NVE

Glaciological investigations in Norway in 2007

Bjarne Kjøllmoen (Ed.)

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Glaciological investigations in Norway in 2007

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Glaciological investigations in Norway in 2007

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Frontpage photo: Engabreen, one of the best known outlet glaciers from the Vestre Svartisen icecap. The photo was taken 1st June 2007 by Hallgeir Elvehøy.

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Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2007 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, Surface elevation change, Meteorology, Subglacial laboratory

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May 2008

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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 2007. 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, May 2008

Morten Johnsrud
Director,
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Thomas Skaugen
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Summary

Mass balance

Mass balance investigations were performed on fourteen glaciers in Norway in 2007. Twelve of these glaciers are in southern Norway and two are in northern Norway.

The winter balance was greater than average for nine of twelve measured glaciers in southern Norway. Rembesdalsskåka had the fifth greatest winter balance since measurements started in 1963. In northern Norway the winter balance was greater than average on Engabreen and approximately average on Langfjordjøkelen.

The summer balance was about average or slightly less at the maritime glaciers and above average at the inland glaciers.

In southern Norway the net balance was positive at the maritime glaciers and negative at the inland glaciers. Blomstølskardsbreen (+1.9 m) and Svelgjabreen (+1.3 m), two outlets at southern Folgefonna, had the greatest surplus. In Jotunheimen, Hellstugubreen and Gråsubreen had the greatest deficit with −0.7 m water equivalent. In northern Norway, Engabreen had a surplus of 1.0 m, while Langfjordjøkelen had a deficit of −0.8 m water equivalent.

Glacier length change

Glacier length changes were measured at 21 glaciers in southern Norway and seven glaciers in northern Norway in 2007. Twenty four of the glacier outlets had a retreat in length, three were unchanged and one outlet advanced. Kjenndalsbreen had a retreat of 182 m. This is the greatest annual recession since the 1940s. The recession of Briksdalsbreen continues and since 1999 both Kjenndalsbreen and Briksdalsbreen have retreated about 500 metres.

Sammendrag

Massebalanse

I 2007 ble det utført massebalansemålinger på 14 breer i Norge – tolv i Sør-Norge og to i Nord-Norge.

Vinterbalansen ble større enn gjennomsnittet på ni av 12 målte breer i Sør-Norge. Rembesdalsskåka fikk den femte største vinterbalansen siden målingene startet i 1963. I Nord-Norge ble vinterbalansen større enn gjennomsnittet på Engabreen og omtrent som gjennomsnittet på Langfjordjøkelen.

Sommerbalansen ble omtrent som gjennomsnittet eller litt mindre på de maritime breene og litt over gjennomsnittet på breene i innlandet.

I Sør-Norge ble det positiv nettobalanse på de maritime breene og negativ nettobalanse på breene i innlandet. Størst overskudd fikk Blomstølskardsbreen (1,9 m) og Svelgjabreen (1,3 m) på Søndre Folgefonna. I Jotunheimen fikk Hellstugubreen og Gråsubreen det største underskuddet med –0,7 m vannekvivalenter. I Nord-Norge fikk Engabreen overskudd (1,0 m), mens Langfjordjøkelen (–0,8 m) fikk underskudd.

Lengdeendringer

Lengdeendringer ble målt på 21 breer i Sør-Norge og sju breer i Nord-Norge i 2007. Tjuefire av breutløperne hadde tilbakegang, tre var uendret og én hadde framgang. Kjenndalsbreen hadde tilbakegang på 182 m. Det er den største tilbakegangen målt over ett år siden 1940-tallet. Briksdalsbreen fortsetter å smelte tilbake og siden 1999 har både Kjenndalsbreen og Briksdalsbreen hatt en samlet tilbakegang med omkring 500 meter.

1. Glacier investigations in Norway in 2007

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

Summer and net balance

Summer and net balances are obtained from stake measurements, usually performed in September or October. 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 1-1
Snow density measurements at Gråfjellsbrea, Folgefonna in April 2007.
Photo: Hallgeir Elvehøy.

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. On 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 2007 mass balance measurements were performed on 14 glaciers in Norway - 12 in southern Norway and 2 in northern Norway. In southern Norway, 6 of the glaciers have been measured for 45 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.e. Storbreen in Jotunheimen has the longest series of all glaciers in Norway with 59 years of measurements, while Engabreen at Svartisen has the longest series (38 years) in northern Norway. In 2007, mass balance measurements were started on Svelgjabreen and Blomstølskardsbreen, two adjacent south facing outlet glaciers from Folgefonna. The location of the glaciers investigated is shown in Figure 1-2. 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 2007 are reported.

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.

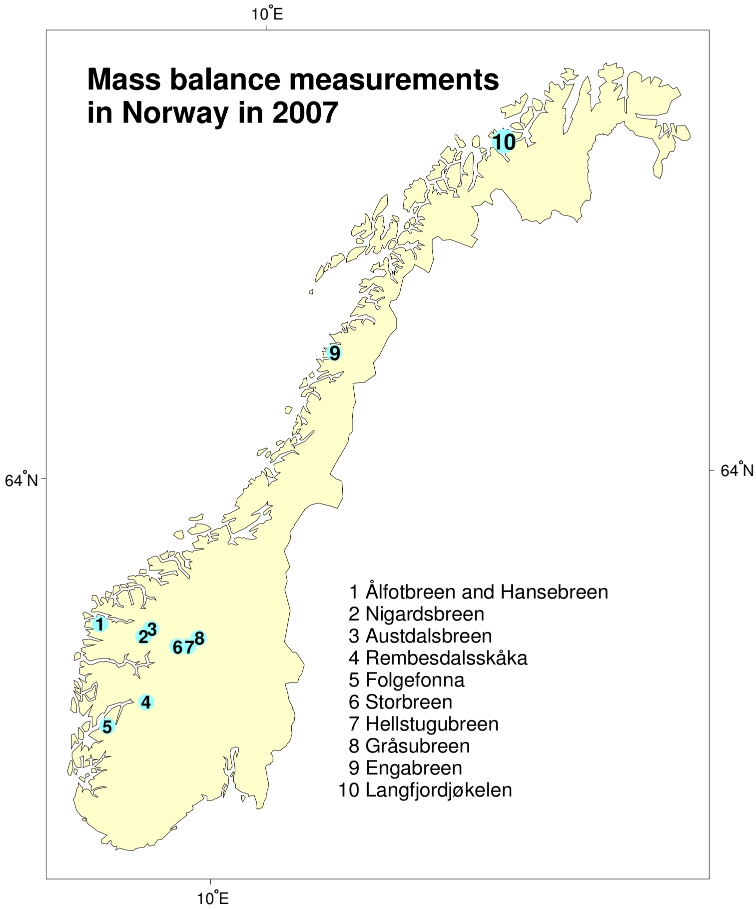


Figure 1-2
Location of the glaciers at which mass balance studies were performed in 2007.

Weather conditions and mass balance results

Wintry weather

In general the 2006/2007 winter season was mild and snow-rich over most of the country. November, December and January were characterised by high temperatures and heavy snowfall. February and March were dry in northern Norway, but rather variable in southern Norway. April was snow-rich in western and northern Norway.

Snow accumulation and winter balance

The winter balance was greater than average at nine of twelve measured glaciers in southern Norway. The long-term (20 years or more) glaciers in western Norway had results of 112 to 149 % of their average winter balance. The western part of Hardanger-jøkulen, called Rembesdalsskåka, had the fifth greatest winter balance (3.1 m w.e.) since measurements began in 1963. The glaciers in Jotunheimen had between 79 and 94 % of average. In northern Norway, Engabreen had 114 % and Langfjordjøkelen 98 % of average.

Summer weather

The summer season in 2007 was slightly warmer than normal over the whole country. June was much warmer than normal in southern Norway. July however, was cool in the south but warm in the northern parts of the country. September was cool over most of the country.

Ablation and summer balance

The summer balance was about average or below at the maritime glaciers in southern Norway. The long-term glaciers in western Norway had summer balances between 81 and 103 % of their average. Hansebreen had the lowest relative summer balance. The glaciers in Jotunheimen had between 101 and 122 % of their average. In northern Norway, both Engabreen and Langfjordjøkelen had approximately summer balances as average.

Net balance

In southern Norway, net balance was positive for nine of twelve measured glaciers in 2007. The greatest surplus was measured at Ålfotbreen (+1.3 m w.e.), Rembesdalsskåka (+1.2 m w.e.) and Nigardsbreen (+1.0 m w.e.). The three measured glaciers in Jotunheimen all had slightly negative net balances. In northern Norway, Langfjordjøkelen had a distinct deficit (–0.8 m w.e.).

The results from the mass balance measurements in Norway in 2007 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.e.) 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 2007. The glaciers in southern Norway are listed from west to east.

Glacier	*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	1963-07	4.5	903-1382	4.49	121	−3.22	90	1.27	0.14	1000	97
Hansebreen	1986-07	3.1	930-1327	4.07	119	−3.23	81	0.84	−0.55	1042	89
Blomstølskardsbreen	2007-	22.8	1013-1636	4.17	-	−2.30	-	1.88	-	1230	89
Svelgjabreen	2007-	22.5	832-1636	3.89	-	−2.54	-	1.35	-	1205	78
Breidablikkbrea	1963-68 2003-07	3.9 3.6	1219-1660 1236-1659	3.42	[1]155	−2.99	[1]101	0.43	−0.19 [1]−0.76	1400	70
Gråfjellsbrea	1964-68 1974-75 2003-07	9.4 8.9	1039-1660 1051-1659	3.58	[2]154	−2.80	[2]102	0.78	0.20 [2]−0.42	1375	80
Nigardsbreen	1962-07	47.8	320-1960	3.09	131	−2.05	103	1.04	0.38	1320	91
Austdalsbreen	1988-07	11.8	1200-1757	2.46	112	[3]−2.28	93	0.18	−0.31	1405	75
Rembesdalsskåka	1963-07	17.1	1020-1865	3.10	149	−1.93	96	1.17	0.09	1570	85
Storbreen	1949-07	5.4	1390-2100	1.35	94	−1.74	101	−0.39	−0.29	1835	30
Hellstugubreen	1962-07	3.0	1480-2210	1.03	94	−1.70	116	−0.67	−0.38	1975	25
Gråsubreen	1962-07	2.3	1830-2290	0.61	79	−1.32	122	−0.71	−0.36	2265	1
Engabreen	1970-07	39.6	10-1575	3.37	114	−2.34	100	1.03	0.60	1035	84
Langfjordjøkelen	1989-93 1996-07	3.7	280-1050	2.09	[4]98	−2.90	[4]94	−0.81	−0.10 [4]−0.95	870	42

[1] Calculated for the measured periods 1963-68 and 2003-06
[2] Calculated for the measured periods 1964-68, 1974-74 and 2003-06
[3] Contribution from calving amounts to 0.25 m for b_s
[4] Calculated for the measured periods 1989-93 and 1996-2006

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2007. The west-east gradient is evident for both winter and summer balances. All twelve glaciers have positive net balance.

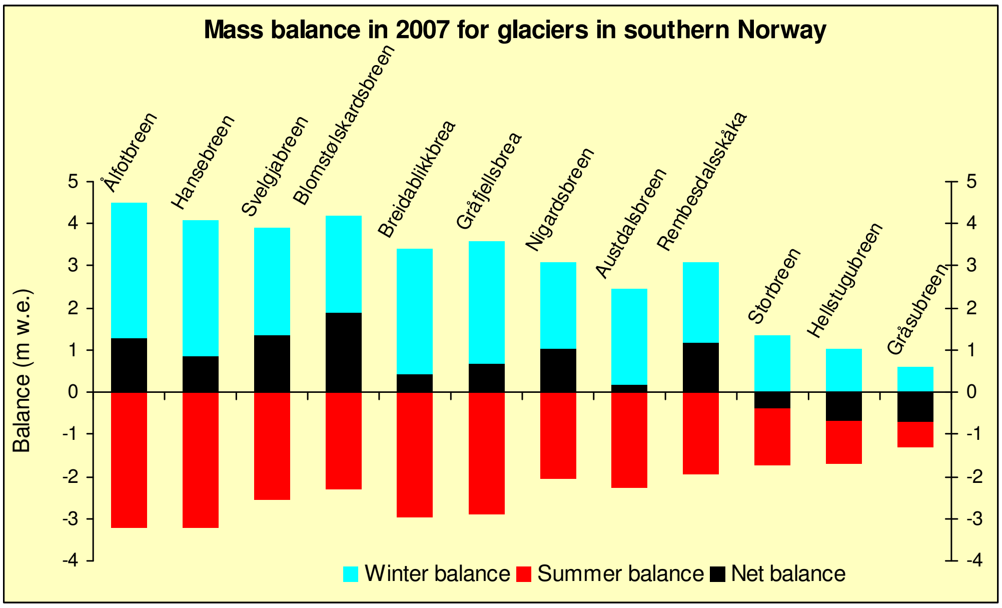


Figure 1-3
Mass balance 2007 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-time series during the period 1963-2007 is shown in Figure 1-4. 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 2007 also show a positive net balance for nine of twelve measured glaciers in southern Norway; only the continental glaciers in Jotunheimen had a negative net balance.

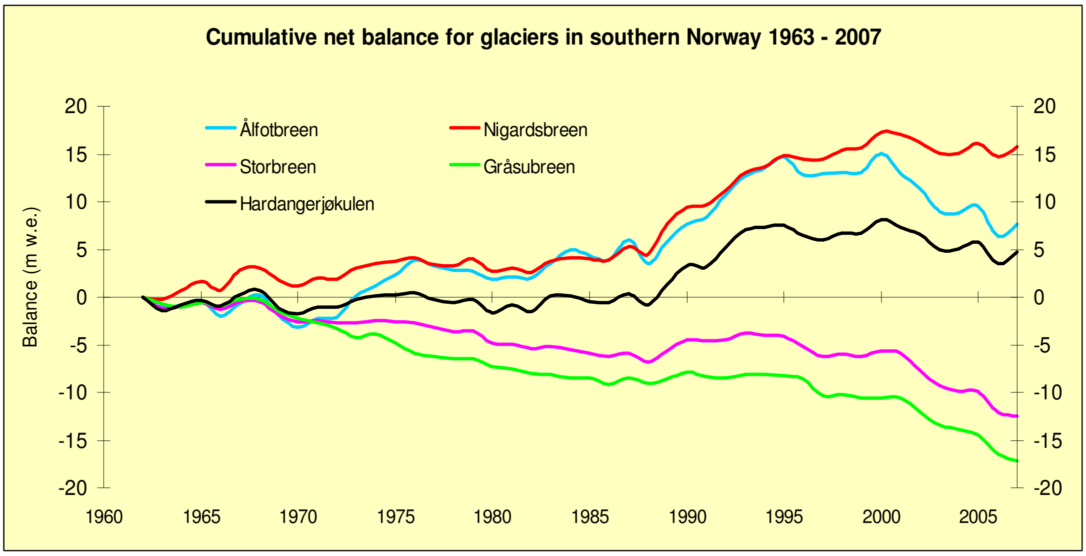


Figure 1-4
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka (Hardangerjøkulen), Storbreen and Gråsubreen during the period 1963-2007.

Other investigations

Glacier length change measurements were performed at 28 glaciers in Norway in 2007. Some of the glaciers have a measurement series going back to about 1900. The length changes are described in a separate chapter (chap. 12).

Glacier dynamics (velocity and surface elevation change) have been studied at Austdalsbreen since 1987 (chap. 5). The measurements continued in 2007.

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.

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. Since then two more jøkulhlaups have occurred, the first in August 2005 and the second in August 2007 (chap. 12).

2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45'N, 5°40'E) has an area of 17 km², 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 km²) and Hansebreen (3.1 km²). The westernmost of these two has been the subject of mass balance investigations since 1963, and has always been reported as Ålfotbreen. The adjacent glacier to the east of Ålfotbreen has been given the name Hansebreen, and has been measured since 1986. None of the outlet glaciers from the icecap are given names on the official maps. Ålfotbreen, including its component parts and surroundings, is shown in Figure 2-1.

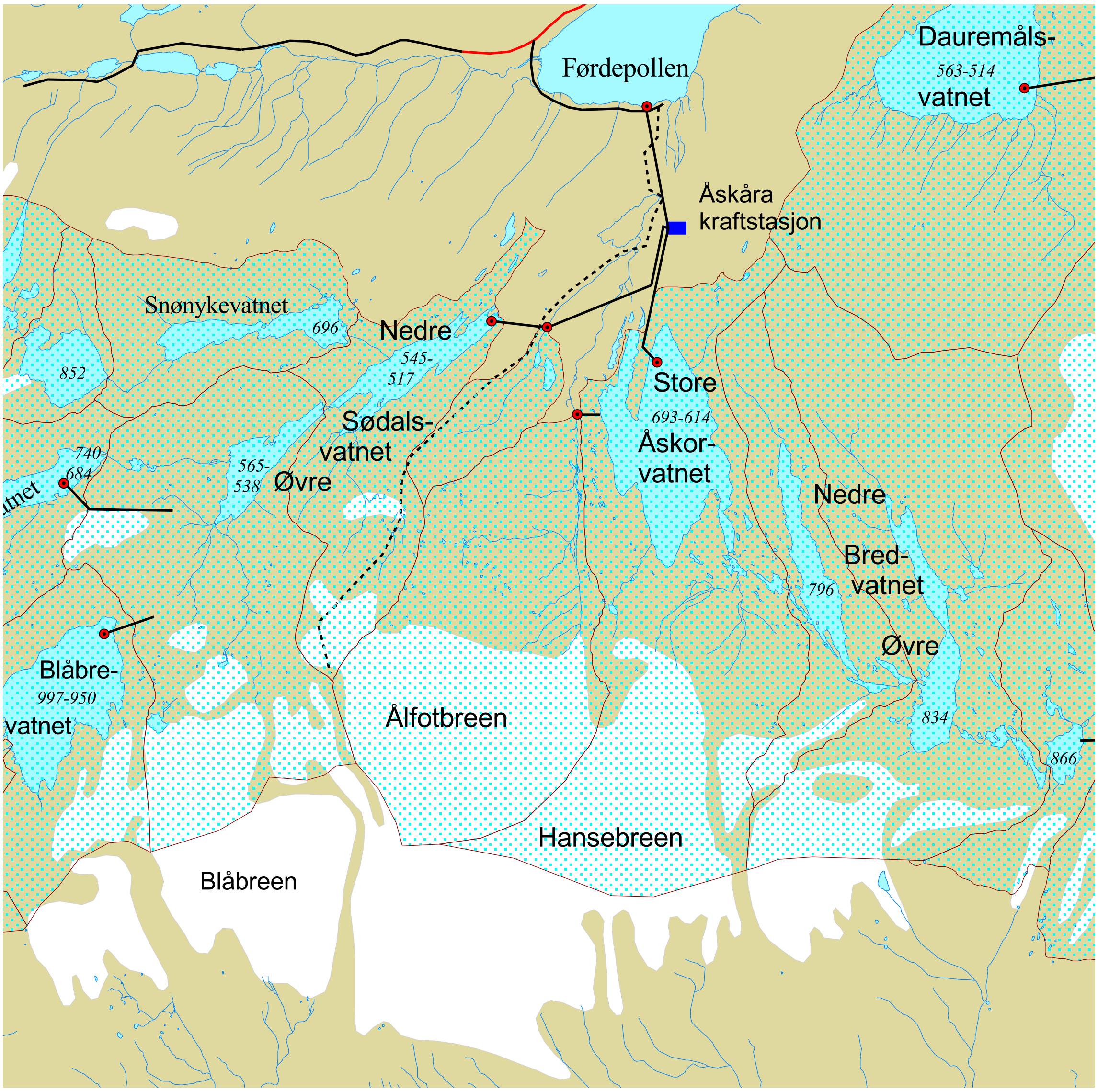


Figure 2-1
Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

2.1 Mass balance 2007

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 2nd and 3rd May. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Measurements of stake replacements and older stakes that appeared during the melt season at positions 12 (960 m a.s.l.), 13 (1090 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. Measurements of stake replacements and older stakes that appeared during the melt season in positions 50 (1020 m a.s.l.), 60 (1070 m a.s.l.), 80 (1125 m a.s.l.), 85 (1195 m a.s.l.) and 90 (1310 m a.s.l.) on Hansebreen.
- 47 snow depth soundings between 925 and 1380 m elevation on Ålfotbreen, and 47 snow depth soundings between 955 and 1310 m elevation on Hansebreen. The snow depth at Ålfotbreen was generally between 7 and 9 m, while measurements at Hansebreen showed snow depths between 6 and 8 m. In spite of deep snow, much of it high-density, the summer surface (SS) could be identified easily on both glaciers.
- Snow density was measured down to 6.8 m depth (SS) at stake position 37.

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

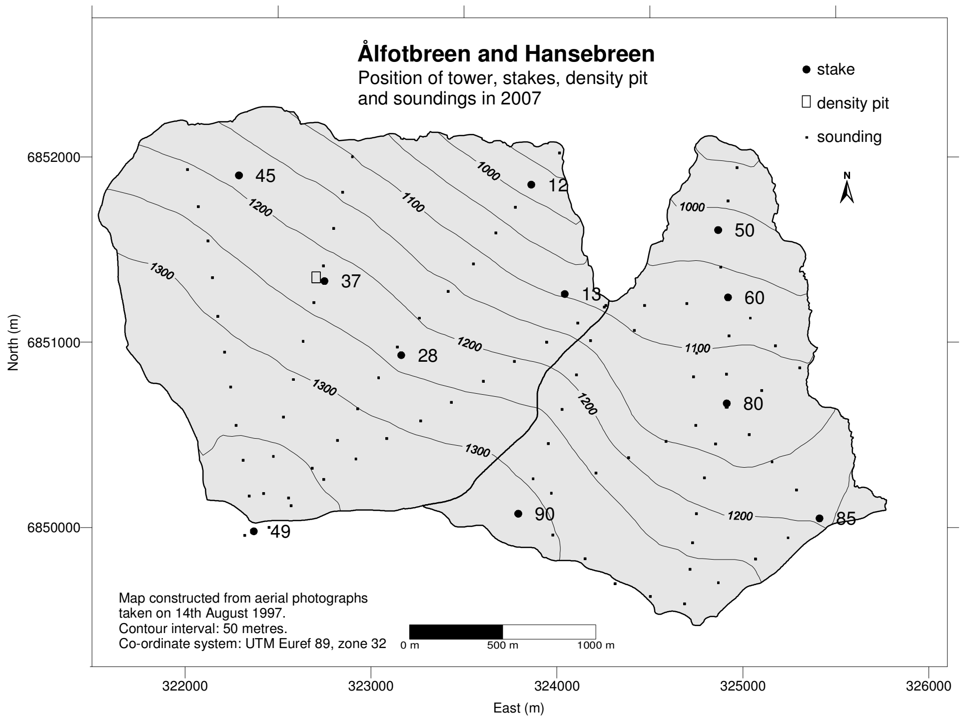


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen and Hansebreen in 2007.

Ablation measurements

Ablation was measured on 5th October. The net balance was measured directly at stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was between 2.5 and 3 m of snow remaining in the upper areas of the glacier. At the time of the ablation measurements up to 60 cm of fresh snow had fallen.

Results

The calculations are based on a glacier map from 1997.

Winter balance

The calculation of winter balance is based on point measurements of snow depth (stakes and probings) and on measurement of snow density in one location. There was no melting after the final measurements in October 2006.

A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 6.8 m snow was 0.57 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 2007 was 4.5 ±0.2 m w.e., corresponding to a volume of 20 ±1 mill. m^3 of water. The result is 121 % of the mean winter balance for 1963-2006, and 114 % of the mean for 1986-2006 (same period as Hansebreen).

The winter balance at Hansebreen was 4.1 ±0.2 m w.e., corresponding to a volume of 12 ±1 mill. m^3 of water. The result is 119 % of the mean value in the period of investigation.

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

Summer balance

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

The summer balance at Ålfotbreen was measured and calculated directly at stakes in six different positions. At 960 m elevation the measured summer balance was −4.2 m w.e. Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −3.2 ±0.3 m w.e., corresponding to −14 ±1 mill. m^3 of water. The result is 90 % of the average between 1963 and 2006, and 84 % of the average between 1986 and 2006.

The summer balance for Hansebreen was measured and calculated at stakes in five different positions. It increased from −2.9 m w.e. at 1310 m elevation to −3.9 m w.e. at 1020 m elevation. Based on the stake measurements and the estimated density, the summer balance was calculated as −3.2 ±0.3 m w.e. or −10 ±1 mill. m^3 of water. The result is 81 % of the mean value. Only five years have shown a lower summer balance on Hansebreen.

The summer balance for both Ålfotbreen and Hansebreen is the lowest measured since 1994.

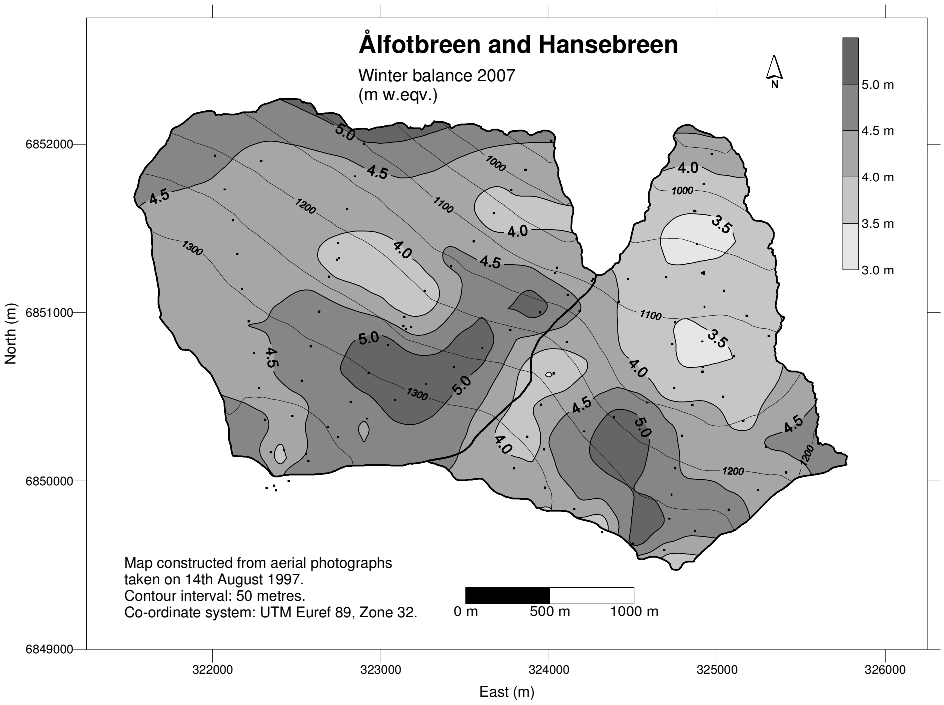


Figure 2-3
Winter balance at Ålfotbreen and Hansebreen in 2007 interpolated from 116 snow depth measurements, shown by (·).

Net balance

The net balance at Ålfotbreen for 2007 was positive, at +1.3 ±0.4 m w.e., or a surplus of 6 ±2 mill. m^3 of water. The mean net balance between 1963 and 2006 is +0.14 m w.e., and +0.09 m w.e. during 1986-2006 (same measurement period as Hansebreen). Since measurements started in 1963 the cumulative net balance is +7.6 m w.e. Since 1996, however, the net balance shows a deficit of −7.1 m w.e.

The net balance at Hansebreen was calculated as +0.8 ±0.4 m w.e., or a surplus of 3 ±1 mill. m^3 of water. The mean value for the period 1986-2006 is −0.55 m w.e. Only four years have shown a greater surplus on Hansebreen; 1987, 1992, 1993 and 2000. After six successive years with negative net balance this is the first year with surplus on Hansebreen since 2000. Since measurements began in 1986 the cumulative net balance is −10.8 m w.e.

According to Figure 2-4 the Equilibrium Line Altitude (ELA) lies at 1000 m a.s.l. on Ålfotbreen and at 1042 m a.s.l. on Hansebreen. Consequently, the AAR is 97 % and 89 % 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.

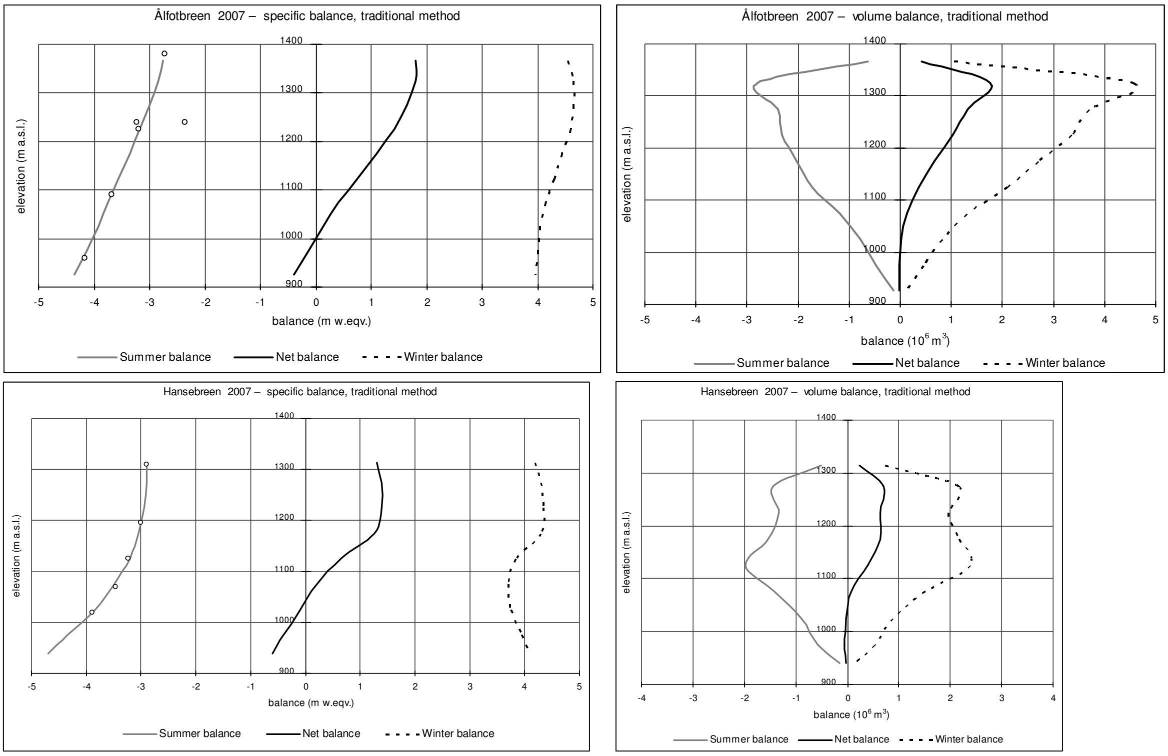


Figure 2-4
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2007 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).

Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2007. The mean values for Ålfotbreen during the period 1963-2006 are 3.71 m (b_w), −3.56 m (b_s) and +0.14 m w.e. (b_n). The corresponding values for Hansebreen during the period 1986-2006 are 3.43 m, −3.99 m and −0.55 m w.e.

Mass balance Ålfotbreen 2006/07 – traditional method

		Winter balance Measured 3th May 2007		Summer balance Measured 5th Oct 2007		Net balance Summer surfaces 2006 - 2007	
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	4.55	1.1	-2.75	-0.6	1.80	0.4
1300 - 1350	0.98	4.65	4.6	-2.85	-2.8	1.80	1.8
1250 - 1300	0.80	4.65	3.7	-3.00	-2.4	1.65	1.3
1200 - 1250	0.73	4.60	3.4	-3.18	-2.3	1.43	1.0
1150 - 1200	0.61	4.45	2.7	-3.35	-2.0	1.10	0.7
1100 - 1150	0.49	4.30	2.1	-3.55	-1.7	0.75	0.4
1050 - 1100	0.32	4.15	1.3	-3.75	-1.2	0.40	0.1
1000 - 1050	0.20	4.05	0.8	-3.93	-0.8	0.13	0.0
950 - 1000	0.11	4.00	0.5	-4.13	-0.5	-0.13	0.0
903 - 950	0.03	3.95	0.1	-4.35	-0.1	-0.40	0.0
903 - 1382	**4.50**	**4.49**	**20.2**	**-3.22**	**-14.5**	**1.27**	**5.7**

Mass balance Hansebreen 2006/07 – traditional method

		Winter balance Measured 3th May 2007		Summer balance Measured 5th Oct 2007		Net balance Summer surface 2006 - 2007	
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	4.20	0.74	-2.90	-0.51	1.30	0.23
1250 - 1300	0.50	4.30	2.15	-2.90	-1.45	1.40	0.70
1200 - 1250	0.45	4.35	1.97	-2.95	-1.33	1.40	0.63
1150 - 1200	0.51	4.30	2.18	-3.05	-1.55	1.25	0.63
1100 - 1150	0.62	3.85	2.39	-3.20	-1.99	0.65	0.40
1050 - 1100	0.40	3.70	1.49	-3.50	-1.41	0.20	0.08
1000 - 1050	0.23	3.75	0.88	-3.85	-0.90	-0.10	-0.02
950 - 1000	0.13	3.95	0.53	-4.35	-0.58	-0.40	-0.05
930 - 950	0.03	4.10	0.13	-4.70	-0.15	-0.60	-0.02
930 - 1327	**3.06**	**4.07**	**12.5**	**-3.23**	**-9.9**	**0.85**	**2.6**

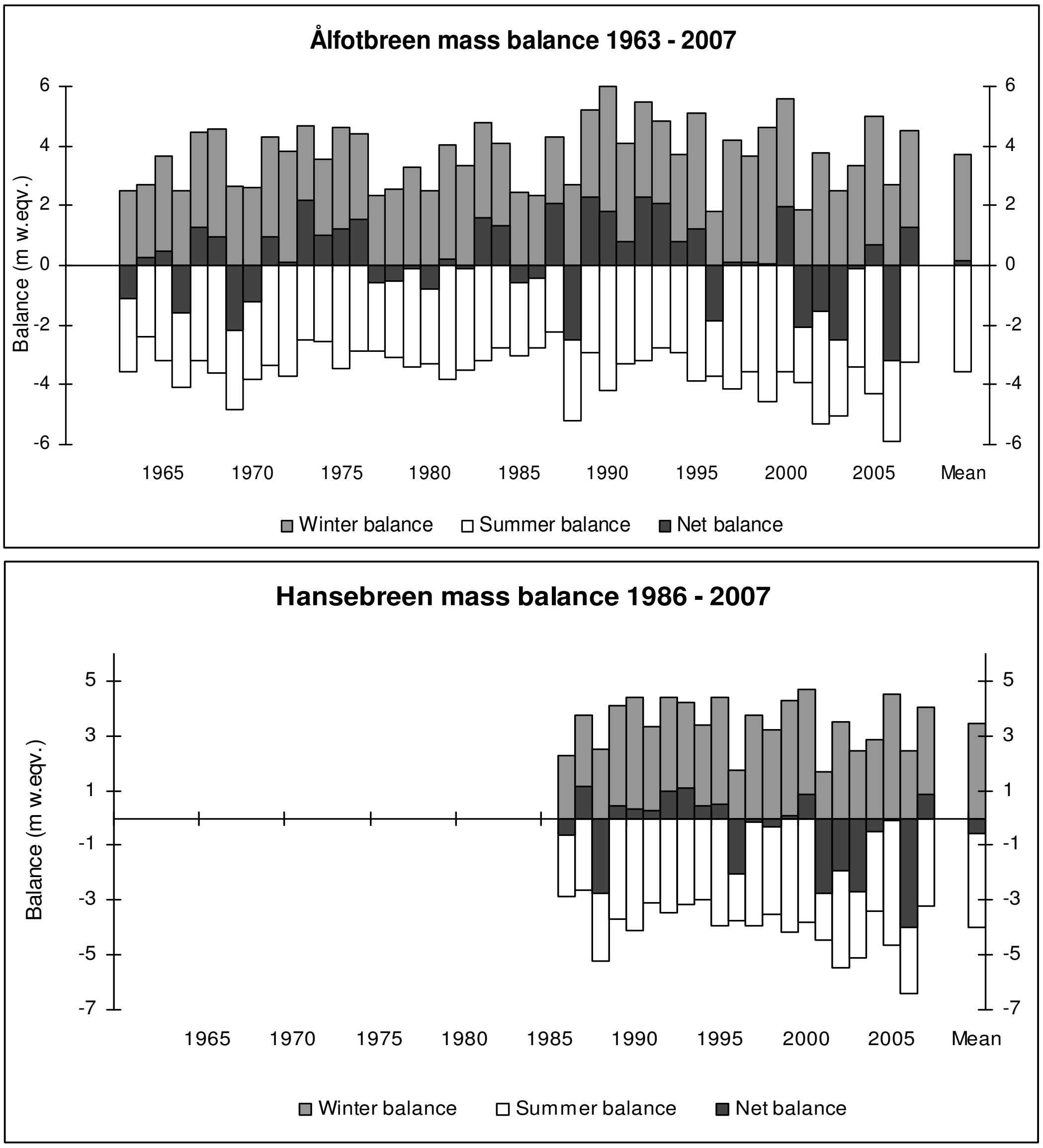


Figure 2-5
Mass balance at Ålfotbreen (upper) during the period 1963-2007 and Hansebreen (lower) during the period 1986-2007. The bar furthest to the right on each figure indicates the mean values.

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. Southern Folgefonna is the third largest (161 km^2 in 2007) ice cap in Norway. In 2003 mass balance measurements began on two adjacent westward-facing outlet glaciers of Southern Folgefonna (60°4'N, 6°24'E) – Breidablikkbrea (3.4 km^2) and Gråfjellsbrea (8.4 km^2). In 2007 mass balance measurements began on two more outlet glaciers of Southern Folgefonna – the two adjacent southward-facing glaciers Svelgjabreen (22.5 km^2) and Blomstølskardsbreen (22.8 km^2).

Mass balance measurements were previously 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 3-4. Mass balance measurements were also carried out at Svelgjabreen/Blomstølskardsbreen (then called Blomsterskardsbreen) in 1971 (Tvede, 1973), and net balance only was measured in the period 1972-77.

Figure 3-1
Southern Folgefonna with Breidablikkbrea and Gråfjellsbrea in the northwest and Svelgjabreen and Blomstølskardsbreen in the south.

3.1 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2007

Fieldwork

Snow accumulation measurements

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

- Measurement of stakes at positions 40 (1255 m a.s.l.), 41 (1280 m a.s.l.) and 50 (1475 m a.s.l.) on Breidablikkbrea and measurement of a stake in position 20 (1360 m a.s.l.) on Gråfjellsbrea. Measurements of stake replacements and older stakes that appeared during the melt season at position 56 (1570 m a.s.l.) on Breidablikkbrea and position 25 (1485 m a.s.l.) on Gråfjellsbrea.
- 26 snow depth soundings between 1255 and 1659 m a.s.l. on Breidablikkbrea, and 67 snow depth soundings between 1095 and 1654 m a.s.l. on Gråfjellsbrea. Generally, the sounding conditions were reasonable on both glaciers. The snow depth varied between 5 and 8 m.
- A core sample and snow density was measured down to the summer surface (6.5 m) at position 25 at Gråfjellsbrea.

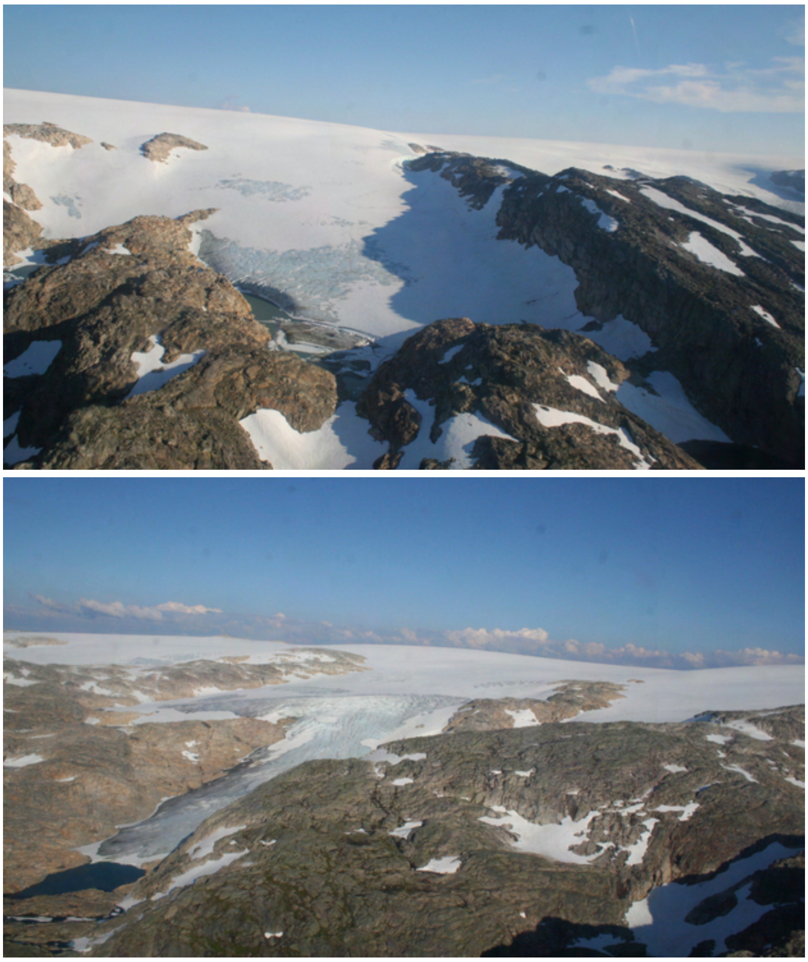


Figure 3-2 Breidablikkbrea (upper) and Gråfjellsbrea (lower) photographed on 9th August 2007. Photo: Hallgeir Elvehøy.

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

Ablation measurements

Ablation was measured on 27th September. The net balance was measured at stakes in seven different positions on Breidablikkbrea and six positions on Gråfjellsbrea. There was up to 3 m of snow remaining in the upper areas of the glacier. Up to 50 cm fresh snow had fallen at the time of the ablation measurements.

The glacier was visited again on 3rd December. The stakes were extended and the fresh snow layer was sounded. A comparison of the stake measurements and the probings showed that some melting had occurred after the ablation measurements in late September. At the stakes below 1550 m a.s.l. between 5 and 35 cm melting had occurred.

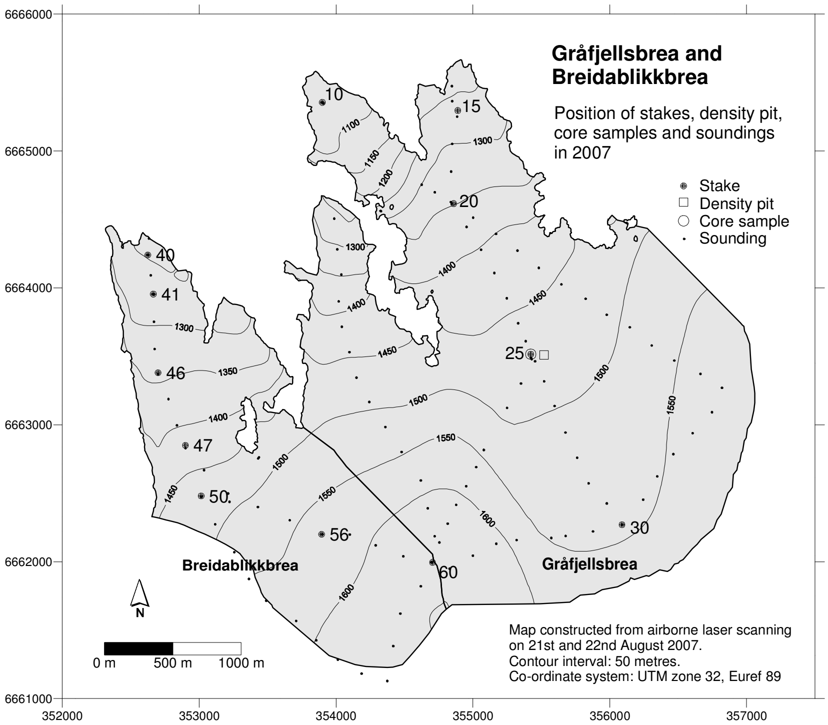


Figure 3-3 Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2007.

Results

The calculations are based on a glacier map from 2007.

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 in October 2006.

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 0.55 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. 3-5) and a mean value for each 50 m height interval was estimated (Tab. 3-1).

Winter balance at Breidablikkbrea in 2007 was 3.4 ±0.2 m w.e., corresponding to a volume of 12 ±1 mill. m^3 of water. The result is 155 % of the average for the study periods 1963-68 and 2003-06.

The winter balance at Gråfjellsbrea was 3.6 ±0.2 m w.e., corresponding to a volume of 32 ±1 mill. m^3 of water. This result is 154 % of the average for 1964-68, 1974-75 and 2003-06. This is the greatest winter balance measured on Gråfjellsbrea, including the periods 1964-68 and 1974-75.

As verification, the winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 3-4). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. This method gave results of 3.5 m w.e. for Breidablikkbrea and 3.6 m w.e. for Gråfjellsbrea.

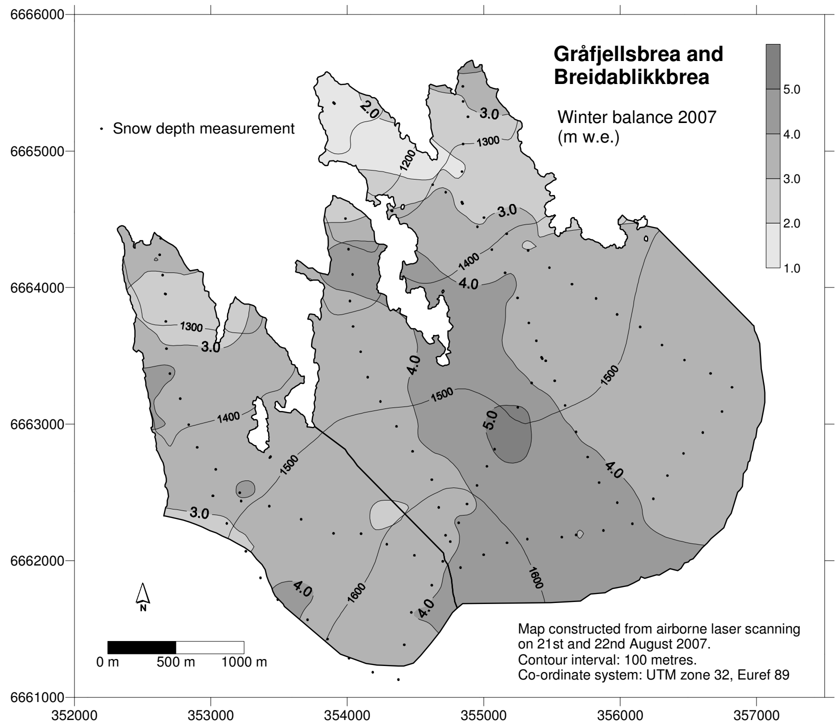


Figure 3-4
Winter balance at Breidablikkbrea and Gråfjellsbrea in 2007 interpolated from 110 snow depth measurements (·).

Summer balance

When calculating the summer balance the density of remaining snow was estimated as 0.60 g/cm^3. The density of melted ice was assumed to be 0.90 g/cm^3.

The melting that occurred after the ablation measurement at the end of September 2007 is included in the summer balance for 2007. Stake 10 was not measured in December and the additional melting is estimated to be 0.5 m w.e. For Breidablikkbrea the additional melting is calculated to be 0.05-0.25 m w.e. at the elevation interval from 1550 to 1236 m a.s.l. For Gråfjellsbrea the melting is calculated as 0.05-0.50 m w.e. between 1550 and 1051 m a.s.l.

The summer balance at Breidablikkbrea was measured and calculated at seven stakes. The stake values increased from 2.2 m w.e. at the topmost stake to 4.1 m w.e. at the lowest stake position. Based on estimated density and stake measurements the summer balance was calculated as −3.1 ±0.3 m w.e., corresponding to −11 ±1 mill. m^3 of water. This is 104 % of the mean value for 1963-68 and 2003-06.

The summer balance for Gråfjellsbrea was measured and calculated at six stakes. The stake values increased from 2.2 m w.e. at the topmost stake to 4.7 m w.e. at the lowest stake position. Based on the six stakes and the estimated density the summer balance was calculated as −2.9 ±0.3 m w.e. or −26 ±1 mill. m^3 of water. This is 106 % of the mean value for 1964-68, 1974-75 and 2003-06.

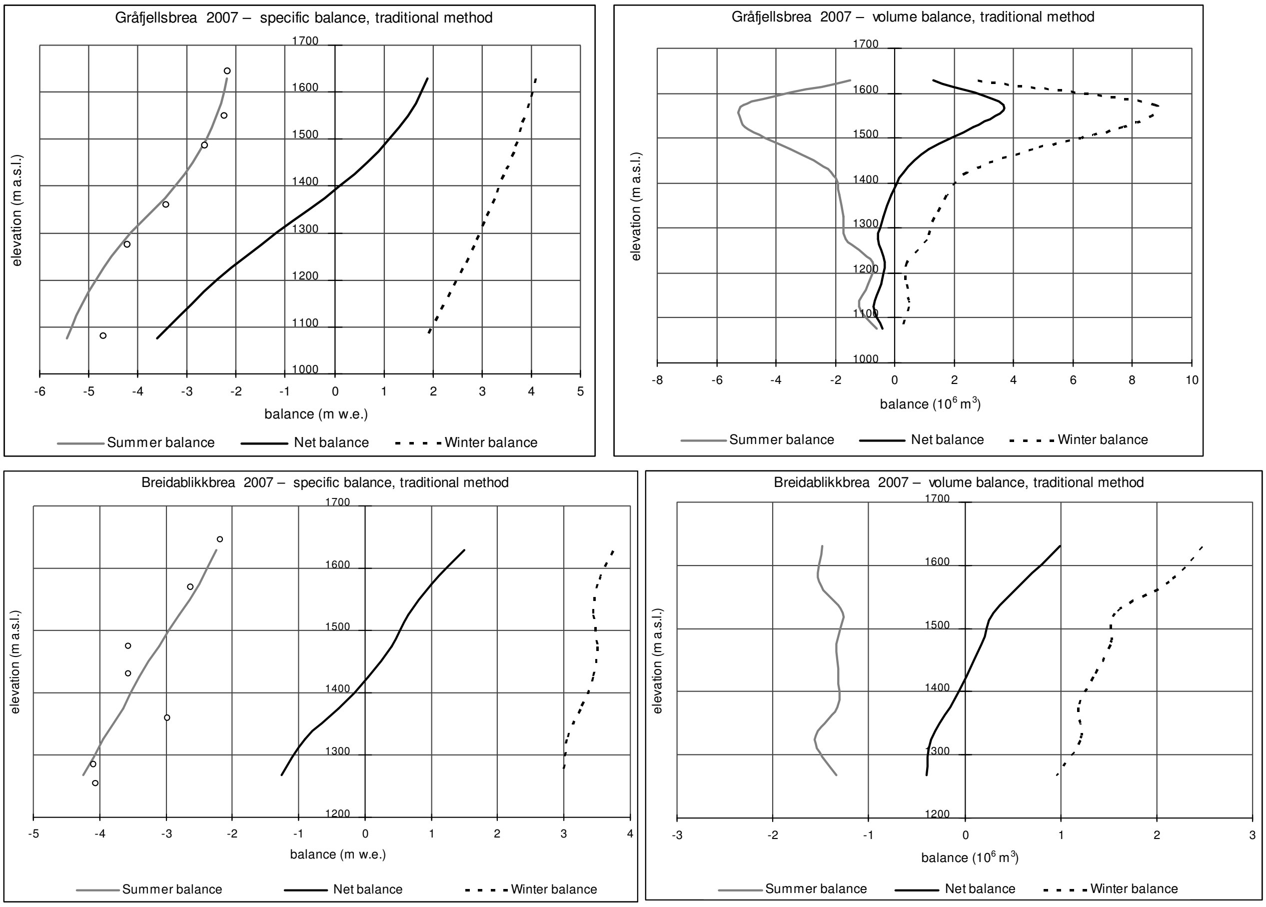


Figure 3-5
Mass balance diagram for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2007 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○). Melting after the ablation measurements on 27th September is included in the summer balance for 2007.

Net balance

The net balance at Breidablikkbrea for 2007 was calculated as +0.3 ±0.4 m w.e. or a surplus of 1 ±2 mill. m^3 of water. The mean net balance for 1963-68 and 2003-06 is −0.76 m w.e.

The net balance at Gråfjellsbrea was calculated as +0.7 ±0.4 m w.e. or a surplus of 6 ±2 mill. m^3 of water. The mean value for the years 1964-68, 1974-75 and 2003-06 is –0.42 m w.e.

This is the first year with positive net balance on Gråfjellsbrea and Breidablikkbrea since measurements were resumed in 2003.

As shown in Figure 3-5, the Equilibrium Line Altitude (ELA) lies at 1420 m a.s.l. on Breidablikkbrea and 1390 m a.s.l. on Gråfjellsbrea. Consequently, the Accumulation Area Ratio (AAR) is 66 % and 79 % respectively.

The mass balance results are shown in Table 3-1. The corresponding curves for specific and volume balance are shown in Figure 3-5. The historical mass balance results are presented in Figure 3-6.

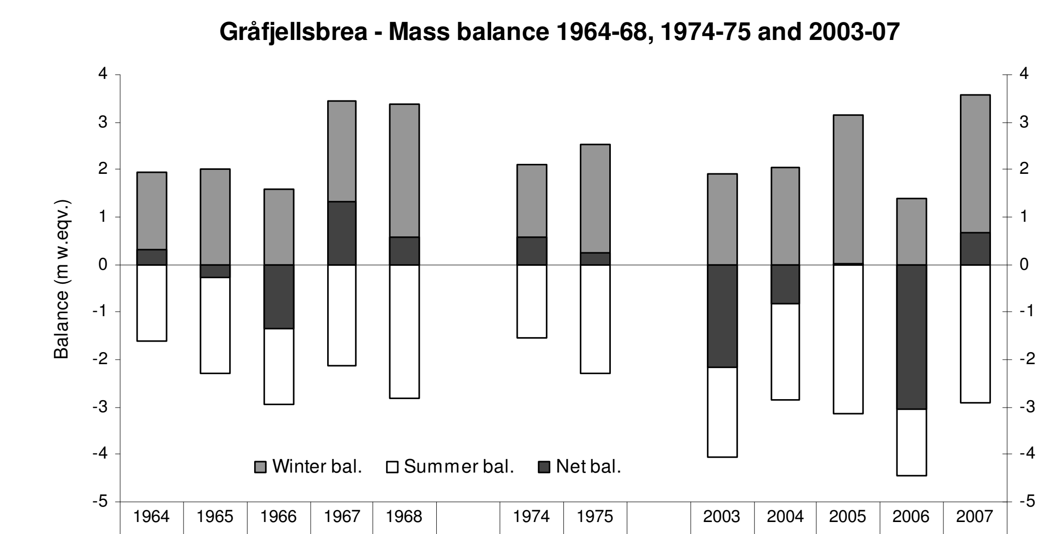
Table 3-1
Winter, summer and net balances for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2007.

Mass balance Gråfjellsbrea 2006/07 – traditional method

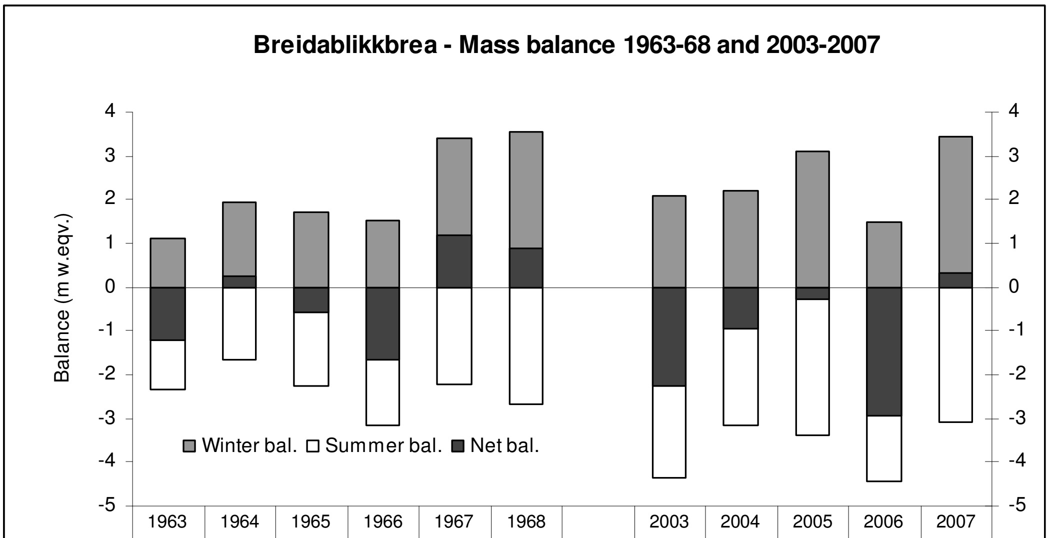
		Winter balance		Summer balance		Net balance	
		Measured 27th April 2007		Measured 27th Sep 2007		Summer surfaces 2006 - 2007	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1651	0.50	4.10	2.0	-2.20	-1.1	1.90	0.9
1550 - 1600	1.72	3.95	6.8	-2.30	-4.0	1.65	2.8
1500 - 1550	2.13	3.80	8.1	-2.50	-5.3	1.30	2.8
1450 - 1500	1.49	3.65	5.5	-2.75	-4.1	0.90	1.3
1400 - 1450	0.81	3.45	2.8	-3.05	-2.5	0.40	0.3
1350 - 1400	0.49	3.25	1.6	-3.45	-1.7	-0.20	-0.1
1300 - 1350	0.41	3.05	1.2	-3.90	-1.6	-0.85	-0.3
1250 - 1300	0.34	2.85	1.0	-4.35	-1.5	-1.50	-0.5
1200 - 1250	0.15	2.60	0.4	-4.70	-0.7	-2.10	-0.3
1150 - 1200	0.08	2.35	0.2	-5.00	-0.4	-2.65	-0.2
1100 - 1150	0.12	2.10	0.3	-5.25	-0.7	-3.15	-0.4
1049 - 1100	0.16	1.85	0.3	-5.45	-0.9	-3.60	-0.6
1049 - 1651	**8.41**	**3.58**	**30.1**	**-2.90**	**-24.4**	**0.69**	**5.8**

Mass balance Breidablikkbrea 2006/07 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 27th April 2007		Measured 27th Sep 2007		Summer surfaces 2006 - 2007	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1651	0.63	3.75	2.4	-2.25	-1.4	1.50	0.9
1550 - 1600	0.58	3.50	2.0	-2.50	-1.5	1.00	0.6
1500 - 1550	0.43	3.45	1.5	-2.80	-1.2	0.65	0.3
1450 - 1500	0.38	3.50	1.3	-3.10	-1.2	0.40	0.2
1400 - 1450	0.28	3.45	1.0	-3.40	-0.9	0.05	0.0
1350 - 1400	0.36	3.25	1.2	-3.65	-1.3	-0.40	-0.1
1300 - 1350	0.34	3.05	1.0	-3.95	-1.3	-0.90	-0.3
1234 - 1300	0.38	3.00	1.1	-4.25	-1.6	-1.25	-0.5
1234 - 1651	**3.37**	**3.41**	**11.5**	**-3.10**	**-10.4**	**0.31**	**1.0**



	1964	1965	1966	1967	1968		1974	1975		2003	2004	2005	2006	2007
Winter bal.	1.94	2.01	1.58	3.46	3.39		2.11	2.53		1.90	2.04	3.16	1.40	3.58
Summer bal.	-1.62	-2.29	-2.93	-2.14	-2.82		-1.53	-2.28		-4.07	-2.85	-3.15	-4.44	-2.91
Net bal.	0.32	-0.28	-1.35	1.32	0.57		0.58	0.25		-2.17	-0.81	0.01	-3.04	0.67



	1963	1964	1965	1966	1967	1968		2003	2004	2005	2006	2007
Winter bal.	1.11	1.92	1.72	1.52	3.40	3.55		2.08	2.21	3.09	1.49	3.42
Summer bal.	-2.32	-1.68	-2.28	-3.17	-2.23	-2.68		-4.35	-3.16	-3.37	-4.43	-3.09
Net bal.	-1.21	0.24	-0.56	-1.65	1.17	0.87		-2.27	-0.95	-0.28	-2.94	0.33

Figure 3-6
Winter, summer and net balance at Gråfjellsbrea for the periods 1963-68 and 2003-07 (upper figure), and at Breidablikkbrea for the periods 1964-68, 1974-75 and 2003-07 (lower figure).

3.2 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2007

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 27th April. The calculation of winter balance at Svelgjabreen and Blomstølskardsbreen is based on (Fig. 3-7):

- 26 snow depth soundings between 981 and 1624 m a.s.l. on Svelgjabreen, and 38 snow depth soundings between 1077 and 1615 m a.s.l. on Blomstølskardsbreen. Generally, the sounding conditions were reasonable on both glaciers, but the snow pack was extremely solid in the lowest 3-4 m. The snow depth varied between 8 and 9.5 m in the areas above 1350 m a.s.l., decreasing to 4.5 m at 980 m elevation.
- Snow density was measured down to 7.2 m (SS at 9.0 m) at stake position 65 (1530 m a.s.l.) at Blomstølskardsbreen.

The location of stakes, density pit and sounding profiles are shown in Figure 3-7.

Ablation measurements

Ablation was measured on 27th September. The net balance was measured at stakes in four different positions on Svelgjabreen and five positions on Blomstølskardsbreen. There was up to 4.5 m of snow remaining in the upper areas of the glacier. Up to 45 cm fresh snow had fallen at the time of the ablation measurements.

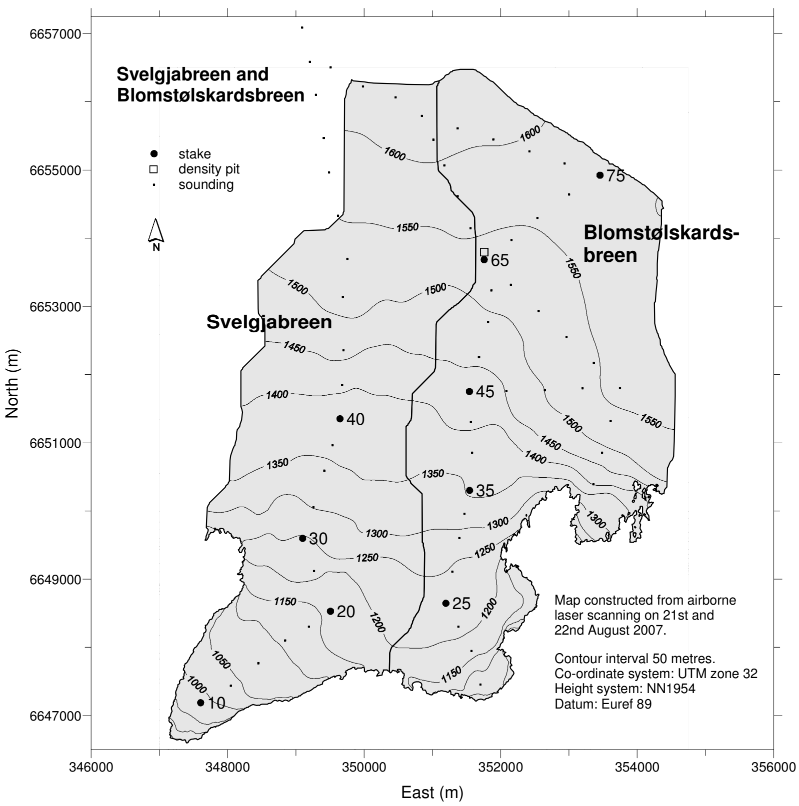


Figure 3-7
Location of stakes, soundings and density pit at Svelgjabreen and Blomstølskardsbreen in 2007.

Results

The calculations are based on a glacier map from 2007.

Winter balance

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

A density profile was modelled from the snow density measured at 1530 m a.s.l. The mean snow density of 9.0 m snow was 0.51 g/cm^3. The density model was assumed to be representative for both Svelgjabreen and Blomstølskardsbreen, 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. 3-9) and a mean value for each 50 m height interval was estimated (Tab. 3-2).

Winter balance at Svelgjabreen in 2007 was 3.9 ±0.2 m w.e. corresponding to a volume of 87 ±1 mill. m^3 of water. The winter balance at Blomstølskardsbreen was 4.2 ±0.2 m w.e. corresponding to a volume of 95 ±1 mill. m^3 of water.

The aerial distribution of winter balance for both glaciers is shown in Figure 3-8.

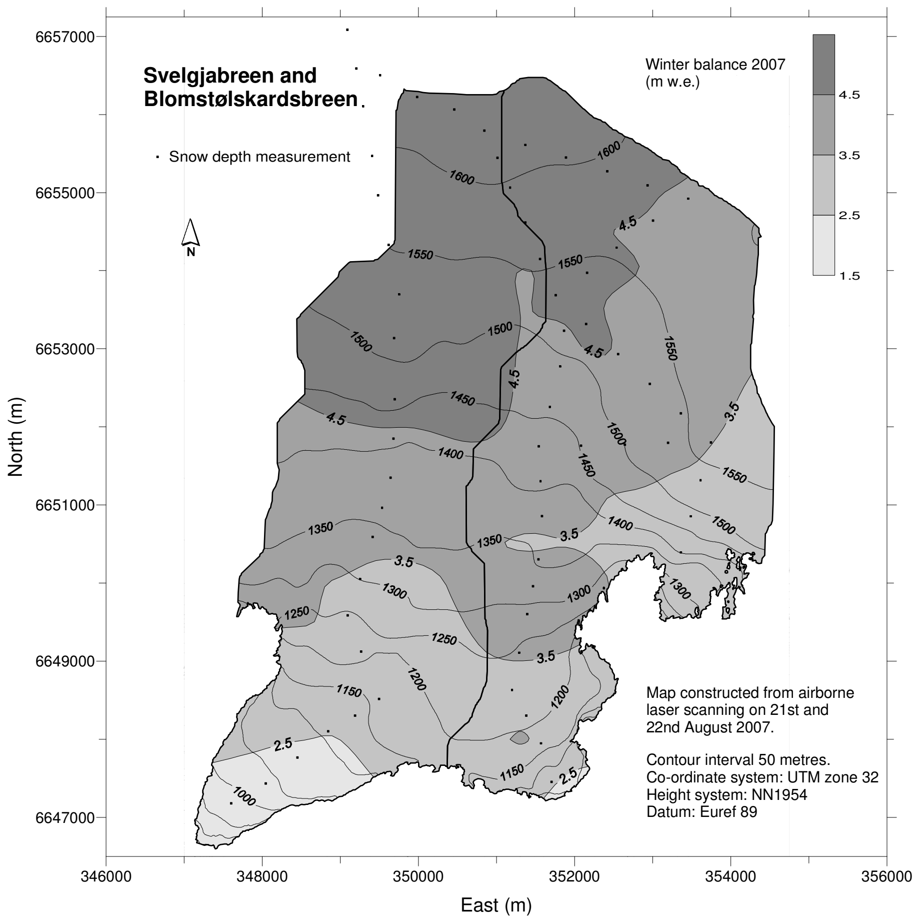


Figure 3-8
Winter balance at Svelgjabreen and Blomstølskardsbreen in 2007 interpolated from 64 snow depth measurements (·).

Summer balance

When calculating the summer balance the density of remaining snow was estimated as 0.60 g/cm^3. The density of melted ice was assumed to be 0.90 g/cm^3.

The summer balance at Svelgjabreen was measured at four stakes. The stake values increased from 2.4 m w.e. (1363 m a.s.l.) to 4.3 m w.e. (981 m a.s.l.). In order to extend the summer balance curve the summer balance value for stake 65 (1531 m a.s.l.) at Blomstølskardsbreen is also used for the calculation of summer balance at Svelgjabreen. Based on estimated density and stake measurements the summer balance was calculated as −2.5 ±0.3 m w.e. corresponding to −57 ±1 mill. m^3 of water.

The summer balance for Blomstølskardsbreen was measured and calculated at five stakes. The stake values increased from 1.7 m w.e. (1585 m a.s.l.) to 3.3 m w.e. (1233 m a.s.l.). Based on the five stakes and the estimated density the summer balance was calculated as −2.3 ±0.3 m w.e. or −52 ±1 mill. m^3 of water.

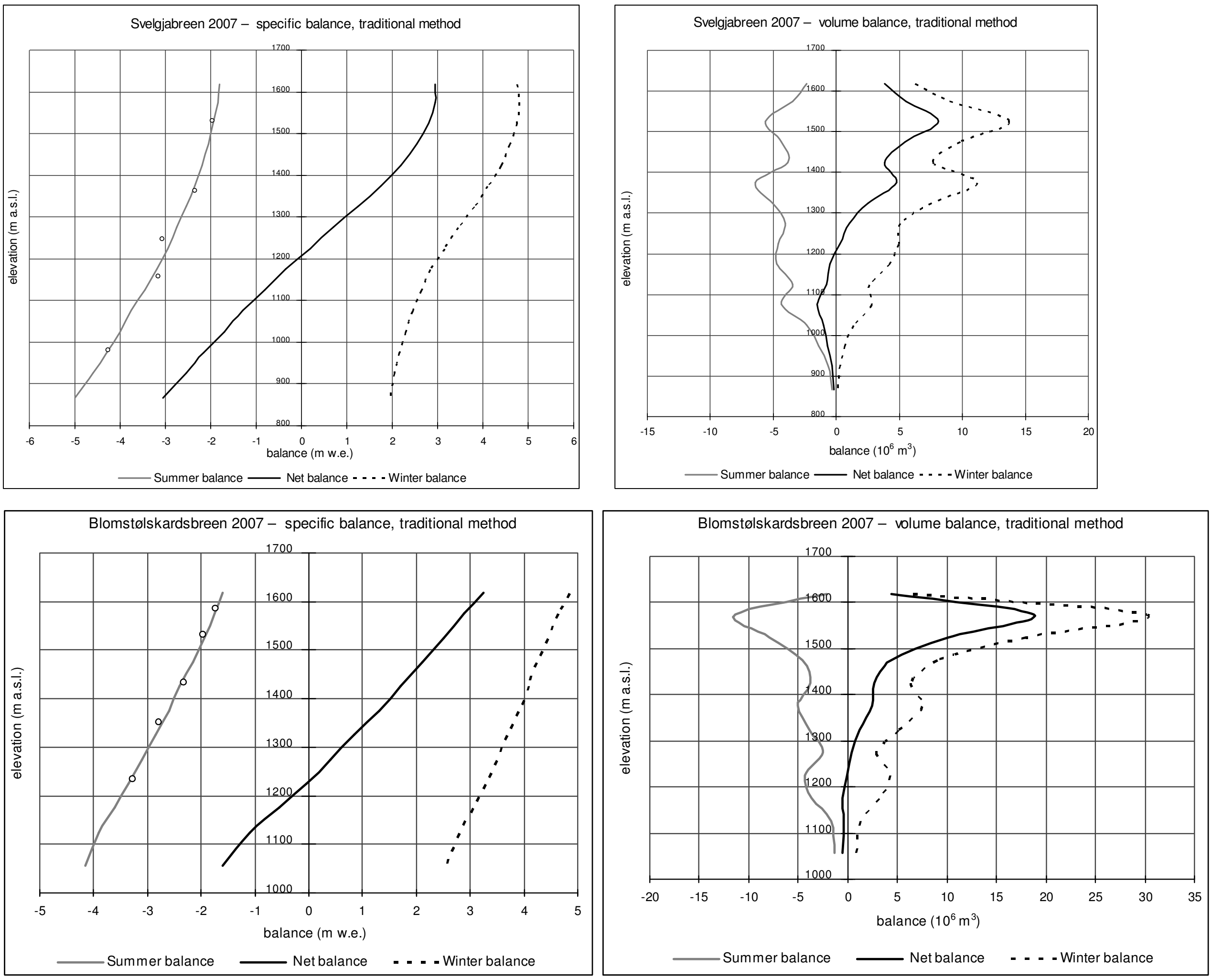


Figure 3-9
Mass balance diagram for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2007 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (◦).

Net balance

The net balance at Svelgjabreen for 2007 was calculated as +1.4 ±0.4 m w.e. or a surplus of 30 ±1 mill. m^3 of water.

The net balance at Blomstølskardsbreen was calculated as +1.9 ±0.4 m w.e. or a surplus of 43 ±1 mill. m^3 of water.

As shown in Figure 3-3, the equilibrium line altitude (ELA) lies at 1205 m a.s.l. on Svelgjabreen and 1230 m a.s.l. on Blomstølskardsbreen. Consequently, the Accumulation Area Ratio (AAR) is 78 % and 89 % respectively.

The mass balance results are shown in Table 3-2. The corresponding curves for specific and volume balance are shown in Figure 3-9.

Table 3-2
Winter, summer and net balances for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2007.

Mass balance Svelgjabreen2006/07 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 28th April 2007 Specific (m w.e.)	Volume (10^6 m^3)	Summer balance Measured 28th Sep 2007 Specific (m w.e.)	Volume (10^6 m^3)	Net balance Summer surface 2006 - 2007 Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1636	1.30	4.75	6.2	-1.80	-2.3	2.95	3.8
1550 - 1600	1.87	4.80	9.0	-1.85	-3.5	2.95	5.5
1500 - 1550	2.89	4.75	13.7	-1.95	-5.6	2.80	8.1
1450 - 1500	2.13	4.60	9.8	-2.05	-4.4	2.55	5.4
1400 - 1450	1.75	4.40	7.7	-2.20	-3.8	2.20	3.8
1350 - 1400	2.73	4.10	11.2	-2.35	-6.4	1.75	4.8
1300 - 1350	1.99	3.80	7.6	-2.55	-5.1	1.25	2.5
1250 - 1300	1.47	3.45	5.1	-2.75	-4.0	0.70	1.0
1200 - 1250	1.57	3.15	4.9	-2.95	-4.6	0.20	0.3
1150 - 1200	1.47	2.85	4.2	-3.20	-4.7	-0.35	-0.5
1100 - 1150	1.00	2.65	2.7	-3.45	-3.5	-0.80	-0.8
1050 - 1100	1.16	2.45	2.8	-3.75	-4.4	-1.30	-1.5
1000 - 1050	0.59	2.30	1.4	-4.00	-2.4	-1.70	-1.0
950 - 1000	0.32	2.15	0.7	-4.30	-1.4	-2.15	-0.7
900 - 950	0.14	2.05	0.3	-4.60	-0.7	-2.55	-0.4
832 - 900	0.06	1.95	0.1	-5.00	-0.3	-3.05	-0.2
832 - 1636	**22.45**	**3.89**	**87.3**	**-2.54**	**-57.1**	**1.35**	**30.2**

Mass balance Blomstølskardsbreen2006/07 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 28th April 2007 Specific (m w.e.)	Volume (10^6 m^3)	Summer balance Measured 28th Sep 2007 Specific (m w.e.)	Volume (10^6 m^3)	Net balance Summer surfaces 2006 - 2007 Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1636	1.35	4.85	6.5	-1.60	-2.2	3.25	4.4
1550 - 1600	6.49	4.65	30.2	-1.75	-11.4	2.90	18.8
1500 - 1550	4.04	4.45	18.0	-1.95	-7.9	2.50	10.1
1450 - 1500	2.11	4.25	9.0	-2.15	-4.5	2.10	4.4
1400 - 1450	1.56	4.10	6.4	-2.40	-3.7	1.70	2.7
1350 - 1400	1.92	3.90	7.5	-2.60	-5.0	1.30	2.5
1300 - 1350	1.37	3.70	5.1	-2.85	-3.9	0.85	1.2
1250 - 1300	0.81	3.50	2.8	-3.10	-2.5	0.40	0.3
1200 - 1250	1.31	3.30	4.3	-3.35	-4.4	-0.05	-0.1
1150 - 1200	1.02	3.05	3.1	-3.60	-3.7	-0.55	-0.6
1100 - 1150	0.45	2.80	1.3	-3.90	-1.8	-1.10	-0.5
1013 - 1100	0.33	2.55	0.9	-4.15	-1.4	-1.60	-0.5
1013 - 1636	**22.77**	**4.17**	**95.0**	**-2.30**	**-52.3**	**1.88**	**42.7**

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 2007 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The glacier snout of Nigardsbreen and the delta photographed on 5th July 2007. Photo: Miriam Jackson.

4.1 Mass balance 2007

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 4th and 5th June and the calculation of winter balance (Fig. 4-2) is based on:

- Uninterrupted measurement of stakes in positions 600 (570 m a.s.l.), 1000 (960 m a.s.l.), T95 (1680 m a.s.l.) and T56 (1800 m a.s.l.). It was also possible to make use of measurements of substitute stakes drilled in June 2007 and older stakes that appeared during the melt season in positions 55 (1465 m a.s.l.), 54 (1610 m a.s.l.) and 94 (1700 m a.s.l.). The stake measurements on the plateau showed snow depth between 5.3 (55) and 7.0 m (T95). Measured snow depth at position 1000 was 1.5 m. Stake readings did not show any indication of melting after the final measurements in October 2006.

- Core samples at positions 55, 54, 94, 96 (1750 m a.s.l.) and 57 (1960 m a.s.l.) showing snow depth between 5.6 (55) and 6.4 m (57).
- 137 snow depth soundings on the plateau between 1320 and 1960 m a.s.l. Above 1800 m elevation it was difficult to define the snow depth. Below 1800 elevation the sounding conditions were reasonable. The snow depth soundings gave a snow thickness between 5.5 and 7.5 m.
- Snow density was measured down to 5.5 m depth (SS at 5.9 m) at position 94 (Fig. 4-2).

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

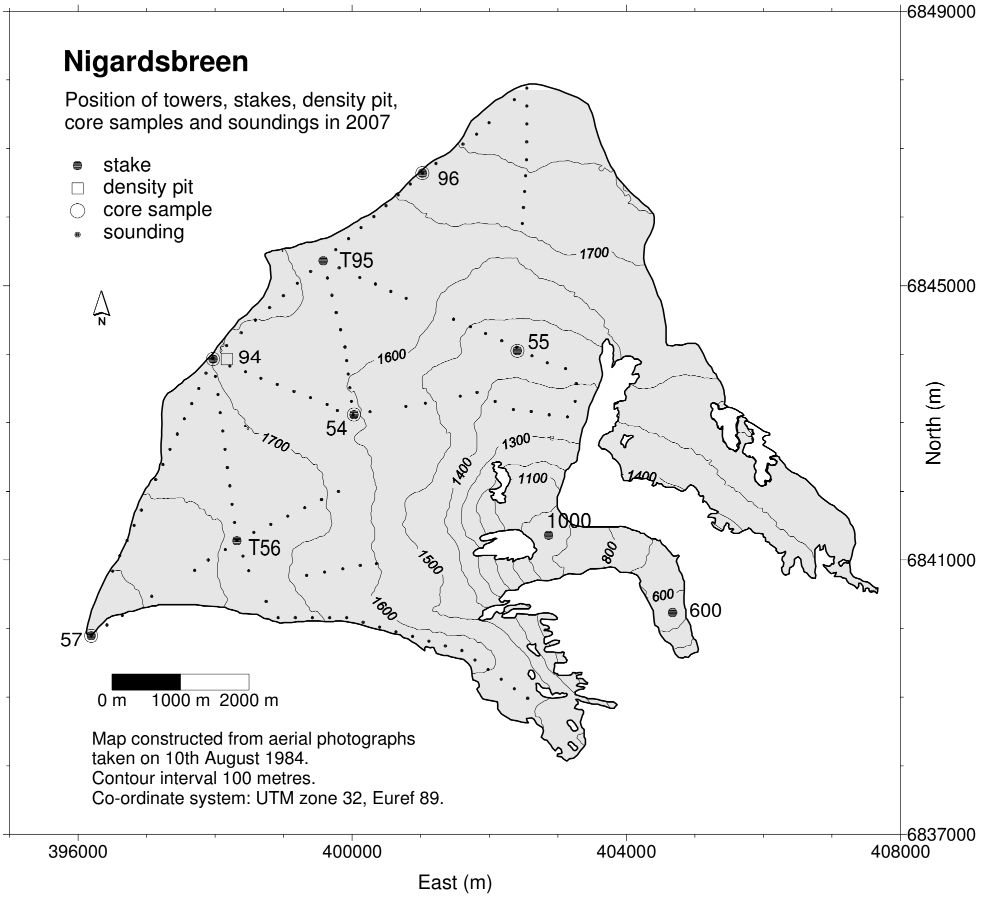


Figure 4-2
Location of towers and stakes, snow pit, core samples and soundings on Nigardsbreen in 2007.

Ablation measurements

Ablation measurements were carried out on 27th September. Measurements were made at seven stakes and two towers in eight different positions. Since snow measurements in June the stakes on the plateau had increased in length between 3.2 and 3.8 m. Hence, there was between 1.5 and 3.4 m of snow remaining from winter 2006/2007. At the time of measurement, up to 1.3 m 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 October 2006. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1700 m altitude (5.5 m depth). Using this model gave a snow density of 0.55 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 point measurements at 960 m and 570 m altitude.

These calculations give a winter balance of 3.1 ±0.2 m w.e., corresponding to a water volume of 148 ±10 mill. m^3. This is 131 % of the average for 1962-2006. Seven years have shown a greater winter balance on Nigardsbreen; the greatest was in 1989 with 4.0 m w.e.

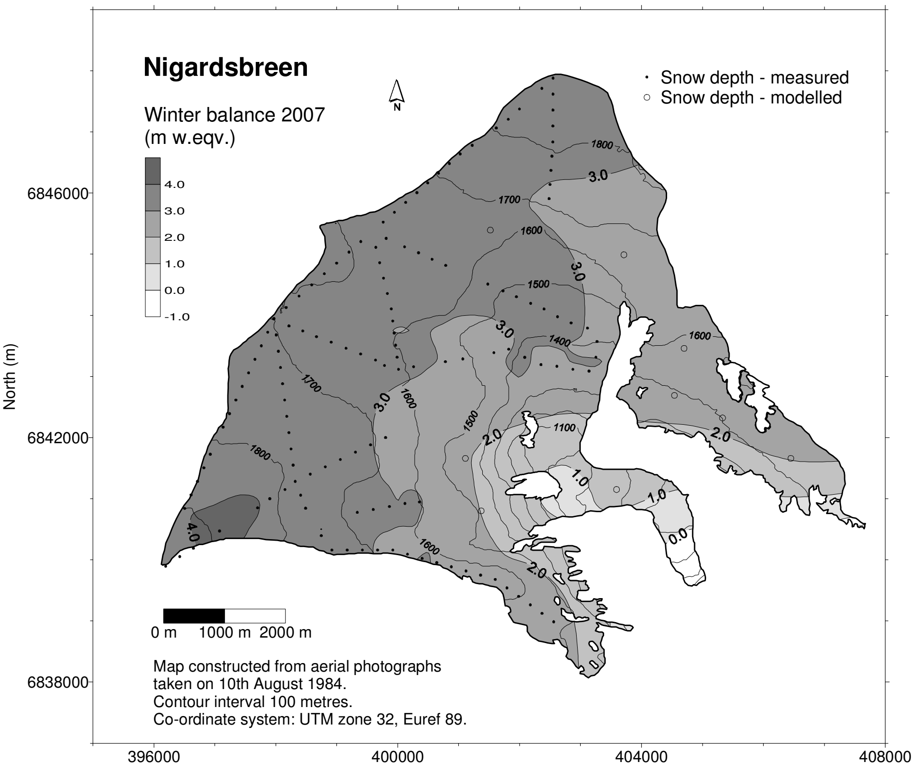


Figure 4-3
Winter balance at Nigardsbreen in 2007 interpolated from 147 measurements (·) of snow depth. In areas with few or no measurements nine extrapolated points (○) are added.

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 4-3). In areas with insufficient measurements some (nine) simulated points were extracted. These point values were calculated 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 result obtained using this gridding method was 2.9 m w.e.

Summer balance

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

The summer balance was calculated at stakes and towers at nine different elevations. At stake 57 the measurements were supplemented with estimated values based on correlation with other stakes. The summer balance increased (in absolute value) from −1.0 m w.e. at the glacier summit (1960 m a.s.l.) to −6.8 m down on the tongue (570 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −2.0 ±0.3 m w.e., which is −98 ±15 mill. m^3 of water. This is 103 % of the average for 1962-2006.

Net balance

The net balance for 2007 was calculated at stakes and towers in nine different positions. The result was a surplus of +1.0 m ±0.3 m w.e., which means a volume increase of 50 ±15 mill.m^3 water. The mean value for the period 1962-2006 is +0.38 m w.e. (Fig. 4-6), while the average for 1996-2006 is −0.01 m w.e.

Based on Figure 4-5, the Equilibrium Line Altitude (ELA) was 1320 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 91 %.

The mass balance for Nigardsbreen in 2007 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.

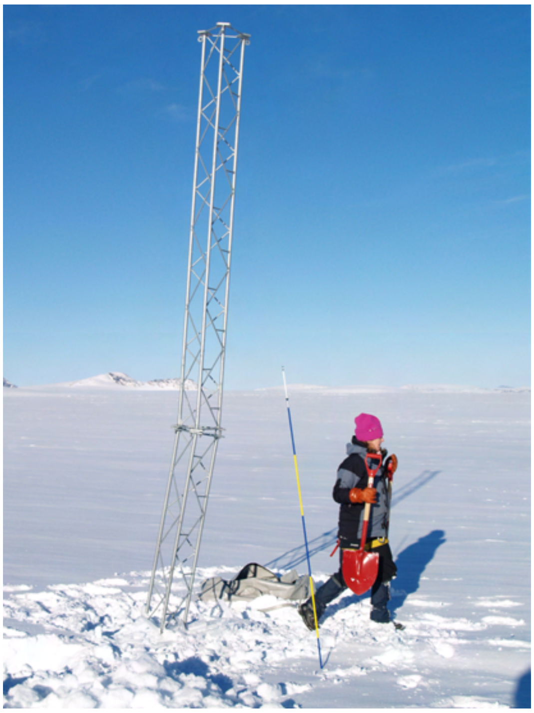


Figure 4-4
In early June the snow depth at position T56 was 6.5 m. At the end of September, when this photo was taken, 3.0 m of snow remained.
Photo: Hallgeir Elvehøy.

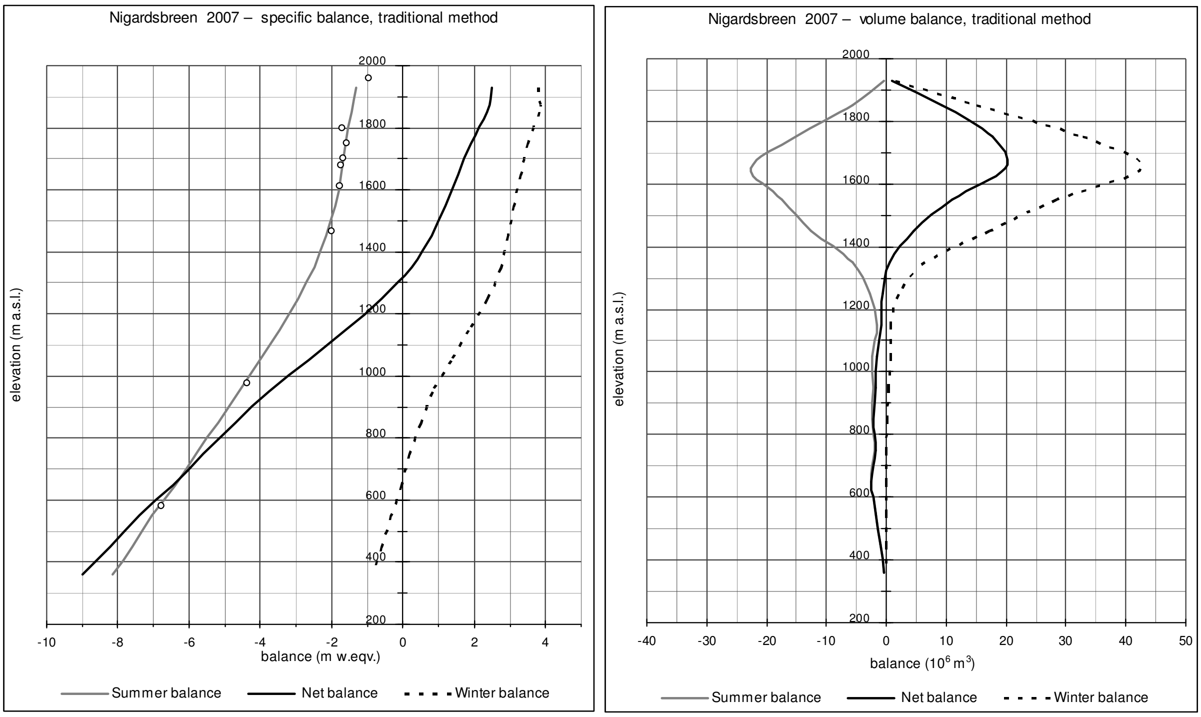


Figure 4-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2007. Specific summer balance at nine stake positions is shown as dots (o). The net balance curve intersects the y-axis and defines the ELA as 1320 m a.s.l. Thus, the AAR was 91 %.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2007. Mean values for the period 1962-2006 are 2.37 (b_s), –1.99 m (b_s) and +0.38 m (b_n) water equivalent.

Mass balance Nigardsbreen 2006/07 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 4th June 2007		Measured 27th Sep 2007		Summer surface 2006 - 2007	
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	3.79	1.4	-1.30	-0.5	2.49	0.9
1800 - 1900	3.92	3.82	15.0	-1.45	-5.7	2.37	9.3
1700 - 1800	9.39	3.50	32.9	-1.60	-15.0	1.90	17.8
1600 - 1700	12.88	3.30	42.5	-1.75	-22.5	1.55	20.0
1500 - 1600	9.18	3.10	28.5	-1.90	-17.4	1.20	11.0
1400 - 1500	5.82	2.95	17.2	-2.15	-12.5	0.80	4.7
1300 - 1400	2.28	2.75	6.3	-2.50	-5.7	0.25	0.6
1200 - 1300	0.90	2.35	2.1	-2.95	-2.7	-0.60	-0.5
1100 - 1200	0.45	1.85	0.8	-3.45	-1.6	-1.60	-0.7
1000 - 1100	0.58	1.35	0.8	-4.00	-2.3	-2.65	-1.5
900 - 1000	0.47	0.85	0.4	-4.60	-2.2	-3.75	-1.8
800 - 900	0.44	0.50	0.2	-5.20	-2.3	-4.70	-2.1
700 - 800	0.33	0.20	0.1	-5.80	-1.9	-5.60	-1.8
600 - 700	0.39	-0.05	0.0	-6.40	-2.5	-6.45	-2.5
500 - 600	0.24	-0.35	-0.1	-7.05	-1.7	-7.40	-1.8
400 - 500	0.12	-0.60	-0.1	-7.60	-0.9	-8.20	-1.0
320 - 400	0.05	-0.85	0.0	-8.15	-0.4	-9.00	-0.5
320 - 1960	**47.82**	**3.09**	**147.9**	**-2.05**	**-97.8**	**1.05**	**50.1**

The cumulative net balance shows a considerable volume increase of 18 m w.e since measurements began in 1962. Almost 60 % of this surplus occurred in the period 1989-95. Over the last twelve years (1996-2007), however, the cumulative net balance is slightly positive (0.9 m w.e.) and only four years show a significant surplus; 1998, 2000, 2005 and 2007.

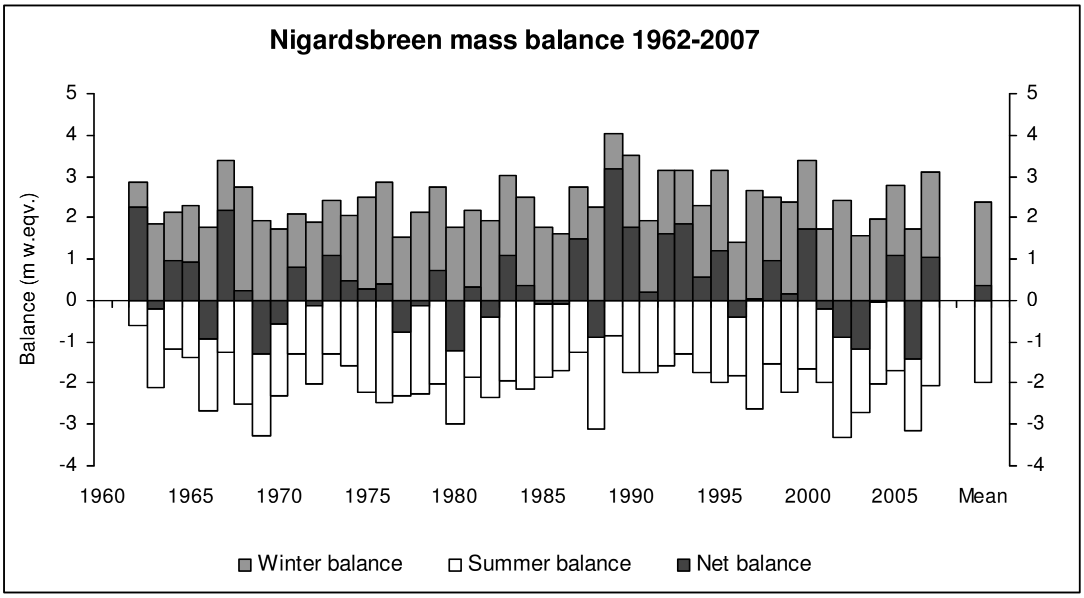


Figure 4-6
Annual mass balance at Nigardsbreen during the period 1962-2007.

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 part of the hydropower reservoir Styggevatnet since 1988. Glaciological investigations at Austdalsbreen started in 1986 in connection with the construction of the hydropower reservoir.

The glaciological investigations in 2007 included mass balance, front position change and glacier velocity. Mass balance has been measured at Austdalsbreen since 1988.

Figure 5-1
Austdalsbreen seen from AUS100 (see Fig. 5-2 for location) on 27th September 2007. The lake level was close to 1200 m a.s.l. which is the highest possible regulated lake level. Photo Miriam Jackson.

5.1 Mass balance 2007

Fieldwork

Four stakes were found on a winter visit on 24th January.

The winter balance was measured on 3rd May. The calculation of winter balance was based on the following data (Fig. 5-2):

- Snow depth at stakes A5 (1.5 m), A6 (1.95 m) A92 (3.25 m), A90 (3.4 m) and T70 (5.85 m).
- Snow density down to the previous summer surface at 5.2 m depth at stake A60 (1490 m a.s.l.). Mean snow density was 0.48 g/cm^3.

* 68 snow depth measurements along 15 km of profiles. Six measurements were excluded during the data analysis. At Austdalsnuten above 1600 m a.s.l. the snow depth was 3 to 5 m. Between 1400 and 1600 m a.s.l. the snow was 4 to 6 m deep. Below 1400 m a.s.l. the snow depth was between 3 and 4.5 m at most locations. The summer surface (SS) from 2006 was easy to detect in all areas.

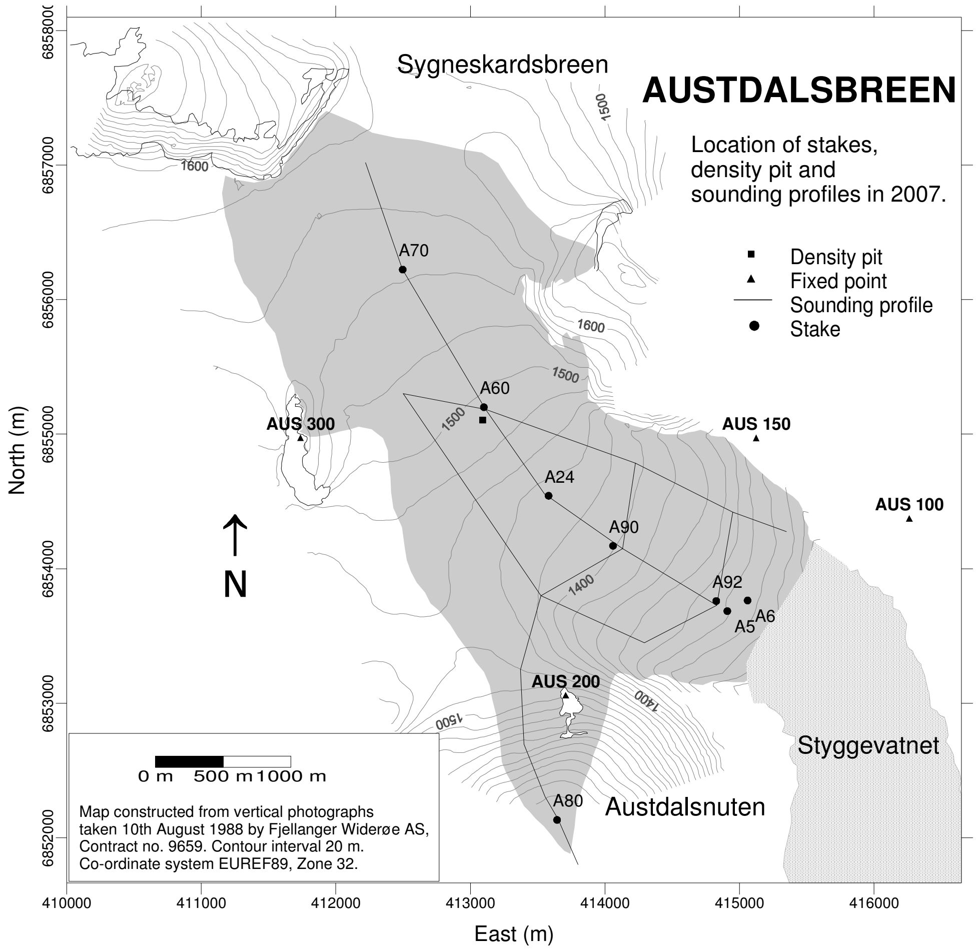


Figure 5-2
Location of stakes, density pit and sounding profiles at Austdalsbreen in 2007.

On 7th July the transient snow line was 1280 m a.s.l., and by 9th August the transient snow line was at about 1300 m a.s.l.

Summer and net balance measurements were carried out on 27th September. The glacier was covered with up to 1 m of new snow. Based on the stake measurements the temporary snow line at the end of the summer season was about 1400 m a.s.l. At stakes above 1400 m a.s.l. 3 to 4 m of snow had melted and 1 to 2 m of snow remained. Between 1200 and 1400 m a.s.l. 3 to 4 m of snow and up to 2 m of ice melted during the summer. At stake A6 (1260 m a.s.l.) 1.7 m of snow and 3.3 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). However, the actual glacier area based on front position measurements (chap. 5-2) has been reduced by 0.43 km^2, and the surface elevation has been reduced accordingly on the lower part of the glacier.

Winter balance

There are no observations indicating significant melting after the stake measurements on 11th October 2006.

The winter balance was calculated from snow depth and snow density measurements on 3rd May. A function correlating snow depth with water equivalent was calculated based on snow density measurements at stake A60 (1490 m a.s.l.).

Snow depth water equivalent values of all snow depth measurements were plotted against altitude. Mean values of altitude and Snow Water Equivalent (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 29 ±2 million m^3 water or 2.5 ±0.2 m w.e., which is 112 % of the 1988-2006 average (2.19 m w.e.).

The winter balance was also calculated using a gridding method based on the spatial distribution of the snow depth measurements (Fig. 5-3). 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 2.6 m w.e.

Summer balance

The summer balance was calculated for nine stakes in eight positions between 1260 and 1730 m a.s.l. The summer balance curve was drawn from these values (Fig. 5-4).

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

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

where ρ_{ice} is 0.9 g/cm^3, u_{ice} is annual glacier velocity (50 ±10 m/a, chap. 5.3), u_f is front position change averaged across the terminus (−30 ±5 m/a, chap. 5.2), W is terminus width (1020 ±20 m) and H is mean ice thickness at the terminus (41 ±5 m). The mean ice thickness was calculated from mean surface altitudes along the calving terminus surveyed on 11th October 2006 (1213 m a.s.l) and 27th September 2007 (1215 m a.s.l.), and mean bottom elevation along the terminus in October 2006 and September 2007 from 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 3 ±1 million m^3 water or 0.3 ±0.1 m w.e. averaged over the glacier area (11.8 km^2).

The summer balance, including calving, was calculated as −2.3 ±0.3 m w.e., which corresponds to −27 ±3 million m^3 of water. The result is 92 % of the 1988-2006 average (−2.49 m w.e.). The calving volume was 11 % of the summer balance.

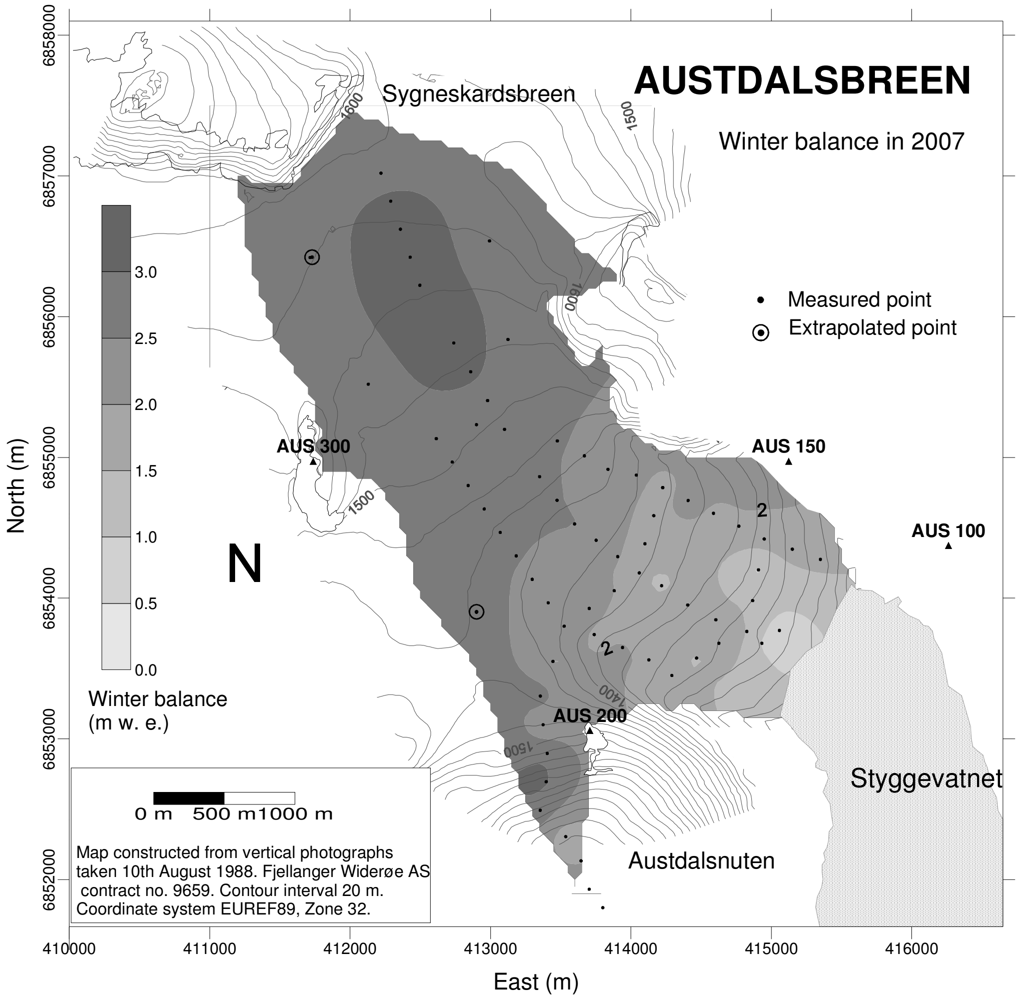
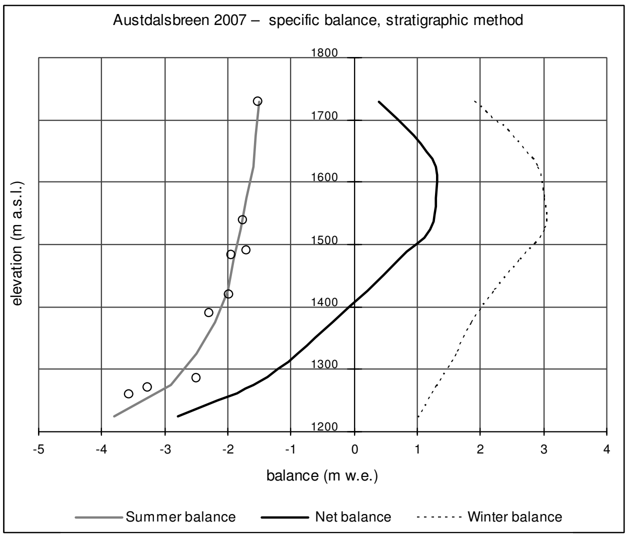


Figure 5-3
Winter balance at Austdalsbreen in 2007 from 64 water equivalent values calculated from snow depth measurements. Two of the locations were estimated based on observations in earlier years.

Net balance

The net balance at Austdalsbreen was calculated as 0.2 ±0.3 m w.e., corresponding to 2 ±3 mill. m^3 water. The 1988-2006 average is −0.31 m w.e. The equilibrium line altitude (ELA) was 1405 m a.s.l. Correspondingly, the Accumulation Area Ratio (AAR) was 75 % in 2007. The altitudinal distribution of winter, summer and net balances is shown in Figure 5-4 and Table 5-1. Results from 1988-2007 are shown in Figure 5-5.



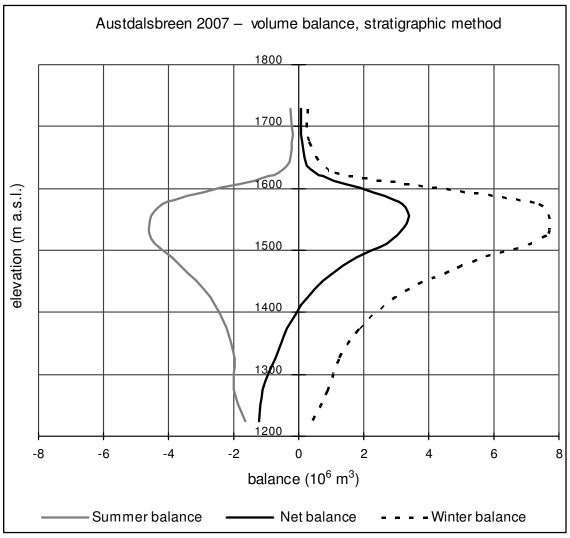


Figure 5-4
Altitudinal distribution of winter-, summer- and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2007. Specific summer balance at nine stakes in eight locations is shown (○).

Table 5-1
Altitudinal distribution of winter-, summer- and net balances at Austdalsbreen in 2007.

Mass balance Austdalsbreen 2006/07 – stratigraphic method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 3rd May 2007: Specific (m w.e.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 27th Sep 2007: Specific (m w.e.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surface 2006 - 2007: Specific (m w.e.)	Net balance: Volume (10^6 m^3)
1700 - 1757	0.16	1.90	0.30	-1.50	-0.24	0.40	0.06
1650 - 1700	0.13	2.50	0.32	-1.55	-0.20	0.95	0.12
1600 - 1650	0.38	2.90	1.09	-1.60	-0.60	1.30	0.49
1550 - 1600	2.45	3.00	7.34	-1.70	-4.16	1.30	3.18
1500 - 1550	2.54	3.00	7.62	-1.80	-4.57	1.20	3.05
1450 - 1500	1.92	2.60	5.00	-1.90	-3.65	0.70	1.35
1400 - 1450	1.36	2.20	2.98	-2.00	-2.71	0.20	0.27
1350 - 1400	1.01	1.85	1.87	-2.20	-2.22	-0.35	-0.35
1300 - 1350	0.79	1.60	1.26	-2.50	-1.97	-0.90	-0.71
1250 - 1300	0.69	1.30	0.89	-2.90	-1.99	-1.60	-1.10
1200 - 1250	0.44	1.00	0.44	-3.80	-1.65	-2.80	-1.22
Calving					-3.0		-3.0
1200 - 1757	**11.84**	**2.46**	**29.1**	**-2.28**	**-27.0**	**0.18**	**2.1**

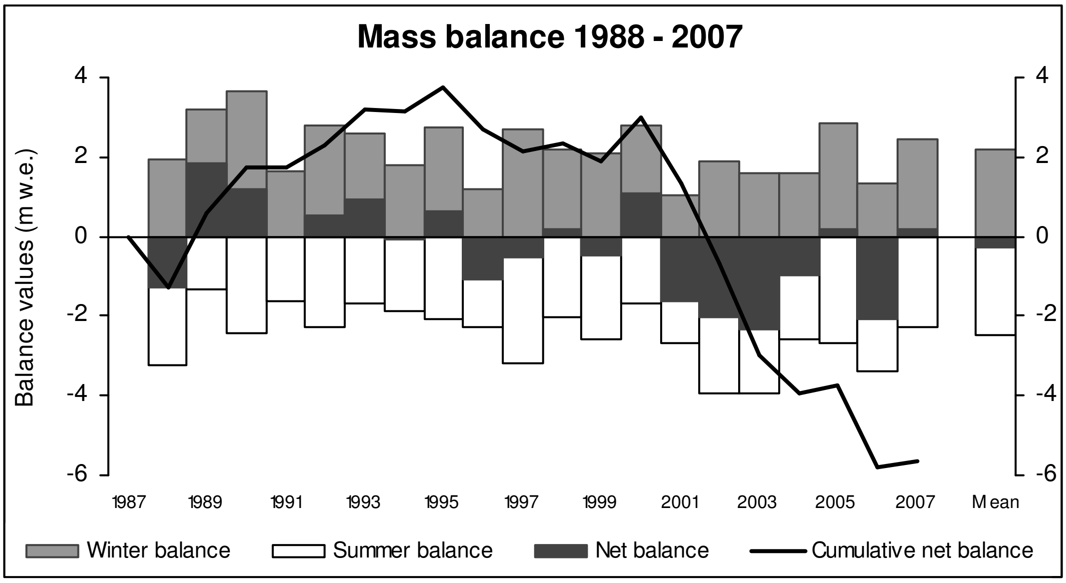


Figure 5-5
Winter, summer and net balances at Austdalsbreen during the period 1988-2007. Mean winter, summer and net balance is 2.20, –2.48 and –0.29 m w.e., respectively. Cumulative net balance in this period was –5.6 m w.e.

5.2 Front position change

Seven points along the calving terminus were surveyed on 27th September 2007. The mean front position change was –30 ±5 m (Fig. 5-6) between 11th October 2006 and 27th September 2007. The width of the calving terminus was 1020 ±20 metres. Since 1988 the glacier terminus has retreated 425 metres, whilst the glacier area has decreased by approximately 0.44 km^2 (Fig. 5-6).

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 5-7 illustrates how the front position at a central flow line has varied over the last 20 years. As a consequence of lake regulation it was expected that the glacier terminus would retreat. Modelling predicted a future change in front position that is shown as a broken line in Figure 5-7. The mean annual net balance used in the model was –0.47 m w.e., whilst the measured mean net balance has been –0.28 m w.e. (1988-2007).

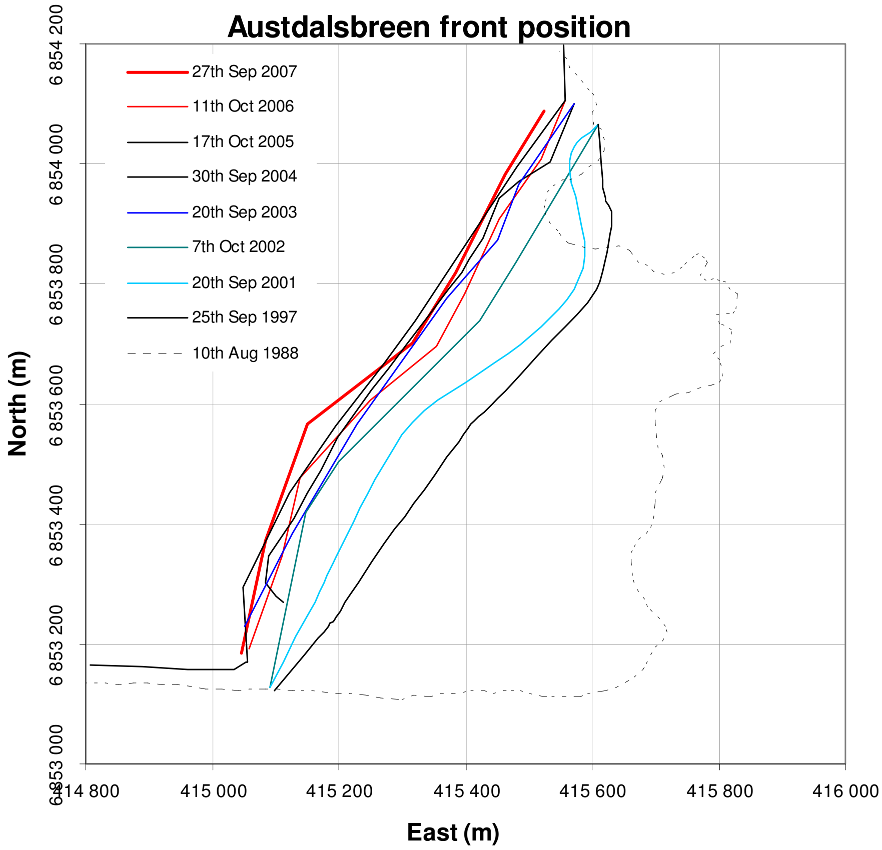


Figure 5-6
Surveyed front position of Austdalsbreen in 1988, when the lake was regulated, and autumn position in 1997-2007. The mean front position change between 11th October 2006 and 27th September 2007 was –30 metres.

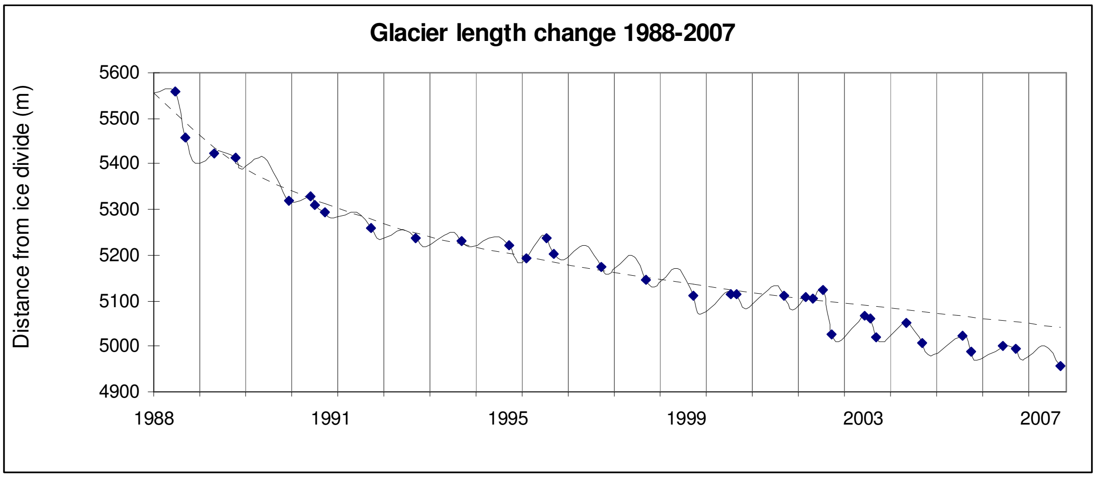


Figure 5-7
Surveyed glacier front position along a central flow line, shown as change in glacier length along this flow line (dots). The solid line indicates annual variation in front position. The glacier terminus advances from December to July when the lake is frozen, and retreats during July-December 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.e. (Laumann & Wold, 1992).

5.3 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 11th August and 11th October 2006, and 3rd May, 9th August and 27th September 2007.

Annual velocities were calculated for three stake locations (stake A92 – 42 m/a, stake A90 – 27 m/a, and stake A24 – 23 m/a). At stake A6, located 200 m up-glacier from the terminus, the mean summer velocity was 0.14 m/d corresponding to an annual velocity of 51 m/a. The stake velocities are slightly lower than in 2006.

The glacier velocity averaged across the front width and thickness must 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 A6 (51 m/a), average distance from the stake to terminus (200 m), and an average strain rate from previous years (0.1 a^{-1}) as 70 m/a. The glacier velocity averaged over the cross-section 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 50 ±10 m/a.

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 flooded by jökulhlaups (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 12. The University of Utrecht, Netherlands, operates an automatic weather station (AWS) close to the terminus of Midtdalsbreen (chap. 6-2).

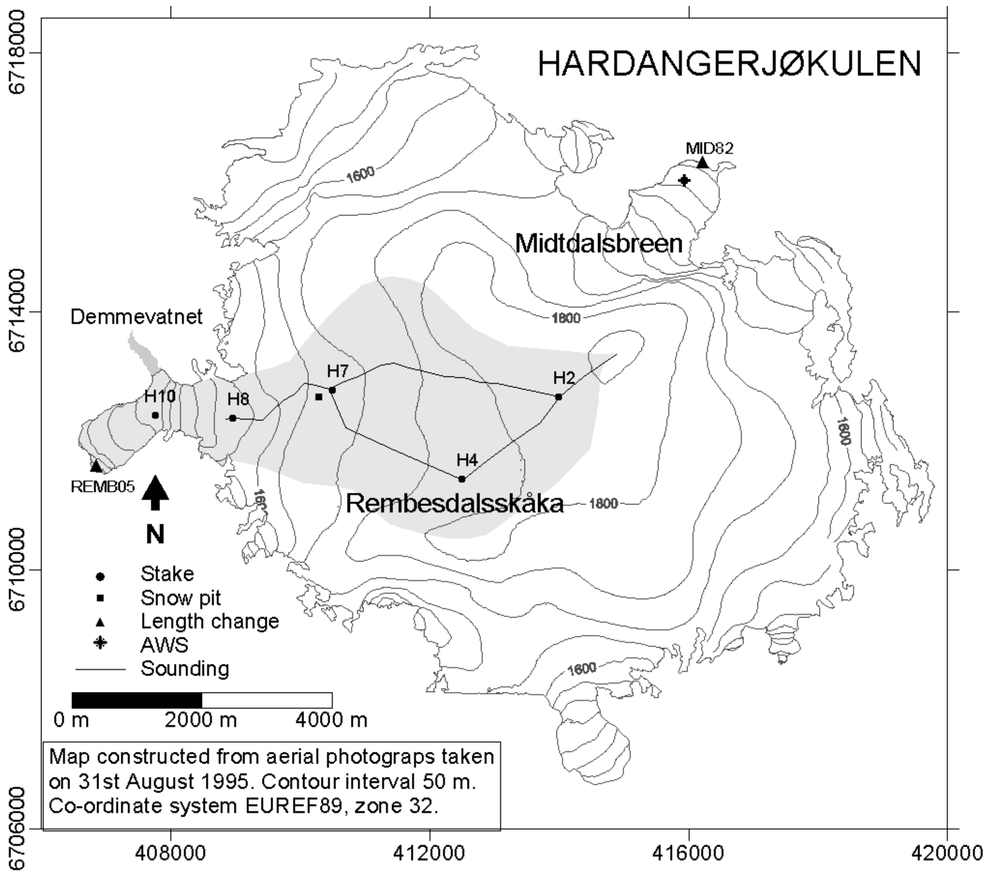


Figure 6-1
Location of sounding profiles, stakes and snow pit at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and an automatic weather station (AWS) at Midtdalsbreen.

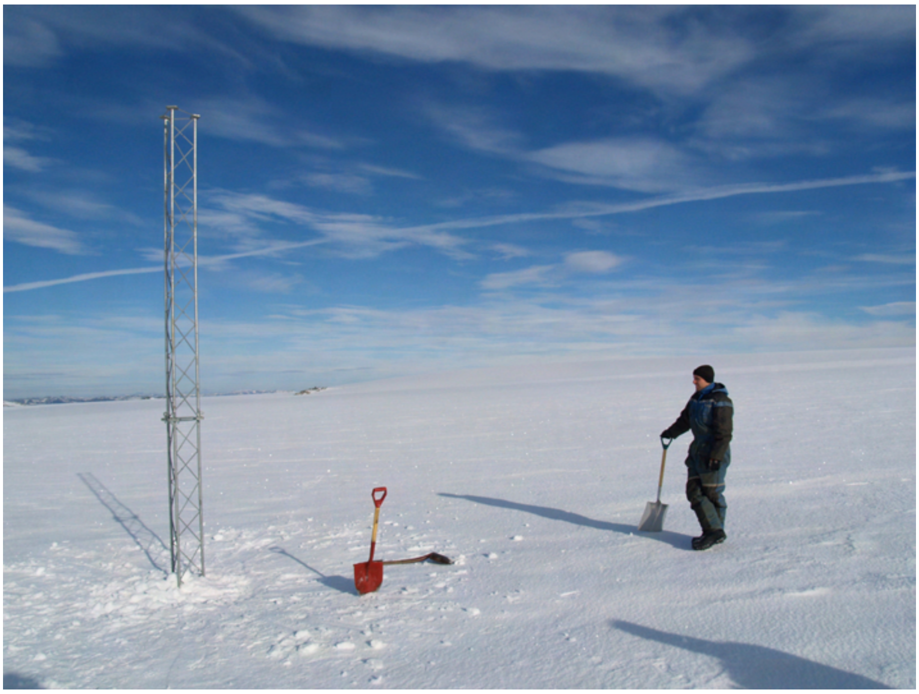


Figure 6-2
A new tower has been erected at position H4 at Rembesdalsskåka on 3rd October 2007. The nunatak Olavarden is shown in the middle background. Photo Hallgeir Elvehøy.

6.1 Mass balance at Rembesdalsskåka in 2007

Fieldwork

The stake network was checked on 22nd January and 22nd March. Stakes were maintained throughout the winter in the lowermost two positions. Snow depth soundings and stake measurements on 5th June gave the amount of late-autumn melting at five locations. At stakes 10 and 8, 0.85 and 0.15 m of ice respectively, had melted.

The winter balance measurements were carried out on 5th June. The calculation of winter balance is based on the following data (see fig. 6-1 for locations):

- Snow depth measurements at stakes H10 (1270 m a.s.l.) and H8 (1510 m a.s.l.), showing snow depths of 3.7 and 3.35 m, respectively.
- Snow depth coring at location H4 (1770 m a.s.l.) and H2 (1830 m a.s.l.) showing snow depths of 5.7 and 6.4 m, respectively.
- Snow density down to 5.1 m depth at location H7 (1660 m a.s.l.).The snow depth to last years summer surface (SS) was 5.7 m. Below the SS there was firn older than 2001.
- 57 snow depth soundings along 11 km of profiles on the glacier plateau above 1500 m a.s.l. Below 1650 m a.s.l. the snow depth was 3 to 5 m at most locations, except for some areas on the tongue where blue ice was exposed. Above 1650 m a.s.l. the snow depth was 5.5 to 7 m. The SS was easy to detect.

On 10th August the temporary snow line (TSL) altitude was about 1525 m a.s.l. At the stakes above the TSL about 3 m of snow had melted. Below the TSL all the snow and about 0.7 m of ice had melted. Between 5th June and 22nd September stakes 10 and 8 had melted out, and all the winter snow on the glacier had melted.

Summer and net balance were measured on 3rd October. Measurements at the stakes showed up to 0.75 m of new snow at stakes above 1525 m a.s.l. The TSL could not be detected due to the new snow cover, but stake readings indicate that the TSL altitude was about 1600 m a.s.l. At the stakes above the TSL, 0.3 to 0.65 m of snow had melted before the accumulation of new snow started – probably late in August. Up to 1.3 m of ice had melted at the stakes below the TSL. At location H4 the snow density of the uppermost 50 cm of new snow and the uppermost 50 cm of old firn were measured in a pit. The density was 0.49 and 0.60 g/cm^3, respectively.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive "summer surfaces", but including melting after10th October 2006 and excluding snow accumulation before 3rd October 2007. The calculations are based on a map from 1995.

Winter balance

The winter balance was calculated as the sum of late autumn ablation measured on 5th June and winter snow accumulation measured on 5th June 2007.

The altitudinal distribution of the late autumn ablation was interpolated from measurements at stakes H10 and H8, and an upper limit at 1600 m a.s.l. The density of melted ice was set to 0.90 g/cm^3. The late autumn melt was estimated as 1.35 m w.e. at the glacier terminus, decreasing to 0.00 m w.e. at 1600 m a.s.l.

The snow accumulation was calculated from snow depth and snow density measurements taken on 5th June 2007. A snow depth-water equivalent profile was calculated based on snow density measurements at location H7 (1660 m a.s.l.). Using the calculated profile, the mean density of 5 m of snow was 0.53 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 accumulation curve was drawn (Fig. 6-3). Below 1510 m a.s.l. the only snow depth measurement was at stake 10, and the snow accumulation curve had to be extrapolated from the measurements at stakes 8 and 10. From this curve a mean value for each 50 m elevation interval was determined.

The winter balance was calculated as the sum of late autumn ablation and snow accumulation in each altitudinal interval. The resulting winter balance was 3.1 ±0.2 m w.e. or 53 ±3 mill. m^3 water. This is 149 % of the 1963-2006 average of 2.08 m w.e., and 167 % of the 2002-2006 average of 1.86 m w.e. Only in 1983, 1989, 1990 and 1992 was the winter balance higher. The altitudinal distribution of the winter balance is shown in Figure 6-3 and Table 6-1.

Summer balance

The summer balance was calculated directly at five locations between 1270 and 1830 m a.s.l. The density of the remaining snow at locations H7, H4 and H2 was set at 0.6 g/cm^3. The density of the melted ice at stakes H8 and H10 was set at 0.9 g/cm^3.

From these five point values the summer balance curve in Figure 6-2 was drawn. The summer balance was calculated as −1.9 ±0.2 m w.e., corresponding to −33 ±3 mill. m^3 of water. This is 96 % of the 1963-2006 average, which is −2.00 m w.e., and 75 % of the 2002-2006 average of −2.56 m w.e.

Net balance

The net balance at Rembesdalsskåka was calculated as +1.2 ±0.3 m w.e. or +20 ±5 mill. m^3 water. The 1963-2006 average is +0.08 m w.e., and the 2002-2006 average is −0.70 m w.e. The altitudinal distribution of winter, summer and net balances is shown in Figure 6-3 and Table 6-1.The equilibrium line altitude (ELA) was set to 1570 m a.s.l. from the net balance in Figure 6-3. The corresponding accumulation area ratio (AAR) was 85 %. Results from 1963-2007 are shown in Figure 6-4. The cumulative net balance is +4.6 m w.e.

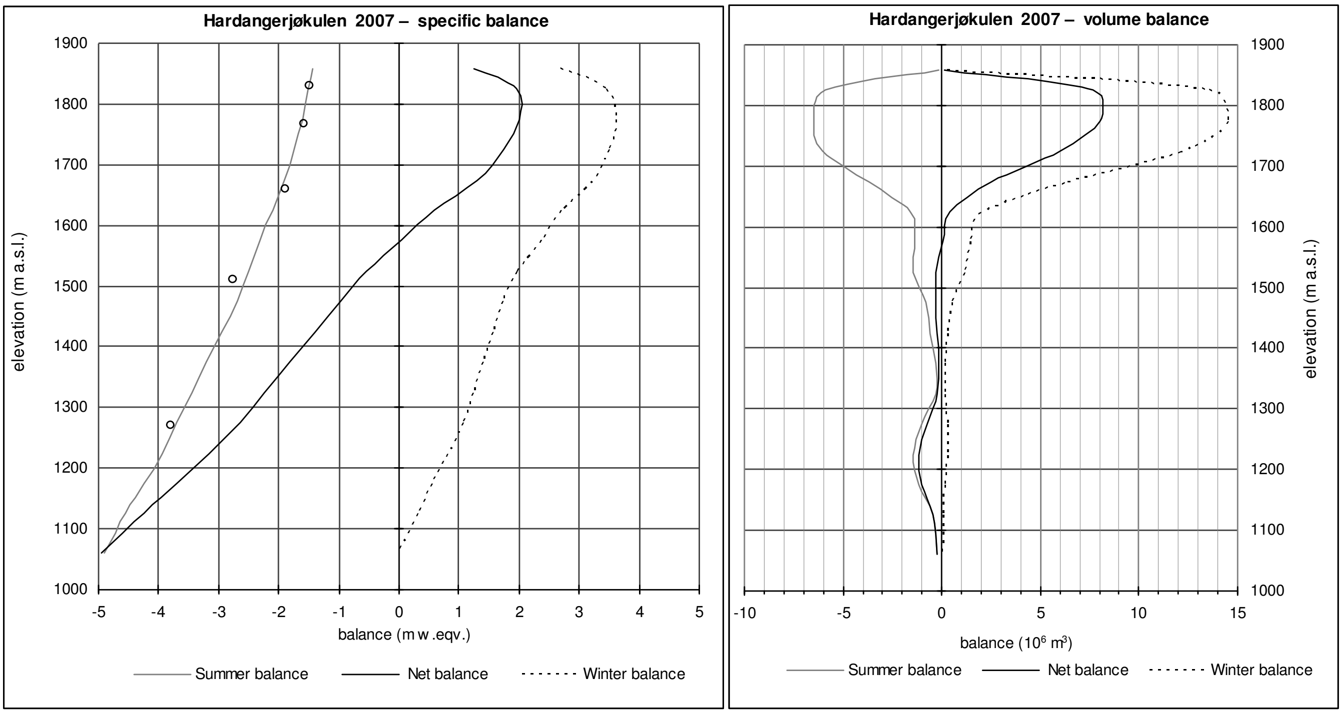


Figure 6-3
Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2007. Specific summer balance at five stakes is shown (○).

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka in 2007.

Mass balance Hardangerjøkulen 2006/07 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 5th Jun 2007		Measured 3rd Oct 2007		Summer surface 2006 - 2007	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1850 - 1865	0.09	2.70	0.2	-1.45	-0.1	1.25	0.1
1800 - 1850	3.93	3.45	13.6	-1.50	-5.9	1.95	7.7
1750 - 1800	4.03	3.60	14.5	-1.60	-6.5	2.00	8.1
1700 - 1750	3.46	3.50	12.1	-1.75	-6.1	1.75	6.1
1650 - 1700	1.94	3.20	6.2	-1.90	-3.7	1.30	2.5
1600 - 1650	0.75	2.70	2.0	-2.10	-1.6	0.60	0.4
1550 - 1600	0.59	2.35	1.4	-2.30	-1.4	0.05	0.0
1500 - 1550	0.57	1.95	1.1	-2.50	-1.4	-0.55	-0.3
1450 - 1500	0.29	1.73	0.5	-2.70	-0.8	-0.97	-0.3
1400 - 1450	0.19	1.56	0.3	-2.95	-0.6	-1.39	-0.3
1350 - 1400	0.10	1.39	0.1	-3.20	-0.3	-1.81	-0.2
1300 - 1350	0.10	1.22	0.1	-3.45	-0.3	-2.23	-0.2
1250 - 1300	0.27	1.05	0.3	-3.70	-1.0	-2.65	-0.7
1200 - 1250	0.36	0.80	0.3	-3.95	-1.4	-3.15	-1.1
1150 - 1200	0.28	0.55	0.2	-4.25	-1.2	-3.70	-1.0
1100 - 1150	0.11	0.30	0.0	-4.55	-0.5	-4.25	-0.4
1020 - 1100	0.05	-0.05	0.0	-4.90	-0.3	-4.95	-0.3
1020 - 1865	**17.1**	**3.10**	**53.0**	**-1.93**	**-33.0**	**1.17**	**20.0**

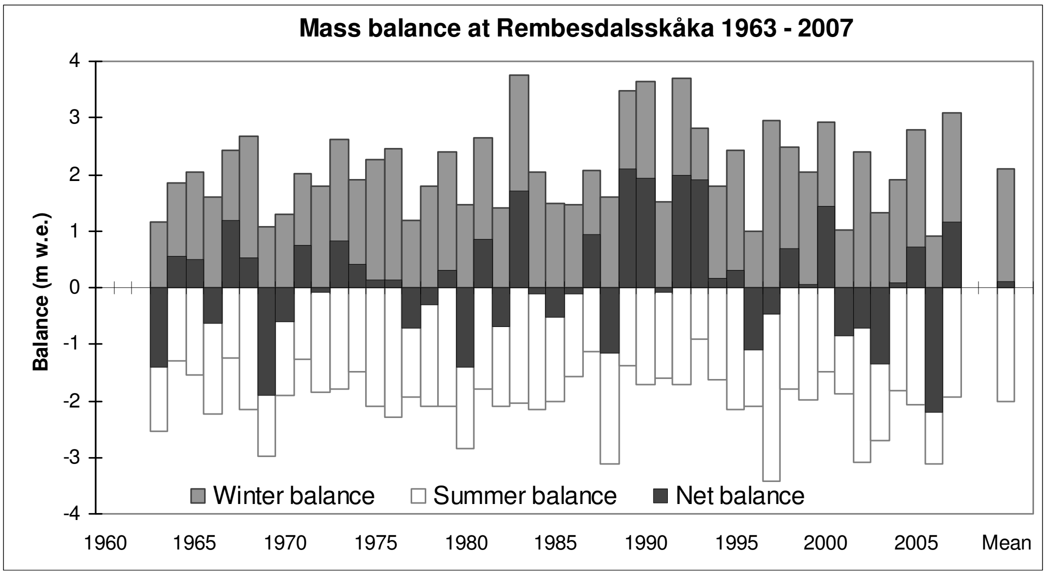


Figure 6-4
Winter-, summer- and net balances at Hardangerjøkulen during the period 1963-2007. Mean values for the period are b_w=2.10 m, b_s=−2.00 m and b_n=+0.10 m water equivalents.

6.2 Meteorological measurements on Hardangerjøkulen (Rianne H. Giesen, Utrecht University)

An automatic weather station (AWS) has been operating in the ablation zone on Midtdalsbreen, a northeasterly outlet glacier of Hardangerjøkulen (Fig. 6-1), since October 2000. The station (Fig. 6-5) 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, distance to the surface, shortwave and longwave radiation 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 a selection of data collected between 8th September 2006 and 15th September 2007. The series have a gap from 25th March to 19th May 2007. During this period measurements were not stored due to an error in the data logger.

Figure 6-5
The AWS on Midtdalsbreen on 25th March 2007.
Photo Rianne H. Giesen.

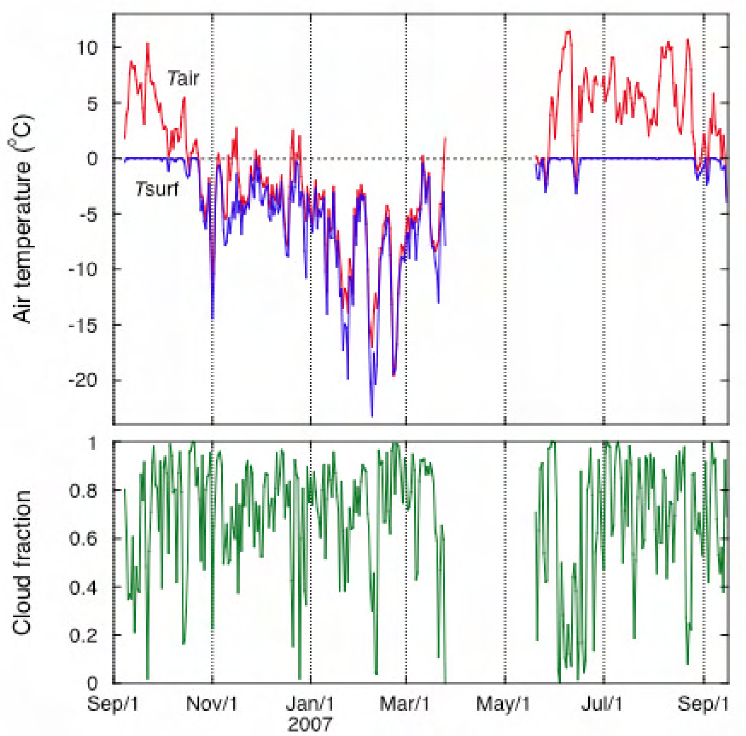


Figure 6-6
Daily mean air and surface temperature (*Tair* and *Tsurf*, upper panel) and cloud fraction (lower panel).

Temperature and cloudiness

Figure 6-6 shows daily mean air and surface temperatures and cloud fraction at the AWS location. Surface temperature was computed from the outgoing longwave radiation; the cloud fraction was estimated from the incoming long wave radiation. Several cold spells occurred in January and February with daily mean temperatures almost as low as −20 °C. The warmest day was 10th June when the daily mean air temperature was 11.5 °C. The remainder of June and the entire month of July were relatively cold. Two warmer periods occurred in August. The cloud fraction shows that June was mainly sunny, with the lowest cloud fractions found on the warmest days. In July and August sunny days occurred rarely. The glacier surface was at the melting point almost continuously during summer; in winter the surface temperature closely followed the air temperature.

Surface albedo and surface height

Daily mean values for the surface height at the AWS site are shown in Figure 6-7, together with the surface albedo. Daily mean surface albedo was calculated as the ratio of the daily sums of reflected and incoming solar radiation. Almost one metre of ice melted in September 2006, due to the high air temperatures (Fig. 6-6). Several snowfall events occurred in October, both seen in the albedo and height records. The build-up of the winter snowpack started at the end of October. During winter, the surface albedo is almost continuously high. A comparison with the cloud fraction (Fig. 6-6) shows that the albedo decreases on clear-sky days. From the end of May the snow depth decreased quickly and all snow had melted by 6th July. The slope of the surface height curve is smaller in July than in August, implying a higher melt rate in August. This is due to the higher air temperatures and a lower surface albedo in August. A major snowfall event occurred at the end of August. In total, 2.5 m of ice had melted by 15th September 2007. This is the lowest value recorded at this date since the AWS was installed, although the amount of melt was only slightly larger in 2001 and 2005.

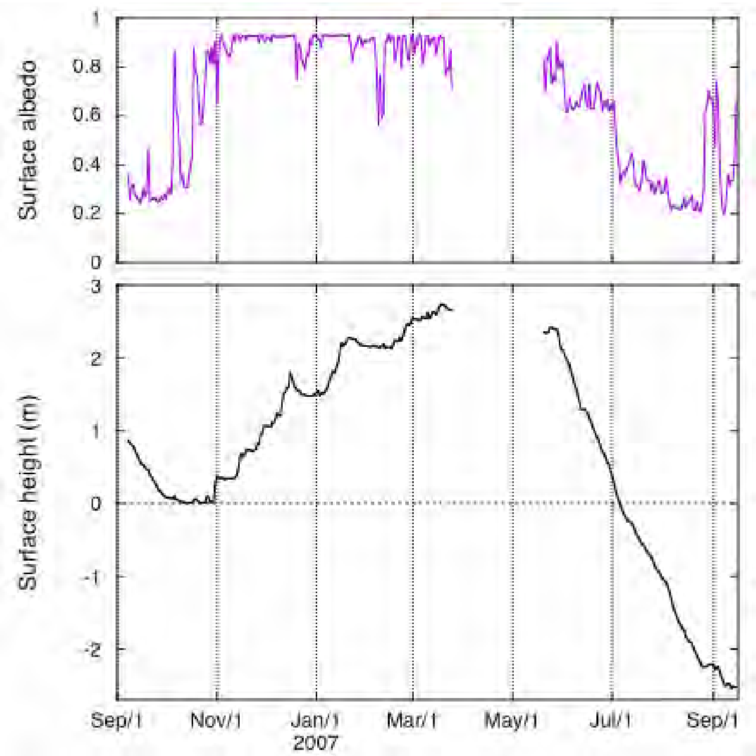


Figure 6-7
Daily mean surface albedo (upper panel) and surface height (lower panel).

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Jotunheimen mountain massif 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 began in 1949 and 2007 is the 59th year of continuous measurements. An automatic weather station (AWS) has been operating on the glacier since September 2001, and since September 2005 an AWS has also been operated at Rundhø, east of the glacier (Fig 7-1).

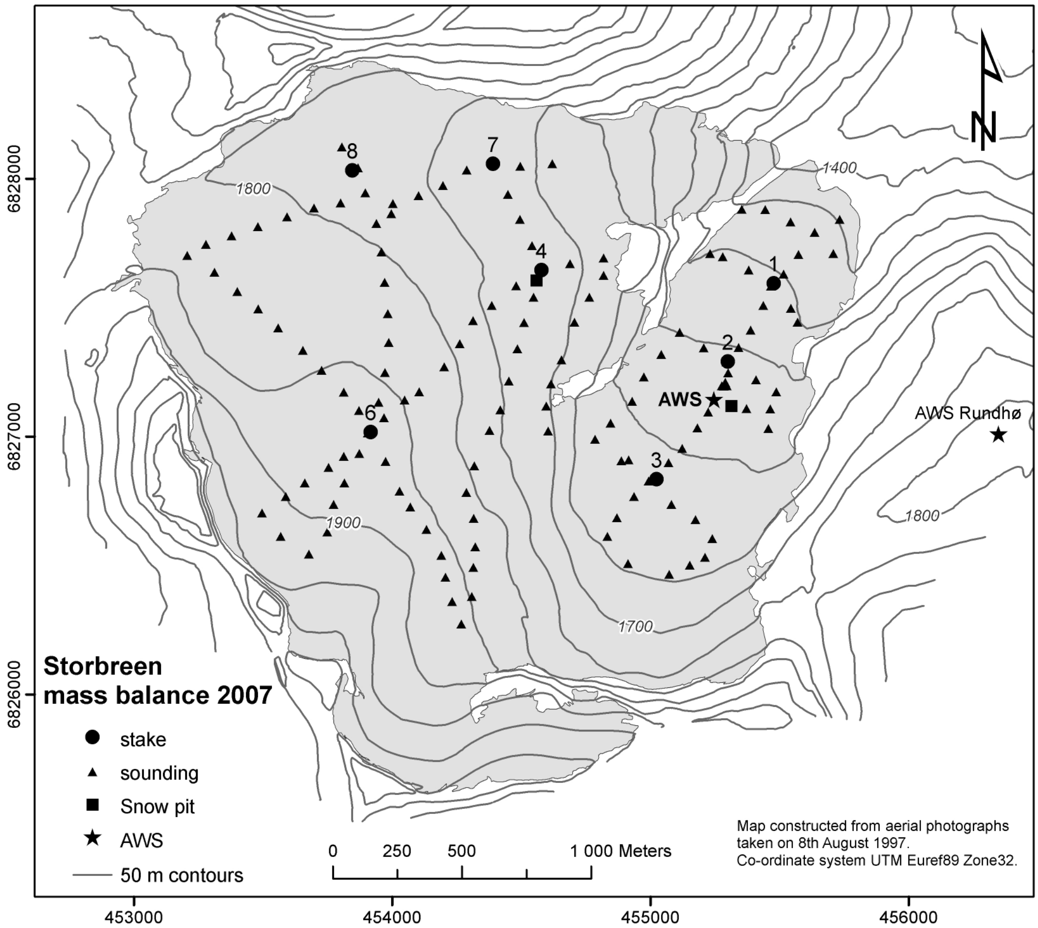


Figure 7-1
Location of stakes, density pits and the automatic weather stations (AWS) at Storbreen in 2007.

7.1 Mass balance 2007

Fieldwork

Accumulation measurements were performed on 2nd May and the calculation of winter balance is based on:

- Measurements of stakes in 6 different positions. The stake readings as well as surface elevation data from the AWS showed considerable additional melting at lowest stakes after the final measurements in the previous mass balance year (9th September 2006).

- Soundings of snow depth in 139 positions between 1445 and 1925 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was easy to identify over the whole glacier. The snow depth varied between 1.75 and 3.75 m, the mean being 3.11 m.
- Snow density was measured at two positions, at the AWS on the glacier at 1570 m a.s.l. and at stake 4 at 1725 m a.s.l.

Ablation measurements were performed on 18th September on stakes in all positions. In addition, the stakes were visited and measured in August 2007 (Fig. 7-2). The locations of stakes, density pits and soundings are shown in Figure 7-1.

Figure 7-2
Stake 1 at Storbreen and view upwards the glacier. The photograph is taken on 8th August 2007. Photo: Liss M. Andreassen.

Results

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

Winter balance

Winter accumulation was calculated from soundings and the snow density measurements. The mean measured snow density was 0.52 g/cm^3 (0.53 g/cm^3 at the AWS and 0.51 g/cm^3 at stake 4). The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval.

The specific winter accumulation was calculated to be 1.6 ±0.2 m w.e. To account for the additional summer melt after final mass balance observations in 2006 in the cumulative balance, the winter balance of 2007 was calculated as the winter accumulation subtracted by the additional melt after 9th September 2006. This resulted in a winter balance of 1.4 ±0.2 m w.e.

This is 86 % of the mean for 1971-2000. If there had been no additional melt to account for, the winter balance would have been 107 % of the mean for 1971-2000.

Summer balance

Summer balance was calculated directly from stakes at 4 locations (2, 4, 6 and 7). 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 −1.7 ±0.3 m w.e., which is 107 % of the mean for 1971-2000.

Net balance

The net balance of Storbreen in 2007 was −0.4 ±0.3 m w.e., which is equivalent to a volume of 2.1 ±1.6 mill. m^3 of water. The ELA calculated from the net balance diagram (Fig. 7-3) was 1835 m a.s.l. and the accumulation area ratio (AAR) was 30 %. The cumulative balance since 1949 is −17.3 m w.e., giving a mean annual net balance of −0.29 m w.e. (Fig. 7-4).

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2007.

Mass balance Storbreen 2006/07

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 3 May 2007		Summer balance Measured 18 Sep 2007		Net balance 9 Sep 2006 - 18 Sep 2007	
		Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)	Specific (m w.eq.)	Volume (10^6 m^3)
2050 - 2100	0.04	1.69	0.07	-0.78	-0.03	0.91	0.04
2000 - 2050	0.15	1.69	0.25	-0.98	-0.15	0.71	0.11
1950 - 2000	0.23	1.70	0.39	-1.15	-0.26	0.55	0.13
1900 - 1950	0.36	1.72	0.62	-1.30	-0.47	0.42	0.15
1850 - 1900	0.57	1.71	0.98	-1.44	-0.82	0.27	0.15
1800 - 1850	0.92	1.49	1.37	-1.57	-1.44	-0.08	-0.07
1750 - 1800	0.75	1.67	1.26	-1.72	-1.29	-0.05	-0.03
1700 - 1750	0.64	1.16	0.74	-1.87	-1.20	-0.71	-0.46
1650 - 1700	0.40	1.07	0.43	-1.99	-0.80	-0.92	-0.37
1600 - 1650	0.49	1.01	0.49	-2.10	-1.03	-1.09	-0.54
1550 - 1600	0.35	0.86	0.30	-2.20	-0.77	-1.34	-0.47
1500 - 1550	0.21	0.67	0.14	-2.30	-0.48	-1.63	-0.34
1450 - 1500	0.18	0.72	0.13	-2.40	-0.43	-1.68	-0.30
1390 - 1450	0.06	1.11	0.07	-2.50	-0.15	-1.39	-0.08
1390 - 2100	**5.35**	**1.35**	**7.23**	**-1.74**	**-9.32**	**-0.39**	**-2.09**

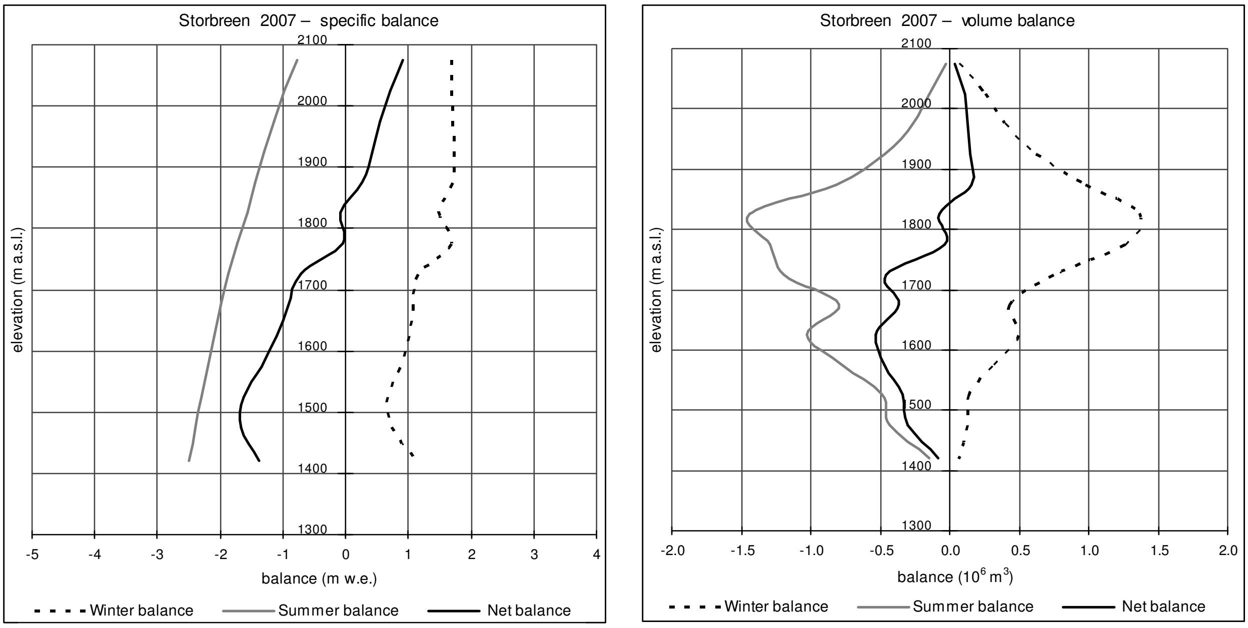


Figure 7-3
Mass balance diagram for Storbreen 2007, showing specific balance on the left and volume balance on the right.

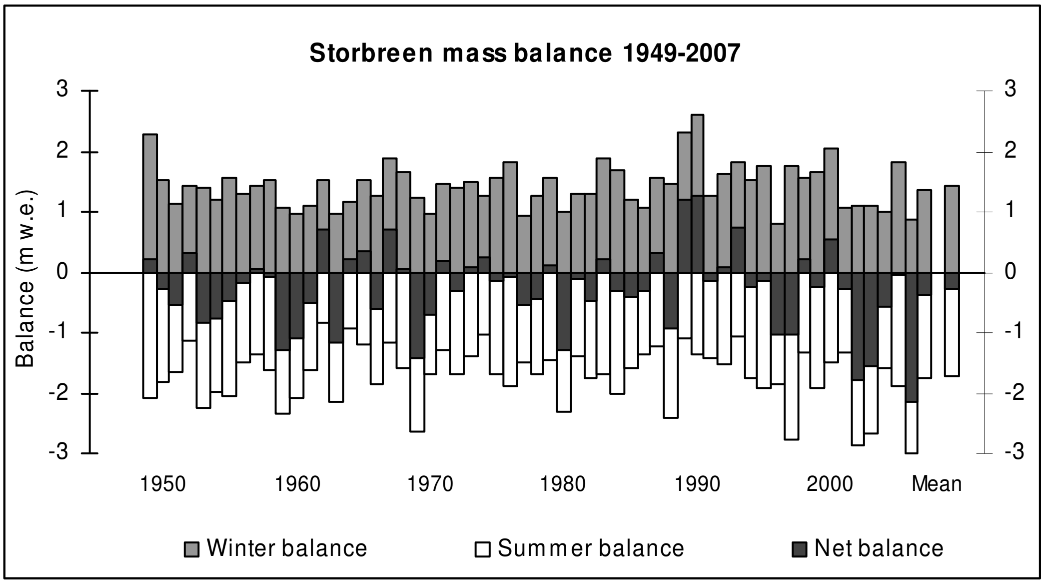


Figure 7-4
Winter, summer and net balance at Storbreen for the period 1949-2007.

7.2 Meteorological measurements

An automatic weather station (AWS) has been operating in the ablation zone of Storbreen, at about 1570 m a.s.l. (Fig. 7-5), since September 2001. The station is part of the Institute of Marine and Atmospheric Research (IMAU) network of AWS on glaciers (contact: J.Oerlemans@phys.uu.nl). The AWS stands freely on the ice and sinks with the melting surface. The station records air temperature, wind speed, wind direction, shortwave and longwave radiation, humidity and instrument height above the surface. The data are used to calculate the local surface energy and mass balance. Further information about the station and analyses of the data from the first five years (2001-2006) are found in Andreassen et al. (2008). Here we present a few results from the 2006/2007-season.

Figure 7-5
The AWS at Storbreen on 3rd May 2007. Photo: Liss M. Andreassen.

Surface elevation

Surface elevation data from the station show that significant melt occurred after the ablation measurements on 9th September 2006 (Fig. 7-6). The surface lowering amounts to nearly 0.7 m. From the end of October a snow pack gradually built up and at the time of the accumulation measurements in the beginning of May there was 2.9 m of snow at the AWS.

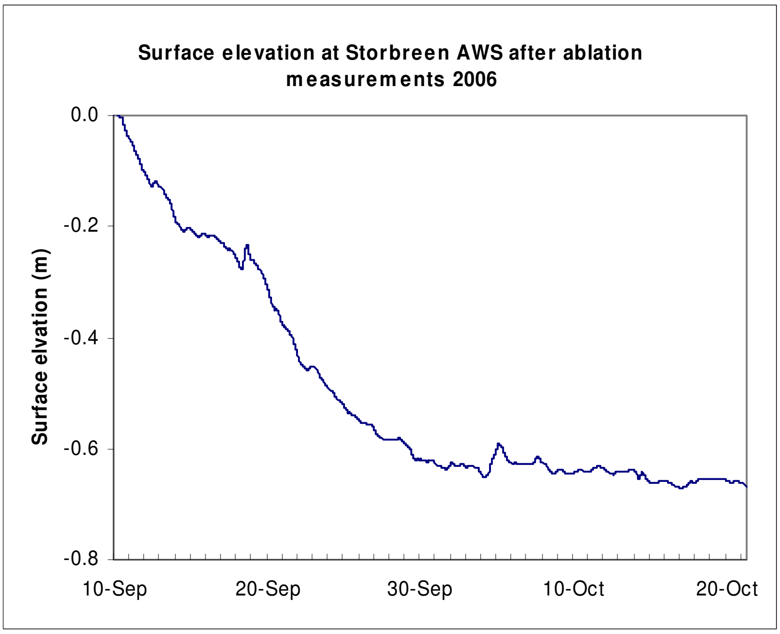


Figure 7-6
Surface elevation in fall 2006 at the AWS at Storbreen measured by a sonic ranger.

Temperature

The daily mean temperature observed at Storbreen AWS in the mass balance year 2006/2007 is compared with the mean of the previous five years in Figure 7-7. The data reveal that the period after the ablation measurerments in 2006 was warmer than the mean for this period. Furthermore, the data also reveal a warm period with daily temperatures above 0 °C in the days before the accumulation measurements in May 2007 explaining the high snow density that was measured. Except for a warm period in end of May and beginning of June, the observed summer temperature was lower in 2007 than the mean of the previous five years. It is worth noting that this five-year period includes three of the warmest years observed in Norway: 2002, 2003, and 2006 (Andreassen et al. 2007).

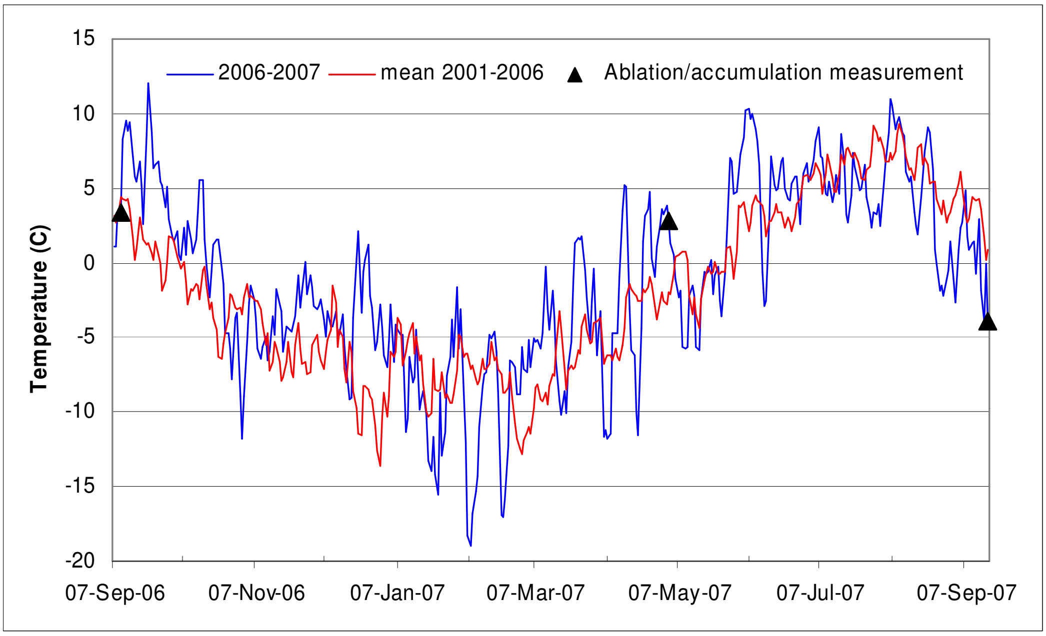


Figure 7-7
Daily mean temperature at Storbreen AWS from 7th September 2006 to 18th September 2007. The mean temperature of the five previous years (7th September 2001 – 6th September 2006) is also shown. The measurements are taken 6 m above the ice surface.

8. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 8-1). The glacier shares a border with vestre Memurubre and ranges in elevation from 1480 to 2210 m a.s.l. It had an area of 3.0 km^2 in 1997, and the glacier terminus has retreated about 100 m since then (Fig. 8-2). Annual mass balance measurements began in 1962 and have continued annually since then.

Figure 8-1
Photograph of Hellstugubreen on 9th August 2007. Photo: Liss M. Andreassen.

8.1 Mass balance 2007

Fieldwork

Accumulation measurements were performed on 2nd May and the calculation of winter balance is based on:

- Measurements of stakes in 13 different positions. Stake readings showed that there had been additional melting at the lowest elevations after the ablation measurements on 22nd September 2006.
- Soundings of snow depth in 91 positions between 1540 and 2130 m a.s.l. covering most of the altitudinal range of the glacier (Fig. 8-2). The snow depth varied between 1.12 and 4.30 m, the mean being 2.35 m.

- The snow density was measured by sampling in a pit at 1960 m a.s.l. where the total snow depth was 2.7 m.

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

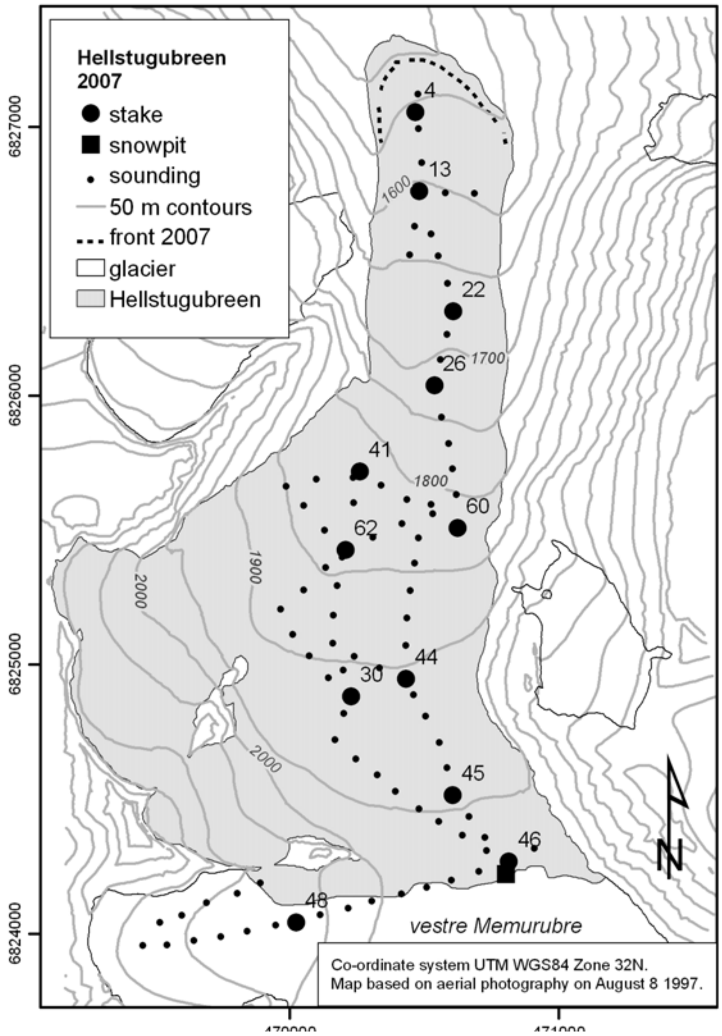


Figure 8-2
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2007. The position of the glacier front in 2007 (measured by handheld GPS) is also indicated.

Results

The mass balance results of 2007 are presented in Table 8-1 and Figure 8-3.

Winter balance

The winter balance was calculated from the soundings and the snow density measurement, which was considered to be representative for the whole glacier. The density in the snow pit was 0.47 g/cm^3.

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The mean winter accumulation was 1.1 ±0.2 m w.e. This is 96 % of the mean for the period 1971-2000. The winter balance, adjusted for additional melting after the ablation measurements on 22nd September 2006, was 1.0 ±0.2 m w.e. or 90 % of the mean for the observation period 1971-2000.

Summer balance

Direct summer balance was calculated from stakes in 9 locations. The density of the melted ice was assumed to be 0.9 g/cm^3 and the density of melted firn to be 0.7. The density of the remaining snow (only at the highest stake, 48) was assumed to be 0.55 m w.e. The summer balance was calculated to be –1.7 ±0.3 m w.e., which is 120 % of the mean value for the period 1971-2000.

Net balance

The net balance of Hellstugubreen in 2007 was –0.7 ±0.3 m w.e., which amounts to a volume loss of –2.0 ±0.9 mill. m^3 water. The equilibrium line altitude (ELA) was 1975 m a.s.l. resulting in an accumulation area ratio (AAR) of 25 % (Fig. 8-4). The cumulative net balance since 1962 is 17.4 m w.e., giving a mean annual deficit of 0.38 m w.e. per year (Fig. 8-4). The calculated annual net balance has been negative for Hellstugubreen since 2001, and 2007 is the seventh year in row with a negative net balance. The cumulative deficit amounts to 7.1 m w.e. for the period 2001-2007.

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2007.

Mass balance Hellstugubreen 2006/07

		Winter balance Measured 2 May 2007		Summer balance Measured 11 Sep 2007		Net balance 22 Sep 2006 - 11 Sep 2007	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
2150 - 2210	0.02	1.20	0.02	-0.60	-0.01	0.60	0.01
2100 - 2150	0.09	1.24	0.11	-0.75	-0.07	0.49	0.04
2050 - 2150	0.28	1.36	0.38	-0.92	-0.26	0.44	0.12
2000 - 2050	0.18	1.49	0.27	-1.05	-0.19	0.44	0.08
1950 - 2000	0.38	1.22	0.46	-1.22	-0.46	0.00	0.00
1900 - 1950	0.61	1.15	0.70	-1.40	-0.86	-0.25	-0.15
1850 - 1900	0.35	0.92	0.32	-1.70	-0.59	-0.78	-0.27
1800 - 1850	0.33	1.08	0.36	-1.90	-0.62	-0.82	-0.27
1750 - 1800	0.13	0.91	0.12	-2.10	-0.28	-1.19	-0.16
1700 - 1750	0.10	0.85	0.09	-2.30	-0.24	-1.45	-0.15
1650 - 1700	0.17	0.77	0.13	-2.50	-0.42	-1.73	-0.29
1600 - 1650	0.13	0.61	0.08	-2.70	-0.34	-2.09	-0.26
1550 - 1600	0.16	0.30	0.05	-3.00	-0.48	-2.70	-0.43
1500 - 1550	0.08	0.17	0.01	-3.25	-0.25	-3.08	-0.24
1480 - 1500	0.02	0.00	0.00	-3.42	-0.06	-3.42	-0.06
1480 - 2210	**3.03**	**1.03**	**3.11**	**-1.70**	**-5.14**	**-0.67**	**-2.03**

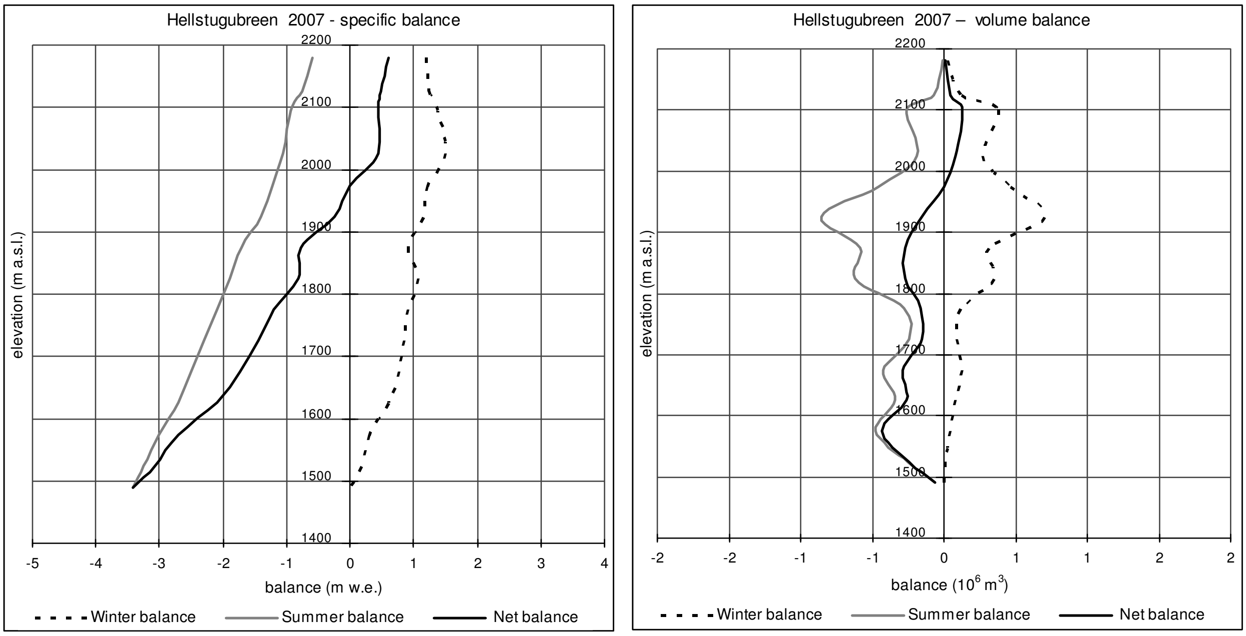


Figure 8-3
Mass balance diagram for Hellstugubreen in 2007, showing specific balance on the left and volume balance on the right.

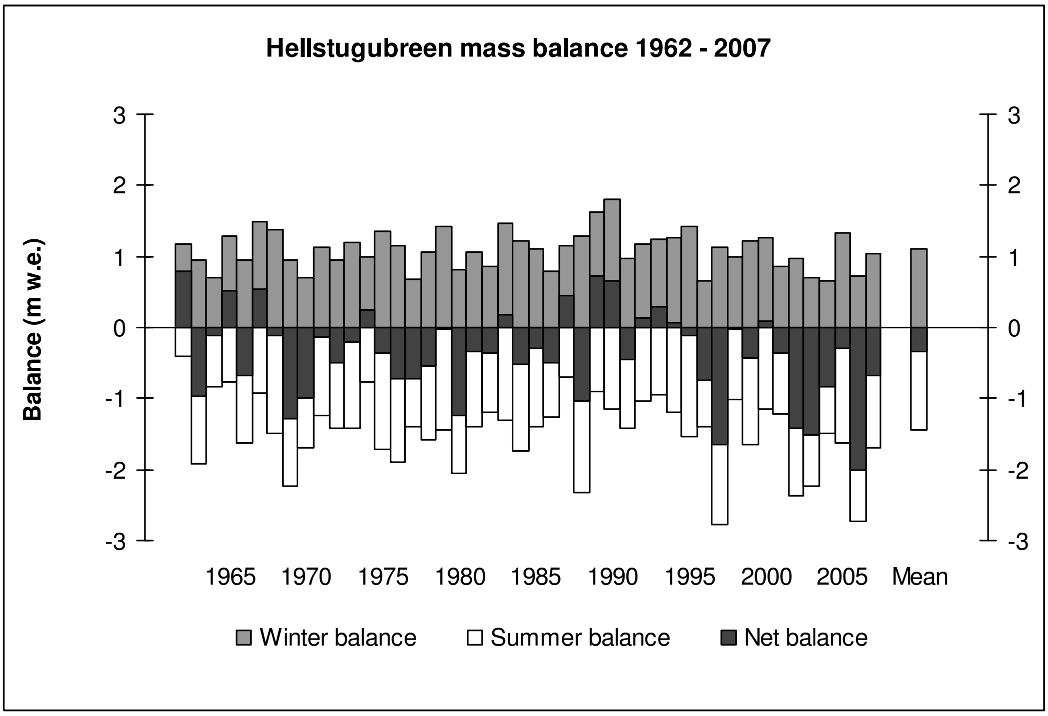


Figure 8-4
Winter, summer and net balance at Hellstugubreen for the period 1962-2007.

9. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is located in the eastern part of the Jotunheimen mountain area in southern Norway (Fig. 9-1). The glacier covers an area of 2.2 km^2 and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 9-2). Mass balance investigations have been carried out annually since 1962 and 2007 is the 46th year of continuous measurements.

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

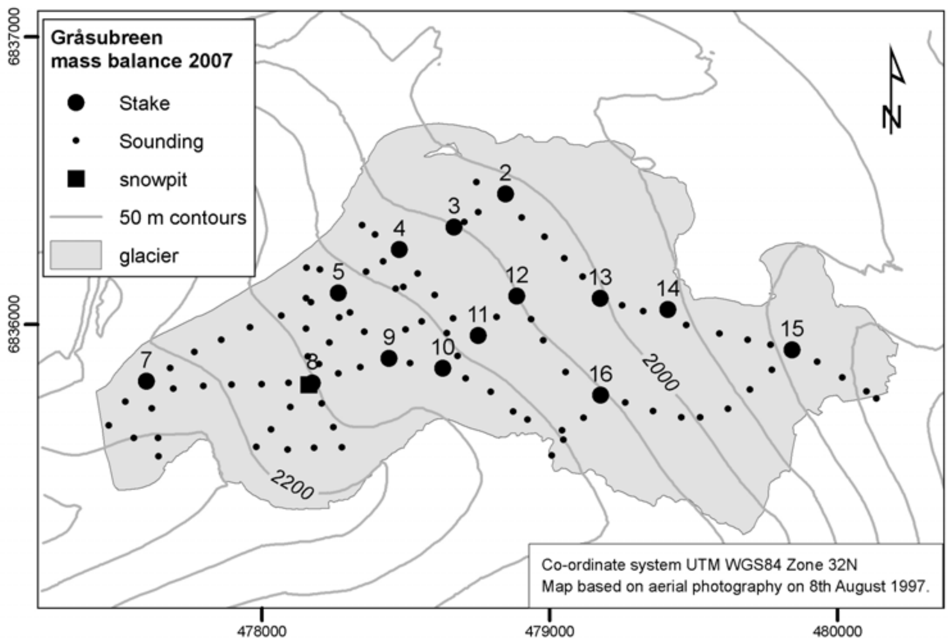


Figure 9-1
Map of Gråsubreen (shaded in grey) showing the location of stakes, snow pit and soundings in 2007.

9.1 Mass balance 2007

Fieldwork

Accumulation measurements were performed on 5th – 6th June 2007. The calculation of winter balance is based on:

- Measurements of stakes in 15 different positions. Stake readings revealed significant additional melting after the ablation measurements on 12th September 2006.
- Soundings of snow depth in 105 positions between 1845 and 2275 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was easy to identify over the whole glacier. The snow depth varied between 0.08 and 5.25 m, the mean being 1.70 m.
- The snow density was measured by sampling in a pit near stake 8 at 2150 m a.s.l. where the total snow depth was 1.46 m (Fig. 9-2, left).

Ablation measurements were carried out on 12th-13th September, when stakes in all locations were measured. A thin, patchy layer of new snow partly covered the glacier at the time of the ablation measurements (Fig. 9-2, right).

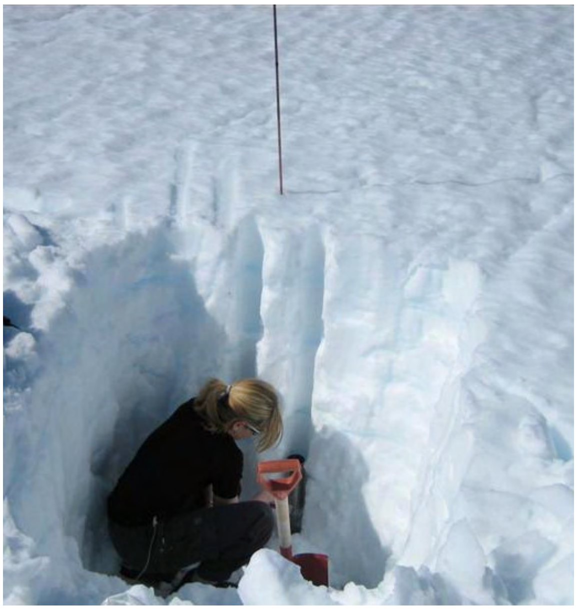


Figure 9-2
Field work at Gråsubreen in 2007. Left: Density measurements (snow pit to depth of 1.5 m) at stake 8 in June. Right: Ablation measurements on 13th September at stake 16 with view towards the southeast. Photos: Kjetil Melvold (left) and Jon Endre Hausberg (right).

Results

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

Winter balance

Winter accumulation was calculated from the soundings and the snow density measurement, which was considered representative for the whole glacier. The mean measured snow density was 0.495 g/cm^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter accumulation of 0.9 ±0.2 m w.e., which is 113 % of the mean winter balance for the period 1971-2000.

The stake recordings showed significant additional melting after the previous year's ablation measurements on 13th September 2006. The winter balance was therefore adjusted for the additional melting by subtracting it from the winter accumulation. The resulting winter balance was 0.6 ±0.2 m w.e. or 80 % of the mean for the period 1971-2000. Formation of superimposed ice was not detected.

Summer balance

Summer balance was calculated from direct measurements of stakes in eleven locations. The density of the melted ice was estimated to be 0.90 g/cm^3. The density of the melted firn was estimated to be 0.80 g/cm^3. The resulting summer balance was −1.3 ±0.3 m w.e. The specific summer balance is 119 % of the mean for the period 1971-2000.

Net balance

The net balance of Gråsubreen in 2007 was -0.7 ±0.3 m w.e. The equilibrium line altitude (ELA) was 2265 m a.s.l., resulting in an accumulation area ratio (AAR) of 1 % (Fig. 9-3). Gråsubreen has had a cumulative mass loss of −16.4 m w.e. since 1962, which is an average of −0.36 m w.e. per year. Most of this mass loss occurred in the 1970s and 1980s, and since 2001.

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2007.

Mass balance Gråsubreen 2006/07

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 5 June 2007		Summer balance Measured 12 Sep 2007		Net balance 13 Sep 2006 - 12 Sep 2007	
		Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
2250 - 2290	0.04	0.74	0.03	-0.70	-0.03	0.04	0.00
2200 - 2250	0.17	0.34	0.06	-0.89	-0.15	-0.55	-0.09
2150 - 2200	0.26	0.56	0.15	-1.11	-0.29	-0.55	-0.14
2100 - 2150	0.34	0.43	0.15	-1.32	-0.45	-0.89	-0.30
2050 - 2100	0.37	0.43	0.16	-1.34	-0.50	-0.91	-0.34
2000 - 2050	0.42	0.60	0.25	-1.57	-0.66	-0.97	-0.41
1950 - 2000	0.36	0.84	0.30	-1.35	-0.48	-0.51	-0.18
1900 - 1950	0.14	0.99	0.14	-1.37	-0.20	-0.38	-0.05
1830 - 1900	0.15	0.88	0.13	-1.41	-0.22	-0.53	-0.08
1830 - 2290	**2.25**	**0.61**	**1.37**	**-1.32**	**-2.96**	**-0.71**	**-1.60**

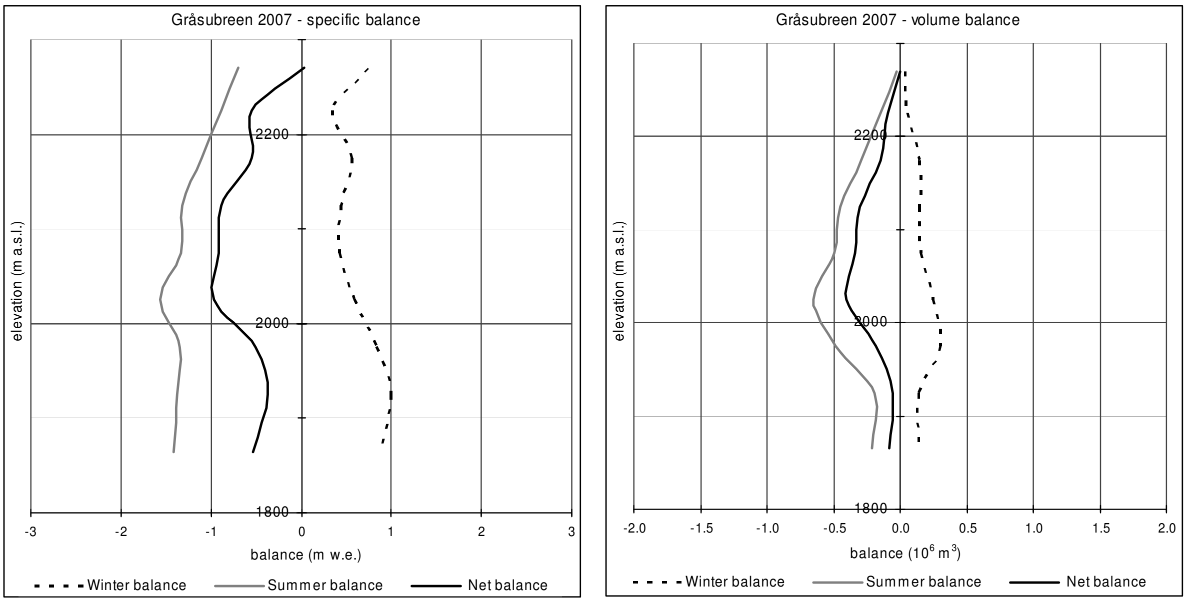


Figure 9-3
Mass balance diagram for Gråsubreen in 2007, showing specific balance on the left and volume balance on the right.

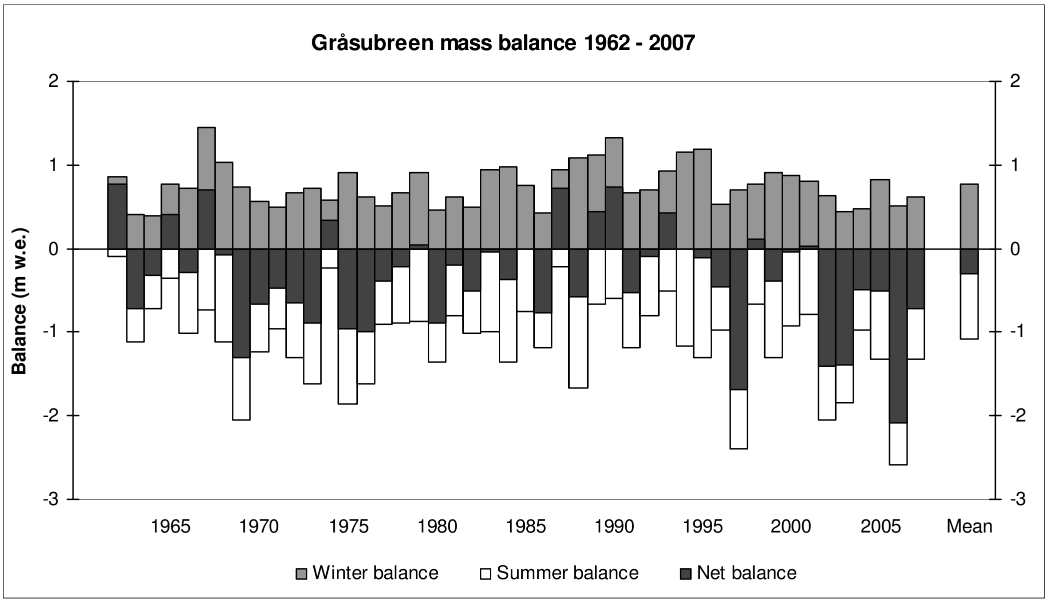


Figure 9-4
Winter, summer and net balance at Gråsubreen during the period 1962-2007.

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 (chap. 12-1). A meteorological station has been operated at the nunatak Skjæret (1364 m a.s.l.) since 1995.

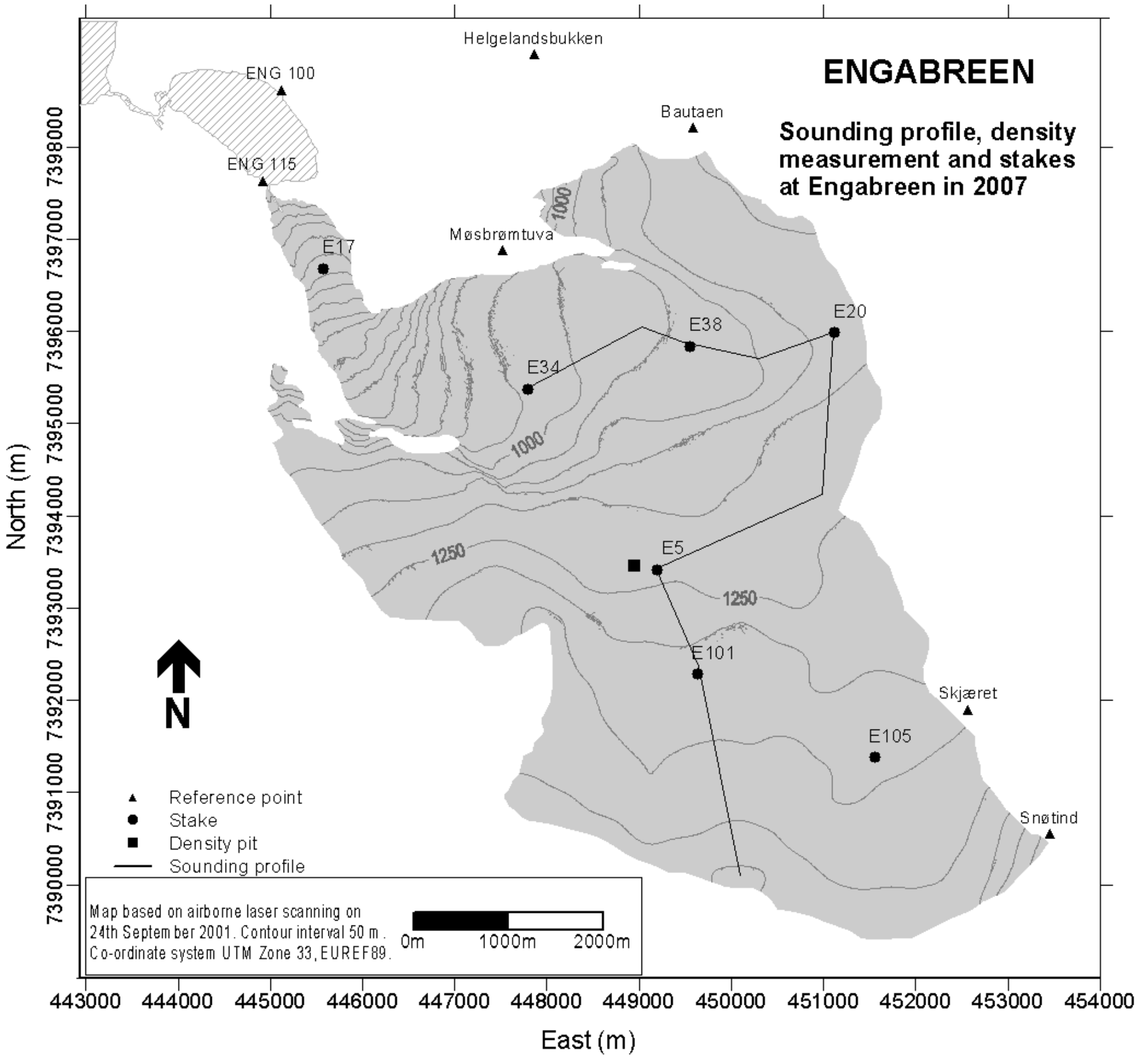


Figure 10-1
Location of stakes, density pit and sounding profiles on Engabreen in 2007.

10.1 Mass balance 2007

Fieldwork

The first fieldwork of 2007 at Engabreen was performed on 8th March. Stakes in positions E105, E101 and E34 were measured. The snow depth at the stakes on the plateau was 3 to

6 metres. On 7th May stake E34 were measured, showing a small amount of additional snow accumulation.

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 the following measurements on 1st June:

- Direct measurement of snow depth at locations E105 (7.9 m), E101 (7.1 m) and E34 (4.25 m).
- Snow depth from coring at stake E5, showing 7.0 m of snow.
- Snow depth sounding at 10 locations on a 9 km long profile. The snow depth was between 7 and 9 m at most of the locations above 1200 m a.s.l., and mainly between 5 and 7 m between 950 and 1200 m a.s.l. The summer surface was difficult to detect, and multiple soundings were carried out at each location.
- Direct measurement of ice melt at location E17, showing 1.3 m of melt.
- The transient snow line altitude at approximately 500 m a.s.l.
- Snow density measured down to the summer surface (SS) at 7.0 m depth at stake E5. The mean snow density was 0.53 g/cm^3.

Between 1st June and 2nd August the stake in position E17 at the tongue melted out. More than 4 m of ice had melted. At the plateau, between 3 and 4 m of snow melted in this period.

The net and summer balance measurements were carried out on 13th November. There was up to 2 m of new snow on the glacier plateau. Stakes were found in five locations (E17, E38, E20, E101 and E105). Stakes in two locations on the plateau (E5 and E34) had been lost due to new snow. The depth of new snow at the stakes on the plateau was measured by coring and probing. Between 2nd August and 13th November 4 m of ice melted on the glacier tongue. At stake E38, 1.8 m of snow melted before the snow accumulation started. At stakes E101 and E105, 0.7 and 0.5 m of snow, respectively, melted before the snow accumulation started. From stake measurements the transient snow line altitude was between 960 and 1050 m a.s.l.

The net balance was observed directly at four locations between 1050 and 1350 m a.s.l. The depth of remaining winter snow was calculated as 1.70 m, 1.05 m, 3.10 m and 4.15 m at stakes E38, E20, E101 and E105 respectively.

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.

Winter balance

Temperature measurements at Skjæret (Fig. 10-1 and chap. 10-2) show that the air temperature stayed close to or above zero for most of the first half of October 2006. This must have led to some additional melting after the net balance measurements on

4th October 2006. There was a slight difference between snow depth from stake readings at E101 and E105 (0.4 and 0.2 m, respectively) which can be related to a combination of late autumn melting and compaction of firn between the summer surface (SS) from 2006 and the lower end of the mast (at 14.4 and 9.5 m depth, respectively, on 4th October 2006). At stake E34 snow depth sounding close to the stake indicated 0.3 m of ice accumulation between 4th October and 1st June. The date of maximum snow-water-equivalents (SWE) was probably around 28th May 2007 when the last precipitation event prior to the snow measurements on 1st June was recorded at the precipitation station at Reipå (station no 87610), 30 km NNW of Engabreen. At the lower part of the glacier the melting started earlier, and some run-off probably took place before 1st June. This run-off volume has not been calculated.

The number of locations where snow depth was measured was considerably smaller than previous years (2005 – 133 locations, 2006 – 53 locations). The winter balance for 2007 is calculated using the same procedure as in previous years.

The calculation of winter balance was based on point measurements of snow depth (stake readings, coring and snow depth soundings) and on snow density measurements (Fig. 10-1). 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 960 m a.s.l. the winter balance curve was interpolated based on the observed snow depth at stake E34 and the observed negative winter balance at stake E17. Based on this altitudinal distribution curve, the winter balance was calculated as 3.4 ±0.3 m w.e., which corresponds to a volume of 130 ±10 mill. m^3 of water. This is 114 % of the mean value for the period 1970-2006 (2.95 m w.e.), and 127 % of the mean value for the 5-year period 2002-2006 (2.65 m w.e.).

Summer balance

The summer balance was measured directly at stakes E105 and E101. It was calculated from snow depth sounding and stake measurements at stakes E38 and E20. At locations E5, E34 and E17 some of the summer melting had to be estimated. An altitudinal distribution curve was drawn based on the calculated summer balance in seven locations between 300 and 1350 m a.s.l (Fig. 10-2). The summer balance was calculated as −2.3 ±0.2 m w.e., which equals a volume of −92 ±8 mill. m^3 water. This is 101 % of the average for the period 1970-2006 (−2.32 m w.e.), but 82 % of the average for the 5-year period 2002-2006 (−2.83 m w.e.).

Net balance

The net balance of Engabreen for 2007 was calculated as 1.0 ±0.3 m w.e., which corresponds to a mass gain of 40 ±10 mill. m^3 water. The mean value for the period 1970-2006 is +0.59 m w.e., but −0.18 m w.e for 2002-2006. The equilibrium line altitude (ELA) was determined as 1035 m a.s.l. from the net balance curve in Figure 10-2. This corresponds to an accumulation area ratio (AAR) of 84 %. The mass balance results are shown in Figure 10-2 and Table 10-1. The results from 2007 are compared with mass balance results for the period 1970-2006 in Figure 10-3.

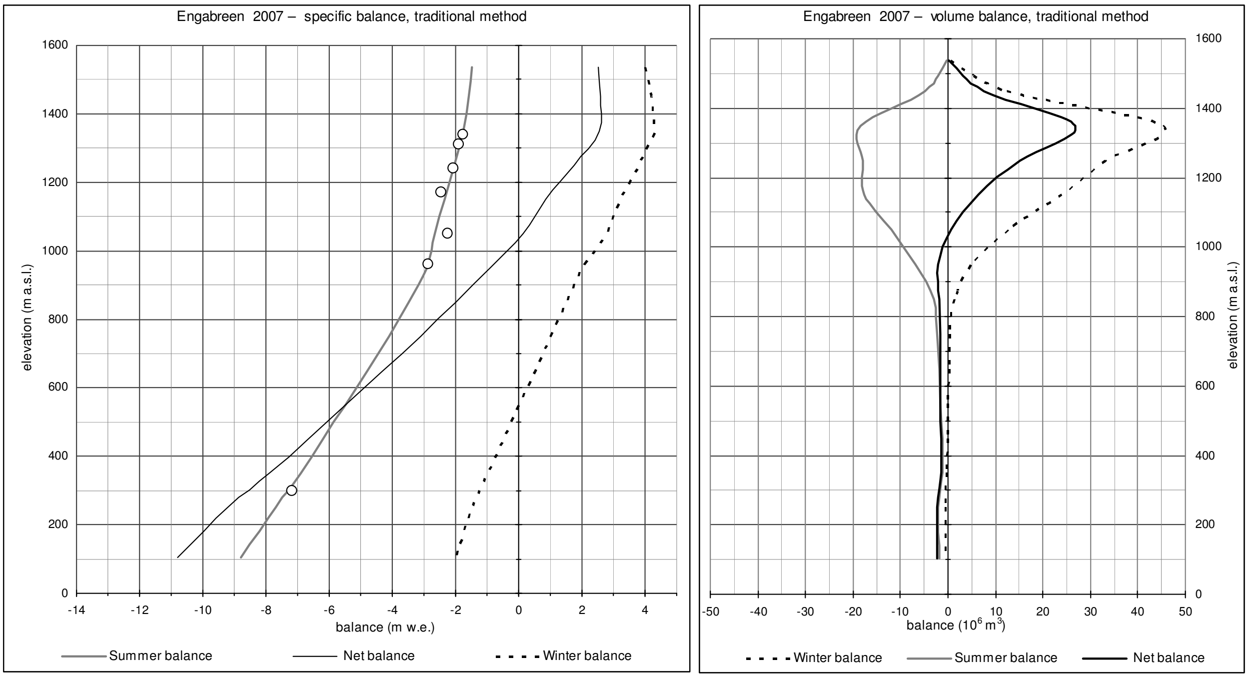


Figure 10-2
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2007. Summer balance at stakes and towers is shown as circles (○).

Table 10-1
Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2007.

Mass balance Engabreen 2006/07 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 1st Jun 2007: Specific (m w.e.)	Winter balance, Measured 1st Jun 2007: Volume (10^6 m^3)	Summer balance, Measured 13th Nov 2007: Specific (m w.e.)	Summer balance, Measured 13th Nov 2007: Volume (10^6 m^3)	Net balance, Summer surface 2006 - 2007: Specific (m w.e.)	Net balance, Summer surface 2006 - 2007: Volume (10^6 m^3)
1500 - 1575	0.13	4.00	0.5	-1.50	-0.2	2.50	0.3
1400 - 1500	2.94	4.20	12.3	-1.60	-4.7	2.60	7.6
1300 - 1400	10.52	4.30	45.2	-1.75	-18.5	2.55	26.8
1200 - 1300	8.68	3.80	33.0	-2.05	-17.8	1.75	15.2
1100 - 1200	7.47	3.20	23.9	-2.35	-17.6	0.85	6.3
1000 - 1100	4.52	2.80	12.7	-2.65	-12.0	0.15	0.7
900 - 1000	2.38	2.00	4.8	-2.90	-6.9	-0.90	-2.1
800 - 900	0.87	1.50	1.3	-3.50	-3.0	-2.00	-1.7
700 - 800	0.54	1.00	0.5	-4.10	-2.2	-3.10	-1.7
600 - 700	0.38	0.50	0.2	-4.80	-1.8	-4.30	-1.6
500 - 600	0.28	0.00	0.0	-5.50	-1.5	-5.50	-1.5
400 - 500	0.20	-0.50	-0.1	-6.20	-1.2	-6.70	-1.3
300 - 400	0.17	-1.00	-0.2	-6.90	-1.2	-7.90	-1.3
200 - 300	0.26	-1.50	-0.4	-7.70	-2.0	-9.20	-2.4
10 - 200	0.21	-2.00	-0.4	-8.80	-1.8	-10.80	-2.3
10 - 1575	**39.6**	**3.37**	**133.4**	**-2.34**	**-92.5**	**1.03**	**40.9**

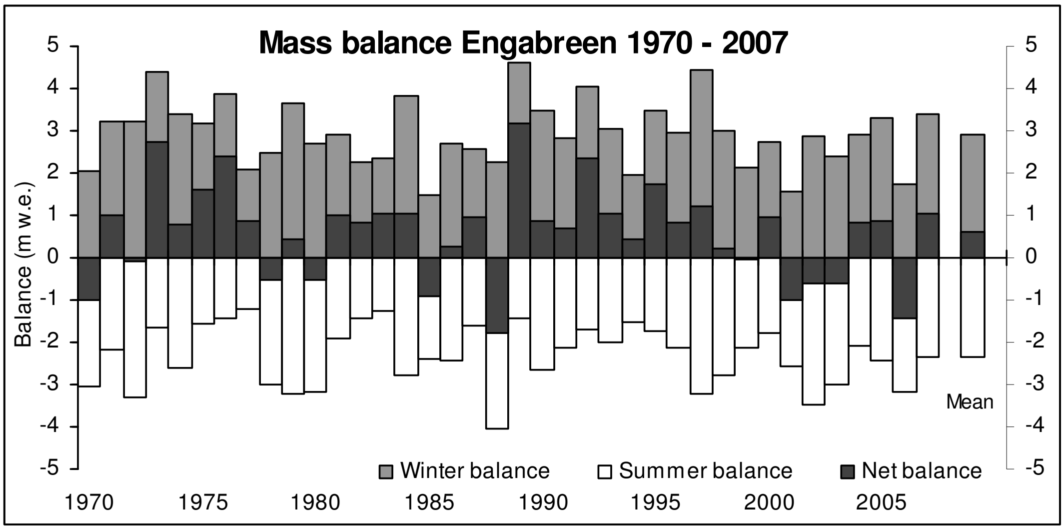


Figure 10-3
Mass balance at Engabreen during the period 1970-2007. The accumulated surplus amounts to 23 m water equivalent. The average winter, summer and net balances are b_w =2.9 m w.e., b_s =–2.3 m w.e., and b_n =0.6 m w.e.

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 meteorological station is 80700 Glomfjord (39 m a.s.l.), 19 km north of Skjæret. This station has been operated by the Norwegian Meteorological Institute (DNMI) since 1916. The precipitation record has been incomplete since 2004.

In 2007, data was collected at Skjæret until 13th November with no gaps (Fig. 10-4). After the autumn measurements on 3rd October 2006 the air temperature was close to or above freezing during the first half of October. The coldest period this winter was around 20th February when the daily mean temperature was below –20 °C. The first period in spring with midday temperatures above 0 °C was 13th to 15th April, and following this the temperature was at or below freezing until 29th May when the temperature increased considerably and stayed above 5 °C until 11th June. The snow measurements were done on 1st June. The maximum daily temperature was measured on 8th August (11.9 °C). Except for a cold period between 12th and 19th June the air temperature was at or above 0 °C until 25th August. The temperature was then below freezing except in the warm periods between 23rd September and 6th October and 20th to 28th October.

In Glomfjord the mean annual temperature in 2007 was 5.8 °C, which is 0.8 °C above the 1961-90 average. The summer temperature in Glomfjord (1st June -30th September, 11.8 °C) was 0.7 °C higher than the 1961-90 average. At Skjæret the summer mean temperature was 2.7 °C which is 1.4 °C lower than in the warm summers of 2002 and 2006 but similar to 2001 and 2005.

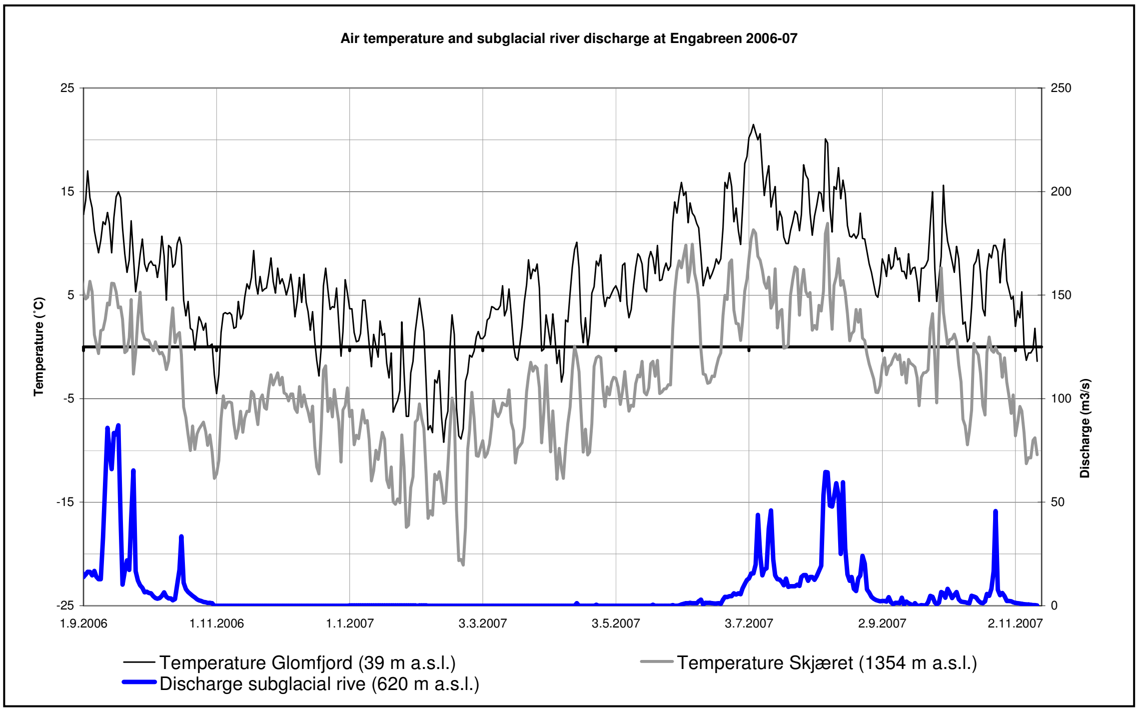


Figure 10-4
Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700), and discharge in the subglacial river intake beneath Engabreen between 1st September 2006 and 31st December 2007.

The precipitation station 80740 Reipå (9 m a.s.l.) is located 28 km north of Engabreen and 19 km north-west of Glomfjord, and has been recording since July 1995. The 1961-90 annual mean is estimated as 1452 mm (71 % of Glomfjord). A comparison of winter precipitation sums (1st October – 31st May) from 1997-2002 indicates that Reipå gets 67 % of the winter precipitation in Glomfjord (Fig. 10-5). The recorded winter precipitation at Reipå in 2007 was 1100 mm, which is less than in 1997 and 2000 but comparable to 2002 and 2005.

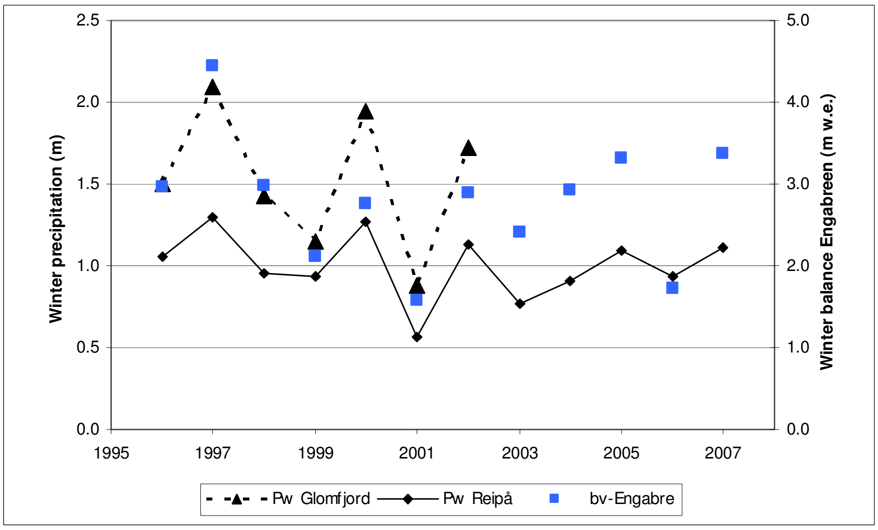


Figure 10-5
Winter (Oct-May) precipitation at Reipå (80740) and Glomfjord (80700), and winter balance at Engabreen.

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. 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). Four of these load cells were still functioning in 2007. A further two load cells were installed in November 1997 and were also still operating in 2007 (Fig. 10-6). There are gaps in the load cell data from 9th March to 29th March and from 7th July to 15th July due to temporary problems downloading the data. A seventh load cell (number 7, Fig 10-6), has recorded intermittently since installation in November 2003, hence these results are not included here. Note that the graphs of load cell pressure variations have different axes.

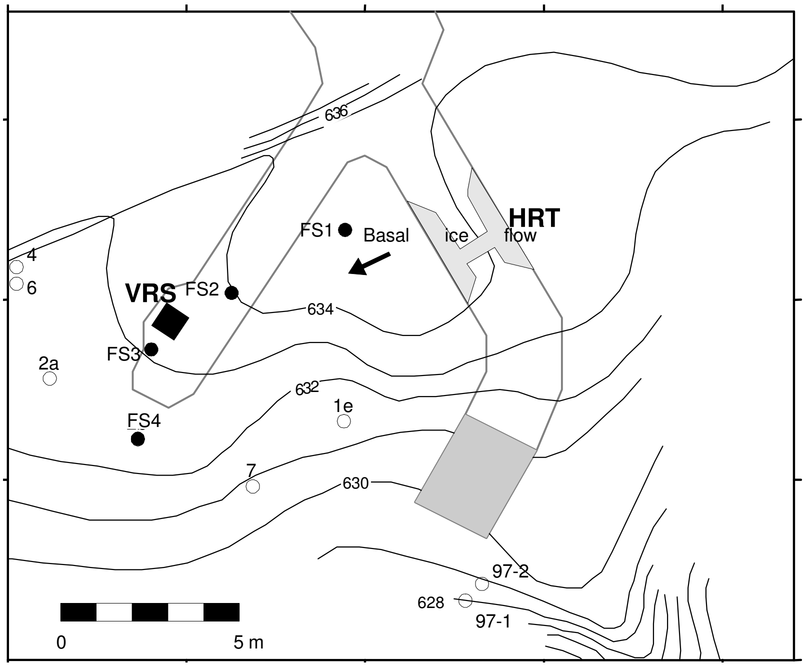


Figure 10-6
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 97-1 and 97-2 and boreholes, marked FS.

Pressure sensor records for winter 2007 from 1st January to 8th March are shown in Figure 10-7. The records are typical for the winter period - relatively quiet and stable, corresponding with very low discharge measured in the subglacial tunnel. Temperatures as measured at the meteorological station (Fig. 10-4) at Skjæret were low (below −20º C for several days in late February) and although there was frequent rain (as recorded at the meteorological station in Bodø) for much of January and early February, there were no major precipitation events. The records show that the pressure measured was stable at all of the pressure sensors (some of them tend to be slightly noisier, such as 2a, 97-1 and 97-2, due to their locations). Although the pressure for 97-1 was similar to that measured in 2006, 97-2 was more stable with slightly higher values. Sensors 4 and 6 were also stable, with 6 being higher than 2006, while 2a showed significantly lower values (by 1 – 1.5 bars) than in 2006.

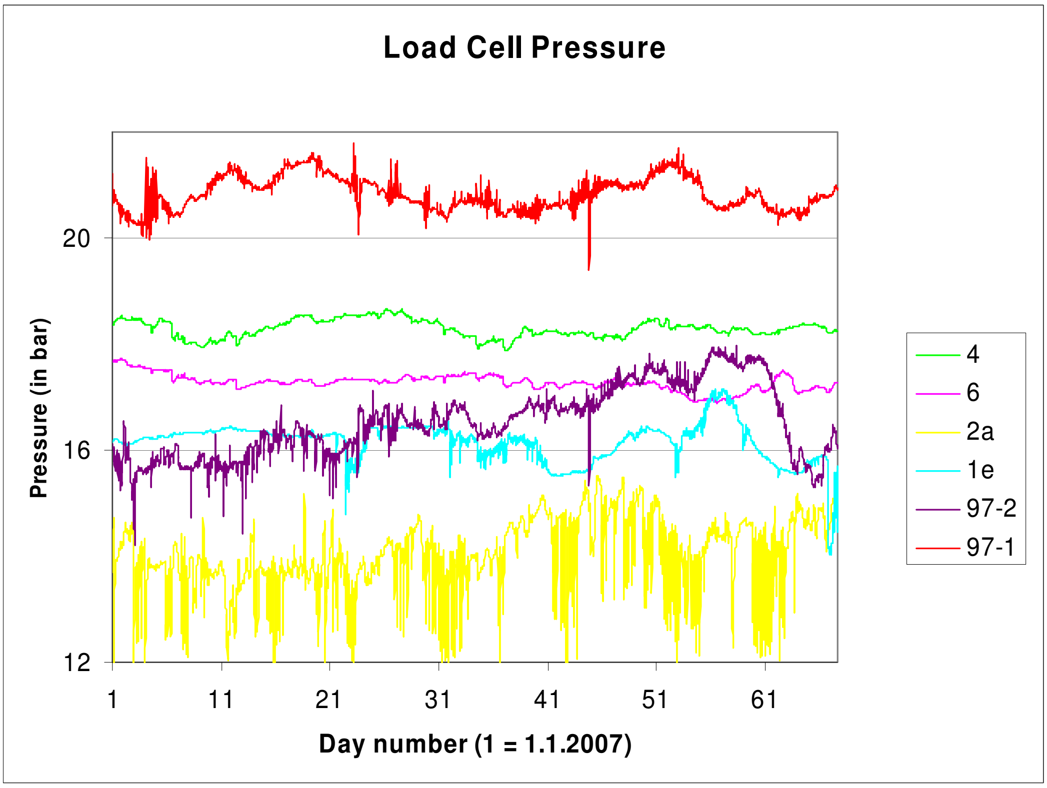


Figure 10-7
Pressure records for 1st January to 8th March.

Pressure sensor records for the late-spring and early- summer, from 30th March to 6th July, are shown in Figure 10-8. These show a lot of variation and thus reflect the increased meltwater under the glacier, as also shown in records of discharge in the subglacial tunnel (Fig. 10-4). The first real peak in subglacial discharge after the winter period occurs on 15th April and corresponds with persistent, heavy rain in this period (recorded at Bodø), and warm temperatures rising to above 0º C at Skjæret. The discharge peaks at 2 m^3/s, twenty times the normal winter discharge. All six of the pressure sensors record this increased discharge as a sharp drop in pressure, quickly followed by a sharp rise, further followed by a gradual decrease, thus reflecting the presence of increased meltwater under the glacier. Another sharp increase in subglacial discharge occurs on 24th April, corresponding with heavy rain. This registers strongly at pressure sensors 4 and 6 (usually the two that show least variation) but less so at the other four sensors. A warm period from 28th May to 9th June gives a broad peak in the subglacial discharge, which has its maximum on 10th June at 4 m^3/s. Sensors 4 and 6 exhibit a diurnal signal in pressure variations in this period. Generally, the records are similar to those of the same period in 2006, although 97-1 and 97-2 show less variation.

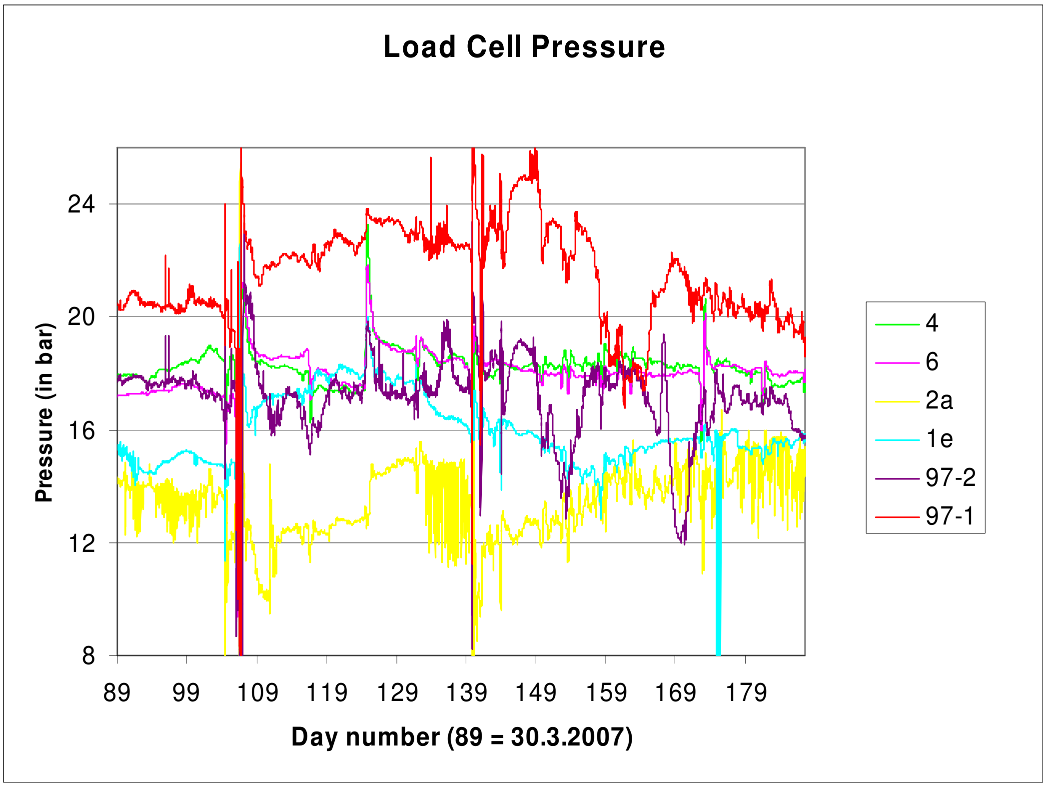


Figure 10-8
Pressure records for 30th March to 6th July.

Pressure sensor records for the summer and early autumn, from 16th July to 30th September, are shown in Figure 10-9. These are fairly typical for the summer period. The changes in pressure recorded at the sensors are well-correlated with each other, with the slight exception of 2a, which shows generally the same variations but also a lot more 'noise'. Presumably, changes in hydrology at the base of the glacier occur over a widespread area in the summer/autumn hydrology regime, as opposed to the winter/spring regime when changes in hydrology are more restricted. The peaks and troughs in pressure do not show an obvious correlation with the subglacial discharge measured beneath the glacier. The pressure magnitudes are by and large similar to those for this period in 2006, although 97-2, 1e, 4 and 6 show slightly higher values.

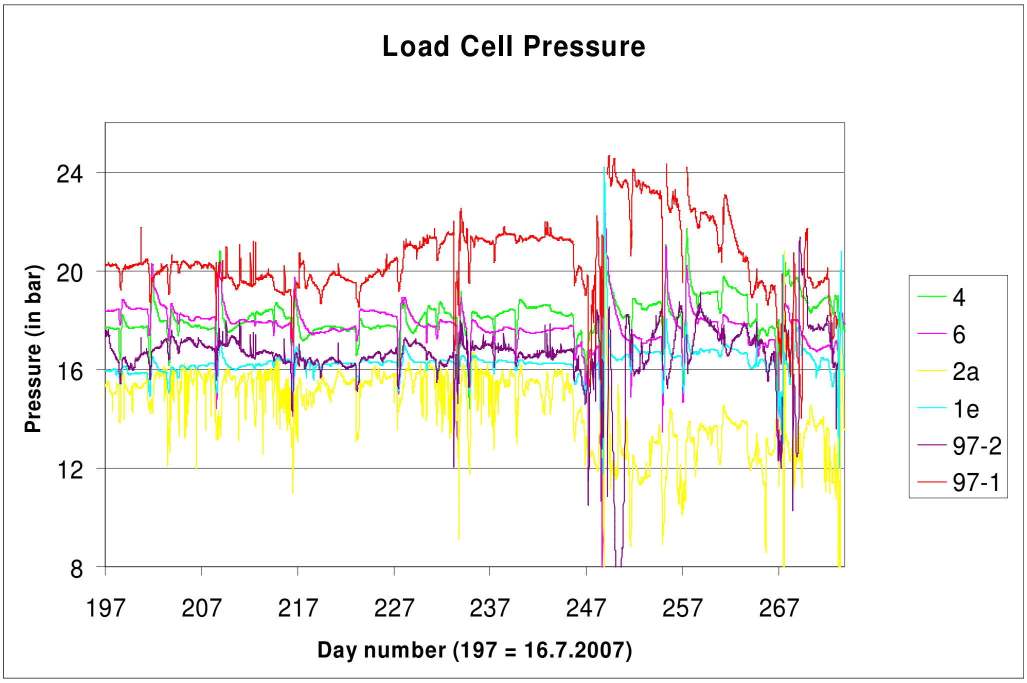


Figure 10-9
Pressure records for 16th July to 30th September.

Figure 10-10 shows the pressure sensor records for the late autumn / early winter period, from 1st October to 31st December. There are large variations at the beginning of this period. These correspond to fluctuating temperatures - above zero at Skjæret meteorological station in the first few days, dropping to –12° C on 10th October, only to quickly rise above zero again on 13th, followed by another rapid drop and rise (Fig. 10-4). These warm periods gave rise to high subglacial discharge, with peaks in discharge corresponding to the warm periods on the glacier. This resulted in a discharge peak of over 50 m^3/s on 24th October, and the pressure records are correspondingly highly variable. The data for sensors 97-1 and 97-2 showed such wide fluctuations in this period that it has been omitted from the graph. Note that melting of an ice tunnel in the subglacial laboratory in the period day 324 – 330 caused non-natural pressure fluctuations. This event registers at all the sensors, especially 97-1 and 97-2 which are very close to where the tunnel was melted out. Heavy rainfall around 21st December resulted in a steep drop in pressure and rapid recovery as registered at all the load cells, especially 4 and 6. Records of subglacial discharge are not yet available for later than 26th November.

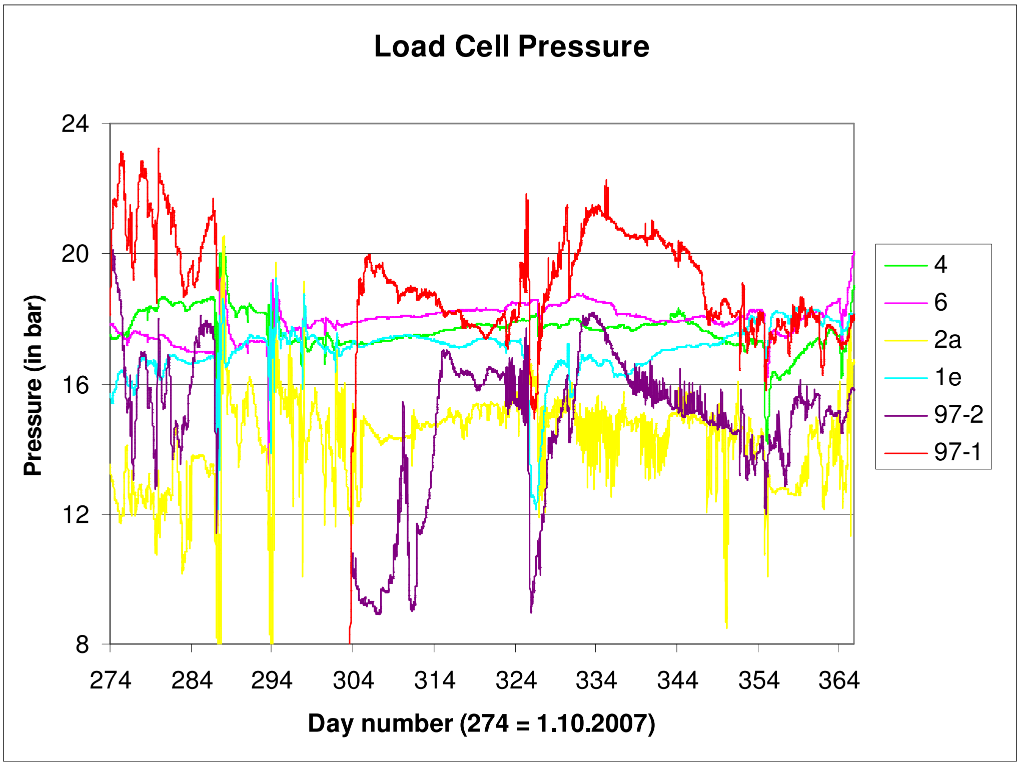


Figure 10-10
Pressure records for 1st October to 31st December.

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

The glaciological investigations in 2007 include mass balance and change in glacier length (chap. 12). Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

11.1 Mass balance 2007

Fieldwork

Snow accumulation measurements

Snow accumulation was measured on 22nd May and the calculation of winter balance is based on (Fig. 11-2):

- Measurements of stakes in positions 10 (485 m a.s.l.), 20 (640 m a.s.l.), 25 (730 m a.s.l.) and 30 (890 m a.s.l.) showing snow depths of 2.2, 3.9, 4.1 and 4.3 m respectively.
- 81 snow depth soundings between 381 and 1053 m elevation. The summer surface (SS) was distinct over the whole glacier. In general the snow depth varied between 2 and 5 m.
- Snow density was measured down to SS at 4.1 m depth at stake position 30.

Figure 11-1
The outlet of Langfjordjøkelen photographed on 22nd May. Photo: Miriam Jackson.

Ablation measurements

Ablation was measured on 3rd November. The net balance was measured at nine stakes in all five locations between 485 and 1053 m a.s.l. Since snow measurements in May the stakes had increased in length between 3.9 m (1053 m a.s.l.) and 6.0 m (485 m a.s.l.). There was about 1 m of snow remaining at the top of the glacier from the winter season 2006/2007. At the time of measurements up to 30 cm of fresh snow had fallen.

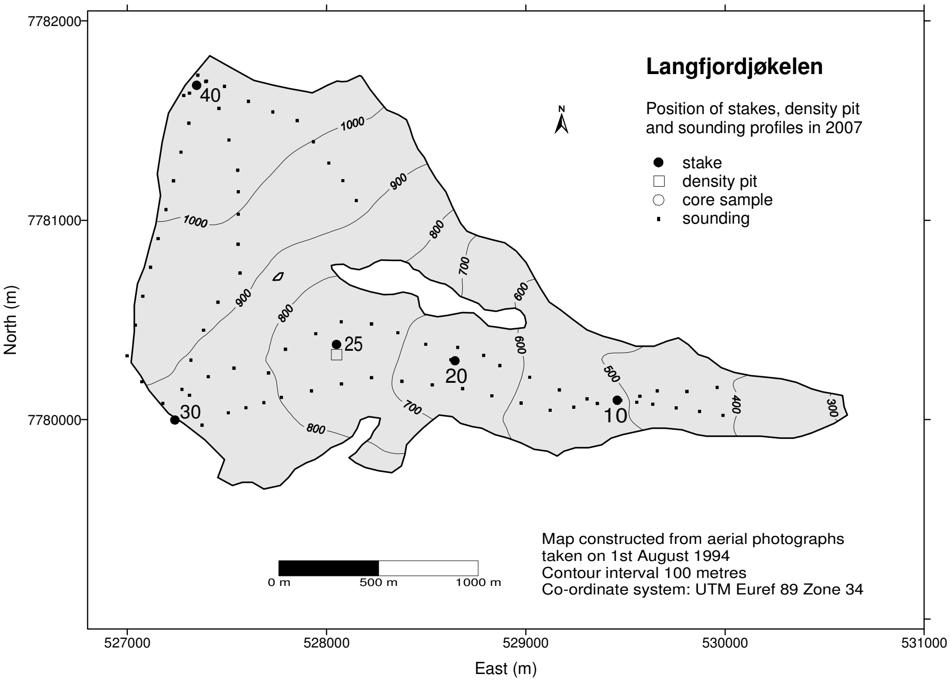


Figure 11-2
Location of stakes, soundings and snow pit at Langfjordjøkelen in 2007.

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 and soundings) and on one snow density measurement.

There was no melting after the final measurements in October 2006. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measurement at 730 m altitude. The mean density of 4.1 m snow was 0.50 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. 11-4) and a mean value for each 100 m height interval was estimated (Tab. 11-1).

The winter balance was calculated as 2.1 ±0.2 m w.e., corresponding to a water volume of 8 ±1 mill. m^3. The result is 98 % of the mean value for the periods 1989-1993 and 1996-2006.

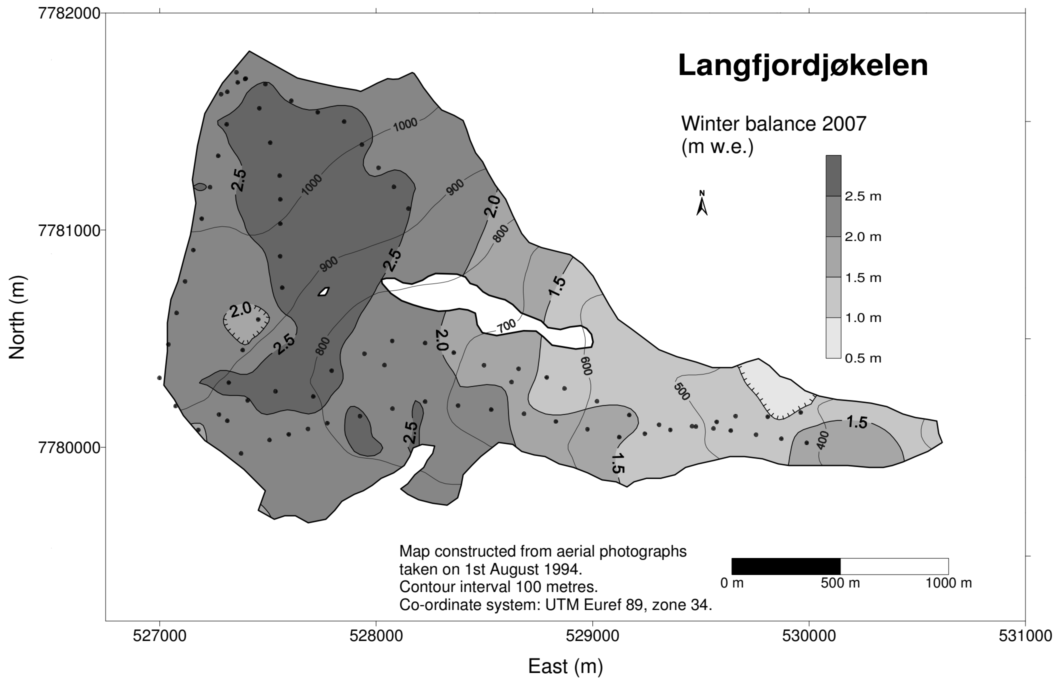


Figure 11-3
Winter balance at Langfjordjøkelen in 2007 interpolated from 81 snow depth measurements (•).

The winter balance was also calculated using different gridding methods and different spacing based on the aerial distribution of the snow depth measurements (Fig. 11-3). Water equivalent for each cell in the grid was calculated and summarised. These calculations gave an average of 2.1 m w.e. also.

Summer balance

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

The summer balance was calculated at stakes at all five elevations. The summer balance increased from −1.9 m w.e. at position 40 (1053 m a.s.l.) to −4.5 m w.e. at position 10 (485 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −2.9 ±0.3 m w.e., which is −11 ±1 mill. m^3 of water. This result is 94 % of the average for the periods 1989-1993 and 1996-2006. This is the lowest summer balance measured since 1999.

Net balance

The net balance at Langfjordjøkelen for 2007 was −0.8 ±0.3 m w.e., which equals a volume loss of −3 ±1 mill. m^3 of water (Tab. 11-1). The mean value for the measurement periods 1989-93 and 1996-2006 is −0.95 m w.e. (Fig. 11-5), while the average over the 5-year period 2002-2006 is −1.6 m w.e.

Based on Figure 11-4, the Equilibrium Line Altitude (ELA) lies at 870 m a.s.l. Accordingly, the Accumulation Area Ratio is 42 %.

The mass balance results are shown in Table 11-1. The corresponding curves for specific and volume balance are shown in Figure 11-4. The historical mass balance results are presented in Figure 11-5.

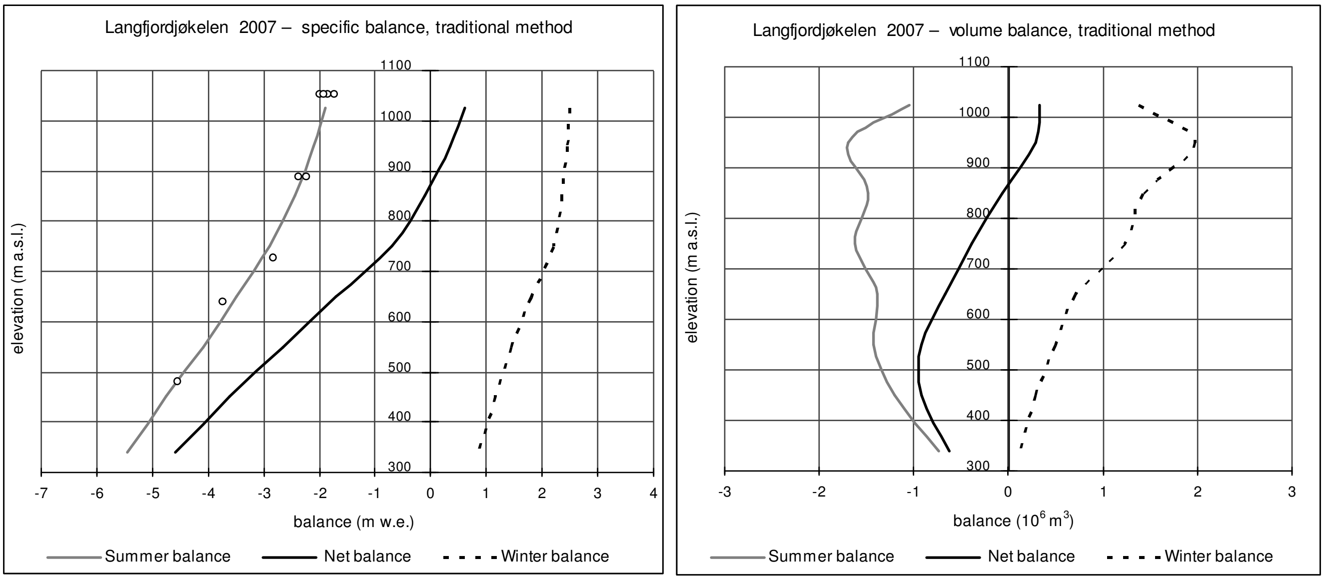


Figure 11-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2007. Summer balance for stakes at three different sites is shown (o).

Table 11-1
Winter, summer and net balance for Langfjordjøkelen in 2007. Mean values for the periods 1989-93 and 1996-2007 are b_w = 2,13 m, b_s = –3,08 m and b_n = –0,95 m w.e.

Mass balance Langfjordjøkelen 2006/07 – traditional method

		Winter balance Measured 22nd May 2007		Summer balance Measured 3rd Nov 2007		Net balance Summer surface 2006 - 2007	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1000 - 1050	0.55	2.50	1.4	-1.90	-1.0	0.60	0.3
900 - 1000	0.81	2.45	2.0	-2.10	-1.7	0.35	0.3
800 - 900	0.61	2.35	1.4	-2.45	-1.5	-0.10	-0.1
700 - 800	0.56	2.20	1.2	-2.90	-1.6	-0.70	-0.4
600 - 700	0.39	1.80	0.7	-3.50	-1.4	-1.70	-0.7
500 - 600	0.35	1.45	0.5	-4.10	-1.4	-2.65	-0.9
400 - 500	0.25	1.15	0.3	-4.75	-1.2	-3.60	-0.9
280 - 400	0.14	0.85	0.1	-5.45	-0.7	-4.60	-0.6
280 - 1050	**3.65**	**2.09**	**7.6**	**-2.90**	**-10.6**	**-0.81**	**-3.0**

The balance year 2006/2007 is the eleventh successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2007 (estimated values for 1994 and 1995 included) is −17 m w.e. Most of this mass loss (94 %) has occurred over the last eleven years (1997-2007).

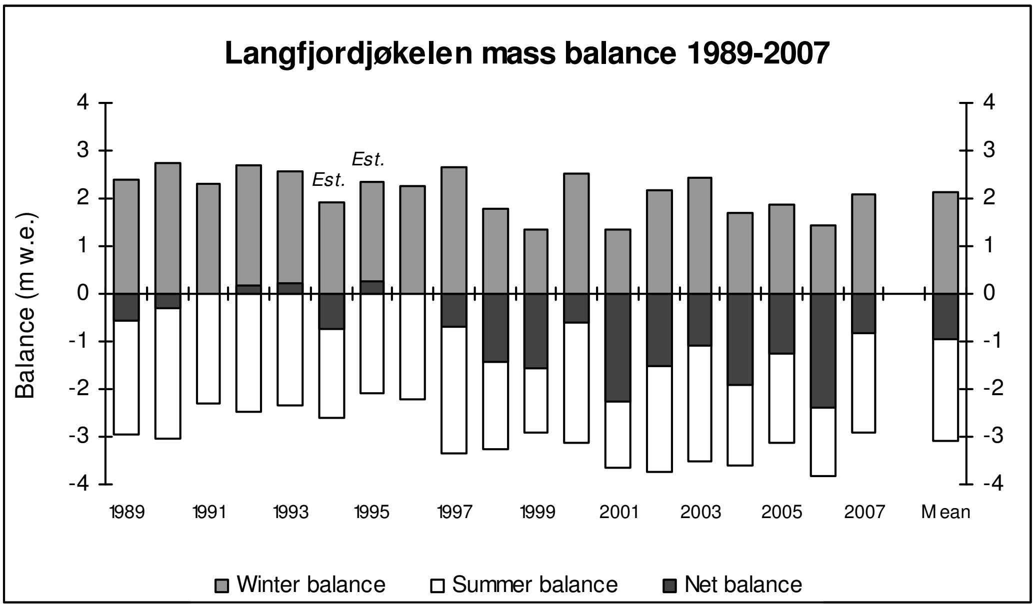


Figure 11-5
Mass balance at Langfjordjøkelen during the period 1989-2007. The total accumulated deficit over 1989-2007 is 16.6 m w.e. (includes estimated values for 1994 and 1995).

12. Glacier monitoring

(Hallgeir Elvehøy and Miriam Jackson)

12.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started around 1900. In 2007, glacier length change was measured for 29 glaciers - 22 in southern Norway and seven glaciers in northern Norway (Fig. 12-2). Sydbreen in Lyngen (Fig. 12-3) and two outlet glaciers from Folgefonna are included in the monitoring network for the first time. One glacier, Bergsetbreen from Jostedalsbreen, has been removed from the monitoring programme because the lower tongue has separated from the main glacier, and the active terminus is now inaccessible (Fig 12-2).

Figure 12-1
Bødalsbreen, a northern outlet from Jostedalsbreen was photographed on 22nd September 2007. The glacier area is 8.9 km^2 and covers the altitudinal interval between 660 and 1920 m a.s.l. More than 75 % of its area is above 1600 m a.s.l. (1994). Glacier length change was monitored between 1900 and 1953. Bødalsbreen advanced prior to 1912 and between 1924 and 1930. From 1931 until the measurements were terminated in 1953, the glacier retreated 600 metres. Lake Sætravatnet (602 m a.s.l. – lower left corner in the picture) was deglaciated in this period. Glacier length change measurements were resumed by Dr. Stefan Winkler in 1996. Photo: Hallgeir Elvehøy.

Methods

The distance to the glacier terminus is measured from one or several fixed points in defined directions, usually in September or October each year. The 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 how representative the measurement is for the entire glacier tongue. Nevertheless, the measurements give valuable information about glacier fluctuations, as well as regional tendencies and variations when longer time periods are considered (Andreassen et al., 2005).

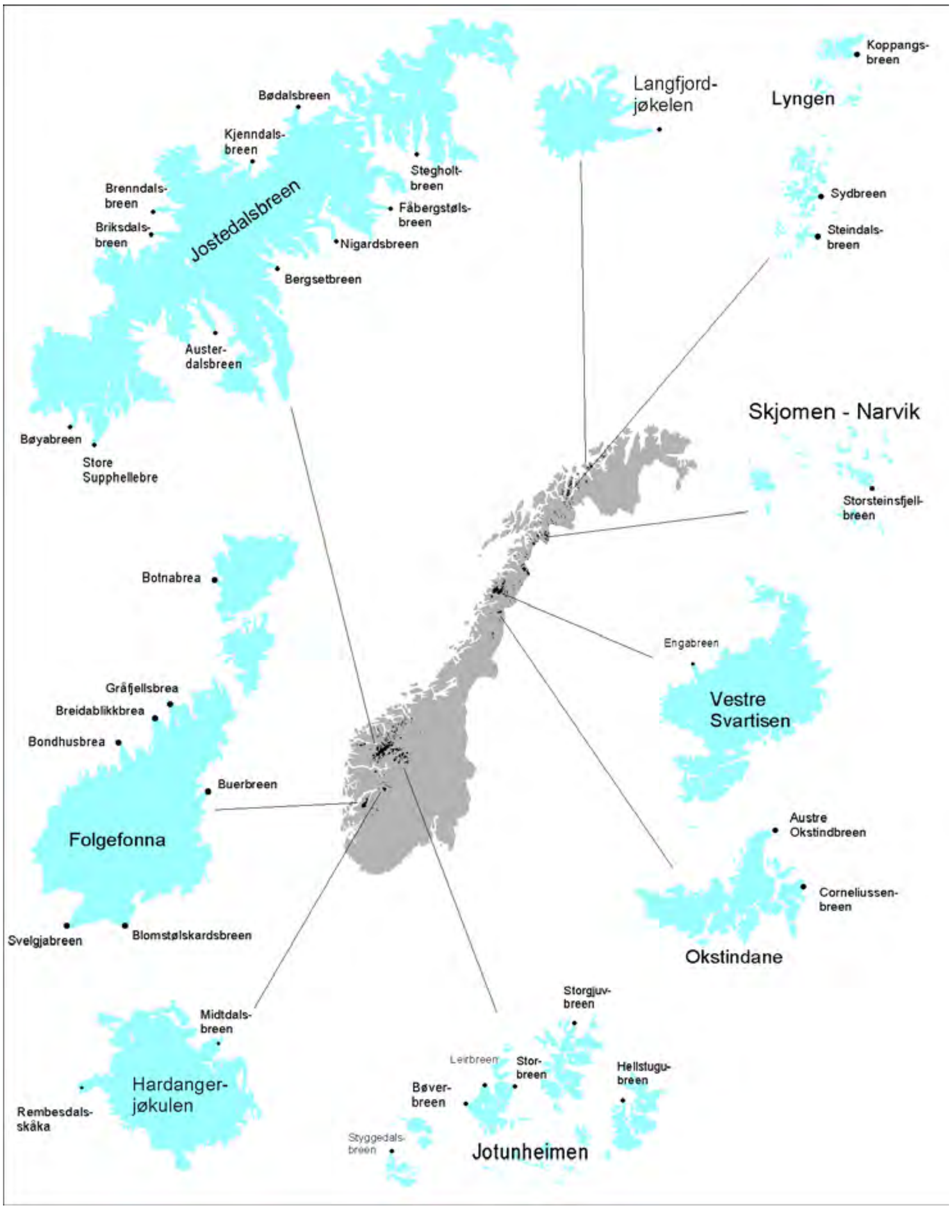


Figure 12-2
Location map showing glaciers where length change observations were performed in 2007. Note that the different glacier areas are not to the same scale.

Results 2007

In 2007, 29 glaciers were measured, seven in northern Norway and 22 glaciers in southern Norway. The glacier length changes at the observed glaciers are listed in Table 12-1.

At Jostedalsbreen, Kjenndalsbreen retreated 180 m, and has retreated 500 m since 2000. The average retreat of ten outlet glaciers from Jostedalsbreen was 51 metres. Four out of ten measured glacier tongues retreated more than 50 metres.

At Folgefonna, Buerbreen retreated 79 metres. Bondhusbrea retreated 49 m in 2007 and has retreated 237 m since 1996 when measurements resumed. The most recent advance at Bondhusbrea started slowly about 1970. The glacier advanced approximately 30 metres between 1973 and 1982, and another 60 m from about 1982 until about 1996. It is several hundred years since the length of Bondhusbrea has been this short. At Hardangerjøkulen, Rembesdalsskåka retreated 22 metres, and has retreated 284 m since 1997.

In Jotunheimen, Styggedalsbreen, Bøverbreen and Storgjuvbreen advanced slightly in the second half of the 1990s. The other three glaciers have been retreating continually as have most of the glaciers in Jotunheimen. Hellstugubreen and Leirbreen have retreated 110 m since 1990 (an average length decrease of 7 m/a). The observations at Leirbreen indicate a small advance. However, this year's length increase is probably an adjustment to a relatively large change in 2006.

In Nordland, Engabreen has retreated 220 m since the last advance ended in 1999. Corneliussenbreen advanced during the 1970s, -80s and -90s, but has retreated 220 metres from its most recent end moraine which was formed late in the 1990s. Austre Okstindbreen has not changed significantly during the last year, but it has retreated about 1750 m since 1908. Storsteinsfjellbreen in Skjomen had retreated 470 m between 1963 and 2006 (−11 m/a), but it retreated only 3 metres last year. However, the glacier tongue had thinned considerably.

In Troms and Finnmark the glaciers have been retreating for several decades. Langfjordjøkelen has retreated 410 m since 1994 (−31 m/a), whilst Steindalsbreen and Koppangsbreen in Lyngen have retreated about 160 m since 1998 (−18 m/a).

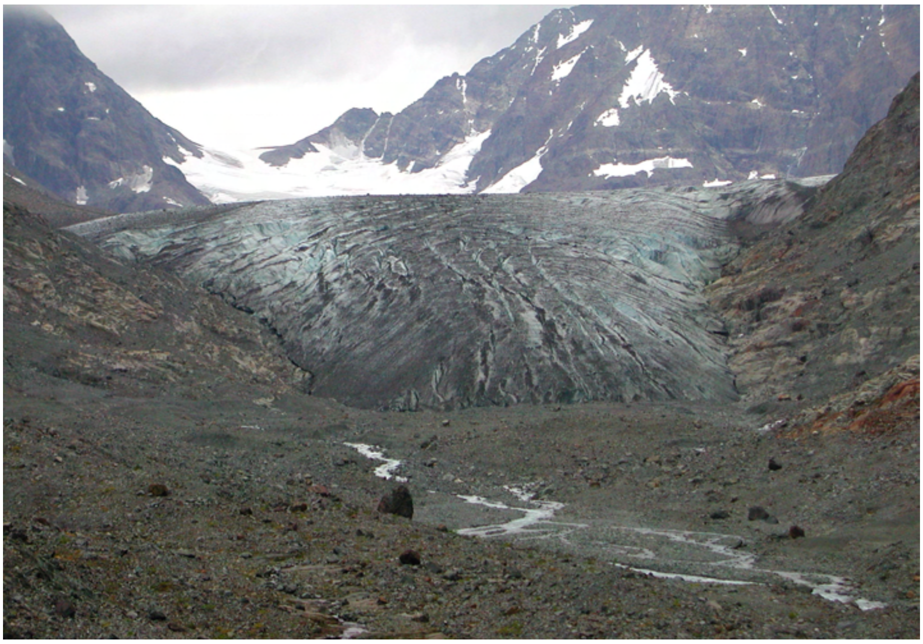


Figure 12-3
Photograph showing the terminus of Sydbreen, an east-facing valley glacier in Lyngen, Troms, on 2nd September 2001. In 1993 the total glacier area was 6.0 km^2 and covered the altitudinal interval between 405 and 1834 m a.s.l. The upper glacier (1.8 km^2, 1350-1834 m a.s.l.) is part of the glacier complex on Jiekkevarre, and feeds the lower glacier (4.2 km^2, 405-1120 m a.s.l.) through avalanching. Glacier length change measurements were initiated in 2007. Sydbreen has been retreating for several decades. Photo: Miriam Jackson.

Table 12-1
Glacier length change between autumn 2006 and autumn 2007. See Figure 12-2 for locations.

Region	Glacier	Change (m)	Measured by	Measured since
Jostedalsbreen	Austerdalsbreen	−20	NVE	1933+
	Bergsetbreen	NM[1]	NVE	1996+
	Brenndalsbreen	−87	Dr. S. Winkler, Germany	1996+
	Briksdalsbreen	−53	NVE / Prof. A. Nesje, U. Bergen	1900
	Bødalsbreen	−13	Dr. S. Winkler, Germany	1996+
	Fåbergstølsbreen	−14	NVE	1899
	Kjenndalsbreen	−182	Dr. S. Winkler, Germany	1996+
	Nigardsbreen	−4	Statkraft	1899
	Stegholtbreen	−39	NVE	1903
	Bøyabreen	−74	Norsk Bremuseum	2003+
	Store Supphellebreen	−20	Norsk Bremuseum	1992+
Folgefonna	Bondhusbrea	−49	Statkraft	1996+
	Botnabrea	NM[2]	G. Knutsen, Tyssedal	1996
	Blomstølskardsbreen	−2	Sunnhordland Kraftlag	1994
	Breidablikkbrea	NM[3]	Statkraft	2002
	Buerbreen	−79	NVE	1995+
	Gråfjellsbrea	−53	Statkraft	2002
	Svelgjabreen	X	Sunnhordland Kraftlag	2007
Hardangerjøkulen	Midtdalsbreen	−31	Prof. A. Nesje, U. Bergen	1982
	Rembesdalsskåka	−22	Statkraft	1995+
Jotunheimen	Bøverbreen	−1	Dr. S. Winkler, Germany	1997+
	Hellstugubreen	−10	NVE	1901
	Leirbreen	6	NVE	1909
	Storbreen	−1	NVE	1902
	Storgjuvbreen	−3	Dr. S. Winkler, Germany	1997+
	Styggedalsbreen	−19	NVE	1901
Okstindane	Austre Okstindbreen	1	NVE	2006+
	Corneliussenbreen	−42	NVE	2006
Svartisen	Engabreen	−34	Statkraft	1903
Skjomen	Storsteinsfjellbreen	−3	NVE	2006
Lyngen	Koppangsbreen	−12	NVE	1998
	Sydbreen	X	NVE	2007
	Steindalsbreen	−30	NVE	1998
Finnmark	Langfjordjøkelen	−51	NVE	1998

1996+ length change measurements in earlier periods

X measurements started in 2007

NM not measured in 2007

[1] The lower tongue has separated. Measurements are no longer representative for the glacier length

[2] The terminus was snow-covered

[3] The terminus is thinning without corresponding length change

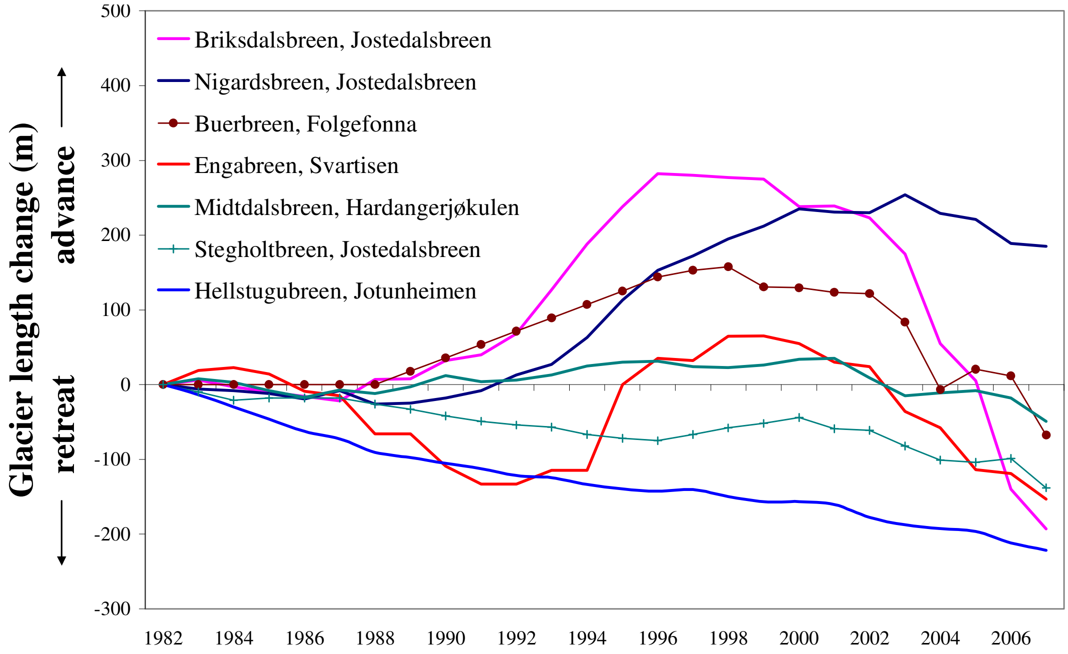


Figure 12-4
Cumulative glacier length change since 1982 at seven glaciers. See Figure 12-2 for locations.

Changes since 1982

In the 1980s, most of the observed glaciers retreated slowly (Fig. 12-4). Many outlet glaciers from coastal ice caps started to advance late in the 1980s. This advance ended before the turn of the century. At Stegholtbreen the advance didn't begin until 1996 and lasted four years. The more continental glaciers such as Hellstugubreen have been retreating slowly for decades.

Photographic documentation of front position change at Jostedalsbreen (Stefan Winkler)

Photogrammetric monitoring of 12 outlet glaciers from Jostedalsbreen started around 1990. The glacier tongues have been photographed from the same position once or twice per year. The goal was to document glacier front position changes not covered by annual length measurements. The photographic documentation provides supplementary information about changes of the geometry of the glacier tongue or snow avalanches that influence the ablation on the tongue.

Photo documentation of Bergsetbreen illustrates changes not shown by annual length measurements (Fig. 12-5). During the summer of 2003, areas of bedrock were exposed within the ice fall for the first time since the culmination of the recent advance around 2000. The exposed bedrock "window" enlarged and between mid-June and mid-August 2006 the lower tongue became completely separated from the glacier. Consequently, the length change measurements have been terminated. The new, active terminus is inaccessible for glacier length observations. In addition, the photographic documentation of front position changes plays an important role for the visualisation of glacier/climate change in the media and in an educational context.

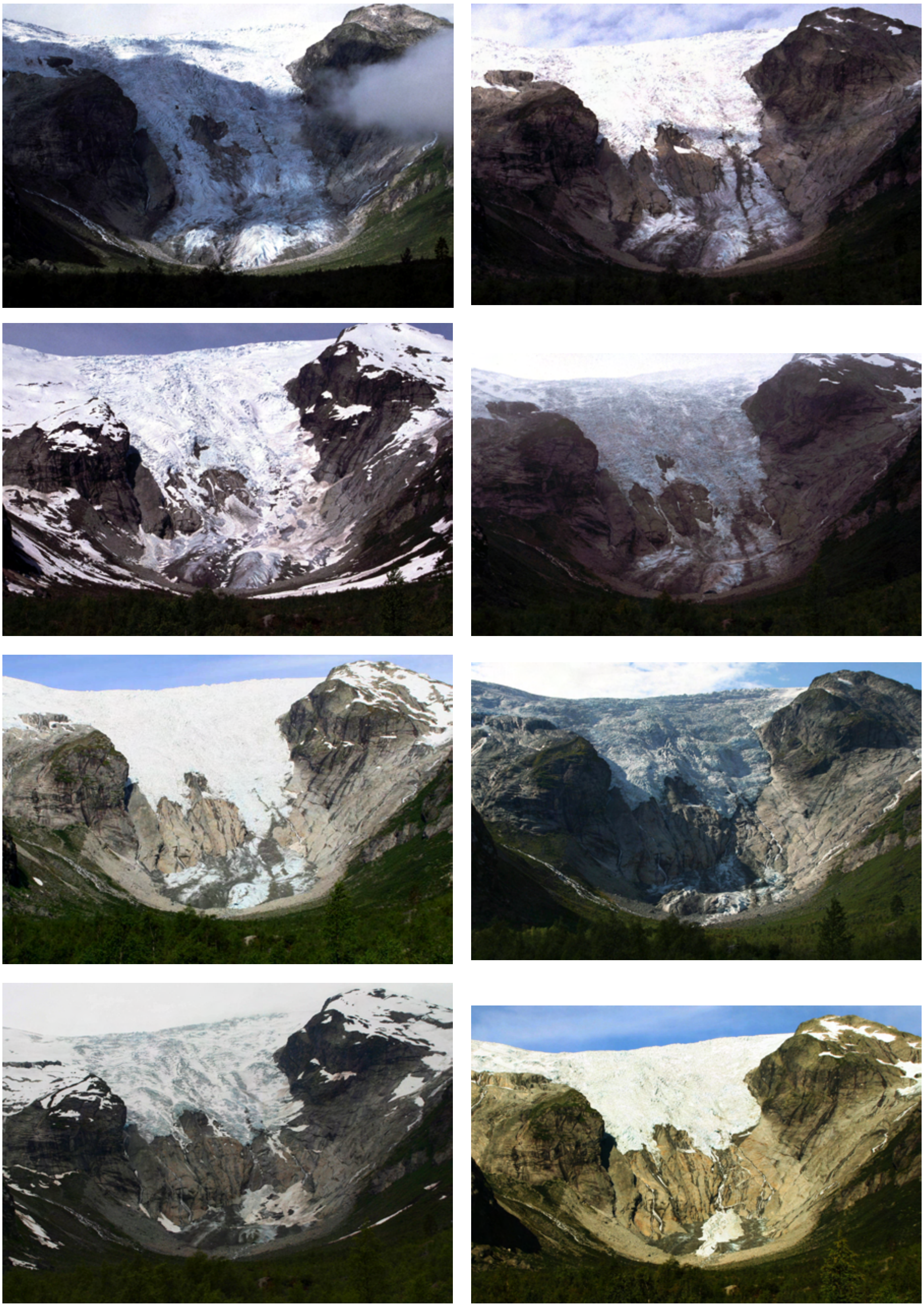


Figure 12-5
The top two pictures show Bergsetbreen in August 2003 (left) and August 2004 (right). Thereafter, June 2005-2007 are shown in the left column, and August 2005-2007 in the right. Photo: Stefan Winkler.

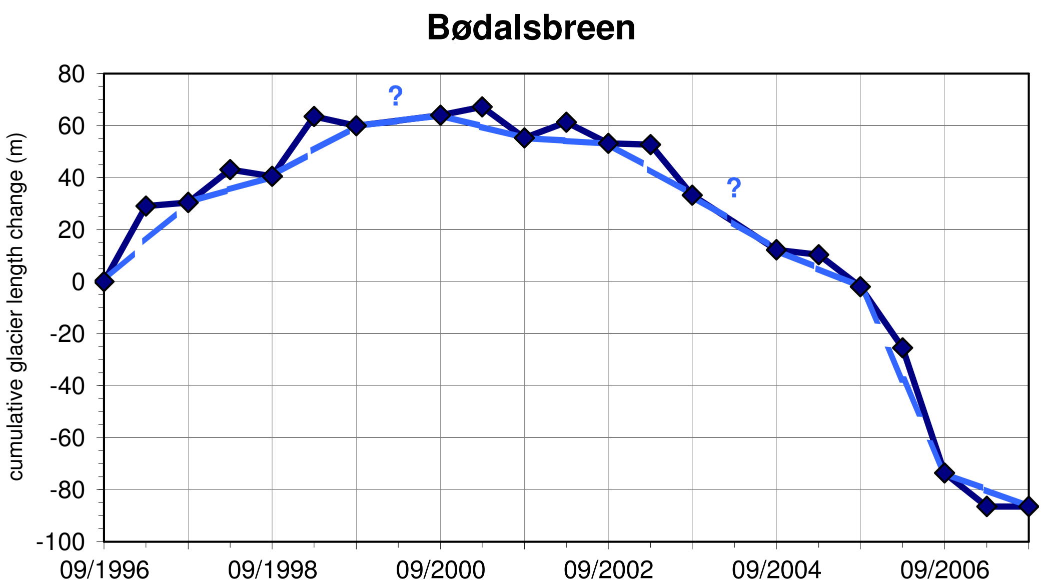


Figure 12-6
Cumulative glacier length change of Bødalsbreen (Fig. 12-1). The solid line gives the 'seasonal' length change, the broken line the annual change barely based on the measurements in September.

Eleven years of bi-annual glacial length measurements

(Stefan Winkler)

At Brenndalsbreen, Bødalsbreen and Kjenndalsbreen, three outlet glaciers of Jostedalsbreen in Stryn, bi-annual length change measurements have been carried out since 1996 (Fig. 12-6). Measurements have been conducted in early and late summer to register seasonal glacier-length variations. Seasonal advances have been shown to have sufficient power to form moraines similar to those representing multi-year advances (Winkler 1996, Winkler & Nesje 1999), thus the results are interesting in a geochronological context. The strongest winter advances were between 20 and 30 metres. The seasonal length change was most accentuated in the years with small annual length changes. During the last few years of strong frontal retreat, no 'winter advance' could be detected. However, the summer retreat from mid-June to September during the year 2007 was smaller than expected. It could, therefore, be concluded that an important part of the annual retreat in 2007 took place prior to the first measurement in mid-June 2007.

12.2 Jøkulhlaup at Blåmannsisen

A new jøkulhlaup (outburst flood) occurred from Blåmannsisen in northern Norway (Fig. 12-7) in August 2007. This is the third known jøkulhlaup to occur at Blåmannsisen, the first two having occurred in 2001 and 2005 (Engeset et al, 2005; Kjøllmoen et al, 2006).

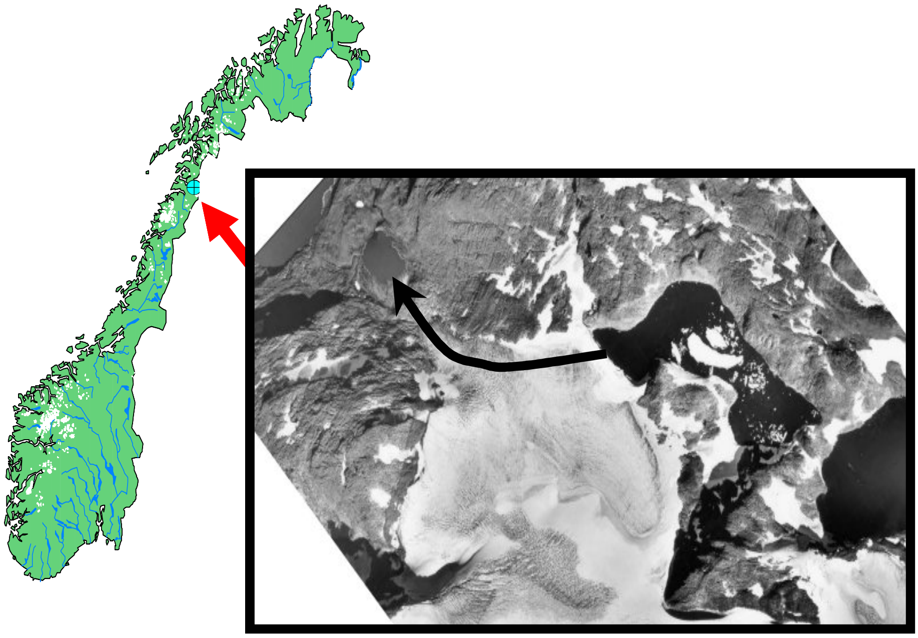


Figure 12-7
Location map of Blåmannsisen. The black arrow shows the approximate path of the subglacial drainage channel under the glacier dam.

The first jøkulhaup occurred on 8th September 2001 and was totally unexpected. It was discovered when the lake level in Sisovatnet, a hydropower reservoir downstream of the glacier, suddenly rose 2.5 m in a period of only 36 hours. The cause was a glacier-dammed lake (Øvre Messingmalmvatn) that normally drains to Sweden, had suddenly drained 40 million cubic metres of water under the glacier and thence to Sisovatnet. Measurements of the elevation of the glacier, and comparison of these with previous measurements, show that the glacier has thinned considerably in recent years in the area of the ice dam (whilst increasing at higher elevations). The decrease in thickness at the dam was about 15-20 m from 1960 to 1990, a further 10 m occurred in the following decade from 1990 to 2001, and a further 10 m of thinning has occurred since 2001. This has thus made it easier for water to drain under the glacier. After the first event in 2001 it took three years for Øvre Messingmalmvatn to fill up and reach its previous level and it was expected that when this happened another jøkulhlaup would soon occur. However, it was not until one year later, in August 2005, that the next flood occurred. This time 35 million cubic metres drained under the glacier and then into Sisovatnet. The third jøkulhlaup on 29th August 2007 was also somewhat unexpected, this one occurring only two years after the previous one and when the water level in Øvre Messingmalmvatn was 9 m under full capacity (Fig. 12-8).

The three jøkulhlaups had a total volume of about 95 million cubic metres of water, which generated an extra 150 GWh of electricity in the power station. If the glacier hadn't thinned, this water would have drained east and thus not been available for hydropower.

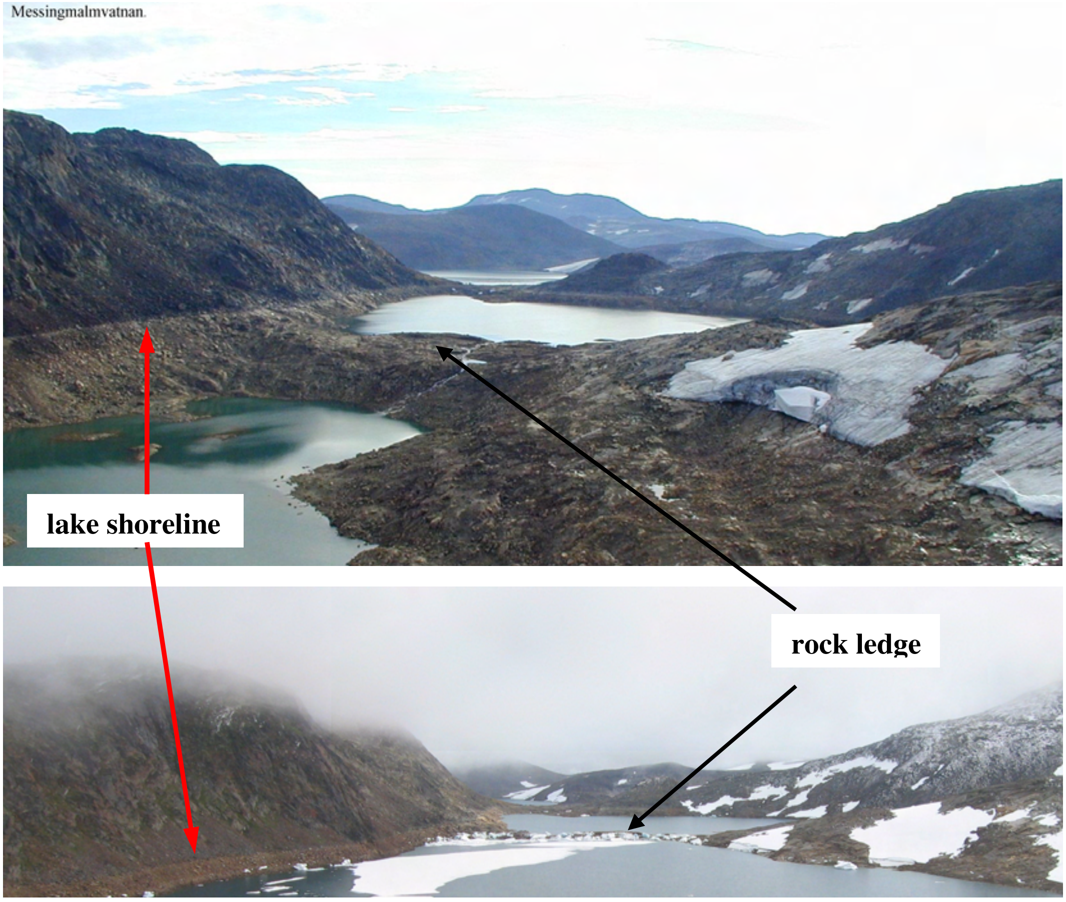


Figure 12-8
Photographs of the drained lake, Øvre Messingmalmvatn, taken on 18th September 2001 after the first event (upper) and on 4th September 2007 after the third event (lower). Note the difference in lake levels. Photos: Hans Martin Hjemaas.

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Appendix A

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Appendix B

Mass balance measurements in Norway – an overview

During the period 1949-2007 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	Area (km^2)	Altitude (m a.s.l.)	Period	No. of years
Ålfotbreen				
1 Ålfotbreen	4.5	903-1382	1963-	45
2 Hansebreen	3.1	930-1327	1986-	22
Folgefonna				
3 Blomsterskardsbreen	45.7	850-1640	1970-77	8
3a Svelgjabreen*	22.5	832-1636	2007-	1
3b Blomstølskardsbreen*	22.8	1013-1636	2007-	1
4 Bondhusbrea	10.7	480-1635	1977-81	5
5 Breidablikkbrea	3.4	1234-1651	1963-68, 2003-	11
6 Gråfjellsbrea	8.4	1049-1651	64-68, 74-75, 2003-	12
7 Blåbreen and Ruklebreen	4.5	1065-1610	1963-68	6
8 Midtre Folgefonna	8.7	1100-1570	1970-71	2
Jostedalsbreen				
9 Jostefonn	3.8	960-1622	1996-2000	5
10 Vesledalsbreen	4.2	1130-1730	1967-72	6
11 Tunsbergdalsbreen	50.1	540-1930	1966-72	7
12 Nigardsbreen	47.8	320-1960	1962-	46
13 Store Supphellebreen	12.0	80-300/ 720-1740	1964-67, 73-75, 79-82	11
14 Austdalsbreen	11.8	1200-1757	1988-	20
15 Spørteggbreen	27.9	1260-1770	1988-91	4
16 Harbardsbreen	13.2	1250-1960	1997-2001	5
Hardangerjøkulen				
17 Rembesdalsskåka	17.1	1020-1865	1963-	45
18 Midtdalsbreen	6.7	1380-1862	2000-2001	2
19 Omnsbreen	1.5	1460-1570	1966-70	5
Jotunheimen				
20 Tverråbreen	5.9	1415-2200	1962-63	2
21 Blåbreen	3.6	1550-2150	1962-63	2
22 Storbreen	5.4	1390-2100	1949-	59
23 Vestre Memurubre	9.0	1570-2230	1968-72	5
24 Austre Memurubre	8.7	1630-2250	1968-72	5
25 Hellstugubreen	3.0	1480-2210	1962-	46
26 Gråsubreen	2.3	1830-2290	1962-	46
Okstindbreene				
27 Charles Rabot Bre	1.1	1090-1760	1970-73	4
28 Austre Okstindbre	14.0	730-1750	1987-96	10
Svartisen				
29 Høgtuvbreen	2.6	590-1170	1971-77	7
30 Svartisheibreen	5.5	770-1420	1988-94	7
31 Engabreen	39.6	10-1575	1970-	38
32 Storglombreen	59.0 62.4	520-1580 520-1580	1985-88 2000-05	10
33 Tretten-null-tobreen	4.3	580-1260	1985-86	2
34 Glombreen	2.2	870-1110	1954-56	3
35 Kjølbreen	3.9	850-1250	1954-56	3
36 Trollbergdalsbreen	1.8 1.6	900-1375 900-1300	1970-75 1990-94	11
Blåmannsisen				
37 Rundvassbreen	11.6	788-1537	2002-04	3
Skjomen				
38 Blåisen	2.2	850-1200	1963-68	6
39 Storsteinsfjellbreen	6.1 5.9	920-1850 970-1850	1964-68 1991-95	10
40 Cainhavarre	0.7	1210-1540	1965-68	4
Vest-Finnmark				
41 Svartfjelljøkelen	2.7	500-1080	1978-79	2
42 Langfjordjøkelen	3.7	280-1050	1989-93, 1996-	17

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 571 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 km^2 (1997)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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
44	06	2.69	-5.88	-3.19	6.33	>1382
45	07	4.49	-3.22	1.27	7.60	1000
Mean 1963-2007		3.72	-3.56	0.17		

2 Hansebreen - 3.1 km^2 (1997)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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
21	06	2.45	-6.43	-3.98	-11.63	>1327
22	07	4.07	-3.23	0.84	-10.79	1042
Mean 1986-2007		3.46	-3.95	-0.49		

3 Blomsterskardsbreen - 45.7 km^2 (1959)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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		

3a Svelgjabreen - 22.5 km^2 (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	2007	3.89	-2.54	1.35	1.35	1205
Mean 2007-		3.89	-2.54	1.35		

3b Blomstølskardsbreen - 22.8 km^2 (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	2007	4.17	-2.30	1.87	1.87	1230
Mean 2007-		4.17	-2.30	1.87		

4 Bondhusbrea - 10.7 km^2 (1979)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 - 3.4 km² (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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
10	06	1.49	-4.43	-2.94	-6.44	>1659
11	07	3.41	-3.10	0.31	-6.13	1420
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-07		2.46	-3.68	-1.23		

6 Gråfjellsbrea - 8.4 km² (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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
11	06	1.40	-4.44	-3.04	-6.01	>1659
12	07	3.58	-2.90	0.68	-5.33	1390
Mean 1964-68		2.48	-2.36	0.12		
Mean 1974-75		2.32	-1.91	0.42		
Mean 2003-07		2.42	-3.48	-1.07		

7 Blåbreen and Ruklebreen - 4.5 km² (1959)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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
45	06	1.75	-3.15	-1.40	16.96	1850
46	07	3.09	-2.05	1.04	18.00	1320
Mean 1962-2007		2.38	-1.99	0.39		

13 Store Supphellebreen - 12.0 km^2 (1966)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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
19	06	1.32	-3.38	-2.06	-5.82	>1757
20	07	2.46	-2.28	0.18	-5.64	1405
Mean 1988-2007		2.20	-2.48	-0.28		

15 Spørteggbreen - 27.9 km^2 (1988)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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
44	06	0.90	-3.12	-2.22	3.79	>1860
45	07	3.10	-1.93	1.17	4.96	1570
Mean 1963-2007		2.11	-2.00	0.11		

18 Midtdalsbreen - 6.7 km^2 (1995)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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.e.)	bs	bn (m w.e.)	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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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
58	06	0.86	-3.01	-2.15	-16.89	>2100
59	07	1.35	-1.74	-0.39	-17.28	1835
Mean 1949-2007		1.43	-1.72	-0.29		

23 Vestre Memurubre - 9.0 km^2 (1966)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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
45	06	0.73	-2.74	-2.01	-16.74	>2210
46	07	1.03	-1.7	-0.67	-17.41	1975
Mean 1962-2007		1.09	-1.47	-0.38		

26 Gråsubreen - 2.3 km^2 (1997)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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
45	06	0.51	-2.59	-2.08	-15.74	>2290
46	07	0.61	-1.32	-0.71	-16.45	2265
Mean 1962-2007		0.76	-1.12	-0.36		

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

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

28 Austre Okstindbre - 14.0 km^2 (1962)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 km^2 (1972)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 km^2 (1985)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 km^2 (2001)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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
37	06	1.73	-3.16	-1.43	21.75	1325
38	07	3.37	-2.83	0.54	22.29	1100
Mean 1970-2007		2.92	-2.33	0.59		

32 Storglombreen - 62.4 km^2 (1968)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1968)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1953)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1953)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1985)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1998)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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 km^2 (1960)

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

39 Storsteinsfjellbreen - 5.9 km^2 (1993)

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

40 Cainhavarre - 0.7 km^2 (1960)

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

41 Svartfjelljøkelen - 2.7 km^2 (1966)

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

42 Langfjordjøkelen - 3.7 km^2 (1994)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	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
16	06	1.42	-3.83	-2.41	-14.78	>1050
17	07	2.09	-2.90	-0.81	-15.59	870
Mean 1989-93		2.54	-2.63	-0.10		
Mean 1996-2007		1.97	-3.27	-1.30		

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