardangerjøkulen, in 2004.

Mass balance Hardangerjøkulen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 26th May 2004		Measured 6th Oct 2004		Summer surface 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)	Specific (m w.eqv.)	Volume (10^6 m^3)
1850 - 1865	0,09	1,60	0,1	-1,15	-0,1	0,45	0,0
1800 - 1850	3,93	2,15	8,5	-1,20	-4,7	0,95	3,7
1750 - 1800	4,03	2,25	9,1	-1,35	-5,4	0,90	3,6
1700 - 1750	3,46	2,15	7,4	-1,50	-5,2	0,65	2,2
1650 - 1700	1,94	1,75	3,4	-1,70	-3,3	0,05	0,1
1600 - 1650	0,75	1,55	1,2	-2,00	-1,5	-0,45	-0,3
1550 - 1600	0,59	1,40	0,8	-2,30	-1,4	-0,90	-0,5
1500 - 1550	0,57	1,10	0,6	-2,60	-1,5	-1,50	-0,9
1450 - 1500	0,29	1,00	0,3	-2,95	-0,9	-1,95	-0,6
1400 - 1450	0,19	0,90	0,2	-3,30	-0,6	-2,40	-0,5
1350 - 1400	0,10	0,80	0,1	-3,75	-0,4	-2,95	-0,3
1300 - 1350	0,10	0,70	0,1	-4,15	-0,4	-3,45	-0,3
1250 - 1300	0,27	0,60	0,2	-4,55	-1,2	-3,95	-1,1
1200 - 1250	0,36	0,55	0,2	-5,00	-1,8	-4,45	-1,6
1150 - 1200	0,28	0,50	0,1	-5,45	-1,5	-4,95	-1,4
1100 - 1150	0,11	0,45	0,0	-5,95	-0,6	-5,50	-0,6
1020 - 1100	0,05	0,20	0,0	-6,50	-0,3	-6,30	-0,3
1020 - 1865	17,1	1,89	32,3	-1,81	-30,9	0,08	1,4

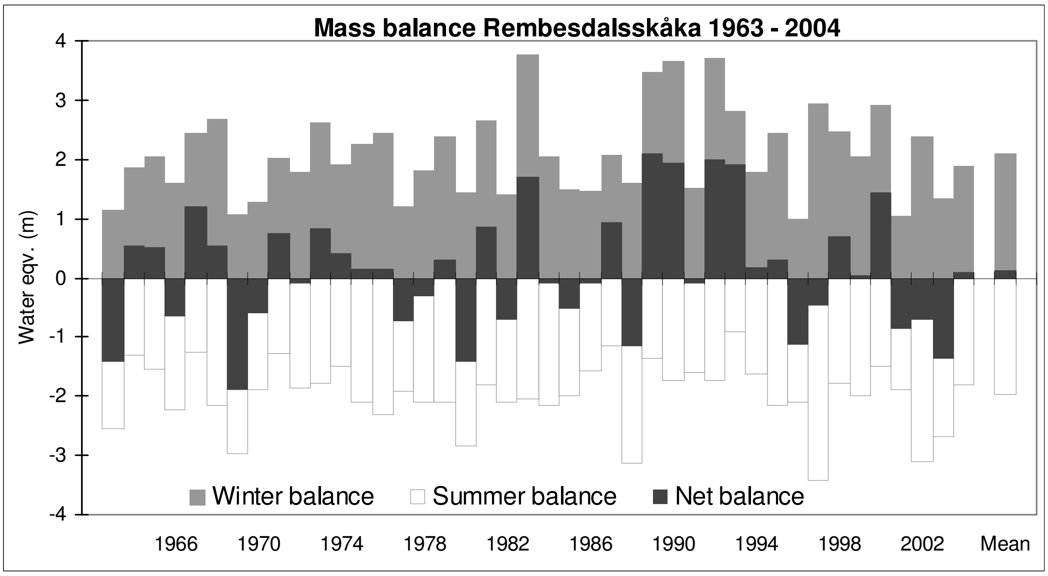


Figure 6-3
Winter, summer and net balances at Hardangerjøkulen during the period 1963-2004. Mean values for the period are b_w=2.09 m, b_s=−1.98 m and b_n=+0.11 m water equivalent.

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Leirdalen valley in the central part of Jotunheimen, a mountainous area in central southern Norway (Fig. 7-1). The glacier has a total area of 5.4 km^2 and ranges in altitude from 1390 to 2090 m a.s.l. (Fig. 7-2). Mass balance measurements were initiated in 1949 and 2004 is the 56th year of continuous measurements. Since September 2001 an automatic weather station (AWS) has been operating on the glacier and data from 2003/2004 are summarised in section 7.2.

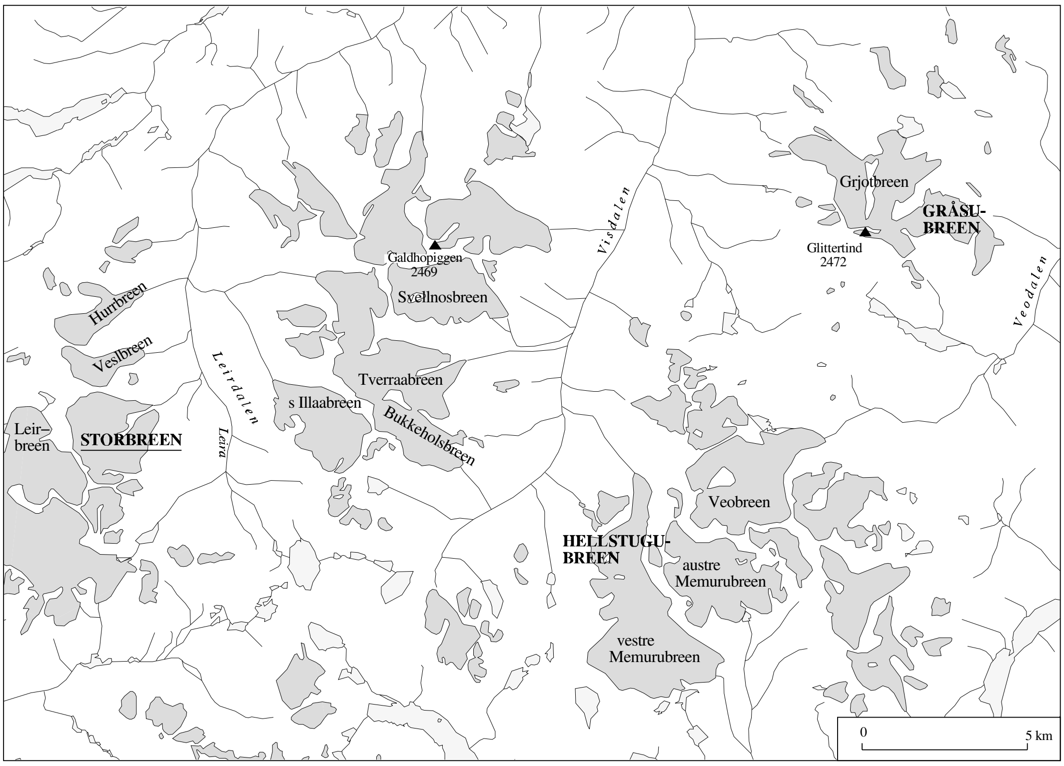


Figure 7-1
Location map showing Storbreen and other glaciers (shaded) in the Jotunheimen mountain area. Mass balance measurements are carried out on Storbreen and Hellstugubreen in the central part and on Gråsubreen in the eastern part.

7.1 Mass balance 2004

Fieldwork

Accumulation measurements were performed on 12th and 13th May and the calculation of winter balance is based on:

- Measurements of stakes in eleven different positions. Stake readings did not show any indications of melting after the final measurements in September 2003.
- 175 snow depth soundings along approximately 19 km of profiles between 1450 and 1960 m a.s.l. covering most of the altitudinal range of the glacier. Identifying the summer surface (SS) was easy over the whole glacier. The snow depth varied between 0.33 m and 3.94 m, the mean being 1.95 m.

- Snow density was measured down to SS at three positions, the AWS (1570 m a.s.l.), stake 4 (1725 m a.s.l.) and stake 6 (1570 m a.s.l.).

Location of stakes, density pits and sounding profiles are shown in Figure 7-2.

Ablation measurements were performed on stakes in 10 locations from 1512 to 1866 m a.s.l.

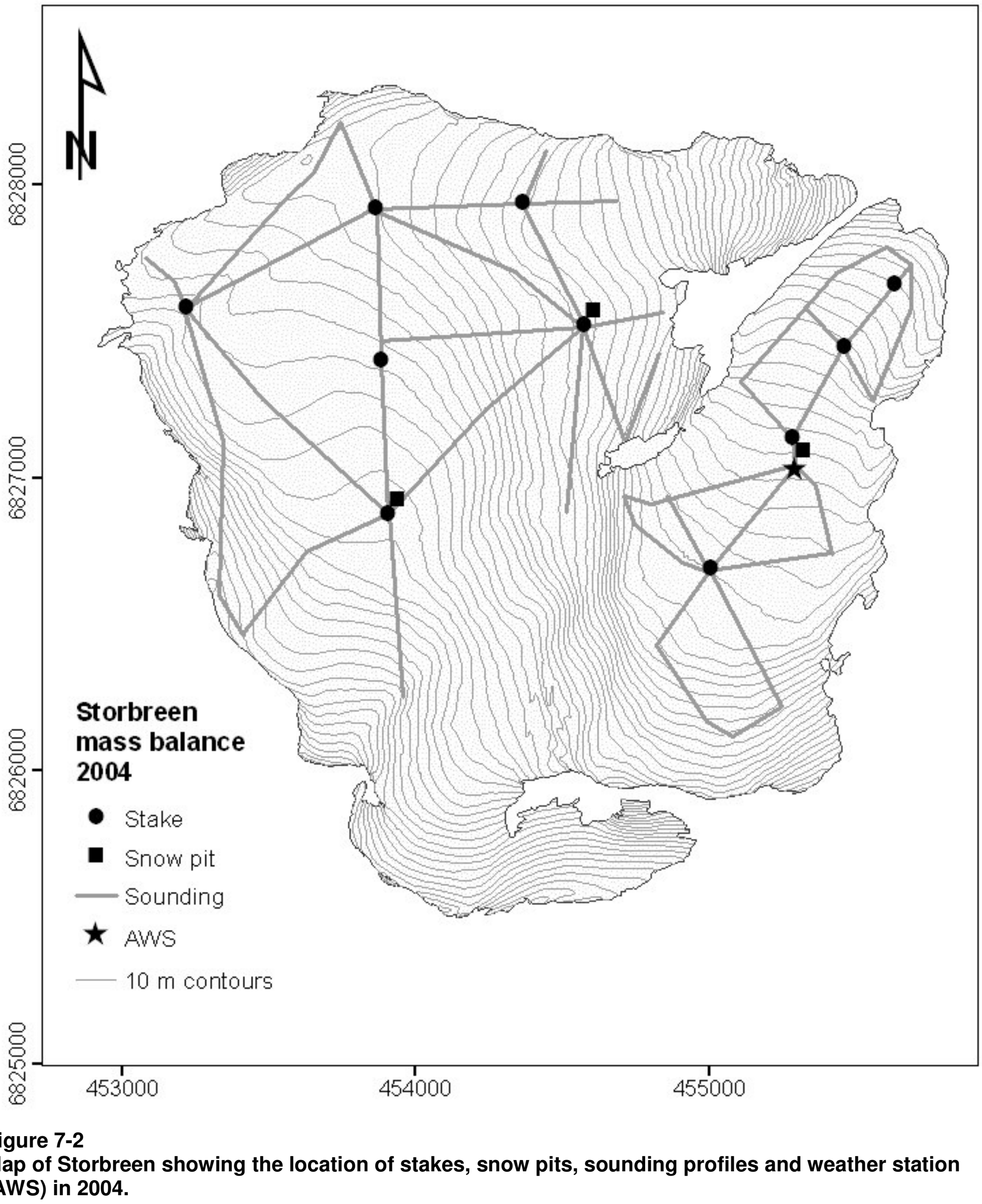


Figure 7-2
Map of Storbreen showing the location of stakes, snow pits, sounding profiles and weather station (AWS) in 2004.

Results

The mass balance results are shown in Table 7-1 and Figure 7-3.

Winter balance

Winter accumulation was calculated from soundings and the snow density measurements. The mean measured snow density was 0.47 g/cm^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. There was no additional melting after the ablation measurements the previous year.

The specific winter balance was calculated to be 1.01 ±0.2 m w.eqv. This is 70 % of the mean for the period 1949-2003.

Summer balance

Summer balance was calculated directly from stakes at ten locations. There was no remaining snow at any of the stakes. The density of the melted firn was assumed to be 0.8 g/cm^3. The density of the melted ice was assumed to be 0.9 g/cm^3. The summer balance was calculated to be −1.59 ±0.3 m w.eqv., which is 94 % of the mean for the period 1949-2002.

Net balance

The net balance of Storbreen in 2004 was −0.58 ±0.3 m w.eqv., which is equivalent to a volume of −3.1 ±0.16 10^6 m^3 of water. The ELA was estimated to be 1855 m a.s.l. and the accumulation area ratio (AAR) 22 %. The total deficit of the glacier since 1949 amounts to −14.7 m w.eqv., giving a mean annual net balance of −0.26 m w.eqv. for the 56 years of measurements (Fig. 7-4). Figure 1-3 (p. 12) shows the cumulative balance of Storbreen and four other glaciers since 1963.

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2004.

Mass balance Storbreen 2003/04 – traditional method

		Winter balance Measured 12 May 2004		Summer balance Measured 14 Sep 2004		Net balance Summer surfaces 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2050 - 2100	0.04	1.46	0.06	-0.42	-0.02	1.04	0.04
2000 - 2050	0.15	1.46	0.22	-0.53	-0.08	0.93	0.14
1950 - 2000	0.23	1.46	0.33	-0.68	-0.16	0.78	0.18
1900 - 1950	0.36	1.30	0.47	-0.85	-0.31	0.45	0.16
1850 - 1900	0.57	1.25	0.71	-1.00	-0.57	0.25	0.14
1800 - 1850	0.92	0.91	0.84	-1.24	-1.14	-0.33	-0.30
1750 - 1800	0.75	1.05	0.79	-1.50	-1.13	-0.45	-0.34
1700 - 1750	0.64	0.80	0.51	-1.72	-1.10	-0.92	-0.59
1650 - 1700	0.40	1.11	0.44	-1.95	-0.78	-0.84	-0.34
1600 - 1650	0.49	0.94	0.46	-2.20	-1.08	-1.26	-0.62
1550 - 1600	0.35	0.79	0.28	-2.45	-0.86	-1.66	-0.58
1500 - 1550	0.21	0.57	0.12	-2.70	-0.57	-2.13	-0.45
1450 - 1500	0.18	0.58	0.10	-2.98	-0.54	-2.40	-0.43
1390 - 1450	0.06	0.70	0.04	-3.25	-0.20	-2.55	-0.15
1390 - 2100	**5.35**	**1.01**	**5.38**	**-1.59**	**-8.51**	**-0.58**	**-3.13**

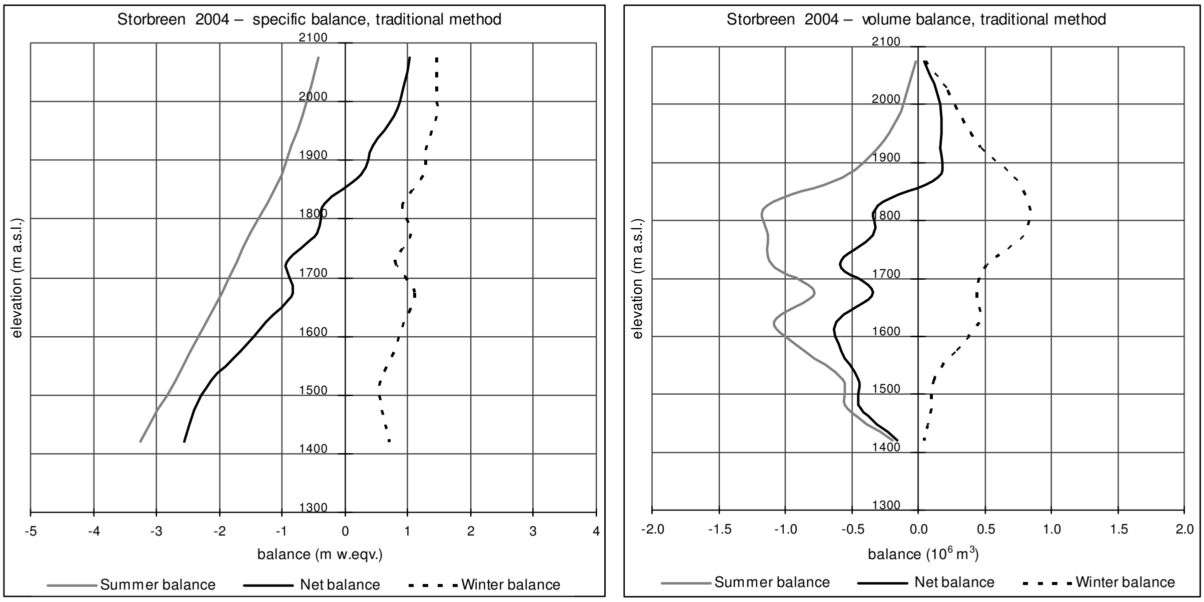


Figure 7-3
Mass balance diagram for Storbreen 2004, showing specific balance on the left and volume balance on the right.

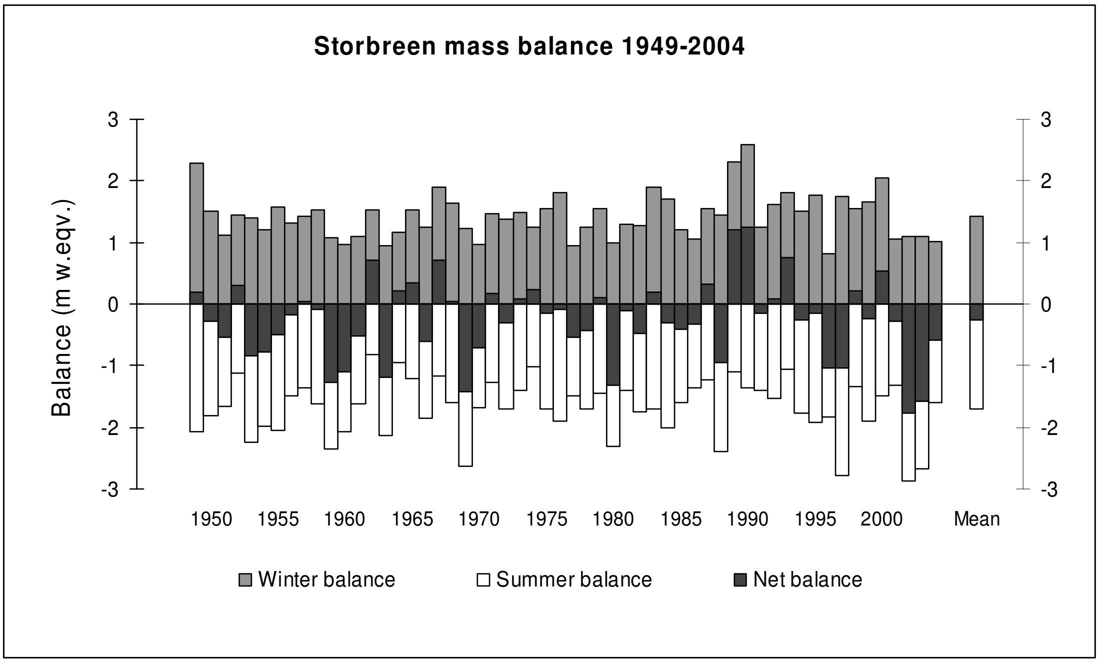


Figure 7-4
Winter, summer and net balance at Storbreen for the period 1949-2004.

7.2 Meteorological measurements

An automatic weather station (AWS) has been operating in the ablation zone of Storbreen, at about 1580 m a.s.l. (Fig. 7-2) since September 2001. The station was erected by the Institute of Marine and Atmospheric Research (IMAU), University of Utrecht and is operated by IMAU (contact: J. Oerlemans [j.oerlemans@phys.uu.nl]) in co-operation with NVE. The station records air temperature, wind speed, wind direction, shortwave and longwave radiation, humidity and instrument height above the surface. Measurements are done every 2 minutes and 30-minute mean values are recorded. The results from the AWS are used to monitor the local climate of Storbreen and to calibrate an energy-balance model for Storbreen. Here we briefly present some of the data from the 2003/2004 season until July 22nd. Due to technical problems data from 22nd July to 17th August are unusable (Fig 7-5). Data from the rest of the season have not yet been downloaded and analysed.

Figure 7-5
The AWS fell down on July 22nd due to opening of a crevasse. The station was fixed in August. Photo Liss M. Andreassen

Surface height

The distance between the ice surface and the temperature sensor (surface height) is plotted together with temperature in Figure 7-6. High temperatures in late April and early May caused early melting and densification of the surface. After the accumulation measurements on 12th May new snowfalls covered the surface around 20th May and in mid-June.

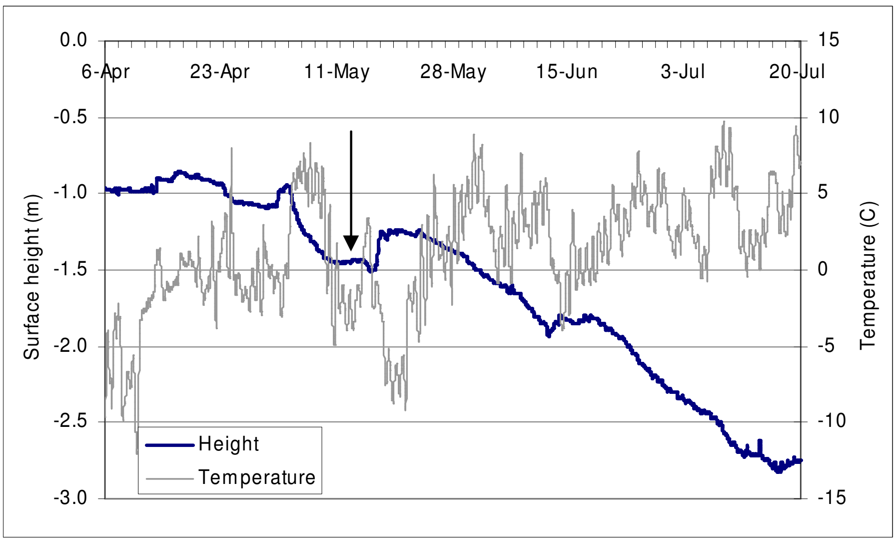


Figure 7-6
The surface height (m) and temperature (°C) at 6 m during spring and early summer 2004. The timing of the accumulation measurements (12th May) is marked with an arrow.

Radiation and albedo

The incoming and outgoing shortwave radiation between September 2003 and July 2004 is shown in Figure 7-7. Between October and March very little radiation reaches the surface.

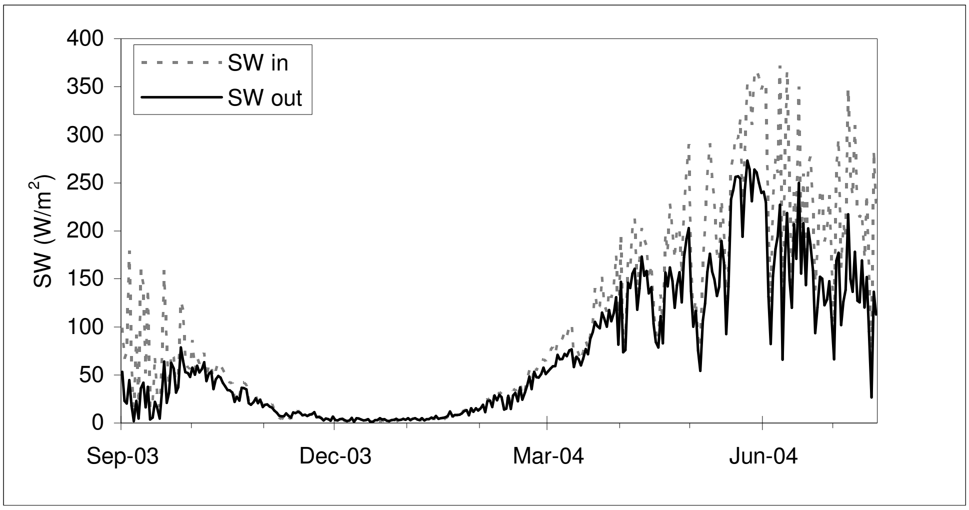


Figure 7-7
Shortwave incoming (SW in) and outgoing (SW out) radiation from September 2003 to July 2004.

The daily albedo is calculated as α = SW out / SW in. The albedo varied between 0.7 and 0.9 until late April. In May and the first half of June periods of snowfalls and melting occur. From mid June the albedo gradually decreases to 0.38 on July 21st, indicating that the surface became ice-free at this time.

Wind speed

The daily mean wind speed at the 2 m and 6 m level is shown in Figure 7.8. For the period October to July 2004 the mean wind speed was 3.8 m/s at the highest level (6 m) and 3.3 m/s at the lowest level (2 m). The largest wind speeds are found in the winter months and the wind speed decreases towards the summer.

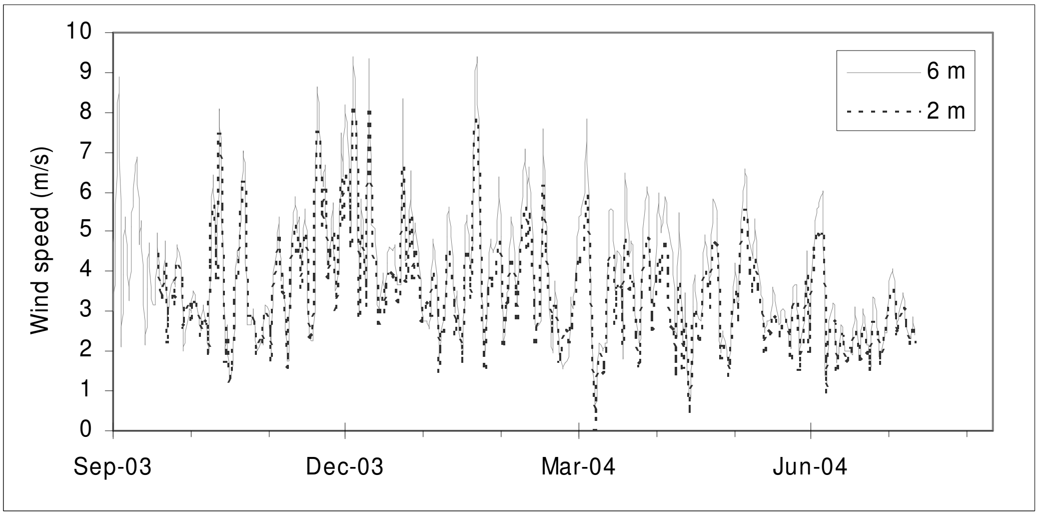


Figure 7-8
Mean daily wind speed at 2 m and 6 m level from September 2003 to July 2004.

8. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 8-1). It ranges in elevation from 1480 to 2210 m a.s.l. and has an area of 3.0 km^2 (Fig. 8-2). Mass balance investigations have been carried out annually since 1962 and 2004 is the 43rd year of continuous measurements.

Figure 8-1
Hellstugubreen photographed on 28th May 2004 when accumulation measurements were performed. Photo: Liss M. Andreassen.

8.1 Mass balance 2004

Fieldwork

Accumulation measurements were carried out on 28th May. Some snow had already melted at the lower part of the glacier at this time (Fig. 8-1). Stakes were visible in 14 locations. Snow depth was measured at 130 points along 13.8 km of profiles covering most of the glacier (Fig. 8-2). The probing conditions were good, and the summer surface from the previous year was easy to identify over the whole glacier. The snow depth varied between 0.05 and 3.1 metres, with a mean depth of 1.5 m. The snow density was measured by sampling in a pit at 1960 m a.s.l. The total snow depth was 1.95 m. Ablation measurements were carried out as late as 11th October at stakes in 12 locations. A layer of snow covered the whole glacier, the snow layer being 15 cm thick at 1555 m a.s.l. increasing to 1.2 m at 2070 m a.s.l. The location of stakes, density pit and sounding profiles are shown in Figure 8-2.

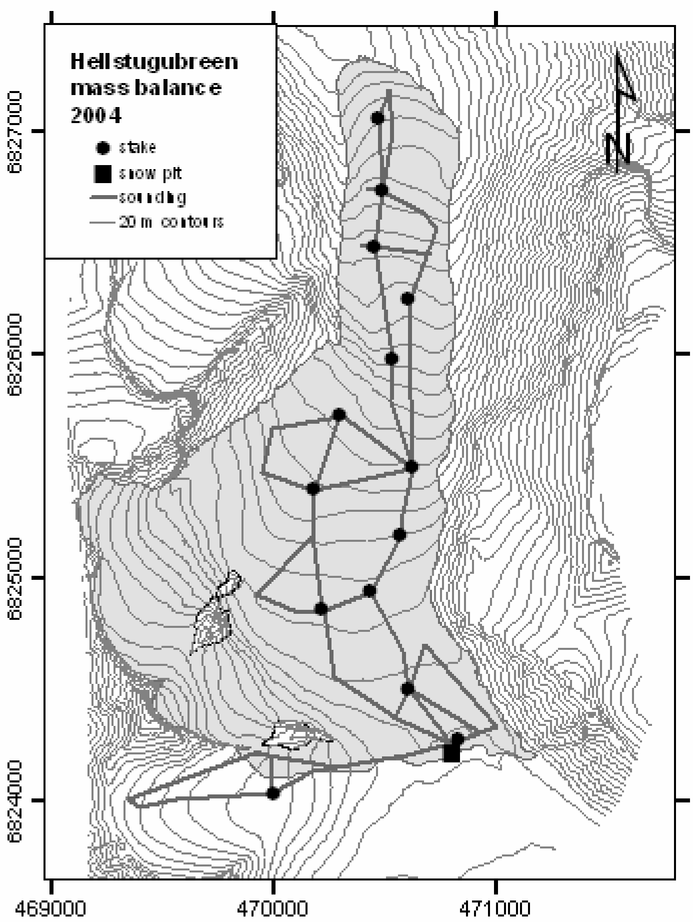


Figure 8-2
Map of Hellstugubreen showing location of stakes, sounding profiles and snow pit in 2004. Figure 7-1 shows a location map of the study glaciers in Jotunheimen.

Results

The mass balance results are presented in Table 8-1 and Figure 8-3.

Winter balance

The winter balance was calculated from the soundings and the snow density measurement, which was considered to be representative for the whole glacier. The density was 0.44 g/cm^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The mean winter accumulation was 0.72 m w.eqv. The measurements of the lower stakes indicated additional melt after the previous year's ablation measurement and must be accounted for by subtracting the melt from the winter accumulation. The winter balance was 0.65 ±0.2 m w.eqv. This is only 60 % of the mean for the period 1962-2003.

Summer balance

The summer balance was calculated from stakes in 9 locations. Only at the highest elevated stake position was snow remaining from the winter at the end of the summer season. The density of the remaining snow at this stake (–0.9 m) was assumed to be 0.6 g/cm^3. The density of the melted firn was estimated to be between 0.70 and 0.75 g/cm^3

depending on the age of the firn. The density of the melted ice was assumed to be 0.9 g/cm^3. The summer balance was calculated to be −1.43 ±0.3 m w.eqv., which is 104 % of the mean value for the entire observation period.

Net balance

The net balance of Hellstugubreen in 2004 was –0.84 ±0.3 m w.eqv., which amounts to a volume loss of –2.6 ±0.09 mill. m^3 water. The deficit was caused by the low winter balance The equilibrium line altitude (ELA) was not observed due to fresh snow covering the entire glacier in October, but was calculated to be above 1980 m a.s.l. giving an accumulation area ratio (AAR) of 23 % (Fig. 8-3). Since 1962 Hellstugubreen has had a cumulative mass loss of 14.4 m w.eqv., the equivalent of –0.34 m w.eqv. per year (Fig. 8-4).

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2004.

Mass balance Hellstugubreen 2003/04 – traditional method

		Winter balance Measured 28th May 2004		Summer balance Measured 11th Oct 2004		Net balance Summer surfaces 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2150 - 2210	0.02	1.10	0.02	-0.47	-0.01	0.63	0.01
2100 - 2150	0.09	1.05	0.10	-0.54	-0.05	0.51	0.05
2050 - 2150	0.28	0.90	0.25	-0.69	-0.19	0.21	0.06
2000 - 2050	0.18	1.10	0.20	-0.79	-0.14	0.31	0.06
1950 - 2000	0.38	0.90	0.34	-0.94	-0.36	-0.04	-0.02
1900 - 1950	0.61	0.72	0.44	-1.12	-0.69	-0.40	-0.24
1850 - 1900	0.35	0.59	0.20	-1.32	-0.46	-0.73	-0.25
1800 - 1850	0.33	0.60	0.20	-1.64	-0.54	-1.04	-0.34
1750 - 1800	0.13	0.57	0.08	-1.90	-0.25	-1.33	-0.18
1700 - 1750	0.10	0.53	0.05	-2.15	-0.22	-1.62	-0.17
1650 - 1700	0.17	0.41	0.07	-2.40	-0.40	-1.99	-0.34
1600 - 1650	0.13	0.20	0.03	-2.74	-0.35	-2.54	-0.32
1550 - 1600	0.16	-0.03	-0.01	-3.18	-0.51	-3.21	-0.51
1500 - 1550	0.08	-0.07	-0.01	-3.60	-0.28	-3.67	-0.29
1480 - 1500	0.02	-0.20	0.00	-3.90	-0.07	-4.10	-0.07
1480 - 2210	**3.03**	**0.65**	**1.97**	**-1.49**	**-4.52**	**-0.84**	**-2.55**

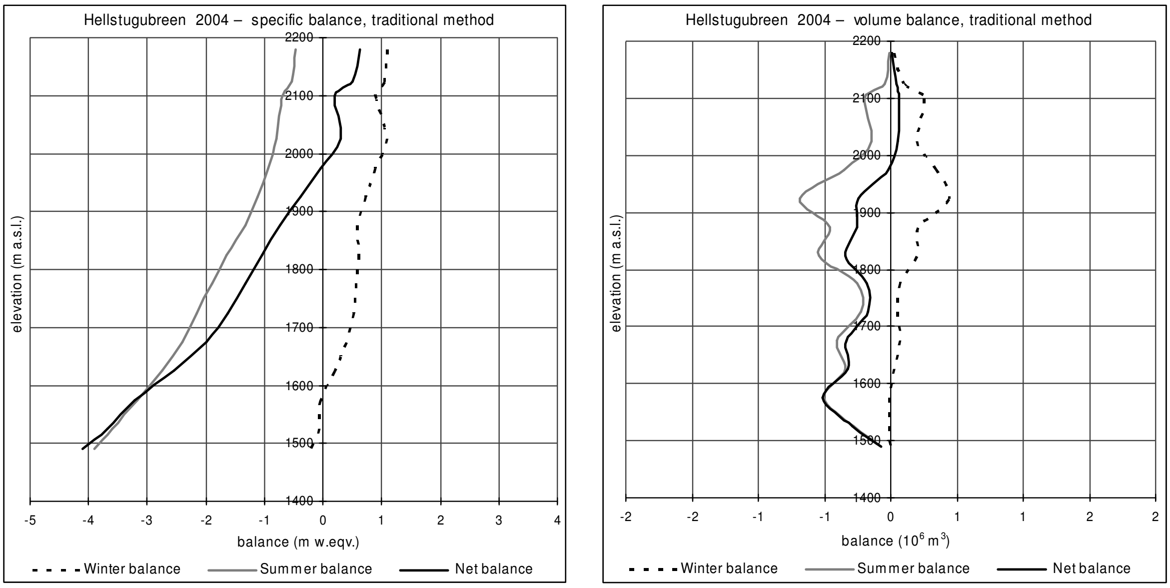


Figure 8-3
Mass balance diagram for Hellstugubreen 2004, showing specific balance on the left and volume balance on the right.

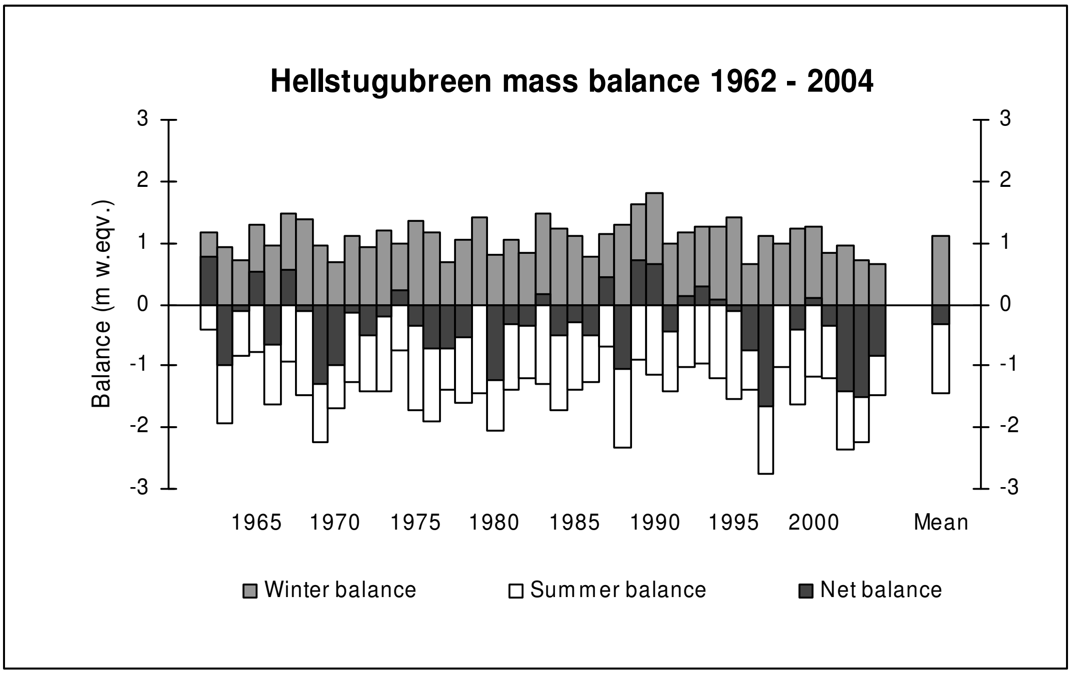


Figure 8-4
Winter, summer and net balance at Hellstugubreen for the period 1962-2004.

9. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is located in the eastern part of the Jotunheimen mountain area in southern Norway (Fig. 9-1). The glacier covers an area of 2.2 km^2 and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 9-2). Annual mass balance measurements began in 1962 and have continued annually since then.

Gråsubreen is a polythermal glacier. Superimposed ice occurs in the central parts of the glacier where snowdrift causes a relatively thin snow pack.

Figure 9-1
Gråsubreen in Veodalen, Jotunheimen. The glacier is located in front of Glittertind (2464 m asl, the second highest peak in Norway). Photo: Laila P. Høvik.

9.1 Mass balance 2004

Fieldwork

Accumulation measurements were carried out on 25-26th May. Stakes in 17 locations were measured. A total of 126 snow depth measurements were made along 13 km of profiles, covering most of the glacier (Fig. 9-2). The probing conditions were good, and the previous year's summer surface was easy to identify over the entire glacier. Snow depth varied between 0.04 and 3.12 m, with a mean of 1.10 m. The snow density was measured at 2180 m a.s.l. in a pit dug through the winter snow pack (0.9 m snow).

Ablation measurements were carried out on 16-17th September, when stakes in 17 locations were measured (Fig. 9-2). A fresh layer of 2-15 cm of snow covered most of the surface.

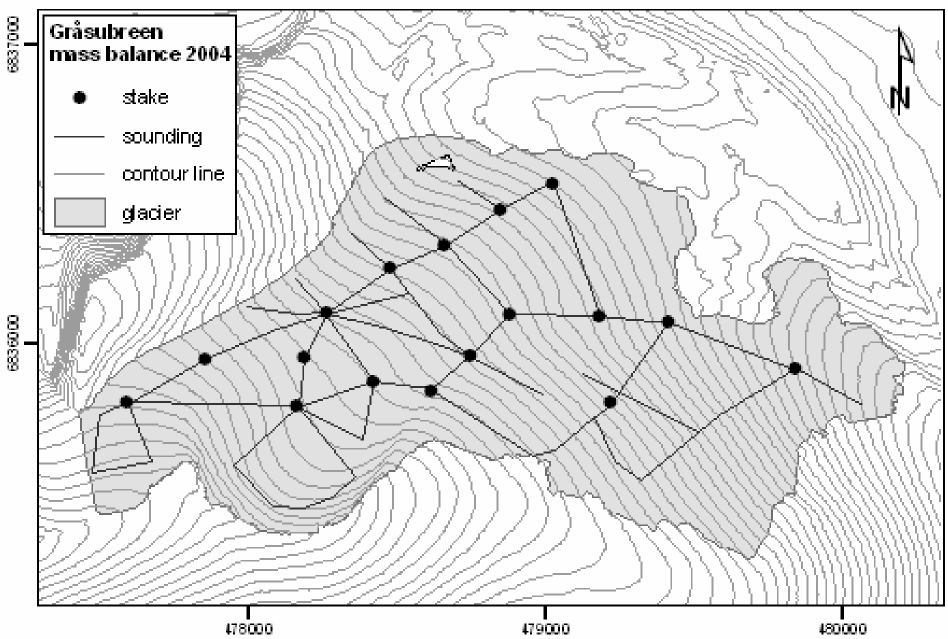


Figure 9-2
Map of Gråsubreen (shaded in grey) showing the location of stakes, snow pit and sounding profiles in 2004. A location map of Gråsubreen and other glaciers in Jotunheimen is shown in Figure 7-1.

Results

The mass balance results are presented in Table 9-1 and Figure 9-3.

Winter balance

Winter accumulation was calculated from the soundings and the snow density measurement, which was considered representative for the whole glacier. The mean measured snow density was 0.40 g/cm^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter balance of 0.48 ±0.2 m w.eqv., which is 62 % of the mean for the period 1962-2003.

The stake recordings showed neither significant additional melting after the previous year's ablation measurements, nor any significant formation of superimposed ice. Therefore, the winter balance was not adjusted for these factors.

Summer balance

Summer balance was calculated from direct measurements of stakes in 16 locations. There was no remaining snow left from the winter at any of the stakes. The density of the melted ice and firn was estimated to be 0.90 and 0.8 g/cm^3 respectively. The resulting summer balance was −0.97 ±0.3 m w.eqv. This is 90 % of the mean for the period 1963-2002.

Net balance

Gråsubreen had a mass loss in 2004, the net balance being –0.49 ±0.3 m w.eqv. The equilibrium line altitude (ELA) at the end of the season was not observed in the field due to fresh snow covering most of the glacier, but was calculated to be 2210 m a.s.l. The accumulation area ratio (AAR) was 7 % (Fig. 9-3).

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2004.

Mass balance Gråsubreen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 16 mai 2004		Measured 16 sep 2004		Summer surfaces 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2250 - 2290	0.04	0.35	0.02	-0.25	-0.01	0.10	0.00
2200 - 2250	0.17	0.38	0.06	-0.35	-0.06	0.03	0.00
2150 - 2200	0.26	0.35	0.09	-0.52	-0.14	-0.17	-0.04
2100 - 2150	0.34	0.30	0.10	-0.72	-0.24	-0.42	-0.14
2050 - 2100	0.37	0.37	0.14	-0.94	-0.35	-0.57	-0.21
2000 - 2050	0.42	0.44	0.18	-1.18	-0.49	-0.74	-0.31
1950 - 2000	0.36	0.61	0.22	-1.32	-0.47	-0.71	-0.26
1900 - 1950	0.14	0.78	0.11	-1.39	-0.20	-0.61	-0.09
1830 - 1900	0.15	1.00	0.15	-1.43	-0.22	-0.43	-0.07
1830 - 2290	**2.25**	**0.48**	**1.07**	**-0.97**	**-2.18**	**-0.49**	**-1.11**

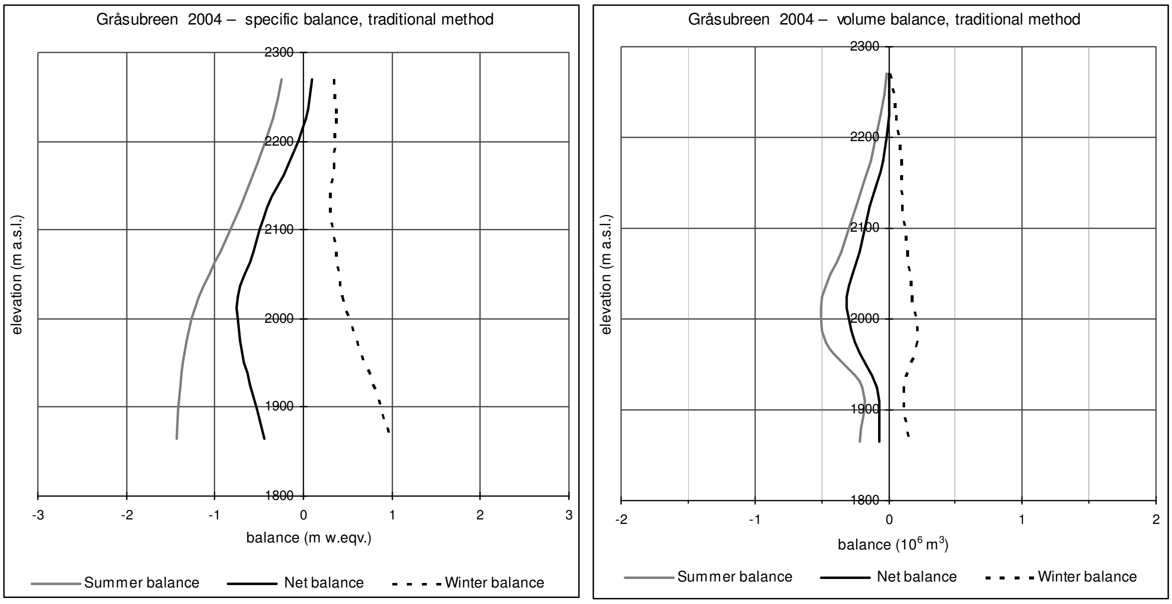


Figure 9-3
Mass balance diagram for Gråsubreen 2004, showing specific balance on the left and volume balance on the right.

Since 1962 Gråsubreen has had a cumulative mass loss of −13.2 m w.eqv., or −0.31 m w.eqv. per year. Most of this mass loss occurred in the 1970s and 1980s. However, the glacier has had a pronounced deficit of −3.3 m w.eqv. over the past three years (Fig 9-4). Figure 1-3 (p.12) shows the cumulative balance of Gråsubreen and four other glaciers since 1963, clearly showing the difference in mass development between the continental glaciers Storbreen and Gråsubreen and the coastal glaciers which have had a mass surplus over the same period.

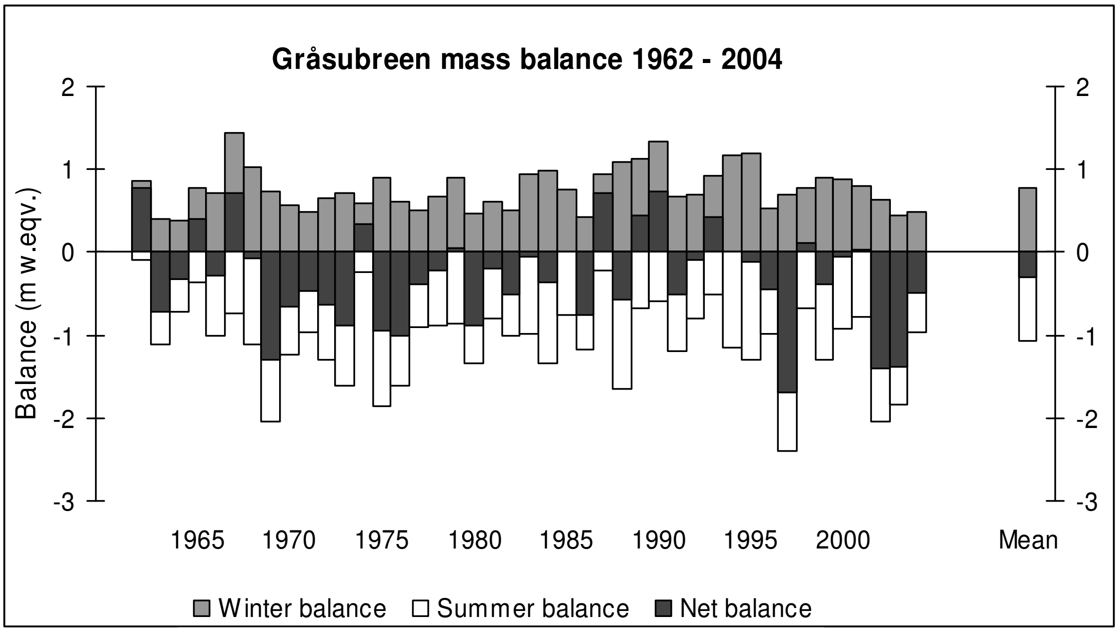


Figure 9-4
Winter, summer and net balance at Gråsubreen during the period 1962-2004.

10. Engabreen (Hallgeir Elvehøy)

Engabreen (66°40'N, 13°45'E) is a 40 km^2 north-western outlet from the western Svartisen ice cap. It covers an altitude range from 1575 m a.s.l. (at Snøtind) down to 10 m a.s.l. (at Engabrevatnet), as shown in Figure 10-1. Mass balance measurements have been performed annually since 1970, and length change observations started in 1903.

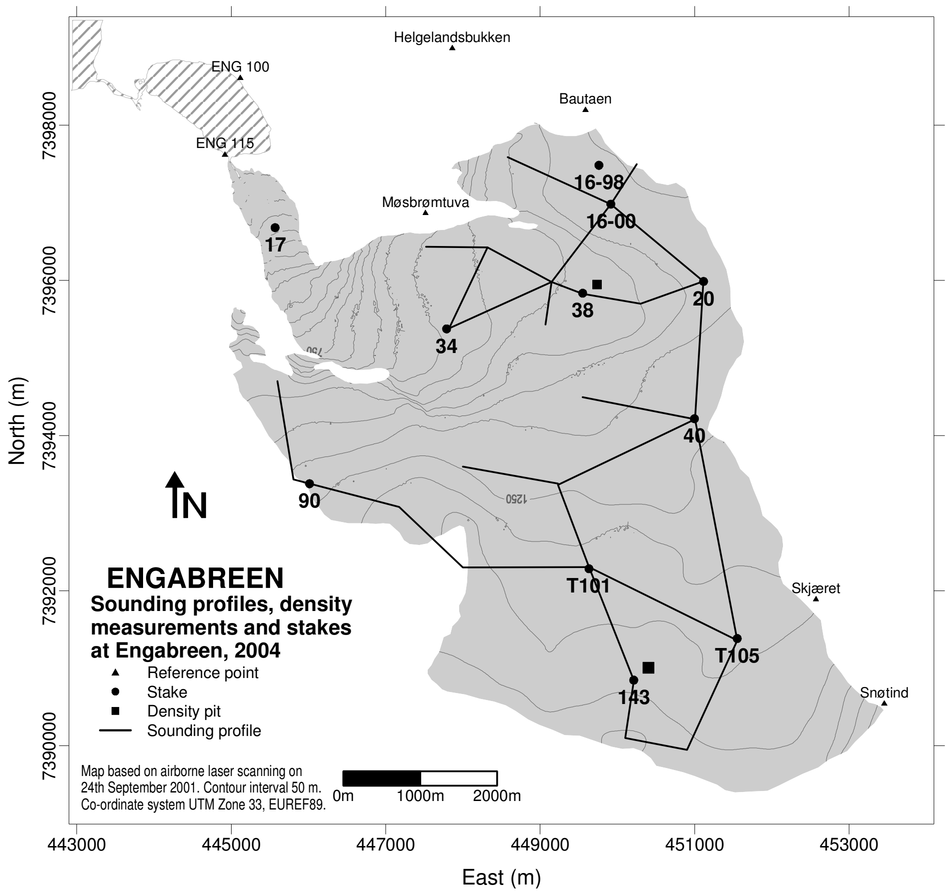


Figure 10-1
Location of stakes, density pits and sounding profiles on Engabreen in 2004.

10.1 Mass balance 2004

New map of Engabreen

The mass balance of Engabreen was previously calculated using a map constructed from aerial photographs taken on 25th August 1968. The drainage divide was defined from the surface topography defining the glacial area draining to a discharge station in the pro-glacial lake Engabrevatnet. The small glacier outlet Litlebreen situated between Møsbrømtuva and Bautaen is regarded as a part of Engabreen.

As part of the EU 5th Framework project OMEGA (Operational Monitoring of European Glacial Areas), the Institute of Geography at the University of Innsbruck constructed a 5 x 5 m DEM and map covering Engabreen and Litlebreen (hereafter referred to as Engabreen) from airborne laser scanner data acquired on 24th September 2001 (TopScan

GmbH, Rheine, Germany)(Fig. 10-1). The DEM was constructed from 30 million single xyz-points with an average point-to-point distance of 0.9 m and a vertical accuracy of approximately ±0.15 m. The drainage divide on the plateau has been calculated previously from glacier bottom topography and ice thickness (Kennett & Elvehøy, 1995).

The two area-elevation distributions are compared in Figure 10-2. The calculated area of Engabreen increased from 38.0 km^2 to 39.6 km^2. Even though the glacier terminus had a net advance between 1968 and 2001, the main reason for the area-increase is a shift in the calculated drainage divide due to the effect of the bottom topography in an area close to Skjæret (see Fig. 10-1).

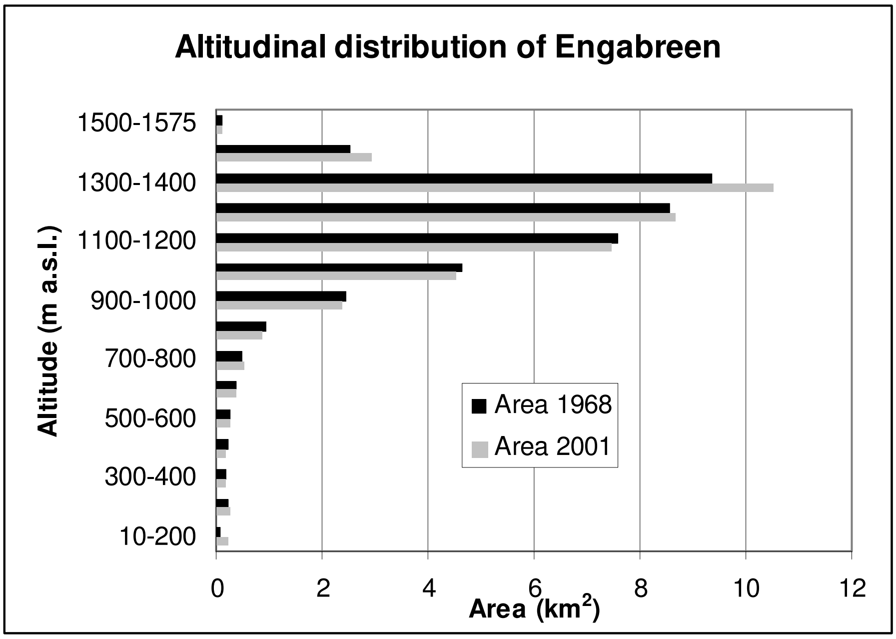


Figure 10-2
Altitudinal area-distribution for Engabreen (including Litlebreen) in 1968 and 2001.

Fieldwork

Snow accumulation measurements were carried out between 24th and 28th May. The locations of stakes and towers, density pits, core samples and sounding profiles are shown in Figure 10-1. The calculation of winter balance is based on:

- Direct measurements of snow depth at stakes 34, T101 and T105, showing 3.3, 6.45 and 7.15 m of snow.
- The transient snow line altitude at 600 m a.s.l.
- Snow density measured to a depth of 4.25 m at stake 38 (where the snow depth was 5.2 m), and to the previous summer surface at 7.6 m depth at stake 143. Mean snow density was 0.52 g/cm^3 and 0.53 g/cm^3, respectively.
- 134 snow depth soundings along 34 km of profiles. Another 30 snow depth soundings were excluded because the summer surface was not correctly identified. The snow depth was between 5 and 8 m above 1200 m a.s.l., and between 4 and 6 m between 950 and 1200 m a.s.l.

The net balance measurements were carried out on 16th October on the glacier plateau, and on the 21st October on the glacier tongue. Above 1000 m a.s.l. there was up to 0.5 m of new snow on the glacier. From stake measurements the transient snow line altitude was about 1000 m a.s.l., too.

The net balance was observed at 11 positions between 300 and 1400 m a.s.l. At the glacier tongue (300 m a.s.l.), 8 m of ice had melted during the summer. At 960 m a.s.l. all the winter snow and 2 m of ice had melted. Above 1000 m a.s.l. 3 to 4 m of snow melted during the summer. The remaining snow pack was up to 4.55 m thick (at stake 143).

Results

The mass balance is calculated using the stratigraphic method, which reports the balance between two successive "summer surfaces", excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The late autumn melting is normally restricted to the lower parts of the glacier. It is insignificant compared with winter accumulation and summer ablation, and is usually difficult to determine accurately. The extent of late autumn melting is considered to be insignificant based on comparison of stake readings and snow depth soundings.

Winter balance

The calculation of winter balance was based on point measurements of snow depth (stake readings, coring and snow depth soundings) and on snow density measurements (Fig. 10-1). Water equivalent profiles were modelled from the snow density measured at stakes 38 and 143. Using these models, the mean snow density for 5 m of snow was calculated as 0.51 g/cm^3 at stake 38 and 0.52 g/cm^3 at stake 143. The models based on the density profiles at stake 38 and 143 were then used to calculate the water equivalent value of the snow depth measurements below and above 1225 m a.s.l., respectively.

Point values of the snow water equivalent (SWE) were plotted against altitude, and a curve was drawn based on visual evaluation. Below 950 m a.s.l. the winter balance curve was interpolated based on the observed snow depth around stake 34, the transient snow line altitude, and the observed negative winter balance at stake17. Based on this altitudinal distribution curve, the winter balance was calculated as 2.9 ±0.2 m w.eqv., which corresponds to a volume of 115 ±8 million m^3 of water. This is 100 % of the mean value for the period from 1970-2003 (2.93 m w.eqv.), and 130 % of the mean value for the 5-year period 1999-2003.

Summer balance

The summer balance was measured and calculated directly at nine locations between 300 and 1400 m a.s.l. An altitudinal distribution curve was drawn based on the measurements (Fig. 10-2). The summer balance was calculated as −2.1 ± 0.2 m w.eqv., which equals a volume of −83 ± 8 million m^3 water. This is 91 % of the average for the period 1970-2003 (−2.30 m w.eqv.), and 84 % of the average for the 5-year period 1999-2003.

Net balance

The net balance of Engabreen for 2004 was calculated as +0.8 ±0.3 m w.eqv., which corresponds to a volume gain of 30 ±10 mill. m^3 water. The mean value for the period 1970-2003 is +0.63 m w.eqv., and −0.25 m w.eqv for 1999-2003. The equilibrium line altitude (ELA) was determined as 1040 m a.s.l. from the net balance curve in Figure 10-3. This gives an accumulation area ratio (AAR) of 83 %. The mass balance results are shown in Figure 10-3 and Table 10-1. The results from 2004 are compared with mass balance results for the period 1970 - 2003 in Figure 10-4.

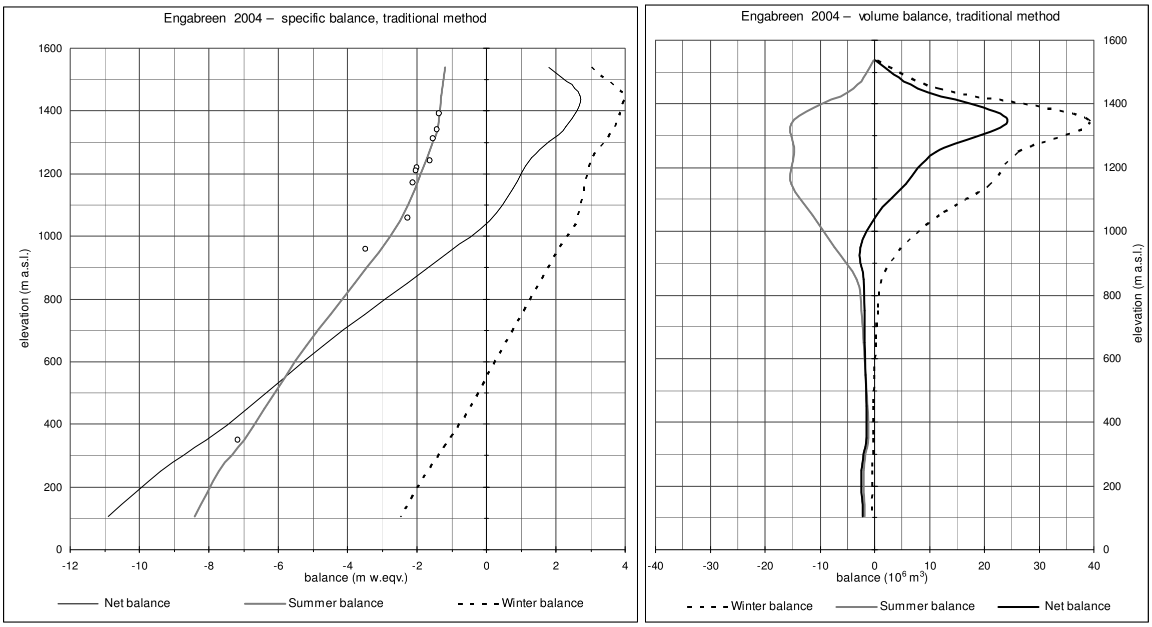


Figure 10-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2004. Summer balance at stakes and towers is shown as circles (○).

Table 10-1
Specific and volume winter, summer, and net balance calculated for 100 m elevation intervals at Engabreen in 2004.

Mass balance Engabreen 2003/04 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 26th May 2004: Specific (m w.eqv.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 16th Oct 2004: Specific (m w.eqv.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surface 2003 - 2004: Specific (m w.eqv.)	Net balance: Volume (10^6 m^3)
1500 - 1575	0,13	3,00	0,4	-1,20	-0,2	1,80	0,2
1400 - 1500	2,94	4,00	11,8	-1,30	-3,8	2,70	7,9
1300 - 1400	10,52	3,70	38,9	-1,40	-14,7	2,30	24,2
1200 - 1300	8,68	3,00	26,0	-1,70	-14,8	1,30	11,3
1100 - 1200	7,47	2,80	20,9	-2,05	-15,3	0,75	5,6
1000 - 1100	4,52	2,60	11,8	-2,50	-11,3	0,10	0,5
900 - 1000	2,38	2,00	4,8	-3,10	-7,4	-1,10	-2,6
800 - 900	0,87	1,50	1,3	-3,80	-3,3	-2,30	-2,0
700 - 800	0,54	1,00	0,5	-4,50	-2,4	-3,50	-1,9
600 - 700	0,38	0,50	0,2	-5,20	-2,0	-4,70	-1,8
500 - 600	0,28	0,00	0,0	-5,80	-1,6	-5,80	-1,6
400 - 500	0,20	-0,50	-0,1	-6,40	-1,3	-6,90	-1,4
300 - 400	0,17	-1,10	-0,2	-7,00	-1,2	-8,10	-1,4
200 - 300	0,26	-1,70	-0,4	-7,70	-2,0	-9,40	-2,4
10 - 200	0,21	-2,50	-0,5	-8,40	-1,8	-10,90	-2,3
10 - 1575	39,6	2,92	115,3	-2,10	-83,0	0,82	32,3

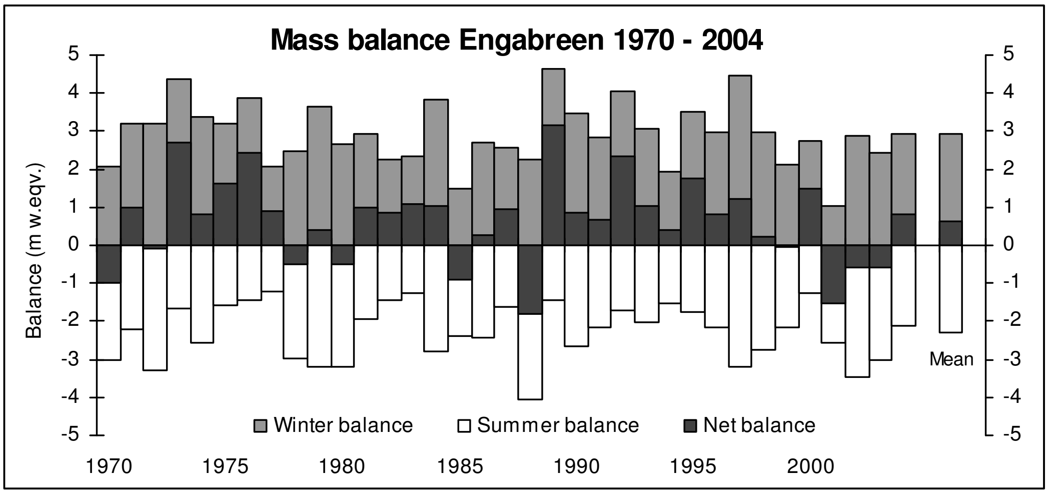


Figure 10-4
Mass balance at Engabreen during the period 1970-2004. The accumulated surplus amounts to 22 m water equivalent.

10.2 Meteorological measurements

A meteorological station recording air temperature, global radiation, precipitation, wind speed and wind direction is located on the nunatak Skjæret (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig. 10-1). The station has recorded data since 1995 with some data gaps. Otherwise, the nearest meteorological station is Glomfjord (39 m a.s.l.) 19 km north of Skjæret. This station has been operated by the Norwegian Meteorological Institute (DNMI) since 1916.

In 2004, the station at Skjæret was operational from the 3rd March with some data gaps in June-July. Between 3rd March and 15th October the station has recorded 199 days of observations. At Glomfjord the mean annual temperature in 2004 was 6.0 ºC which is 1.0 ºC above the 1961-90 average. The summer temperature (15/5 – 15/9, 11.2 ºC) was 3.0 and 1.4 ºC lower than in 2002 and 2003, respectively, but similar to the temperature in 2000 and 2001.

The temperature record from Glomfjord and the discharge record from the glacier river in Svartisen Subglacial Observatory (Engabreen subglacial intake) show that limited melting took place on the glacier plateau after 15th September 2003. Up to 1 m of new snow accumulated before the 28th September. After 28th September, limited melting, possibly in connection with rainfall, took place on the lower part of the plateau around 17th and 28th October and 7th November.

The temperature record at Skjæret and the discharge record at the subglacial intake show that some melting took place on the plateau between 3rd and 9th May, 15 days before the winter balance measurements. After the net balance measurements on 16th October 2004 there were one period of melting and/or rainfall recorded at the subglacial discharge station. However, there was up to 0.5 m of new snow on the glacier on 16th October (above 1000 m a.s.l.), implying that late autumn melting did not affect the summer balance for most of Engabreen. At the glacier tongue melting normally occurs periodically throughout the winter.

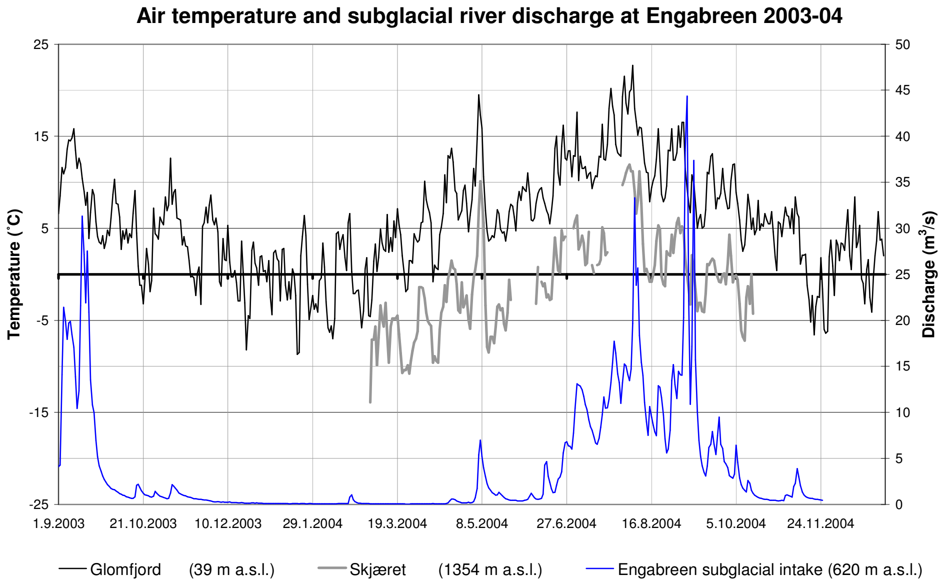


Figure 10-5
Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700) between 1st September 2003 and 31st December 2004, and daily discharge at a subglacial river intake (159.11) draining most of the plateau area of Engabreen above 800 m a.s.l. (ca. 32 km^2).

10.3 Svartisen subglacial laboratory

Svartisen Subglacial Laboratory is a unique facility situated under Engabreen. It allows direct access to the bed of the glacier for the purposes of measuring sub-glacial parameters and performing experiments on the ice. Further general information about the laboratory is available in report number 14 in NVE's document series for 2000, entitled 'Svartisen Subglacial Laboratory' (Jackson, 2000).

Pressure measurements

Six load cells were installed at the bed of the glacier in December 1992 in order to measure variations in subglacial pressure. Four of these were still operating in 2004. A further two load cells were installed in November 1997 and were also still operating in 2004 (Fig. 10-6). The load cells are Geonor P-105 Earth Pressure Cells. Readings are recorded from the load cells at 15 minute intervals (more frequently when experiments are being performed). The load cells recorded data from 1st January to 1st September. Problems with the storage module mean that no intelligible data were recorded between 2nd September and 4th November. Data recorded from 5th November to the end of the year were not available at the time of writing and are not reported here. A seventh load cell, installed in November 2003, recorded intermittently as it was damaged during experimental work in March. Hence, results from this load cell are not reported here.

Pressure sensor records for 1st January to 24th March 2004 are shown in Figure 10-7. This shows a lot more activity than is usual for the winter months, especially for load cells 97-1 and 97-2. This activity appears to be unrelated to discharge measured at the subglacial intake (Fig. 10-5). This shows only one clear event of increased subglacial discharge on about 20th February, which is reflected in the load cell records. The cause of other pressure events is unclear. The amount of activity at load cells 97-1 and 97-2 suggests the presence of water channels during much of this period.

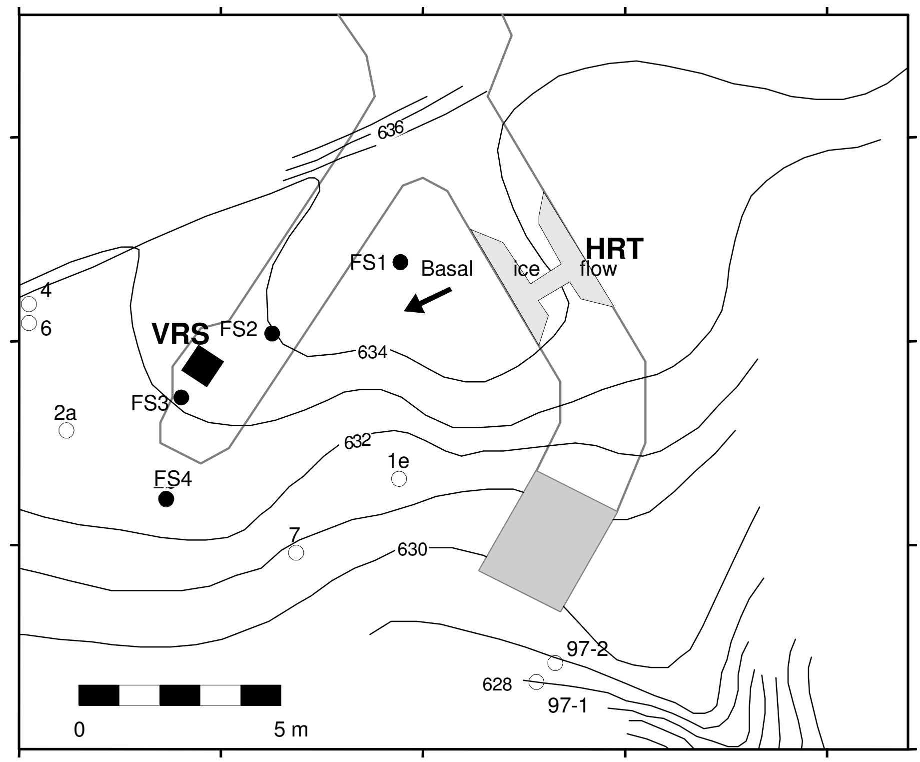


Figure 10-6
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 7 (recorded intermittently in 2005), 97-1 and 97-2 and boreholes, marked FS.

Data for the period from 25th March to 6th April are not shown, as there was experimental work in progress during this period leading to very noisy data, and the experimental results will be reported elsewhere.

Pressure sensor records for the late spring period from 7th April to 25th May are shown in Figure 10-8. These records are fairly typical for the springtime regime. High temperatures for several days from 16th April (see Fig. 10-5) led to increased subglacial discharge of 2 m^3/s, which was twenty times the previous values and this sudden increase in water flow is clearly shown in the load cell pressure records for 19th/20th April when there must have been increased meltwater at the glacier base. A major event about 5th May when the presence of channels is shown at load cells 97-1 and 97-2 is due to high temperatures of up to 15 °C at Skjæret and a sudden increase in subglacial discharge from less than 1 m^3/s to more than 10 m^3/s. Towards the end of this period, the pressure signal is more noisy and shows that the subglacial regime is now developing into a standard summer regime.

Pressure sensor records for the summer period, from 25th May to 1st September, are shown in Figure 10-9. These are typical for the summer period and show lots of activity in the pressure records suggesting a well-developed drainage system at the glacier base. Both 97-1 and 97-2 show negative values, probably due to drift in the calibration for these load cells.

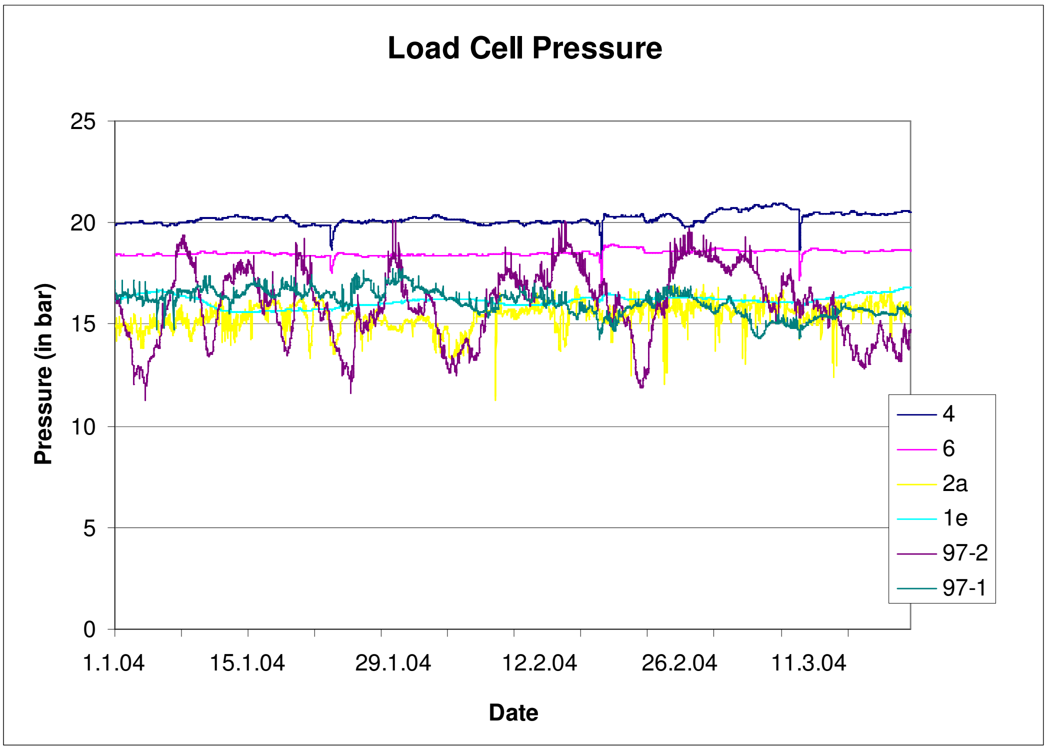


Figure 10-7
Pressure records for the period January to late March.

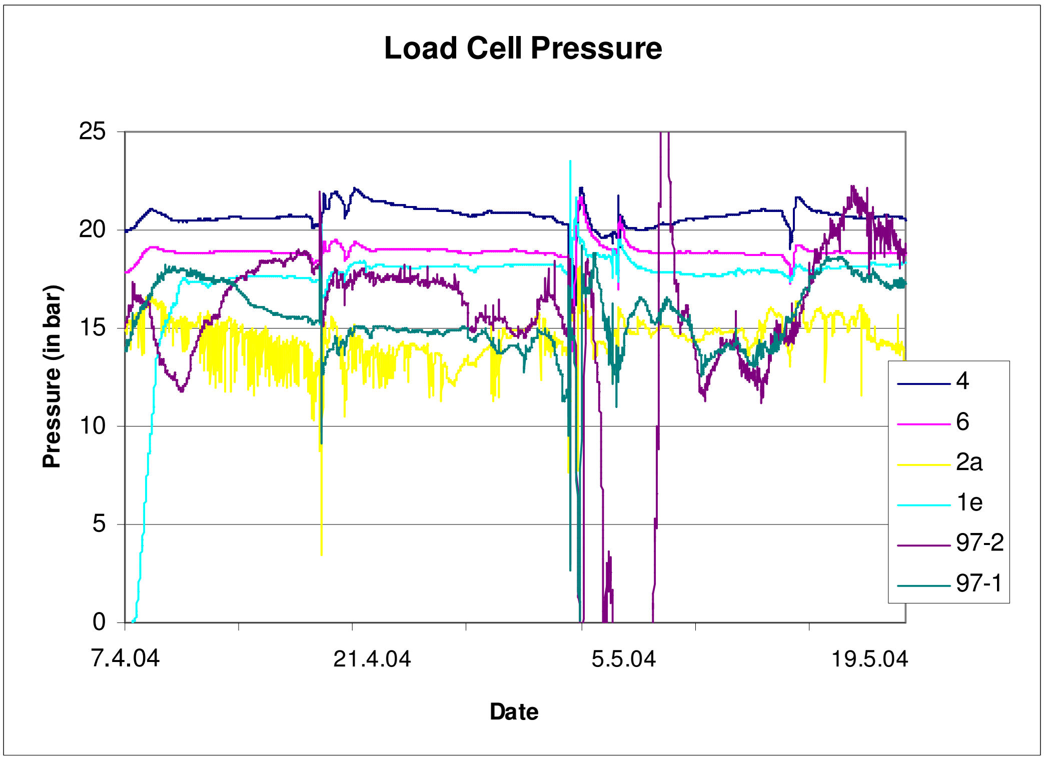


Figure 10-8
Pressure records for the period April to late May.

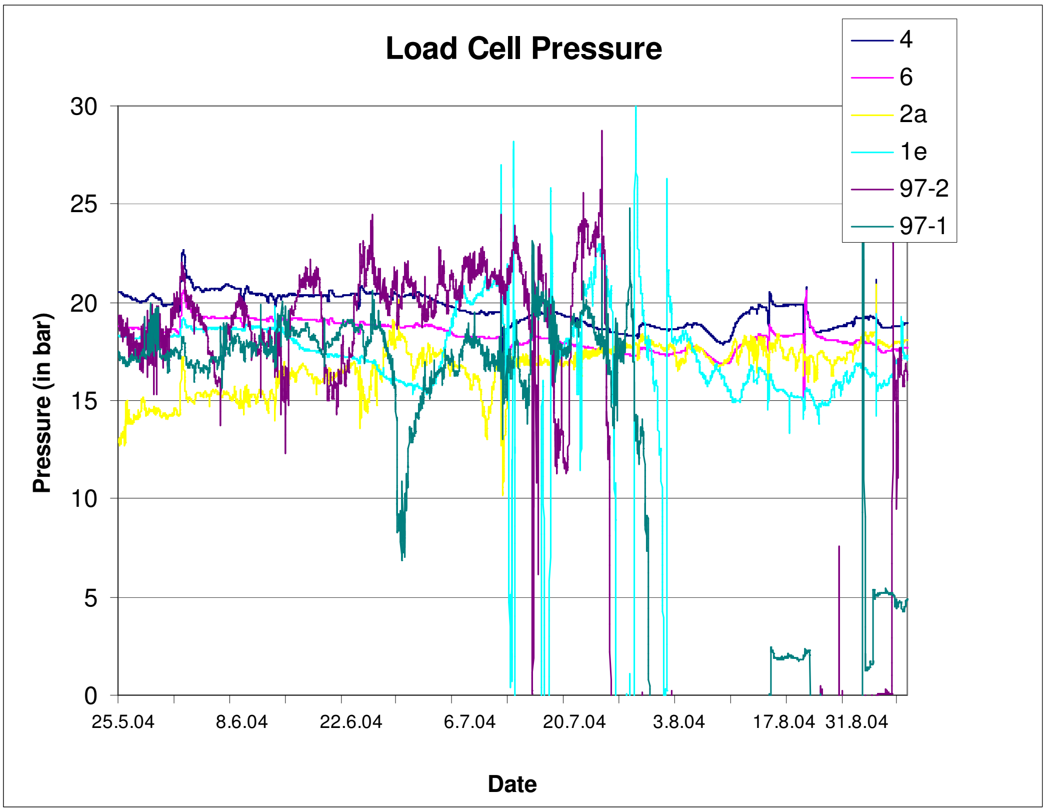


Figure 10-9
Pressure records for the period late May to the beginning of September.

10.4 Svartisheibreen

Svartisheibreen (5.5 km^2, 774 – 1530 m a.s.l., 66°35'N, 13°45'E) is located 10 km south-west of Engabreen. The glacier has been monitored since 1987 in connection with a planned hydropower development. The monitoring program included mass balance (1988 – 1994), bed topography, glacier velocity, volume change, and lake level recording in the proglacial lake Heiavatnet. The lake has been subject to jøkulhlaups at least three times between 1991 and 1999. The glacier was not visited during 2004.

The net balance of Svartisheibreen in 2004 was calculated from a linear regression model between net balance at Engabreen and net balance at Svartisheibreen. Using this model, the specific net balance of Svartisheibreen was +0.5 m w.eqv., which corresponds to a mass gain of 2 mill. m^3 water (Fig 10-10). The cumulative net balance at Svartisheibreen since 1969 equals +11 m w.eqv. The cumulative net balance at Engabreen in the same period is +22 m w.eqv.

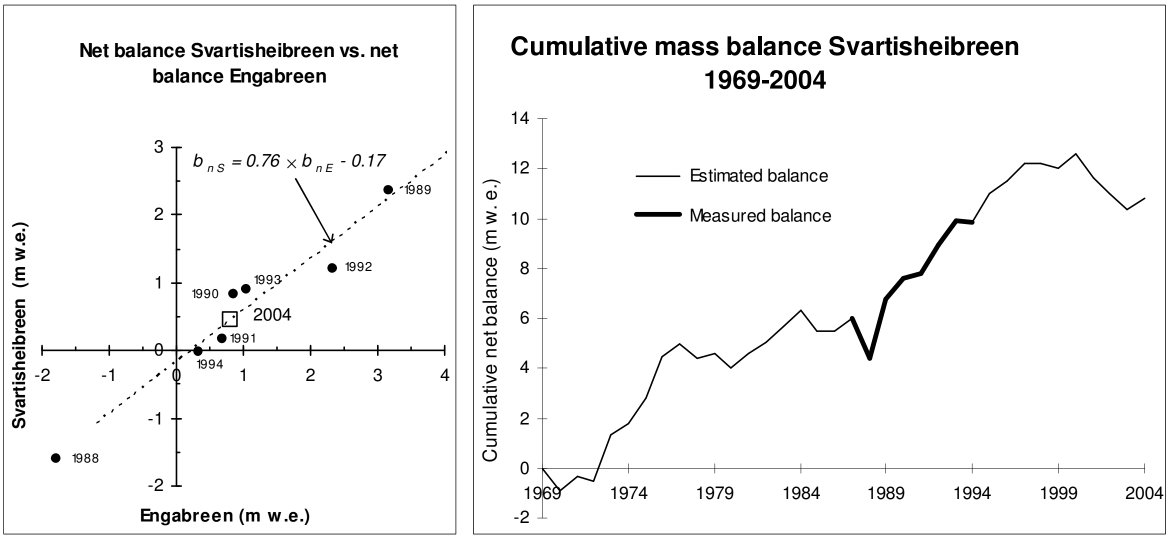


Figure 10-10
Net balance at Svartisheibreen modelled from measured net balance at Engabreen and Svartisheibreen in 1988-94 (left), and cumulative specific net balance at Svartisheibreen for the period 1969-2004 (right).

11. Storglombreen (Hallgeir Elvehøy)

Storglombreen (66°41'N, 14°00'E) is the largest outlet from the Svartisen icecap. It covers an area of 62.4 km^2 and drains the western Svartisen ice cap to Lake Storglomvatnet (Fig. 11-1). Most of its area is located between 900 and 1300 m a.s.l. The glacier calves into the lake in tree distinct outlets. Mass balance measurements were carried out during the four years from 1985 to 1988, and recommenced in 2000. In addition, front position changes are monitored.

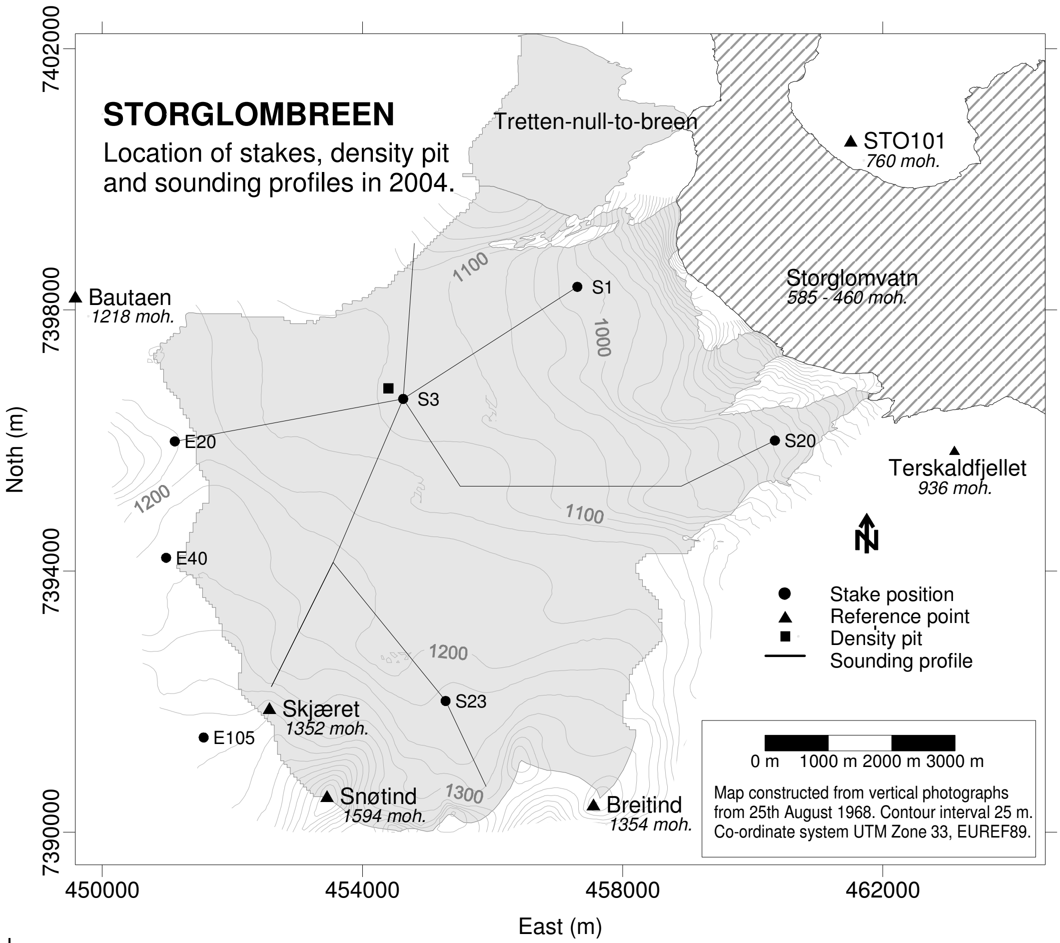


Figure 11-1
Location of stakes, density pit and sounding profiles at Storglombreen in 2004. Three stakes on Engabreen located close to Storglombreen are also used in the calculations.

Based on an extensive monitoring program from 1985 to 1988, a simplified observation network for mass balance measurements was established. A linear regression was established between mean water equivalent for all snow depths along the selected profiles (corresponding to the profiles in Fig.11-1), and specific winter balance for the entire glacier from winter balance maps. A linear regression between summer balance at stake 3 and specific summer balance (without calving) for the entire glacier was also established (Kjøllmoen, 2001).

11.1 Mass balance 2004

Fieldwork

Snow accumulation measurements were carried out on the 28th May. The location of stakes, density pit and sounding profiles are shown in Figure 11-1. The calculation of the winter balance was based on:

- Snow depth at stakes S1, S20 and E105 showing 3.30, 0.30 and 7.15 m, respectively.
- Snow density measured to a depth of 4.75 m at stake S3. Mean snow density was 0.48 g/cm^3.
- Snow depth measured by coring at locations S23, E20 and E40 showing 4.95, 5.35 and 5.4 m of snow, respectively.
- 99 snow depth soundings along 25 km of profiles between 900 and 1300 m a.s.l. Most observations showed between 4 and 6 m of snow. The summer surface was generally well defined.

Net balance measurements were carried out on the 16th October. At that time up to 0.15 m of new snow had fallen on the glacier. Based on stake observations, the snow line altitude was between 1000 and 1100 m a.s.l. During the summer, 0.3 m of snow and 4.5 m of ice melted at stake S20, while 3.3 m of snow and 1.0 m of ice melted at stake S1. At the stakes on the plateau 3 to 4 m of snow melted, and 1 to 4 m of snow remained.

Results

The calculations were based on a map from 1968 and drainage divides calculated from bottom topography and ice thickness (Kennett et al. 1997). The mass balance was also calculated using the regression equations established from the observation period 1985-1988.

Winter balance

The winter balance was calculated from point measurements of snow depth (stakes and soundings) and measurements of snow density at stake S3. The snow density measurements were used to model a water equivalent profile. According to this model, the mean snow density of 5 m of snow was 0.49 g/cm^3. This model was used to convert all snow depth observations to water equivalent values.

The total winter balance was calculated from the altitudinal distribution of the snow depth soundings. Point values of the snow water equivalent were plotted against altitude, and a representative curve was drawn based on the mean value in each 100 m elevation interval. As snow depth was observed only between 900 and 1300 m a.s.l., the mean balance curve for the period 1985-1988 was used as a basis for the curve below 900 m a.s.l. and above 1300 m a.s.l. The altitudinal winter balance distribution is shown in Figure 11-2 and Table 11-1. Using this method the total winter balance was calculated as 140 ±10 mill. m^3 water, which corresponds to 2.3 ±0.2 m w.eqv. The calculated winter balance is 109 % of the 1985-88 and 2000-03 average (2.07 m w.eqv.). At Engabreen the winter balance (2.9 m w.eqv.) was 129 % of the 1985-88 and 2000-03 average (2.27 m w.eqv.).

The winter balance was also calculated using the regression equation defined from measurements as well as results from 1985-88. The mean water equivalent for 93 snow depth measurements along the profiles shown in Figure 11-1 was 2.54 m. This corresponds to a specific winter balance of 2.2 m, which is close to the result above.

Summer balance

The summer balance was calculated at four locations on Storglombreen (S20, S1, S3 and S23), and three locations on Engabreen (E20, E40 and E105) located close to the ice divide (Fig. 11-1). The summer balance curve (Fig. 11-2) was drawn from these seven point values and the mean balance curve for the period 1985-1988.

The contribution from calving and ice avalanches was estimated as −7 mill. m^3 water, as it was in 1985-1988. This contribution was estimated from a terminus length of 1.6 km, a mean terminus height of 50 m and a glacier velocity of 100 m/a. The total summer balance, including the calving contribution, was −130 ±20 million m^3 water, which is equal to a specific balance of –2.1 ±0.3 m w.eqv. The calculated summer balance is 76 % of the mean summer balance for 1985-1988 and 2000-2003 (−2.82 m w.eqv.). At Engabreen the summer balance (−2.1 m w.eqv.) was 81 % of the 1985-88 and 2000-03 average (−2.61 m w.eqv.).

The summer balance was also calculated using a regression model. The summer balance at stake 3 was −1.6 m w.eqv., corresponding to a specific summer balance including calving of −2.0 m w.eqv., which is close to the result above.

Net balance

The net balance of Storglombreen for 2004 was 0.1 ±0.4 m w.eqv., which corresponds to a mass gain of 10 ±30 mill. m^3 water. The mass balance results are shown in Table 11-1 and Figure 11-2. The mean value for 1985-1988 and 2000-03 is -0.75 m w.eqv. At Engabreen the net balance was +0.8 m w.eqv., which is 1.1 m above the 1985-88 and 2000-03 average. From the net balance curve the equilibrium line altitude (ELA) is defined as 1075 m a.s.l. (1040 m a.s.l. on Engabreen). The accumulation area ratio (AAR) was 78 % (83 % on Engabreen).

The results from 2004 are compared with mass balance results for the period 1985-1988 and 2000-03 in Figure 11-3.

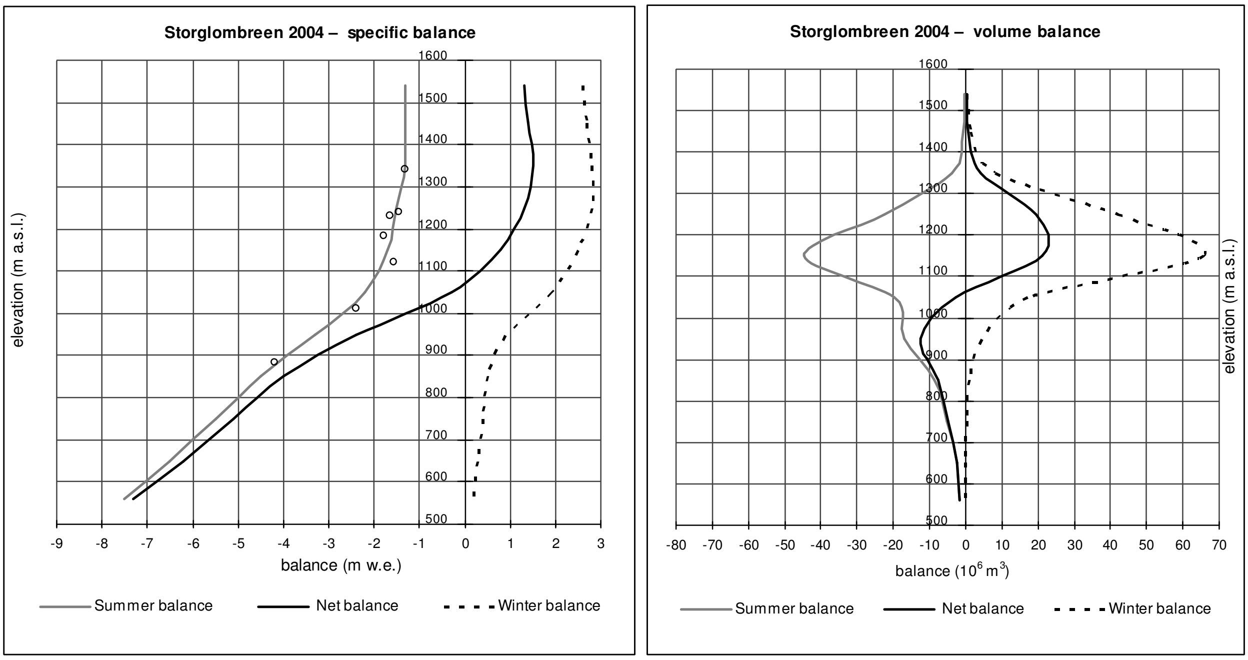


Figure 11-2
Winter, summer and net balance for Storglombreen in 2004, showing specific balance (left) and volume balance (right). Summer balance at stakes is shown as circles (°).

Table 11-1
Specific and volume winter, summer, and net balance calculated for 100 m elevation intervals for Storglombreen in 2004.

Mass balance Storglombreen 2003/04 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 28th May 2004 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 16th Oct 2004 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 2003 - 2004 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1500 - 1580	0,18	2,60	0,47	-1,30	-0,23	1,30	0,23
1400 - 1500	0,58	2,70	1,56	-1,30	-0,75	1,40	0,81
1300 - 1400	2,89	2,80	8,08	-1,30	-3,75	1,50	4,33
1200 - 1300	15,02	2,80	42,06	-1,50	-22,53	1,30	19,53
1100 - 1200	26,23	2,50	65,58	-1,70	-44,60	0,80	20,99
1000 - 1100	8,91	1,90	16,93	-2,20	-19,60	-0,30	-2,67
900 - 1000	5,16	0,90	4,65	-3,30	-17,04	-2,40	-12,40
800 - 900	1,91	0,50	0,95	-4,50	-8,58	-4,00	-7,63
700 - 800	0,95	0,40	0,38	-5,50	-5,21	-5,10	-4,83
600 - 700	0,38	0,30	0,11	-6,50	-2,45	-6,20	-2,34
520 - 600	0,22	0,20	0,04	-7,50	-1,68	-7,30	-1,64
Calving					-7,2		-7,2
520 - 1580	62,4	2,26	140,8	-2,14	-133,6	0,11	7,2

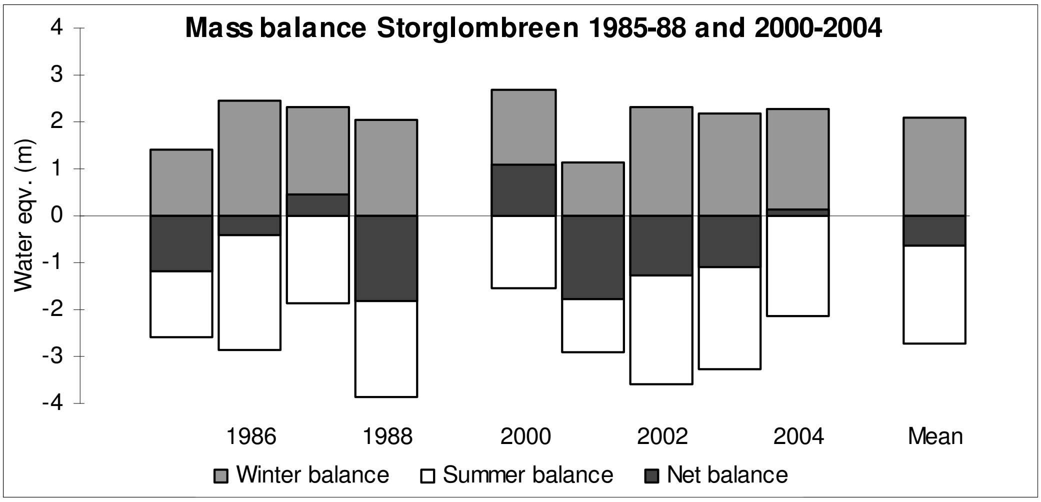


Figure 11-3
Mass balance at Storglombreen during the period 1985-1988 and 2000-2004. The nine year mean values are b_v=2.09 m w.eqv., b_s=–2.74 m w.eqv., and b_n= –0,65 m w.eqv.

11.2 Front position change

Storglombreen has three distinct termini that calve into Storglomvatnet (Fig. 11-1). Observations of front position changes began in 2000, and will continue in order to document changes associated with changes in the lake level of the reservoir. The calving terminus of the glacier Tretten-null-to-breen is observed also (Fig. 11-1).

The termini were surveyed on the 16th October from the survey point STO101 using Terskaldfjellet as a reference point (Fig. 11-4). A Geodimeter total station was used to sight on eight reflectors located in the helicopter window. The terminus position was measured by observing the reflectors as the helicopter touched the ice edge, if possible, along the front perimeter. The accuracy of this method depends on the geometry of the glacier front and the flight conditions, and such measurements may therefore be relatively uncertain. Horizontal uncertainty of individual points is estimated to be less than ±2 m. Figure 11-4 shows the observations, and the observed terminus position in 1985 and 1968**.** At the time of the field visit, the lake level was 579 m a.s.l., six meter below the highest level.

Tretten-null-to-breen

The 150 m long terminus was defined by measuring three points. The terminus had advanced approximately 10 m between 2002 and 2003 at the right hand side.

North Storglombreen

The 400 m long terminus was defined by measuring four points. No change was detected between 2003 and 2004.

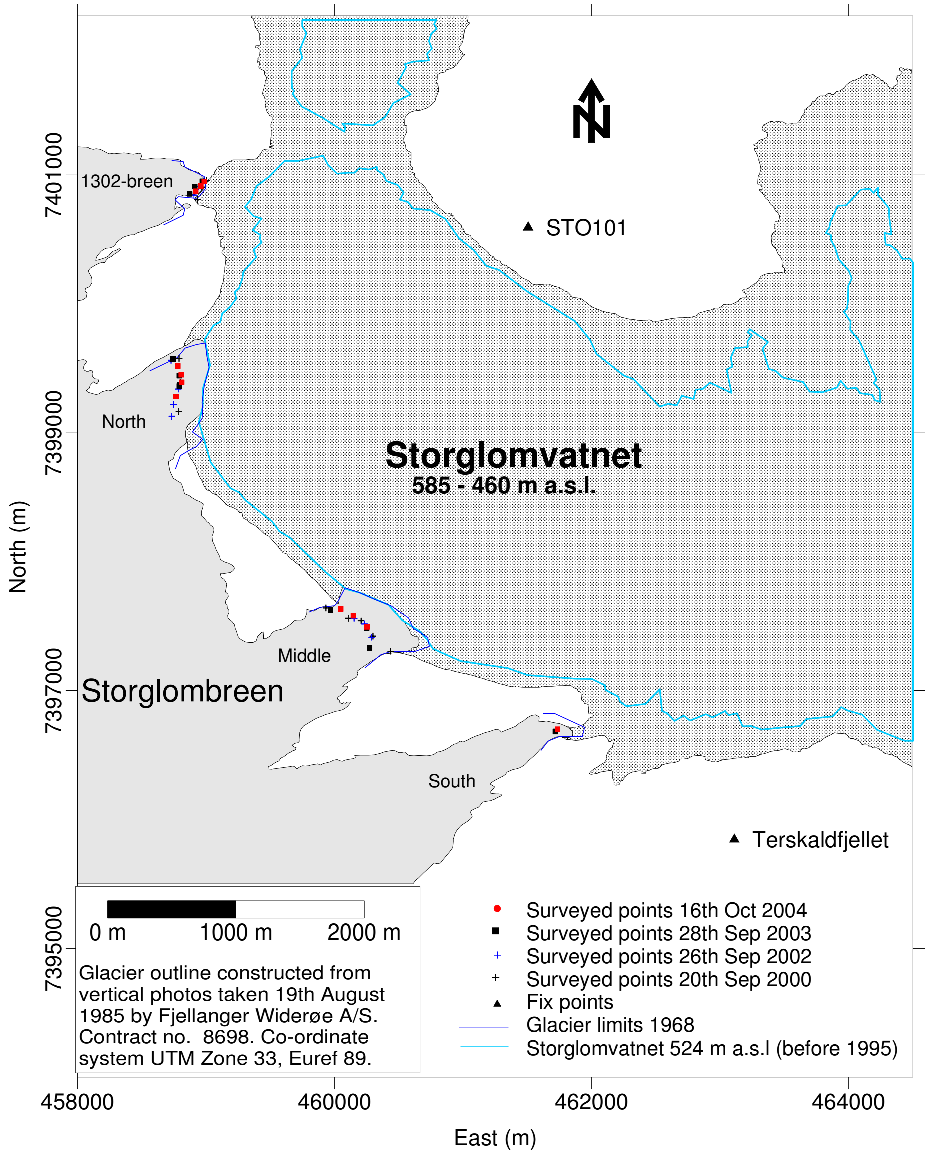


Figure 11-4
Front position changes of the termini that calve into the Storglomvatnet reservoir.

Middle Storglombreen

The terminus was defined by measuring three points. No significant change was detected.

South Storglombreen

This terminus is not visible from STO101. The glacier terminated in the lake. The front position was measured using hand-held GPS. Comparison of GPS positions and photographs from 2003 suggests that no significant change has taken place.

12. Rundvassbreen (Rune V. Engeset)

Rundvassbreen (Fig. 12-1) is a 11.6 km^2 northeastern outlet glacier of the icecap Blåmannsisen (67°20'N, 16°05'E) which, at 87 km^2, is the fifth largest glacier in Norway. Rundvassbreen extends from 1536 m elevation down to 788 m a.s.l. Rundvassbreen is the glacier outlet that drains past lake Øvre Messingmalmvatn, from which a jøkulhlaup in September 2001 drained about 40 million cubic metres of water under the glacier. This event led to a detailed study of the glacier and jøkulhlaup by the hydropower company Elkem Energi Siso AS. An observation programme was begun in 2001 and includes mass balance, lake level change of Øvre Messingmalmvatn and ice surface motion (Engeset 2002 and Engeset 2003). The mass balance observations and results are described in this chapter.

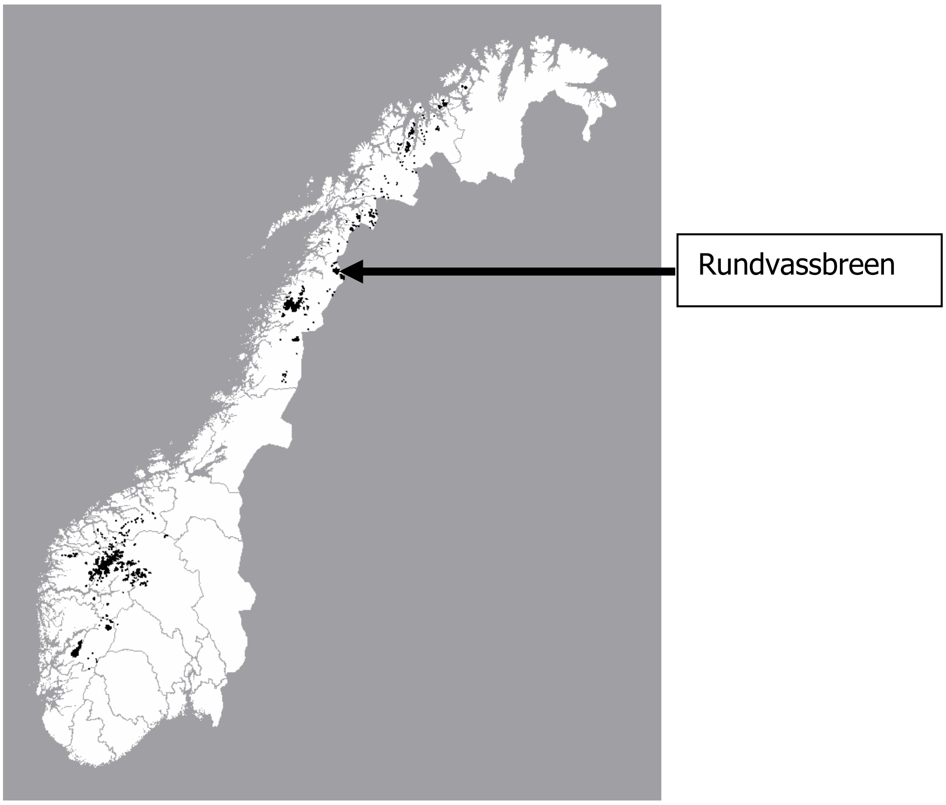


Figure 12-1
Location map.

12.1 Mass balance 2004

Fieldwork

Snow accumulation measurements were carried out on 22nd April. The calculation of winter balance is based on:

- Measurement of snow depth at 6 of the 7 stakes. The stake at the highest elevation was still under snow at this time.

- Snow depth measured at 147 locations spaced every 150 m along a 25 km profile. Identification of the summer surface was relatively easy, albeit more difficult above 1350 m a.s.l. Snow depth was about 4-6 m above 1300 m a.s.l., which is approximately the same as for 2003. Below this elevation the snow depth varied between less than 1 m to more than 5 m.
- Snow density cores obtained at stake 50 (1330 m a.s.l.). A snow density cylinder was used to 2.0 m depth and cores retrieved at greater depths down to 5.0 m. The mean snow density was 0.468 g/cm^3.

Ablation measurements were carried out on 4th October. Between 0.5 and 0.8 m of fresh snow was found in the lower areas and between 0.8 and 1.5 m in the upper areas. Thus, the firn and snow lines were not visible. Stake readings indicated that the snow line at the end of the ablation season was located close to stake 40 (1270 m a.s.l,).

Results

Winter balance

The calculation of winter balance is based on point measurements of snow depth (147 soundings and 6 stakes) and snow density at one location.

Snow water equivalent (SWE) was calculated by the fitting a function between observed depth and density:

$$SWE = 0.3277878 \text{ x snow depth } ^{\wedge 1.2182649}$$

The winter balance calculation was performed by plotting measurements (water equivalent) on a diagram. A curve was drawn based on visual evaluation, and a mean value for each 50 m height interval was estimated (Tab. 12-1). This gives a *winter balance* of 2.0 m w.eqv., corresponding to a water volume of 23 mill. m^3, which is 104 % of the previous year's winter balance.

Simulation of the glacier mass balance (Engeset 2002) for the period 1962-2001 (40 years) gave an annual mean of 1.7 m w.eqv. (winter balance), −1.8 (summer balance) and −0.1 (net balance). The 2004 winter balance is 113 % of simulated annual mean for 1962-2001.

Summer balance

In calculating the summer balance the density of the remaining snow was estimated as 600 kg/m^{-3}, and the density of melted ice as 900 kg/m^{-3}. Fresh snow (0.5-1.5 m depth) is not included in the summer balance calculation.

The summer balance was calculated at 7 stakes and estimated for each 50-m elevation interval. Based on estimated density and stake measurements the *summer balance* was calculated as −2.2 m w.eqv., which is −25 mill. m^3 of water. This is 73 % of the value for 2003, and 118 % of the simulated annual mean for 1962-2001.

Net balance

The *net balance* was calculated as −0.2 m w.eqv., which equals a deficit of 2 mill. m^3 water (Fig. 12-2 and Tab. 12-1). Cumulative net balance is shown in Figure 12-3.

The diagram in Figure 12-2 indicates that the equilibrium line altitude (ELA) was 1260 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 51 %.

The diagram in Figure 12-2 shows the specific net balance curve as a function of elevation. The curve differs from those of the two previous years. In 2002 and 2003 the summer balance was relatively stable in the areas above 1375 m a.s.l. In 2004, however, the summer balance decreased from –1.8 m w.eqv. at 1375 m altitude to –0.4 m w.eqv. in the uppermost areas (above 1500 m altitude). These disparities can be explained by measurement errors in the uppermost area. Sounding conditions and maintenance of two of the stakes have been difficult. Hence, it is supposed that the results from the uppermost area are more inaccurate than those from the lower areas.

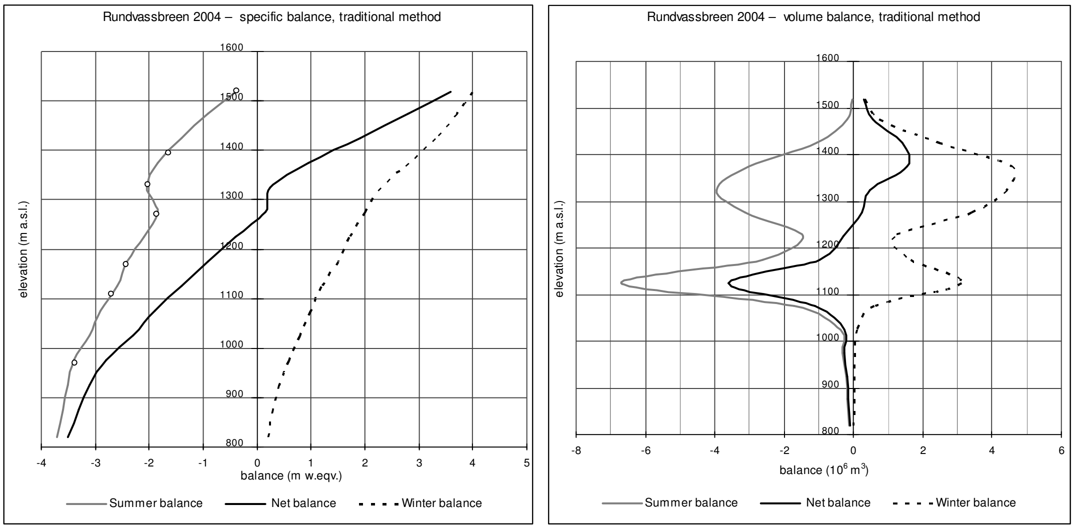


Figure 12-2
Specific balance (left) and volume balance (right) for Rundvassbreen in 2004.

Table 12-1
Winter, summer and net balance for Rundvassbreen in 2004.

Mass balance Rundvassbreen 2003/04 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 28th April 2004		Measured 4th Oct 2004		Summer surfaces 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1500 - 1537	0.09	4.00	0.3	-0.40	0.0	3.60	0.3
1450 - 1500	0.20	3.70	0.7	-0.90	-0.2	2.80	0.6
1400 - 1450	0.75	3.30	2.5	-1.40	-1.0	1.90	1.4
1350 - 1400	1.62	2.80	4.5	-1.85	-3.0	0.95	1.5
1300 - 1350	1.92	2.30	4.4	-2.05	-3.9	0.25	0.5
1250 - 1300	1.69	2.00	3.4	-1.85	-3.1	0.15	0.3
1200 - 1250	0.70	1.70	1.2	-2.10	-1.5	-0.40	-0.3
1150 - 1200	1.09	1.50	1.6	-2.40	-2.6	-0.90	-1.0
1100 - 1150	2.58	1.20	3.1	-2.60	-6.7	-1.40	-3.6
1050 - 1100	0.59	1.00	0.6	-2.90	-1.7	-1.90	-1.1
1000 - 1050	0.12	0.80	0.1	-3.10	-0.4	-2.30	-0.3
950 - 1000	0.10	0.60	0.1	-3.40	-0.3	-2.80	-0.3
900 - 950	0.06	0.40	0.0	-3.50	-0.2	-3.10	-0.2
850 - 900	0.05	0.30	0.0	-3.60	-0.2	-3.30	-0.2
788 - 850	0.03	0.20	0.0	-3.70	-0.1	-3.50	-0.1
788-1537	**11.6**	**1.95**	**22.6**	**-2.16**	**-25.0**	**-0.21**	**-2.4**

13. Langfjordjøkelen (Bjarne Kjøllmoen)

Langfjordjøkelen (70º10'N, 21º45'E) is a plateau glacier situated on the border of Troms and Finnmark counties, approximately 60 km northwest of the city of Alta. It has an area of about 8.4 km^2 (1994), and of this 3.7 km^2 drains eastward (Fig. 13-1). The investigations are performed on this east facing part, ranging from 280 to 1050 m a.s.l.

The glaciological investigations in 2004 include mass balance and change in front position. Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

Figure 13-1
The east-facing outlet of Langfjordjøkelen. The photo was taken on 23rd July 2004.
Photo: Bjarne Kjøllmoen.

13.1 Mass balance 2004

Fieldwork

Snow accumulation measurements

Snow accumulation was measured on 29th April and the calculation of winter balance is based on (Fig. 13-3):

- Uninterrupted measurements of stakes in positions 10 (510 m a.s.l.), 25 (740 m a.s.l.) and 30 (885 m a.s.l.). Measurements of substitute stakes drilled in April 2004 and older stakes that appeared during the melt season in positions 20 (660 m a.s.l.) and 40 (1050 m a.s.l.). Stake readings did not show any indication of melting *after* the final measurements in October 2003.
- Core samples at positions 20 and 40.

- 66 snow depth soundings along approximately 11 km of profiles between 360 and 1050 m a.s.l. Above 900 m altitude several layers of ice and solid snow made it difficult to define the summer surface (SS). Below this altitude the SS was quite distinct. The snow depth varied from 1.5 m at the glacier snout to 4-5 m in the uppermost areas.
- Snow density was measured down to 2.6 m depth (SS at 2.8 m) at 885 m altitude (stake position 30).

Figure 13-2
Snow density measurements at stake 30 (885 m a.s.l.). Photo: Turid-Anne Drageset.

Location of stakes, density pit and sounding profiles are shown in Figure 13-3.

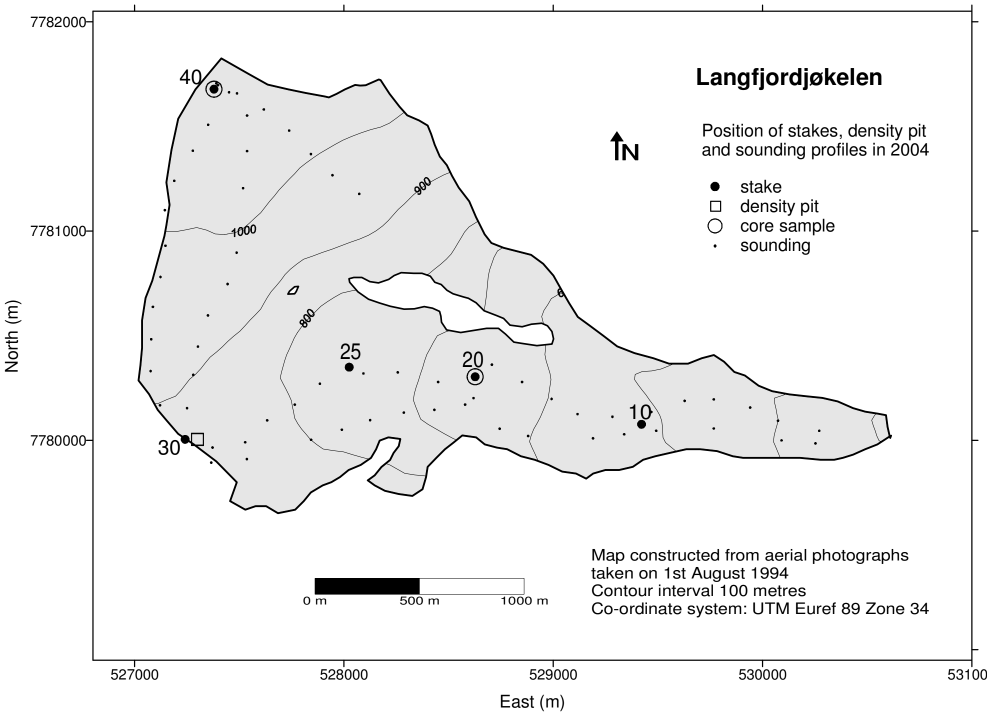


Figure 13-3
Location of stakes, soundings and density pit at Langfjordjøkelen in 2004.

Ablation measurements

Ablation was measured on 4th October. The net balance was measured directly at eight stakes in all five locations between 510 and 1050 m a.s.l. There was no snow remaining on the glacier from winter 2003/2004 at this time. In the areas above 900 m altitude between 45 and 75 cm of fresh snow had fallen.

Results

The calculations are based on a glacier map from 1994.

Winter balance

The calculations of winter balance are based on several point measurements of snow depth (stakes, core samples and soundings) and on one snow density measurement.

A density profile was modelled from the snow density measurement at 885 m altitude. The mean density of 2.8 m snow was 0.457 g/cm^3. The density model was used to convert all measured snow depths to water equivalent.

The winter balance calculations were performed by plotting the measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 13-5) and a mean value for each 100 m height interval was estimated (Tab. 13-1).

The winter balance was calculated as 1.7 ±0.2 m w.eqv., corresponding to a water volume of 6 ±1 mill. m^3. The result is 75 % of the mean value for the periods 1989-1993 and 1996-2003.

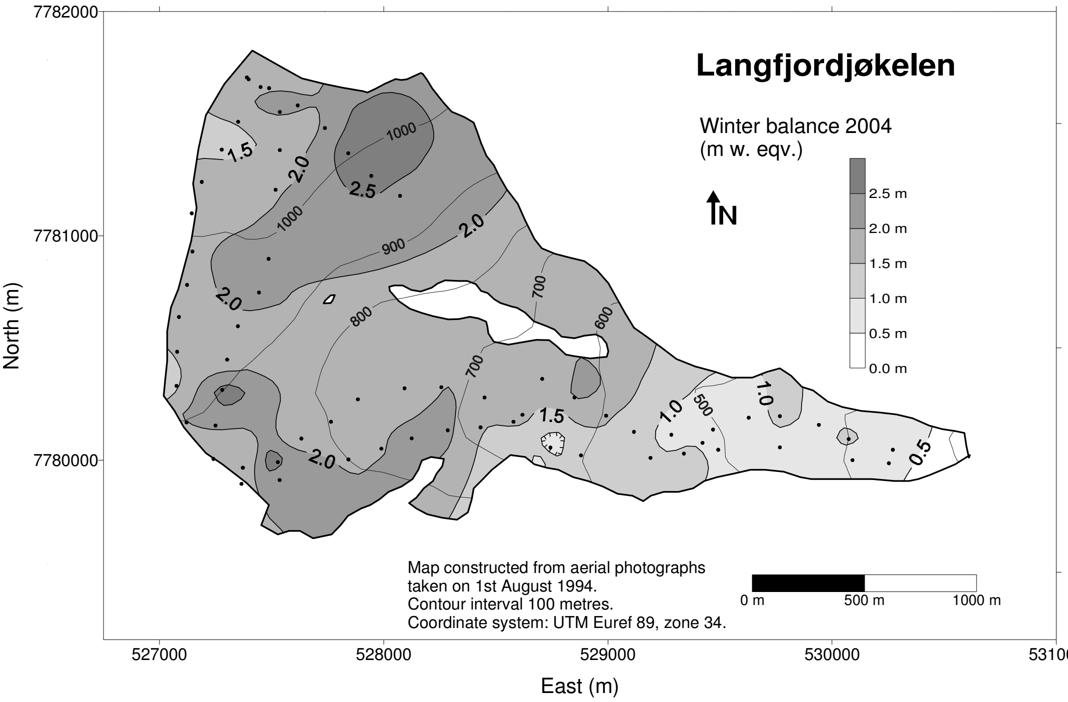


Figure 13-4
Winter balance at Langfjordjøkelen in 2004 interpolated from 66 snow depth measurements (•).

The winter balance was also calculated using different gridding methods and different spacing based on the aerial distribution of the snow depth measurements (Fig. 13-4). Water equivalent for each cell in the grid was calculated and summarised. The calculations gave results between 1.7 m and 1.8 m w.eqv.

Summer balance

The density of melted firn was estimated as 0.65 g/cm^3, while the density of melted ice was calculated as 0.90 g/cm^3.

The summer balance was measured and calculated at all five stake positions, and increased from −2.5 m w.eqv. at position 40 (1050 m a.s.l.) to −5.1 m w.eqv. at position 10 (510 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −3.6 ±0.3 m w.eqv., which is −13 ±1 mill. m^3 of water. The result is 121 % of the average for the periods 1989-1993 and 1996-2003. This is the third greatest summer loss since the measurements began in 1989, and the four greatest summer balances have occurred during the last four years.

Net balance

Hence, the net balance at Langfjordjøkelen for 2004 was −1.9 ±0.3 m w.eqv., which equals a volume loss of −7 ±1 mill. m^3 of water (Tab. 13-1). The mean value for the measurement periods 1989-93 and 1996-2003 is –0.74 m w.eqv. (Fig. 13-6), while the average over the last 5-year period 1999-2003 is −1.4 m w.eqv.

Figure 13-5 indicates that the equilibrium line altitude (ELA) was above the glacier summit (1050 m a.s.l.). Accordingly, the Accumulation Area Ratio (AAR) was 0 %.

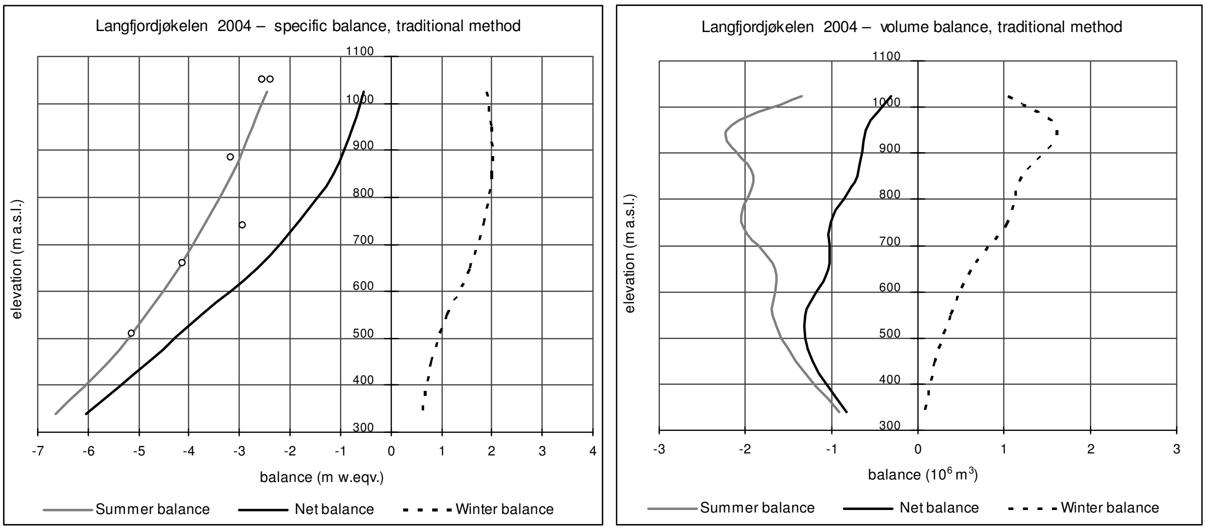


Figure 13-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2004. Summer balance for stakes at three different sites is shown (o).

Table 13-1
Winter, summer and net balance for Langfjordjøkelen in 2004. Mean values for the periods 1989-93 and 1996-2004 are b_w = 2,25 m, b_s = –2,99 m and b_n = –0,74 m w.eqv.

Mass balance Langfjordjøkelen 2003/04 – traditional method

		Winter balance Measured 29th April 2004		Summer balance Measured 4th Oct 2004		Net balance Summer surface 2003 - 2004	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1000 - 1050	0.55	1.90	1.0	-2.45	-1.3	-0.55	-0.3
900 - 1000	0.81	2.00	1.6	-2.75	-2.2	-0.75	-0.6
800 - 900	0.61	2.00	1.2	-3.15	-1.9	-1.15	-0.7
700 - 800	0.56	1.85	1.0	-3.65	-2.0	-1.80	-1.0
600 - 700	0.39	1.55	0.6	-4.20	-1.7	-2.65	-1.0
500 - 600	0.35	1.10	0.4	-4.85	-1.7	-3.75	-1.3
400 - 500	0.25	0.80	0.2	-5.60	-1.4	-4.80	-1.2
280 - 400	0.14	0.60	0.1	-6.65	-0.9	-6.05	-0.8
280 - 1050	**3.65**	**1.69**	**6.2**	**-3.61**	**-13.2**	**-1.92**	**-7.0**

The balance year 2003/2004 is the eighth successive year with significant negative net balance at Langfjordjøkelen, and the second highest deficit since the measurements began in 1989 (Fig. 13-6). The cumulative net balance for the period 1989-2004 is –12 m w.eqv. Most of this mass loss (92 %) has occurred over the last eight years (1997-2004).

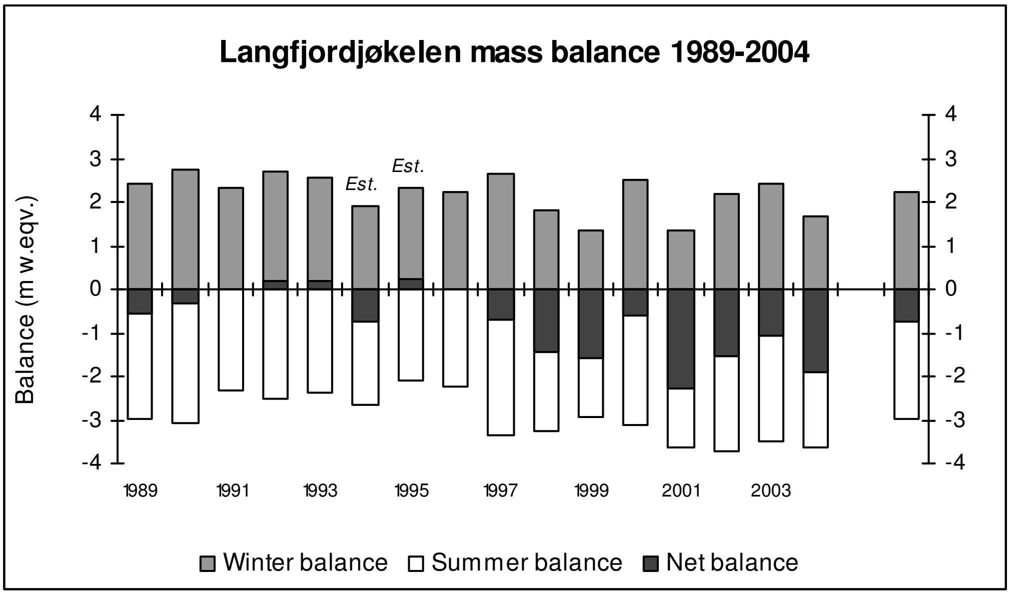


Figure 13-6
Mass balance at Langfjordjøkelen during the period 1989-2004. The total accumulated deficit over 1989-2004 is 12 m water equivalents (includes estimated values for 1994 and 1995).

14. Glacier monitoring

(Hallgeir Elvehøy and Miriam Jackson)

14.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started around 1900. In 2004, glacier length change was measured for 26 glaciers, 24 in southern Norway and 2 in northern Norway (Fig. 14-1).

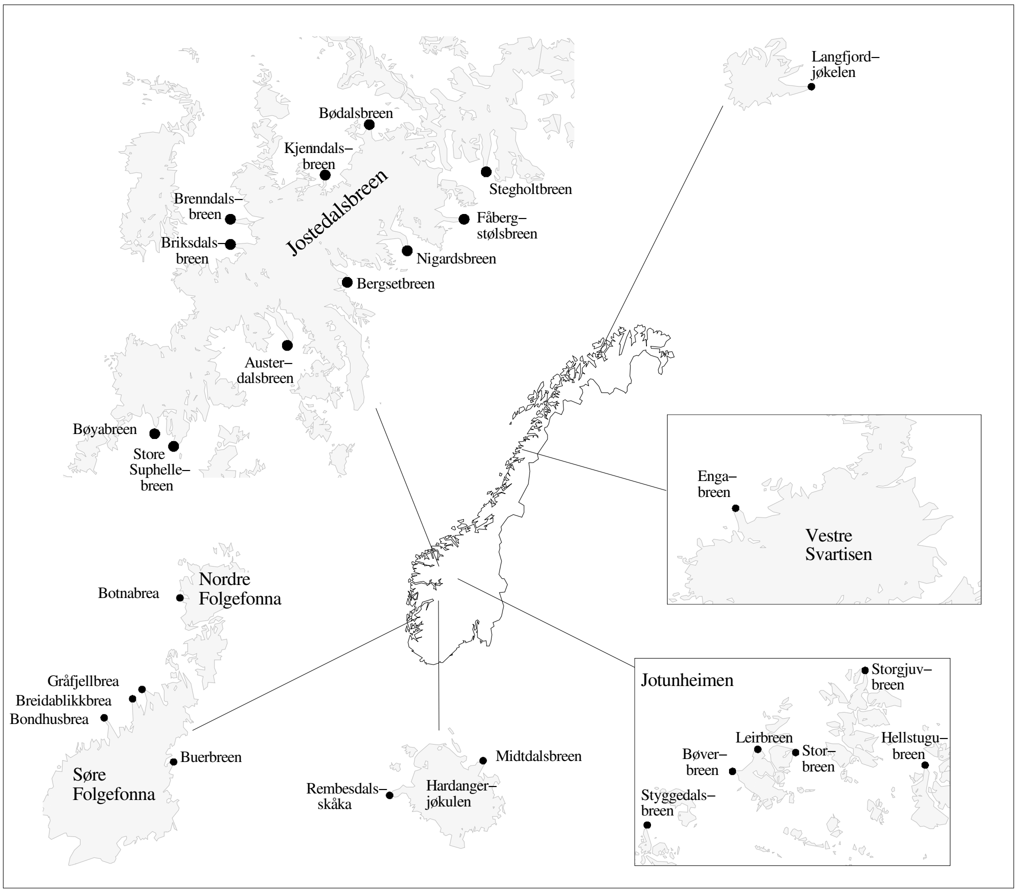


Figure 14-1
Location map showing glaciers where front position measurements were performed in 2004. Note that the different glacier areas are not to the same scale.

Methods

The distance to the glacier terminus is measured from one or several established cairns or painted marks on rocks in defined directions, normally in September or October each year. Change in distance gives a rough estimate of the length change of the glacier. These measurements have a fairly high degree of uncertainty as to what extent the measurement is representative for the entire glacier tongue. Nevertheless, the measurements give valuable information about glacier fluctuations and regional tendencies and variations when longer time periods are considered (Andreassen et al., 2005).

Results 2004

The front position changes from autumn 2003 to autumn 2004 at the observed glaciers are shown in Table 14-1. The main trend in Norway was glacier retreat.

Briksdalsbreen retreated 96 metres, the largest annual retreat there since observations began in 1900. Since 1999 the glacier has retreated 176 m, and the pro-glacial lake that was filled by the glacier tongue in the 1990s has reappeared. Buerbreen retreated 90 m in 2004, and has retreated 164 m altogether since 1998. Its present length corresponds to the situation before the last advance started late in the 1980s. In 2004 twelve glaciers retreated more than 20 metres. Minor or no changes (between –2 and +2 m) were observed at two glaciers. Midtdalsbreen, on the northern side of Hardangerjøkulen, was the only glacier showing a small advance. However, this was probably an adjustment to a 50 metre retreat during the preceding two years.

Table 14-1
Net glacier length change between autumn 2003 and autumn 2004 for 26 glaciers in Norway. See Figure 14-1 for locations.

Area	Glacier	Change (m)	Measured by
Jostedalsbreen	Austerdalsbreen	-5	NVE
	Bergsetbreen	-45	NVE
	Brenndalsbreen	-20	Stefan Winkler, Germany
	Briksdalsbreen	-96	NVE
	Bødalsbreen	-21	Stefan Winkler, Germany
	Fåbergstølsbreen	-1	NVE
	Kjenndalsbreen	-59	Stefan Winkler, Germany
	Nigardsbreen	-25	Statkraft
	Stegholtbreen	-19	NVE
	Bøyabreen	-8	Norsk Bremuseum
	Store Supphellebre	-27	Norsk Bremuseum
Folgefonna	Bondhusbrea	-37	Statkraft
	Botnabrea	-8	Statkraft
	Breidablikkbrea	0	Statkraft
	Buerbreen	-90	NVE
	Gråfjellsbrea	-20	Statkraft
Hardangerjøkulen	Midtdalsbreen	4	University of Bergen
	Rembesdalsskåka	-30	Statkraft
Jotunheimen	Bøverbreen	-3	Stefan Winkler, Germany
	Hellstugubreen	-5	NVE
	Leirbreen	-3	NVE
	Storbreen	-5	NVE
	Storgjuvbreen	-5	Stefan Winkler, Germany
	Styggedalsbreen	-7	NVE
Svartisen	Engabreen	-22	Statkraft
Finnmark	Langfjordjøkelen	-17	NVE

Changes since 1982

In the 1980s, most of the observed glaciers retreated slowly (Fig. 14-2). The number of monitored glaciers was at a minimum around 1990 (7 glaciers observed in 1992). Many outlet glaciers from coastal ice caps started to advance late in the 1980s, and the number of monitored glaciers increased as a response to public and scientific interest in glacier fluctuations in general. The advance ended around the turn of the century. At Briksdalsbreen the advance stopped as early as in 1996, while most of the glaciers stopped in 2000. At Stegholtbreen the advance didn't start until 1996 and lasted 4 years. At the same time many continental glaciers such as Hellstugubreen were slowly retreating.

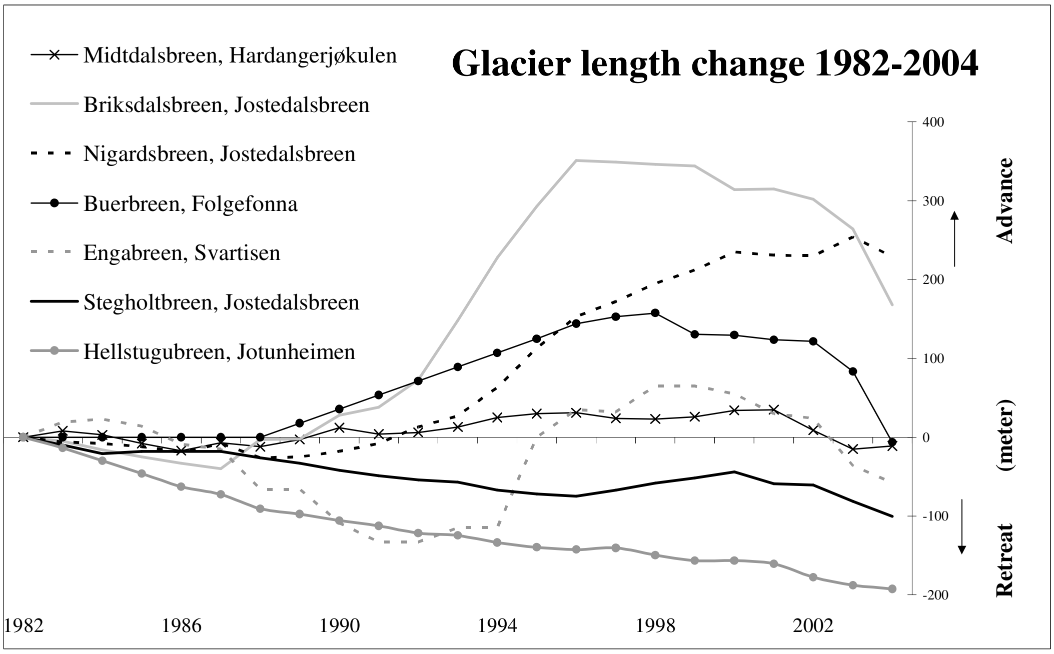


Figure 14-2
Cumulative glacier length change since 1982 at seven glaciers. See Figure 14-1 for locations.

14.2 Monitoring of Baklibreen

Baklibreen (61°40′N, 7°05′E) is an outlet glacier of Jostedalsbreen. It has an area of 3 km^2 and covers an elevation range from 1950 m a.s.l. to about 1200 m a.s.l. An ice avalanche occurred from the glacier in the summer of 1986. The ice fell a total of 600-700 m and killed three tourists walking along the footpath below. The ice that fell is thought to have covered an area of 4000 m^2 and to have had a total volume of 200 000 m^3.

An observation programme was set up in 1987 to study the risk of future icefalls, and was in operation until 1999. A more limited monitoring programme has been in existence since 2000 and between 2001and 2003 this was carried out as part of the European Union 5th Framework Glaciorisk project.

Figure 14-3 shows photographs taken in 2002 and 2004. These show that ice loss from the glacier front that has been observed in previous years is continuing. A comparison of aerial photographs from 1964 and 1984 show that ice thickness decreased significantly over most of the glacier over this period.

Previous measurements

A comparison of glacier surface measurements done in 1989 with the 1984 aerial photographs shows little change in this period. The biggest increase took place in the period between 1989 and 1994 when ice thickness increased between 10 m and 20 m on the surveyed part of the glacier (area below 1300 m a.s.l.). A slight increase was measured between 1994 and 1996, and little change was registered between 1996 and 1999. More detailed information on these measurements is available in Kjøllmoen (ed.) (2000). Subsequent measurements show lowering of the glacier surface of 0 – 8 metres per year.

Figure 14-3
Baklibreen, September 2004 at left, October 2002 at right.
Photos: Hallgeir Elvehøy (left) and Bjarne Kjøllmoen (right).

2004 measurements

Measurements on Baklibreen since 1993 have been made from a survey point established on a nearby prominent rock outcrop, and sightings are then made with a GDM to different points on the glacier. These points are visited by helicopter, and prisms are used for sighting. Survey points on the glacier in 2002 and 2004 are shown in Figure 14-4. The 2002 survey was performed on 8th October, and the 2004 survey was performed on 29th September. For points that are coincidental or almost coincidental for both years, there is a lowering of between 4 and 8 m, with the 2004 points having the lower elevation. This gives an annual lowering of between 2 m and 4 m, thus the surface lowering is somewhat less than measured in previous years, but the continuing trend is one of surface lowering due to negative net mass balance. Points measured in 2002 rather than 2003 are used for comparison, as the positions correspond better. For those survey points that are not exactly coincident in both years, an interpolated elevation was used.

Scenario

Continued surface lowering of Baklibreen suggest that a large icefall, such as occurred in 1986, is less likely to occur. However, smaller icefalls can occur. The continued frontal retreat of neighbouring glacier Bergsetbreen also means that there is increased risk of people being in the danger zone of an ice fall. Bergsetbreen advanced 360 m from the mid 1980s to 1997, and the footpath under Baklibreen became inaccessible. However, Bergsetbreen has retreated 94 m since 2000, including 45 m in the past year, and the footpath may again become accessible.

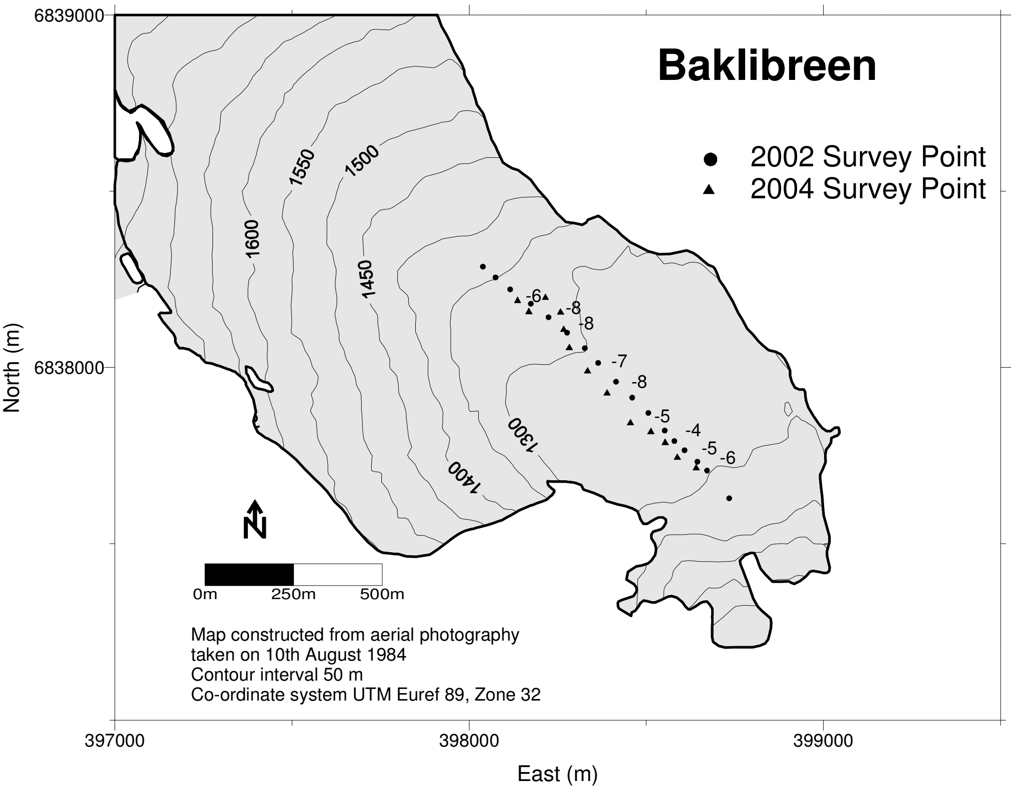


Figure 14-4
Map of Baklibreen showing survey points on the glacier in 2002 and 2004. Numbers to right of survey points are elevation change from 2002 to 2004 in metres.

14.3 Jøkulhlaup from Flatbreen

Flatbreen (61°30′N, 6°50′E) is an outlet glacier of the southern part of Jostedalsbreen. The glacier slopes gently from 1700 to 1000 m elevation where it terminates in an ice cliff. From here the ice avalanches 700 m down to a regenerated glacier in Supphelledalen (Fig. 14-5). On the western side of the ice-fall there is a moraine ridge from around year 1900 (named the 1900-moraine). Due to glacier retreat after 1900, a small lake formed between the moraine and the glacier (Fig. 14-6). Until the glacier advanced in the 1990's there was a gap in the moraine ridge, draining the lake.

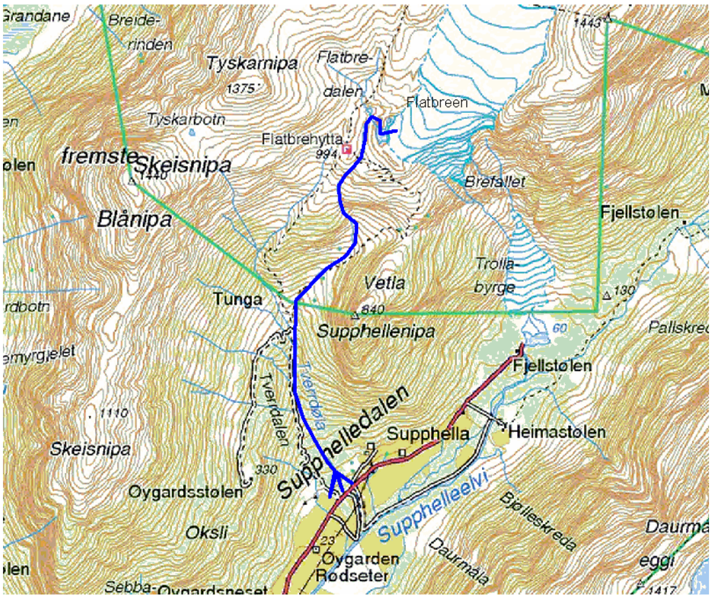


Figure 14-5
Map of lower part of Flatbreen and the regenerated glacier in Supphelledalen. The flood trajectory is shown also. Map courtesy of Norwegian Mapping Authority.

In 2004, April and the first days of May were fairly cold, resulting in only limited melting on the glaciers. A period of warm and humid weather started on the 4th of May, and discharge in the rivers increased quickly. The calving in the large icefall of Flatbreen was observed to have increased, indicating increased glacier velocities. Around 12:45 on 8th of May people in Fjærland observed that the discharge in the small river from Flatbreen had increased dramatically. At 12:58 the road in the valley was flooded, and soon after the road was covered by a thick layer of large boulders. After one hour the discharge was down to normal again. Four people were nearly taken by the flood water, and five people were evacuated by helicopter. The sediment transported into the valley covered 0.2-0.3 km^2 of farm land in the flat valley bottom.

Late in winter the subglacial channels are small or non-existent, adapted to very low subglacial discharge. When huge amounts of water suddenly flow into the glacier, small channels and water pockets form. Water can be stored temporarily in isolated water pockets or larger areas until a channel network is established. The subglacial water pressure increases, and this can influence the glacier dynamics.

Figure 14-6
The western part of Flatbreen terminating at the 1900-moraine on 11th May (top) and 3rd August 2004 (bottom). The subglacial tunnel entered the lake where the snow/ice is dirty on the glacier side of the lake (Fig. 14-7). Fjærlandsfjorden is seen in the upper right corner. Photos: Hallgeir Elvehøy.

A subglacial channel connecting the subglacial drainage system to the moraine-dammed lake had opened. Traces on the glacier surface close to the lake show that water had flooded out of the glacier (Fig. 14-7). The lake level increased and the lowest part of the moraine ridge was breached. The flood water eroded the moraine, extending the breach (Fig. 14-8).

The flood's abrupt end (after approximately one hour) implies that a finite volume of water was released from a "reservoir area". The amount of water released into the lake can have been substantial. The lake itself contributed only a fraction of the total water volume flowing into the valley.

From historic sources, a similar but smaller event was observed on 11th November 1947. Another event may have taken place in the 1920's.

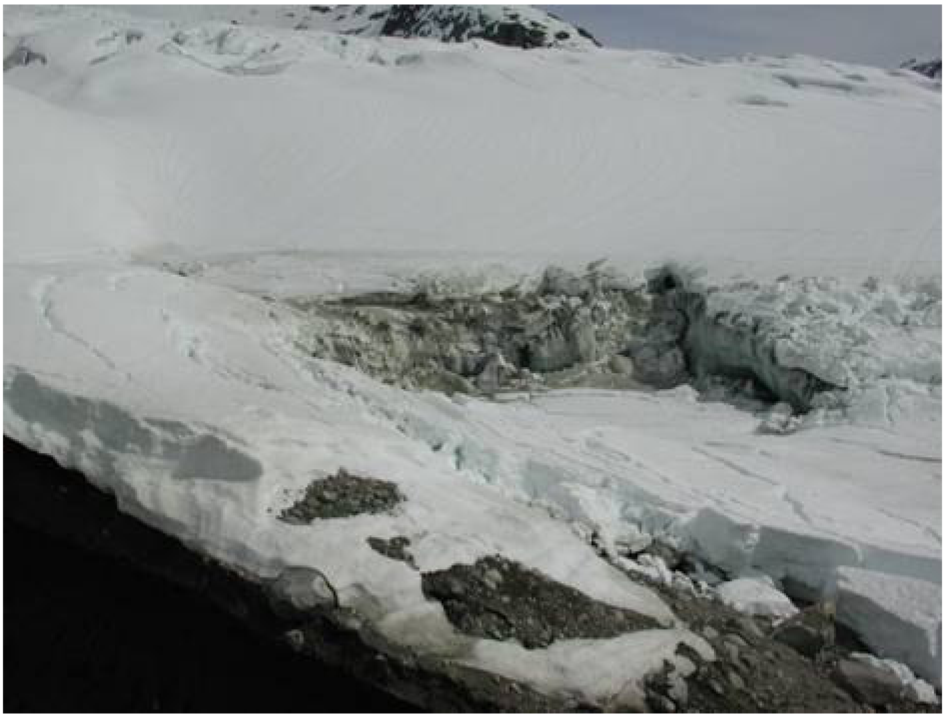


Figure 14-7
Outlet of the subglacial channel seen from the 1900-moraine. The highest lake level during the event is indicated by a colour difference in the snow behind the tunnel outlet.
Photo: Hallgeir Elvehøy, 11th May 2004.

Figure 14-8
The breach in the 1900-moraine seen from outside the moraine. The central, darkest area is an ice block remnant from the 1990's advance. Notice two persons in the breach for scale.
Photo: Hallgeir Elvehøy, 11th May 2004.

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Appendix B

Mass balance measurements in Norway – an overview

During the period 1949-2004 there are carried out mass balance measurements at 42 Norwegian glaciers. The table below shows some characteristic data for the individual glaciers.

Area/ No. Glacier	No. of WGMS	Area (km^2)	Altitude (m a.s.l.)	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	BL004	4.5	903-1382	1963-	42
2 Hansebreen	BO002	3.1	930-1327	1986-	19
Folgefonna					
3 Blomsterskardsbreen	AJ008	45.7	850-1640	1970-77	8
4 Bondhusbrea	AJ002	10.7	480-1635	1977-81	5
5 Breidablikkbrea	AJ001	3.9	1219-1660	1963-68, 2003-	8
6 Gråfjellsbrea	AK007	9.4	1039-1660	64-68, 74- 75, 2003-	9
7 Blåbreen and Ruklebreen	AJ011/AJ026	4.5	1065-1610	1963-68	6
8 Midtre Folgefonna	AJ017/AJ024	8.7	1100-1570	1970-71	2
Jostedalsbreen					
9 Jostefonn	BA005	3.8	960-1622	1996-2000	5
10 Vesledalsbreen	BU033	4.2	1130-1730	1967-72	6
11 Tunsbergdalsbreen	A4007	50.1	540-1930	1966-72	7
12 Nigardsbreen	A4014	47.8	320-1960	1962-	43
13 Store Supphellebreen	A8015	12.0	80-300/ 720-1740	1964-67, 73- 75, 79-82	11
14 Austdalsbreen	A4023	11.8	1200-1757	1988-	17
15 Spørteggbreen	*	27.9	1260-1770	1988-91	4
16 Harbardsbreen	A2004	13.2	1250-1960	1997-2001	5
Hardangerjøkulen					
17 Rembesdalsskåka	AO001	17.1	1020-1865	1963-	40
18 Midtdalsbreen	AG002	6.7	1380-1862	2000-2001	2
19 Omnsbreen	AG003/AY002	1.5	1460-1570	1966-70	5
Jotunheimen					
20 Tverråbreen	AD022	5.9	1415-2200	1962-63	2
21 Blåbreen	AB040	3.6	1550-2150	1962-63	2
22 Storbreen	AD041	5.4	1390-2100	1949-	56
23 Vestre Memurubre	AB031	9.0	1570-2230	1968-72	5
24 Austre Memurubre	AB033	8.7	1630-2250	1968-72	5
25 Hellstugubreen	AD011	3.0	1480-2210	1962-	43
26 Gråsubreen	AB047	2.3	1830-2290	1962-	43
Okstindbreene					
27 Charles Rabot Bre	CV020	1.1	1090-1760	1970-73	4
28 Austre Okstindbre	CW002/CW003	14.0	730-1750	1987-96	10
Svartisen					
29 Høgtuvbreen	C2019	2.6	590-1170	1971-77	7
30 Svartisheibreen	CX009	5.5	770-1420	1988-94	7
31 Engabreen	C4011	38.0	40-1594	1970-	35
32 Storglombreen	C7013/C7014	59.0 62.4	520-1580 520-1580	1985-88 2000-04	9
33 Tretten-null-tobreen	C7016	4.3	580-1260	1985-86	2
34 Glombreen	C6003/C6004	2.2	870-1110	1954-56	3
35 Kjølbreen	CX023	3.9	850-1250	1954-56	3
36 Trollbergdalsbreen	DE007	1.8 1.6	900-1375 900-1300	1970-75 1990-94	11
Blåmannsisen					
37 Rundvassbreen	DI021/DI022	11.6	788-1537	2002-04	3
Skjomen					
38 Blåisen	DZ011	2.2	850-1200	1963-68	6
39 Storsteinsfjellbreen	DW011	6.1 5.9	920-1850 970-1850	1964-68 1991-95	10
40 Cainhavarre	DW034	0.7	1210-1540	1965-68	4
Vest-Finnmark					
41 Svartfjelljøkelen	ET001	2.7	500-1080	1978	1
42 Langfjordjøkelen	ET008	3.7	280-1050	1989-93, 1996-	14

*A3001/A3003/A3004/A4027/A4028/A4029/A4030

Appendix C

Mass balance measurements in Norway – annual results

There are results from 532 years of measurements at Norwegian glaciers. The following tables show winter (bw), summer (bs) and net balance (bn) together with cumulative net balance (Cum. bn) and equilibrium line altitude (ELA) for every single year at each glacier. In front of each table there is a heading containing the name and the area of the glacier. The reported year (in brackets) corresponds to the given area.

1 Ålfotbreen - 4.5 km² (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963	2.48	-3.58	-1.10	-1.10	1300
2	64	2.69	-2.41	0.28	-0.82	1140
3	65	3.64	-3.16	0.48	-0.34	1150
4	66	2.47	-4.08	-1.61	-1.95	>1380
5	67	4.46	-3.18	1.28	-0.67	950
6	68	4.55	-3.60	0.95	0.28	1075
7	69	2.66	-4.83	-2.17	-1.89	>1380
8	1970	2.60	-3.83	-1.23	-3.12	>1380
9	71	4.29	-3.35	0.94	-2.18	1140
10	72	3.81	-3.70	0.11	-2.07	1195
11	73	4.67	-2.49	2.18	0.11	<870
12	74	3.57	-2.54	1.03	1.14	1065
13	75	4.64	-3.43	1.21	2.35	1050
14	76	4.40	-2.87	1.53	3.88	<870
15	77	2.33	-2.89	-0.56	3.32	1280
16	78	2.56	-3.07	-0.51	2.81	1290
17	79	3.28	-3.41	-0.13	2.68	1240
18	1980	2.51	-3.30	-0.79	1.89	1275
19	81	4.04	-3.82	0.22	2.11	1210
20	82	3.35	-3.48	-0.13	1.98	1240
21	83	4.79	-3.19	1.60	3.58	1010
22	84	4.09	-2.77	1.32	4.90	1050
23	85	2.44	-3.00	-0.56	4.34	1290
24	86	2.35	-2.76	-0.41	3.93	1255
25	87	4.29	-2.22	2.07	6.00	<870
26	88	2.73	-5.21	-2.48	3.52	>1380
27	89	5.20	-2.93	2.27	5.79	1030
28	1990	5.98	-4.19	1.79	7.58	995
29	91	4.09	-3.30	0.79	8.37	1035
30	92	5.48	-3.19	2.29	10.66	1050
31	93	4.81	-2.74	2.07	12.73	<870
32	94	3.71	-2.92	0.79	13.52	925
33	95	5.10	-3.90	1.20	14.72	1120
34	96	1.83	-3.71	-1.88	12.84	>1380
35	97	4.22	-4.14	0.08	12.92	1200
36	98	3.66	-3.55	0.11	13.03	1240
37	99	4.61	-4.55	0.06	13.09	1245
38	2000	5.57	-3.58	1.99	15.08	1025
39	01	1.86	-3.95	-2.09	12.99	>1382
40	02	3.78	-5.31	-1.53	11.46	>1382
41	03	2.52	-5.03	-2.51	8.95	>1382
42	04	3.32	-3.42	-0.10	8.85	1225
Mean 1963-2004		3.70	-3.49	0.21		

2 Hansebreen - 3.1 km² (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1986	2.28	-2.87	-0.59	-0.59	1200
2	87	3.76	-2.63	1.13	0.54	1100
3	88	2.50	-5.24	-2.74	-2.20	>1320
4	89	4.13	-3.71	0.42	-1.78	1140
5	1990	4.42	-4.10	0.32	-1.46	1140
6	91	3.37	-3.11	0.26	-1.20	1125
7	92	4.41	-3.43	0.98	-0.22	1125
8	93	4.23	-3.15	1.08	0.86	<925
9	94	3.39	-2.97	0.42	1.28	1120
10	95	4.38	-3.90	0.48	1.76	1140
11	96	1.74	-3.76	-2.02	-0.26	>1320
12	97	3.77	-3.92	-0.15	-0.41	1160
13	98	3.21	-3.51	-0.30	-0.71	1170
14	99	4.30	-4.19	0.11	-0.60	1155
15	2000	4.69	-3.82	0.87	0.27	1075
16	01	1.71	-4.43	-2.72	-2.45	>1327
17	02	3.51	-5.44	-1.93	-4.38	>1327
18	03	2.45	-5.12	-2.67	-7.05	>1327
19	04	2.87	-3.38	-0.51	-7.56	1220
Mean 1986-2004		3.43	-3.83	-0.40		

3 Blomsterskardsbreen - 45.7 km² (1959)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1970					1370
2	71	2.85	-1.87	0.98	0.98	1240
3	72			0.32	1.30	1340
4	73			1.57	2.87	1180
5	74			0.51	3.38	1325
6	75			1.70	5.08	1170
7	76			1.40	6.48	1210
8	77			-1.40	5.08	>1640
Mean 1971-77				0.73		

4 Bondhusbrea - 10.7 km² (1979)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	77	1.96	-2.96	-1.00	-1.00	1620
2	78	2.37	-2.88	-0.51	-1.51	1540
3	79	2.82	-2.49	0.33	-1.18	1445
4	1980	2.33	-2.78	-0.45	-1.63	1500
5	81	3.32	-2.00	1.32	-0.31	1460
Mean 1977-81		2.56	-2.62	-0.06		

5 Breidablikkbrea - 3.6 km² (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963	1.11	-2.32	-1.21	-1.21	1635
2	64	1.92	-1.68	0.24	-0.97	1450
3	65	1.72	-2.28	-0.56	-1.53	1525
4	66	1.52	-3.17	-1.65	-3.18	>1660
5	67	3.40	-2.23	1.17	-2.01	1355
6	68	3.55	-2.68	0.87	-1.14	1360
7	2003	2.08	-4.35	-2.27	-2.27	>1659
8	04	2.21	-3.16	-0.95	-3.22	1605
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-04		2.15	-3.76	-1.61		

6 Gråfjellsbrea - 8.9 km² (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1964	1.94	-1.62	0.32	0.32	1385
2	65	2.01	-2.29	-0.28	0.04	1490
3	66	1.58	-2.93	-1.35	-1.31	>1660
4	67	3.46	-2.14	1.32	0.01	1355
5	68	3.39	-2.82	0.57	0.58	1380
6	1974	2.11	-1.53	0.58	0.58	1370
7	75	2.53	-2.28	0.25	0.83	1420
8	2003	1.90	-4.07	-2.17	-2.17	>1659
9	04	2.04	-2.85	-0.81	-0.81	1565
Mean 1964-68		2.48	-2.36	0.12		
Mean 1974-75		2.32	-1.91	0.42		
Mean 2003-04		1.97	-3.46	-1.49		

7 Blåbreen and Ruklebreen - 4.5 km² (1959)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963[1)]	1.30	-3.40	-2.10	-2.10	1620
2	64	2.18	-1.68	0.50	-1.60	1350
3	65	2.53	-2.48	0.05	-1.55	1450
4	66	1.76	-3.26	-1.50	-3.05	>1620
5	67	3.86	-2.56	1.30	-1.75	1300
6	68	3.18	-2.80	0.38	-1.37	1395
Mean 1963-68		2.47	-2.70	-0.23		

[1)] Blåbreen only

8 Midtre Folgefonna - 8.7 km² (1959)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1970	2.07	-2.69	-0.62	-0.62	>1580
2	71	2.33	-1.96	0.37	-0.25	1260
Mean 1970-71		2.20	-2.33	-0.13		

9 Jostefonn - 3.8 km² (1993)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1996	1.19	-2.72	-1.53	-1.53	>1620
2	97	3.59	-3.87	-0.28	-1.81	1500
3	98	2.84	-2.54	0.30	-1.51	1250
4	99	2.92	-2.54	0.38	-1.13	1200
5	2000	3.49	-2.47	1.02	-0.11	1050
Mean 1996-2000		2.81	-2.83	-0.02		

10 Vesledalsbreen - 4.2 km² (1966)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1967	2.06	-1.71	0.35	0.35	1400
2	68	3.14	-2.50	0.64	0.99	1320
3	69	1.26	-3.44	-2.18	-1.19	>1730
4	1970	1.52	-2.66	-1.14	-2.33	>1730
5	71	2.21	-1.80	0.41	-1.92	1375
6	72	1.92	-2.27	-0.35	-2.27	1570
Mean 1967-72		2.02	-2.40	-0.38		

11 Tunsbergdalsbreen - 50.1 km² (1964)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1966	1.57	-2.66	-1.09	-1.09	1640
2	67	3.31	-1.52	1.79	0.70	1160
3	68	2.74	-2.70	0.04	0.74	1550
4	69	1.53	-3.22	-1.69	-0.95	1700
5	1970	1.54	-2.38	-0.84	-1.79	1590
6	71	2.36	-1.79	0.57	-1.22	1240
7	72	2.02	-2.52	-0.50	-1.72	1490
Mean 1966-72		2.15	-2.40	-0.25		

12 Nigardsbreen - 47.8 km² (1984)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1962	2.88	-0.63	2.25	2.25	1260
2	63	1.87	-2.09	-0.22	2.03	1550
3	64	2.13	-1.18	0.95	2.98	1400
4	65	2.29	-1.38	0.91	3.89	1395
5	66	1.76	-2.68	-0.92	2.97	1700
6	67	3.40	-1.24	2.16	5.13	1310
7	68	2.72	-2.50	0.22	5.35	1550
8	69	1.95	-3.26	-1.31	4.04	1850
9	1970	1.73	-2.29	-0.56	3.48	1650
10	71	2.11	-1.29	0.82	4.30	1400
11	72	1.88	-2.02	-0.14	4.16	1570
12	73	2.40	-1.30	1.10	5.26	1410
13	74	2.06	-1.58	0.48	5.74	1490
14	75	2.50	-2.23	0.27	6.01	1450
15	76	2.88	-2.48	0.40	6.41	1540
16	77	1.52	-2.29	-0.77	5.64	1650
17	78	2.12	-2.25	-0.13	5.51	1590
18	79	2.75	-2.04	0.71	6.22	1500
19	1980	1.77	-2.99	-1.22	5.00	1730
20	81	2.19	-1.88	0.31	5.31	1560
21	82	1.94	-2.36	-0.42	4.89	1600
22	83	3.02	-1.93	1.09	5.98	1445
23	84	2.49	-2.15	0.34	6.32	1500
24	85	1.77	-1.87	-0.10	6.22	1590
25	86	1.61	-1.71	-0.10	6.12	1590
26	87	2.73	-1.25	1.48	7.60	1350
27	88	2.24	-3.13	-0.89	6.71	1660
28	89	4.05	-0.85	3.20	9.91	1175
29	1990	3.52	-1.75	1.77	11.68	1430
30	91	1.95	-1.75	0.20	11.88	1520
31	92	3.16	-1.56	1.60	13.48	1360
32	93	3.13	-1.28	1.85	15.33	1300
33	94	2.28	-1.72	0.56	15.89	1400
34	95	3.16	-1.97	1.19	17.08	1320
35	96	1.40	-1.81	-0.41	16.67	1660
36	97	2.66	-2.62	0.04	16.71	1500
37	98	2.50	-1.53	0.97	17.68	1350
38	99	2.38	-2.21	0.17	17.85	1470
39	2000	3.38	-1.66	1.72	19.57	1250
40	01	1.75	-1.97	-0.22	19.35	1560
41	02	2.41	-3.30	-0.89	18.46	1715
42	03	1.56	-2.72	-1.16	17.30	>1960
43	04	1.97	-2.01	-0.04	17.26	1530
Mean 1962-2004		2.37	-1.97	0.40		

13 Store Supphellebreen - 12.0 km² (1966)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1964	2.20	-1.50	0.70	0.70	1190
2	65	2.32	-1.76	0.56	1.26	1250
3	66	1.63	-2.40	-0.77	0.49	1590
4	67	2.72	-1.50	1.22	1.71	1190
5	73			1.50	1.50	
6	74			0.80	2.30	
7	75			1.00	3.30	
8	79			1.10	1.10	
9	1980			-1.40	-0.30	
10	81			0.20	-0.10	
11	82			-1.70	-1.80	
Mean 1964-67		2.22	-1.79	0.43		
Mean 1973-75				1.10		
Mean 1979-82				-0.45		

14 Austdalsbreen - 11.8 km² (1988)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1988	1.94	-3.22	-1.28	-1.28	1570
2	89	3.18	-1.34	1.84	0.56	1275
3	1990	3.65	-2.45	1.20	1.76	1310
4	91	1.64	-1.64	0.00	1.76	1435
5	92	2.80	-2.26	0.54	2.30	1375
6	93	2.60	-1.69	0.91	3.21	1320
7	94	1.81	-1.88	-0.07	3.14	1425
8	95	2.72	-2.10	0.62	3.76	1360
9	96	1.20	-2.27	-1.07	2.69	1565
10	97	2.67	-3.20	-0.53	2.16	1450
11	98	2.20	-2.01	0.19	2.35	1420
12	99	2.08	-2.56	-0.48	1.87	1435
13	2000	2.77	-1.66	1.11	2.98	1315
14	01	1.04	-2.66	-1.62	1.36	>1757
15	02	1.91	-3.92	-2.01	-0.65	>1757
16	03	1.60	-3.89	-2.29	-2.94	>1757
17	04	1.60	-2.56	-0.96	-3.90	1495
Mean 1988-2004		2.20	-2.43	-0.23		

15 Spørteggbreen - 27.9 km² (1988)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1988	1.61	-3.15	-1.54	-1.54	>1770
2	89	2.76	-1.62	1.14	-0.40	1410
3	1990	3.34	-2.33	1.01	0.61	1390
4	91	1.40	-1.37	0.03	0.64	1540
Mean 1988-91		2.28	-2.12	0.16		

16 Harbardsbreen - 13.2 km² (1996)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.eqv.)		(m w.eqv.)		(m a.s.l.)
1	1997	2.17	-2.72	-0.55	-0.55	>1960
2	98	1.66	-1.60	0.06	-0.49	1500
3	99	1.81	-2.15	-0.34	-0.83	>1960
4	2000	2.30	-1.52	0.78	-0.05	1250
5	01	0.88	-1.99	-1.11	-1.16	>1960
Mean 1997-2001		1.76	-2.00	-0.23		

17 Rembesdalsskåka - 17.1 km² (1995)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963	1.15	-2.55	-1.40	-1.40	>1860
2	64	1.85	-1.31	0.54	-0.86	1620
3	65	2.05	-1.54	0.51	-0.35	1620
4	66	1.60	-2.24	-0.64	-0.99	1750
5	67	2.44	-1.25	1.19	0.20	1540
6	68	2.68	-2.15	0.53	0.73	1600
7	69	1.07	-2.97	-1.90	-1.17	>1860
8	1970	1.29	-1.89	-0.60	-1.77	1780
9	71	2.02	-1.28	0.74	-1.03	1600
10	72	1.78	-1.86	-0.08	-1.11	1650
11	73	2.62	-1.79	0.83	-0.28	1570
12	74	1.91	-1.50	0.41	0.13	1615
13	75	2.25	-2.10	0.15	0.28	1620
14	76	2.45	-2.30	0.15	0.43	1620
15	77	1.20	-1.92	-0.72	-0.29	>1860
16	78	1.80	-2.10	-0.30	-0.59	
17	79	2.40	-2.10	0.30	-0.29	
18	1980	1.45	-2.85	-1.40	-1.69	>1860
19	81	2.65	-1.80	0.85	-0.84	1590
20	82	1.40	-2.10	-0.70	-1.54	1800
21	83	3.75	-2.05	1.70	0.16	1450
22	84	2.05	-2.15	-0.10	0.06	1675
23	85	1.48	-2.00	-0.52	-0.46	1715
24	86	1.47	-1.57	-0.10	-0.56	1670
25	87	2.08	-1.14	0.94	0.38	1535
26	88	1.98	-3.13	-1.15	-0.77	1860
27	89	3.48	-1.37	2.11	1.34	1420
28	1990	3.65	-1.72	1.93	3.27	1450
29	91	1.52	-1.61	-0.09	3.18	1660
30	92	3.71	-1.72	1.99	5.17	1525
31	93	2.82	-0.91	1.91	7.08	1450
32	94	1.79	-1.63	0.16	7.24	1600
33	95	2.44	-2.14	0.30	7.54	1575
34	96	0.99	-2.10	-1.11	6.43	>1860
35	97	2.94	-3.41	-0.47	5.96	1700
36	98	2.47	-1.78	0.69	6.65	1585
37	99	2.04	-1.99	0.05	6.70	1685
38	2000	2.93	-1.50	1.43	8.13	1425
39	01	1.03	-1.88	-0.85	7.28	1760
40	02	2.39	-3.10	-0.71	6.57	1750
41	03	1.33	-2.69	-1.36	5.21	>1860
42	04	1.89	-1.81	0.08	5.29	1670
Mean 1963-2004		2.10	-1.98	0.13		

18 Midtdalsbreen - 6.7 km² (1995)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	2000	2.89	-1.57	1.32	1.32	1500
2	01	1.26	-1.90	-0.64	0.68	1785
Mean 2000-2001		2.08	-1.74	0.34		

19 Omnsbreen - 1.5 km² (1969)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1966	1.44	-2.28	-0.84	-0.84	
2	67	2.21	-1.72	0.49	-0.35	
3	68	2.20	-2.38	-0.18	-0.53	1520
4	69	1.09	-3.68	-2.59	-3.12	
5	1970	1.12	-2.62	-1.50	-4.62	
Mean 1966-70		1.61	-2.54	-0.92		

20 Tverråbreen - 5.9 km² ()

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	2.03	-1.28	0.75	0.75	
2	63	1.24	-2.46	-1.22	-0.47	
Mean 1962-63		1.64	-1.87	-0.24		

21 Blåbreen - 3.6 km² (1961)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	1.15	-0.35	0.80	0.80	<1550
2	63	0.85	-1.71	-0.86	-0.06	1970
Mean 1962-63		1.00	-1.03	-0.03		

22 Storbreen - 5.4 km² (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	49	2.28	-2.08	0.20	0.20	1650
2	1950	1.52	-1.81	-0.29	-0.09	1750
3	51	1.13	-1.67	-0.54	-0.63	1770
4	52	1.44	-1.13	0.31	-0.32	1630
5	53	1.40	-2.25	-0.85	-1.17	1850
6	54	1.21	-1.98	-0.77	-1.94	1830
7	55	1.57	-2.06	-0.49	-2.43	1800
8	56	1.31	-1.48	-0.17	-2.60	1705
9	57	1.42	-1.37	0.05	-2.55	1680
10	58	1.54	-1.62	-0.08	-2.63	1700
11	59	1.07	-2.35	-1.28	-3.91	1930
12	1960	0.98	-2.07	-1.09	-5.00	1910
13	61	1.10	-1.62	-0.52	-5.52	1820
14	62	1.54	-0.82	0.72	-4.80	1510
15	63	0.96	-2.14	-1.18	-5.98	1900
16	64	1.16	-0.95	0.21	-5.77	1655
17	65	1.54	-1.2	0.34	-5.43	1650
18	66	1.25	-1.86	-0.61	-6.04	1815
19	67	1.89	-1.17	0.72	-5.32	1570
20	68	1.64	-1.59	0.05	-5.27	1700
21	69	1.22	-2.64	-1.42	-6.69	2020
22	1970	0.97	-1.69	-0.72	-7.41	1840
23	71	1.46	-1.28	0.18	-7.23	1690
24	72	1.39	-1.7	-0.31	-7.54	1770
25	73	1.48	-1.4	0.08	-7.46	1705
26	74	1.26	-1.02	0.24	-7.22	1630
27	75	1.55	-1.7	-0.15	-7.37	1760
28	76	1.81	-1.9	-0.09	-7.46	1740
29	77	0.94	-1.48	-0.54	-8.00	1840
30	78	1.26	-1.7	-0.44	-8.44	1815
31	79	1.55	-1.45	0.10	-8.34	1700
32	1980	0.99	-2.3	-1.31	-9.65	1975
33	81	1.30	-1.4	-0.10	-9.75	1730
34	82	1.28	-1.75	-0.47	-10.22	1780
35	83	1.90	-1.7	0.20	-10.02	1625
36	84	1.70	-2	-0.30	-10.32	1760
37	85	1.20	-1.6	-0.40	-10.72	1790
38	86	1.05	-1.37	-0.32	-11.04	1770
39	87	1.55	-1.23	0.32	-10.72	1580
40	88	1.45	-2.4	-0.95	-11.67	1970
41	89	2.30	-1.1	1.20	-10.47	1550
42	1990	2.60	-1.35	1.25	-9.22	1530
43	91	1.26	-1.41	-0.15	-9.37	1740
44	92	1.61	-1.53	0.08	-9.29	1715
45	93	1.81	-1.06	0.75	-8.54	1610
46	94	1.52	-1.77	-0.25	-8.79	1800
47	95	1.77	-1.93	-0.16	-8.95	1810
48	96	0.81	-1.84	-1.03	-9.98	1890
49	97	1.75	-2.78	-1.03	-11.01	1875
50	98	1.55	-1.33	0.22	-10.79	1690
51	99	1.67	-1.91	-0.24	-11.03	1850
52	2000	2.04	-1.49	0.55	-10.48	1650
53	01	1.05	-1.32	-0.27	-10.75	1855
54	02	1.09	-2.87	-1.78	-12.53	>2290
55	03	1.11	-2.68	-1.57	-14.10	2025
56	04	1.01	-1.59	-0.58	-14.68	1855
Mean 1949-2004		1.43	-1.69	-0.26		

23 Vestre Memurubre - 9.0 km² (1966)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1968	1.70	-1.46	0.24	0.24	1820
2	69	1.05	-2.11	-1.06	-0.82	2170
3	1970	0.84	-1.63	-0.79	-1.61	1990
4	71	1.30	-1.19	0.11	-1.50	1845
5	72	1.19	-1.47	-0.28	-1.78	1885
Mean 1968-72		1.22	-1.57	-0.36		

24 Austre Memurubre - 8.7 km² (1966)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1968	1.77	-1.76	0.01	0.01	1960
2	69	0.99	-2.45	-1.46	-1.45	2130
3	1970	0.81	-1.71	-0.90	-2.35	2090
4	71	1.33	-1.51	-0.18	-2.53	1960
5	72	1.02	-1.42	-0.40	-2.93	1985
Mean 1968-72		1.18	-1.77	-0.59		

25 Hellstugubreen - 3.0 km^2 (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	1.18	-0.40	0.78	0.78	
2	63	0.94	-1.92	-0.98	-0.20	2020
3	64	0.71	-0.83	-0.12	-0.32	1900
4	65	1.29	-0.77	0.52	0.20	1690
5	66	0.95	-1.62	-0.67	-0.47	1940
6	67	1.48	-0.93	0.55	0.08	1800
7	68	1.38	-1.49	-0.11	-0.03	1875
8	69	0.95	-2.23	-1.28	-1.31	2130
9	1970	0.70	-1.70	-1.00	-2.31	2020
10	71	1.12	-1.25	-0.13	-2.44	1860
11	72	0.94	-1.43	-0.49	-2.93	1950
12	73	1.20	-1.41	-0.21	-3.14	1880
13	74	1.00	-0.76	0.24	-2.90	1785
14	75	1.35	-1.71	-0.36	-3.26	1950
15	76	1.16	-1.89	-0.73	-3.99	1970
16	77	0.68	-1.40	-0.72	-4.71	2075
17	78	1.05	-1.59	-0.54	-5.25	1890
18	79	1.43	-1.45	-0.02	-5.27	1820
19	1980	0.81	-2.05	-1.24	-6.51	2050
20	81	1.06	-1.39	-0.33	-6.84	1950
21	82	0.85	-1.20	-0.35	-7.19	1920
22	83	1.47	-1.30	0.17	-7.02	1820
23	84	1.22	-1.73	-0.51	-7.53	1965
24	85	1.11	-1.40	-0.29	-7.82	1880
25	86	0.78	-1.27	-0.49	-8.31	1940
26	87	1.15	-0.70	0.45	-7.86	1690
27	88	1.28	-2.32	-1.04	-8.90	2025
28	89	1.62	-0.90	0.72	-8.18	1660
29	1990	1.81	-1.15	0.66	-7.52	1640
30	91	0.98	-1.43	-0.45	-7.97	1950
31	92	1.17	-1.03	0.14	-7.83	1850
32	93	1.25	-0.95	0.30	-7.53	1670
33	94	1.26	-1.19	0.07	-7.46	1850
34	95	1.42	-1.54	-0.12	-7.58	1885
35	96	0.65	-1.39	-0.74	-8.32	1955
36	97	1.12	-2.77	-1.65	-9.97	2200
37	98	1.00	-1.02	-0.02	-9.99	1870
38	99	1.22	-1.64	-0.42	-10.41	1930
39	2000	1.26	-1.16	0.10	-10.31	1840
40	01	0.85	-1.21	-0.36	-10.67	1910
41	02	0.96	-2.37	-1.41	-12.08	2080
42	03	0.71	-2.23	-1.52	-13.60	2200
43	04	0.65	-1.49	-0.84	-14.44	1980
Mean 1962-2004		1.10	-1.43	-0.34		

26 Gråsubreen - 2.3 km^2 (1997)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1962	0.86	-0.09	0.77	0.77	1870
2	63	0.40	-1.11	-0.71	0.06	2275
3	64	0.39	-0.71	-0.32	-0.26	2160
4	65	0.77	-0.36	0.41	0.15	1900
5	66	0.72	-1.01	-0.29	-0.14	2150
6	67	1.45	-0.74	0.71	0.57	1870
7	68	1.03	-1.11	-0.08	0.49	2140
8	69	0.74	-2.04	-1.30	-0.81	2275
9	1970	0.57	-1.23	-0.66	-1.47	2200
10	71	0.49	-0.96	-0.47	-1.94	2200
11	72	0.66	-1.30	-0.64	-2.58	2240
12	73	0.72	-1.61	-0.89	-3.47	2275
13	74	0.58	-0.24	0.34	-3.13	1870
14	75	0.91	-1.86	-0.95	-4.08	2275
15	76	0.62	-1.62	-1.00	-5.08	2275
16	77	0.51	-0.90	-0.39	-5.47	2275
17	78	0.67	-0.89	-0.22	-5.69	2140
18	79	0.91	-0.87	0.04	-5.65	2025
19	1980	0.46	-1.35	-0.89	-6.54	2225
20	81	0.62	-0.81	-0.19	-6.73	2180
21	82	0.50	-1.01	-0.51	-7.24	2275
22	83	0.94	-0.99	-0.05	-7.29	2090
23	84	0.98	-1.35	-0.37	-7.66	2275
24	85	0.75	-0.75	0.00	-7.66	2100
25	86	0.42	-1.18	-0.76	-8.42	2275
26	87	0.94	-0.22	0.72	-7.70	1870
27	88	1.08	-1.66	-0.58	-8.28	2195
28	89	1.12	-0.67	0.45	-7.83	1870
29	1990	1.33	-0.60	0.73	-7.10	1870
30	91	0.67	-1.19	-0.52	-7.62	1950
31	92	0.70	-0.80	-0.10	-7.72	
32	93	0.93	-0.51	0.42	-7.30	<1850
33	94	1.16	-1.16	0.00	-7.30	2075
34	95	1.19	-1.30	-0.11	-7.41	2180
35	96	0.53	-0.98	-0.45	-7.86	2205
36	97	0.70	-2.39	-1.69	-9.55	>2290
37	98	0.78	-0.67	0.11	-9.44	undef.
38	99	0.91	-1.30	-0.39	-9.83	2210
39	2000	0.87	-0.92	-0.05	-9.88	undef.
40	01	0.80	-0.78	0.02	-9.86	2070
41	02	0.63	-2.05	-1.42	-11.28	>2290
42	03	0.45	-1.84	-1.39	-12.67	>2290
43	04	0.48	-0.97	-0.49	-13.16	2210
Mean 1962-2004		0.77	-1.07	-0.31		

27 Charles Rabots Bre - 1.1 km^2 (1965)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1970			-1.90	-1.90	
2	71			0.47	-1.43	
3	72			-1.04	-2.47	
4	73			1.44	-1.03	
Mean 1970-73				-0.26		

28 Austre Okstindbre - 14.0 km^2 (1962)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1987	2.30	-1.60	0.70	0.70	1280
2	88	1.50	-3.40	-1.90	-1.20	>1750
3	89	3.70	-2.20	1.50	0.30	1275
4	1990	3.00	-2.70	0.30	0.60	1310
5	91	1.80	-2.30	-0.50	0.10	1315
6	92	2.88	-1.65	1.23	1.33	1260
7	93	2.22	-2.01	0.21	1.54	1290
8	94	1.45	-1.62	-0.17	1.37	1310
9	95	2.25	-1.79	0.46	1.83	1280
10	96	1.62	-1.92	-0.30	1.53	1330
Mean 1987-96		2.27	-2.12	0.15		

29 Høgtuvbreen - 2.6 km² (1972)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1971	3.05	-3.78	-0.73	-0.73	950
2	72	3.34	-4.30	-0.96	-1.69	970
3	73	3.90	-2.82	1.08	-0.61	720
4	74	3.46	-3.68	-0.22	-0.83	900
5	75	3.00	-2.27	0.73	-0.10	760
6	76	3.66	-2.75	0.91	0.81	730
7	77	2.20	-2.72	-0.52	0.29	900
Mean 1971-77		3.23	-3.19	0.04		

30 Svartisheibreen - 5.5 km² (1985)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1988	2.42	-4.03	-1.61	-1.61	1180
2	89	3.72	-1.36	2.36	0.75	900
3	1990	3.79	-2.97	0.82	1.57	930
4	91	2.61	-2.44	0.17	1.74	950
5	92	3.89	-2.68	1.21	2.95	890
6	93	3.50	-2.59	0.91	3.86	910
7	94	1.83	-1.85	-0.02	3.84	975
Mean 1988-94		3.11	-2.56	0.55		

31 Engabreen - 38.0 km² (1968)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1970	2.05	-3.04	-0.99	-0.99	1280
2	71	3.20	-2.19	1.01	0.02	1070
3	72	3.22	-3.29	-0.07	-0.05	1150
4	73	4.37	-1.65	2.72	2.67	830
5	74	3.39	-2.59	0.80	3.47	1030
6	75	3.18	-1.57	1.61	5.08	960
7	76	3.86	-1.45	2.41	7.49	910
8	77	2.08	-1.20	0.88	8.37	1000
9	78	2.48	-2.99	-0.51	7.86	1250
10	79	3.64	-3.22	0.42	8.28	1130
11	1980	2.68	-3.18	-0.50	7.78	1270
12	81	2.91	-1.93	0.98	8.76	965
13	82	2.27	-1.43	0.84	9.60	1030
14	83	2.34	-1.28	1.06	10.66	1020
15	84	3.83	-2.78	1.05	11.71	1000
16	85	1.50	-2.40	-0.90	10.81	1375
17	86	2.70	-2.45	0.25	11.06	1170
18	87	2.57	-1.63	0.94	12.00	1000
19	88	2.26	-4.05	-1.79	10.21	1400
20	89	4.62	-1.45	3.17	13.38	890
21	1990	3.49	-2.64	0.85	14.23	1035
22	91	2.83	-2.14	0.69	14.92	1090
23	92	4.05	-1.71	2.34	17.26	875
24	93	3.06	-2.02	1.04	18.30	985
25	94	1.95	-1.53	0.42	18.72	1050
26	95	3.50	-1.76	1.74	20.46	940
27	96	2.97	-2.14	0.83	21.29	970
28	97	4.44	-3.22	1.22	22.51	1010
29	98	2.98	-2.77	0.21	22.72	1100
30	99	2.12	-2.15	-0.03	22.69	1215
31	2000	2.76	-1.27	1.49	24.18	970
32	01	1.05	-2.58	-1.53	22.65	>1594
33	02	2.89	-3.48	-0.59	22.06	1200
34	03	2.41	-3.00	-0.59	21.47	1195
35	04	2.92	2.10	5.02	26.49	1040
Mean 1970-2004		2.93	-2.17	0.76		

32 Storglombreen - 62.4 km² (1968)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1985	1.40	-2.59	-1.19	-1.19	1300
2	86	2.45	-2.87	-0.42	-1.61	1100
3	87	2.32	-1.87	0.45	-1.16	1020
4	88	2.06	-3.88	-1.82	-2.98	1350
5	2000	2.66	-1.55	1.11	1.11	1000
6	01	1.15	-2.91	-1.76	-0.65	>1580
7	02	2.35	-3.60	-1.25	-1.90	>1580
8	03	2.18	-3.28	-1.10	-3.00	>1580
9	04	2.26	-2.14	0.12	-2.88	1075
Mean 1985-88		2.06	-2.80	-0.75		
Mean 2000-04		2.12	-2.70	-0.58		

33 Tretten-null-tobreen - 4.9 km² (1968)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1985	1.47	-3.20	-1.73	-1.73	>1260
2	86	2.40	-2.84	-0.44	-2.17	1100
Mean 1985-86		1.94	-3.02	-1.09		

34 Glombreen - 2.2 km² (1953)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1954	2.30	-3.50	-1.20	-1.20	
2	55	2.60	-2.70	-0.10	-1.30	
3	56	1.50	-2.10	-0.60	-1.90	
Mean 1954-56		2.13	-2.77	-0.63		

35 Kjølbreen - 3.9 km² (1953)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1954	1.90	-2.60	-0.70	-0.70	
2	55	2.10	-2.80	-0.70	-1.40	
3	56	1.10	-1.10	0.00	-1.40	
Mean 1954-56		1.70	-2.17	-0.47		

36 Trollbergdalsbreen - 1.6 km² (1985)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1970	1.74	-4.21	-2.47	-2.47	>1370
2	71	2.14	-2.47	-0.33	-2.80	1100
3	72	2.44	-3.68	-1.24	-4.04	1160
4	73	3.19	-2.43	0.76	-3.28	<900
5	74	2.57	-2.97	-0.40	-3.68	1090
6	75			-0.28	-3.96	1090
7	1990	2.94	-3.23	-0.29	-0.29	1075
8	91	2.29	-2.45	-0.16	-0.45	1070
9	92	2.63	-2.13	0.50	0.05	<900
10	93	2.45	-2.38	0.07	0.12	1045
11	94	1.49	-2.59	-1.10	-0.98	1180
Mean 1970-74(75)		2.42	-3.15	-0.66		
Mean 1990-94		2.36	-2.56	-0.20		

37 Rundvassbreen - 11.6 km² (1998)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	2002	2.14	-3.19	-1.05	-1.05	1320
2	03	1.88	-2.95	-1.07	-2.12	1360
3	04	1.95	-2.16	-0.21	-2.33	1260
Mean 2002-04		1.99	-2.77	-0.777		

38 Blåisen - 2.2 km² (1960)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1963	2.60	-2.40	0.20	0.20	1050
2	64	2.30	-1.67	0.63	0.83	980
3	65	2.00	-1.46	0.54	1.37	960
4	66	1.12	-2.39	-1.27	0.10	>1200
5	67	1.38	-2.35	-0.97	-0.87	1175
6	68	1.62	-1.36	0.26	-0.61	1010
Mean 1963-68		1.84	-1.94	-0.10		

39 Storsteinsfjellbreen - 5.9 km^2 (1993)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1964	1.85	-1.20	0.65	0.65	1220
2	65	1.69	-1.25	0.44	1.09	1270
3	66	1.05	-1.88	-0.83	0.26	1500
4	67	1.37	-1.77	-0.40	-0.14	1450
5	68	1.44	-0.99	0.45	0.31	1275
6	1991	1.59	-1.63	-0.04	-0.04	1395
7	92	2.21	-1.10	1.11	1.07	1250
8	93	2.10	-1.29	0.81	1.88	1260
9	94	1.15	-1.35	-0.20	1.68	1375
10	95	1.81	-1.24	0.57	2.25	1280
Mean 1964-68		1.48	-1.42	0.06		
Mean 1991-95		1.77	-1.32	0.45		

40 Cainhavarre - 0.7 km^2 (1960)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1965	1.41	-1.20	0.21	0.21	1300
2	66	1.12	-2.07	-0.95	-0.74	>1550
3	67	1.63	-1.79	-0.16	-0.90	1450
4	68	1.31	-1.05	0.26	-0.64	1290
Mean 1965-68		1.37	-1.53	-0.16		

41 Svartfjelljøkelen - 2.7 km^2 (1966)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	1978	2.30	-2.40	-0.10	-0.10	
2	79	2.10				
Mean 1978-79		2.20				

42 Langfjordjøkelen - 3.7 km^2 (1994)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (m a.s.l.)
1	89	2.40	-2.96	-0.56	-0.56	870
2	1990	2.74	-3.06	-0.32	-0.88	780
3	91	2.31	-2.31	0.00	-0.88	710
4	92	2.68	-2.49	0.19	-0.69	700
5	93	2.55	-2.35	0.20	-0.49	740
6	96	2.25	-2.23	0.02	0.02	700
7	97	2.65	-3.34	-0.69	-0.67	820
8	98	1.80	-3.24	-1.44	-2.11	>1050
9	99	1.33	-2.91	-1.58	-3.69	970
10	2000	2.51	-3.12	-0.61	-4.30	860
11	01	1.36	-3.64	-2.28	-6.58	>1050
12	02	2.19	-3.73	-1.54	-8.12	>1050
13	03	2.44	-3.51	-1.07	-9.19	>1050
14	04	1.69	-3.61	-1.92	-11.11	>1050
Mean 1989-93		2.54	-2.63	-0.10		
Mean 1996-2004		2.02	-3.26	-1.23		