Glaciological investigations in Norway in 2005

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Glaciological investigations in Norway in 2005

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Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2005 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, Glacier length change, Glacier velocity, Jøkulhlaup

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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 investigations of several Norwegian glaciers. Measurements of mass balance, glacier length change, glacier velocity, meteorology and other glaciological investigations are presented. Most of the investigations were ordered by private companies and have been published previously as reports to the respective companies. The annual results from mass balance and glacier length changes are also reported to the World Glacier Monitoring Service (WGMS) in Switzerland.

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 2005. 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 NVE.

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

Oslo, April 2006

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Summary

Mass balance

Mass balance investigations were performed on thirteen glaciers in Norway in 2005. Ten of these glaciers are in southern Norway and three are in northern Norway.

The winter balance was greater than average for all ten measured glaciers in southern Norway. Hansebreen had the second highest winter balance since measurements started in 1986. In northern Norway the winter balance was lower than average on Langfjordjøkelen and greater than average on Engabreen.

The summer balance was greater than average for nine of ten measured glaciers in southern Norway. Only Nigardsbreen had a lower summer balance than the average. For the measured glaciers in northern Norway the summer balance was about the same as the average.

Four of the measured glaciers in southern Norway had significantly positive net balances. The greatest surplus was measured at Nigardsbreen (+1.1 m w.eqv.). All three measured glaciers in Jotunheimen showed slightly negative net balances. In northern Norway, Engabreen had a surplus of 0.9 m w.eqv., whilst Langfjordjøkelen had a significant deficit of 1.3 m w.eqv.

Glacier length change

Glacier length changes were measured at 24 glaciers in southern Norway and four glaciers in northern Norway in 2005. Sixteen of the glacier outlets had a retreat in length. Four outlets show a frontal advance, whilst eight outlets show minor changes (±4 m). Engabreen (Svartisen), Brenndalsbreen (Jostedalsbreen) and Rembesdalsskåka (Hardangerjøkulen) all showed recession of between 50 and 60 m. Since 1999, Engabreen has had a total retreat of 179 m, whilst Rembesdalsskåka has had a total retreat of 206 m since 2000.

Sammendrag

Massebalanse

I 2005 ble det utført massebalansemålinger på 13 breer i Norge – ti i Sør-Norge og tre i Nord-Norge.

Vinterbalansen ble større enn gjennomsnittet på alle 10 målte breer i Sør-Norge. Hansebreen fikk den nest største vinterbalansen siden målingene startet i 1986. På breene i Nord-Norge ble vinterbalansen mindre enn gjennomsnittet på Langfjordjøkelen og større enn gjennomsnittet på Engabreen.

Sommerbalansen ble større enn gjennomsnittet på ni av 10 målte breer i Sør-Norge. Bare Nigardsbreen hadde mindre sommerbalanse enn gjennomsnittet. På de målte breene i Nord-Norge ble sommerbalansen omtrent som normalt.

I Sør-Norge ble det signifikant overskudd på fire breer. Det største overskuddet ble målt på Nigardsbreen (+1,1 m vannekvivalenter). De tre målte breene i Jotunheimen fikk alle små underskudd. I Nord-Norge fikk Engabreen et overskudd med 0,9 m vannekv., mens Langfjordjøkelen fikk et solid underskudd med 1,3 m vannekvivalenter.

Frontendringer

Frontendringer ble målt på 24 breer i Sør-Norge og fire breer i Nord-Norge i 2004. Seksten av breutløperne hadde tilbakegang, fire hadde framgang, mens åtte utløpere viste bare små endringer (±4 m). Engabreen (Svartisen), Brenndalsbreen (Jostedalsbreen) og Rembesdalsskåka (Hardangerjøkulen) hadde alle tilbakegang mellom 50 og 60 m det siste året. Siden 1999 har Engabreen gått tilbake 179 m, mens Rembesdalsskåka har hatt en samlet tilbakegang på 206 m siden 2000.

1. Glacier investigations in Norway in 2005

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 (Fig. 1-1). 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 (Fig. 1-1). Snow density is measured in pits at one or two locations at different elevations on each glacier.

Figure 1-1
Snow depth is normally measured by probing to the previous year's summer surface (right). If the summer surface is difficult to distinguish, particularly in snow-rich winters, snow coring is also used to determine the snow depth (left). Photos: Ole Magnus Tønsberg, NVE.

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
Ablation stakes are usually re-drilled during the summer season.
Photo: Hallgeir Elvehøy, NVE.

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 that 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 quantify the accuracy of the individual factors. The determined values of accuracy are therefore based on a subjective estimate.

Mass balance program

In 2005 mass balance measurements were performed on 13 glaciers in Norway - 10 in southern Norway and 3 in northern Norway. In southern Norway, 6 of the glaciers have been measured for 43 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 57 years of measurements, while Engabreen at Svartisen has the longest series (36 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 2005 are reported. The numbers from 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 presented in 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.

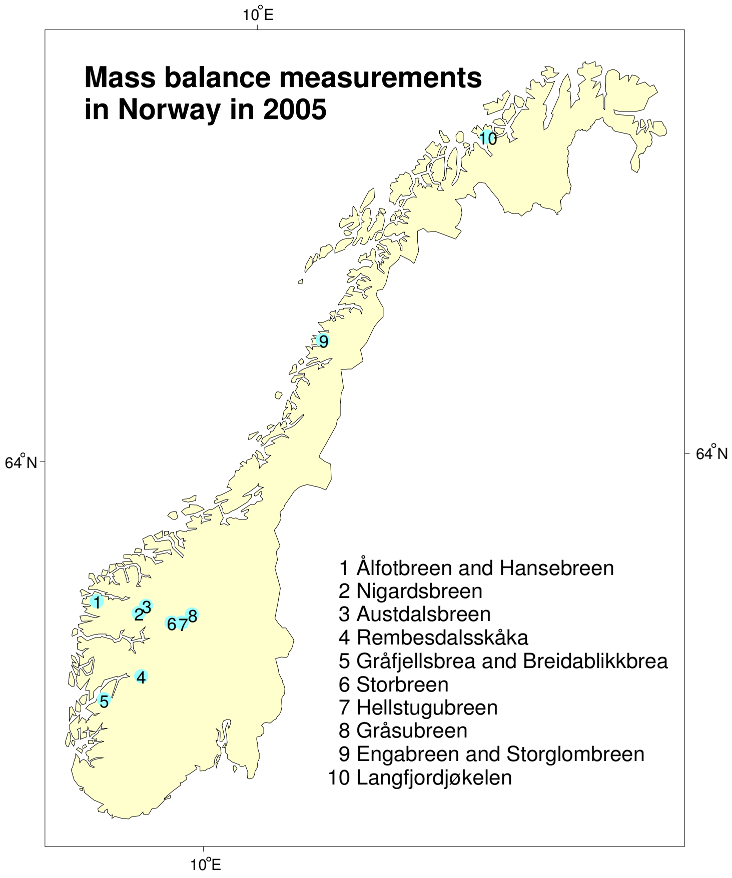


Figure 1-3
Location of the glaciers at which mass balance studies were performed in 2005.

Weather conditions and mass balance results

Wintry weather

The winter season 2004/2005 started with a dry October month over most of the country. The following winter period November-January however, was very snow-rich, particularly in western Norway and most parts of northern Norway. The remaining winter season was rather variable. February was snow-rich in the northern parts of western Norway, while Jotunheimen and Nordland had dry weather. March was dry over most of the country, only the coastal regions in Finnmark and Troms having more precipitation than usual. April was snow-rich in western Norway and in Finnmark. Over the whole winter season 2004/2005 there was more precipitation than normal over most mountain areas from Folgefonna in the south to Svartisen in the north.

Snow accumulation and winter balance

The winter balance was greater than average at all ten measured glaciers in southern Norway. The glaciers in western Norway had results of 118 to 135 % of their average winter balance. Hansebreen had the second highest winter balance (4.5 m w.eqv.) since measurements began in 1986, the greatest being measured in 2000 (4.7 m). The glaciers in Jotunheimen had between 107 and 127 % of average. In northern Norway winter balance was less than average on Langfjordjøkelen (85 %) and greater than average on Engabreen (112 %).

Summer weather

June 2005 was characterised by warm weather in northern Norway and cold weather in southern Norway. July was warmer than normal over the whole country. Except for the coastal regions in western Norway, August was also warmer than normal. The autumn months September and October were also warmer than normal, particularly in western Norway north of Sognefjorden. The total summer season in 2005 was warmer than normal over most of the country, only some regions in western Norway having average summer temperatures lower than usual.

Ablation and summer balance

In southern Norway the summer balance was greater than average at nine of the ten measured glaciers, only Nigardsbreen having a summer balance below average (86 %). In northern Norway, summer balance was about average at both Langfjordjøkelen (103 %) and Engabreen (105 %).

Net balance

In southern Norway net balance was significantly positive for four of the ten measured glaciers. The greatest surplus was measured at Nigardsbreen (+1.1 m w.eqv.). Of the glaciers in Jotunheimen, Hellstugubreen and Gråsubreen were positive, while Storbreen was approximately in balance. In northern Norway, Langfjordjøkelen had a solid deficit (−1.3 m), while Engabreen was positive with +0.9 m w.eqv.

The results from the mass balance measurements in Norway in 2005 are shown in Table 1-1. Winter ($\mathbf{b_w}$,), summer ($\mathbf{b_s}$) and net balance ($\mathbf{b_n}$) 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 2005. The glaciers in southern Norway are listed from west to east. Each glacier is reported in the number system of the 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*	1963-05	4.5	903-1382	4.99	135	−4.32	124	0.67	0.21	1135	78
Hansebreen	*BO002*	1986-05	3.1	930-1327	4.52	132	−4.61	121	−0.09	−0.40	1150	53
Breidablikkbrea	*AJ001*	1963-68 2003-05	3.9 3.6	1219-1660 1236-1659	3.09	[1]141	−3.37	[1]123	−0.28	−0.19 [1]−0.55	1500	48
Gråfjellsbrea	*AK007*	1964-68 1974-75 2003-05	9.4 8.9	1039-1660 1051-1659	3.16	[2]136	−3.15	[2]126	0.01	0.20 [2]−0.17	1460	67
Nigardsbreen	*A4014*	1962-05	47.8	320-1960	2.80	118	−1.70	86	1.10	0.40	1395	87
Austdalsbreen	*A4023*	1988-05	11.8	1200-1757	2.85	130	[3]−2.66	109	0.19	−0.23	1385	78
Rembesdalsskåka	*AO001*	1963-05	17.1	1020-1865	2.79	133	−2.07	105	0.72	0.12	1590	84
Storbreen	*AD041*	1949-05	5.4	1390-2100	1.83	128	−1.89	112	−0.06	−0.26	1795	43
Hellstugubreen	*AD011*	1962-05	3.0	1480-2210	1.34	122	−1.63	114	−0.29	−0.34	1930	39
Gråsubreen	*AB047*	1962-05	2.3	1830-2290	0.83	107	−1.33	124	−0.50	−0.31	2180	13
Storglombreen	*C7013/ C7014*	1985-88 2000-05	59.0 62.4	520-1580	2.74	[4]128	[5]−2.41	[4]87	0.33	−0.75 [4]−0.65	1060	79
Engabreen	*C4011*	1970-05	39.6	10-1575	3.31	112	−2.42	105	0.89	0.64	1060	80
Langfjordjøkelen	*ET008*	1989-93 1996-05	3.7	280-1050	1.88	[6]85	−3.14	[6]103	−1.26	−0.10 [6]−0.83	940	28

[1]Calculated for the measured periods 1963-68 and 2003-04
[2]Calculated for the measured periods 1964-68, 1974-74 and 2003-04
[3]Contribution from calving amounts to 0.37 m for b_s
[4]Calculated for the measured periods 1985-88 and 2000-2004
[5]Contribution from calving amounts to 0.12 m for b_s
[6]Calculated for the measured periods 1989-93 and 1996-2004

Figure 1-4 gives a graphical presentation of the mass balance results in southern Norway for 2005. The west-east gradient is evident for both winter and summer balances. Six glaciers have a significant positive net balance, two are distinctly negative and five glaciers are approximately in balance.

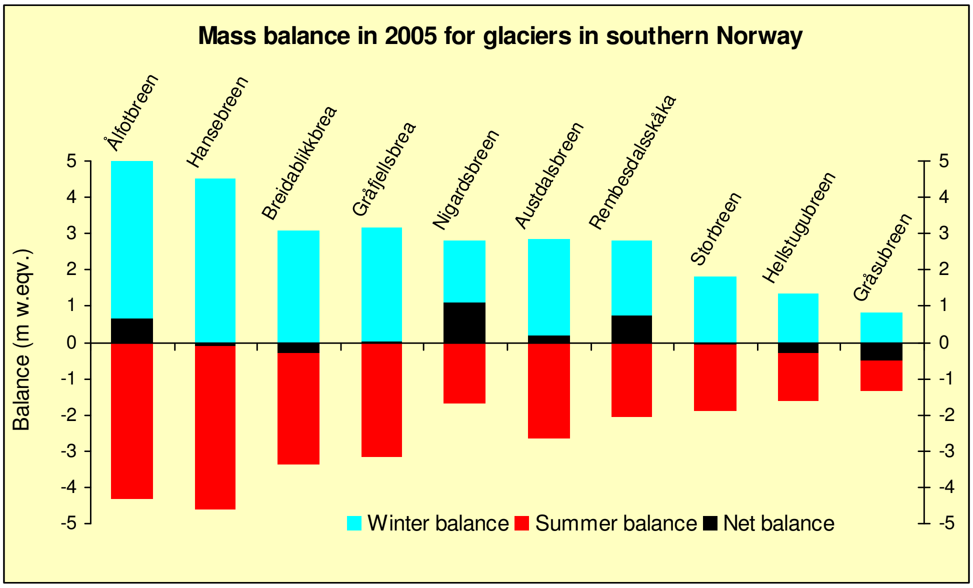


Figure 1-4
Mass balance 2005 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-time series during the period 1963-2005 is shown in Figure 1-5. The maritime glaciers – Ålfotbreen, Nigardsbreen and Rembesdalsskåka showed a marked increase in volume during the period 1989-95. The surplus was mainly the result of several winters with heavy snowfall. The results for 2005 also show positive net balance for these three glaciers. However, over the last five years (2001-05) the net balance has become negative for all 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.

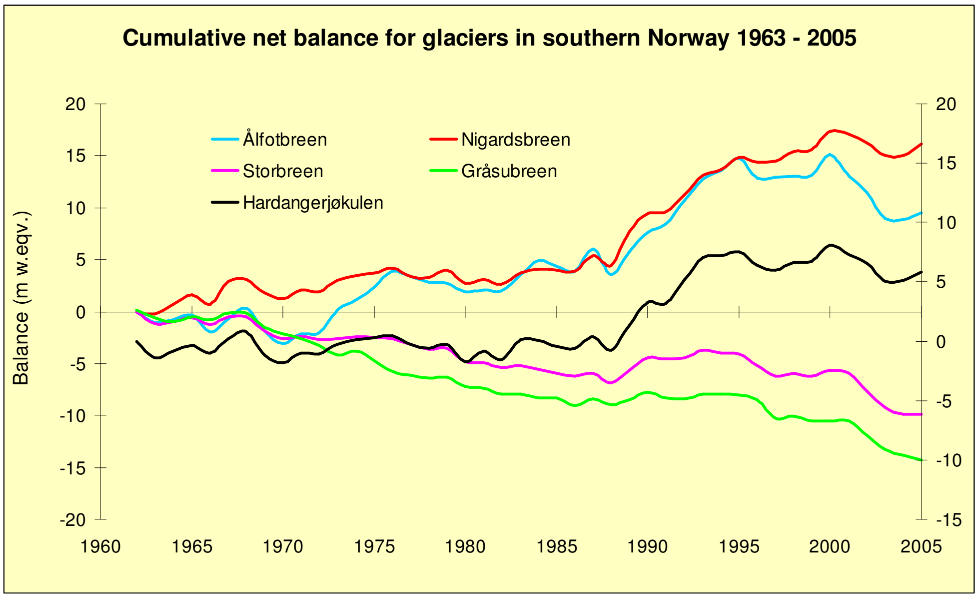


Figure 1-5
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka, Storbreen and Gråsubreen during the period 1963-2005.

1.2 Other investigations

Glacier length change measurements were performed at 28 glaciers in Norway in 2005. Some of the glaciers have a measurement series going back to about 1900. The length changes are described in a separate chapter (chap. 13).

Glacier dynamics (velocity and surface elevation change) has been studied at Austdalsbreen since 1987 (chap. 5). Similar measurements started at Storbreen in September 2004 and continued in 2005 (chap. 7).

Volume calculations of ice masses based on map comparison is performed for Folgefonna (chap. 3).

Meteorological observations have been performed at Hardangerjøkulen (chap. 6), 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 2005 (chap. 13).

In September 2001 a large amount of water that was previously dammed by a glacier arm of Blåmannsisen flowed under the glacier into a reservoir. The jøkulhlaup was a consequence of climate change. Another jøkulhlaup occurred in August 2005 (chap. 13).

Based on regression analyses the net balances for 2005 are modelled for Tunsbergdalsbreen (chap. 4) and Svartisheibreen (chap. 10).

2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45'N, 5°40'E) has an area of 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.

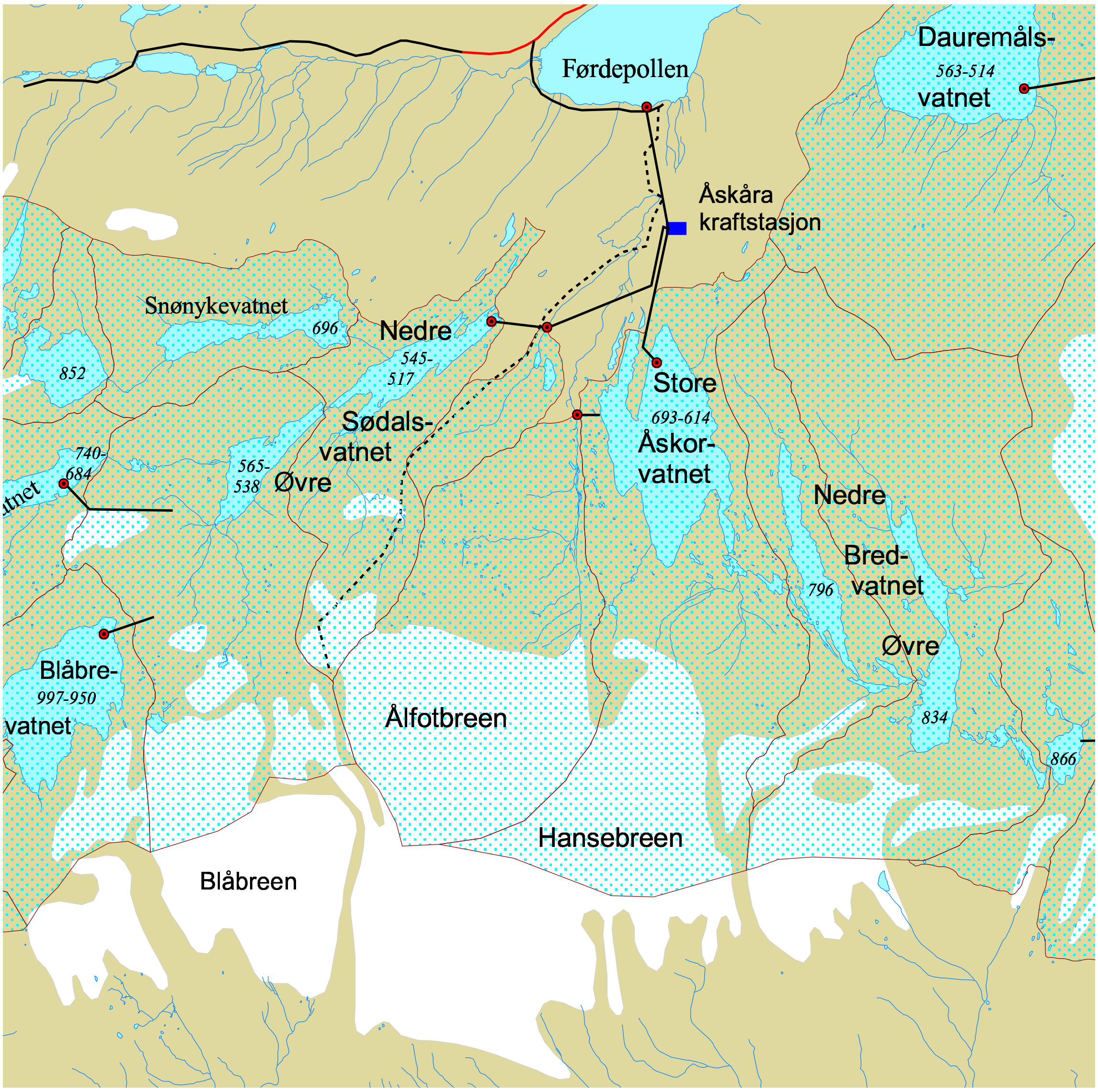


Figure 2-1
Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

2.1 Mass balance 2005

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed from 18th to 20th April. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Measurement of stakes at positions 12 (965 m a.s.l.), 45 (1180 m a.s.l.), 37 (1225 m a.s.l.), 28 (1240 m a.s.l.) and 49 (1380 m a.s.l.) on Ålfotbreen, and measurement of stakes in positions 50 (1025 m a.s.l.), 60 (1070 m a.s.l.), 80 (1125 m a.s.l.), 85 (1195 m a.s.l.) and 90 (1305 m a.s.l.) on Hansebreen.
- 55 snow depth soundings between 925 and 1380 m elevation on Ålfotbreen, and 36 snow depth soundings between 960 and 1300 m elevation on Hansebreen. The snow depth at Ålfotbreen was between 10 and 11.5 m above 1250 m a.s.l. and between 8 and 10 m below 1250 m elevation. At Hansebreen the snow depth was between 10 and 11.5 m in the uppermost areas in south and south-west, and between 7 and 9 m in the remaining areas. In spite of large snow depths the sounding conditions were good with a compact and distinct summer surface (SS) on both glaciers.
- Snow density was measured down to 7.9 m depth (SS at 8.0 m) at stake position 37.

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

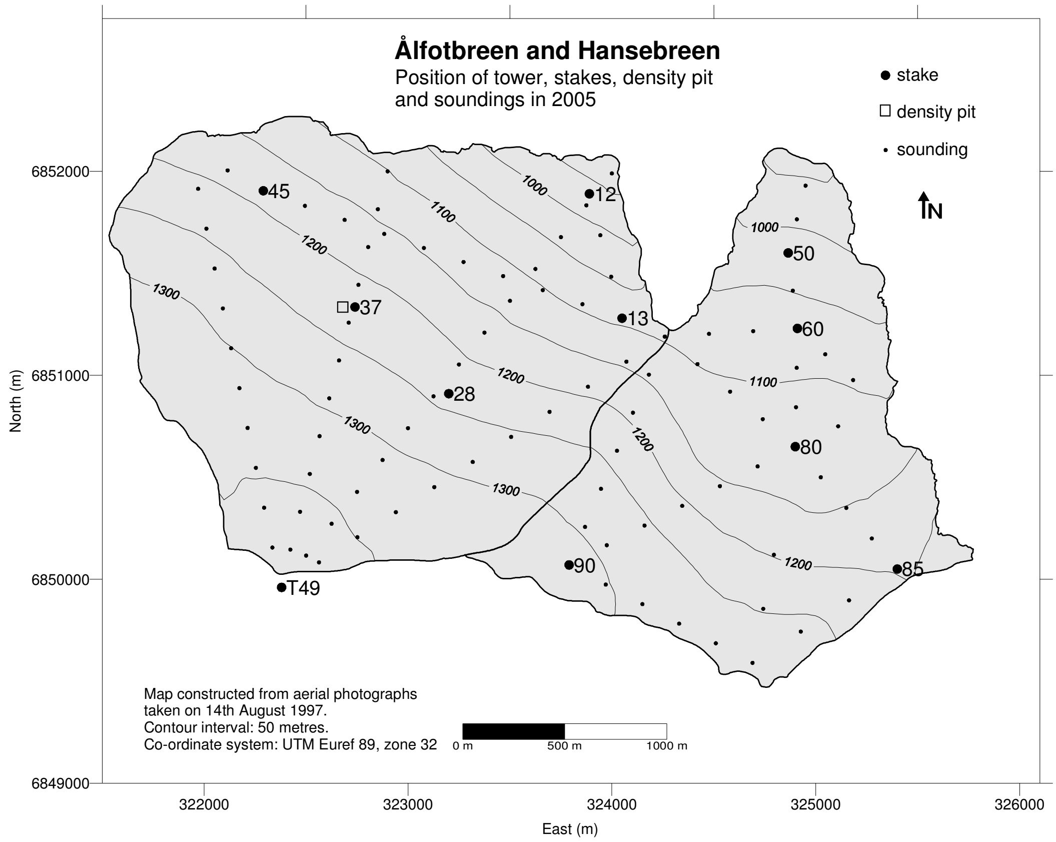


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen and Hansebreen in 2005.

Ablation measurements

Ablation was measured on 16th October. The net balance was directly measured on stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was 2 m of snow remaining at the top of Ålfotbreen (1380 m a.s.l.) and approximately 1.5 m at the top of Hansebreen. At the lowest stake positions all the snow had melted, and about 1 m of ice had melted on Ålfotbreen (965 m a.s.l.) and 1.5 m of ice on Hansebreen (1025 m a.s.l.). At the time of the ablation measurements up to 10 cm of fresh snow had fallen in the uppermost areas.

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 2004.

A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 8.0 m snow was 0.50 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 2005 was 5.0 ±0.2 m w.eqv., corresponding to a volume of 22 ±1 mill. m^3 of water. The result is 135 % of the mean winter balance for 1963-2004, and 126 % of the mean for 1986-2004 (same period as Hansebreen). Only five years have shown a greater winter balance on Ålfotbreen since the measurements started in 1963, all after 1989.

The winter balance at Hansebreen was 4.5 ±0.2 m w.eqv., corresponding to a volume of 14 ±1 mill. m^3 of water. The result is 132 % of the mean value, and the second largest winter balance ever measured in the period of investigation. The largest was in 2000 (4.7 m eqv.).

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 at both glaciers.

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 six stakes. At 1380 m elevation the measured summer balance was −4.3 m, and at 965 m elevation −4.7 m w.eqv. Usually the difference between summer balance in the uppermost and lowest elevation is much higher. Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −4.3 ±0.3 m w.eqv., corresponding to −19 ±1 mill. m^3 of water. The result is 124 % of the mean value for 1963-2004, and 116 % of the mean value for 1986-2004. There are only five years with a greater summer balance on Ålfotbreen.

The summer balance for Hansebreen was measured and calculated at five stakes and increased from −4.2 m w.eqv. at 1305 m elevation to −5.4 m at 1025 m elevation. Based on the five stakes and the estimated density, the summer balance was calculated as −4.6 ±0.3 m w.eqv. or −14 ±1 mill. m^3 of water. The result is 121 % of the mean value, and is the third highest summer balance measured at Hansebreen in the period of investigation.

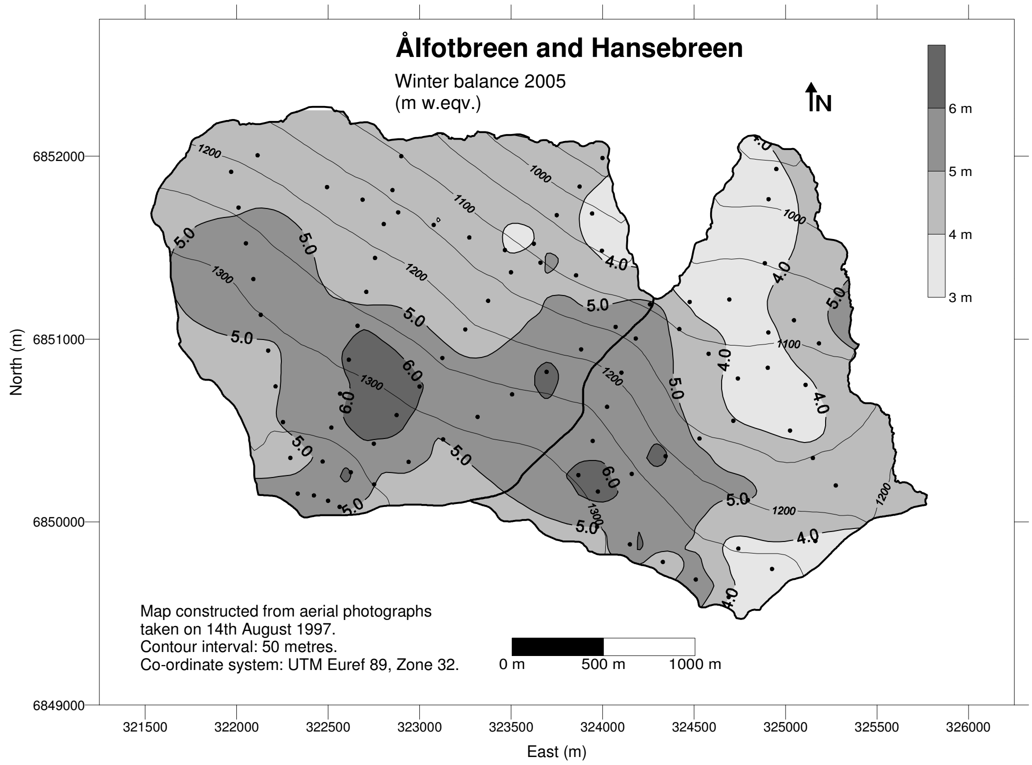


Figure 2-3
Winter balance at Ålfotbreen and Hansebreen in 2005 interpolated from 91 snow depth measurements, shown by (•).

Net balance

The net balance at Ålfotbreen for 2005 was positive, at 0.7 ±0.4 m w.eqv., or a surplus of 3 ±2 mill. m^3 of water. The mean net balance between 1963 and 2004 is +0.21 m w.eqv., and +0.24 m during 1986-2004 (same period as Hansebreen).

The net balance at Hansebreen was calculated as −0.1 ±0.4 m w.eqv., or a deficit of 0.3 ±1 mill. m^3 of water. The mean value for the period 1986-2004 is –0.40 m w.eqv.

According to Figure 2-4 the equilibrium line altitude (ELA) is 1135 m a.s.l. on Ålfotbreen and 1150 m a.s.l. on Hansebreen. Consequently, the AAR is 78 % and 53 % 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.

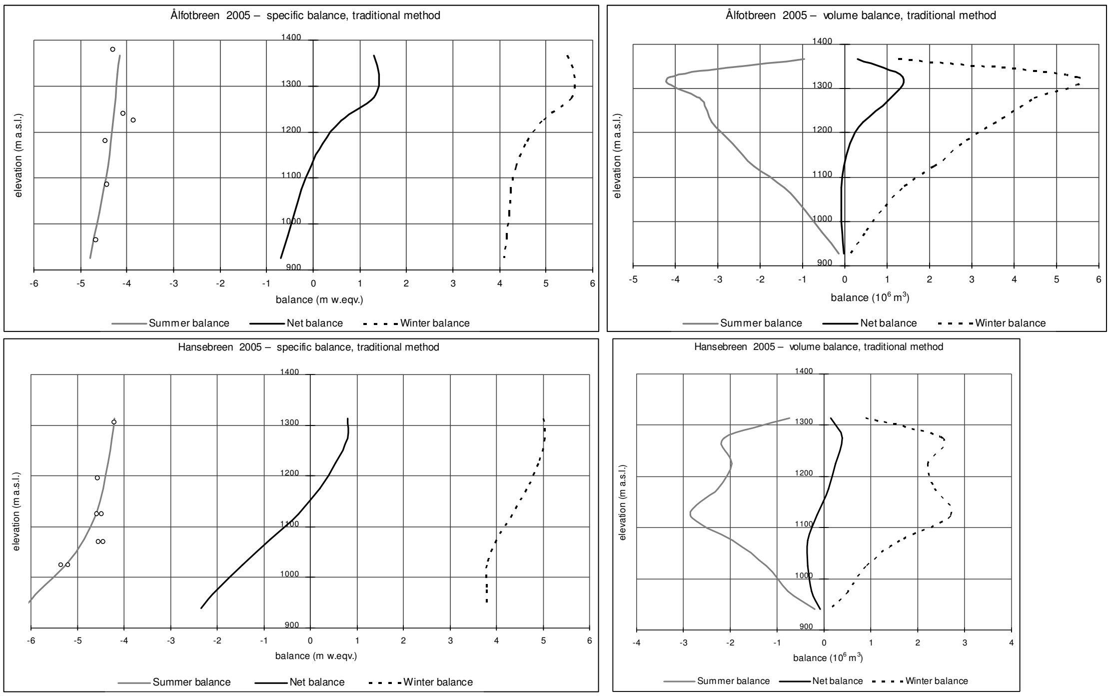


Figure 2-4
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2005 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (o).

Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2005. The mean values for Ålfotbreen during the period 1963-2004 are 3.70 m (bw), −3.49 m (bs) and +0.21 m w.eqv. (bn). The corresponding values for Hansebreen during the period 1986-2004 are 3.43 m, −3.83 m and −0.40 m w.eqv.

Mass balance Ålfotbreen 2004/05 – traditional method

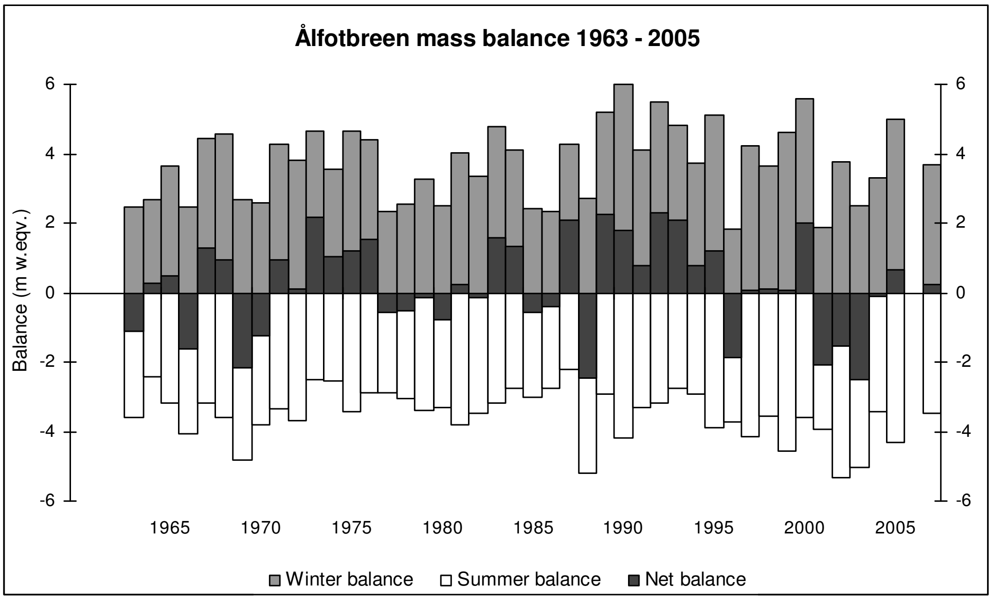
		Winter balance Measured 19th Apr 2005		Summer balance Measured 16th Oct 2005		Net balance Summer surfaces 2004 - 2005	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1350 - 1382	0.23	5.45	1.3	-4.15	-1.0	1.30	0.3
1300 - 1350	0.98	5.60	5.5	-4.20	-4.1	1.40	1.4
1250 - 1300	0.80	5.55	4.4	-4.25	-3.4	1.30	1.0
1200 - 1250	0.73	4.90	3.6	-4.30	-3.1	0.60	0.4
1150 - 1200	0.61	4.55	2.8	-4.35	-2.6	0.20	0.1
1100 - 1150	0.49	4.35	2.1	-4.40	-2.1	-0.05	0.0
1050 - 1100	0.32	4.25	1.3	-4.50	-1.4	-0.25	-0.1
1000 - 1050	0.20	4.20	0.8	-4.60	-0.9	-0.40	-0.1
950 - 1000	0.11	4.15	0.5	-4.70	-0.5	-0.55	-0.1
903 - 950	0.03	4.10	0.1	-4.80	-0.1	-0.70	0.0
903 - 1382	**4.50**	**4.99**	**22.4**	**-4.32**	**-19.4**	**0.67**	**3.0**

Mass balance Hansebreen 2004/05 – traditional method

		Winter balance Measured 19th Apr 2005		Summer balance Measured 16th Oct 2005		Net balance Summer surface 2004 - 2005	
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	5.00	0.88	-4.20	-0.74	0.80	0.14
1250 - 1300	0.50	5.05	2.53	-4.25	-2.13	0.80	0.40
1200 - 1250	0.45	4.90	2.21	-4.35	-1.97	0.55	0.25
1150 - 1200	0.51	4.65	2.36	-4.45	-2.26	0.20	0.10
1100 - 1150	0.62	4.35	2.70	-4.60	-2.85	-0.25	-0.16
1050 - 1100	0.40	4.00	1.61	-4.85	-1.95	-0.85	-0.34
1000 - 1050	0.23	3.80	0.89	-5.25	-1.23	-1.45	-0.34
950 - 1000	0.13	3.80	0.51	-5.80	-0.77	-2.00	-0.27
930 - 950	0.03	3.80	0.12	-6.15	-0.20	-2.35	-0.08
930 - 1327	**3.06**	**4.52**	**13.8**	**-4.61**	**-14.1**	**-0.09**	**-0.3**

The balance year 2004/2005 is the first year with positive net balance at Ålfotbreen since 2000. Since measurements started in 1963 the cumulative net balance is +9.5 m w.eqv. Since 1996, however, the net balance shows a deficit of −5.2 m w.eqv.

At Hansebreen the balance year 2004/2005 is the fifth successive year with negative net balance. However, last year's deficit (−0.1 m) is not significant. Since measurements started in 1986 the cumulative net balance is −7.7 m w.eqv.



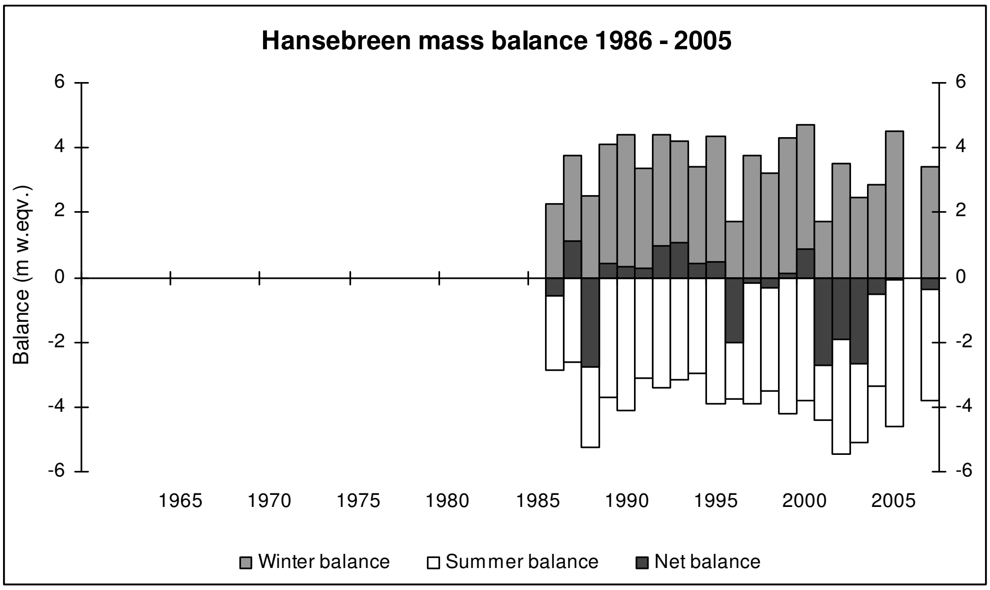


Figure 2-5
Mass balance at Ålfotbreen (upper) during the period 1963-2005 and Hansebreen (lower) during the period 1986-2005.

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 2005

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 26th and 27th April. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-1):

- Measurement of stakes at positions 40 (1260 m a.s.l.), 45 (1345 m a.s.l.), 50 (1480 m a.s.l.), 55 (1565 m a.s.l.) and 60 (1645 m a.s.l.) on Breidablikkbrea and measurement of stakes in positions 10 (1095 m a.s.l.), 15 (1280 m a.s.l.), 20 (1360 m a.s.l.), 25 (1480 m a.s.l.), 30 (1550 m a.s.l.) and 60 (1645 m a.s.l.) on Gråfjellsbrea. One stake position (60) is located on the boundary between the two glaciers and is included in the calculations for both glaciers.
- 44 snow depth soundings between 1260 and 1650 m a.s.l. on Breidablikkbrea, and 75 snow depth soundings between 1080 and 1645 m a.s.l. on Gråfjellsbrea. The summer surface (SS) was difficult to distinguish in the uppermost areas (above 1500 m elevation) on both glaciers. The variation in snow depth was considerable, even within the same height interval. At Breidablikkbrea most snow depths varied between 5 and 7 m, and between 5 and 8 m at Gråfjellsbrea.
- Core samples at eight positions on Breidablikkbrea and five positions on Gråfjellsbrea showing snow depths between 4.8 and 7.1 m and 4.4 and 7.3 m, respectively.
- Snow density was measured down to the SS (6.5 m) at stake position 25 (1480 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 7th October. The net balance was measured at stakes in nine different positions on Breidablikkbrea and six positions on Gråfjellsbrea. In areas above 1500 m elevation there was about 2 m of snow remaining on the glacier surface. No fresh snow had fallen at the time of the ablation measurement.

Due to mild weather in October a supplementary ablation measurement was carried out on 8th December. The stake measurements showed additional melting (ca. 0.4 m w.eqv.) after 7th October. Thus, the end of the melt season is taken to be 8th December. At this time, between 0.2 and 1.3 m fresh snow had fallen.

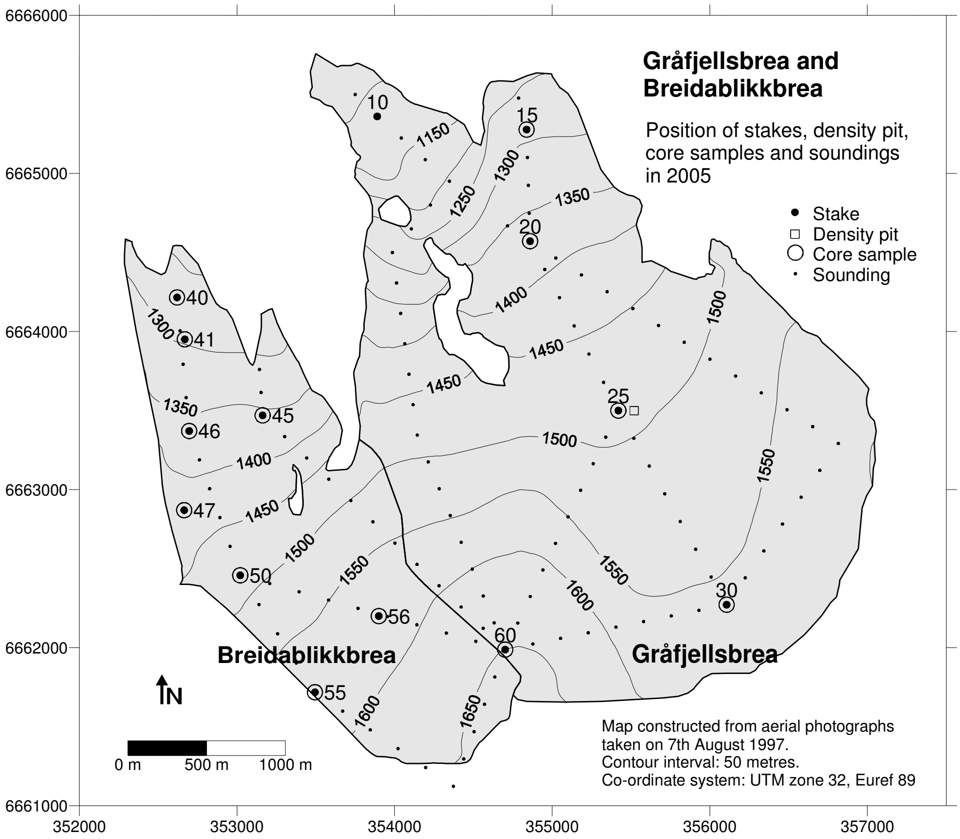


Figure 3-1
Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2005.

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, core samples and soundings) and on measurement of snow density at one representative location. There was no melting after the final measurements at the end of September 2004.

A density profile was modelled from the snow density measured at 1480 m a.s.l. The mean snow density of 6.5 m snow was 0.506 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 2005 was 3.1 ±0.2 m w.eqv., corresponding to a volume of 11 ±1 mill. m^3 of water. The result is 141 % of the average for the study period 1963-68 and 2003-04.

The winter balance at Gråfjellsbrea was 3.2 ±0.2 m w.eqv., corresponding to a volume of 28 ±1 mill. m^3 of water. The result is 136 % of the average for 1964-68, 1974-75 and 2003-04.

As verification, the winter balance was also calculated using two different gridding methods based on the aerial distribution of the snow depth measurements (Fig. 3-2). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. This method gave 3.0 m w.eqv. for Breidablikkbrea and 3.1 m w.eqv. for Gråfjellsbrea.

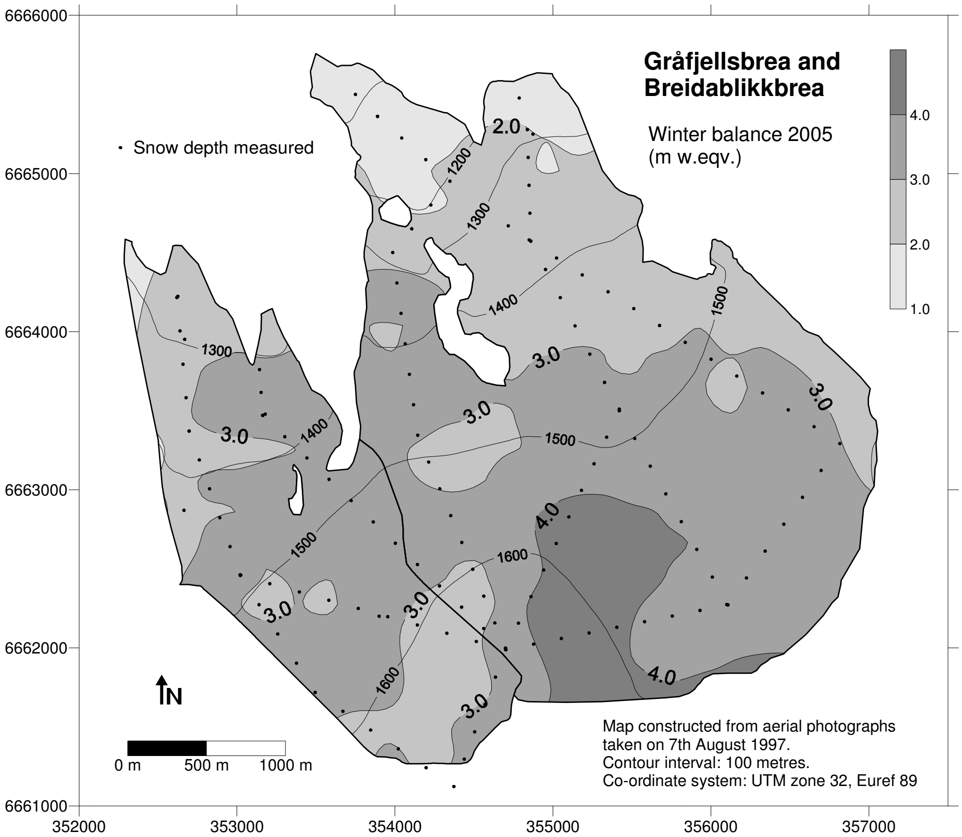


Figure 3-2
Winter balance at Breidablikkbrea and Gråfjellsbrea in 2005 interpolated from 144 snow depth measurements (•).

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 ice was determined as 0.90 g/cm^3.

The summer balance at Breidablikkbrea was measured and calculated at nine stakes, and increased from −2.5 m w.eqv. at 1645 m altitude to −4.5 m at 1255 m altitude. Based on estimated density and stake measurements the summer balance was calculated as −3.4 ±0.3 m w.eqv., corresponding to −12 ±1 mill. m^3 of water. The result is 123 % of the mean value for 1963-68 and 2003-04.

The summer balance for Gråfjellsbrea was measured and calculated at six stakes and increased from −2.5 m w.eqv. at 1645 m altitude to −6.1 m at 1095 m altitude. Based on the six stakes and the estimated density the summer balance was calculated as −3.2 ±0.3 m w.eqv. or −28 ±1 mill. m^3 of water. The result is 126 % of the mean value for 1964-68, 1974-75 and 2003-04.

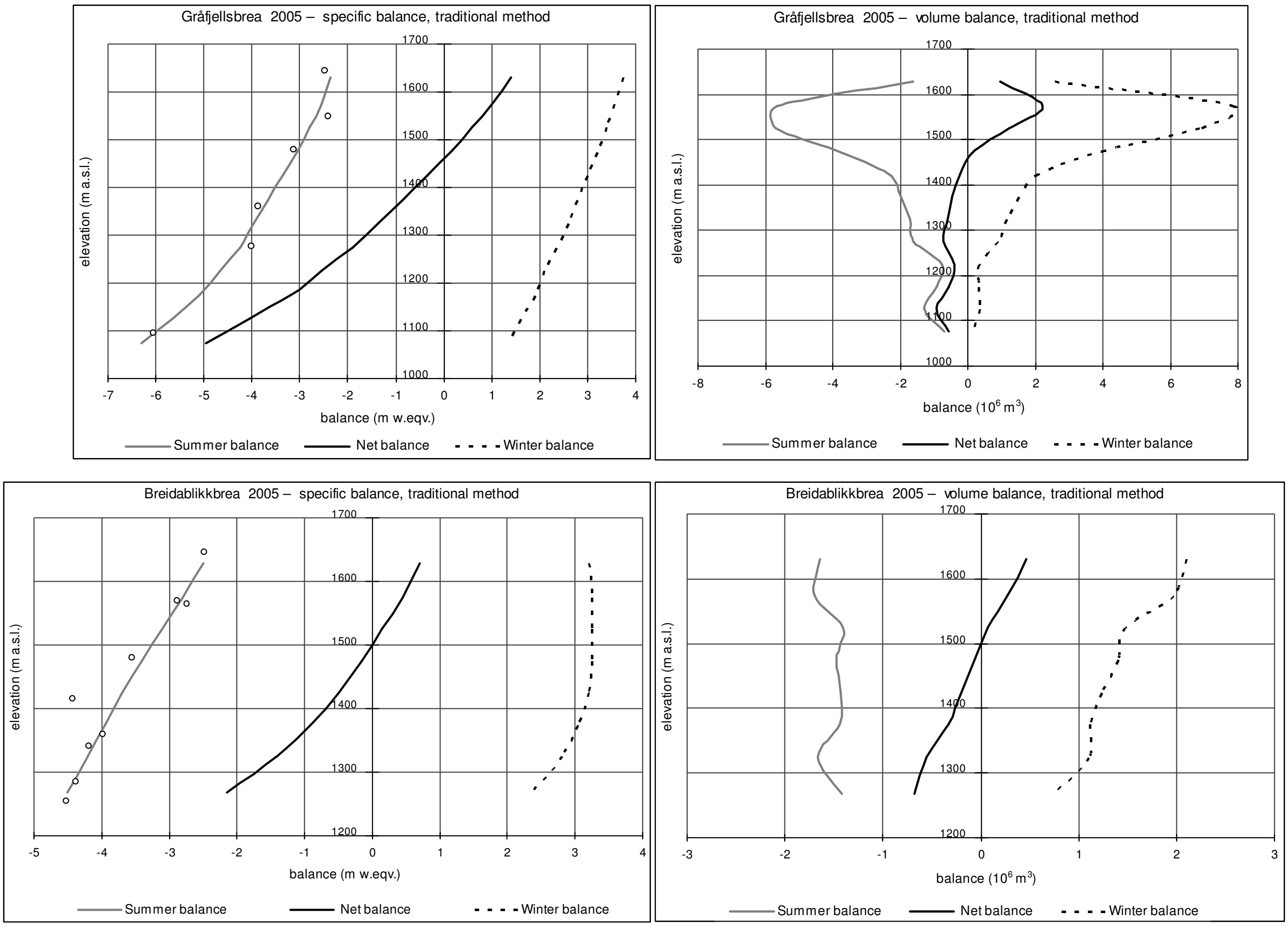


Figure 3-3
Mass balance diagram for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2005 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (o).

Net balance

The net balance at Breidablikkbrea for 2005 was calculated as −0.3 ±0.4 m w.eqv., or a volume loss of 1 ±1 mill. m^3 of water. The mean net balance for 1963-68 and 2003-04 is −0.55 m w.eqv.

The net balance at Gråfjellsbrea was calculated as 0.0 ±0.4 m w.eqv., which means that the glacier was in balance. The mean value for the years 1964-68, 1974-75 and 2003-04 is −0.17 m w.eqv.

Based on Figure 3-3 the equilibrium line altitude (ELA) lies at 1500 m a.s.l. on Breidablikkbrea and 1460 m a.s.l. on Gråfjellsbrea. Consequently, the Accumulation Area Ratios (AAR) are 48 % and 67 %, 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.

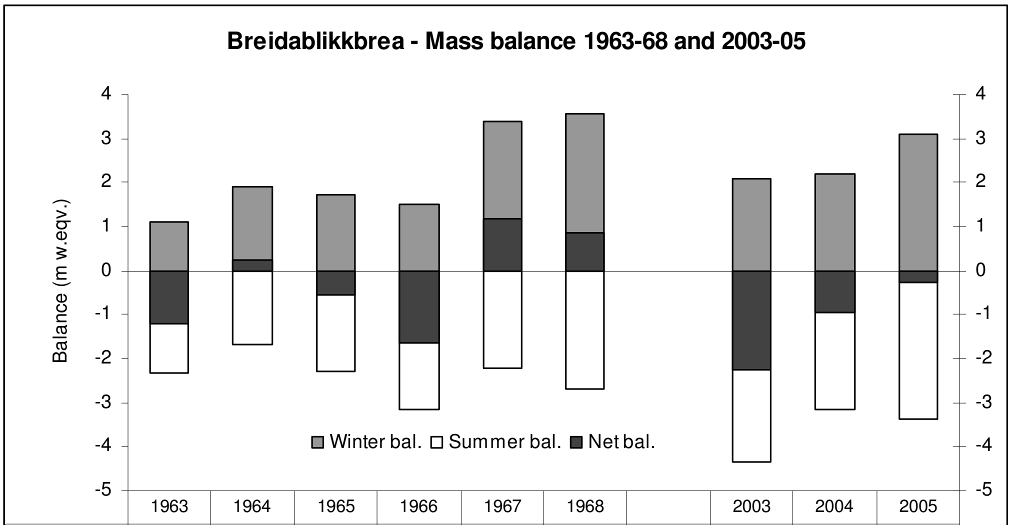
Table 3-1
Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2005.

Mass balance Breidablikkbrea 2004/05 – traditional method

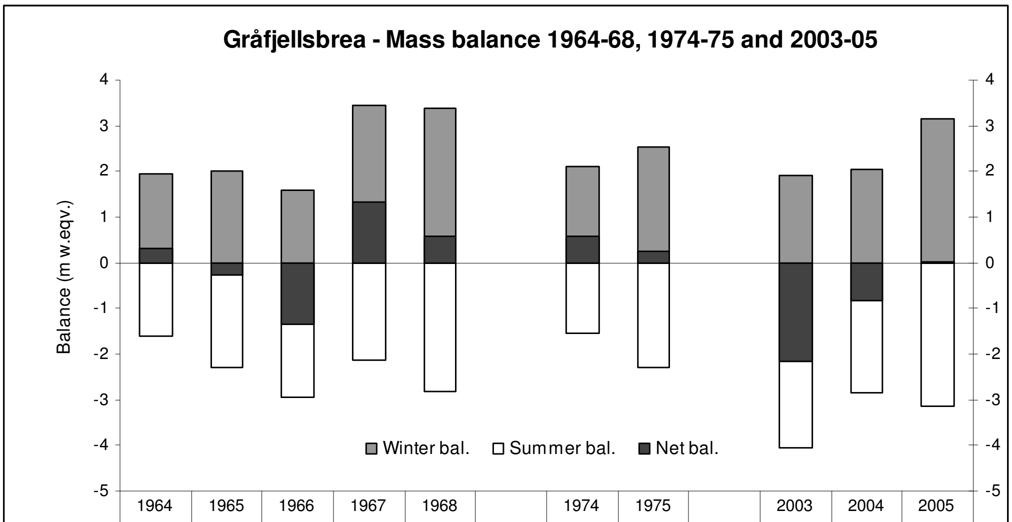
		Winter balance Measured 26th April 2005		Summer balance Measured 10th Oct 2005		Net balance Summer surfaces 2004 - 2005	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
1600 - 1659	0.66	3.20	2.1	-2.50	-1.6	0.70	0.5
1550 - 1600	0.61	3.25	2.0	-2.80	-1.7	0.45	0.3
1500 - 1550	0.45	3.25	1.5	-3.10	-1.4	0.15	0.1
1450 - 1500	0.43	3.25	1.4	-3.40	-1.5	-0.15	-0.1
1400 - 1450	0.39	3.20	1.2	-3.70	-1.4	-0.50	-0.2
1350 - 1400	0.36	3.05	1.1	-3.95	-1.4	-0.90	-0.3
1300 - 1350	0.40	2.80	1.1	-4.20	-1.7	-1.40	-0.6
1236 - 1300	0.31	2.35	0.7	-4.50	-1.4	-2.15	-0.7
1236 - 1659	**3.61**	**3.09**	**11.2**	**-3.37**	**-12.2**	**-0.28**	**-1.0**

Mass balance Gråfjellsbrea 2004/05 – traditional method

		Winter balance Measured 26th April 2005		Summer balance Measured 10th Oct 2005		Net balance Summer surfaces 2004 - 2005	
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)
1600 - 1659	0.68	3.75	2.6	-2.35	-1.6	1.40	1.0
1550 - 1600	2.21	3.55	7.8	-2.55	-5.6	1.00	2.2
1500 - 1550	2.03	3.40	6.9	-2.80	-5.7	0.60	1.2
1450 - 1500	1.28	3.20	4.1	-3.05	-3.9	0.15	0.2
1400 - 1450	0.70	3.00	2.1	-3.35	-2.3	-0.35	-0.2
1350 - 1400	0.54	2.80	1.5	-3.65	-2.0	-0.85	-0.5
1300 - 1350	0.44	2.60	1.1	-3.95	-1.7	-1.35	-0.6
1250 - 1300	0.38	2.35	0.9	-4.25	-1.6	-1.90	-0.7
1200 - 1250	0.16	2.10	0.3	-4.65	-0.8	-2.55	-0.4
1150 - 1200	0.18	1.90	0.3	-5.10	-0.9	-3.20	-0.6
1100 - 1150	0.23	1.60	0.4	-5.65	-1.3	-4.05	-0.9
1051 - 1100	0.11	1.35	0.2	-6.30	-0.7	-4.95	-0.6
1051 - 1659	**8.94**	**3.16**	**28.2**	**-3.15**	**-28.1**	**0.01**	**0.1**



	1963	1964	1965	1966	1967	1968		2003	2004	2005
Winter bal.	1.11	1.92	1.72	1.52	3.40	3.55		2.08	2.21	3.09
Summer bal.	-2.32	-1.68	-2.28	-3.17	-2.23	-2.68		-4.35	-3.16	-3.37
Net bal.	-1.21	0.24	-0.56	-1.65	1.17	0.87		-2.27	-0.95	-0.28



	1964	1965	1966	1967	1968		1974	1975		2003	2004	2005
Winter bal.	1.94	2.01	1.58	3.46	3.39		2.11	2.53		1.90	2.04	3.16
Summer bal.	-1.62	-2.29	-2.93	-2.14	-2.82		-1.53	-2.28		-4.07	-2.85	-3.15
Net bal.	0.32	-0.28	-1.35	1.32	0.57		0.58	0.25		-2.17	-0.81	0.01

Figure 3-4
Winter, summer and net balance at Breidablikkbrea for the periods 1963-68 and 2003-05 (upper figure), and at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-05 (lower figure).

3.2 Volume change 1959-1997

Methods

Calculating the volume change of ice masses over a period of time is possible using various methods. The volume change for parts of Folgefonna over the period 1959-1997 are calculated using the photogrammetric (also called cartographic) method. For this purpose the method includes scanning and adjustment of air photography and printed map, providing digital map data and generating Digital Elevation Models (DEMs). The volume change can be calculated by comparison of the DEMs from 1959 and 1997, respectively.

The data processing involves generation of DEMs from the digital map data sets using a grid-based graphics program. The surface elevation changes are calculated by subtracting the DEMs on a cell-by-cell basis. The result is a regular grid with elevation differences. For comparison with volume change calculations derived from other methods, the elevation difference are converted to the difference in water equivalents by multiplying the grid with the density of ice, taken as 900 kg/m^3. The volume change values are not modified for melting that may have occurred after the date of photography, because the two dates are nearly identical, 10th August 1959 and 7th August 1997, respectively.

Data material

1959

The basis for generating a DEM and constructing glacier boundaries for 1959 is paper copies of three map sheets covering the three ice caps North, Middle and South Folgefonna. The map sheets, which are at a scale of 1:20 000, are constructed from vertical air photographs taken on 10th August 1959 at a scale of 1:40 000. By scanning, vectorising and georeferencing the paper map sheets, glacier boundaries and contour lines are converted to digital map data.

1997

The basis for generating a DEM and constructing glacier boundaries for 1997 is vertical air photographs taken on 7th August 1997. A stereo model was established and digital map data generated (DEM) and constructed (boundaries). To confirm a proper determination of the ice divide the glacier surface was surveyed with dGPS in 2004 and 2005.

Table 3-2
The data basis for generating DEMs and constructing glacier boundaries for 1959 and 1997, respectively.

Vertical air photograph			Derived data set	
Date	**Contract No.**	**Scale**	**Data (XYZ)**	**Contour interval**
10th Aug 1959	1061	1:40 000	Contour lines	10 m
7th Aug 1997	FW 12176	1:30 000	Irregular grid	

Data processing

Generation of a DEM requires regularly gridded points. The choice of grid method and grid size are both dependent on the input data characteristics and will influence the interpolation procedures. The selected gridding method used was *Kriging*. Calculations were tested using four different grid sizes, 20, 30, 50 and 100 metres. The results were approximately the same for all attempts.

Grid files were created separately for North, Middle and South Folgefonna. The South Folgefonna ice cap is divided into four subbasins; Blådal, Gråfjell, Breidablikk and Bondhus.

The volume change was calculated by extracting the 1959 and 1997 grids and converting to water equivalent by multiplying by 0.9 (density of glacier ice).

Results

The volume change between 1959 and 1997 is calculated for the glacier basins located within the drainage area used by the power company Statkraft. The results of the volume change calculations are shown in Table 3-3. The chosen grid size used is 30 metres. Maps showing the elevation changes are shown in Figures 3-5, 3-6 and 3-7.

Table 3-3
Volume change (water equivalent) from 1959 to 1997 for glacier basins draining westward on North, Middle and South Folgefonna. The glacier areas for 1959 and 1997 are also shown.

Glacier basin	Area 1959 (km^2)	Area 1997 (km^2)	Volume change 1959-1997: Volume (mill. m^3)	Specific (m w.eqv.)	Spec. annual (m w.eqv.)
North	17.0	17.1	−95	−5.6	−0.15
Middle	5.3	5.4	−45	−8.5	−0.22
Blådal	7.0	6.7	−93	−13.3	−0.35
Gråfjell	9.8	8.9	−164	−16.8	−0.44
Breidablikk	3.9	3.6	−57	−14.6	−0.38
Bondhus	17.8	17.6	−37	−2.1	−0.06

As Table 3-3 shows, all glacier basins had negative volume change over the period 1959-1997. The specific volume loss was greatest on three of the basins on southern Folgefonna, Blådal, Gråfjell and Breidablikk. However, the fourth basin on southern Folgefonna, Bondhus, had the least volume loss of all basins.

Volume change is not calculated for the east-draining basins. However, Figures 3-5, 3-6 and 3-7 show an appreciable difference in elevation change between the western and eastern parts, particularly on North Folgefonna. While the west-draining areas had a general surface lowering from 1959 to 1997, some of the east-draining areas show an increase in surface elevation. The difference is particularly distinct on North Folgefonna.

Accuracy

The accuracy of the final result is affected by several factors. The quality of the ground control points will influence the x, y and z data processing. Generating x, y and z data over snow-covered areas based on air photographs is difficult due to poor contrast, and the accuracy will be lower in those areas. Data conversions and interpolation routines providing regular grid models will impair the accuracy. The overlay operation and volume calculation will also introduce errors. Based on these sources of errors the uncertainty of the results is estimated to be ±3.0 m w.eqv.

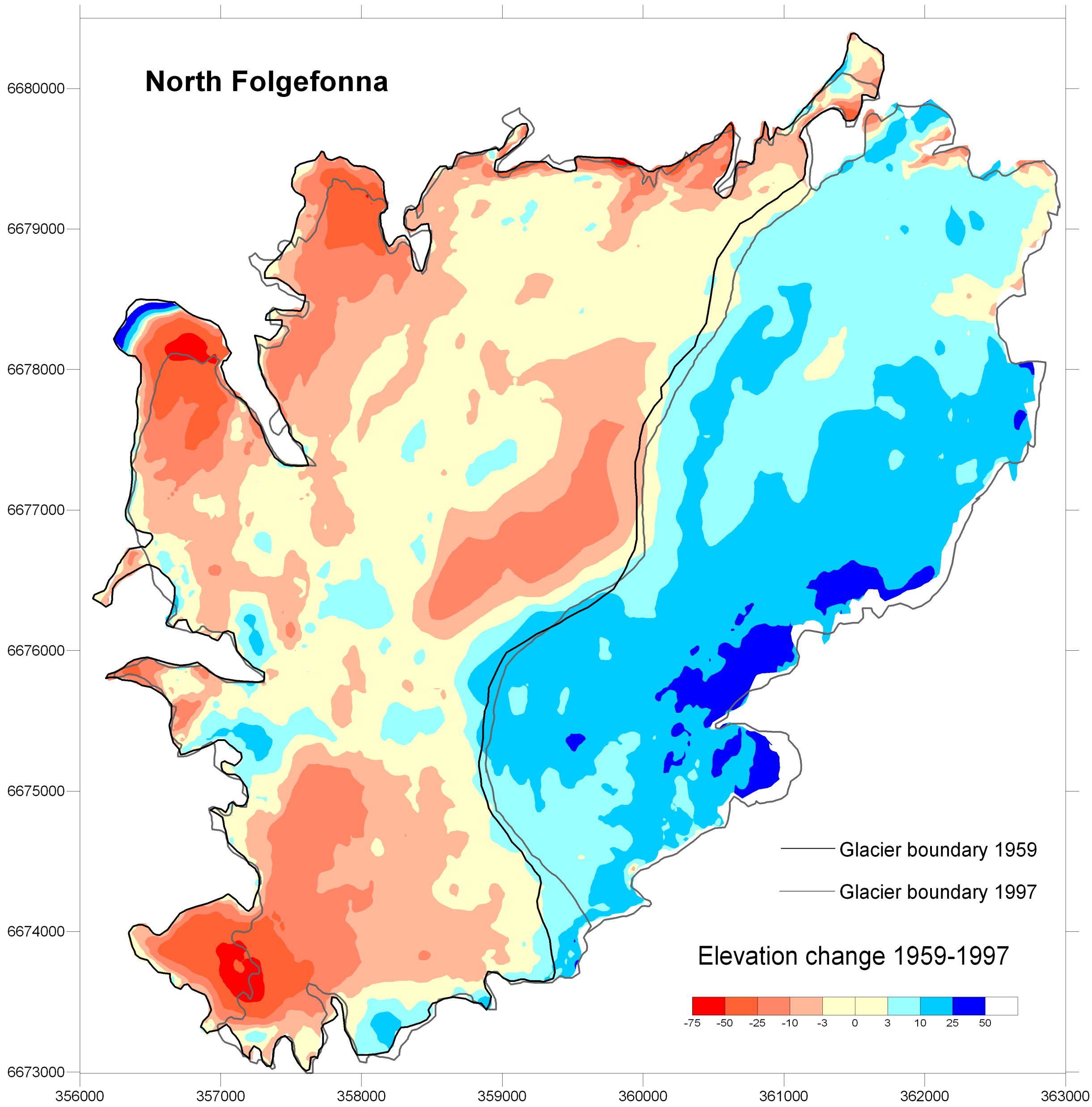


Figure 3-5
Elevation change on North Folgefonna between 10th August 1959 and 7th August 1997. Red colours show areas with significant lowering of the glacier surface, while blue colours show areas where the surface is higher. Yellow (±3 m) indicates areas with no significant change in surface height. Note the marked difference between the western and the eastern part. Most of the area draining westward has decreased, while almost the whole area draining eastward has increased in volume. Volume change is calculated for the west-draining areas only.

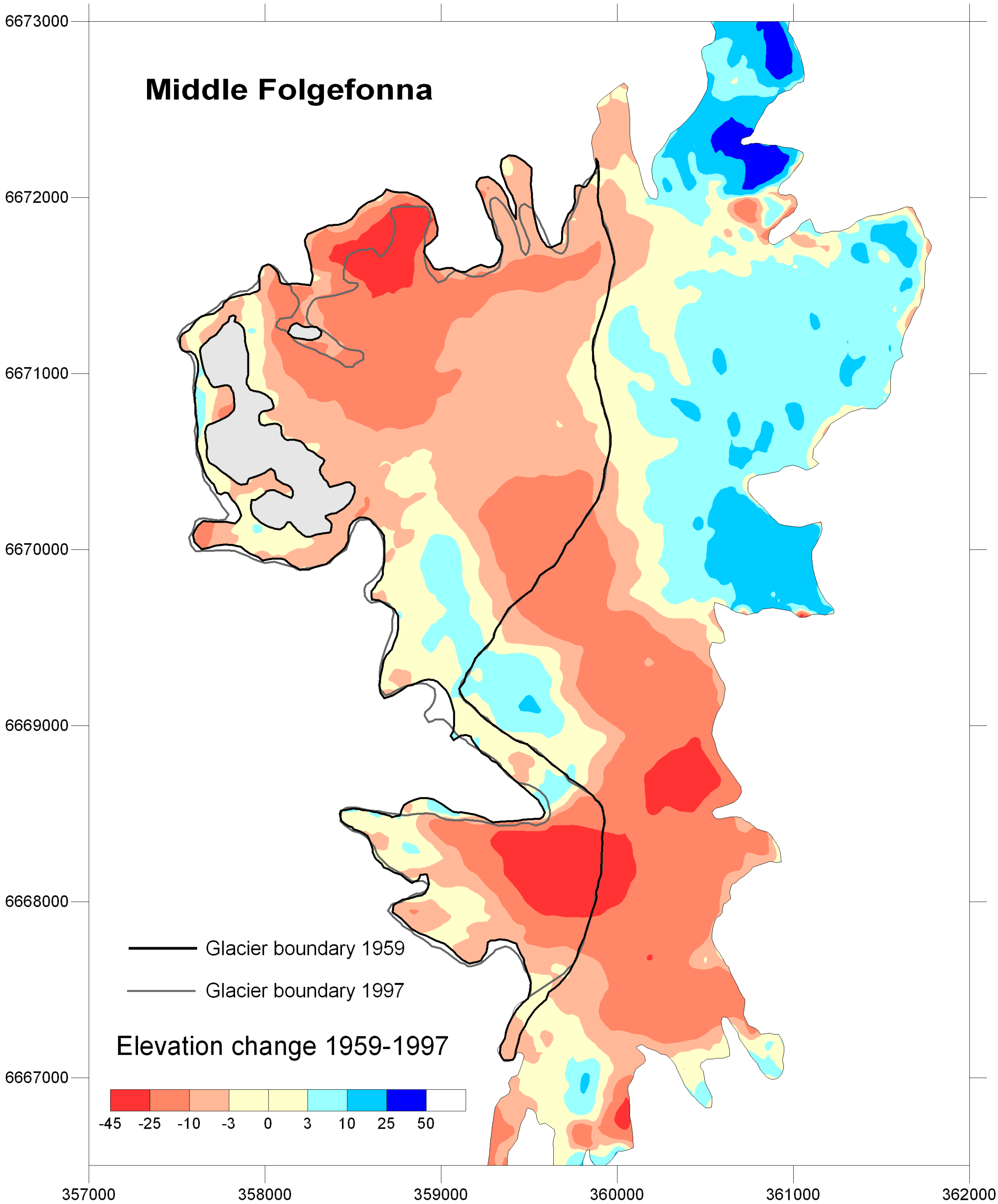


Figure 3-6
Elevation change on Middle Folgefonna between 10th August 1959 and 7th August 1997. Red colours show areas with significant lowering of the glacier surface, while blue colours show areas where the surface is higher. The yellow colour (±3 m) indicates areas with no significant change in surface height. Most of the area draining westward has decreased in volume. The north-eastern part of the east-draining ice cap shows significant increase in surface. Volume change is calculated for the west-draining areas only.

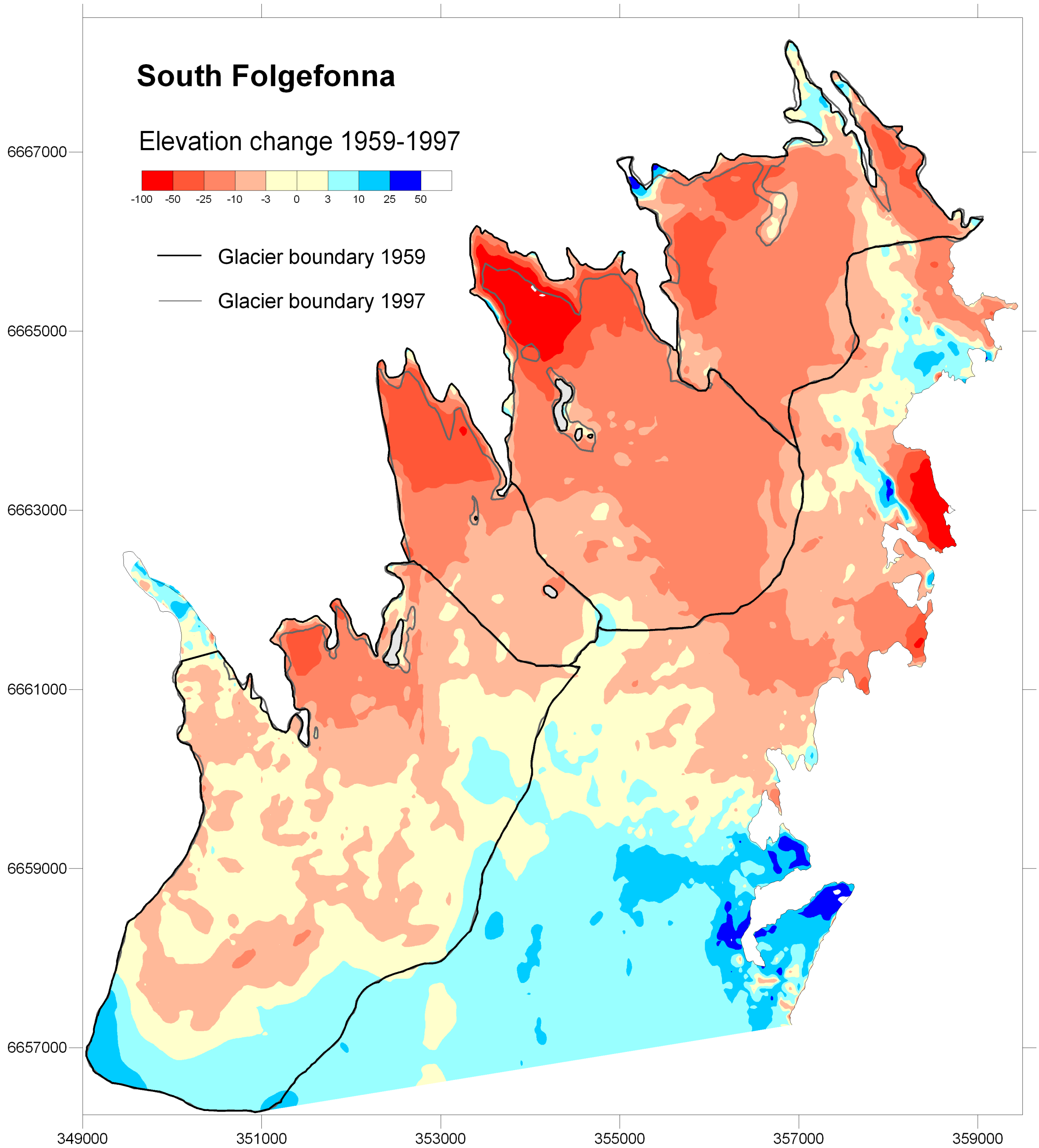


Figure 3-7
Elevation change on South Folgefonna between 10th August 1959 and 7th August 1997. Red colours show areas with significant lowering of the glacier surface, while blue colours show areas where the surface is higher. Yellow (±3 m) indicates areas with no significant change in surface height. The three northernmost glacier basins had a distinct lowering of the surface from 1959 to 1997. The southernmost basin, however, had both lowering and elevation of the surface. Volume change is calculated for the west-draining areas only.

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 2005 include mass balance and front position change. An observation of the ice-dammed lake Brimkjelen at Tunsbergdalsbreen has also been performed. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The glacier snout of Nigardsbreen photographed on 16th October 2005. Photo: Miriam Jackson.

4.1 Mass balance 2005

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed from 11th to 13th of May and the calculation of winter balance (Fig. 4-2) is based on:

- Uninterrupted measurements of stake 600. It was also possible to make use of measurements of substitute stakes drilled in May 2005 and older stakes that appeared during the melt season in four more positions (54, T95, 94 and T56). The stake measurements on the plateau showed snow depth between 6.0 and 7.8 m. Measured snow depth at stake 600 was 1.2 m. Stake readings did not show any indication of melting after the final measurements in September 2004.
- Core samples at positions 57, T56, 94, T95, 54, 55 and 1000 showing snow depth between 4.5 and 8.5 m.

- 93 snow depth soundings on the plateau between 1325 and 1960 m a.s.l. Due to several ice layers in the snow pack and indistinct summer surface (SS) it was difficult to estimate the snow depth on the plateau. The snow depth soundings gave snow thickness between 7 and 9 m in the areas above 1650 m a.s.l. and between 5 and 7 m in the height interval 1325-1650 m a.s.l. At 1000 m elevation the snow depth was about 4 m and at 600 m elevation 1-1.5 m.
- Snow density was measured down to SS (8.0 m) at position T95 (Fig. 4-3).

Location of stakes, towers, snow pit, core samples and soundings are shown in Figure 4-2.

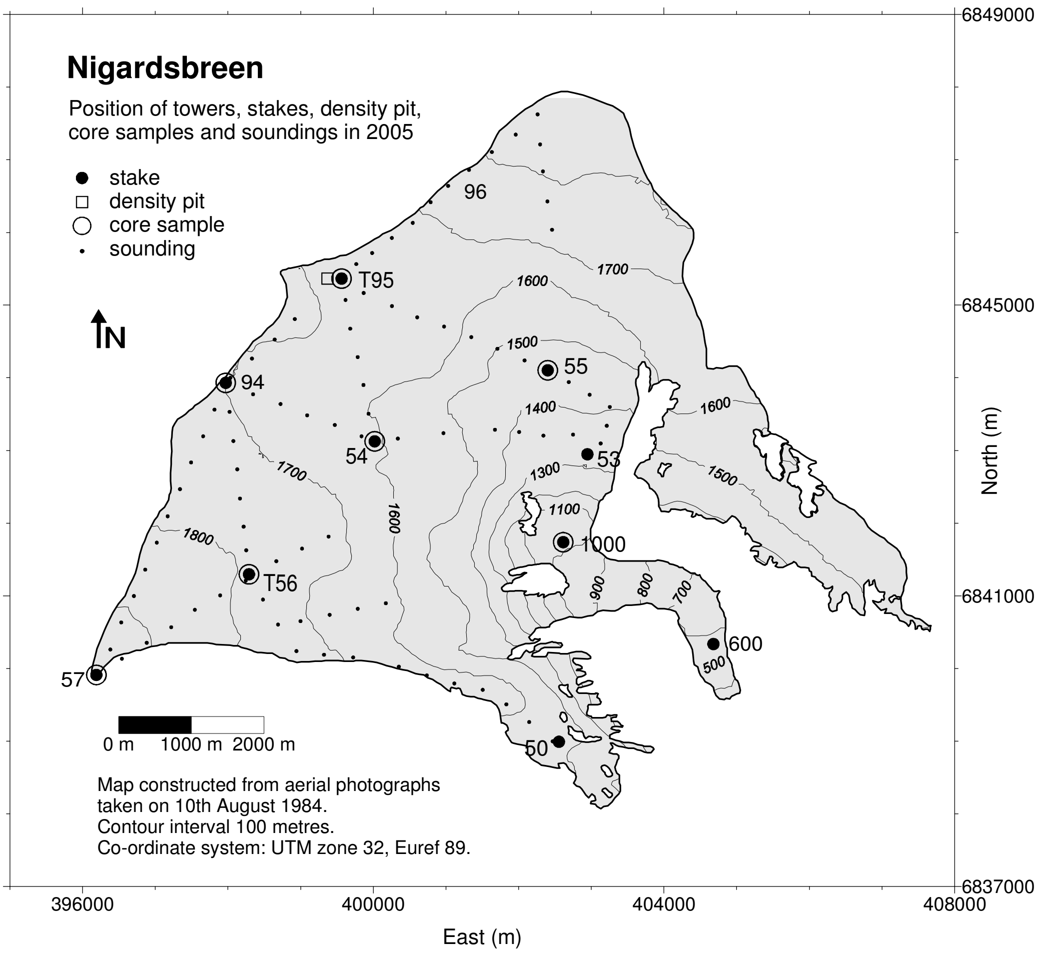


Figure 4-2
Location of towers and stakes, snow pit, core samples and soundings on Nigardsbreen in 2005.

Ablation measurements

Ablation measurements were carried out on 16th and 17th October. Measurements were made at eleven stakes and two towers in ten different positions. Since snow measurements in May the stakes on the plateau had increased in length between 2.7 and 4.6 m. Hence, there was between 1.5 and 4.0 m of snow remaining from winter 2004/2005. At the time of measurement, up to 20 cm of fresh snow had fallen in the upper areas.

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 one representative location.

There was no melting after the final measurements in September 2004. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1685 m altitude (8.0 m depth). Using this model gave a snow density of 0.475 g/cm^3. This model was used for all snow depth measurements.

The winter balance calculation was performed by plotting measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 4-5), 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 1020 m and 590 m altitude.

These calculations give a winter balance of 2.8 ±0.2 m w.eqv., corresponding to a water volume of 134 ±10 mill. m^3. The result is 118 % of the average for 1962-2004.

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 4-4). 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 250 x 250 m grid were calculated and summarised. The calculation performed using this gridding method was 2.9 m w.eqv.

Figure 4-3
The tower T95 photographed on 16th October. Snow density was measured at this position in May. The mountain peak in the background is Kjenndalskruna (1830 m a.s.l.). Photo: Miriam Jackson.

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 ice was taken as 0.90 g/cm^3.

The summer balance was calculated at stakes and towers in eight different elevations. At stake 600 (590 m a.s.l.) the measurements were supplemented with estimated values based on correlation with stake 1000 (1020 m a.s.l.). The summer balance increased (in absolute value) from −0.7 m w.eqv. at the glacier summit (1960 m a.s.l.) to −7.9 m down on the tongue (590 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −1.7 ±0.3 m w.eqv., which is −81 ±15 mill. m^3 of water. The result is 86 % of the average for 1962-2004.

Net balance

The net balance for 2005 was calculated at stakes and towers in ten different positions. The result was a surplus +1.1 m ±0.3 m w.eqv., which means that Nigardsbreen has increased in volume by 52 ±15 mill.m^3 water. The mean value for the period 1962-2004 is +0.40 m w.eqv. (Fig. 4-6), while the average for 1996-2004 is +0.02 m w.eqv.

Based on Figure 4-5, the Equilibrium Line Altitude (ELA) was 1395 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 87 %.

The mass balance in 2005 for Nigardsbreen is shown in Table 4-1 and the corresponding curves are shown in Figure 4-5. The historical mass balance results are presented in Figure 4-6.

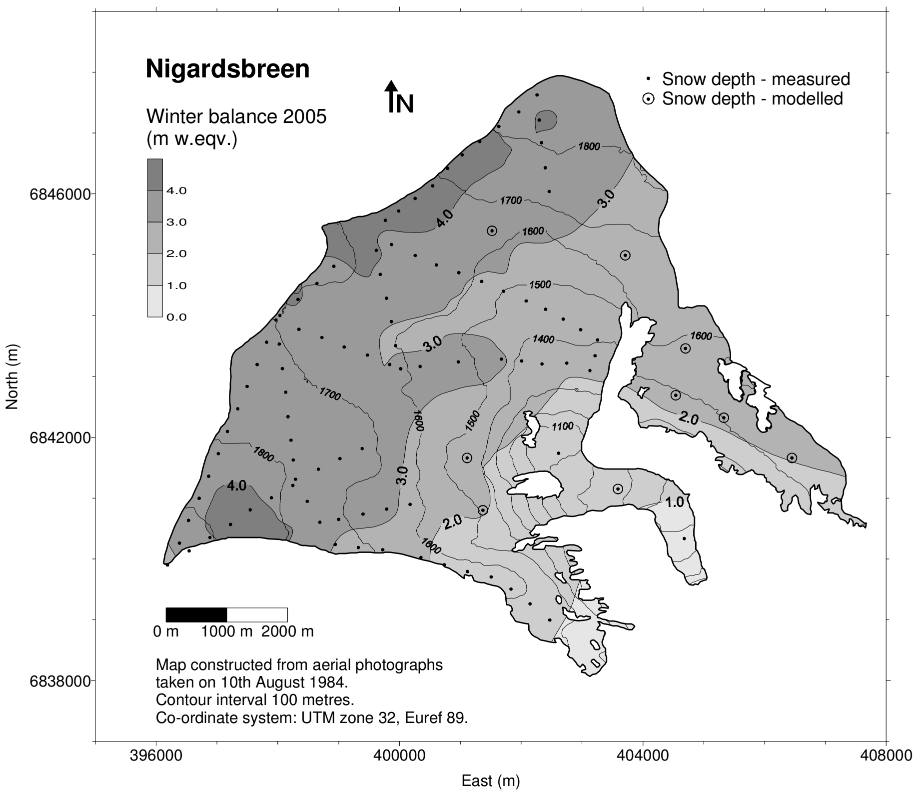


Figure 4-4
Winter balance at Nigardsbreen in 2005 interpolated from 95 measurements (•) of snow depth. In areas with few or no measurements nine extrapolated points (◉) are added.

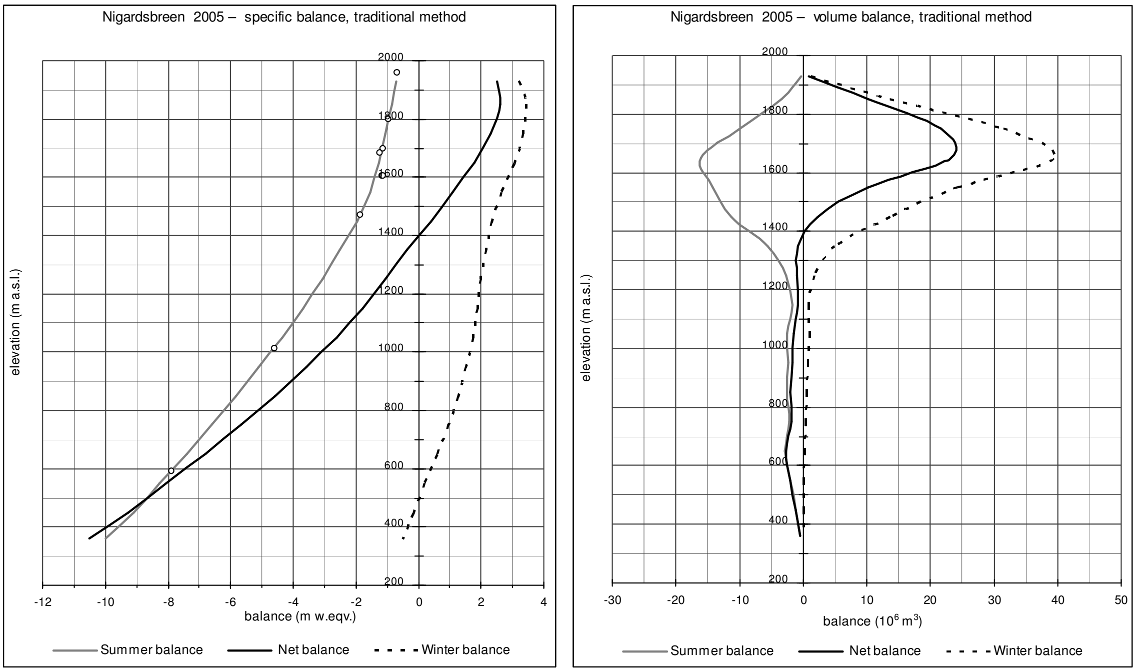


Figure 4-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2005. Specific summer balance at nine stakes is shown as dots (o). The net balance curve intersects the y-axis and defines the ELA as 1395 m a.s.l. Thus, the AAR was 87 %.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2005. Mean values for the period 1962-2004 are 2.37 (b_s), –1.97 m (b_s) and +0.40 m (b_n) water equivalent.

Mass balance Nigardsbreen 2004/05 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 12th May 2005		Measured 16th Oct 2005		Summer surface 2004 - 2005	
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	3.20	1.2	-0.70	-0.3	2.50	1.0
1800 - 1900	3.92	3.45	13.5	-0.85	-3.3	2.60	10.2
1700 - 1800	9.39	3.35	31.5	-1.05	-9.9	2.30	21.6
1600 - 1700	12.88	3.05	39.3	-1.25	-16.1	1.80	23.2
1500 - 1600	9.18	2.65	24.3	-1.55	-14.2	1.10	10.1
1400 - 1500	5.82	2.35	13.7	-1.95	-11.3	0.40	2.3
1300 - 1400	2.28	2.15	4.9	-2.50	-5.7	-0.35	-0.8
1200 - 1300	0.90	2.00	1.8	-3.05	-2.7	-1.05	-0.9
1100 - 1200	0.45	1.90	0.9	-3.70	-1.7	-1.80	-0.8
1000 - 1100	0.58	1.75	1.0	-4.35	-2.5	-2.60	-1.5
900 - 1000	0.47	1.50	0.7	-5.10	-2.4	-3.60	-1.7
800 - 900	0.44	1.25	0.6	-5.85	-2.6	-4.60	-2.0
700 - 800	0.33	0.95	0.3	-6.60	-2.2	-5.65	-1.9
600 - 700	0.39	0.60	0.2	-7.40	-2.9	-6.80	-2.7
500 - 600	0.24	0.20	0.0	-8.25	-2.0	-8.05	-1.9
400 - 500	0.12	-0.15	0.0	-9.10	-1.1	-9.25	-1.1
320 - 400	0.05	-0.50	0.0	-10.00	-0.5	-10.50	-0.5
320 - 1960	**47.82**	**2.80**	**133.9**	**-1.70**	**-81.4**	**1.10**	**52.5**

The mass balance year 2004/2005 is the first year with positive net balance at Nigardsbreen since the balance year 1999/2000. Over the last ten years (1996-2005) the cumulative net balance is slightly positive with +1.3 m w.eqv. In the last 10 year period only three years show a significant positive net balance, 1998, 2000 and 2005. However, during the entire period of investigations (1962-2005) the cumulative net balance is 18.4 m w.eqv.

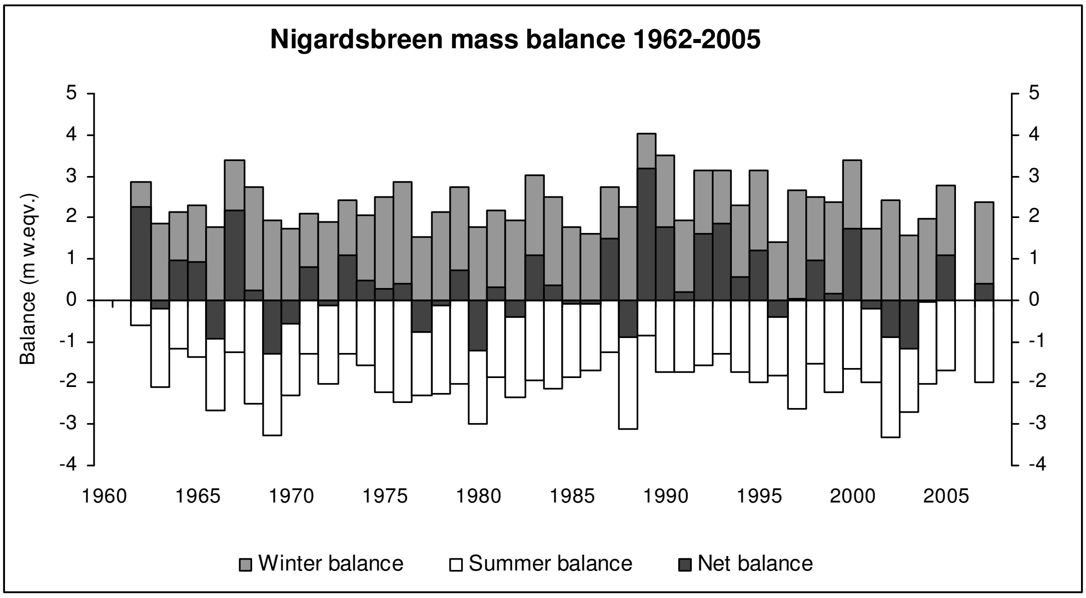


Figure 4-6
Annual mass balance at Nigardsbreen during the period 1962-2005.

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:

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

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

For 2005 the net balance at Tunsbergdalsbreen was estimated as +0.80 ±0.45 m w.eqv., corresponding to a surplus of about 40 ±20 mill. m^3 of water. Since 1962 the estimated accumulated net balance is about +5.5 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 2005 was about 1260 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 2005 by photography on 16th October (Fig. 4-7). At the time of observation the lake was empty.

Figure 4-7
Brimkjelen photographed on 16th October. Photo: Miriam Jackson.

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 1757 m a.s.l. The glacier terminates in Austdalsvatnet which has been a part of the hydro power reservoir Styggevatnet since 1988. Glaciological investigations started at Austdalsbreen in 1986 in connection with the construction of the hydro power reservoir.

The glaciological investigations in 2005 included mass balance, front position change and glacier velocity. Mass balance has been measured at Austdalsbreen since 1988.

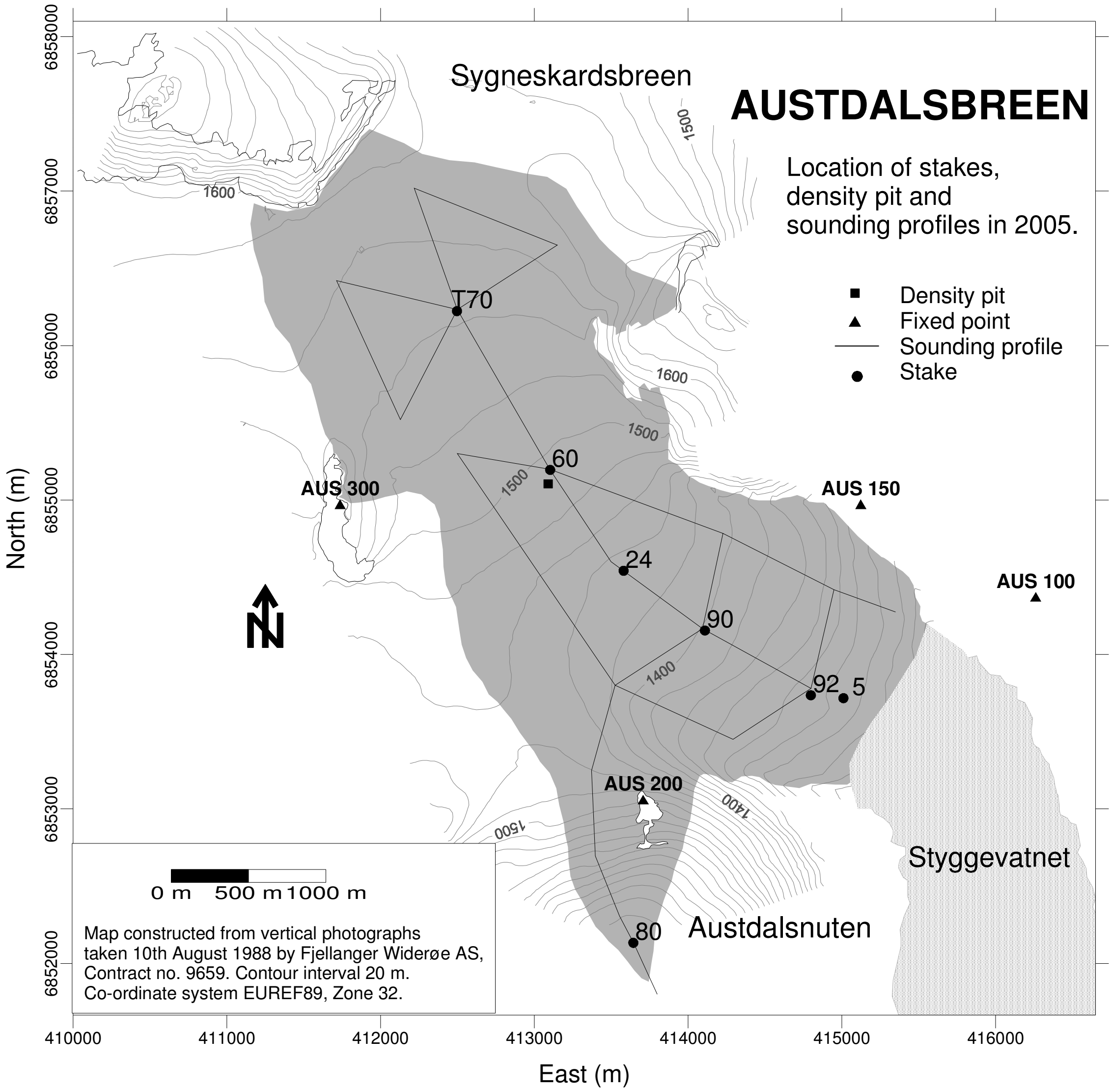


Figure 5-1
Location of stakes, density pit and sounding profiles at Austdalsbreen in 2005.

5.1 Mass balance 2005

Fieldwork

The winter balance was measured on 15th June. The calculation of winter balance was based on the following data (Fig. 5-1):

- Snow depth at stake T70, which was 6.20 metres.
- Snow depth by coring at stakes 5, 92 and 60, which showed snow depths of 2.0, 3.4, and 5.65 m, respectively.
- 87 snow depth measurements along 19 km of profiles. At Austdalsnuten above 1700 m a.s.l. the snow depth was 4 to 5 m. Between 1500 and 1600 m a.s.l. the snow depth was about 6 m. Between 1400 and 1500 m a.s.l. the soundings showed snow depths of 4 to 6 m. Between 1300 and 1400 m a.s.l. the snow was 3 to 4 m deep. The summer surface (SS) from 2004 was easy to detect in all areas.
- Snow density down to the previous summer surface at 5.65 m depth at stake 60-05 (1495 m a.s.l.). Mean snow density was 0.55 g/cm^3.

Summer and net balance measurements were carried out on 17th October. The transient snow line altitude could not be detected due to new snow, but stake measurements indicate that the temporary snow line (TSL) was between 1390 (stake 90) and 1425 (stake 24) m a.s.l. At Austdalsnuten (stake 80), 4.0 m of winter snow had melted, and 0.9 m of snow remained. At stakes T70, 60 and 24, between 3.8 to 4.0 m of snow had melted. At these locations, between 2.2 and 1.3 m of snow remained. At stake 90, 3.9 m of snow and 0.6 m of ice melted, while at stake 92, 3.5 m of snow and 1 m of ice had melted. At stake 5 close to the terminus, 2 m of snow and 3.1 m of ice had melted.

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 30th September 2004.

The late date for the winter balance measurements implies that some melting and run-off can have taken place before the measurements were performed. The minimum lake level of Styggevatnet was recorded on 27th May. After this date there was inflow to the reservoir from liquid precipitation or melting in the drainage basin. At a snow pillow on Sognefjellet (2.382 Sognefjell, 1435 m a.s.l.), 42 km south-east of Austdalsbreen, the maximum snow water equivalent (SWE) was recorded between 20th May and 3rd June. Between 3rd June and 17th June the SWE value of the snow pack was reduced from 638 mm to 416 mm. For Austdalsbreen, this implies that the date of maximum SWE probably was around 1st June. Even though there may have been some refreezing in the snow pack, some run-off probably took place before 15th June, especially on the lower part of the glacier. This volume has not been calculated.

The winter balance was calculated from snow depth and snow density measurements on 15th June. A function correlating snow depth with water equivalent was calculated based on snow density measurements at stake 60 (1495 m a.s.l.).

Snow depth water equivalent values of all snow depth measurements were plotted against altitude. Mean values of altitude and SWE in 50 m altitude intervals were calculated and plotted. An altitudinal winter balance curve was drawn from a visual evaluation of the mean values, and from this a mean value for each 50 m altitude interval was determined. The winter balance was 34 ±2 million m^3 water or 2.8 ±0.2 m w.eqv., which is 130 % of the 1988-2004 average (2.20 m w.eqv.). This is the third largest winter balance measured at Austdalsbreen, only 1990 (3.65 m w.eqv.) and 1989 (3.18 m w.eqv.) being larger.

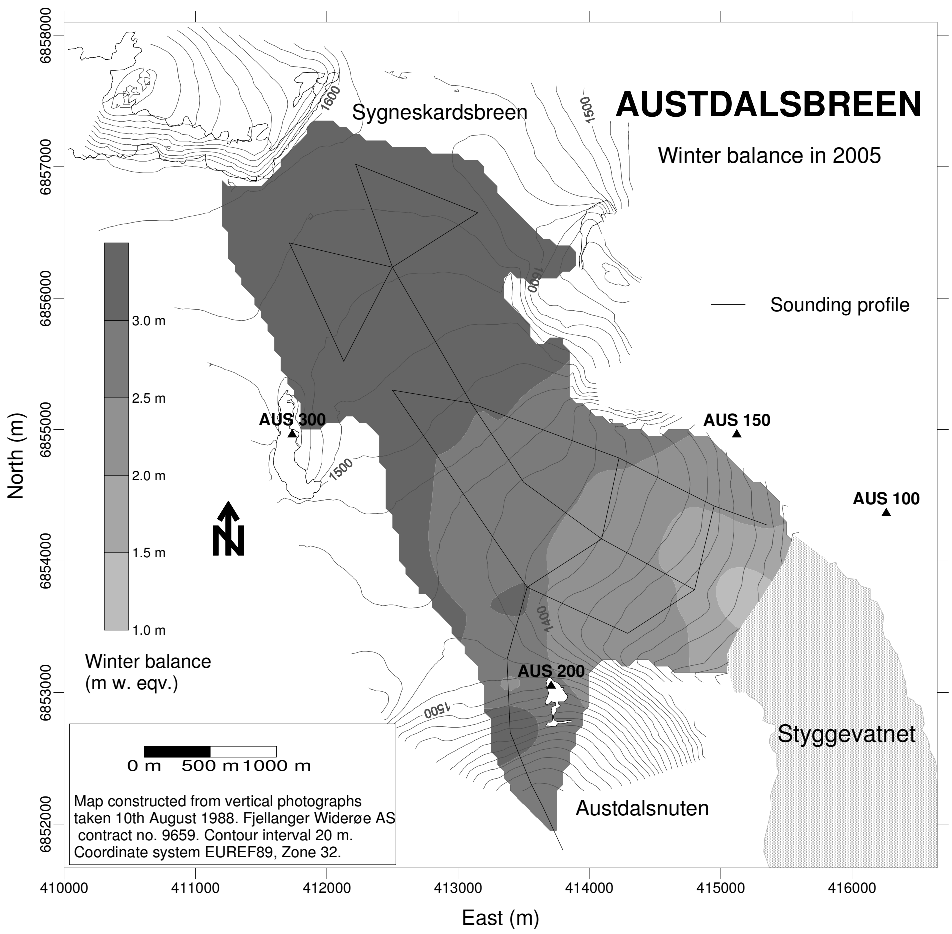


Figure 5-2
Winter balance at Austdalsbreen in 2005 from 91 water equivalent values calculated from snow depth measurements.

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, showed a winter balance of 2.96 m w.eqv.

Summer balance

The summer balance was calculated for ten stakes in seven positions between 1260 and 1730 m a.s.l. At T70 the summer balance could be calculated directly. At stakes put out in

June the summer balance was calculated from snow depth coring and stake readings. Where stakes didn’t survive the winter, the summer balance was calculated from snow depth sounding in their estimated positions, and stake readings. 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/cm³, u_{ice} is annual glacier velocity (60 ±10 m/a, chapter 5.3), u_f is front position change averaged across the terminus (−22 ±5 m/a, chapter 5.2), W is terminus width (1150 ±25 m), and H is mean ice thickness at the terminus (52 ±5 m) based on surface altitude surveyed August and September 2005, 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 4 ±1 million m³ water or 0.4 ±0.1 m w.eqv. averaged across the glacier area (11.8 km²).

The summer balance, including calving, was calculated as −2.7 ±0.3 m w.eqv., which corresponds to −31 ±3 million m³ of water. The calving volume was 14 % of the summer balance. The result is 109 % of the 1988-2004 average (−2.43 m w.eqv.).

Net balance

The net balance at Austdalsbreen was calculated as 0.2 ±0.3 m w.eqv., corresponding to 2 ±3 mill. m³ water. The 1988-2004 average is −0.23 m w.eqv. The equilibrium line altitude (ELA) is defined at 1385 m a.s.l. from the net balance curve. The Accumulation Area Ratio (AAR) was 78 % in 2005. The altitudinal distribution of winter, summer and net balances are shown in Figure 5-3 and Table 5-1. Results from 1988-2005 are shown in Figure 5-4.

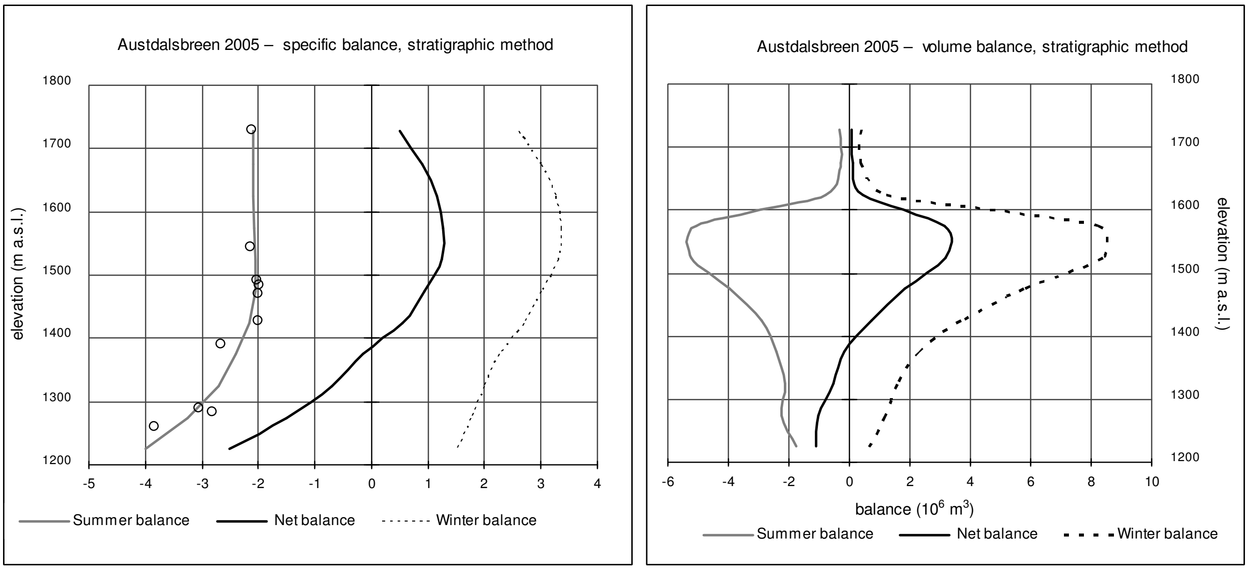


Figure 5-3
Altitudinal distribution of winter-, summer- and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2005. Specific summer balance at ten stakes in seven locations is shown (o).

Table 5-1
Altitudinal distribution of winter-, summer- and net balances at Austdalsbreen in 2005.

Mass balance Austdalsbreen 2004/05 – stratigraphic method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 15th Jun 2005: Specific (m w.eqv.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 17th Oct 2005: Specific (m w.eqv.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surface 2004 - 2005: Specific (m w.eqv.)	Net balance: Volume (10^6 m^3)
1700 - 1757	0.16	2.60	0.41	-2.10	-0.33	0.50	0.08
1650 - 1700	0.13	3.00	0.38	-2.10	-0.27	0.90	0.12
1600 - 1650	0.38	3.25	1.22	-2.10	-0.79	1.15	0.43
1550 - 1600	2.45	3.35	8.20	-2.07	-5.07	1.28	3.13
1500 - 1550	2.54	3.30	8.38	-2.05	-5.20	1.25	3.17
1450 - 1500	1.92	3.00	5.77	-2.05	-3.94	0.95	1.83
1400 - 1450	1.36	2.70	3.66	-2.15	-2.91	0.55	0.75
1350 - 1400	1.01	2.25	2.27	-2.40	-2.42	-0.15	-0.15
1300 - 1350	0.79	2.00	1.57	-2.70	-2.12	-0.70	-0.55
1250 - 1300	0.69	1.75	1.20	-3.25	-2.23	-1.50	-1.03
1200 - 1250	0.44	1.50	0.65	-4.00	-1.74	-2.50	-1.09
Calving					-4.4		-4.4
1200 - 1757	**11.84**	**2.85**	**33.7**	**-2.66**	**-31.4**	**0.19**	**2.3**

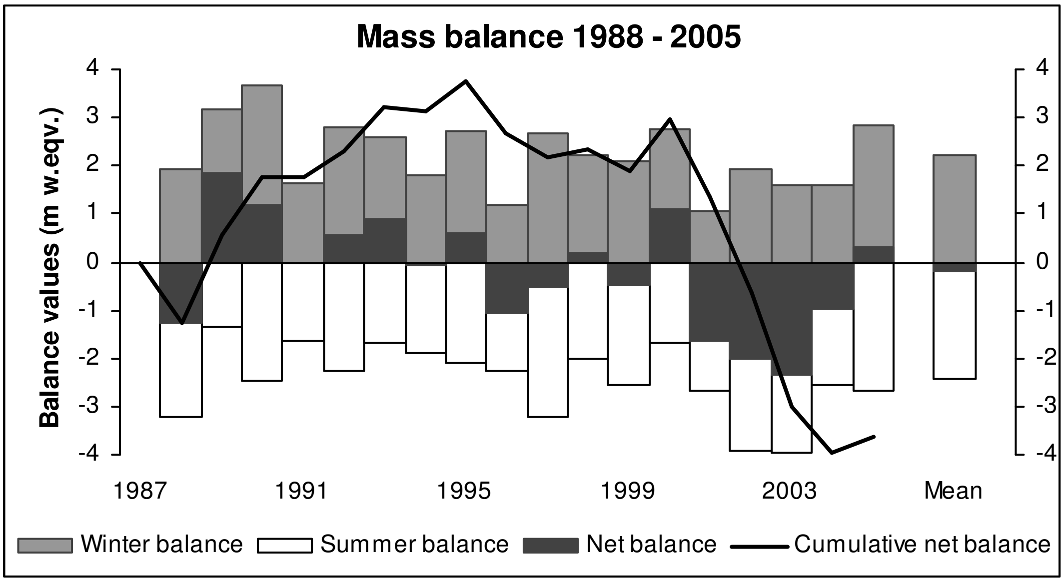


Figure 5-4
Winter, summer and net balances at Austdalsbreen during the period 1988-2005. Mean winter, summer and net balance is 2.24, –2.45 and –0.21 m w.eqv., respectively. Cumulative net balance in this period was –3.8 m w.eqv.

5.2 Front position change

Seven points along the calving terminus were surveyed on 17th October 2005. In addition, twenty-eight points along the glacier border on both sides of the calving front were positioned, using a handheld GPS. Between 30th September 2004 and 17th October 2005 the mean front position change was −22 ±5 m (Fig. 5-5). Since 1988 the glacier terminus has retreated 420 metres, while the glacier area has decreased by approximately 0.44 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 18 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. The predicted mean annual net balance used in the model was −0.47 m w.eqv., while the actual mass balance has been −0.23 m w.eqv.

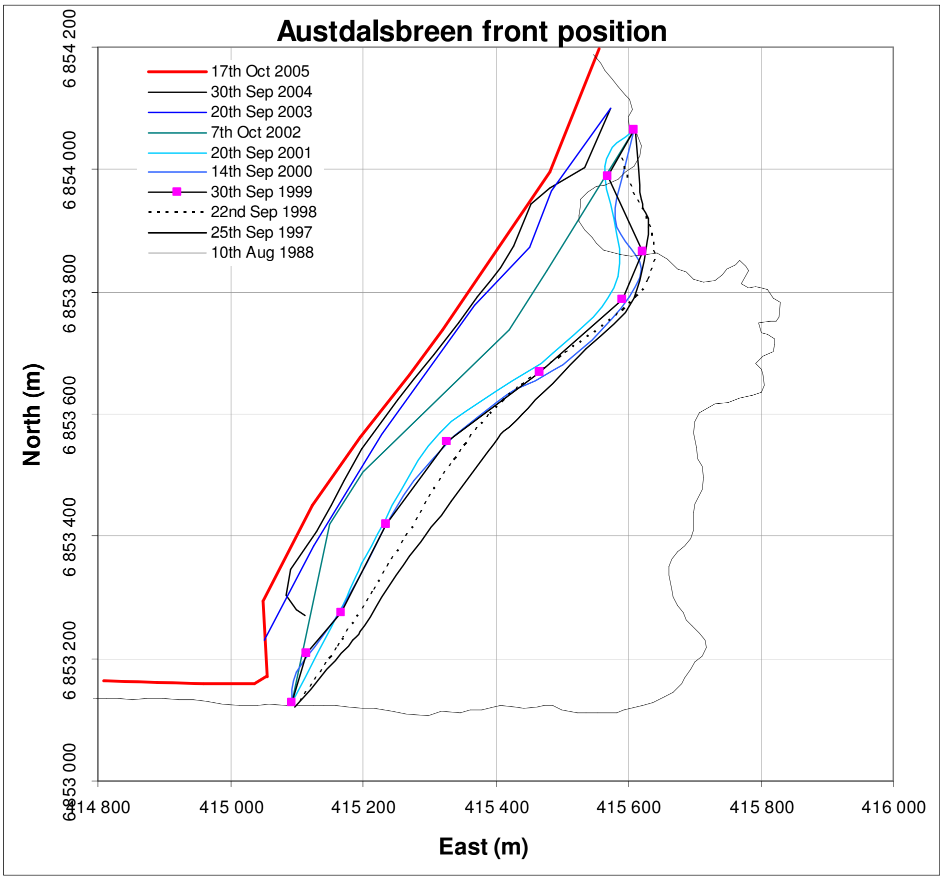


Figure 5-5
Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, and autumn position in 1997-2005. Mean front position change between 30th September 2004 and 17th October 2005 was −22 m.

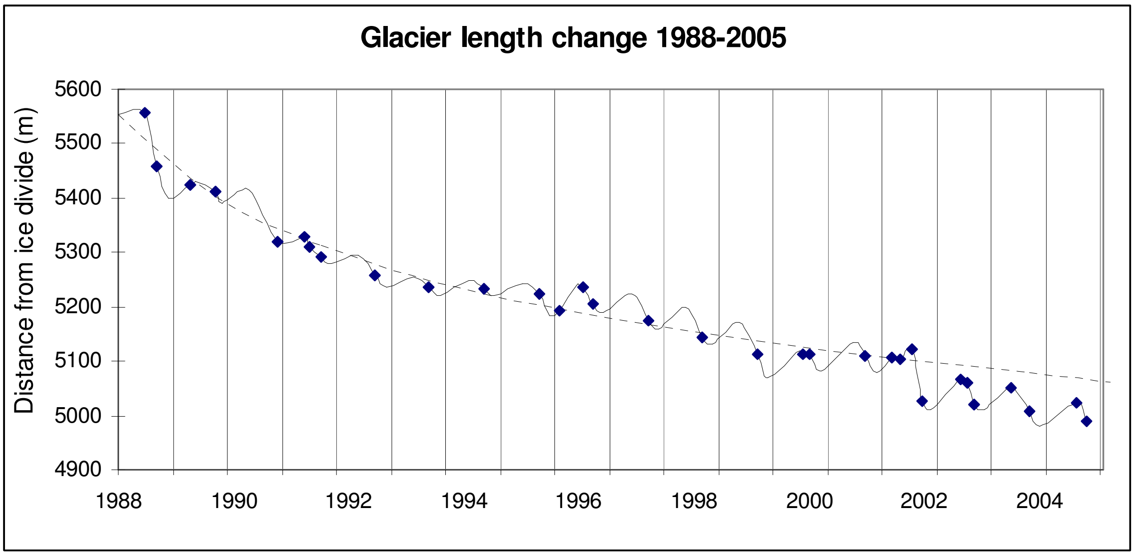


Figure 5-6
Surveyed glacier front position along a central flow line, shown as change in glacier length along this flow line (dots). The solid line indicates annual variation in front position. The glacier terminus advances from December to July when the lake is frozen, and retreats during July-December 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 dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 30th September 2004, and 16th June, 10th August and 17th October 2005.

Annual velocities were calculated for four stake locations (stake 92 – 49 m/a, stake 90 – 32 m/a, stake 24 – 25 m/a and stake T70 – 6 m/a). It was not possible to maintain stakes close to the glacier terminus through the winter, but stake 5 located 250 m up-glacier from the terminus was surveyed three times during the summer season, and the summer velocity there (0.16 m/d) corresponds to an annual velocity of 59 m/a.

The glacier velocity averaged across the front width and thickness had to be estimated in order to calculate the calving volume (chap. 5.1). The surface centre line velocity at the terminus was calculated from summer measurements at stake 5 (59 m/a), average distance from the stake to terminus (230 m), and an average strain rate from previous years (0.1 1/a) to 82 m/a. 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.

The surface elevation at stakes surveyed on 10th August 2005 was compared with the map from 1988 to calculate elevation changes (Fig. 5-7). At stake position 92 the surface elevation decreased 19 m and the thickness decreased approximately 15 %. Half of this thinning has taken place since 2002. At stake 90 the surface elevation decreased 8 m. The corresponding thickness change is about 4 %. This thickness-reduction took place after 2000. At stakes 24 and 60 the surface elevation decreased 3-4 m compared with 1988, but the glacier was thickening in this area in the 1990s, implying more thinning during the last five years than shown by the comparison. At stake T70 the surface elevation is slightly lower than in 1988. The maximum thickness was reached in 2000. After 2000, the thickness is reduced by 7.5 m at this location.

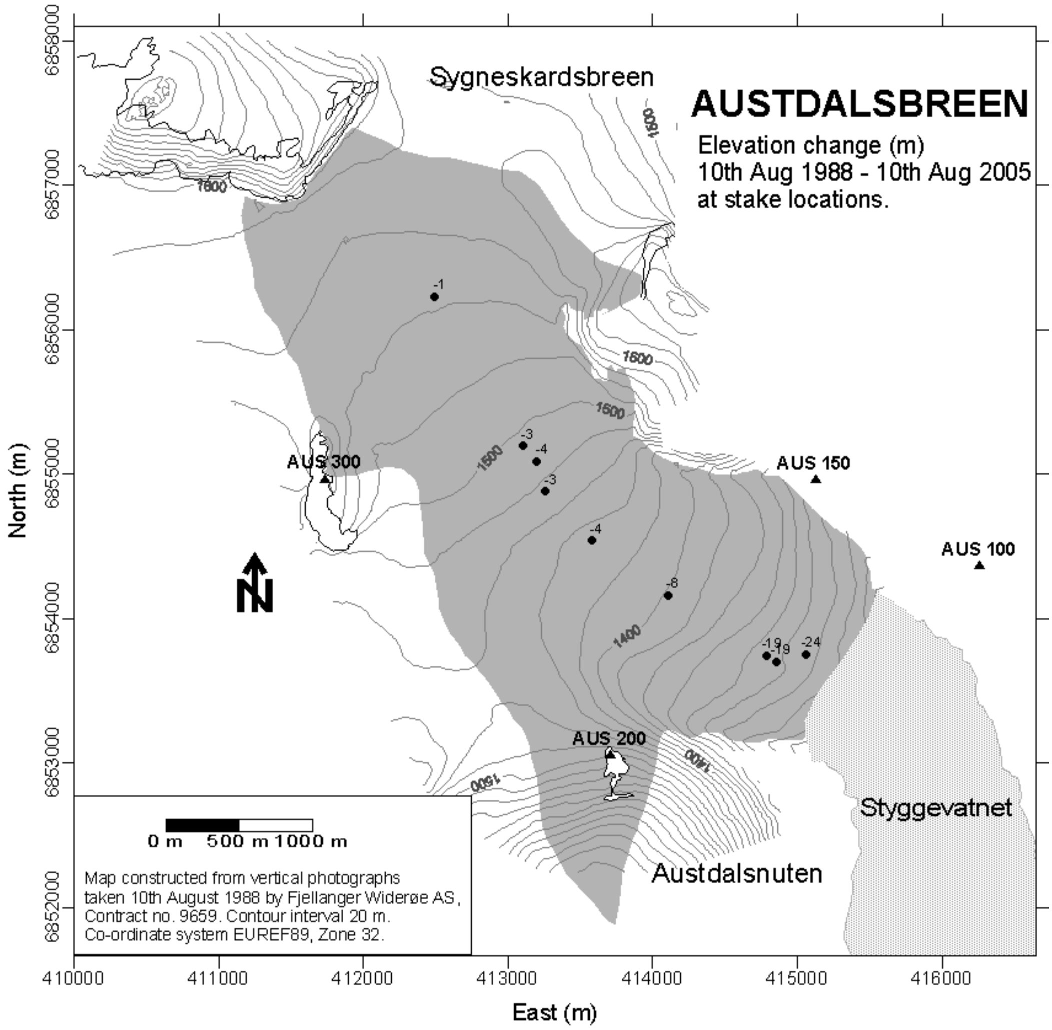


Figure 5-7
Elevation change between 1988 and 2005 computed from elevation at stake locations surveyed on 10th August 2005, and a map based on aerial photographs taken on 10th August 1988.

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. In the past Simadalen has been floodedd by jøkulhlaups (outburst floods) from the glacier-dammed lake Demmevatnet, the most recent occurring in 1937 and 1938.

The Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalsskåka since 1985. The investigated basin covers the altitudinal range between 1020 and 1865 m a.s.l. At Rembesdalsskåka, glacier length observations were initiated in 1917 by Johan Rekstad at Bergen Museum. Observations were conducted in several periods during the 20th century. Statkraft Energy AS re-initiated the observations at Rembesdalsskåka in 1995. At Midtdalsbreen, glacier length observations were started by Prof. Atle Nesje at the University of Bergen in 1982. Glacier length observations are described in chapter 13. The University of Utrecht, Netherlands, operates automatic weather stations (AWS) close to the terminus of Midtdalsbreen and at the summit of the ice cap.

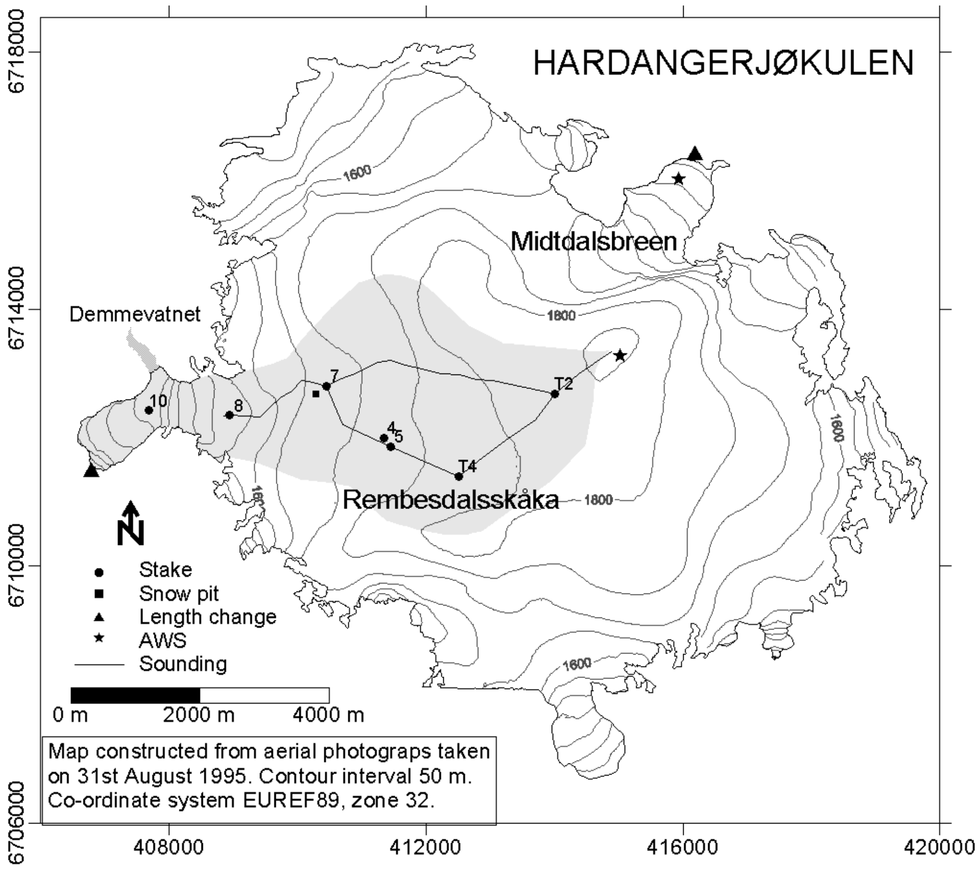


Figure 6-1
Location of sounding profiles, stakes and snow pit at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and automatic weather stations (AWS) at Midtdalsbreen and at the summit of Hardangerjøkulen.

6.1 Mass balance at Rembesdalsskåka in 2005

Fieldwork

The winter balance measurements were carried out on 11th May. The calculation of winter balance is based on the following data (see fig. 6-1 for locations):

- Snow depth measurements at stakes 10 (1270 m a.s.l.), 7 (1660 m a.s.l.), T4 (1770 m a.s.l.) and T2 (1830 m a.s.l.) showing snow depths of 3.35, 6.05, 6.40 and 5.90 m, respectively.
- Snow depth coring at stake 8 (1510 m a.s.l.) showing 4.45 m of snow.
- Snow density down to the summer surface (SS) at 6.05 m depth at stake 7 (1660 m a.s.l.). Below the SS there was firn.
- 27 snow depth soundings along 11 km of profiles on the glacier plateau above 1500 m a.s.l. Between 1500 and 1650 m a.s.l. the snow depth was 4 to 5 m. Above 1650 m a.s.l. the snow depth was 5.5 to 6.5 m. The SS was easy to detect.

Summer and net balance was measured on 7th October. There was fresh snow on the glacier above 1600 m a.s.l. Measurements at the stakes indicated up to 0.25 m of new snow. The temporary snow line could not be detected, but it was probably about 1600 m a.s.l. 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 (1660 m a.s.l.) the remaining snow depth was 2.35, 2.70, 2.25, 2.45 and 1.65 m, respectively. At stakes 8 (1510 m a.s.l.) and 10 (1270 m a.s.l.), 1.55 and 3.80 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 11th May 2005.

A snow depth-water equivalent profile for 11th May 2005 was calculated based on snow density measurements in a pit at stake 7 (1660 m a.s.l.). The mean snow density of the snow pack (6.05 m) was 0.53 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 2.8 ±0.2 m w.eqv. or 48 ±3 mill. m^3 water. This is 133 % of the 1963-2004 average of 2.09 m w.eqv., and 146 % of the 2000-2004 average of 1.91 m w.eqv.

Summer balance

The summer balance was calculated for eight stakes at six locations between 1270 and 1830 m a.s.l. 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 −2.1 ±0.2 m w.eqv., corresponding to −35 ±3 mill. m^3 of water. This is 105 % of the 1963-2004 average, which is −1.98 m w.eqv., but 94 % of the 2000-2004 average of −2.20 m w.eqv.

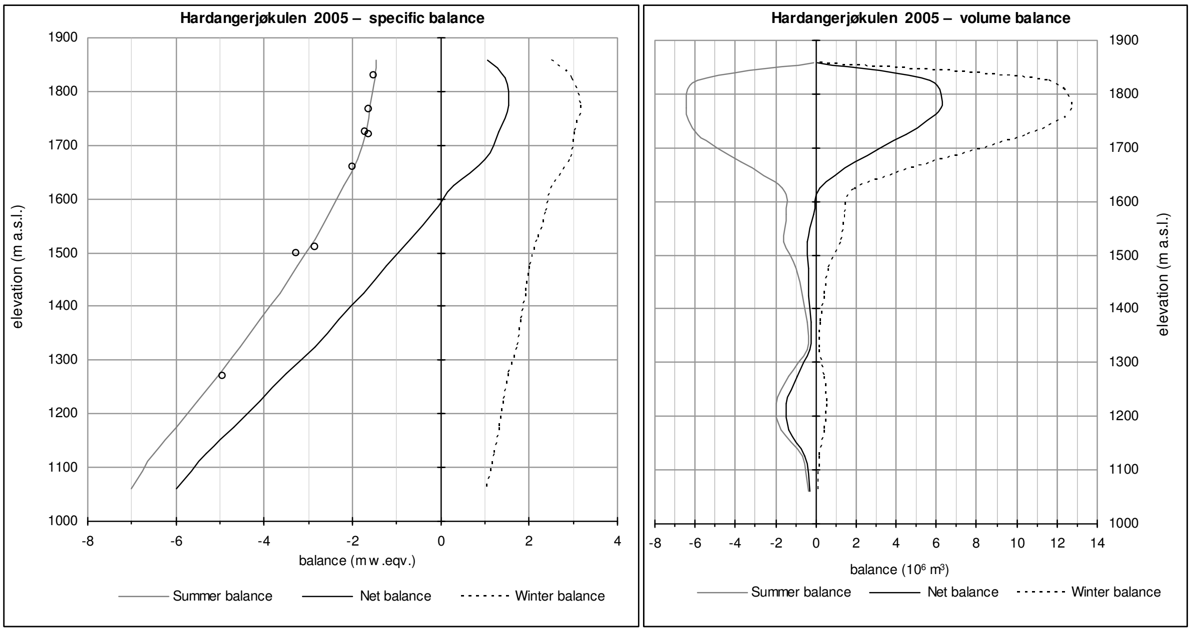


Figure 6-2
Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2005. Specific summer balance at eight stakes is shown (o).

Net balance

The net balance at Rembesdalsskåka was calculated as 0.7 ±0.3 m w.eqv., or 12 ±5 mill. m^3 water. The 1963-2004 average is +0.12 m w.eqv., and the 2000-2004 average is –0.28 m. The altitudinal distribution of winter, summer and net balances is shown in Figure 6-2 and Table 6-1. The ELA is determined from the net balance curve as 1590 m a.s.l. The accumulation area ratio (AAR) was 84 %. Results from 1963-2005 are shown in Figure 6-3.

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka, Hardangerjøkulen, in 2005.

Mass balance Hardangerjøkulen 2004/05 – traditional method

		Winter balance Measured 11th May 2005		Summer balance Measured 7th Oct 2005		Net balance Summer surface 2004 - 2005	
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	2.50	0.2	-1.45	-0.1	1.05	0.1
1800 - 1850	3.93	2.95	11.6	-1.50	-5.9	1.45	5.7
1750 - 1800	4.03	3.15	12.7	-1.60	-6.5	1.55	6.3
1700 - 1750	3.46	3.00	10.4	-1.70	-5.9	1.30	4.5
1650 - 1700	1.94	2.90	5.6	-1.90	-3.7	1.00	1.9
1600 - 1650	0.75	2.50	1.9	-2.20	-1.6	0.30	0.2
1550 - 1600	0.59	2.35	1.4	-2.50	-1.5	-0.15	-0.1
1500 - 1550	0.57	2.15	1.2	-2.85	-1.6	-0.70	-0.4
1450 - 1500	0.29	2.00	0.6	-3.25	-1.0	-1.25	-0.4
1400 - 1450	0.19	1.90	0.4	-3.65	-0.7	-1.75	-0.3
1350 - 1400	0.10	1.80	0.2	-4.10	-0.4	-2.30	-0.2
1300 - 1350	0.10	1.70	0.2	-4.55	-0.4	-2.85	-0.3
1250 - 1300	0.27	1.50	0.4	-5.00	-1.4	-3.50	-0.9
1200 - 1250	0.36	1.40	0.5	-5.50	-2.0	-4.10	-1.5
1150 - 1200	0.28	1.30	0.4	-6.00	-1.7	-4.70	-1.3
1100 - 1150	0.11	1.20	0.1	-6.50	-0.7	-5.30	-0.6
1020 - 1100	0.05	1.00	0.1	-7.00	-0.4	-6.00	-0.3
1020 - 1865	17.1	2.79	47.8	-2.07	-35.4	0.72	12.4

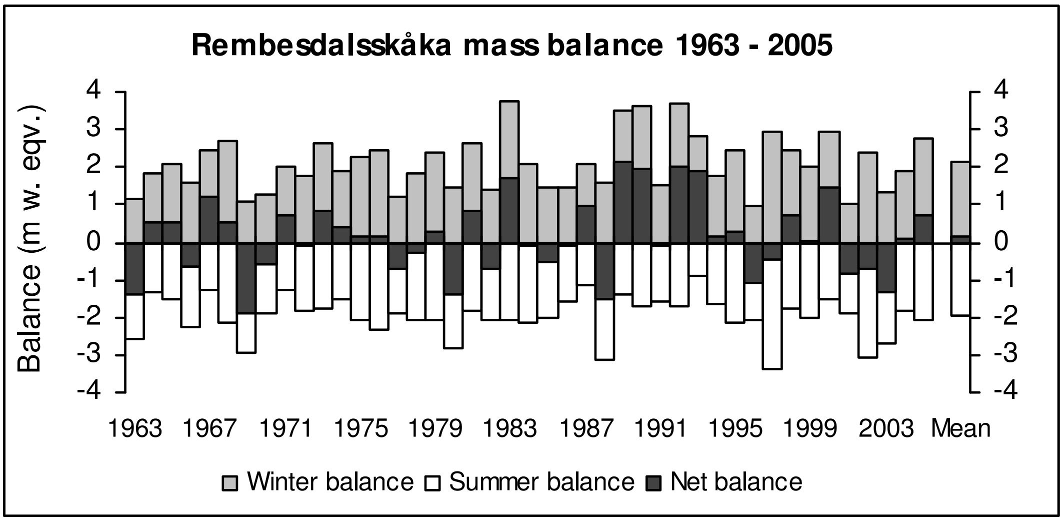


Figure 6-3
Winter-, summer- and net balances at Hardangerjøkulen during the period 1963-2005. Mean values for the period are b_w=2.11 m, b_s=–1.98 m and b_n=+0.13 m water equivalent.

6.2 Meteorological measurements on Midtdalsbreen

(Rianne H. Giesen, University of Utrecht)

An automatic weather station (AWS) has been operating on Midtdalsbreen, a northern outlet glacier of Hardangerjøkulen since October 2000 (Fig. 6-1). The station (Fig. 6-4) is owned and maintained by the Institute of Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: J.Oerlemans@phys.uu.nl). The station records air temperature, relative humidity, wind speed and direction (at 2 m and 6 m in the mast), distance to the surface, short wave and long wave radiation (at 6 m) and air pressure. Sampling is done every few minutes (depending on the sensor) and 30-minute averages are stored. The measurements are used to study the local microclimate at Hardangerjøkulen and to calibrate a mass balance model for the glacier. Here, we present some interesting aspects from the data collected up to July 2005.

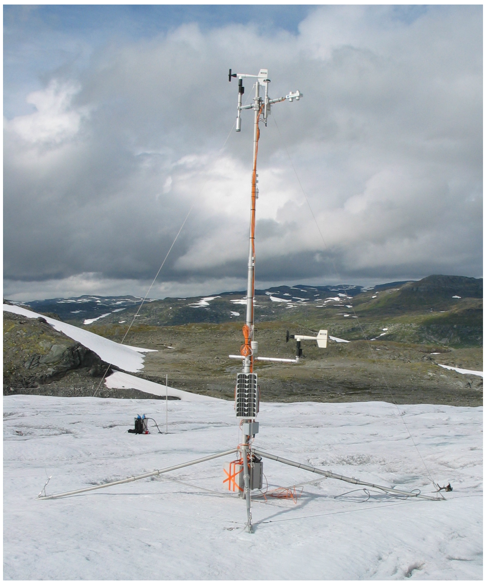


Figure 6-4
The AWS on Midtdalsbreen, 26th August 2005. Photo: C.H. Tijm-Reijmer.

Air temperature

Daily mean air temperature (Fig. 6-5) typically ranges between −15°C and 10°C, with an annual mean temperature of −1.25°C. July and August 2002 were exceptionally warm, which may have caused the large negative summer mass balance in 2002 (Fig. 6-3).

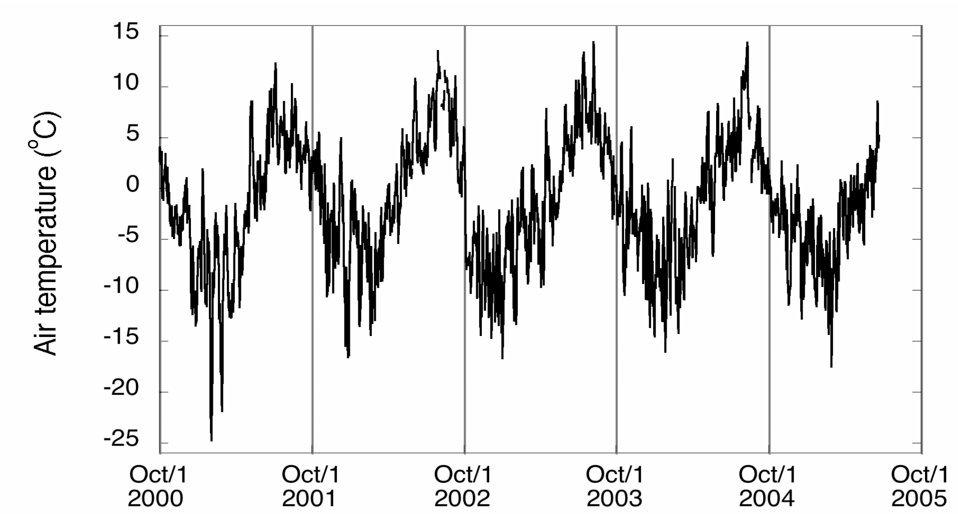


Figure 6-5
Daily mean air temperature (2 m) at Midtdalsbreen 2000-2005.

Solar radiation and albedo

Daily mean incoming (SWin) and reflected (SWout) solar radiation from October 2003 to July 2005 are shown in Figure 6-6. A very pronounced annual cycle, typical for the higher latitudes, is visible. Also plotted is the surface albedo, which is the ratio SWout/SWin. In winter, when snow covers the surface, the albedo is close to 1. During the summer, the albedo decreases to the ice albedo, around 0.27. A snowfall event on 21st August 2004 can be seen as a peak in the surface albedo.

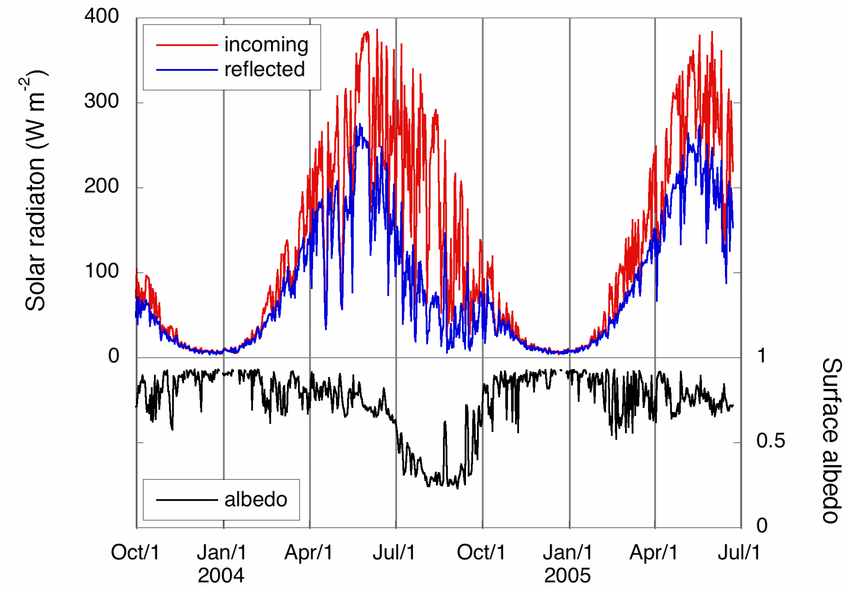


Figure 6-6
Daily mean incoming and reflected solar radiation and surface albedo from October 2003 to July 2005.

Wind speed and wind direction

Figure 6-7 shows a scatter plot of all 30-minute wind speed and wind direction measurements at 6 m height for the 2003/2004 season. The dominant wind directions are from west and south-east, which can be attributed to the orientation of the valley around Finse. The highest wind speeds occur in storms from the west. There is a third preferred wind direction from south-west, blowing down-glacier. This katabatic wind is created by the glacier's microclimate and is often found on glaciers ('glacier wind').

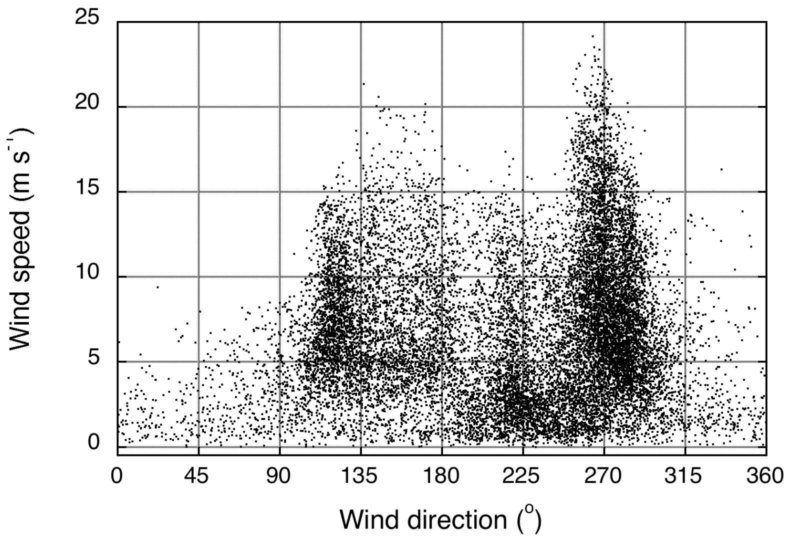


Figure 6-7
30-minute wind speed and wind direction for the 2003/2004 season.

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the central part of Jotunheimen in central southern Norway. The glacier has a total area of 5.4 km^2 and ranges in altitude from 1390 to 2090 m a.s.l. (Fig. 7-1). Mass balance measurements were initiated in 1949 and 2005 is the 57th year of continuous measurements. An automatic weather station (AWS) has been operating on the glacier since September 2001 and data from 2004/2005 are summarised in section 7.2. In 2005, measurements of ice velocity were carried out on Storbreen and the results are reported in chapter 7.3.

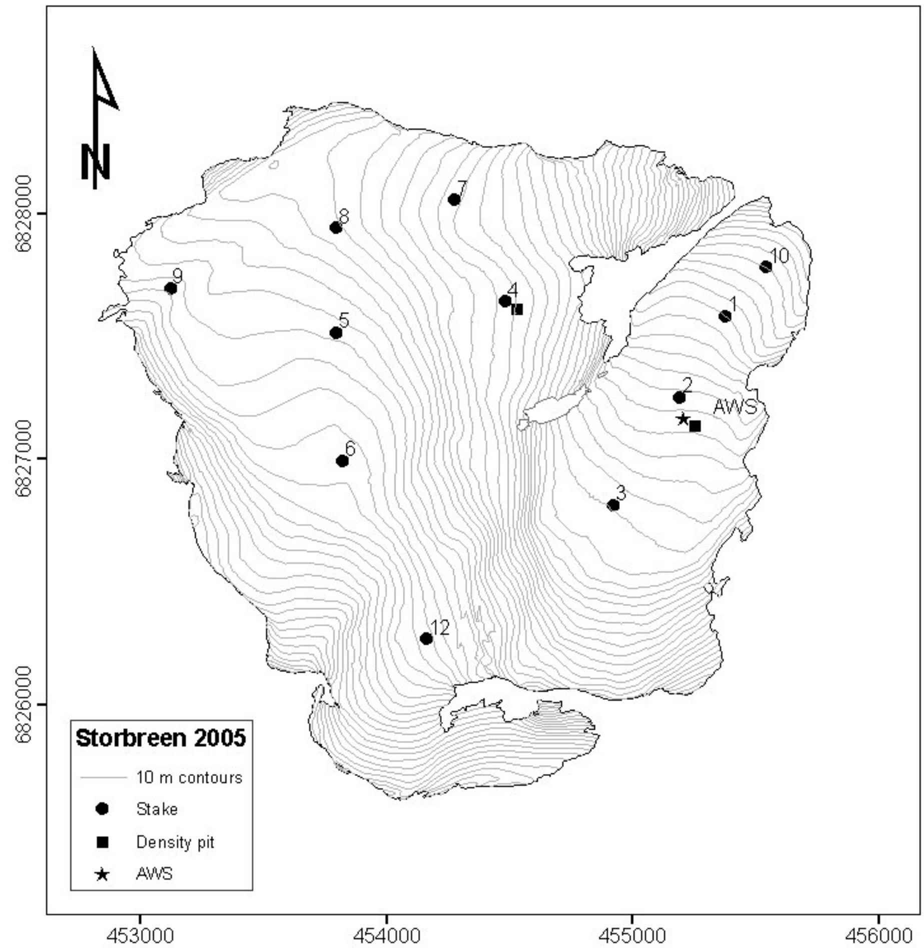


Figure 7-1 Location of stakes, density pits and the automatic weather station (AWS).

7.1 Mass balance 2005

Fieldwork

Accumulation measurements were performed on 12th -14th May and the calculation of winter balance is based on:

- Measurements of stakes in 12 different positions. Stake readings did not show any indication of melting after the final measurements in September 2004.
- Soundings of snow depth in 179 positions (18.5 km of profiles) between 1440 and 1930 m a.s.l., covering most of the altitudinal range of the glacier. Probing conditions

in the accumulation area were more difficult than in previous years and several ice layers were found. The snow depth varied between 1.6 and 7.4 m, the mean being 3.9 m.

- Snow density was measured down to SS at two positions, at the AWS (to 3.2 m depth at 1570 m a.s.l.) and stake 4 (to 3.4 m depth at 1725 m a.s.l.).

Ablation measurements were performed on 30th September on stakes in 11 locations from 1512 to 1866 m a.s.l. The locations of stakes, density pits and soundings are shown in Figure 7-1.

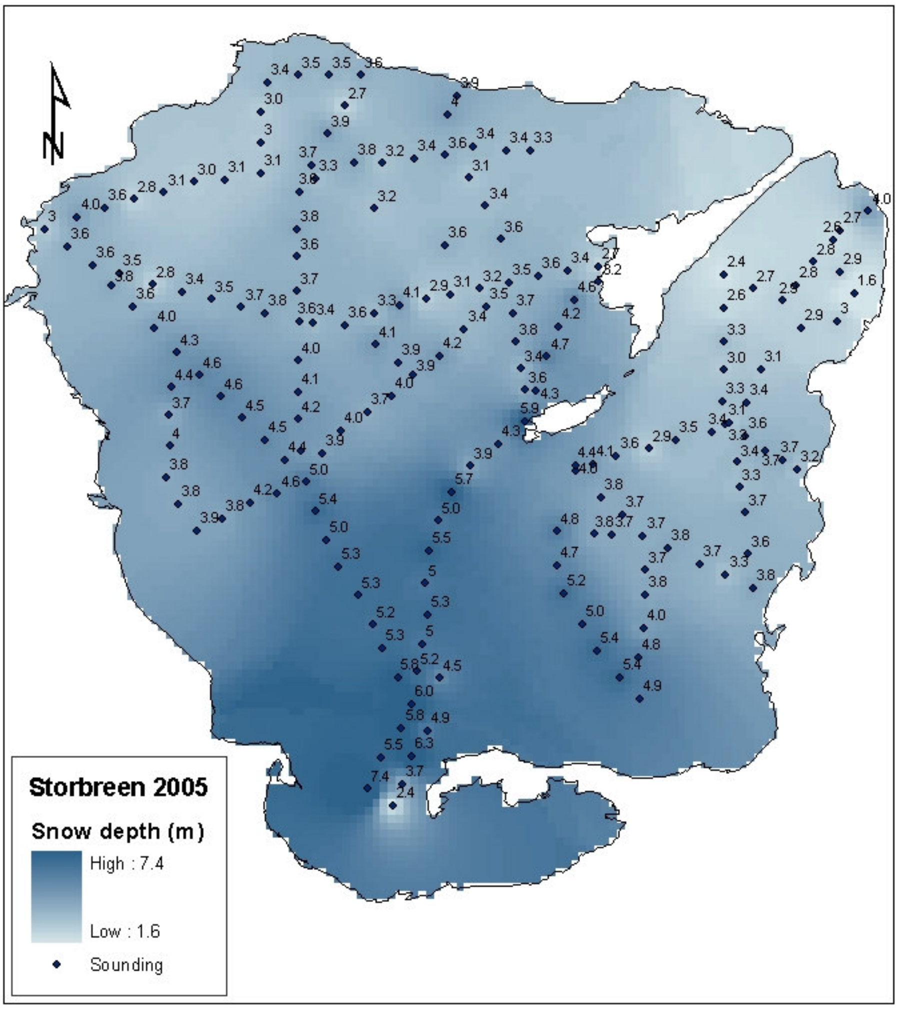


Figure 7-2
Map of Storbreen showing interpolated snow depth (using IDW interpolation) and the snow depth soundings on May 12th-14th.

Results

The mass balance results are shown in Table 7-1 and Figure 7-4.

Winter balance

Winter accumulation was calculated from soundings and the snow density measurements. The mean measured snow density was 0.45 g/cm^3 (0.44 g/cm^3 at the AWS and 0.46 g/cm^3

at stake 4). The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. Data from the sonic ranger at the AWS (see chap. 7.2) as well as measurements at the stakes showed no noticeable melting after the ablation measurements the previous year (mid-September 2004).

The specific winter balance was calculated to be 1.8 ±0.2 m w.eqv. This is above average, 120 % of the mean for 1971-2000 and 128 % of the mean for the observation period 1949-2004.

The winter balance was also calculated using Inverse Distance Weighting (IDW) based on the distribution of the snow depth measurements (Fig. 7-2). The calculation performed using this gridding method gave also 1.8 m w.eqv.

Summer balance

Summer balance was calculated directly from stakes at ten locations. There was between 0.15 and 2.2 m remaining snow at the five highest stake locations. The density of the remaining snow was assumed to be 0.6 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 −1.9 ±0.3 m w.eqv., which is 116 % of the mean period 1971-2000 and 112 % of the mean for the observation period 1949-2004.

Net balance

The net balance of Storbreen in 2005 was −0.1 ±0.3 m w.eqv., which is equivalent to a volume of −0.3 ±1.6 10^6 m^3 of water. The ELA was estimated to be 1795 m a.s.l. and the accumulation area ratio (AAR) 43 %. 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 57 years of measurements (Fig. 7-3).

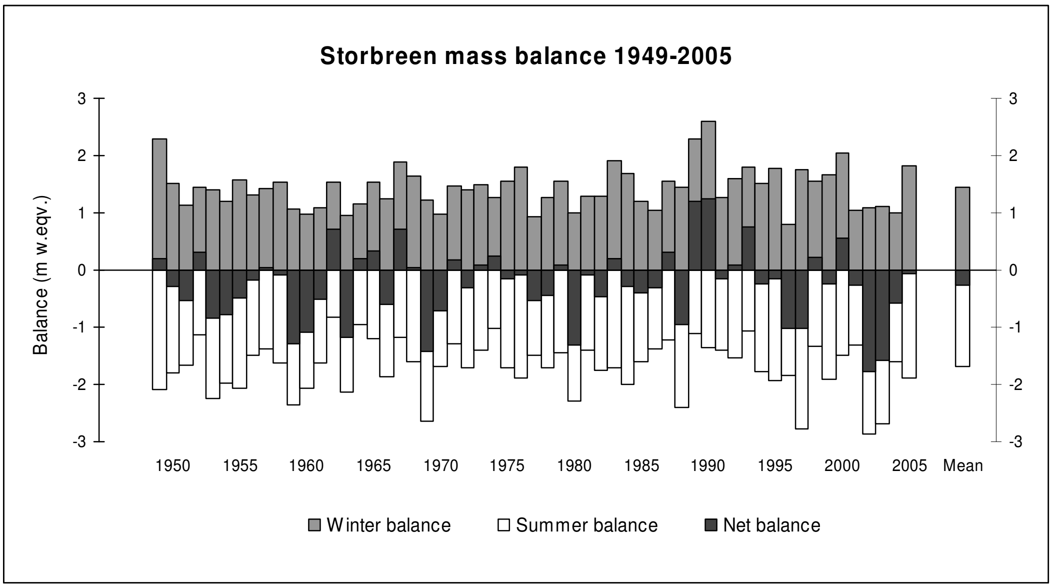
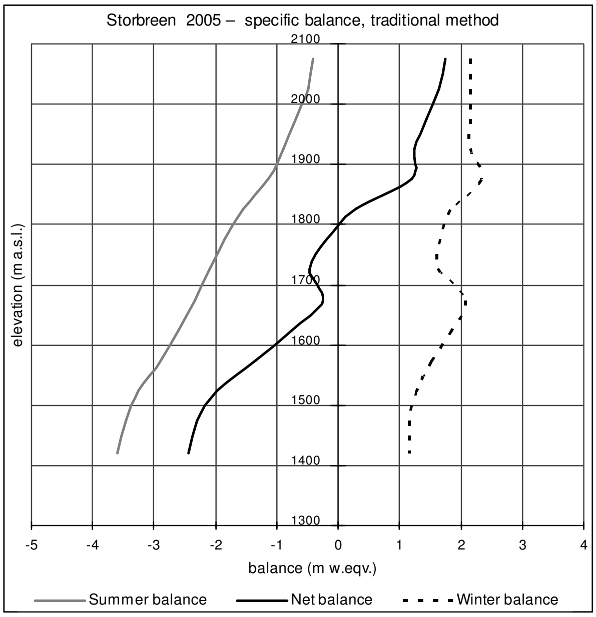


Figure 7-3
Winter, summer and net balance at Storbreen for the period 1949-2005.

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2005.

Mass balance Storbreen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 12 May 2005 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 30 Sep 2005 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2004 - 2005 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
2050 - 2100	0.04	2.14	0.09	-0.40	-0.02	1.74	0.07
2000 - 2050	0.15	2.14	0.32	-0.50	-0.08	1.64	0.25
1950 - 2000	0.23	2.14	0.49	-0.70	-0.16	1.44	0.33
1900 - 1950	0.36	2.14	0.77	-0.90	-0.32	1.24	0.45
1850 - 1900	0.57	2.34	1.33	-1.15	-0.66	1.19	0.68
1800 - 1850	0.92	1.83	1.68	-1.55	-1.43	0.28	0.25
1750 - 1800	0.75	1.66	1.25	-1.85	-1.39	-0.19	-0.14
1700 - 1750	0.64	1.63	1.04	-2.10	-1.34	-0.47	-0.30
1650 - 1700	0.40	2.08	0.83	-2.33	-0.93	-0.25	-0.10
1600 - 1650	0.49	1.84	0.90	-2.60	-1.27	-0.76	-0.37
1550 - 1600	0.35	1.53	0.54	-2.88	-1.01	-1.35	-0.47
1500 - 1550	0.21	1.27	0.27	-3.25	-0.68	-1.98	-0.42
1450 - 1500	0.18	1.16	0.21	-3.45	-0.62	-2.29	-0.41
1390 - 1450	0.06	1.16	0.07	-3.60	-0.22	-2.44	-0.15
1390 - 2100	**5.35**	**1.83**	**9.79**	**-1.89**	**-10.12**	**-0.06**	**-0.33**



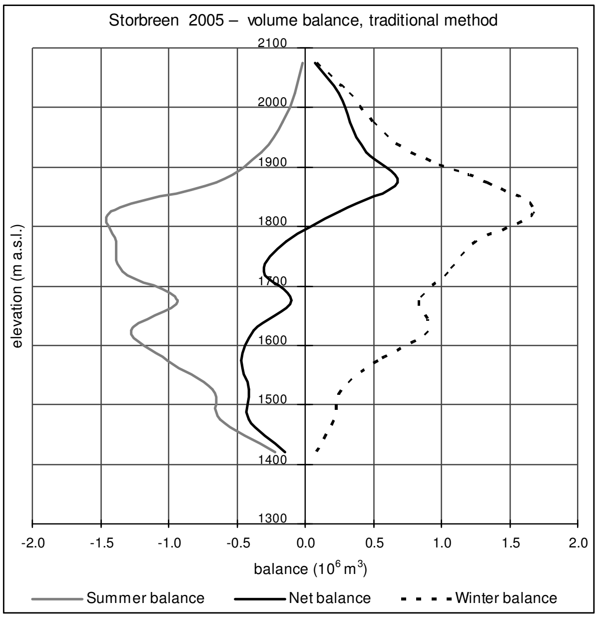


Figure 7-4
Mass balance diagram for Storbreen 2005, showing specific balance on the left and volume balance on the right.

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. 7-1), 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 of humidity, temperature and wind are done at two levels, 2 m and 6 m, above the ice surface. Measurements are done every few minutes depending on the sensor and 30-minute mean values are recorded. The results from the AWS are used to monitor the micro-climate of the glacier surface and to calibrate an energy-balance model for Storbreen. Here we present some of the data from the 2004/2005 season (until 23rd August 2005 when data was downloaded).

Figure 7-5
The upper arm of the AWS in March 2005. The lower arm was already covered by snow on 2nd January. Photo: NVE.

Surface height

The surface height and snow depth measured from the sonic rangers is shown in Figure 7-6. The measurements show that there was no notable melting of the ice surface after the ablation measurements in mid-September 2004. There was already more than 2 m of snow by the beginning of January and the lower level of the AWS was buried. The maximum snow depth of 3.5 m was reached in the beginning of May. The measurements also reveal that there was no major snowfall after the accumulation measurements in mid-May.

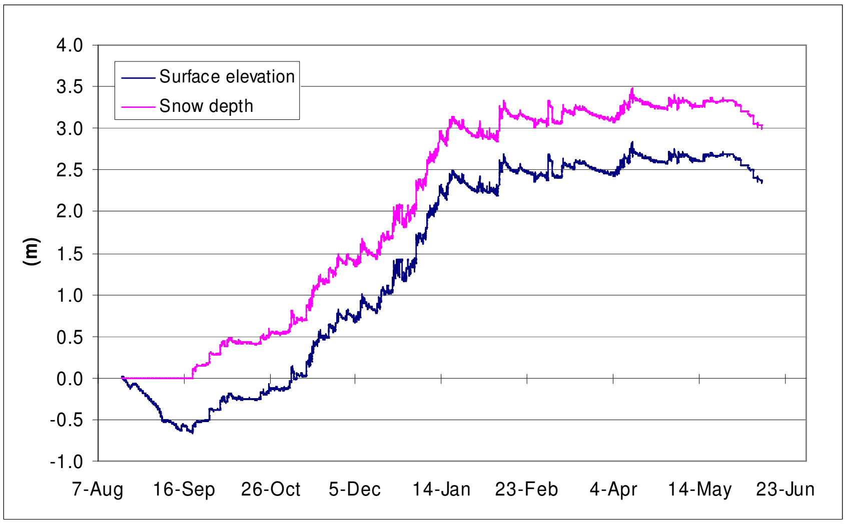


Figure 7-6
Surface elevation measured from the sonic rangers.

Radiation and albedo

The daily albedo, α, is calculated as the ratio between the outgoing and ingoing shortwave radiation (α = SW out / SW in). At the beginning of September 2004 the surface at the AWS was glacier ice and the albedo was below 0.3 (Fig. 7-7). From the middle of September the surface was covered by snow and the albedo ranged between 0.80 and 0.95 in the winter months. During spring 2005, the albedo showed larger variation due to snowfall events, and melting and densification. The albedo dropped to 0.3 on 11th August indicating that the surface was snow-free. The ice albedo at the end of August was 0.25.

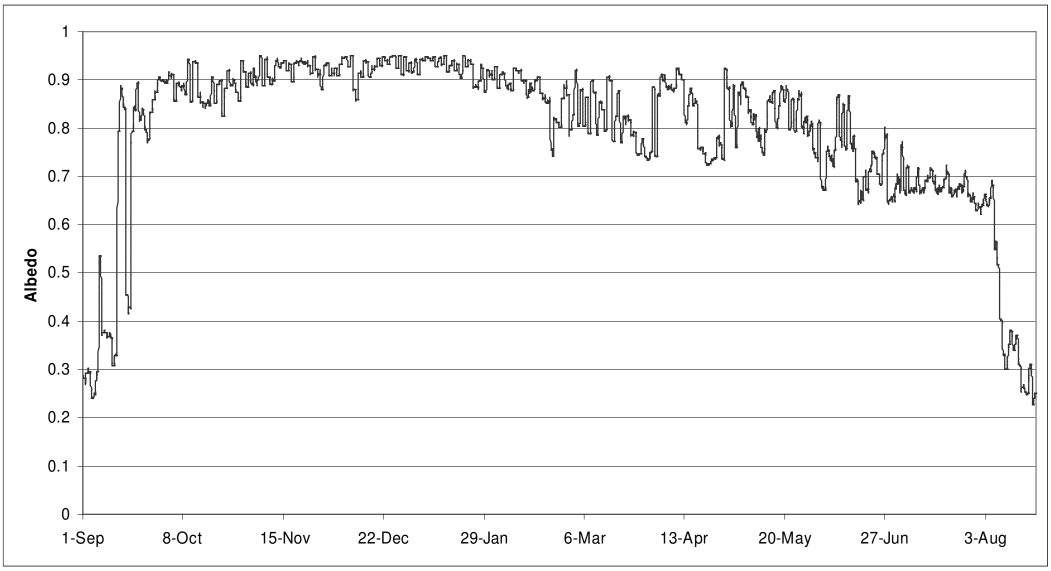


Figure 7-7
Daily albedo from 1st September 2004 to 23rd August 2005.

Temperature

The mean temperature for 2004/2005 (for the period 1st September 2004-23rd August 2005, Fig. 7-8) was −2.5 °C at the 6 m level. The lowest temperature measured was −22.7 °C on 1st March. The highest temperature was 12.7 °C, measured on 9th July. There were a few, short periods during winter when temperatures were above 0 °C, which probably caused some melting within the snow pack.

Humidity and wind

The mean relative humidity at the 6 m level for the 2004/2005-season was 80 %. The mean wind speed at the 6 m level was 4.0 m/s. The maximum wind speed was 18 m/s, measured on 30th December. The largest wind speeds were, as usual, in the winter months and the wind speed decreased towards the summer.

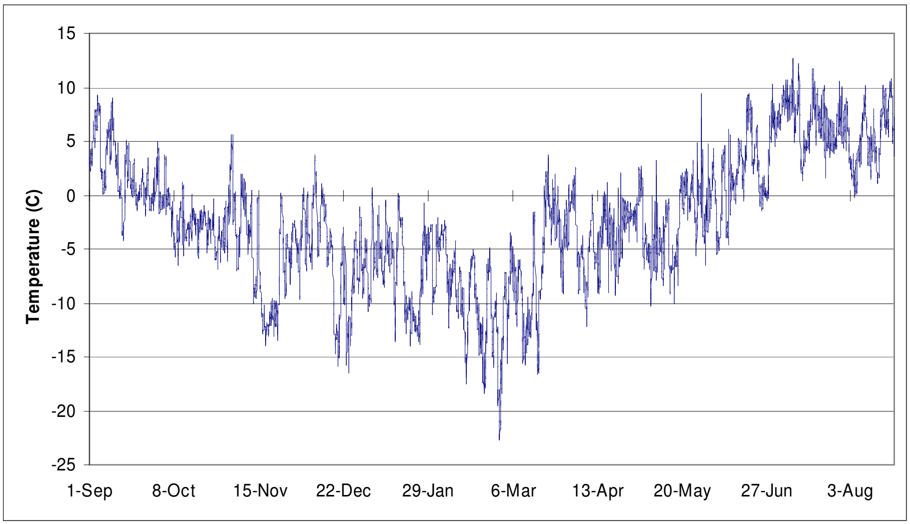


Figure 7-8
Temperature at 6m level from 1st September 2004 to 23rd August 2005.

7.3 Ice velocity

Measurements

In order to measure the surface velocity of Storbreen, two base stations for GPS measurements were established close to the glacier in September 2004, one point was established in Leirdalen and one close to the hut. Four of the stakes on Storbreen were measured in September 2004. In 2005, the stakes were measured three times, on 26th-27th April, 26th July and 30th September. Measurements were carried out using differential GPS (dGPS), with one receiver at the base station and one at the stake (Fig. 7-9).

Figure 7-9
GPS measurements at stake 1 at Storbreen on 30th September 2005. Photo: Liss M. Andreassen.

Results

Positions of the four stakes measured over a year revealed surface velocities in the order of 12-15 m/a at stake 2, 3 and 7 and 5 m/a at stake 4 (see Fig. 7-1 for stake location). The measured seasonal velocities showed that summer velocities were generally higher than winter velocities. The largest velocity was measured for stake 12, the surface movement was 9.5 m from 26th April to30th September which is estimated to correspond to about 18 m/a.

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 2005 is the 44th year of continuous measurements.

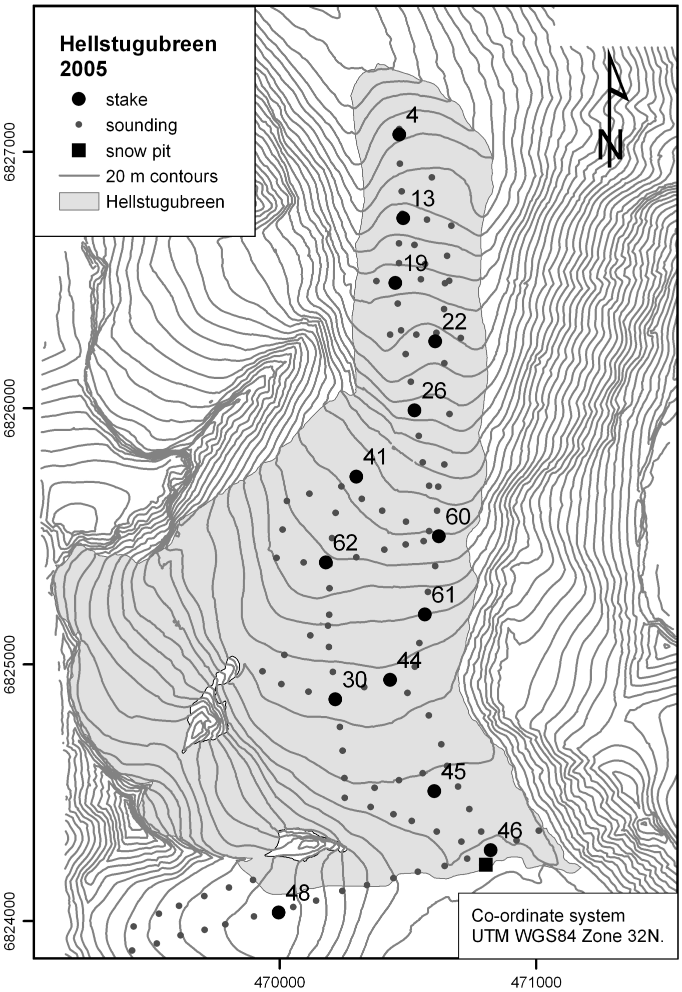
Figure 8-1
Hellstugubreen on 27th July 2005. Photo: Liss M. Andreassen.

8.1 Mass balance 2005

Fieldwork

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

- Measurements of stakes in 11 different positions. Stake readings did not show any indication of melting after the final measurements in September 2004.
- Soundings of snow depth in 115 positions (12.5 km of profiles) between 1550 and 2140 m a.s.l. covering most of the altitudinal range of the glacier (Fig. 8-3). The snow depth varied between 1.2 and 5.7 m, the mean being 3.0 m.
- The snow density was measured by sampling in a pit at 1960 m a.s.l. where the total snow depth was 3.4 m.



Ablation measurements were carried out 30th September on stakes in 11 locations. A layer of 5-20 cm of fresh snow covered the glacier. The location of stakes, density pit and sounding profiles are shown in Figure 8-2.

Figure 8-2
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2005.

Results

The mass balance results of 2005 are presented in Table 8-1 and Figure 8-4.

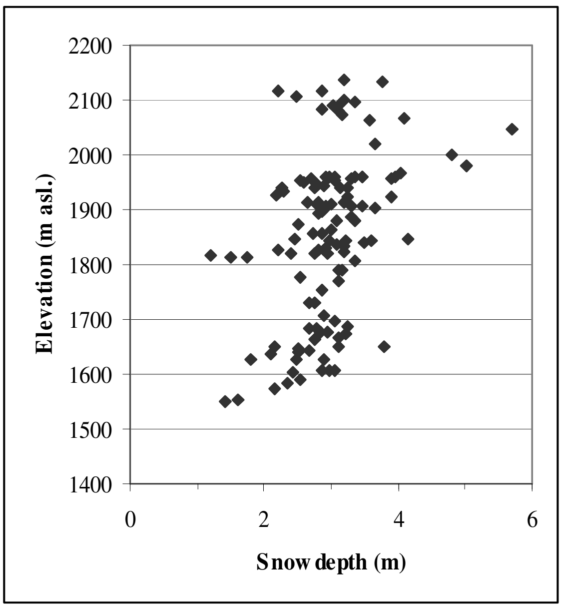


Figure 8-3
Snow depth soundings on Hellstugubreen 2005.

Winter balance

The winter balance was calculated from the soundings (Fig. 8-3) and the snow density measurement, which was considered to be representative for the whole glacier. The density was 0.45 g/cm^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The mean winter balance was 1.3 ±0.2 m w.eqv. This is 117 % of the mean for the period 1971-2000, or 122 % of the mean for the observation period 1962-2004.

Summer balance

The summer balance was calculated from stakes in 8 locations. At stake 44 (1905 m a.s.l.) and above there was snow remaining from the winter at the end of the summer season. The density of the remaining snow was estimated to be 0.60 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 −1.6 ±0.3 m w.eqv., which is 142 % of the mean value for the period 1971-2000.

Net balance

Although the winter balance was above normal, the summer balance exceeded the winter balance. The resulting net balance of Hellstugubreen in 2005 was −0.3 ±0.3 m w.eqv., which amounts to a volume loss of 0.9 ±0.9 mill. m^3 water. The equilibrium line altitude (ELA) was not observed due to fresh snow covering the glacier, but was calculated to be 1930 m a.s.l. giving an accumulation area ratio (AAR) of 39 % (Fig. 8-4). Since 1962 Hellstugubreen has had a cumulative mass loss of 14.7 m w.eqv., the mean annual deficit is 0.33 m w.eqv. per year (Fig. 8-5).

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2005.

Mass balance Hellstugubreen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 13th May 2005 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 30th Sep 2005 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2004 - 2005 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
2150 - 2210	0.02	1.30	0.03	-0.65	-0.01	0.65	0.01
2100 - 2150	0.09	1.34	0.12	-0.78	-0.07	0.56	0.05
2050 - 2150	0.28	1.47	0.41	-0.83	-0.23	0.64	0.18
2000 - 2050	0.18	2.29	0.42	-1.00	-0.18	1.29	0.24
1950 - 2000	0.38	1.57	0.59	-1.15	-0.43	0.42	0.16
1900 - 1950	0.61	1.25	0.77	-1.30	-0.80	-0.05	-0.03
1850 - 1900	0.35	1.37	0.48	-1.50	-0.52	-0.13	-0.04
1800 - 1850	0.33	1.34	0.44	-1.75	-0.57	-0.41	-0.13
1750 - 1800	0.13	1.26	0.17	-1.95	-0.26	-0.69	-0.09
1700 - 1750	0.10	1.45	0.15	-2.18	-0.23	-0.73	-0.08
1650 - 1700	0.17	1.14	0.19	-2.45	-0.41	-1.31	-0.22
1600 - 1650	0.13	1.19	0.15	-2.75	-0.35	-1.56	-0.20
1550 - 1600	0.16	0.59	0.09	-3.20	-0.51	-2.61	-0.42
1500 - 1550	0.08	0.59	0.05	-3.60	-0.28	-3.01	-0.23
1480 - 1500	0.02	0.47	0.01	-4.00	-0.07	-3.53	-0.06
1480 - 2210	**3.03**	**1.34**	**4.07**	**-1.63**	**-4.93**	**-0.29**	**-0.87**

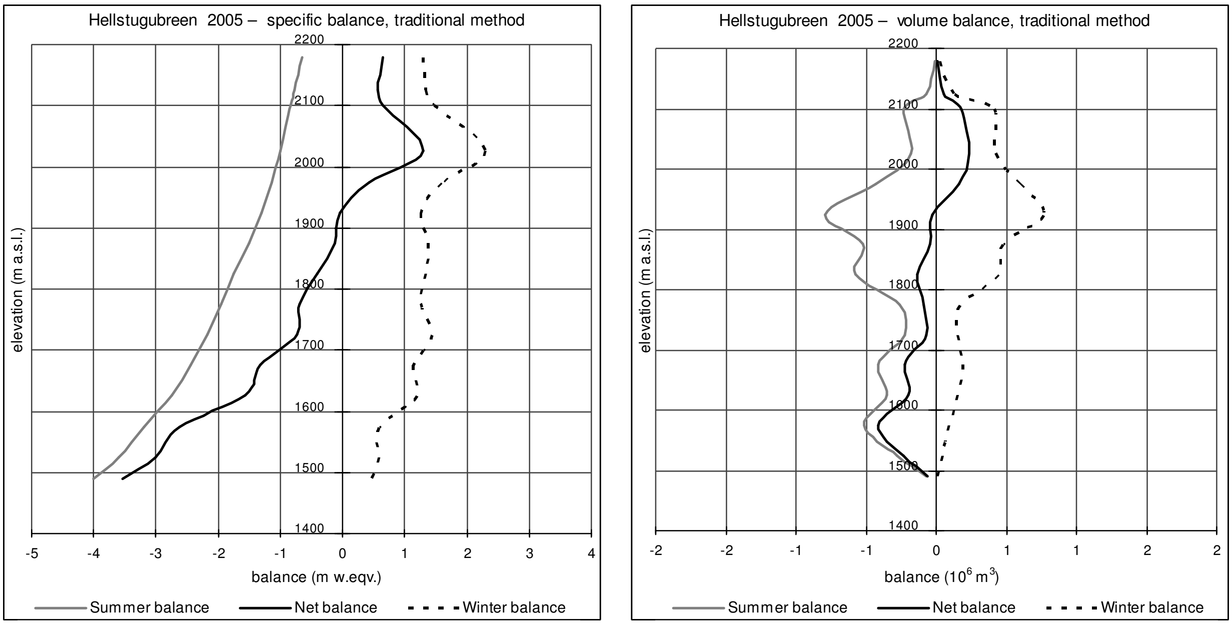


Figure 8-4
Mass balance diagram for Hellstugubreen in 2005, showing specific balance on the left and volume balance on the right.

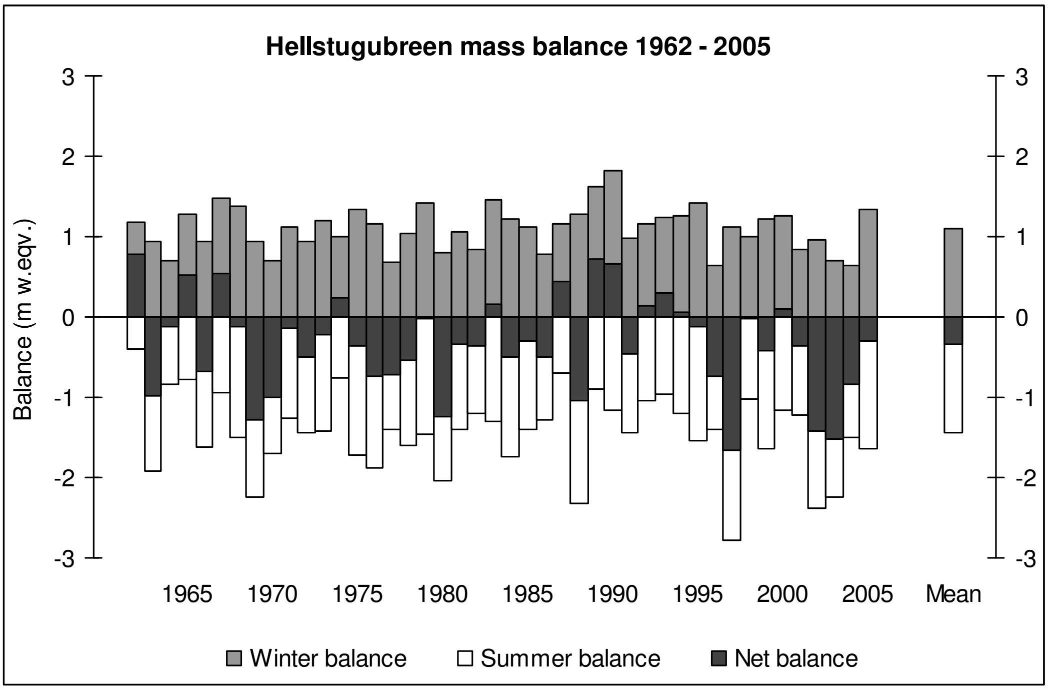


Figure 8-5
Winter, summer and net balance at Hellstugubreen for the period 1962-2005.

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. The glacier covers an area of 2.2 km^2 and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 9-1). 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.

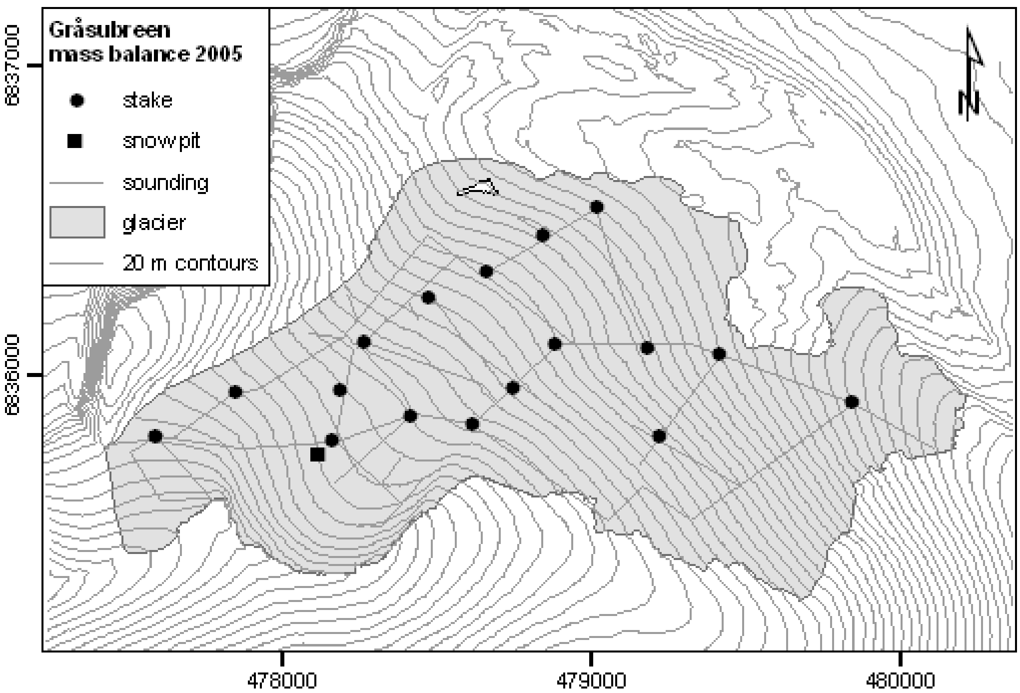


Figure 9-1
Map of Gråsubreen (shaded in grey) showing the location of stakes, snow pit and sounding profiles in 2005.

9.1 Mass balance 2005

Fieldwork

Accumulation measurements were carried out relatively late, on 3rd June. Stakes in 17 locations were measured. A total of 129 snow depth measurements were made along 12 km of profiles, covering most of the glacier (Fig. 9-1). The probing conditions were good, and the previous year's summer surface was easy to identify over the entire glacier. Snow depth varied between 0.6 and 3.5 m, with a mean of 2.0 m. The snow density was measured at 2180 m a.s.l. in a pit dug through the winter snow pack (2.3 m snow).

Ablation measurements were carried out on 28th September, when stakes in 15 locations were measured (Fig. 9-1). Parts of the glacier were covered by a thin snow layer (0-15 cm).

Results

The mass balance results are presented in Table 9-1 and Figure 9-2.

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 0.44 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 0.8 ±0.2 m w.eqv., which is 105 % of the mean for the period 1971-2000.

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 15 locations. The density of the remaining snow left from the winter was assumed to be 0.60 g/cm^3. The density of the melted ice was estimated to be 0.90 g/cm^3. The resulting summer balance was −1.3 ±0.3 m w.eqv. This is 169 % of the mean for the period 1971-2000.

Net balance

Gråsubreen had a mass loss in 2005 of 0.5 ±0.3 m w.eqv, almost the same as in 2004. The equilibrium line altitude (ELA) was calculated to be 2180 m a.s.l. The accumulation area ratio (AAR) was 13 % (Fig. 9-2).

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2005.

Mass balance Gråsubreen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 3rd June 2005 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 28th Sep 2005 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2004 - 2005 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
2250 - 2290	0.04	1.32	0.06	-0.90	-0.04	0.42	0.02
2200 - 2250	0.17	1.28	0.21	-1.22	-0.20	0.06	0.01
2150 - 2200	0.26	0.85	0.22	-0.88	-0.23	-0.03	-0.01
2100 - 2150	0.34	0.72	0.24	-1.38	-0.46	-0.66	-0.22
2050 - 2100	0.37	0.95	0.35	-1.32	-0.49	-0.38	-0.14
2000 - 2050	0.42	0.80	0.34	-1.45	-0.61	-0.65	-0.27
1950 - 2000	0.36	0.59	0.21	-1.40	-0.50	-0.80	-0.29
1900 - 1950	0.14	0.81	0.12	-1.50	-0.21	-0.69	-0.10
1830 - 1900	0.15	0.82	0.13	-1.55	-0.24	-0.73	-0.11
1830 - 2290	**2.25**	**0.83**	**1.88**	**-1.33**	**-2.99**	**-0.49**	**-1.11**

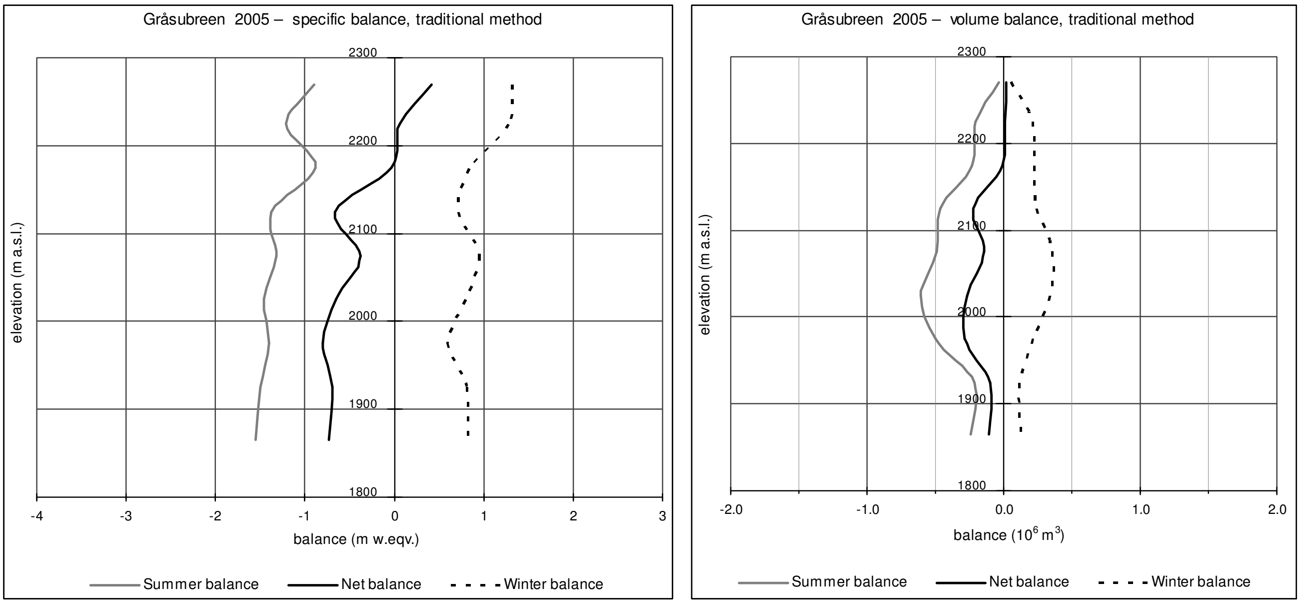


Figure 9-2
Mass balance diagram for Gråsubreen in 2005, showing specific balance on the left and volume balance on the right.

Since 1962 Gråsubreen has had a cumulative mass loss of −13.7 m w.eqv., or −0.31 m w.eqv. per year. Most of this mass loss occurred in the 1970s and 1980s. However, over the past four years Gråsubreen has lost 3.8 m w.eqv. (Fig. 9-3). Figure 1-5 shows the cumulative balance of Gråsubreen and four other glaciers since 1963, clearly revealing 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.

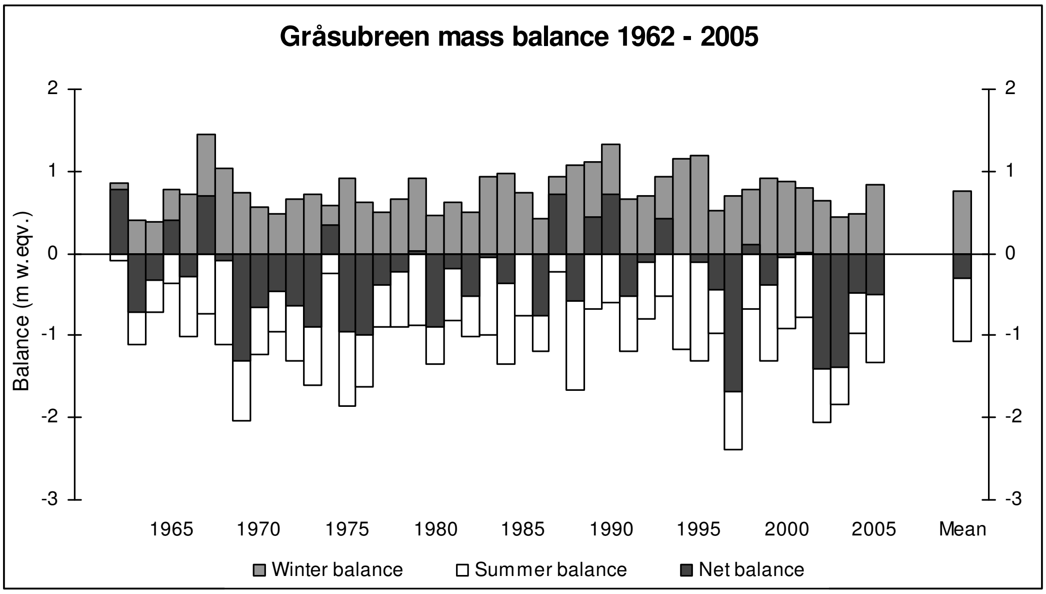


Figure 9-3
Winter, summer and net balance at Gråsubreen during the period 1962-2005.

10. Engabreen (Hallgeir Elvehøy and Miriam Jackson)

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.

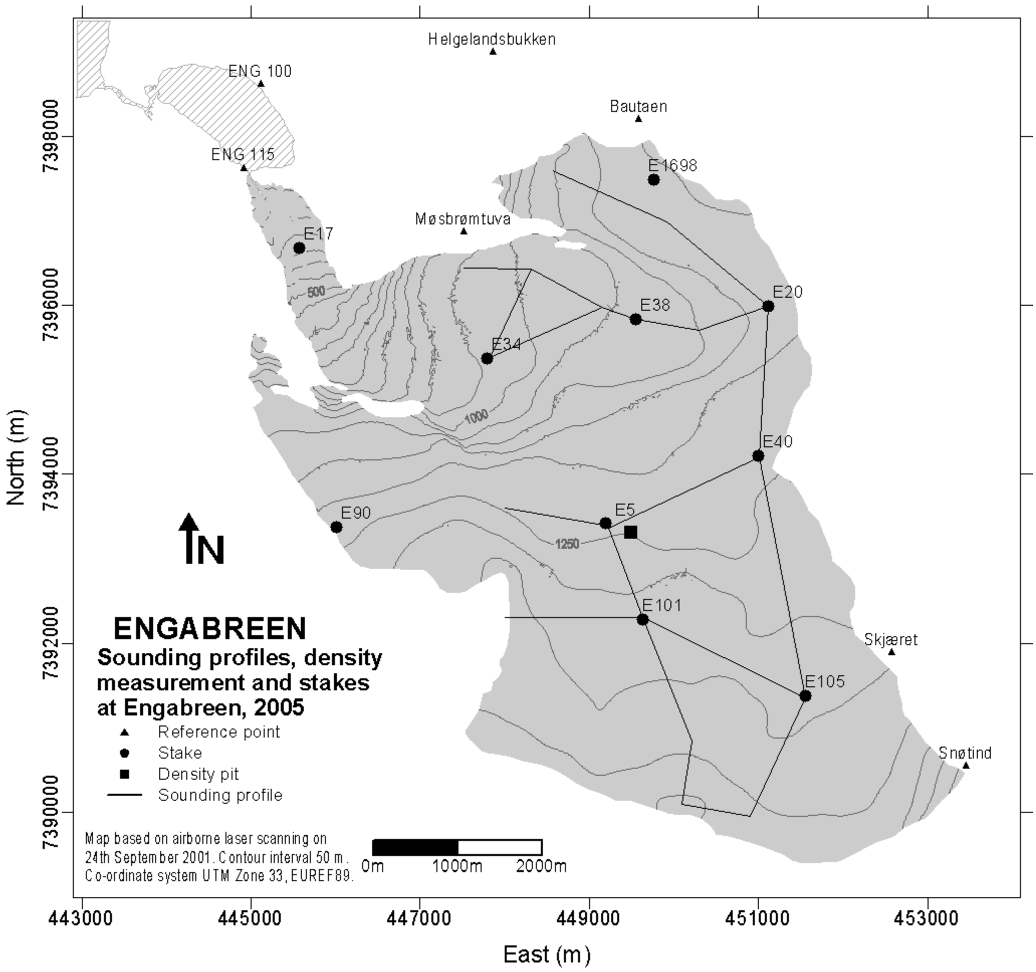


Figure 10-1
Location of stakes, density pit and sounding profiles on Engabreen in 2005.

10.1 Mass balance 2005

Fieldwork

Snow accumulation measurements were carried out between 23rd and 26th May. The locations of stakes and towers, density pit, core samples and sounding profiles are shown in Figure 10-1. The calculation of winter balance is based on:

- Direct measurement of snow depth at stake E105, showing 8.1 m of snow.
- Snow depth from coring at stake E34 and E38, showing 4.2 and 6.35 m of snow, respectively.

- Stake measurements on 16th October 2004 and 26th May 2005 at stake E17, showing 0.2 m of ice melting between these dates.
- The transient snow line altitude at 600 m a.s.l.
- Snow density measured down to the summer surface (SS) at 6.75 m depth at stake E5. Mean snow density was 0.48 g/cm^3.
- 132 snow depth soundings along 27 km of profiles. The snow depth was between 7 and 9 m at most of the sounding points above 1200 m a.s.l., and between 5 and 7 m between 950 and 1200 m a.s.l.

The net balance measurements were carried out on 28th September. Above 1050 m a.s.l. there was up to 0.7 m of new snow on the glacier. From stake measurements the transient snow line altitude was about 1040 m a.s.l.

The net balance was observed at 15 stakes in ten locations between 300 and 1350 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 of the winter snow and 2 m of ice had melted. Above 1000 m a.s.l., 4 to 6 m of snow had melted during the summer. The remaining snow pack was up to 4 m thick (at stake E105).

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 measurement (Fig. 10-1). A water equivalent profile was modelled from the snow density measured at stake E5 (1240 m a.s.l.). This model was then used to calculate the water equivalent value of the snow depth measurements.

Point values of the snow water equivalent (SWE) were plotted against altitude, and a curve was drawn based on visual evaluation (Fig. 10-2). Below 950 m a.s.l. the winter balance curve was interpolated based on the observed snow depth around stake E34, the transient snow line altitude, and the observed negative winter balance at stake E17. Based on this altitudinal distribution curve, the winter balance was calculated as 3.3 ±0.2 m w.eqv., which corresponds to a volume of 131 ±8 mill. m^3 of water. This is 112 % of the mean value for the period from 1970-2004 (2.95 m w.eqv.), and 132 % of the mean value for the 5-year period 2000-2004.

Summer balance

The summer balance was measured and calculated at 15 stakes in ten locations between 300 and 1350 m a.s.l. An altitudinal distribution curve was drawn based on the measurements (Fig. 10-2). The summer balance was calculated as −2.4 ±0.2 m w.eqv., which equals a volume of −96 ±8 mill. m^3 water. This is 105 % of the average for the period 1970-2004 (−2.31 m w.eqv.), and 93 % of the average for the 5-year period 2000-2004.

Net balance

The net balance of Engabreen for 2005 was calculated as +0.9 ±0.3 m w.eqv., which corresponds to a volume gain of 40 ±10 mill. m^3 water. The mean value for the period 1970-2004 is +0.64 m w.eqv., and −0.08 m w.eqv for 2000-2004. The equilibrium line altitude (ELA) was determined as 1060 m a.s.l. from the net balance curve in Figure 10-2. This corresponds to an accumulation area ratio (AAR) of 80 %. The mass balance results are shown in Figure 10-2 and Table 10-1. The results from 2005 are compared with mass balance results for the period 1970-2004 in Figure 10-3.

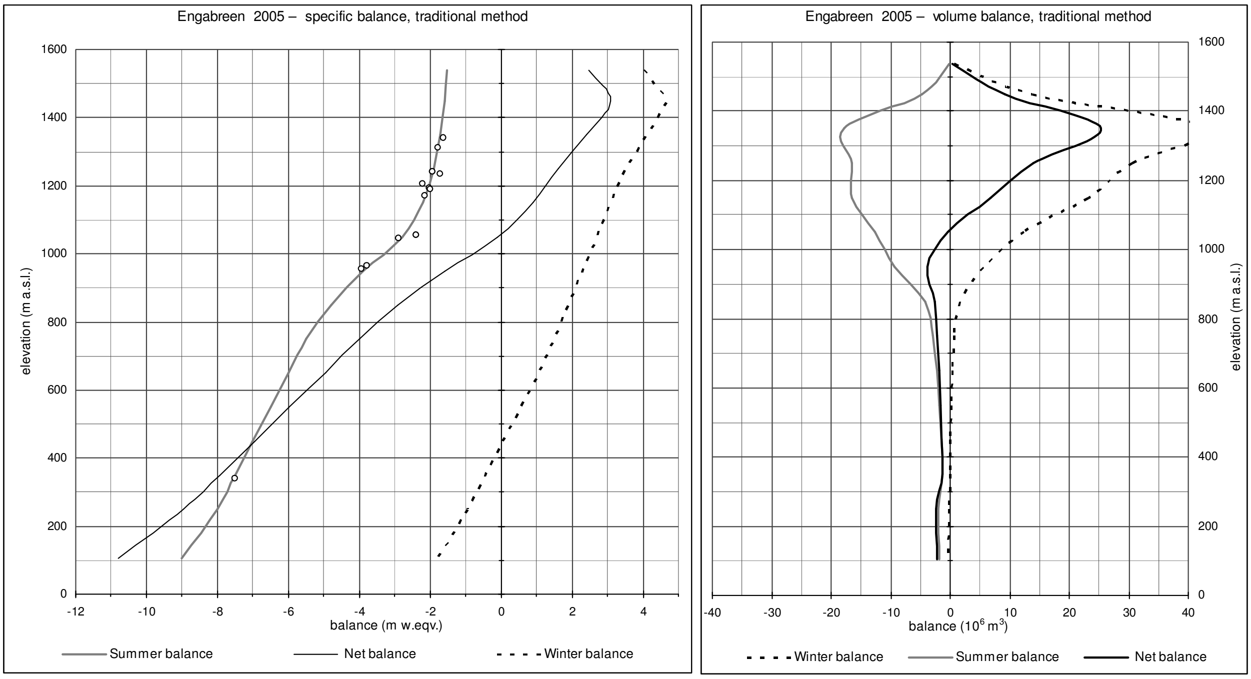


Figure 10-2
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2005. Summer balance at stakes and towers is shown as circles (○).

Mass balance Engabreen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 24th May 2005: Specific (m w.eqv.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 29th Sep 2005: Specific (m w.eqv.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surface 2004 - 2005: Specific (m w.eqv.)	Net balance: Volume (10^6 m^3)
1500 - 1575	0.13	4.00	0.5	-1.52	-0.2	2.48	0.3
1400 - 1500	2.94	4.70	13.8	-1.60	-4.7	3.10	9.1
1300 - 1400	10.52	4.10	43.1	-1.70	-17.9	2.40	25.2
1200 - 1300	8.68	3.50	30.4	-1.90	-16.5	1.60	13.9
1100 - 1200	7.47	3.10	23.2	-2.20	-16.4	0.90	6.7
1000 - 1100	4.52	2.70	12.2	-2.80	-12.7	-0.10	-0.5
900 - 1000	2.38	2.30	5.5	-3.90	-9.3	-1.60	-3.8
800 - 900	0.87	1.90	1.7	-4.80	-4.2	-2.90	-2.5
700 - 800	0.54	1.50	0.8	-5.50	-3.0	-4.00	-2.2
600 - 700	0.38	1.05	0.4	-6.00	-2.3	-4.95	-1.9
500 - 600	0.28	0.55	0.2	-6.50	-1.8	-5.95	-1.7
400 - 500	0.20	0.05	0.0	-7.00	-1.4	-6.95	-1.4
300 - 400	0.17	-0.45	-0.1	-7.50	-1.3	-7.95	-1.4
200 - 300	0.26	-0.95	-0.2	-8.00	-2.1	-8.95	-2.3
10 - 200	0.21	-1.80	-0.4	-9.00	-1.9	-10.80	-2.3
10 - 1575	39.6	3.31	131.0	-2.42	-95.5	0.90	35.5

Table 10-1
Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2005.

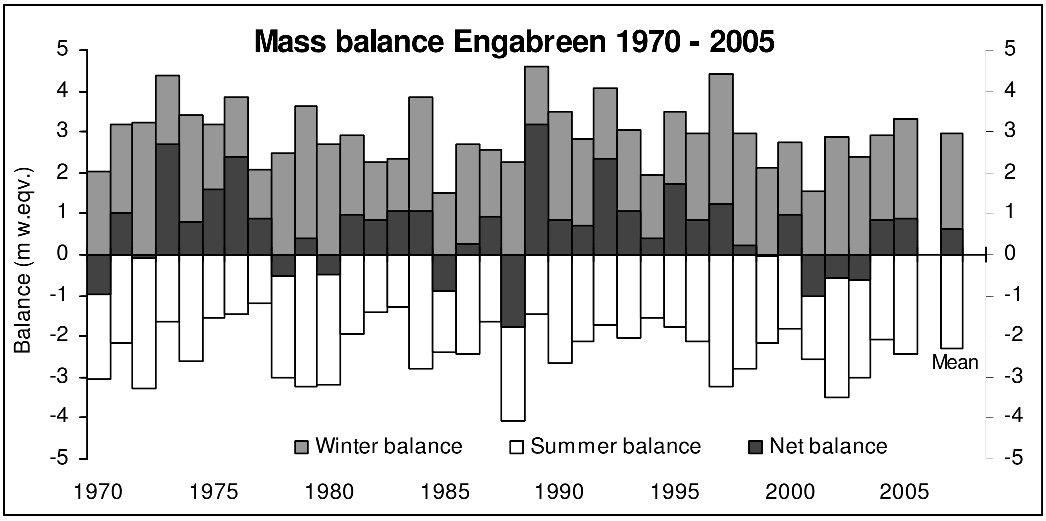


Figure 10-3
Mass balance at Engabreen during the period 1970-2005. The accumulated surplus amounts to 23 m water equivalent.

10.2 Meteorological observations

A meteorological station recording air temperature and global radiation 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 gaps. The nearest standard 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 2005, data was collected at Skjæret until 29th September with no gaps. After the autumn measurements on 16th October 2004 there were only solitary days with daily mean temperatures close to 0 °C. The first period in spring having mid-day temperatures above 0 °C was 22nd -24th May when the snow measurements started. The first warm period started on 8th June and coincided with the start of the melting season on the upper part of the glacier. The maximum midday temperature was measured on 6th and 7th July (15.5 °C). A cold period starting on 9th September probably marked the end of the ablation season on the upper part of the glacier.

At Glomfjord the mean annual temperature in 2005 was 5.8 °C, which is 0.8 °C above the 1961-90 average. The summer temperature (15th May-15th September, 11.4 °C) was 2.8 and 1.2 °C lower than in 2002 and 2003, respectively, but similar to the summer temperature in 2000, 2001 and 2004.

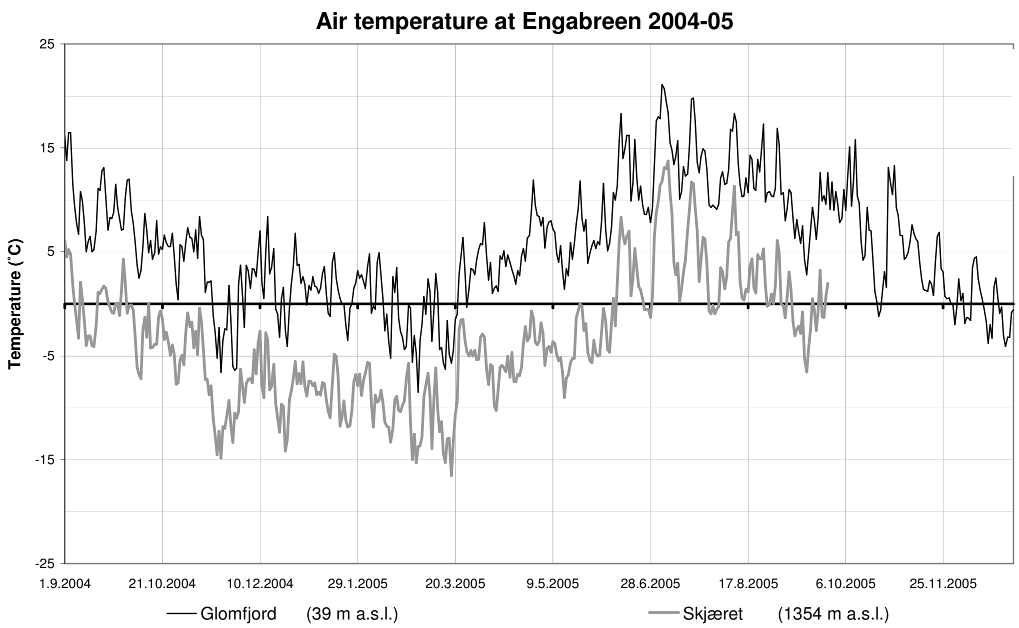


Figure 10-4
Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700) between 1st September 2004 and 31st December 2005.

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 2005. A further two load cells were installed in November 1997 and were also still operating in 2005 (Fig. 10-5). 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 29th September 2005, the time of the last data download. Data from 24th November 2004 to year end 2004 is also included here, as this was not available at the time of writing the last report. Data recorded from 30th September 2005 to year end were not available at the time of writing and are not reported here. A seventh load cell, installed in November 2003, has recorded intermittently since installation; hence these results are not included here.

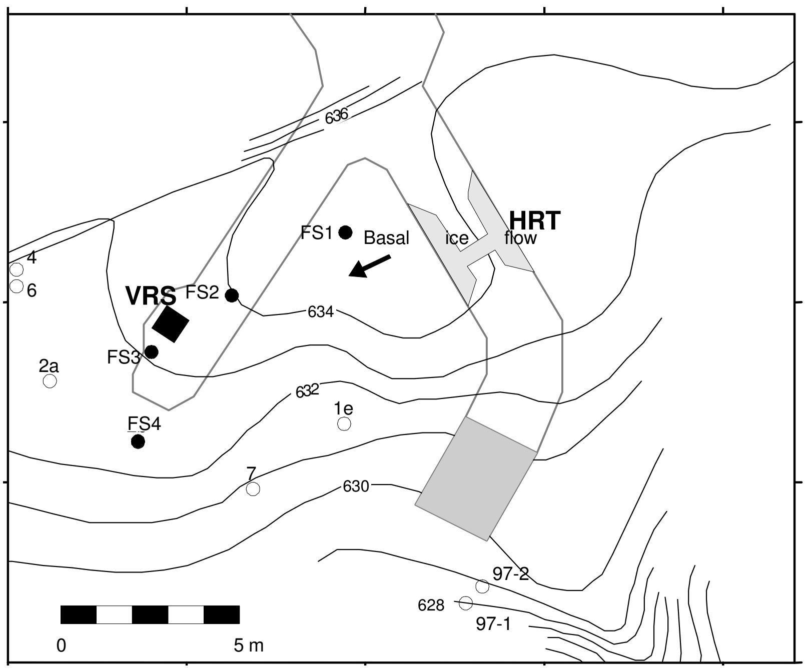


Figure 10-5
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 7 (recorded intermittently in 2005), 97-1 and 97-2 and boreholes, marked FS.

Pressure sensor records for 24th November 2004 to 14th March 2005 are shown in Figure 10-6. The discharge in the subglacial tunnel system was very low at this time, not more than 1 m^3/s, but generally less than 0.5 m^3/s. Figure 10-6 shows quite a lot of variation in pressure in the earliest part of this period, but this may be due to work done the previous week melting out an ice tunnel in the subglacial laboratory. A sharp signal in the pressure is seen on 10th December, related to an increase in the subglacial discharge. Generally the record is fairly quiet and typical for the winter regime. However, load cells 97-1 and 97-2, especially the former, show a lot of variation, suggesting the presence of water channels during much of this period.

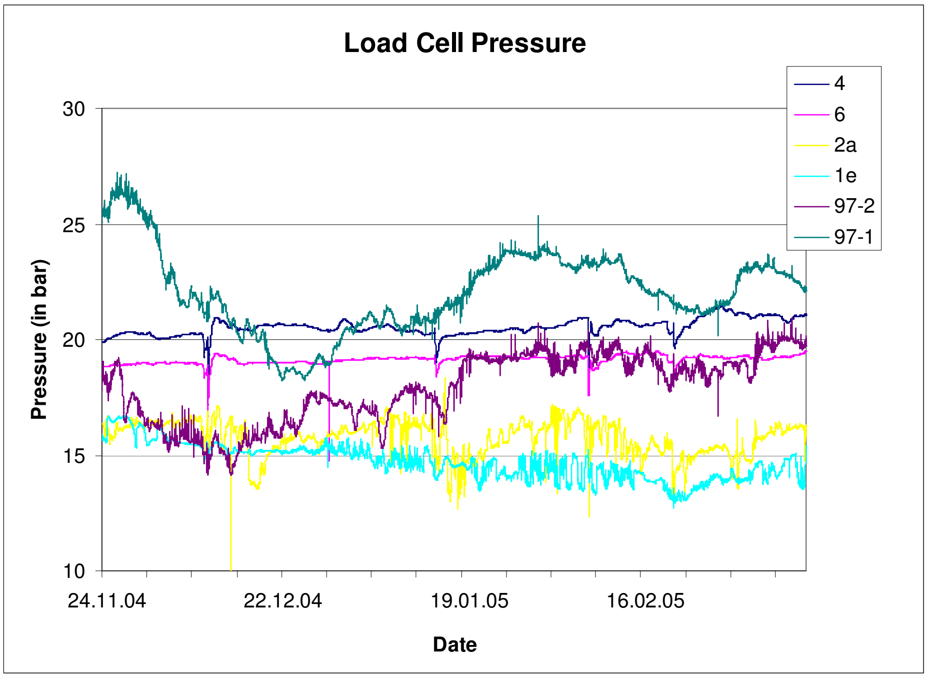


Figure 10-6
Pressure records for the period 24th November 2004 to 14th March 2005.

Pressure sensor records for the late spring period from 14th March to 30th June are shown in Figure 10-7. There is a distinct feature seen on all the load cells on 23rd March. At this time there was a sudden increase in the temperature as measured at Skjæret from −18 ºC on 18th March to 0 ºC on 22nd, and several days of moderate to heavy rain between 21st and 26th March. This led to subglacial discharge, which increased from the base value of 0.02 m^3/s at midday on 22nd March to 0.64 m^3/s by midnight on 24th March, an increase of a factor of 30 in just over 48 hours. This sudden increase in discharge gave minima in pressure measured at the load cells at midday on 23rd, followed by maxima several hours later. A similar event occurred on 4th May. Temperatures were not particularly mild, but heavy precipitation on 4th caused a sudden influx of water to the subglacial system and an increase in subglacial discharge by a factor of ten. Consequentially, this led to sharp minima closely followed by sharp maxima in the pressure measured at the load cells. The pressure records are a little noisier after this, but the subglacial drainage system was not yet developed. From 21st May, mild weather and rain gave a sudden influx of water to the system. The discharge increased by more than a factor of 20 to over 2 m^3/s. Several days later, from 9th June, rain and warm weather raised subglacial discharge to over 16 m^3/s with related sharp troughs and peaks in the pressure. Towards the end of this period, the pressure signal is noisier and shows that the subglacial regime had developed into a standard summer regime.

Pressure sensor records for the period from 1st July to 29th September, are shown in Figure 10-8. These are fairly typical for the summer period, although possibly somewhat quieter than other years. The amount of activity in the pressure records suggests a well-developed drainage system at the glacier base. There are several strong peaks, and in quieter periods a diurnal signal is seen at several of the load cells. There are no periods with a very low pressure recorded at load cells 97-1 or 97-2, as seen in previous years.

Observations on the long-term load cell records are included in the PhD thesis by Gaute Lappegard at the University of Oslo (Lappegard 2006), which also includes experimental work done in the subglacial laboratory and numerical modelling of stress bridging based on the pressure records.

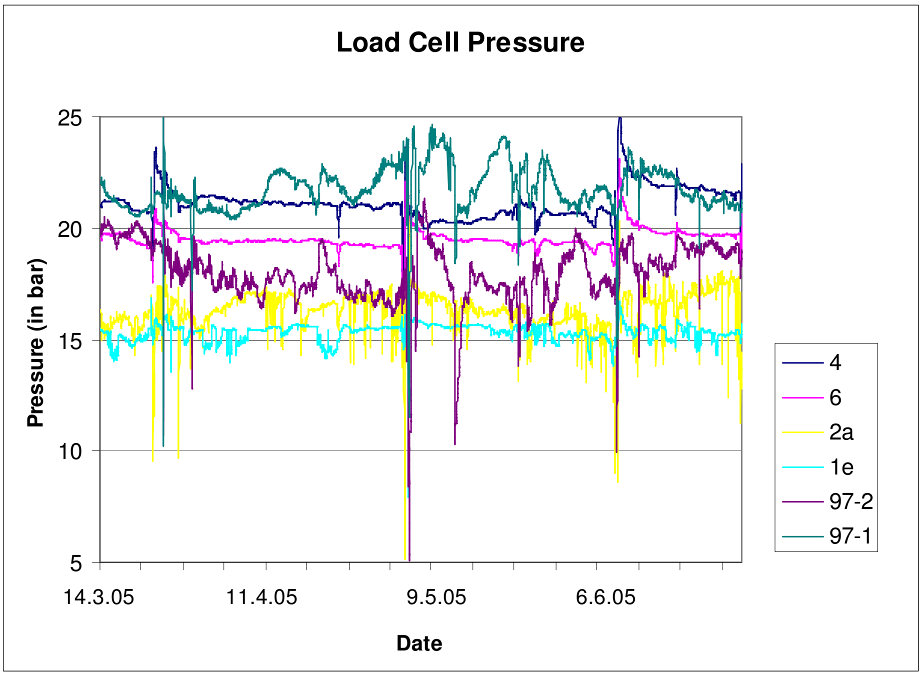


Figure 10-7
Pressure records for 14th March to 30th June.

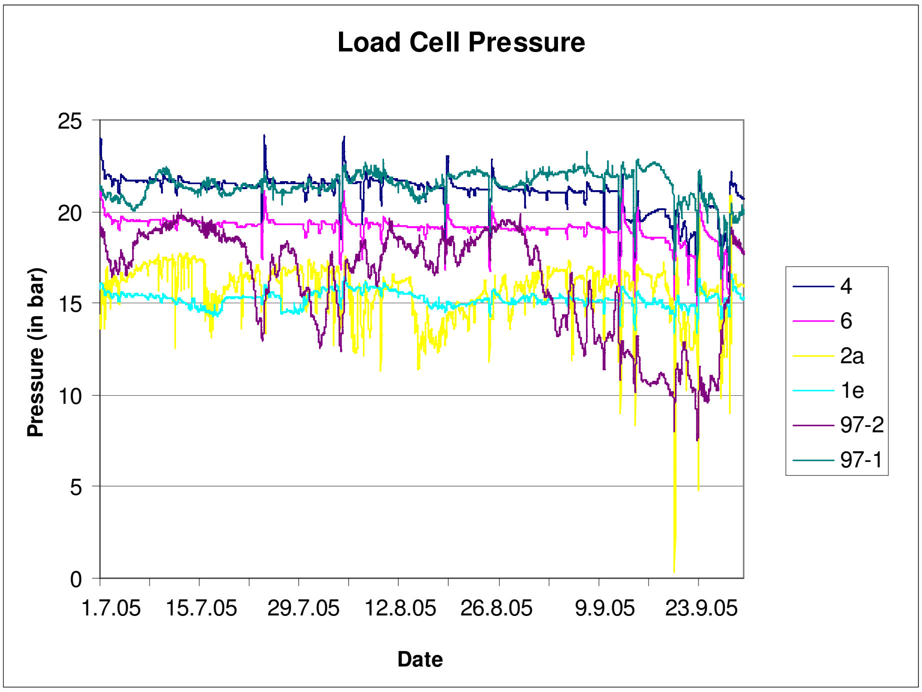


Figure 10-8
Pressure records for the period 1st July to 30th September.

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 2005.

The net balance of Svartisheibreen in 2005 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 3 mill. m^3 water (Fig. 10-9). The cumulative net balance at Svartisheibreen since 1969 equals +11 m w.eqv. The cumulative net balance at Engabreen in the same period is +23 m w.eqv.

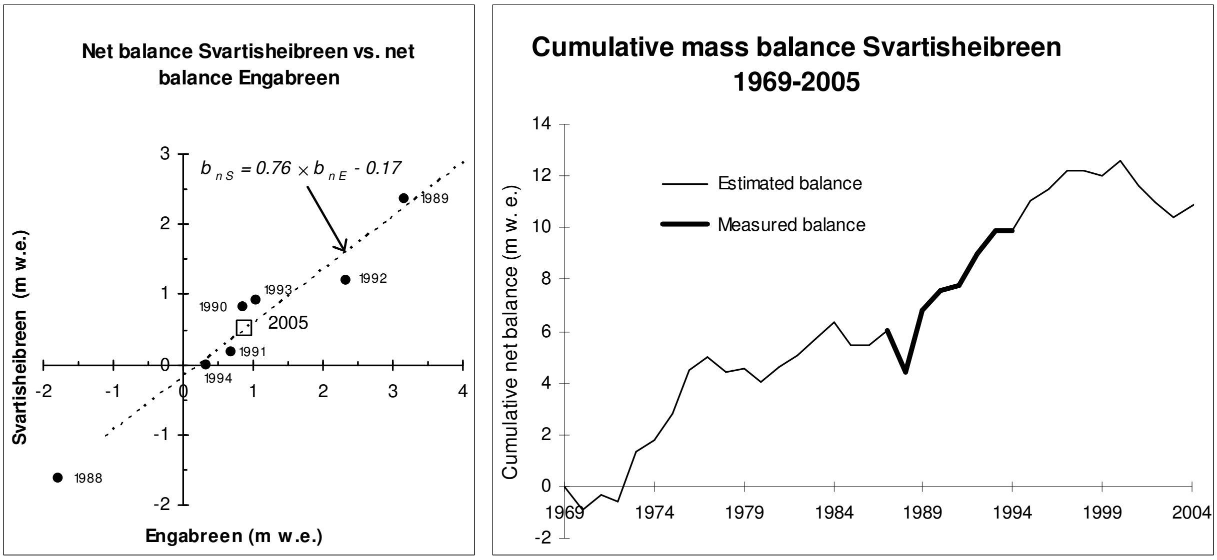


Figure 10-9
Net balance at Svartisheibreen modelled from measured net balance at Engabreen and Svartisheibreen in 1988-94 (left), and cumulative specific net balance at Svartisheibreen for the period 1969-2005 (right).

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 between 900 and 1300 m a.s.l. The glacier calves into the lake in three distinct outlets. Mass balance measurements were carried out during the four years from 1985 to 1988, and recommenced in 2000. In 2005, the mass balance monitoring programme was simplified.

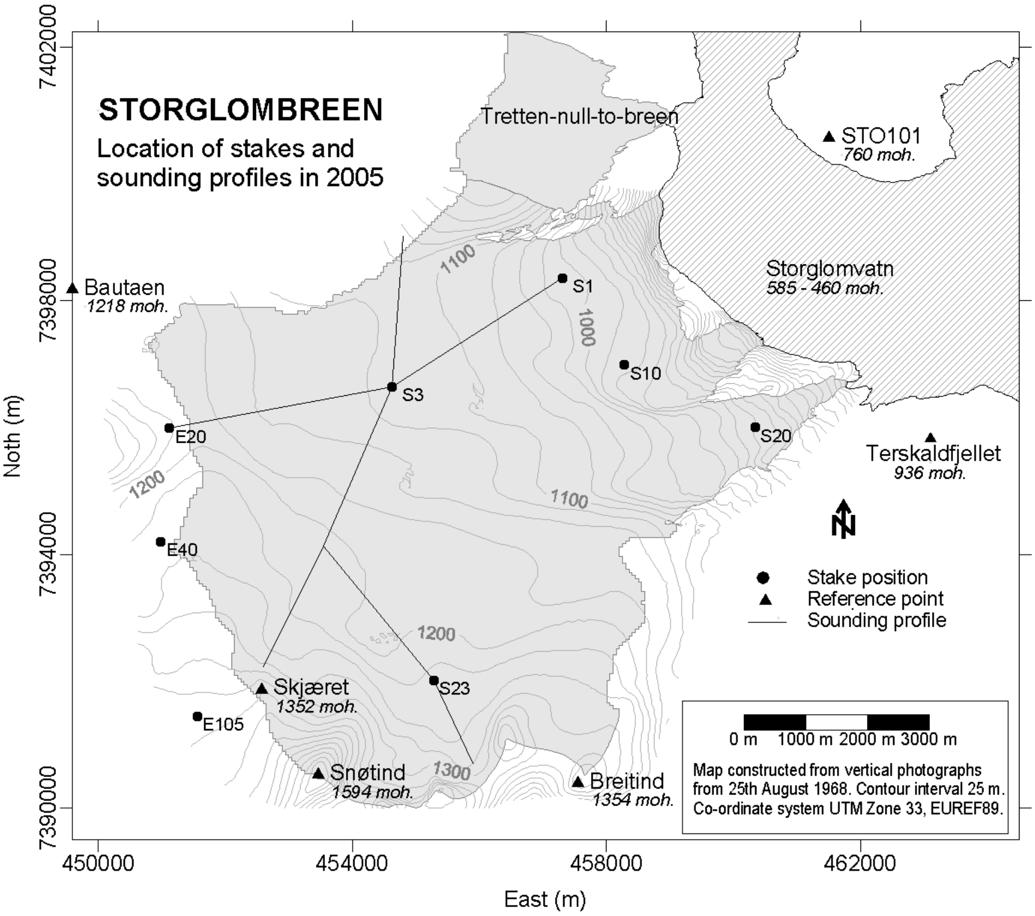


Figure 11-1
Location of stakes and sounding profiles at Storglombreen in 2005. Three stakes on Engabreen located close to Storglombreen are also used in the calculations.

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.

11.1 Mass balance 2005

Fieldwork

Snow accumulation measurements were carried out on 23rd May. The location of stakes and sounding profiles are shown in Figure 11-1. The calculation of the winter balance was based on:

- Snow depth at stakes S10, S20 and E105 showing 1.5, 1.1 and 8.1 m, respectively.
- Snow depth measured by coring at locations S1 and S3 showing 3.95 and 5.7 m of snow, respectively.
- Snow depth sounding verified by stake readings at locations E40, E20 and S23 showing 7.2, 6.15 and 6.45 m of snow, respectively.
- 34 snow depth soundings along 20 km of profiles between 1000 and 1300 m a.s.l. Most observations showed between 6 and 7 m of snow. The summer surface was difficult to detect, and some snow depths had to be corrected using stake observations.
- Snow density measured to a depth of 6.75 m at stake E5 (1240 m a.s.l.) at Engabreen. Mean snow density was 0.48 g/cm^3.

Net balance measurements were carried out on 28th September. At that time up to 0.45 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. At stake S20, 1.1 m of snow and 4.4 m of ice melted during the summer, while at stake S10 1.5 m of snow and 4.45 m of ice melted. At stake S1, 4.2 m of snow and 0.75 m of ice melted. At stakes S3 and S23, 4.3 m of snow melted, and 1.40 and 2.15 m of snow remained. At stakes E20, E40 and E105, 4.85 – 4.50 and 3.90 m of snow melted, and 1.3 – 2.7 and 4.2 m of snow remained, respectively.

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 E5. The snow density measurements were used to model a water equivalent profile. 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 170 ±10 mill. m^3

water, which corresponds to 2.7 ±0.2 m w.eqv. The calculated winter balance is 128 % of the 1985-88 and 2000-04 average (2.13 m w.eqv.). At Engabreen the winter balance (3.3 m w.eqv.) was 138 % of the 1985-88 and 2000-04 average (2.40 m w.eqv.), but 112 % of the mean value for the period from 1970-2004 (2.95 m w.eqv.).

The winter balance was also calculated using the regression equation defined from results from 1985-88. The mean water equivalent for 42 snow depth measurements along the profiles shown in Figure 11-1 was 3.06 m. This corresponds to a specific winter balance of 2.6 m, which is close to the result above.

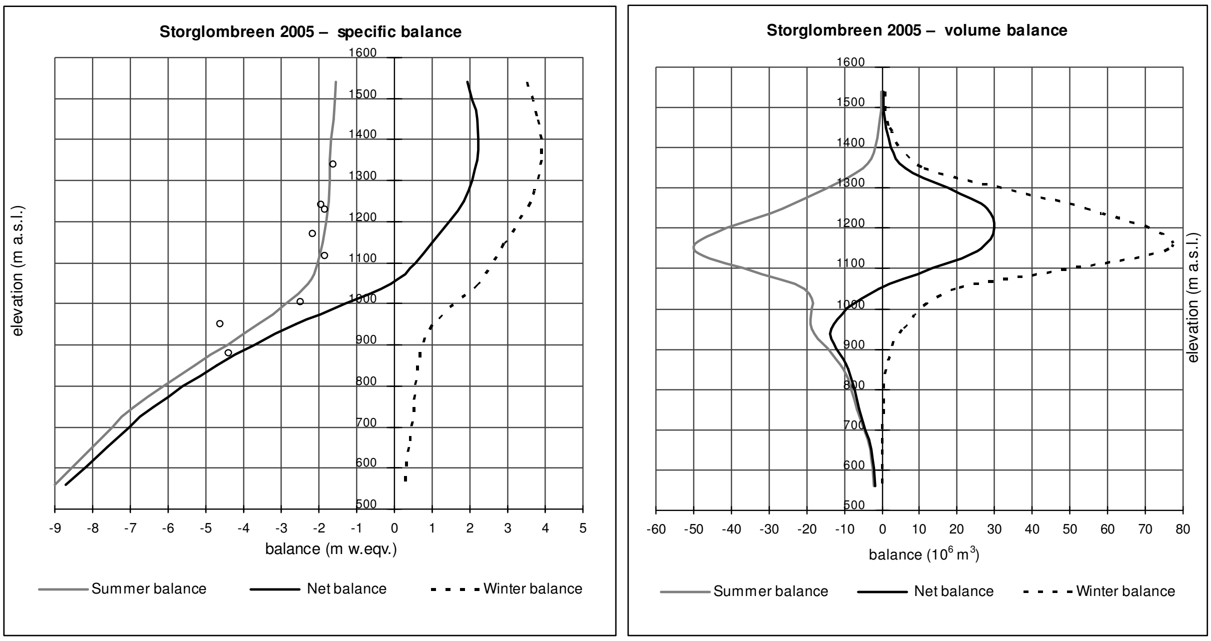


Figure 11-2
Winter, summer and net balance for Storglombreen in 2005, showing specific balance (left) and volume balance (right). Summer balance at eight stakes is shown as circles (°).

Summer balance

The summer balance was calculated at five locations on Storglombreen (S20, S10, S1, S3 and S23), and three locations located close to the ice divide on Engabreen (E20, E40 and E105) (Fig. 11-1). The summer balance curve (Fig. 11-2) was drawn from these eight 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 −150 ±20 mill. m^3 water, which is equal to a specific balance of –2.4 ±0.3 m w.eqv. The calculated summer balance is 87 % of the mean summer balance for 1985-1988 and 2000-2004 (−2.78 m w.eqv.). At Engabreen the summer balance (−2.4 m w.eqv.) was 101 % of the 1985-88 and 2000-04 average (−2.40 m w.eqv.), and 105 % of the 1970-2004 average (−2.31 m w.eqv.).

The summer balance was also calculated using a regression model. The summer balance at stake 3 was −1.8 m w.eqv., corresponding to a specific summer balance including calving of −2.3 m w.eqv., which is close to the result above.

Net balance

The net balance of Storglombreen for 2005 was 0.3 ±0.4 m w.eqv., which corresponds to a mass gain of 20 ±30 mill. m^3 water. The mass balance results are shown in Table 11-1 and Figure 11-2. From the net balance curve the equilibrium line altitude (ELA) at Storglombreen is defined as 1060 m a.s.l. (also 1060 m a.s.l. on Engabreen). The accumulation area ratio (AAR) was 79 % (80 % on Engabreen). The net balance at Storglombreen was 1.0 m higher than the mean value for 1985-1988 and 2000-04 (–0.65 m w.eqv.). At Engabreen the net balance was +0.9 m w.eqv., which is 1.1 m above the 1985-88 and 2000-04 average.

The results from 2005 are compared with mass balance results for the period 1985-1988 and 2000-04 in Figure 11-3.

Table 11-1
Specific and volume winter, summer, and net balance calculated for 100 m elevation intervals for Storglombreen in 2005.

Mass balance Storglombreen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 23rd May 2005 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 28th Sep 2005 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 2004 - 2005 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1500 - 1580	0.18	3.50	0.63	-1.55	-0.28	1.95	0.35
1400 - 1500	0.58	3.80	2.19	-1.60	-0.92	2.20	1.27
1300 - 1400	2.89	3.90	11.26	-1.70	-4.91	2.20	6.35
1200 - 1300	15.02	3.60	54.07	-1.75	-26.29	1.85	27.79
1100 - 1200	26.23	2.90	76.08	-1.90	-49.84	1.00	26.23
1000 - 1100	8.91	2.20	19.60	-2.30	-20.49	-0.10	-0.89
900 - 1000	5.16	1.00	5.16	-3.60	-18.59	-2.60	-13.43
800 - 900	1.91	0.60	1.14	-5.30	-10.11	-4.70	-8.96
700 - 800	0.95	0.50	0.47	-6.90	-6.54	-6.40	-6.06
600 - 700	0.38	0.40	0.15	-8.00	-3.02	-7.60	-2.87
520 - 600	0.22	0.30	0.07	-9.00	-2.02	-8.70	-1.95
Calving					-7.2		-7.2
520 - 1580	62.4	2.74	170.8	-2.41	-150.2	0.33	20.6

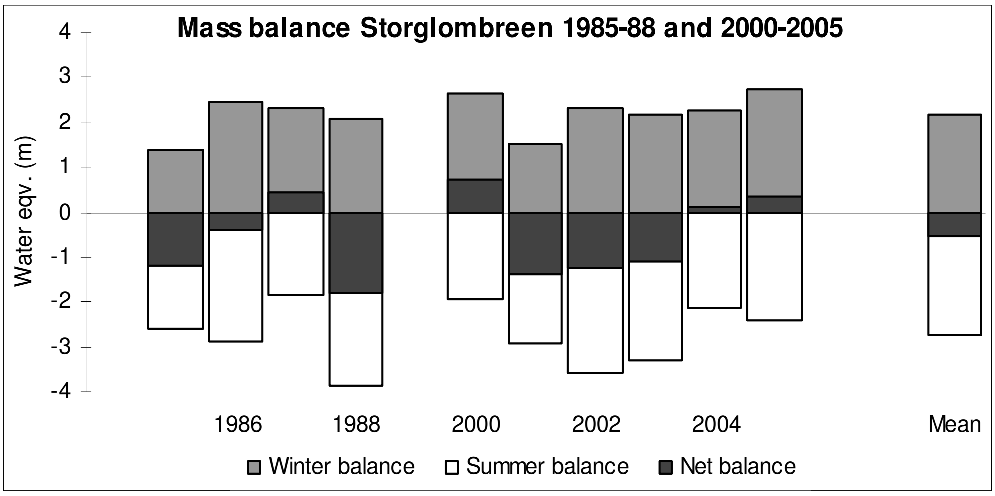


Figure 11-3
Mass balance at Storglombreen during the period 1985-1988 and 2000-2005. The ten year mean values are b_v=2.19 m w.eqv., b_s=–2.75 m w.eqv., and b_n= –0.55 m w.eqv.

12. 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. 12-1). The investigations are performed on this east-facing part, ranging from 280 to 1050 m a.s.l.

The glaciological investigations in 2005 include mass balance and change in glacier length. Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

Figure 12-1
Langfjordjøkelen photographed on 26th May 2005. Photo: Eli Alfnes.

12.1 Mass balance 2005

Fieldwork

Snow accumulation measurements

Snow accumulation was measured on 26th May and the calculation of winter balance is based on (Fig. 12-3):

- Uninterrupted measurements of stakes in positions 10 (490 m a.s.l.), 20 (650 m a.s.l.), 25 (730 m a.s.l.) and 30 (890 m a.s.l.). Measurement of a substitute stake drilled in May 2005 and three older stakes that emerged during the melt season in position 40 (1050 m a.s.l.). Stake readings did not show any indication of melting *after* the final measurements in October 2004.
- Core sample at position 40.

- 72 snow depth soundings between 350 and 1050 m elevation. In some areas above 900 m altitude a solid layer of ice approximately 0.5 m above summer surface (SS) made it difficult to define the summer surface (SS). Below this altitude the SS was distinct. In general the snow depth varied from 2 m at the glacier snout to 4-5 m in the uppermost areas.
- Snow density was measured down to SS at 3.8 m depth at 890 m altitude (stake position 30).

Figure 12-2
72 snow depth soundings were performed in May 2005. Photo: Ole Magnus Tønsberg.

Location of stakes, density pit and sounding profiles at Langfjordjøkelen in 2005 are shown in Figure 12-3.

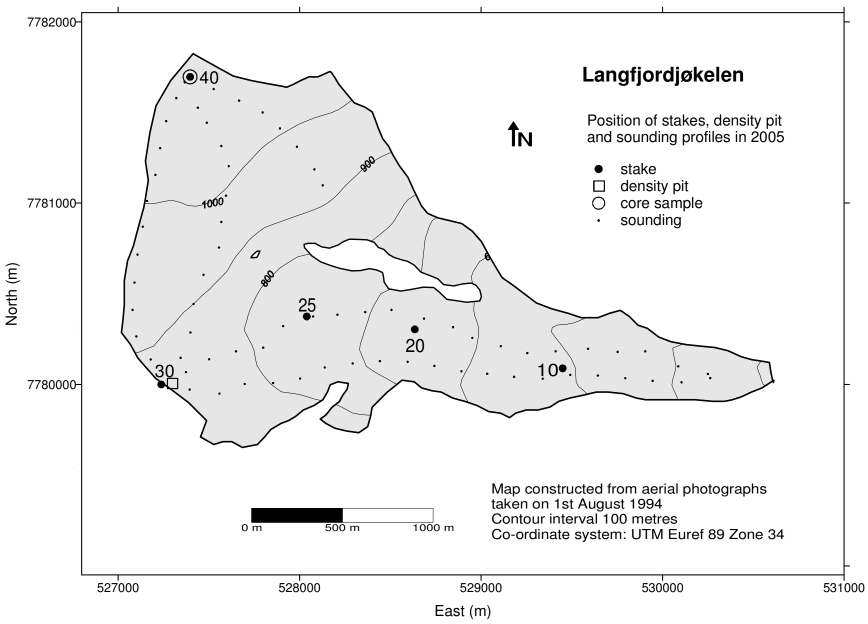


Figure 12-3
Location of stakes, soundings and snow pit at Langfjordjøkelen in 2005.

Ablation measurements

Ablation was measured on 26th October. The net balance was measured at seven stakes in all five locations between 490 and 1050 m a.s.l. The stakes had increased in length between 3.7 m (1050 m a.s.l.) and 5.8 m (650 m a.s.l.) since snow measurements in late May. Hence, there was up to 1 m of snow remaining in the uppermost areas from winter 2004/2005. At the time of measurements between 40 and 80 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 sample and soundings) and on one snow density measurement.

A density profile was modelled from the snow density measurement at 890 m altitude. The mean density of 3.8 m snow was 0.476 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. 12-5) and a mean value for each 100 m height interval was estimated (Tab. 12-1).

The winter balance was calculated as 1.9 ±0.2 m w.eqv., corresponding to a water volume of 7 ±1 mill. m^3. The result is 85 % of the mean value for the periods 1989-1993 and 1996-2004.

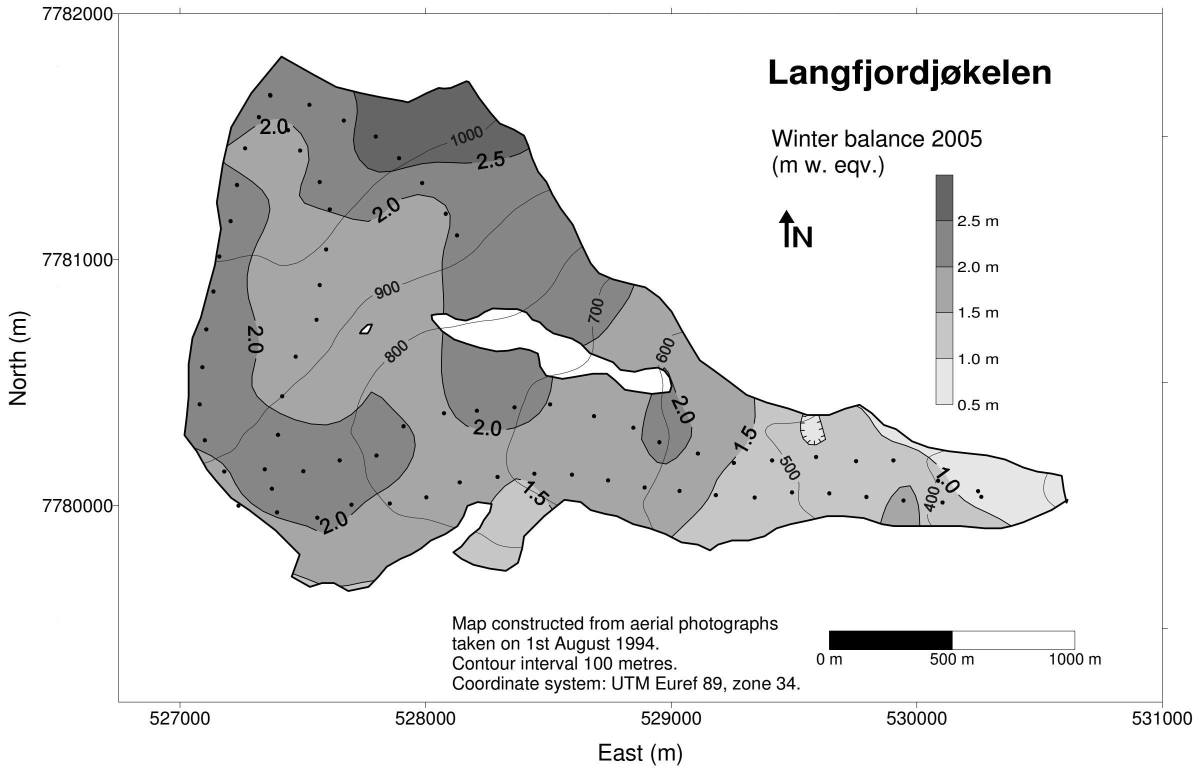


Figure 12-4
Winter balance at Langfjordjøkelen in 2005 interpolated from 84 snow depth measurements (•).

The winter balance was also calculated using different gridding methods and different spacing based on the aerial distribution of the snow depth measurements (Fig. 12-4). Water equivalent for each cell in the grid was calculated and summarised. The calculations gave all results as 1.9 m w.eqv.

Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 0.60 g/cm^3, while the density of melted ice was taken as 0.90 g/cm^3.

The summer balance was calculated at stakes in all five different elevations. At stake 10 (490 m a.s.l.) the measurements were supplemented with estimated values based on correlation with stake 20 (650 m a.s.l.). The summer balance increased from −1.6 m w.eqv. at position 40 (1050 m a.s.l.) to −5.1 m w.eqv. at position 10 (490 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −3.1 ±0.3 m w.eqv., which is −11 ±1 mill. m^3 of water. This is 103 % of the average for the periods 1989-1993 and 1996-2004.

Net balance

The net balance at Langfjordjøkelen for 2005 was −1.3 ±0.3 m w.eqv., which equals a volume loss of −5 ±1 mill. m^3 of water (Tab. 12-1). The mean value for the measurement periods 1989-93 and 1996-2004 is −0.83 m w.eqv. (Fig. 12-6), while the average over the last 5-year period 2000-2004 is −1.5 m w.eqv.

Figure 12-5 indicates that the equilibrium line altitude (ELA) was 940 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 28 %.

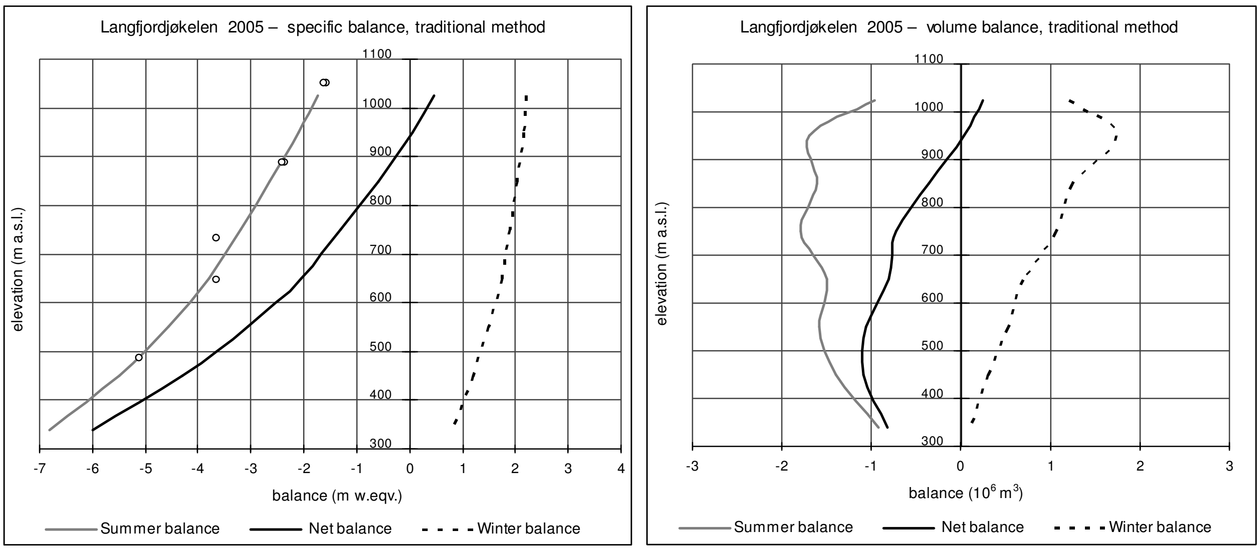


Figure 12-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2005. Summer balance for stakes at three different sites is shown (o).

Table 12-1
Winter, summer and net balance for Langfjordjøkelen in 2005. Mean values for the periods 1989-93 and 1996-2005 are b_w = 2,21 m, b_s = –3,04 m and b_n = –0,83 m w.eqv.

Mass balance Langfjordjøkelen 2004/05 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 26th May 2005 Specific (m w.eq.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 26th Oct 2005 Specific (m w.eq.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 2004 - 2005 Specific (m w.eq.)	Net balance Volume (10^6 m^3)
1000 - 1050	0.55	2.20	1.2	-1.75	-1.0	0.45	0.2
900 - 1000	0.81	2.15	1.7	-2.10	-1.7	0.05	0.0
800 - 900	0.61	2.05	1.2	-2.65	-1.6	-0.60	-0.4
700 - 800	0.56	1.90	1.1	-3.20	-1.8	-1.30	-0.7
600 - 700	0.39	1.75	0.7	-3.80	-1.5	-2.05	-0.8
500 - 600	0.35	1.50	0.5	-4.55	-1.6	-3.05	-1.1
400 - 500	0.25	1.20	0.3	-5.50	-1.4	-4.30	-1.1
280 - 400	0.14	0.80	0.1	-6.80	-0.9	-6.00	-0.8
280 - 1050	**3.65**	**1.88**	**6.9**	**-3.14**	**-11.4**	**-1.25**	**-4.6**

The balance year 2004/2005 is the ninth successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2005 (estimated values for 1994 and 1995 included) is –13 m w.eqv. Most of this mass loss (93 %) has occurred over the last nine years (1997-2005).

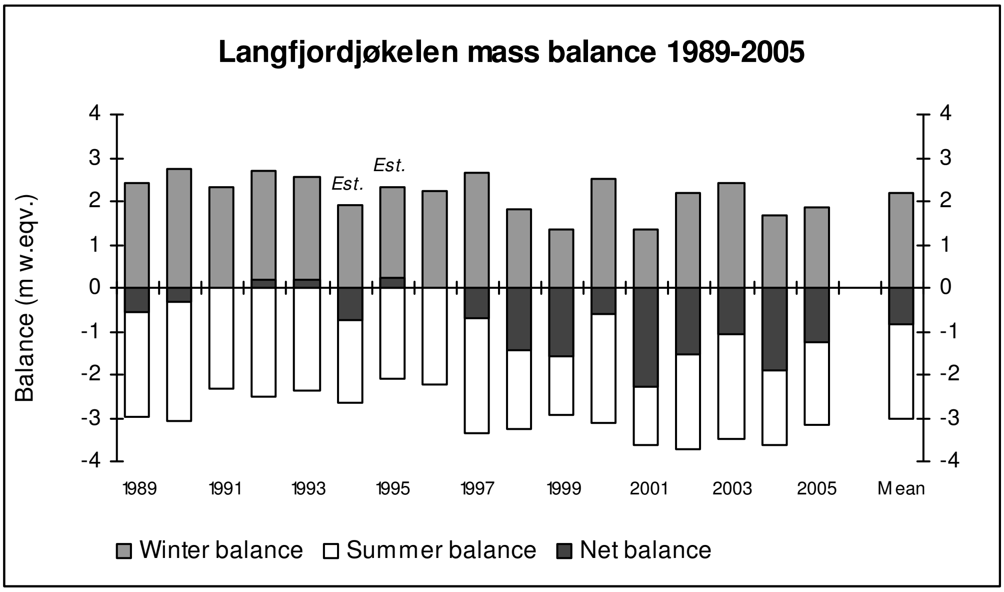


Figure 12-6
Mass balance at Langfjordjøkelen during the period 1989-2005. The total accumulated deficit over 1989-2005 is 13 m w.eqv. (includes estimated values for 1994 and 1995).

13. Glacier monitoring

13.1 Glacier length change (Hallgeir Elvehøy)

Observations of glacier length change at Norwegian glaciers started around 1900. In 2005, glacier length change was measured for 28 glaciers, 24 in southern Norway and four in northern Norway (Fig. 13-1). Two glaciers in Lyngen, Troms are included in the monitoring network. They have been observed intermittently since 1998. Eleven glaciers have records that cover the 20th century.

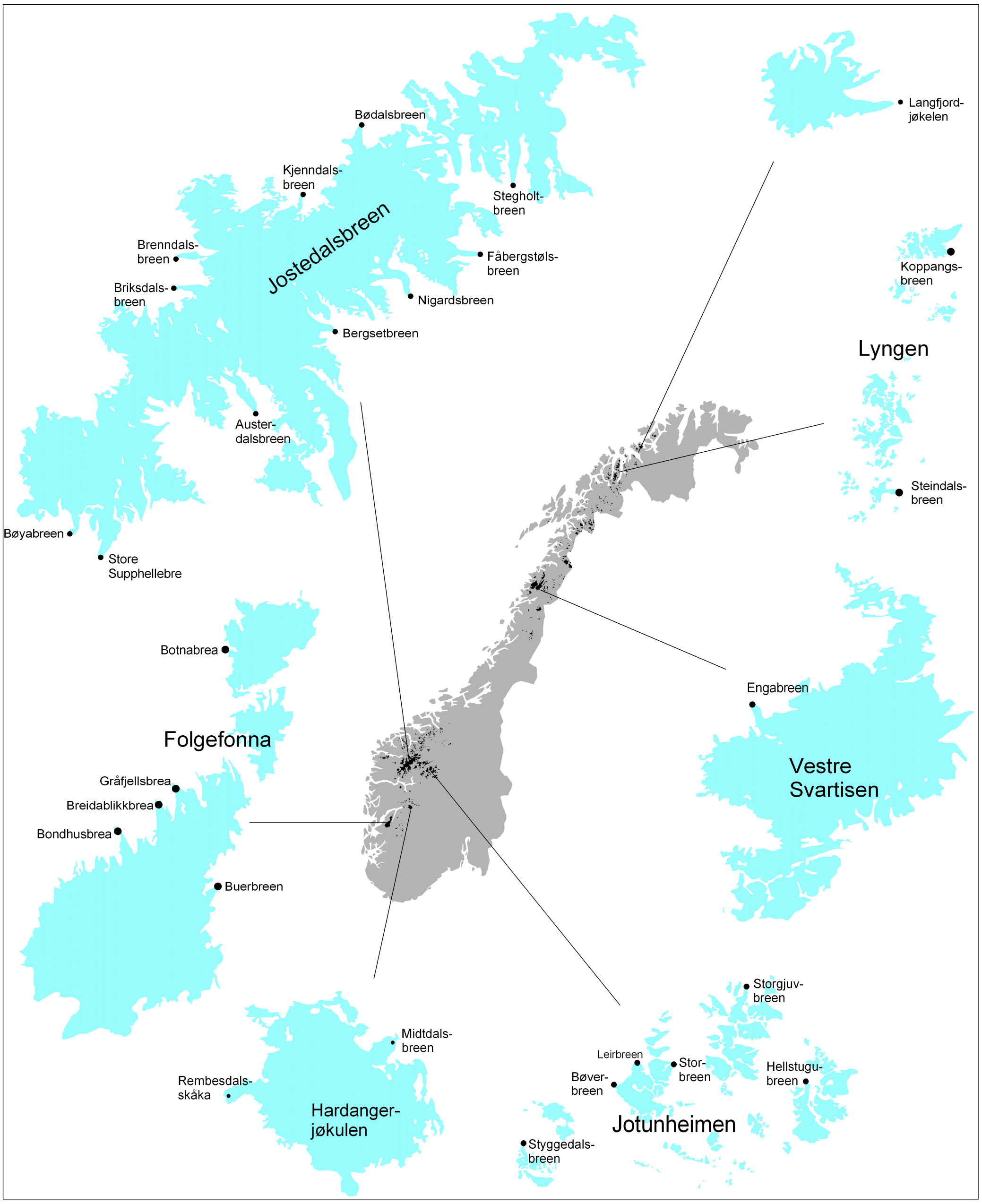


Figure 13-1
Location map showing glaciers where front position measurements were performed in 2005. Note that the different glacier areas are not to the same scale.

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 2005

Twenty-eight glaciers were measured in 2005, four in northern Norway, and 24 glaciers in southern Norway. The glacier length changes at the observed glaciers are shown in Table 13-1. The glacier retreat observed in previous years continued, although at a lower rate.

Sixteen of the measured glaciers retreated. Engabreen (Svartisen), Brenndalsbreen (Jostedalsbreen) and Rembesdalsskåka (Hardangerjøkulen) retreated between 50 and 60 metres. Engabreen has retreated 179 metres since 1999, while Brenndalsbreen and Rembesdalsskåka have retreated 116 and 206 metres since 2000.

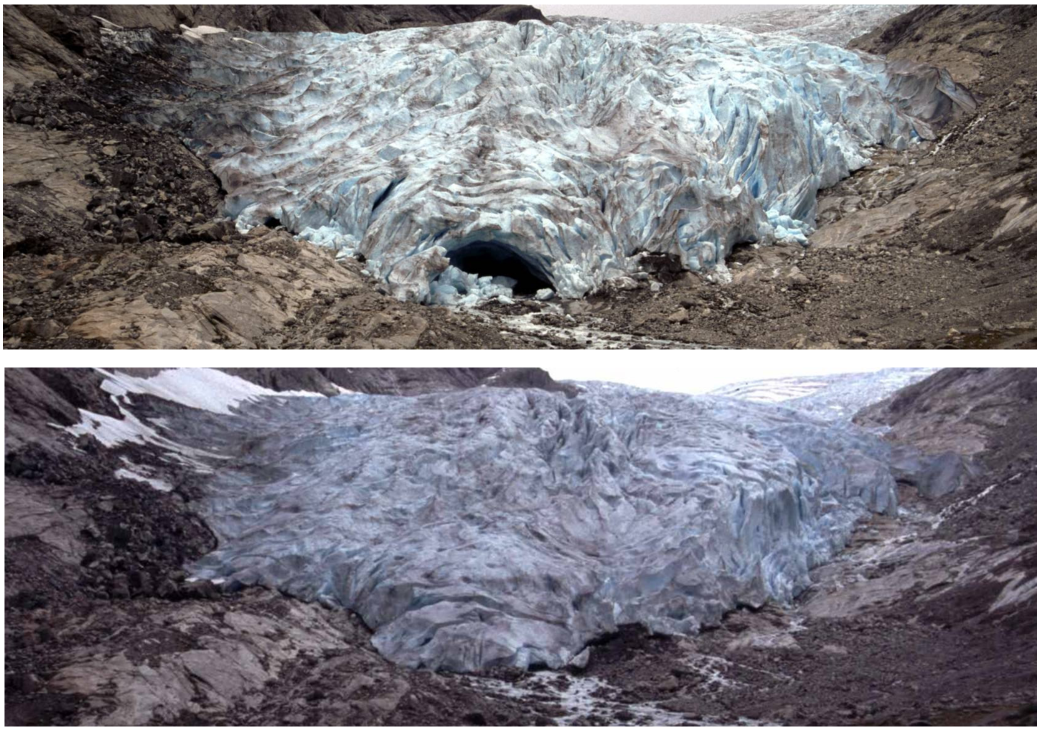


Figure 13-2
Fåbergstølsbreen on 25th August 2003 (upper) and 18th August 2005 (lower). Photo: Stefan Winkler.

At four glaciers the measurements indicate length increase (>+4 m). Usually one line is taken to represent the glacier tongue. Local topographical changes between measurements where this line intersects the glacier boundary can give unrepresentative results. This can occur after a particularly large annual change. At Buerbreen (Folgefonna), the measured change of +27 m adjusted for some of the substantial retreat in 2004 (−90 m). Comparison of photographs from 2004 and 2005 do not show any sign of frontal advance.

At Fåbergstølsbreen (Jostedalsbreen) the measurements showed no change from 2003 to 2004, and 18 m of advance from 2004 to 2005. However, comparison of photos from 2003 and 2005 indicate only small changes (Fig. 13-2).

Table 13-1
Net glacier length change between autumn 2004 and autumn 2005 for 28 glaciers in Norway. See Figure 13-1 for locations.

Area	Glacier	Change (m)	Measured by
Jostedalsbreen	Austerdalsbreen	–9	NVE
	Bergsetbreen	–15	NVE
	Brenndalsbreen	–54	Dr. S. Winkler, Germany
	Briksdalsbreen	–25	NVE
	Bødalsbreen	–15	Dr. S. Winkler, Germany
	Fåbergstølsbreen	18	NVE
	Kjenndalsbreen	–7	Dr. S. Winkler, Germany
	Nigardsbreen	–8	Statkraft
	Stegholtbreen	–4	NVE
	Bøyabreen	–9	Norsk Bremuseum
	Store Supphellebreen	19	Norsk Bremuseum
Folgefonna	Bondhusbrea	–4	Statkraft
	Botnabrea	2	Statkraft
	Breidablikkbrea	–1	Statkraft
	Buerbreen	27	NVE
	Gråfjellsbrea	–14	Statkraft
Hardangerjøkulen	Midtdalsbreen	3	Prof. A. Nesje, U. Bergen
	Rembesdalsskåka	–60	Statkraft
Jotunheimen	Bøverbreen	–4	Dr. S. Winkler, Germany
	Hellstugubreen	–4	NVE
	Leirbreen	–5	NVE
	Storbreen	9	NVE
	Storgjuvbreen	2	Dr. S. Winkler, Germany
	Styggedalsbreen	–7	NVE
Svartisen	Engabreen	–56	Statkraft
Lyngen	Koppangsbreen	–44*	NVE
	Steindalsbreen	–32*	NVE
Finnmark	Langfjordjøkelen	–29	NVE

*since 2002

At Storbreen (Jotunheimen) the terminus was snow-covered during most of the summer, preventing ice melting and resulting in net advance. The tongue of Store Supphellebreen (Jostedalsbreen) is fed by ice avalanches, and this year a larger portion of the avalanches affected the area where the length change is measured.

Eight glaciers showed only minor changes in length (±4 m).

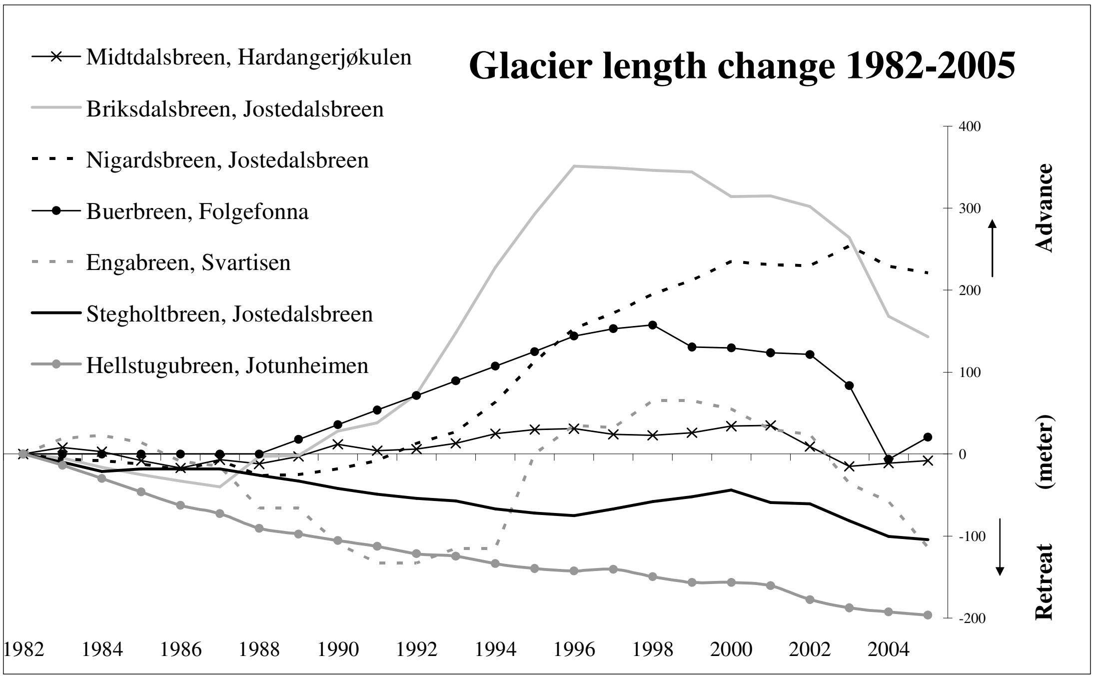


Figure 13-3
Cumulative glacier length change since 1982 at seven glaciers. See Figure 13-1 for locations.

Changes since 1982

In the 1980s, most of the observed glaciers retreated slowly (Fig. 13-3). 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. This advance ended around the turn of the century. At Briksdalsbreen the advance had already ceased in 1996, whilst it continued until 2000 for most glaciers. At Stegholtbreen the advance didn't begin until 1996 and lasted four years. At that time many continental glaciers such as Hellstugubreen were slowly retreating.

13.2 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. In 2005 observations included photographs of the glacier front only, and no measurements on the glacier.

Figure 13-4 shows three photographs of Baklibreen – from 1986 after the icefall, in 2000 when the glacier was at its maximum extent and most recently from 2005. These show that the extent of the glacier is now similar to what it was immediately after the icefall in 1987, after going through a period of advance and retreat.

Figure 13-4
Baklibreen, 1986 at left, 2000 centre, and 2005, at right. Photos: Bjørn Wold, Bjarne Kjøllmoen and Miriam Jackson, respectively.

Previous measurements

A comparison of glacier surface measurements done in 1989 with a map based on aerial photographs from 1984 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.

Scenario

Continued surface lowering of Baklibreen suggests that a large ice avalanche, 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 in front of Baklibreen became inaccessible. However, Bergsetbreen has retreated 109 m since 2000. The lower part of the glacier tongue is mainly detached from the body of the glacier and is now stagnant ice that is rapidly downwasting. This means that there may be more foot traffic in coming years below Baklibreen, increasing the risk of injury due to future icefalls.

13.3 Jökulhlaup at Blåmannsisen

Rundvassbreen is a 11.6 km^2 north-eastern outlet glacier of the icecap Blåmannsisen (67°20'N, 16°05'E) which, at 87 km^2, is the fifth largest glacier in Norway. In August 2005 a jökulhlaup drained more than 35 million cubic metres of water under Rundvassbreen, the glacier outlet that dams lake Øvre Messingmalmvatn. This was the second jökulhlaup, occurring four years after the previous event in 2001.

The jökulhlaup (Fig 13-5) released water to the Sisovatn hydropower reservoir and caused no damage. Most of the water was released in 36 hours and the water level in the receiving reservoir increased by 2.5 m. The maximum discharge is estimated at about 840 cubic metres per second at 2 am on Tuesday 30 August. This volume of water can produce 50 million kWh, which equals the typical annual energy consumption of about 2500 households.

Figure 13-5
Water escaping from a 2.3 km long tunnel under the Rundvassbreen glacier. The photo is taken in the afternoon on Monday 29 August by Hans Martin Hjemaas, Elkem Energi Siso AS.

This is the second known jökulhlaup from lake Øvre Messingmalmvatn. These giant floods began after significant thinning of the lower part of the glacier that was damming the lake.

The jökulhlaup was not unexpected and a series of instruments were deployed to monitor the event, and to investigate whether an early warning system is possible. Geophones placed in the glacier ice and on the bedrock adjacent to the glacier recorded ice shakes two days before the start of the jökulhlaup was visible as a rise in the water level in the receiving reservoir. The ice quakes marked the start of the event, followed shortly by a slow lowering of the water level in the lake that drained. The development of the jökulhlaup is shown in Figure 13-6.

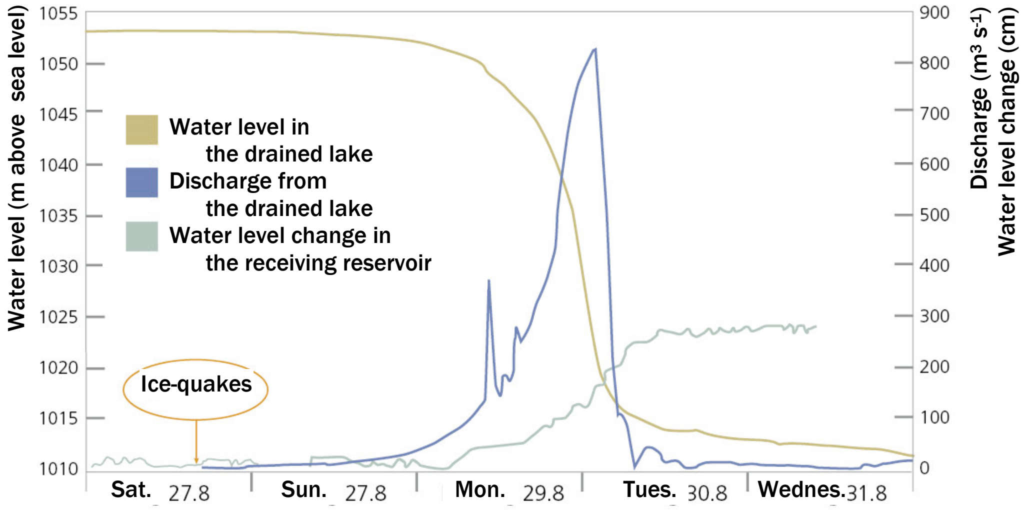


Figure 13-6
The diagram shows observations of water levels in lake Øvre Messingmalmvatn (the drained lake) and lake Sisovatn (the receiving hydropower reservoir), time of recorded ice-quakes and the estimated discharge from the jökulhlaup. The time period shown is from Saturday 27 August to Wednesday 31 August.

The jökulhlaup study is carried out in collaboration with dr. Thomas V. Schuler at the Dept. of Geosciences, University of Oslo, and Elkem Energi Siso AS.

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Appendix B

Mass balance measurements in Norway – an overview

During the period 1949-2005 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 *(km²)*	Altitude *(m a.s.l.)*	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	BL004	4.5	903-1382	1963-	43
2 Hansebreen	BO002	3.1	930-1327	1986-	20
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-	9
6 Gråfjellsbrea	AK007	9.4	1039-1660	64-68, 74- 75, 2003-	10
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-	44
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-	18
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-	43
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-	57
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-	44
26 Gråsubreen	AB047	2.3	1830-2290	1962-	44
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	39.6	10-1575	1970-	36
32 Storglombreen	C7013/C7014	59.0 62.4	520-1580 520-1580	1985-88 2000-05	10
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	1978-79	2
42 Langfjordjøkelen	ET008	3.7	280-1050	1989-93, 1996-	15

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

Appendix C

Mass balance measurements in Norway – annual results

There are results from 545 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
43	05	4.99	-4.32	0.67	9.52	1135
Mean 1963-2005		3.73	-3.51	0.22		

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
20	05	4.52	-4.61	-0.09	-7.65	1150
Mean 1986-2005		3.48	-3.86	-0.38		

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
9	05	3.09	-3.37	-0.28	-3.50	1500
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-05		2.46	-3.63	-1.17		

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	-2.98	1565
10	05	3.16	-3.15	0.01	-2.97	1460
Mean 1964-68		2.48	-2.36	0.12		
Mean 1974-75		2.32	-1.91	0.42		
Mean 2003-05		2.37	-3.36	-0.99		

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 (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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
44	05	2.80	-1.70	1.10	18.36	1395
Mean 1962-2005		2.38	-1.96	0.42		

13 Store Supphellebreen - 12.0 km² (1966)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 km^2 (1988)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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	-3.94	-2.34	-2.99	>1757
17	04	1.60	-2.56	-0.96	-3.95	1495
18	05	2.85	-2.66	0.19	-3.76	1385
Mean 1988-2005		2.24	-2.45	-0.21		

15 Spørteggbreen - 27.9 km^2 (1988)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 km^2 (1996)

No. of years	Year	bw (m w.eqv.)	bs	bn (m w.eqv.)	Cum. bn	ELA (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 km^2 (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
43	05	2.79	-2.07	0.72	6.01	1590
Mean 1963-2005		2.12	-1.98	0.14		

18 Midtdalsbreen - 6.7 km^2 (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 km^2 (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 km^2 ()

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 km^2 (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 km^2 (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	-1.20	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	-1.70	-0.31	-7.54	1770
25	73	1.48	-1.40	0.08	-7.46	1705
26	74	1.26	-1.02	0.24	-7.22	1630
27	75	1.55	-1.70	-0.15	-7.37	1760
28	76	1.81	-1.90	-0.09	-7.46	1740
29	77	0.94	-1.48	-0.54	-8.00	1840
30	78	1.26	-1.70	-0.44	-8.44	1815
31	79	1.55	-1.45	0.10	-8.34	1700
32	1980	0.99	-2.30	-1.31	-9.65	1975
33	81	1.30	-1.40	-0.10	-9.75	1730
34	82	1.28	-1.75	-0.47	-10.22	1785
35	83	1.90	-1.70	0.20	-10.02	1625
36	84	1.70	-2.00	-0.30	-10.32	1765
37	85	1.20	-1.60	-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	1570
40	88	1.45	-2.40	-0.95	-11.67	1970
41	89	2.30	-1.10	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	1605
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	1680
51	99	1.67	-1.91	-0.24	-11.03	1830
52	2000	2.04	-1.49	0.55	-10.48	1650
53	01	1.05	-1.32	-0.27	-10.75	1845
54	02	1.09	-2.87	-1.78	-12.53	2075
55	03	1.11	-2.68	-1.57	-14.10	2025
56	04	1.01	-1.59	-0.58	-14.68	1855
57	05	1.83	-1.89	-0.06	-14.74	1795
Mean 1949-2005		1.44	-1.70	-0.26		

23 Vestre Memurubre - 9.0 km^2 (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 km^2 (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
44	05	1.34	-1.63	-0.29	-14.73	1930
Mean 1962-2005		1.10	-1.44	-0.33		

26 Gråsubreen - 2.3 km² (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
44	05	0.83	-1.33	-0.50	-13.66	2180
Mean 1962-2005		0.77	-1.08	-0.31		

27 Charles Rabots Bre - 1.1 km² (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 km² (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 - 39.6 km² (2001)

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	0.82	22.29	1040
36	05	3.31	-2.42	0.89	23.18	1060
Mean 1970-2005		2.94	-2.30	0.64		

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	2.33	-3.58	-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
10	05	2.74	-2.41	0.33	-2.55	1060
Mean 1985-88		2.06	-2.80	-0.75		
Mean 2000-05		2.22	-2.65	-0.43		

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 km² (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 km² (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 km² (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 km² (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
15	05	1.88	-3.14	-1.26	-12.37	940
Mean 1989-93		2.54	-2.63	-0.10		
Mean 1996-2005		2.01	-3.25	-1.24		

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