Glaciological investigations in Norway in 2009

Bjarne Kjøllmoen (Ed.)

2
2010

REPORT

Glaciological investigations in Norway in 2009

The Norwegian Water Resources and Energy Directorate (NVE)
2010

Report No 2

Glaciological investigations in Norway in 2009

Published by: Norwegian Water Resources and Energy Directorate

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Print: NVE
Number printed: 300
Frontpage photo: Kjenndalsbreen, a north facing outlet glacier from the Jostedalsbreen ice cap. The photo was taken on 2nd September 2009 by Hallgeir Elvehøy.
ISSN: 1502-3540
ISBN: 978-82-410-0719-4

Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2009 are presented in this report. The main part concerns mass balance investigations. Results from investigations of glacier length changes are discussed in a separate chapter.
Subjects: Glaciology, Mass balance, Glacier length change, Glacier velocity, Meteorology, Subglacial laboratory

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May 2010

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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 NVEs Section for Glaciers, Snow and Ice during 2009. 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 2010

Morten Johnsrud
Director,
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Summary

Mass balance

Mass balance investigations were performed on fourteen glaciers in Norway in 2009. Twelve of these glaciers are in southern Norway and two are in northern Norway.

The winter balance for the long-term glaciers was close to the average of the reference period 1971-2000. Nigardsbreen had the lowest relative winter balance with 90 % of the reference period and Hellstugubreen the greatest with 113 %.

The summer balance was greater than the 1971-2000 average for all the long-term glaciers. Engabreen had the greatest relative summer balance with 131 % of the reference period.

Consequently, the net balance was negative for ten of fourteen measured glaciers. Langfjordjøkelen had the greatest deficit with −1.3 m water equivalent, while Blomstølskardsbreen had the greatest surplus with +1.1 m w.e.

Glacier length change

Glacier length changes were measured at 22 glaciers in southern Norway and five glaciers in northern Norway in 2009. Twenty two of the glacier outlets had a retreat in length, three were unchanged and two outlets had a small advance. Kjenndalsbreen, Fåbergstøls-breen and Bødalsbreen, all outlets from Jostedalsbreen, and Langfjordjøkelen in Finnmark, showed retreats of 93, 59, 52 and 53 metres, respectively.

Sammendrag

Massebalanse

I 2009 ble det utført massebalansemålinger på 14 breer i Norge – tolv i Sør-Norge og to i Nord-Norge.

For de breene som har langtids måleserier ble vinterbalansen omtrent som gjennomsnittet for referanseperioden 1971-2000. Nigardsbreen hadde den relativt minste vinterbalansen med 90 % av gjennomsnittet for referanseperioden, mens Hellstugubreen hadde den største med 113 %.

Sommerbalansen ble større enn gjennomsnittet for 1971-2000 for alle breene med langtids måleserier. Engabreen hadde den relativt største sommerbalansen med 131 % av referanseperioden.

Det ble negativ nettobalanse på ti av fjorten målte breer. Langfjordjøkelen fikk størst underskudd med −1,3 m vannekvivalenter, mens Blomstølskardsbreen fikk størst overskudd med +1,1 m vannekvivalenter.

Lengdeendringer

Lengdeendringer ble målt på 22 breer i Sør-Norge og fem breer i Nord-Norge i 2009. Tjueto av breutløperne hadde tilbakegang, tre var uendret og to hadde litt framgang. Kjenndalsbreen, Fåbergstølsbreen og Bødalsbreen, alle utløpere fra Jostedalsbreen, og Langfjordjøkelen i Finnmark, hadde tilbakegang på hhv. 93, 59, 52 og 53 meter.

1. Glacier investigations in Norway in 2009

1.1 Mass balance

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

Method

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

Winter balance

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

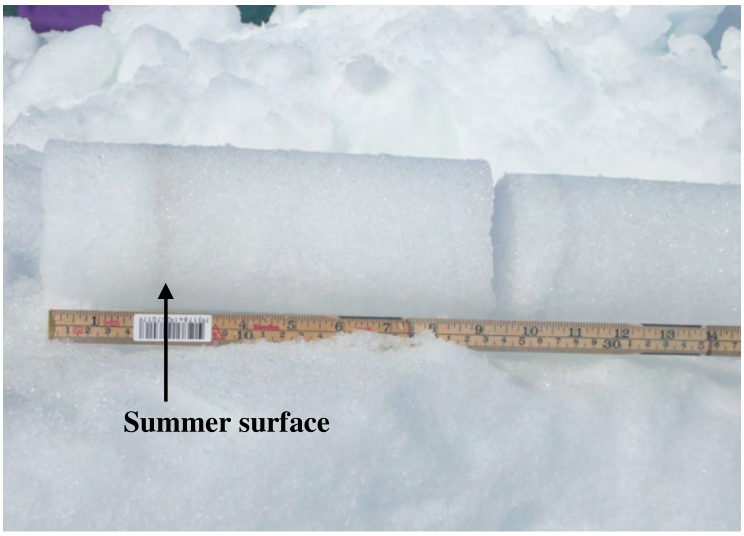


Figure 1-1
The snow depth can be confirmed by coring. The summer surface will often appear as a thin layer of dust or dirt. The old snow is slightly darker (to the right of the summer surface in the photo).
Photo: Hallgeir Elvehøy.

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 600 kg/m^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 650 kg/m^3. The density of melted firn is, depending on the age, assumed to be between 650 and 800 kg/m^3. The density of melted ice is taken as 900 kg/m^3.

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 have fallen. On some occasions ablation *after* the final measurements in September/October can occur. Measuring this additional ablation can sometimes be done later in the autumn, and then will be included in that year's summer balance. However, often measuring and calculating the 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 2009 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 47 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 61 years of measurements, while Engabreen at Svartisen has the longest series (40 years) in northern Norway. 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 2009 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.

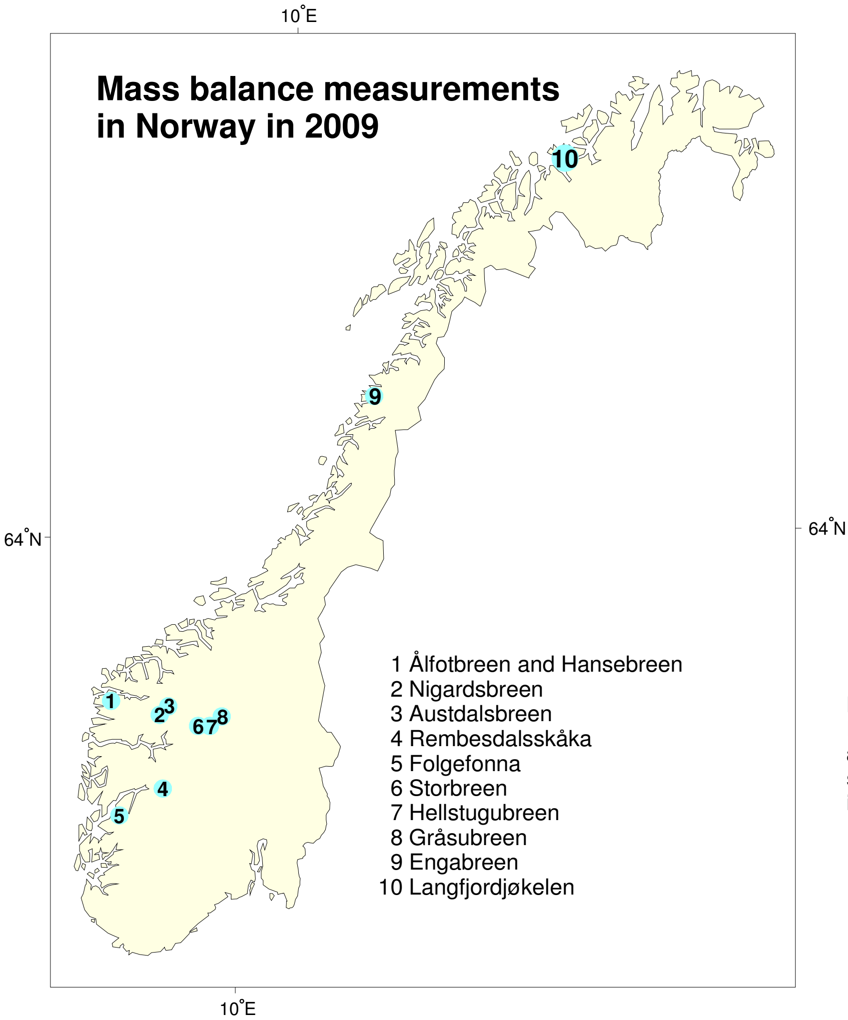


Figure 1-2
Location of the glaciers at which mass balance studies were performed in 2009.

Weather conditions and mass balance results

Winter weather

In western Norway the winter season 2008/2009 started with a cool and snow-rich October. Except for January, the rest of the winter season was rather dry and mild in this part of the country. In northern Norway the winter was generally mild and there was little snow. However, January was snow-rich in Nordland county.

Snow accumulation and winter balance

The winter balance for the long-term glaciers (measurements started in 1971 or earlier) was close to the average of the reference period 1971-2000. The long-term glaciers in western Norway had results of 90 to 106 % of the 1971-2000 average winter balance. Nigardsbreen had the lowest relative winter balance with 90 % (2.2 m w.e.). The glaciers in Jotunheimen had between 102 and 113 % of the reference period average. In northern Norway, Engabreen had 94 % of the 1971-2000 average.

Summer weather

The summer season in 2009 was warmer than normal over most of the country. Both July, August and September were warmer than normal. However, June was rather cool, particularly in the mountain areas in southern Norway and in the northernmost parts of northern Norway.

Ablation and summer balance

The summer balance was greater than the 1971-2000 average at all the long-term glaciers. The long-term glaciers in western Norway had summer balances between 102 and 120 % of the 1971-2000 average. The glaciers in Jotunheimen had between 101 and 112 % of the reference period average. Engabreen had the greatest relative summer balance with 131 % of the reference period.

Net balance

Net balance was negative for ten of fourteen measured glaciers in 2009. The greatest deficit was measured at Langfjordjøkelen with −1.3 m w.e., and was the thirteenth successive year with deficit. Blomstølskardsbreen had the greatest surplus with +1.1 m w.e.

The results from the mass balance measurements in Norway in 2009 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 ref.** column show the current results in percent of the average for the period 1971-2000. 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 2009. The glaciers in southern Norway are listed from west to east.

Glacier	*Period*	*Area* *(km²)*	*Altitude* *(m a.s.l.)*	b_w *(m)*	*% of ref.*	b_s *(m)*	*% of ref.*	b_n *(m)*	b_n *ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-09	4.5	903-1382	3.84	97	–4.00	120	–0.17	0.61	1240	48
Hansebreen	1986-09	3.1	930-1327	3.45	[1] 99	–4.42	[1] 112	–0.97	[1] –0.46	>1327	0
Svelgjabreen	2007-09	22.5	832-1636	3.33	-	–2.97	-	0.36	-	1310	64
Blomstølskardsbreen	2007-09	22.8	1013-1636	3.59	-	–2.52	-	1.07	-	1290	84
Breidablikkbrea	1963-68 2003-09	3.9 3.4	1219-1660 1234-1651	2.47	[2] 105	–2.98	[2] 100	–0.52	–0.19 [2] –0.62	1565	30
Gråfjellsbrea	1964-68 1974-75 2003-09	9.4 8.4	1039-1660 1049-1651	2.34	[3] 96	–2.88	[3] 105	–0.54	0.20 [3] –0.31	1540	31
Nigardsbreen	1962-09	47.2	315-1957	2.20	90	–1.96	102	0.24	0.54	1465	80
Austdalsbreen	1988-09	10.5	1200-1747	1.92	[4] 86	[5] –2.62	[4] 105	–0.70	[4] –0.27	1475	56
Rembesdalsskåka	1963-09	17.1	1020-1865	2.37	106	–2.21	115	0.15	0.32	1655	79
Storbreen	1949-09	5.1	1400-2102	1.60	105	–1.83	112	–0.22	–0.10	1760	53
Hellstugubreen	1962-09	2.9	1482-2229	1.30	113	–1.53	109	–0.23	–0.27	1920	42
Gråsubreen	1962-09	2.1	1833-2283	0.81	102	–1.08	101	–0.28	–0.28	2235	7
Engabreen	1970-09	38.7	89-1574	2.87	94	–2.90	131	-0.03	0.82	1170	63
Langfjordjøkelen	1989-93 1996-09	3.2	302-1050	1.88	[6] 89	–3.21	[6] 106	–1.32	[6] –0.91	>1050	0

[1] Calculated for the measured period 1986-2008
[2] Calculated for the measured periods 1963-68 and 2003-08
[3] Calculated for the measured periods 1964-68, 1974-75 and 2003-08
[4] Calculated for the measured period 1988-2008
[5] Contribution from calving amounts to 0.32 m for b_s
[6] Calculated for the measured periods 1989-93 and 1996-2008

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2009. The west-east gradient is evident for both winter and summer balances. The results for 2009 show negative net balance for eight of twelve measured glaciers in southern Norway.

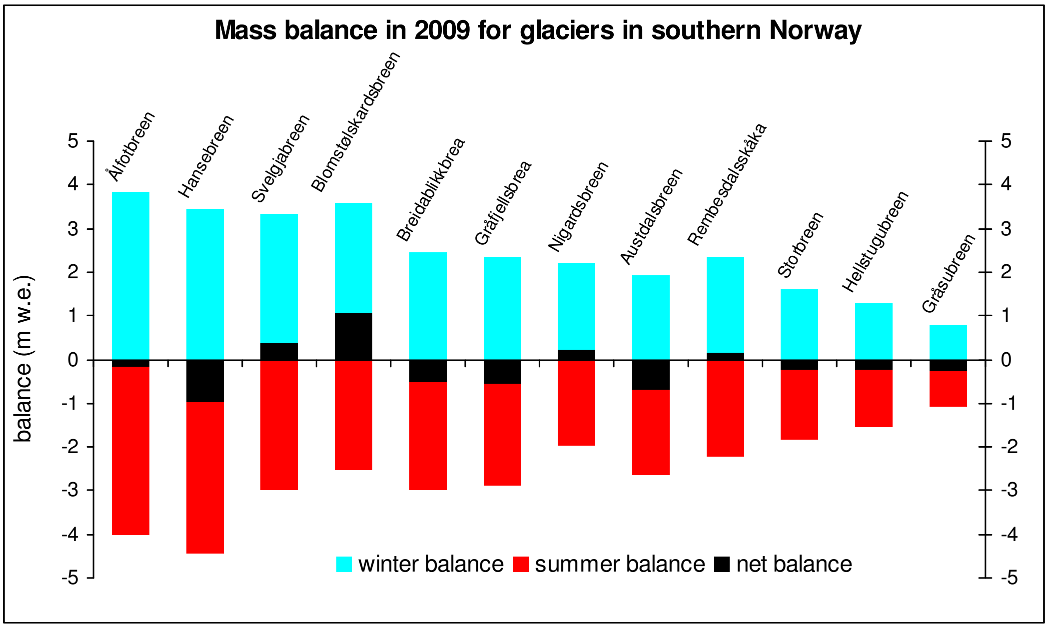


Figure 1-3
Mass balance 2009 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-term series during the period 1963-2009 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.

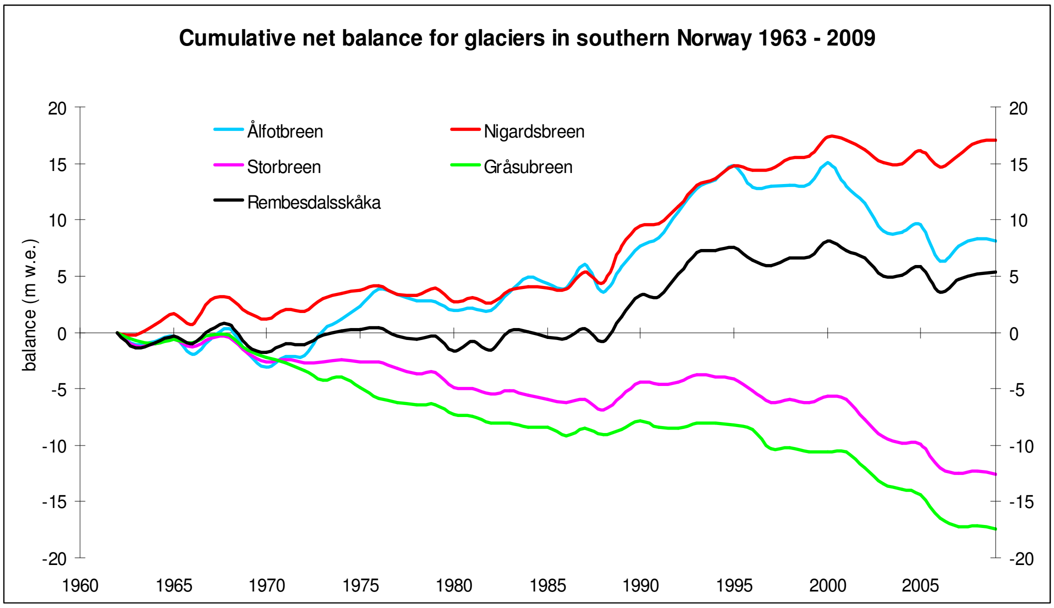


Figure 1-4
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka (Hardangerjøkulen), Storbreen and Gråsubreen during the period 1963-2009.

1.2 Other investigations

Glacier length change measurements were performed at 27 glaciers in Norway in 2009. 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) have been studied at Austdalsbreen since 1987 (chap. 5). The measurements continued in 2009.

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 three more jøkulhlaups have occurred, the first in August 2005, the second in August 2007 and the third in September 2009 (chap. 12).

2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45’N, 5°40’E) has an area of about 17 km^2, and is both the westernmost and the most maritime glacier in Norway. Mass balance studies have been carried out on two adjacent north-facing outlet glaciers - Ålfotbreen (4.5 km^2,) and Hansebreen (3.1 km^2). The westernmost of these two has been the subject of mass balance investigations since 1963, and has always been reported as <u>Ålfotbreen</u>. The adjacent glacier to the east of Ålfotbreen has been given the name <u>Hansebreen</u>, 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.

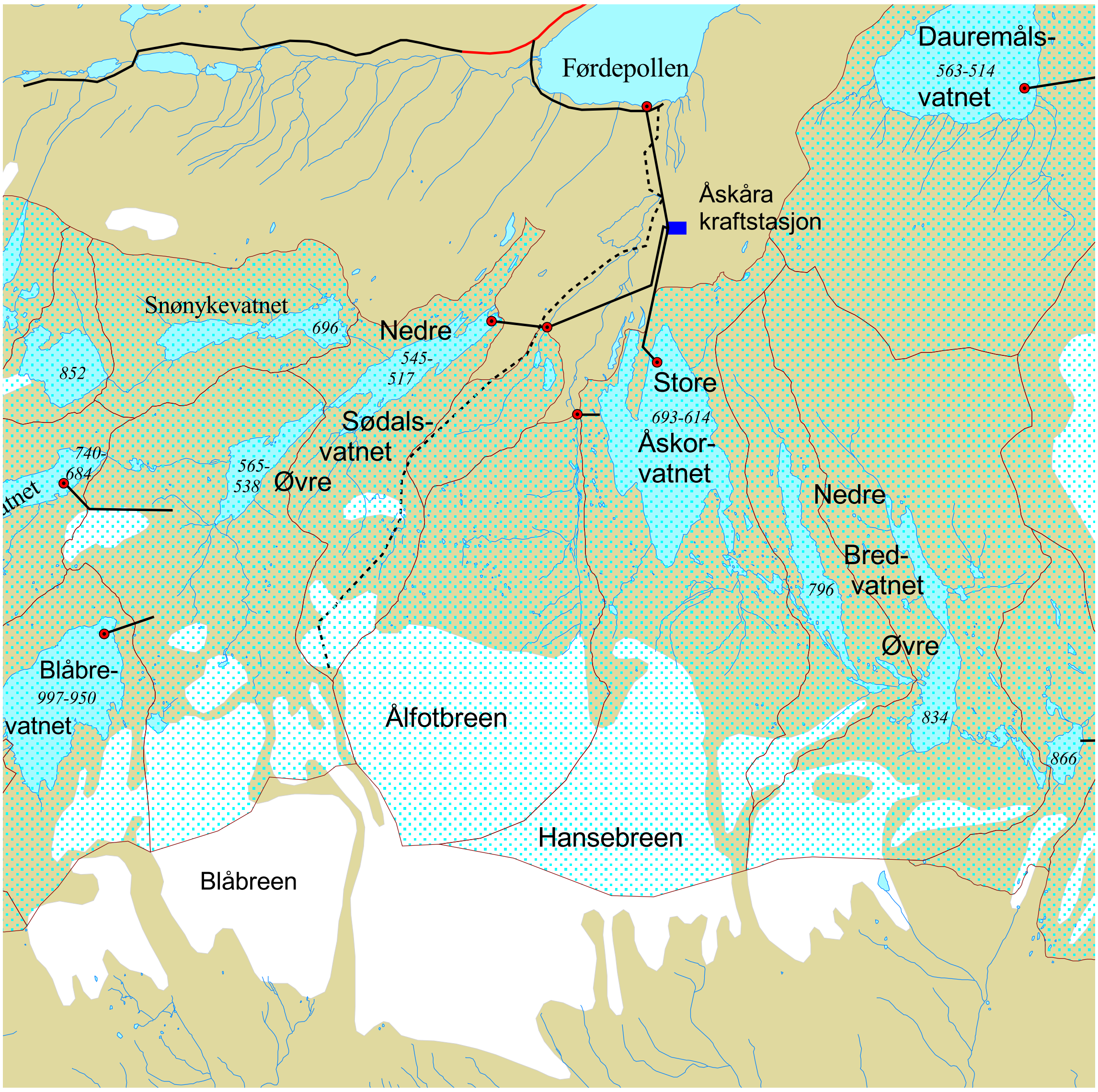


Figure 2-1
Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

2.1 Mass balance 2009

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 29th and 30th April. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Measurements of replacement stakes and older stakes that appeared during the melt season at positions 13 (1086 m a.s.l.), 45 (1185 m a.s.l.), 28 (1247 m a.s.l.) and 49 (1382 m a.s.l.) on Ålfotbreen. Uninterrupted measurements of stakes in positions 80 (1121 m a.s.l.) and 85 (1198 m a.s.l.). Measurements of replacement stakes and older stakes that appeared during the melt season in positions 50 (1020 m a.s.l.), 60 (1067 m a.s.l.) and 90 (1311 m a.s.l.) on Hansebreen.
- Snow depth probings performed in a regular grid of 250 x 250 metres. Previously, the snow depth was sounded along fixed profiles. Snow depth is measured at 74 grid points on Ålfotbreen, and at 49 grid points on Hansebreen. The snow depth was generally between 6 and 8 m. The summer surface was indistinct, and was often a gradual transition from light permeable snow to more solid snow.
- Snow density measured down to S.S. at 5.8 m at stake position 37.

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

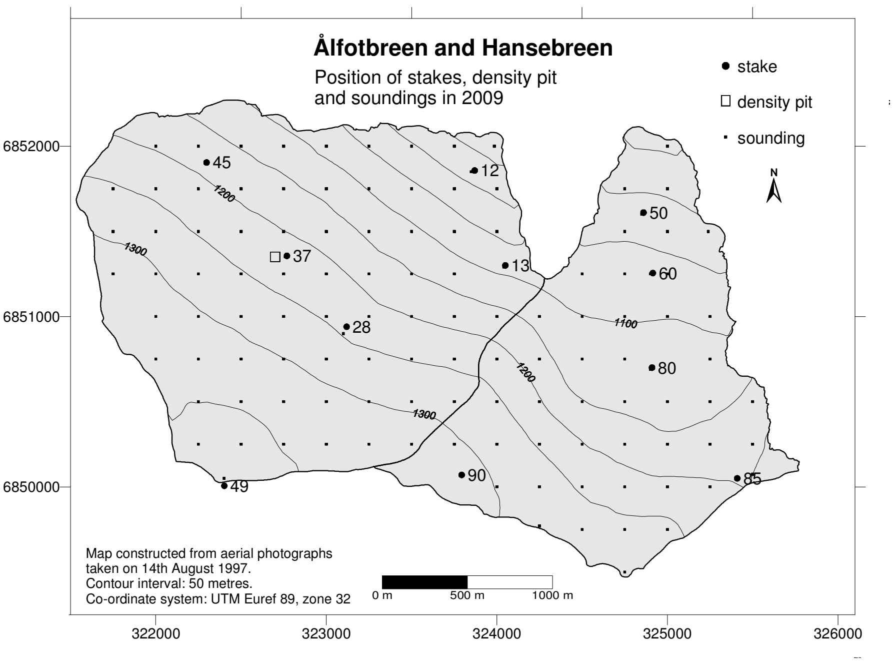


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen (left) and Hansebreen (right) in 2009.

Ablation measurements

Ablation was measured on 22nd October. The net balance was measured directly at stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was about 1 m of snow remaining in the upper areas of Ålfotbreen. Hansebreen, however, was snow-free over the entire glacier surface. At the time of the ablation measurements between 0.7 and 1.2 m of fresh snow had fallen.

Figure 2-3
Snow depth sounding on Hansebreen in late April 2009. Photo: Hallgeir Elvehøy.

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 2008.

A density profile was modelled from the snow density measured at 1222 m a.s.l. The mean snow density of 5.8 m snow was 530 kg/m^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. 2-5) and a mean value for each 50 m height interval was estimated (Tab. 2-1).

Winter balance at Ålfotbreen in 2009 was 3.8 ±0.2 m w.e., corresponding to a volume of 17 ±1 mill. m^3 of water. The result is 97 % of the mean winter balance for the reference period 1971-2000.

The winter balance at Hansebreen was 3.4 ±0.2 m w.e., corresponding to a volume of 11 ±1 mill. m^3 of water. The result is 99 % of the mean winter balance for the measurement period 1986-2008.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 2-4). Water equivalents for each cell in a 100 x 100 m grid were calculated and summed. Using this method, which is a control of the traditional method, gave 3.8 m w.e. for Ålfotbreen and 3.4 m w.e. for Hansebreen.

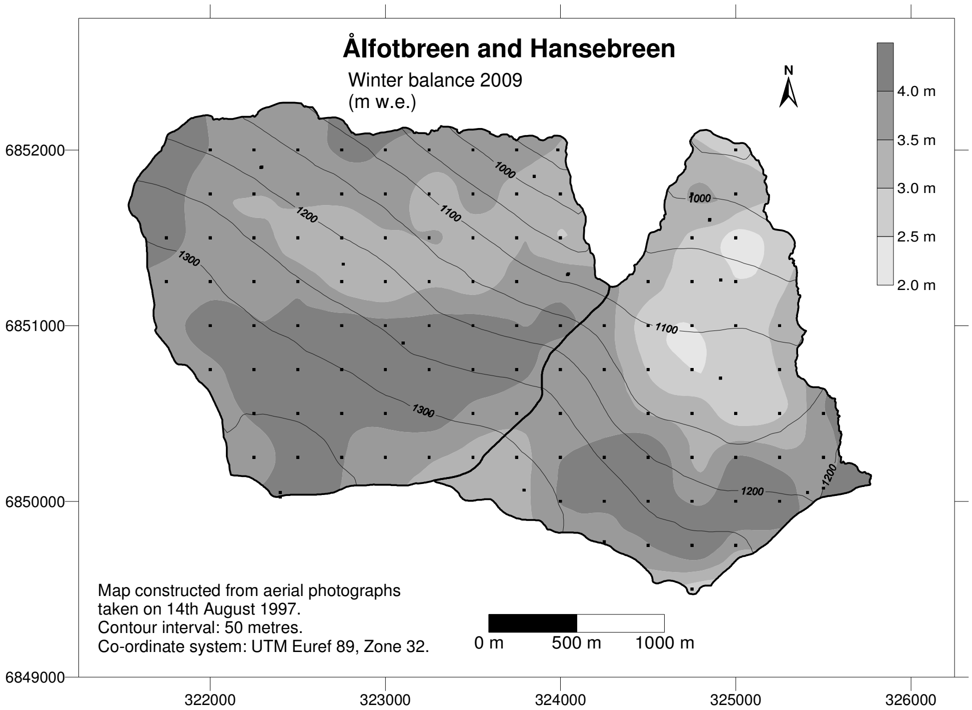


Figure 2-4
Winter balance at Ålfotbreen and Hansebreen in 2009 interpolated from 128 snow depth measurements, shown by (·).

Summer balance

The density of remaining snow was estimated as 600 kg/m^3. The density of one year old melted firn was estimated as 650 kg/m^3, and of two-year old firn as 700 kg/m^3. The density of melted ice was taken as 900 kg/m^3.

The summer balance at Ålfotbreen was measured and calculated directly at stakes in six different positions. The calculated values increased from 3.43 m w.e. at the glacier summit (1381 m a.s.l.) to 5.1 m on the tongue (978 m a.s.l.). Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −4.0 ±0.3 m w.e., corresponding to −18 ±1 mill. m^3 of water. This result is 120 % of the mean summer balance for the reference period 1971-2000.

The summer balance for Hansebreen was measured and calculated at stakes in five different positions. It increased from −3.8 m w.e. at 1312 m elevation to −4.7 m w.e. at 1067 m elevation. Normally the summer balance is greatest (in absolute value) at the lowest stake (50). The measurements for 2009 however, show that the summer balance at stake 50 was 0.4 m w.e. *lower* than measured at the stake that is next higher in elevation (60). This is considered unlikely. Thus, the summer balance curve is drawn irrespective of stake 50. Based on the stake measurements and the estimated density, the summer balance was calculated as −4.4 ±0.3 m w.e. or −14 ±1 mill. m^3 of water. The result is 112 % of the mean summer balance for the measurement period 1986-2008.

Net balance

The net balance at Ålfotbreen for 2009 was slightly negative, at −0.2 ±0.4 m w.e., or a deficit of −1 ±2 mill. m^3 of water. The mean net balance for the reference period 1971-2000 is +0.61 m w.e. Since measurements started at Ålfotbreen in 1963 the cumulative net balance is +8.1 m w.e. Over the last ten years (2000-2009), however, the cumulative net balance is −5.0 m w.e. Six of these years show a negative net balance.

The net balance at Hansebreen was calculated as −1.0 ±0.4 m w.e., or a deficit of 3 ±1 mill. m^3 of water. The mean value for the measurement period 1986-2008 is −0.46 m w.e. Since measurements began in 1986 the cumulative net balance is −11.5 m w.e. Most of this deficit (10.9 m w.e.) has occurred over the last ten years.

According to Figure 2-5 the Equilibrium Line Altitude (ELA) lies at 1240 m a.s.l. on Ålfotbreen, while the ELA lies above the highest summit (>1327 m a.s.l.) on Hansebreen. Consequently, the AAR is 48 % and 0 % respectively.

The mass balance results are shown in Table 2-1. The corresponding curves for specific and volume balance are shown in Figure 2-5. The historical mass balance results are presented in Figure 2-6.

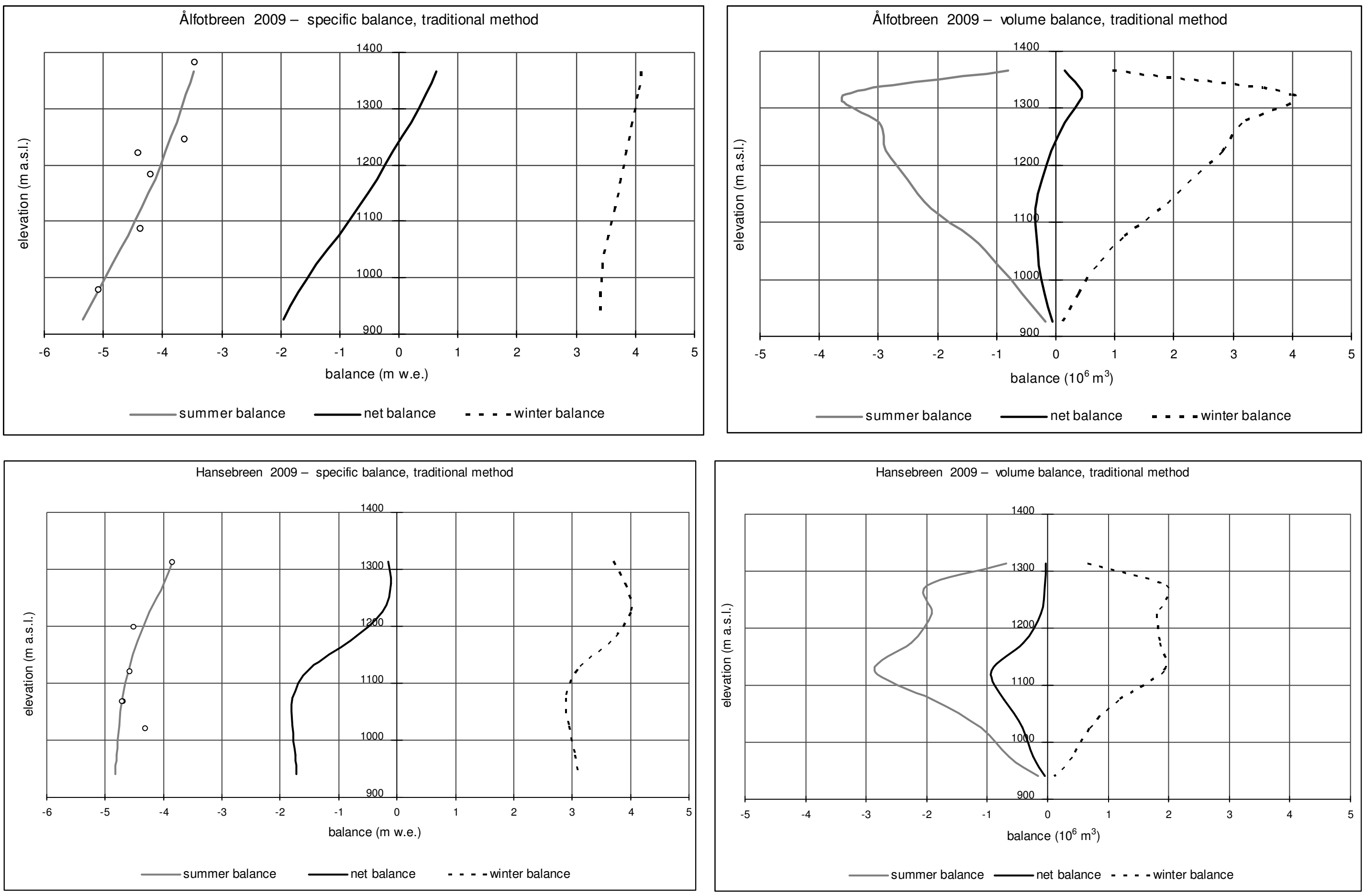


Figure 2-5
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2009 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).

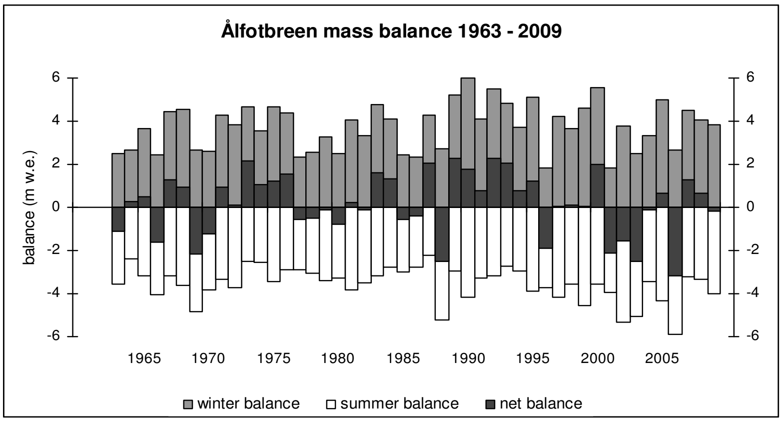
Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2009.

Mass balance Ålfotbreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 29th Apr 2009 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 22nd Oct 2009 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2008 - 2009 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1350 - 1382	0.23	4.10	1.0	-3.48	-0.8	0.63	0.1
1300 - 1350	0.98	4.05	4.0	-3.60	-3.5	0.45	0.4
1250 - 1300	0.80	3.95	3.1	-3.75	-3.0	0.20	0.2
1200 - 1250	0.73	3.85	2.8	-3.95	-2.9	-0.10	-0.1
1150 - 1200	0.61	3.75	2.3	-4.13	-2.5	-0.38	-0.2
1100 - 1150	0.49	3.65	1.8	-4.35	-2.1	-0.70	-0.3
1050 - 1100	0.32	3.55	1.1	-4.58	-1.4	-1.03	-0.3
1000 - 1050	0.20	3.45	0.7	-4.85	-1.0	-1.40	-0.3
950 - 1000	0.11	3.40	0.4	-5.10	-0.6	-1.70	-0.2
903 - 950	0.03	3.40	0.1	-5.35	-0.2	-1.95	-0.1
903 - 1382	**4.50**	**3.84**	**17.2**	**-4.00**	**-18.0**	**-0.17**	**-0.8**

Mass balance Hansebreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 29th Apr 2009 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 22nd Oct 2009 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 2008 - 2009 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1300 - 1327	0.18	3.70	0.65	-3.85	-0.68	-0.15	-0.03
1250 - 1300	0.50	3.90	1.95	-4.00	-2.00	-0.10	-0.05
1200 - 1250	0.45	4.00	1.81	-4.25	-1.92	-0.25	-0.11
1150 - 1200	0.51	3.65	1.85	-4.45	-2.26	-0.80	-0.41
1100 - 1150	0.62	3.10	1.92	-4.60	-2.85	-1.50	-0.93
1050 - 1100	0.40	2.90	1.17	-4.70	-1.89	-1.80	-0.73
1000 - 1050	0.23	2.95	0.69	-4.75	-1.11	-1.80	-0.42
950 - 1000	0.13	3.05	0.41	-4.80	-0.64	-1.75	-0.23
930 - 950	0.03	3.10	0.10	-4.83	-0.16	-1.73	-0.06
930 - 1327	**3.06**	**3.45**	**10.6**	**-4.42**	**-13.5**	**-0.97**	**-3.0**



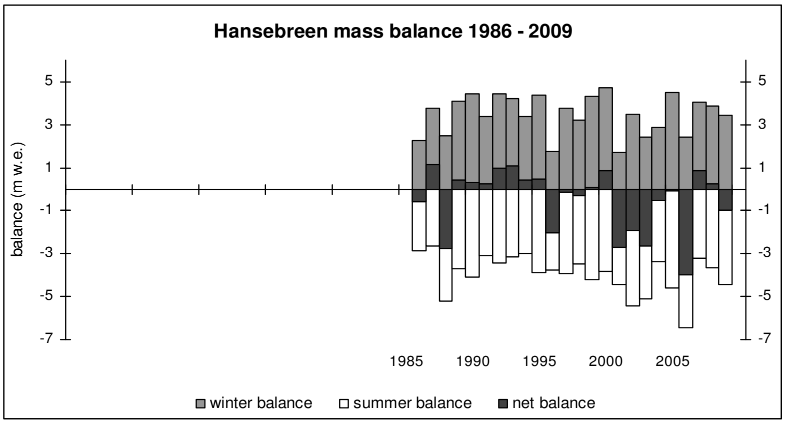


Figure 2-6
Mass balance at Ålfotbreen (upper) 1963-2009 and Hansebreen (lower) 1986-2009.

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 northwest-facing outlet glaciers of Southern Folgefonna (60°4'N, 6°24'E) – Breidablikkbrea (3.4 km^2) and Gråfjellsbrea (8.4 km^2) (Fig. 3-1). In 2007 mass balance measurements began on two more outlet glaciers of Southern Folgefonna – the two adjacent south-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.

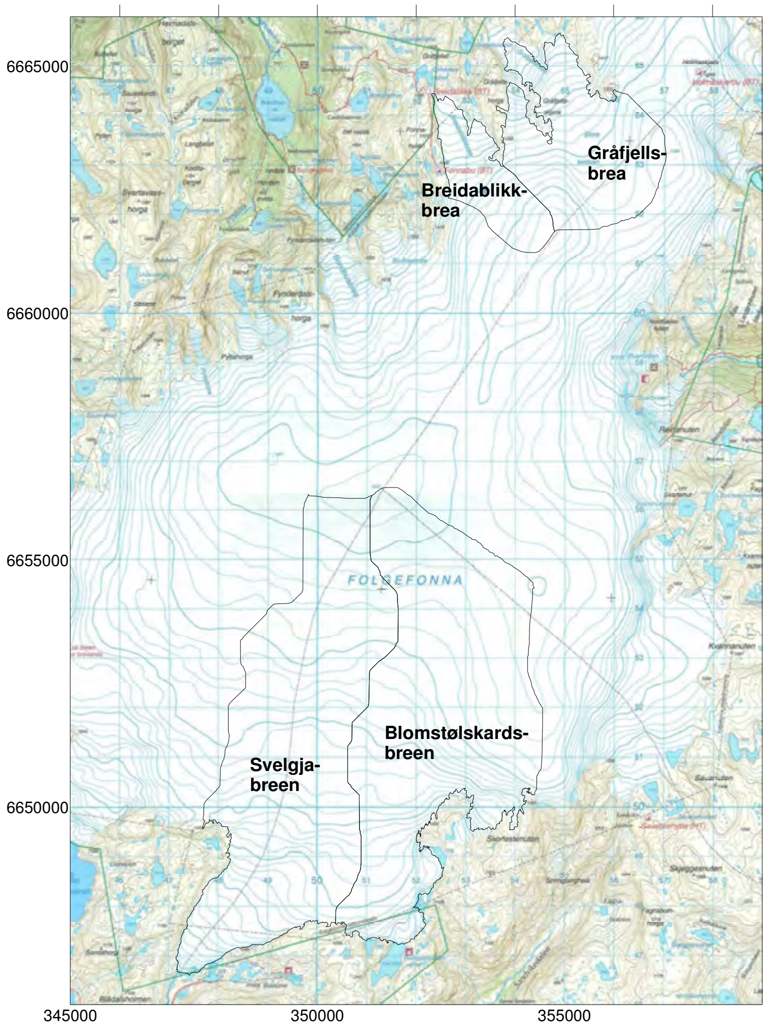


Figure 3-1
Southern Folgefonna with Breidablikkbrea and Gråfjellsbrea in the northwest and Svelgjabreen and Blomstølskardsbreen in the south.

3.1 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2009

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 29th April. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-2):

- Measurement of stakes at positions 50 (1469 m a.s.l.) and T60 (1641 m a.s.l.) on Breidablikkbrea and measurement of a stake in position 20 (1343 m a.s.l.) and T60 on Gråfjellsbrea. Measurements of stake replacements and older stakes that appeared during the melt season at position 41 (1272 m a.s.l.) and 46 (1347 m a.s.l.) on Breidablikkbrea and at position 15 (1267 m a.s.l.) and 30 (1546 m a.s.l.) on Gråfjellsbrea.
- Snow depth probings are performed in a regular grid of 333 x 333 metres. Previously the snow depth was sounded along fixed profiles. Snow depth is measured at 38 grid points on Breidablikkbrea, and at 75 grid points on Gråfjellsbrea. Generally, the sounding conditions were reasonable on both glaciers. However, a solid layer in the upper areas made it somewhat difficult to determine the summer surface on the north side of Gråfjellsbrea. The snow depth varied between 4.5 and 5.5 m.
- Snow density was measured down to 4.7 m (S.S. at 4.8 m) at position 25 on Gråfjellsbrea.

The locations of stakes, density pit and soundings are shown in Figure 3-2.

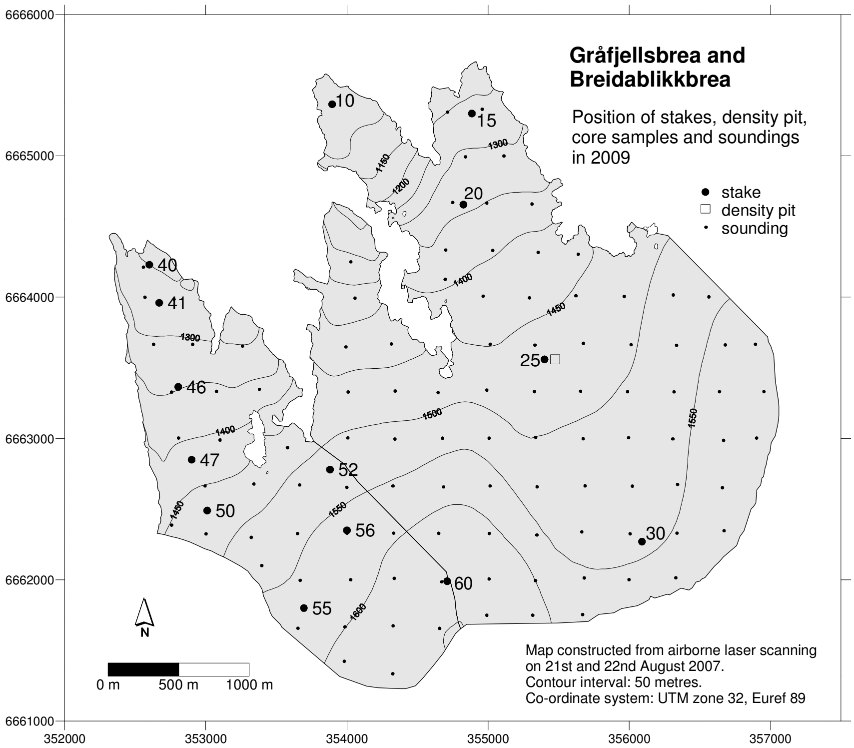


Figure 3-2 Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2009.

Ablation measurements

Ablation was measured on 13th October (Fig. 3-3). The net balance was measured at stakes in seven different positions on Breidablikkbrea and six positions on Gråfjellsbrea. There was up to 1 m of snow remaining in the upper areas of the glacier. At the time of the ablation measurements between 0.4 and 1.0 m of fresh snow had fallen.

Figure 3-3
Almost 1 m of fresh snow had fallen on the top of Gråfjellsbrea on 13th October 2009. Photo: Miriam Jackson.

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 and soundings) and on measurement of snow density at one representative location. Soundings and stake readings in December 2008 indicated some melting after the final measurements in September 2008. This melting was included in the 2008 summer balance.

A density profile was modelled from the snow density measured at 1474 m a.s.l. The mean snow density of 4.8 m snow was 502 kg/m^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 2009 was 2.5 ±0.2 m w.e., corresponding to a volume of 8 ±1 mill. m^3 of water. The result is 105 % of the average for the periods 1963-68 and 2003-08.

The winter balance at Gråfjellsbrea was 2.3 ±0.2 m w.e., corresponding to a volume of 20 ±1 mill. m^3 of water. This result is 96 % of the average for 1964-68, 1974-75 and 2003-08.

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 summed. This method gave 2.5 m w.e. for Breidablikkbrea and 2.4 m w.e. for Gråfjellsbrea.

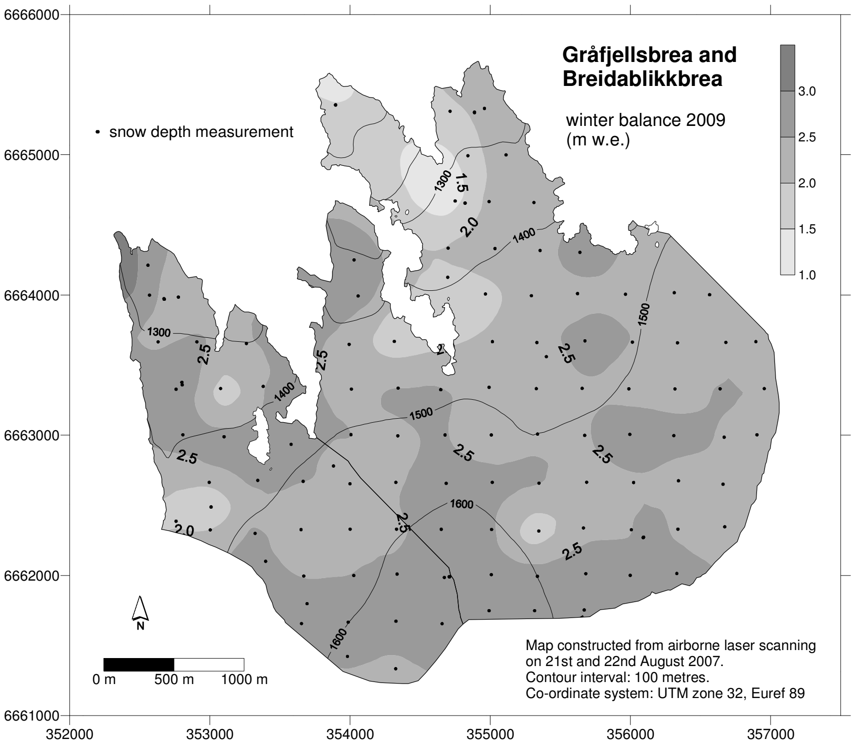


Figure 3-4
Winter balance at Breidablikkbrea and Gråfjellsbrea in 2009 interpolated from 130 snow depth measurements (·).

Summer balance

When calculating the summer balance the density of remaining snow was estimated as 600 kg/m^3. The density of melted firn was estimated as 650-700 kg/m^3, and the density of melted ice was assumed to be 900 kg/m^3.

The summer balance at Breidablikkbrea was measured and calculated at four stakes. The stake values increased from 2.3 m w.e. at the topmost stake to 4.1 m w.e. at the glacier tongue. Based on estimated density and stake measurements the summer balance was calculated as −3.0 ±0.3 m w.e., corresponding to −10 ±1 mill. m^3 of water. This is 100 % of the mean value for 1963-68 and 2003-08.

The summer balance for Gråfjellsbrea was measured and calculated at six stakes. The stake values increased from 2.3 m w.e. at the topmost stake to 4.3 m w.e. at stake 15. Normally the summer balance is greatest at the lowest stake (10). During the snow accumulation measurements in April stake 10 was not accessible and could not be measured. Thus the stake length in April and the summer balance in position 10 are estimated. Accordingly, the summer and net balance curves are uncertain below 1200 m a.s.l. Based on the six stakes and the estimated density, the summer balance was calculated as −2.9 ±0.3 m w.e. or −24 ±1 mill. m^3 of water. This is 105 % of the mean value for 1964-68, 1974-75 and 2003-08.

Net balance

The net balance at Breidablikkbrea for 2009 was calculated as –0.5 ±0.4 m w.e. or a deficit of –2 ±2 mill. m^3 of water. The mean net balance for 1963-68 and 2003-08 is –0.63 m w.e.

The net balance at Gråfjellsbrea was also calculated as –0.5 ±0.4 m w.e. or a deficit of –5 ±2 mill. m^3 of water. The mean value for the years 1964-68, 1974-75 and 2003-08 is –0.31 m w.e.

As shown in Figure 3-5, the Equilibrium Line Altitude (ELA) lies at 1565 m a.s.l. on Breidablikkbrea and 1540 m a.s.l. on Gråfjellsbrea. Consequently, the Accumulation Area Ratios (AAR) are 30 % and 31 % 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.

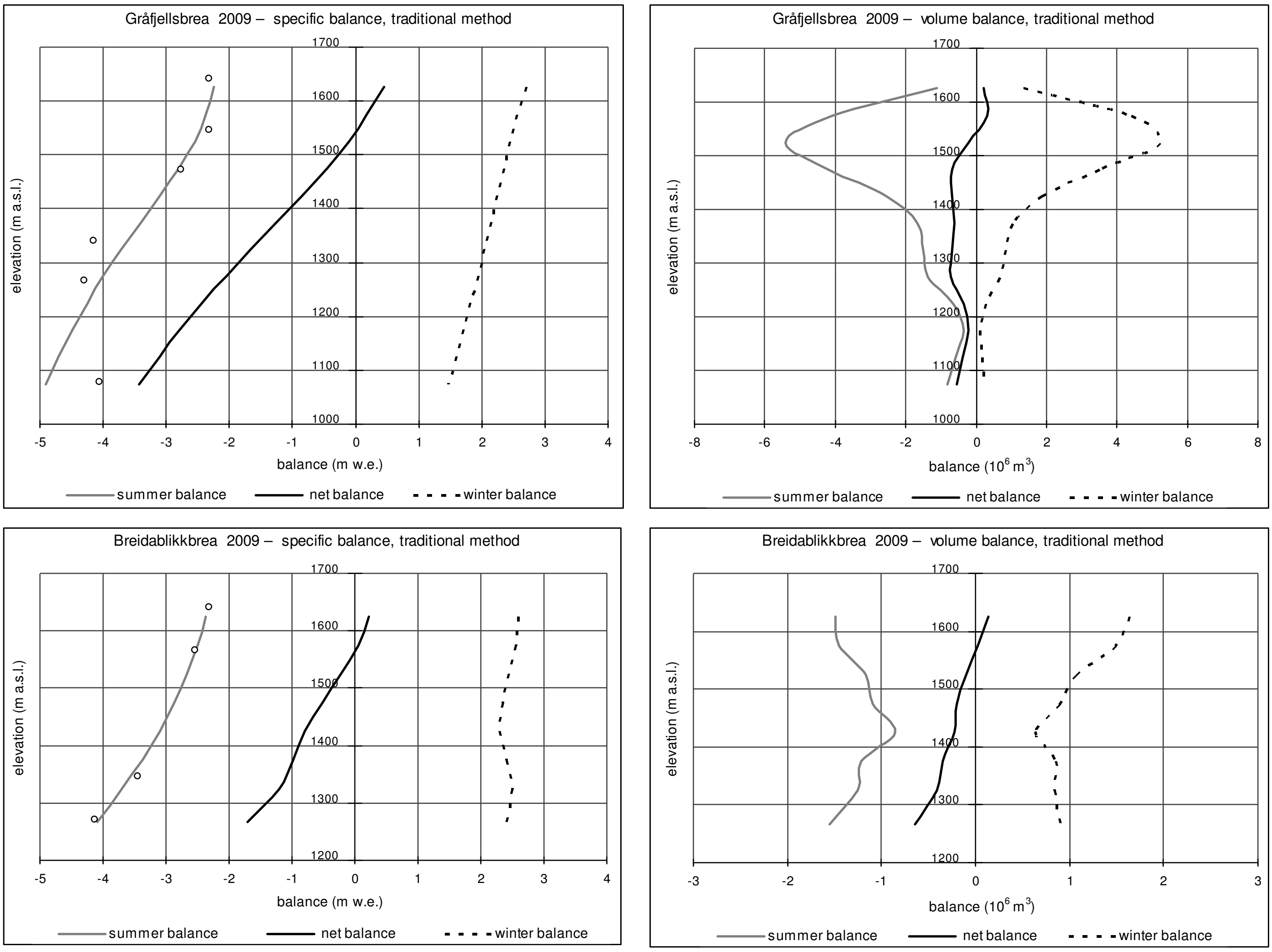


Figure 3-5
Mass balance diagram for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2009 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○). The summer balance value for the lowest stake (10) at Gråfjellsbrea differs from the stakes higher up (upper left diagram). Thus the summer and net balance curves are uncertain below 1200 m a.s.l.

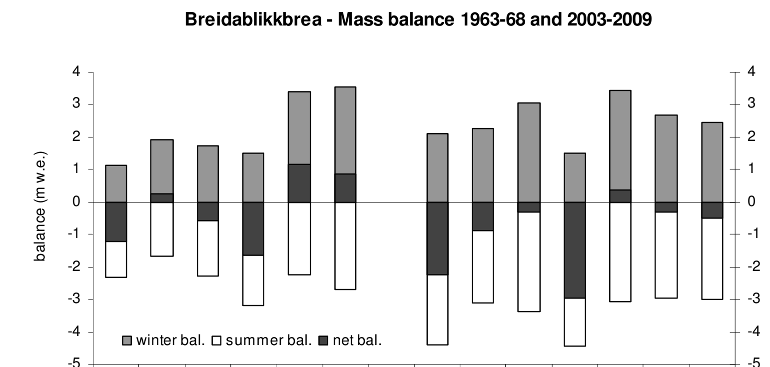
Mass balance Breidablikkbrea 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 29th April 2009 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 13th Oct 2009 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2008 - 2009 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1600 - 1651	0.63	2.60	1.6	-2.38	-1.5	0.23	0.1
1550 - 1600	0.58	2.55	1.5	-2.50	-1.5	0.05	0.0
1500 - 1550	0.43	2.45	1.1	-2.68	-1.2	-0.23	-0.1
1450 - 1500	0.38	2.35	0.9	-2.88	-1.1	-0.53	-0.2
1400 - 1450	0.28	2.30	0.6	-3.10	-0.9	-0.80	-0.2
1350 - 1400	0.36	2.40	0.9	-3.38	-1.2	-0.98	-0.3
1300 - 1350	0.34	2.50	0.8	-3.70	-1.2	-1.20	-0.4
1234 - 1300	0.38	2.40	0.9	-4.10	-1.6	-1.70	-0.6
1234 - 1651	**3.37**	**2.47**	**8.3**	**-2.98**	**-10.1**	**-0.52**	**-1.7**

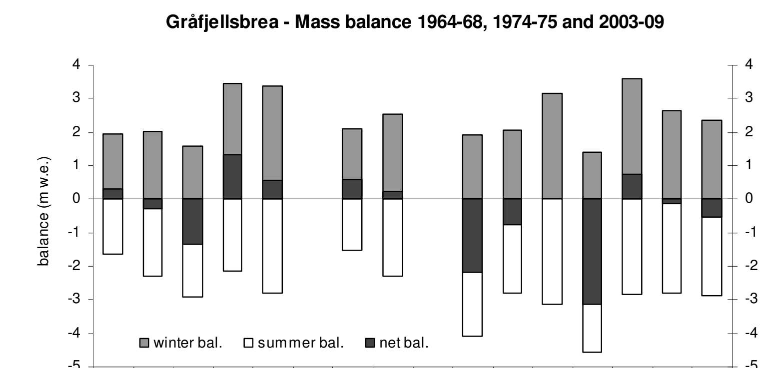
Mass balance Gråfjellsbrea 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 29th April 2009 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 13th Oct 2009 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2008 - 2009 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1600 - 1651	0.50	2.70	1.3	-2.25	-1.1	0.45	0.2
1550 - 1600	1.72	2.55	4.4	-2.38	-4.1	0.18	0.3
1500 - 1550	2.13	2.45	5.2	-2.55	-5.4	-0.10	-0.2
1450 - 1500	1.49	2.35	3.5	-2.80	-4.2	-0.45	-0.7
1400 - 1450	0.81	2.25	1.8	-3.10	-2.5	-0.85	-0.7
1350 - 1400	0.49	2.15	1.1	-3.40	-1.7	-1.25	-0.6
1300 - 1350	0.41	2.05	0.8	-3.70	-1.5	-1.65	-0.7
1250 - 1300	0.34	1.95	0.7	-4.00	-1.4	-2.05	-0.7
1200 - 1250	0.15	1.83	0.3	-4.25	-0.6	-2.43	-0.4
1150 - 1200	0.08	1.70	0.1	-4.48	-0.3	-2.78	-0.2
1100 - 1150	0.12	1.60	0.2	-4.70	-0.6	-3.10	-0.4
1049 - 1100	0.16	1.48	0.2	-4.90	-0.8	-3.43	-0.6
1049 - 1651	**8.41**	**2.34**	**19.7**	**-2.88**	**-24.3**	**-0.54**	**-4.6**

Table 3-1
Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2009.



	1963	1964	1965	1966	1967	1968		2003	2004	2005	2006	2007	2008	2009
winter bal.	1.11	1.92	1.72	1.52	3.40	3.55		2.12	2.25	3.04	1.49	3.42	2.66	2.47
summer bal.	-2.32	-1.68	-2.28	-3.17	-2.23	-2.68		-4.38	-3.12	-3.37	-4.44	-3.07	-2.96	-2.98
net bal.	-1.21	0.24	-0.56	-1.65	1.17	0.87		-2.26	-0.87	-0.33	-2.95	0.36	-0.30	-0.52



	1964	1965	1966	1967	1968		1974	1975		2003	2004	2005	2006	2007	2008	2009
winter bal.	1.94	2.01	1.58	3.46	3.39		2.11	2.53		1.91	2.05	3.15	1.40	3.60	2.66	2.34
summer bal.	-1.62	-2.29	-2.93	-2.14	-2.82		-1.53	-2.28		-4.09	-2.82	-3.13	-4.55	-2.85	-2.80	-2.88
net bal.	0.32	-0.28	-1.35	1.32	0.57		0.58	0.25		-2.18	-0.76	0.02	-3.15	0.75	-0.14	-0.54

Figure 3-6
Winter, summer and net balance at Breidablikkbrea for the periods 1963-68 and 2003-09 (upper figure), and at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-09 (lower figure).

3.2 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2009

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 29th April. The calculation of winter balance at Svelgjabreen and Blomstølskardsbreen is based on (Fig. 3-7):

- Measurement of stakes at positions 10 (975 m a.s.l.), 20 (1156 m a.s.l.), 30 (1242 m a.s.l.) and 40 (1363 m a.s.l.) on Svelgjabreen and measurement of stakes at positions 25 (1231 m a.s.l.), 35-07 (1351 m a.s.l.) and 35-08 (1351 m a.s.l.) on Blomstølskardsbreen.
- Snow depth probings performed in a regular grid of 1000 x 750 m (east x north). In the two previous years (2007 and 2008), the snow depth was sounded along fixed profile lines. Snow depth is measured at 40 grid points on Svelgjabreen and at 42 grid points on Blomstølskardsbreen. Generally, the summer surface was easy to define. The snow depth varied from 2.5 m to 9.5 m at Svelgjabreen, and from 4.4 m to 8.7 m at Blomstølskardsbreen.
- Snow density was measured down to 7.2 m (S.S. at 7.8 m) at stake position 65 (1532 m a.s.l.) at Blomstølskardsbreen.

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

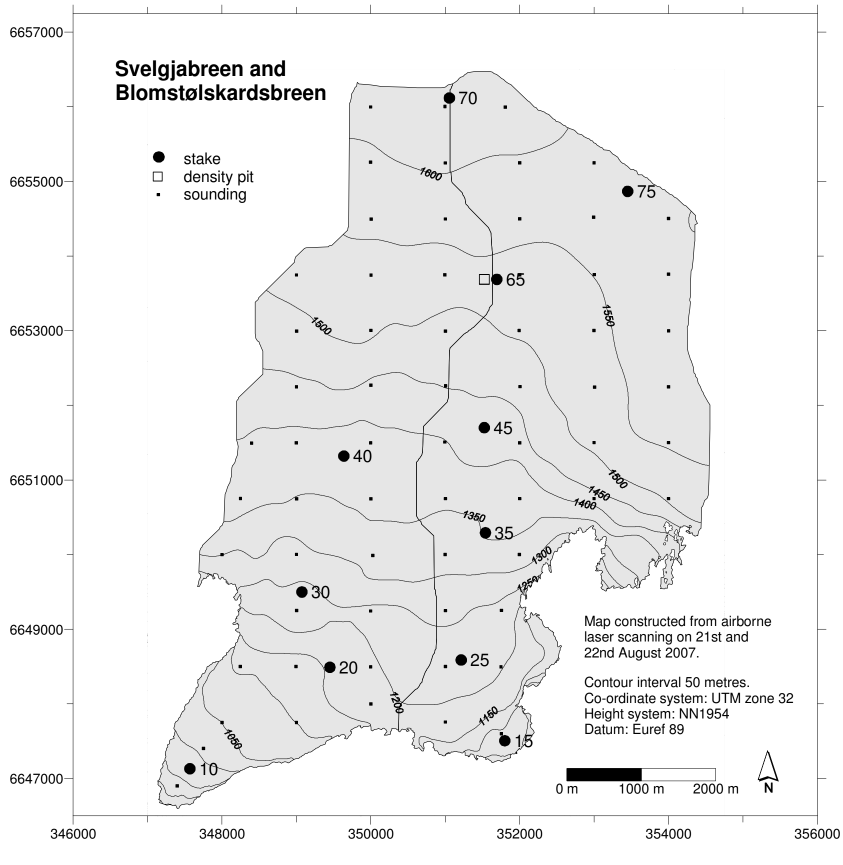


Figure 3-7 Location of stakes, soundings and density pit at Svelgjabreen and Blomstølskardsbreen in 2009.

Ablation measurements

Ablation was measured on 13th October. The net balance was measured at stakes in eleven different positions on the two glaciers. There was 3-4 m of snow remaining in the upper areas of the glacier. At the time of the ablation measurements between 0.4 and 1.4 m of fresh snow had fallen.

Results

The calculations are based on a glacier map from 2007.

Stake measurements in positions 65 and 70 are included in the mass balance calculations for both Svelgjabreen and Blomstølskardsbreen.

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 1532 m a.s.l. The mean snow density of 7.75 m snow was 513 kg/m^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 2009 was 3.3 ±0.2 m w.e., corresponding to a volume of 75 ±4 mill. m^3 of water. The winter balance at Blomstølskardsbreen was 3.6 ±0.2 m w.e., corresponding to a volume of 82 ±1 mill. m^3 of water.

As verification, the winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 3-8). Water equivalents for each cell in a 400 x 400 m grid were calculated and summed. This method gave the same results: 3.3 and 3.6 m w.e., respectively.

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

Summer balance

When calculating the summer balance the density of remaining snow was estimated as 600 kg/m^3. The density of melted ice was assumed to be 900 kg/m^3.

The summer balance at Svelgjabreen was measured at six stakes. The stake values increased from 1.8 m w.e. (1632 m a.s.l.) to 5.5 m w.e. (975 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated as −3.0 ±0.3 m w.e. corresponding to −67 ±6 mill. m^3 of water.

The summer balance for Blomstølskardsbreen was measured and calculated at seven stakes. The stake values increased from 1.8 m w.e. (1632 m a.s.l.) to 4.2 m w.e. (1082 m a.s.l.). Based on the six stakes and the estimated density the summer balance was calculated as −2.5 ±0.3 m w.e. or −57 ±6 mill. m^3 of water.

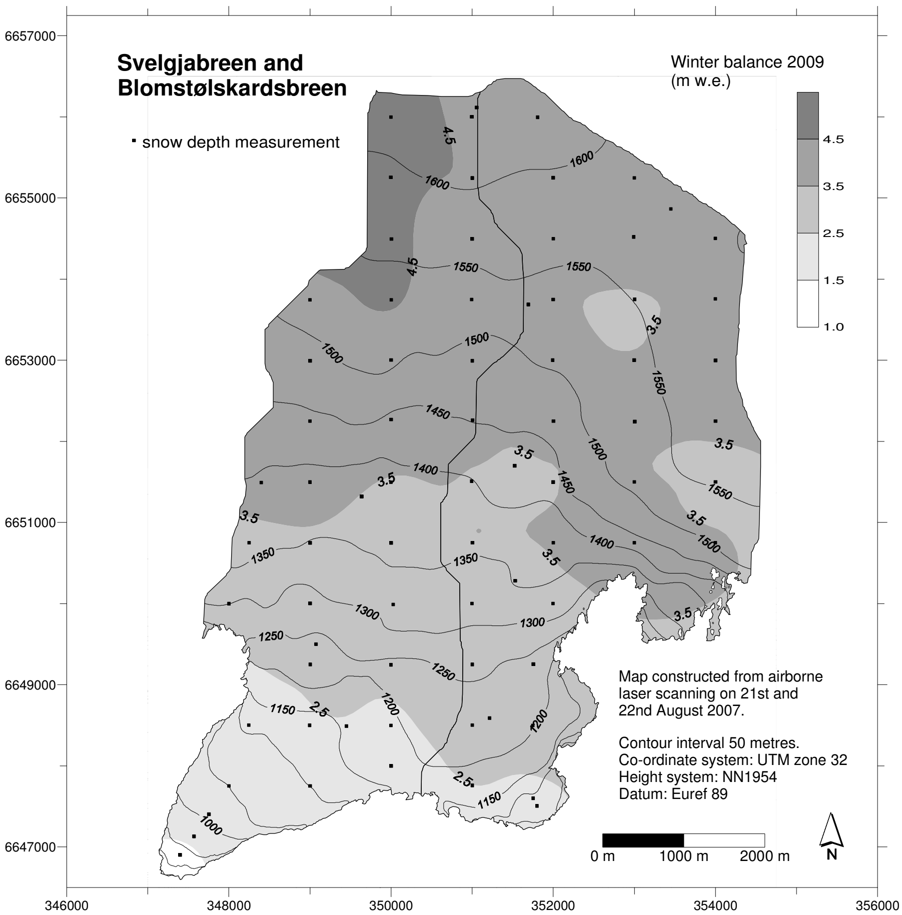


Figure 3-8
Winter balance at Svelgjabreen and Blomstølskardsbreen in 2009 interpolated from 89 snow depth measurements (·).

Net balance

The net balance at Svelgjabreen for 2009 was calculated as +0.4 ±0.4 m w.e. or a surplus of 8 ±9 mill. m^3 of water.

The net balance at Blomstølskardsbreen was calculated as +1.1 ±0.4 m w.e. or a surplus of 24 ±9 mill. m^3 of water.

As shown in Figure 3-9, the equilibrium line altitude (ELA) lies at 1310 m a.s.l. on Svelgjabreen and 1290 m a.s.l. on Blomstølskardsbreen. Consequently, the Accumulation Area Ratios (AAR) are 64 % and 84 % 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.

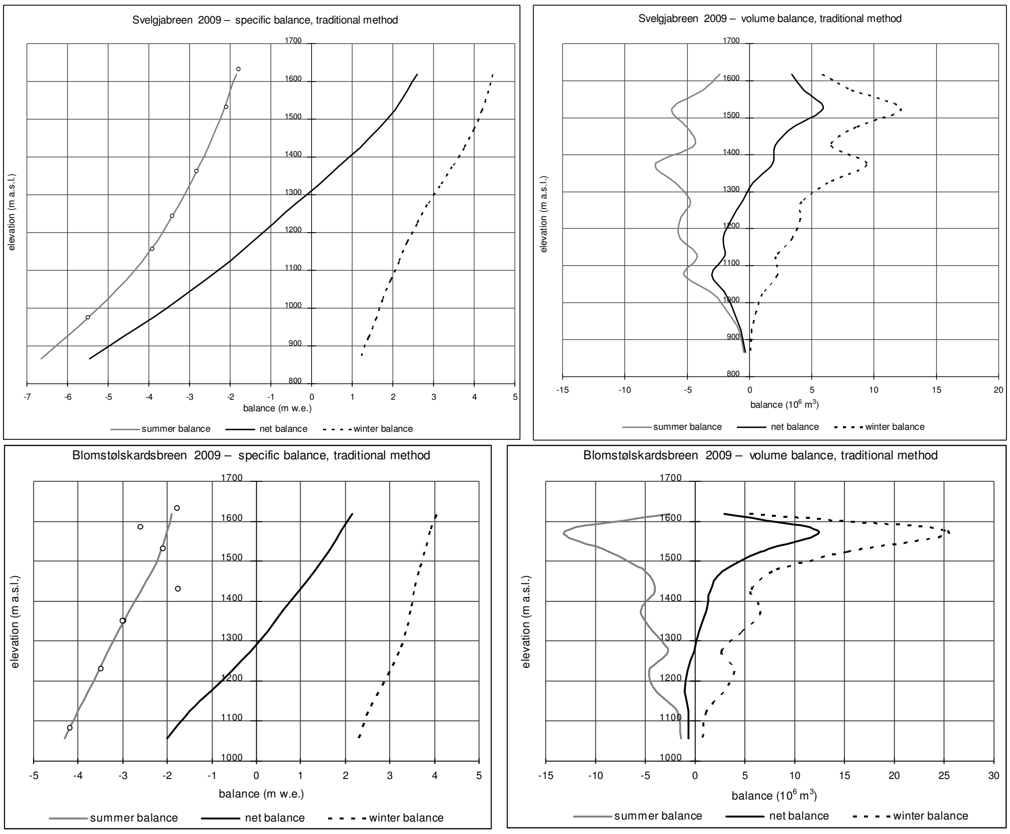


Figure 3-9
Mass balance diagram for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2009.

Table 3-2
Winter, summer and net balances for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2009.

Mass balance Svelgjabreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 29th Apr 2009: Specific (m w.e.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 13th Oct 2009: Specific (m w.e.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surface 2008 - 2009: Specific (m w.e.)	Net balance: Volume (10^6 m^3)
1600 - 1636	1.30	4.45	5.8	-1.85	-2.4	2.60	3.4
1550 - 1600	1.87	4.35	8.1	-2.00	-3.7	2.35	4.4
1500 - 1550	2.89	4.20	12.1	-2.15	-6.2	2.05	5.9
1450 - 1500	2.13	4.00	8.5	-2.35	-5.0	1.65	3.5
1400 - 1450	1.75	3.75	6.6	-2.55	-4.5	1.20	2.1
1350 - 1400	2.73	3.45	9.4	-2.78	-7.6	0.68	1.8
1300 - 1350	1.99	3.15	6.3	-3.00	-6.0	0.15	0.3
1250 - 1300	1.47	2.85	4.2	-3.25	-4.8	-0.40	-0.6
1200 - 1250	1.57	2.60	4.1	-3.53	-5.5	-0.93	-1.5
1150 - 1200	1.47	2.35	3.5	-3.80	-5.6	-1.45	-2.1
1100 - 1150	1.00	2.15	2.2	-4.15	-4.2	-2.00	-2.0
1050 - 1100	1.16	1.95	2.3	-4.55	-5.3	-2.60	-3.0
1000 - 1050	0.59	1.75	1.0	-5.00	-3.0	-3.25	-1.9
950 - 1000	0.32	1.60	0.5	-5.50	-1.8	-3.90	-1.3
900 - 950	0.14	1.40	0.2	-6.03	-0.9	-4.63	-0.7
832 - 900	0.06	1.20	0.1	-6.65	-0.4	-5.45	-0.3
832 - 1636	**22.45**	**3.33**	**74.8**	**-2.97**	**-66.7**	**0.36**	**8.1**

Mass balance Blomstølskardsbreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 29th April 2009: Specific (m w.e.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 13th Oct 2009: Specific (m w.e.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surfaces 2008 - 2009: Specific (m w.e.)	Net balance: Volume (10^6 m^3)
1600 - 1636	1.35	4.05	5.5	-1.90	-2.6	2.15	2.9
1550 - 1600	6.49	3.90	25.3	-2.00	-13.0	1.90	12.3
1500 - 1550	4.04	3.78	15.3	-2.15	-8.7	1.63	6.6
1450 - 1500	2.11	3.65	7.7	-2.35	-5.0	1.30	2.7
1400 - 1450	1.56	3.55	5.5	-2.60	-4.1	0.95	1.5
1350 - 1400	1.92	3.45	6.6	-2.85	-5.5	0.60	1.2
1300 - 1350	1.37	3.35	4.6	-3.10	-4.3	0.25	0.3
1250 - 1300	0.81	3.20	2.6	-3.33	-2.7	-0.13	-0.1
1200 - 1250	1.31	3.00	3.9	-3.55	-4.6	-0.55	-0.7
1150 - 1200	1.02	2.75	2.8	-3.78	-3.8	-1.03	-1.0
1100 - 1150	0.45	2.50	1.1	-4.00	-1.8	-1.50	-0.7
1013 - 1100	0.33	2.30	0.8	-4.30	-1.4	-2.00	-0.7
1013 - 1636	**22.77**	**3.59**	**81.7**	**-2.52**	**-57.4**	**1.07**	**24.3**

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 47.2 km^2 (measured in 2009) 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 1957 m a.s.l. down to 315 m a.s.l.

Glaciological investigations in 2009 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The mountain peak Kjenndalskruna on the Nigardsbreen plateau photographed on 13th May 2009. Photo: Miriam Jackson.

4.1 Mapping

A new mapping of Nigardsbreen was performed in 2009. Aerial photographs were taken on 14th September and airborne laser scanning was carried out on 17th October.

A Digital Elevation Model (DEM) is processed based on the laser scanning data. The glacier boundary is determined mainly from the air photos and the intensity values from the laser scanning. In a few areas with insufficient data, the glacier boundary is determined using orthophotos from 2004 (www.norgeibilder.no).

4.2 Mass balance 2009

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 12th and 13th May and the calculation of winter balance (Fig. 4-2) is based on:

- Uninterrupted measurement of stakes and towers in positions 600 (561 m a.s.l.), T95 (1679 m a.s.l.), 94 (1701 m a.s.l.) and T56 (1792 m a.s.l.). The stake measurements showed snow depths of 0.25 – 5.60 – 5.45 and 5.75 m, respectively. Stake readings did not show any indication of melting after the final measurements in October 2008.
- Snow core samples at positions 55 (1462 m a.s.l.), 54 (1603 m a.s.l.), 96 (1752 m a.s.l.) and 57 (1957 m a.s.l.) showing snow depths of 5.10 – 5.4 – 5.5 and 4.85 m respectively.
- Snow depth probings performed in a regular grid of 500 x 750 metres. Previously, the snow depth was sounded along fixed profiles. Snow depth is measured in 88 grid points on the plateau between 1317 and 1957 m a.s.l. The summer surface (SS) was easy to detect. The snow depth varied between 5 and 6 metres. On the tongue the measured snow depth was 3.6 m (989 m a.s.l.) and 0.1 m (559 m a.s.l.), respectively.
- Snow density was measured down to SS at 5.5 m depth at position 96 (Fig. 4-2).

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

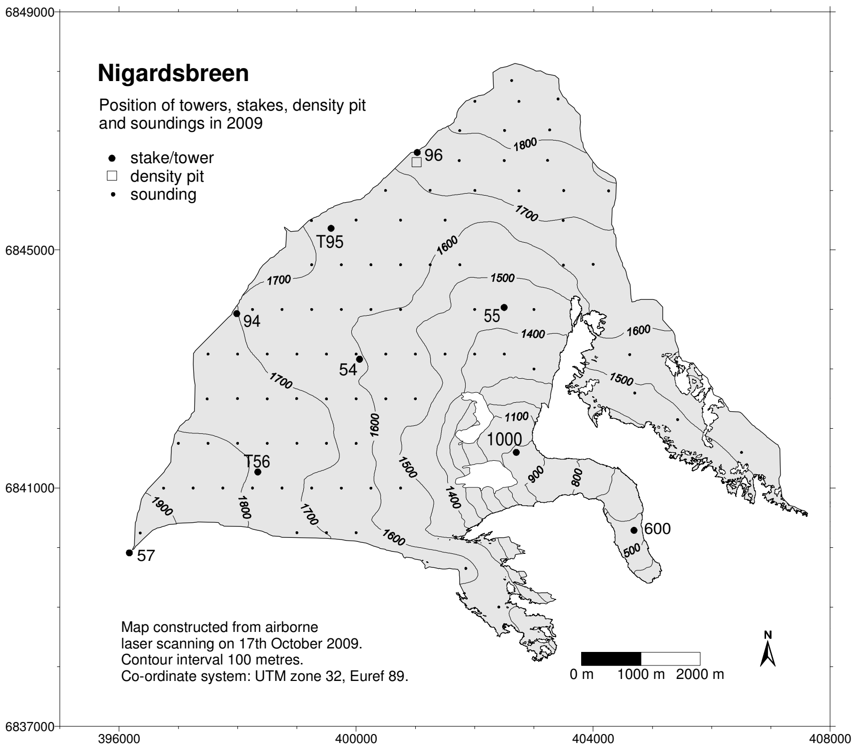


Figure 4-2 Location of towers and stakes, snow pit and soundings on Nigardsbreen in 2009.

Ablation measurements

Ablation measurements were carried out on 13th October. Measurements were made at seven stakes and two towers at eight different locations. Since snow measurements in May the stakes on the plateau had increased in length between 2.7 and 3.9 m. Hence, there was between 1 and 2 m of snow remaining from winter 2008/2009. At the time of measurement, between 0.7 and 1.3 m of fresh snow had fallen in the areas above 1000 m elevation.

Results

The calculations are based on the new DEM from 2009.

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 2008. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1752 m altitude (5.5 m depth). Using this model gave a snow density of 461 kg/m^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. 4-4), and a mean value for each 100 m height interval estimated (Tab. 4-1). The elevations above 1300 m a.s.l. were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 989 and 559 m altitude.

These calculations give a winter balance of 2.2 ±0.2 m w.e., corresponding to a water volume of 104 ±10 mill. m^3. This is 90 % of the mean for the reference period 1971-2000.

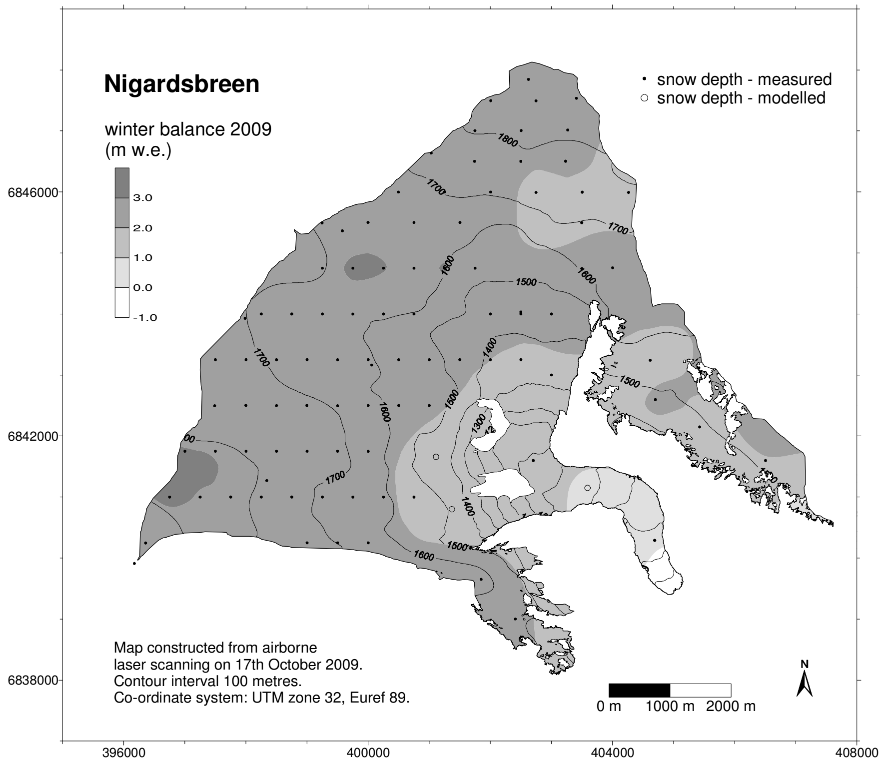


Figure 4-3
Winter balance at Nigardsbreen in 2009 interpolated from 94 measurements (·) of snow depth. In areas with few or no measurements three extrapolated points (○) are added.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 4-3). Water equivalents for each cell in a 250 x 250 m grid were calculated and summed. The result obtained using this gridding method was also 2.2 m w.e.

Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 600 kg/m^3. The density of melted firn was assumed to be 650 kg/m^3, while the density of ice was taken as 900 kg/m^3.

The summer balance was calculated at stakes and towers at eight different elevations. For stake 1000 the melting is estimated for the period 19th August to 13th October. The summer balance increased (in absolute value) from −0.9 m w.e. at the glacier summit (1957 m a.s.l.) to −8.6 m on the tongue (562 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 −92 ±15 mill. m^3 of water. This is 102 % of the mean for the reference period 1971-2000.

Net balance

The net balance was calculated at stakes and towers in eight different positions. The result was a surplus of +0.2 m ±0.3 m w.e., which means a volume increase of 11 ±15 mill.m^3 water. The mean value for the reference period 1971-2000 is +0.54 m w.e., while the average for last ten years (1999-2008) is +0.14 m w.e.

Based on Figure 4-4, the Equilibrium Line Altitude (ELA) was 1465 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 80 %.

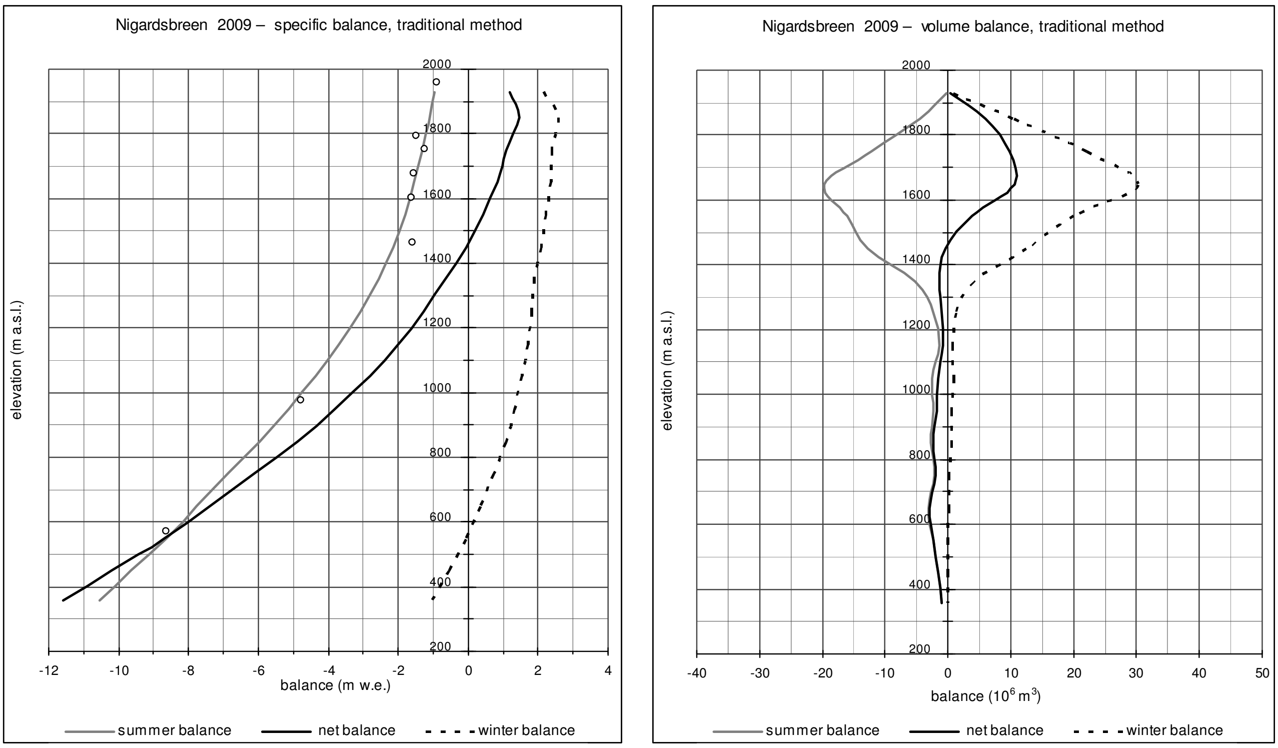


Figure 4-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2009. Specific summer balance at eight stake positions is shown as dots (○). The net balance curve intersects the y-axis and defines the ELA as 1465 m a.s.l. Thus the AAR was 80 %.

The mass balance for Nigardsbreen in 2009 is shown in Table 4-1 and the corresponding curves are shown in Figure 4-4. The historical mass balance results are presented in Figure 4-5.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2009. Mean values for the reference period 1971-2000 are 2.45 (b_w), –1.92 m (b_s) and +0.54 m (b_n) water equivalent.

Mass balance Nigardsbreen 2008/09 – traditional method

		Winter balance, Measured 13th May 2009		Summer balance, Measured 13th Oct 2009		Net balance, Summer surface 2008 - 2009	
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)
1900 - 1957	0.31	2.15	0.7	-0.95	-0.3	1.20	0.4
1800 - 1900	4.06	2.58	10.4	-1.10	-4.5	1.48	6.0
1700 - 1800	9.19	2.40	22.1	-1.33	-12.2	1.08	9.9
1600 - 1700	12.74	2.38	30.3	-1.55	-19.7	0.83	10.5
1500 - 1600	8.94	2.23	19.9	-1.80	-16.1	0.43	3.8
1400 - 1500	5.92	2.08	12.3	-2.15	-12.7	-0.07	-0.4
1300 - 1400	2.08	1.90	4.0	-2.55	-5.3	-0.65	-1.4
1200 - 1300	0.79	1.80	1.4	-3.08	-2.4	-1.28	-1.0
1100 - 1200	0.39	1.70	0.7	-3.70	-1.4	-2.00	-0.8
1000 - 1100	0.58	1.55	0.9	-4.35	-2.5	-2.80	-1.6
900 - 1000	0.46	1.33	0.6	-5.13	-2.3	-3.80	-1.7
800 - 900	0.47	1.08	0.5	-5.95	-2.8	-4.88	-2.3
700 - 800	0.32	0.75	0.2	-6.85	-2.2	-6.10	-2.0
600 - 700	0.41	0.35	0.1	-7.75	-3.1	-7.40	-3.0
500 - 600	0.26	-0.05	0.0	-8.65	-2.3	-8.70	-2.3
400 - 500	0.16	-0.55	-0.1	-9.65	-1.5	-10.20	-1.6
315 - 400	0.09	-1.05	-0.1	-10.55	-1.0	-11.60	-1.1
315 - 1957	**47.16**	**2.20**	**103.8**	**-1.96**	**-92.4**	**0.24**	**11.4**

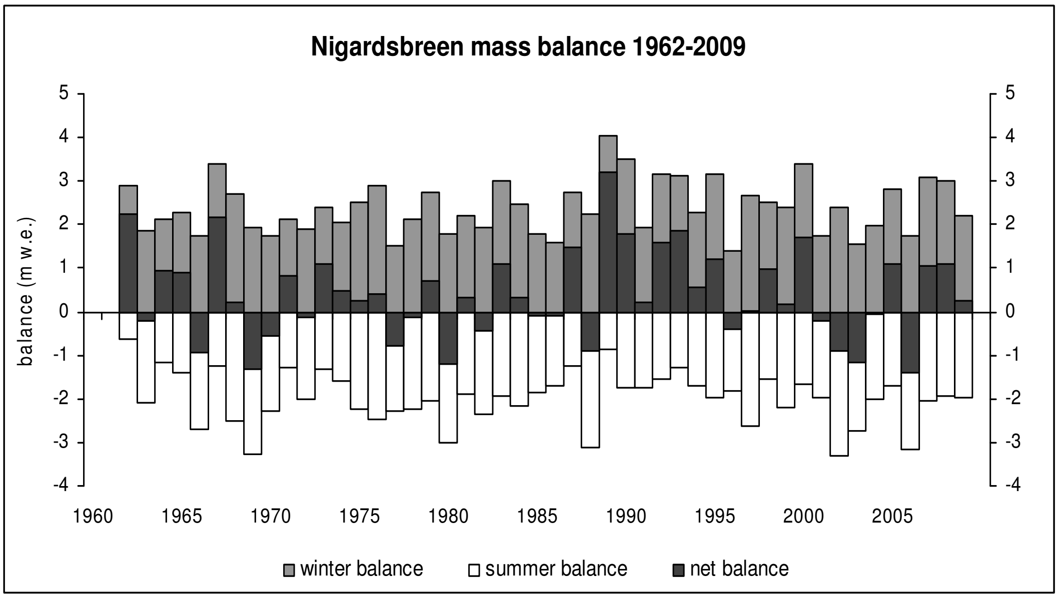


Figure 4-5
Annual mass balance at Nigardsbreen over the period 1962-2009.

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 1747 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 2009 included mass balance, front position change and glacier velocity. In addition, the glacier was mapped using airborne laser scanning (ALS). The mass balance has been measured at Austdalsbreen since 1988.

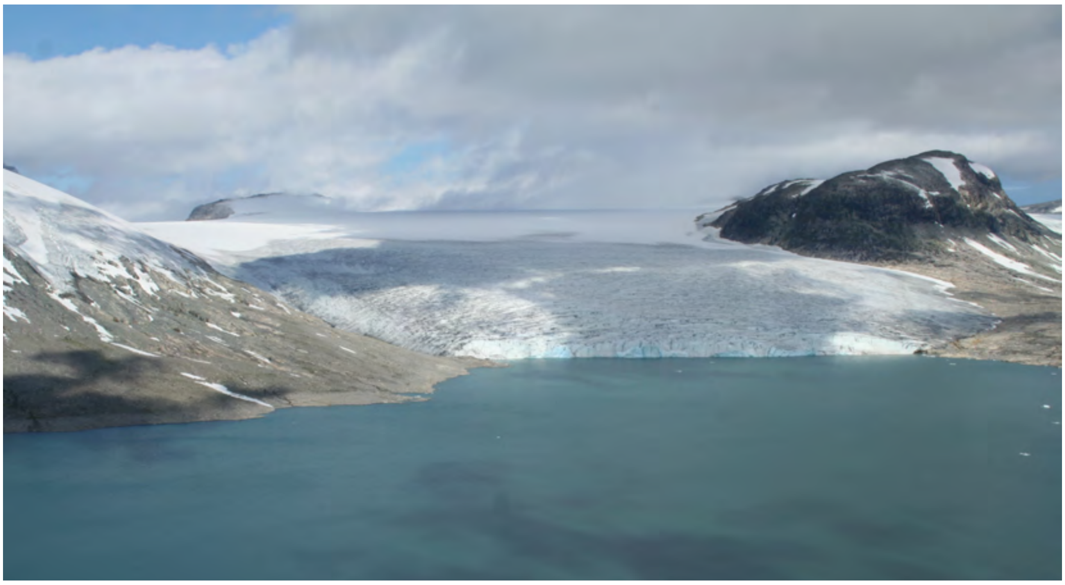


Figure 5-1
Austdalsbreen seen from the southeast on 19th August 2009. The temporary snow line altitude (TSL) was about 1400 m a.s.l. The lake level was 1190.7 m a.s.l. which is 9.3 m below the highest possible regulated lake level. Photo: Hallgeir Elvehøy.

5.1 Mapping

Austdalsbreen was mapped in 2009. Aerial photographs were taken on 14th September and airborne laser scanning was carried out on 17th October (Blom Geomatics AS, contract BN0097044). The mean point density was 0.32 points pr m^2 (3 m^2 pr. point). Comparison of data from crossing flight lines shows that differences are generally less than 0.2 metre.

A Digital Elevation Model (DEM) was processed based on the laser scanning data. The glacier boundary was determined mainly from the air photos. Due to front position change from calving between 14th September and 17th October, the terminus position in October had to be assessed from the DEM and ground surveyed points.

5.2 Mass balance 2009

Fieldwork

Five mass balance stakes were maintained throughout the winter.

The winter balance was measured on 15th May. The calculation of winter balance was based on the following data (Fig. 5-2):

- Snow depth at stakes A92 (4.0 m), A24 (4.3 m) and A70 (4.7 m). Stakes A5 and A6 were in a crevassed area and thus not accessible.
- Snow density down to the previous summer surface at 4.4 m depth at stake A60 (1490 m a.s.l.). The mean snow density was 450 kg/m^3.
- 41 snow depth measurements in a 500 x 500 m grid. At Austdalsnuten above 1600 m a.s.l. the snow depth was about 4 m. Between 1400 and 1600 m a.s.l. the snow was 4 to 5 m deep. Below 1400 m a.s.l. the snow depth was around 3 m at most locations.

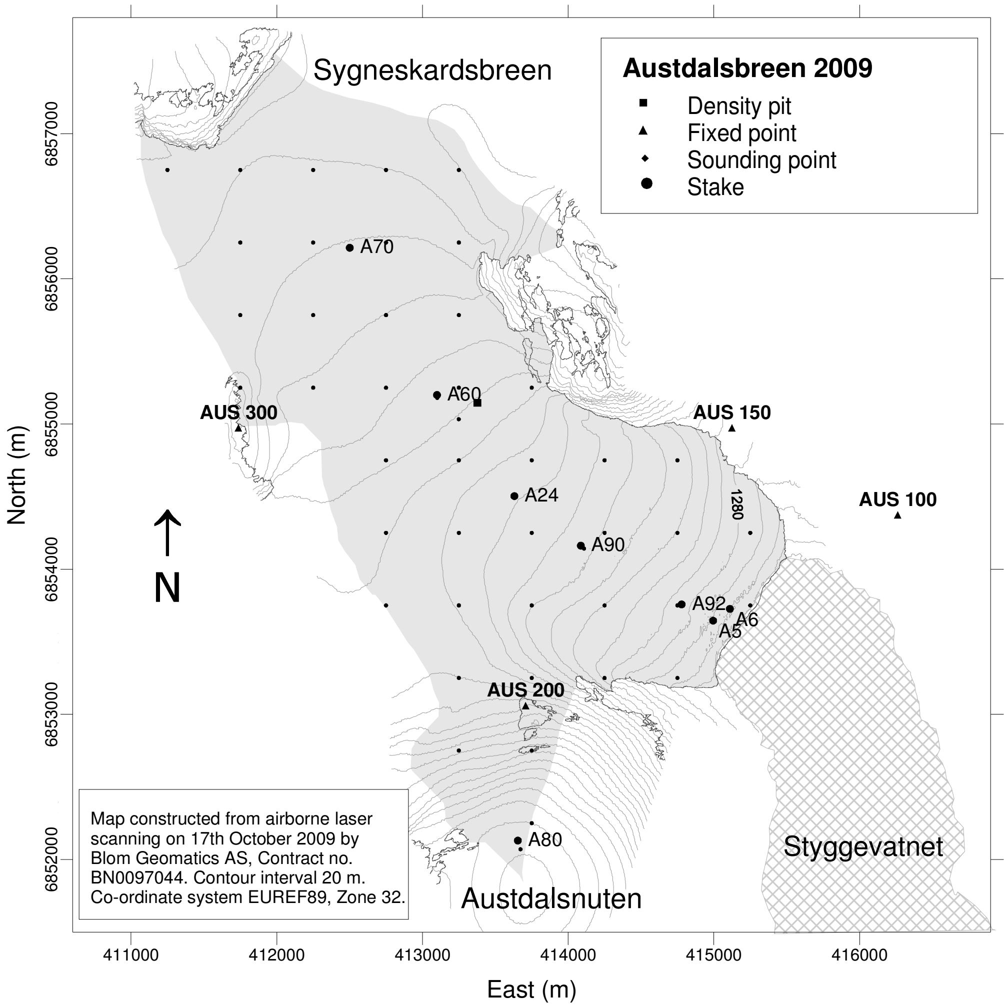


Figure 5-2
Location of stakes, density pit and snow depth sounding points at Austdalsbreen in 2009.

On 19th August the transient snow line was 1400 m a.s.l. The stakes were 3 – 4 metres longer than in May.

Summer and net balance measurements were carried out on 13th October. The glacier was covered with up to 0.9 m of new snow. Eight stakes in seven locations were found. Stake A80 was not found. The stakes were 0.5 to 1.5 m longer than in August. Based on the stake measurements the temporary snow line (TSL) at the end of the summer season was between 1420 and 1490 m a.s.l. At stake A70 0.5 m of snow remained.

Results

The mass balance was calculated according to the stratigraphic method (see chap.1). The calculations are based on a new DTM from 17th October 2009.

Winter balance

The winter balance was calculated from snow depth and snow density measurements on 15th 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 20 ±2 mill. m^3 water or 1.9 ±0.2 m w.e., which is 87 % of the 1988-2008 average (2.22 m w.e.).

The winter balance was calculated using a gridding method also, 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 1.9 m w.e.

Summer balance

The summer balance was calculated directly for six stakes in five locations between 1290 and 1550 m a.s.l. Stakes A5 and A6 melted out between 15th May and 19th August, and stake A80 broke between 19th August and 30th October. The snow and ice melting at stake A5 and A6 was modelled using a Positive Degree Days-model based on temperature measurements at the Styggevatnet Dam about 6 km southeast from the stake locations and at approximately the same elevation. The estimated ice melting between 15th May and 19th August was 3.8 m of ice. Based on a comparison with stakes A70 and A60 the amount of melting at A80 (1725 m a.s.l.) between 19th August and the start of the accumulation season was estimated to be 0.65 m of snow and firn.

The summer balance curve was drawn from these nine point 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 900 kg/m^3, u_{ice} is annual glacier velocity (60 ±10 m/a, chap. 5.3), u_f is front position change averaged across the terminus (−19 ±5 m/a, chap. 5.2), W is terminus width (990 ±20 m) and H is mean ice thickness at the terminus (48 ±5 m). The mean ice thickness was calculated from mean surface altitudes along the calving terminus surveyed on 30th October 2008 (1223 m a.s.l.) and 13th October 2009 (1223 m a.s.l.), and mean bottom elevation along the terminus in October 2008 (1174 m a.s.l.) and October 2009 (1176 m a.s.l.) calculated 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 mill. m^3.

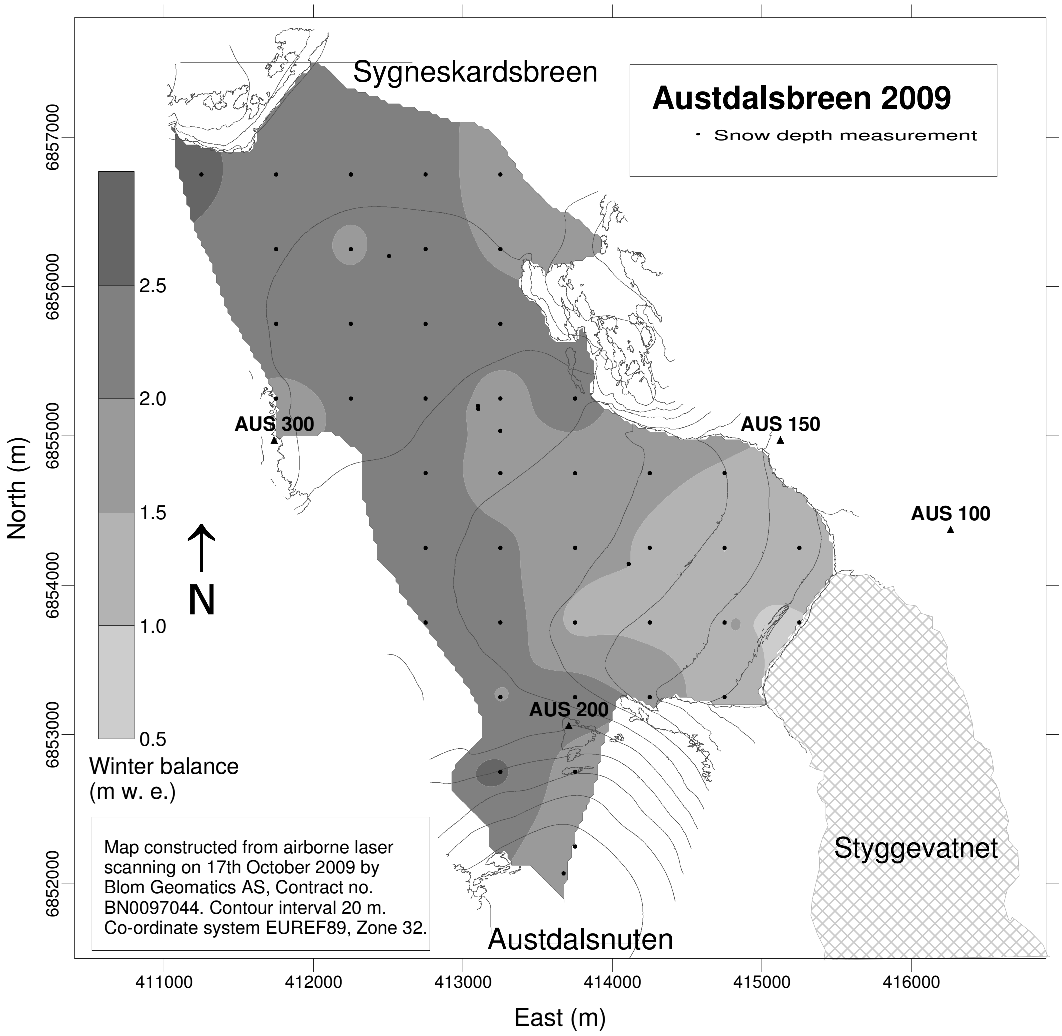


Figure 5-3
Winter balance at Austdalsbreen in 2009 from 41 water equivalent values calculated from snow depth measurements.

The summer balance, including calving, was calculated as −2.6 ±0.3 m w.e., which corresponds to −28 ±3 mill. m^3 of water. The result is 105 % of the 1988-2008 average (−2.49 m w.e.). The calving volume was 12 % of the summer balance.

Net balance

The net balance at Austdalsbreen was calculated as −0.7 ±0.3 m w.e., corresponding to −8 ±3 mill. m^3 water. The 1988-2008 average is −0.27 m w.e. The equilibrium line altitude (ELA) in 2009 is defined from the net balance curve at 1475 m a.s.l. The negative mass balance above 1700 m a.s.l. at A80 is neglected as the winter balance here is reduced locally due to wind effects. The Accumulation Area Ratio (AAR) corresponding to an ELA at 1475 m a.s.l. is 57 %. Due to the negative net balance above 1700 m a.s.l. the AAR was reduced to 56 % in 2009. The altitudinal distribution of winter, summer and net balances is shown in Figure 5-4 and Table 5-1. Results from 1988-2009 are shown in Figure 5-5.

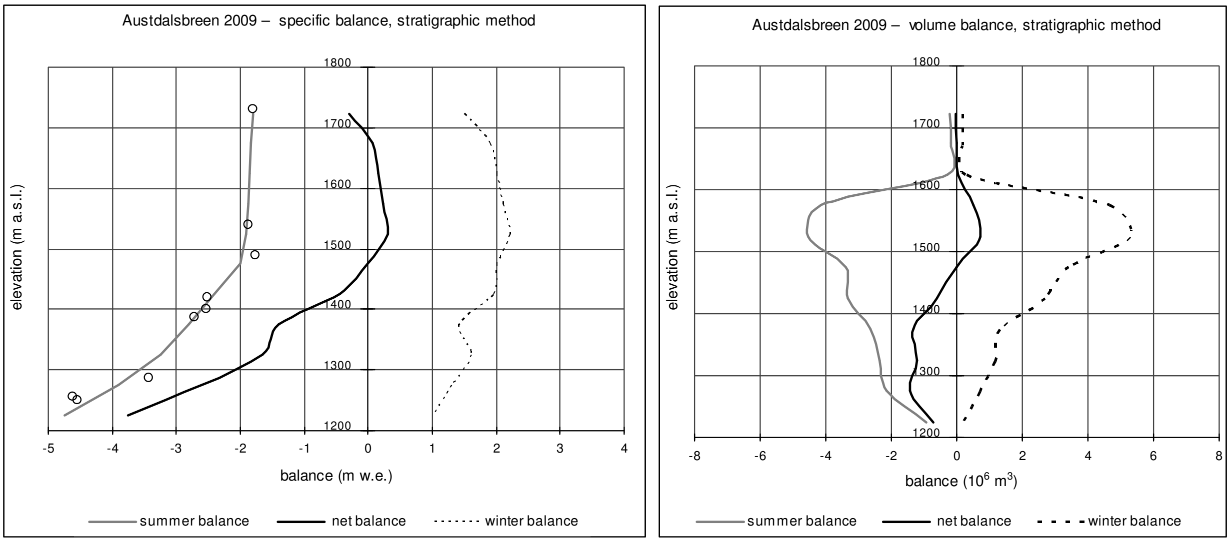


Figure 5-4
Altitudinal distribution of winter, summer and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2009. Specific summer balance at eight stake locations (two stakes at A90) is shown (○).

Table 5-1
Altitudinal distribution of winter, summer and net balances at Austdalsbreen in 2009.

Mass balance Austdalsbreen 2008/09 – stratigraphic method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 15th May 2009		Summer balance Measured 13th Oct 2009		Net balance Summer surface 2008 - 2009	
		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)
1700 - 1747	0.14	1.50	0.21	-1.80	-0.26	-0.30	-0.04
1650 - 1700	0.13	1.90	0.24	-1.83	-0.23	0.07	0.01
1600 - 1650	0.20	2.00	0.40	-1.85	-0.37	0.15	0.03
1550 - 1600	2.31	2.10	4.84	-1.87	-4.31	0.23	0.53
1500 - 1550	2.37	2.20	5.22	-1.90	-4.51	0.30	0.71
1450 - 1500	1.69	2.00	3.38	-2.00	-3.38	0.00	0.00
1400 - 1450	1.38	1.95	2.69	-2.40	-3.30	-0.45	-0.62
1350 - 1400	0.94	1.40	1.32	-2.80	-2.63	-1.40	-1.32
1300 - 1350	0.73	1.60	1.16	-3.25	-2.37	-1.65	-1.20
1250 - 1300	0.55	1.30	0.71	-3.90	-2.14	-2.60	-1.42
1200 - 1250	0.20	1.00	0.20	-4.75	-0.93	-3.75	-0.74
Calving					-3.4		-3.4
1200 - 1747	**10.63**	**1.92**	**20.4**	**-2.62**	**-27.8**	**-0.70**	**-7.4**

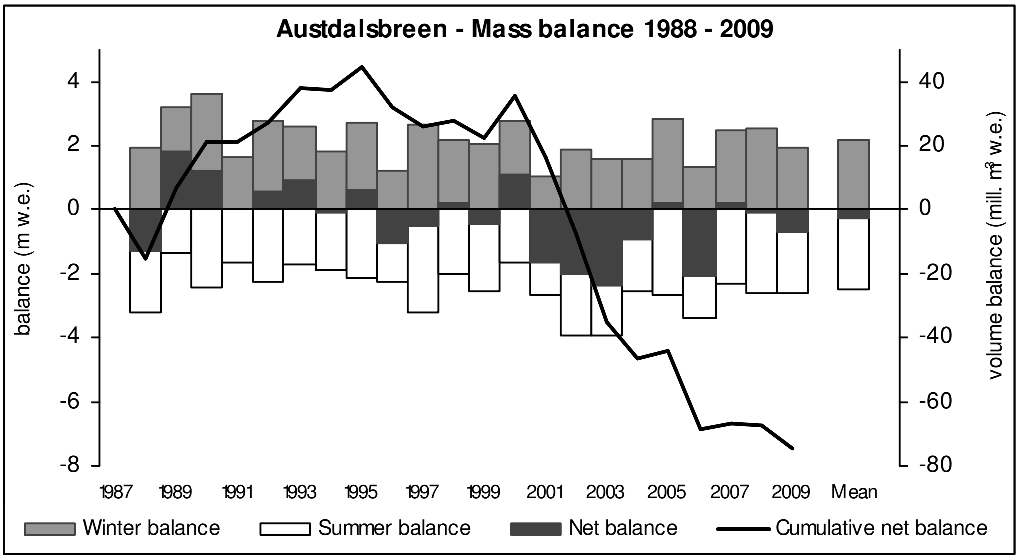


Figure 5-5
Winter, summer and net balances at Austdalsbreen during the period 1988-2009. Mean winter and summer balance is 2.20 and –2.50 m w.e., respectively. The cumulative net balance is –75 mill. m^3 water equivalent.

5.3 Front position change

Nine points along the calving terminus were surveyed on 13th October 2009. The mean front position change was –19 ±5 m (Fig. 5-6) between 30th October 2008 and 13th October 2009. The width of the calving terminus was 990 ±20 metres. Since 1988 the glacier terminus has retreated 478 metres, whilst the glacier area has decreased by approximately 0.50 km^2 (Fig. 5-6).

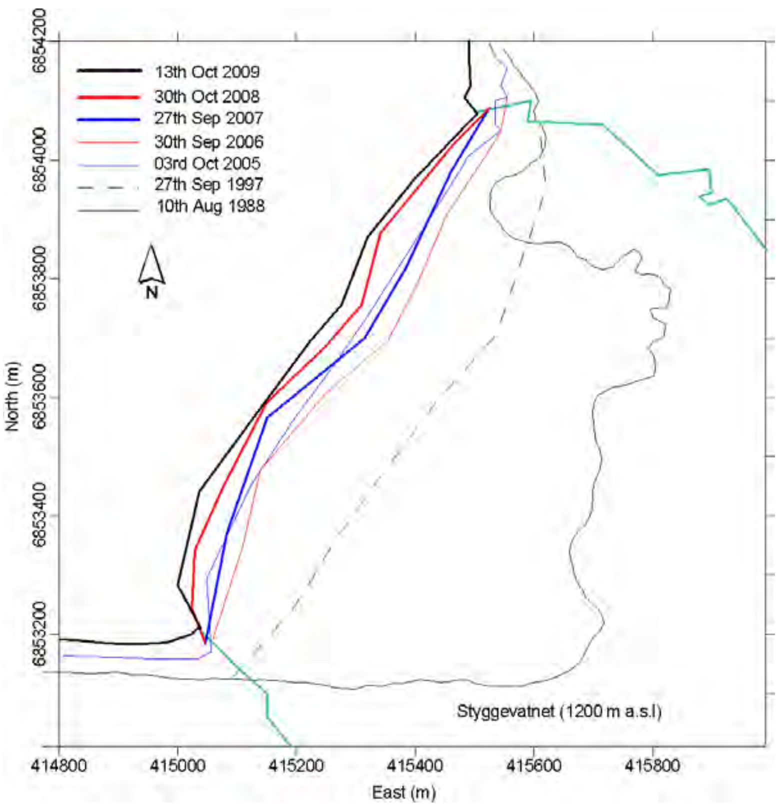


Figure 5-6
Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, in 1997, and in 2005-2009. The mean front position change between 30th October 2008 and 13th October 2009 was –19 metres.

A comparison of surveyed front positions and stake positions at stake A92 shows that in front of this stake the ice cliff calved 52 metres between 30th October 2008 and 13th October 2009. 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.

5.4 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 22nd May, 19th August and 30th October 2008, and 13th October 2009.

Annual velocities were calculated for five stake locations based on surveys on 19th August 2008 and 13th October 2009 (420 days). The annual velocities at stake locations A92, A90, A24 and A60 were 49 m.a^{-1}, 33 m.a^{-1}, 25 m.a^{-1} and 20 m.a^{-1}, respectively. This is similar to velocities calculated for 2007/2008.

The glacier velocity averaged across the front width and thickness must be estimated in order to calculate the calving volume (chap. 5.1).Two stakes close to the terminus melted out between May and August. From stake positions surveyed on 30th October 2008 and 13th October 2009 (±0.3 m), and positions measured by hand-held navigation units on 19th March and 19th August 2009 (±10 m) the annual velocity at A6 is estimated as 80 m.a^{-1}.

The surface centre line velocity at the terminus was calculated from the average distance from stake A6 to the terminus (120 m) and an average strain rate from previous years (0.1 a^{-1}) as 92 m.a^{-1}. 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 glacier velocity averaged across the terminus for 2008/2009 is 60 ±10 m.a^{-1}.

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).

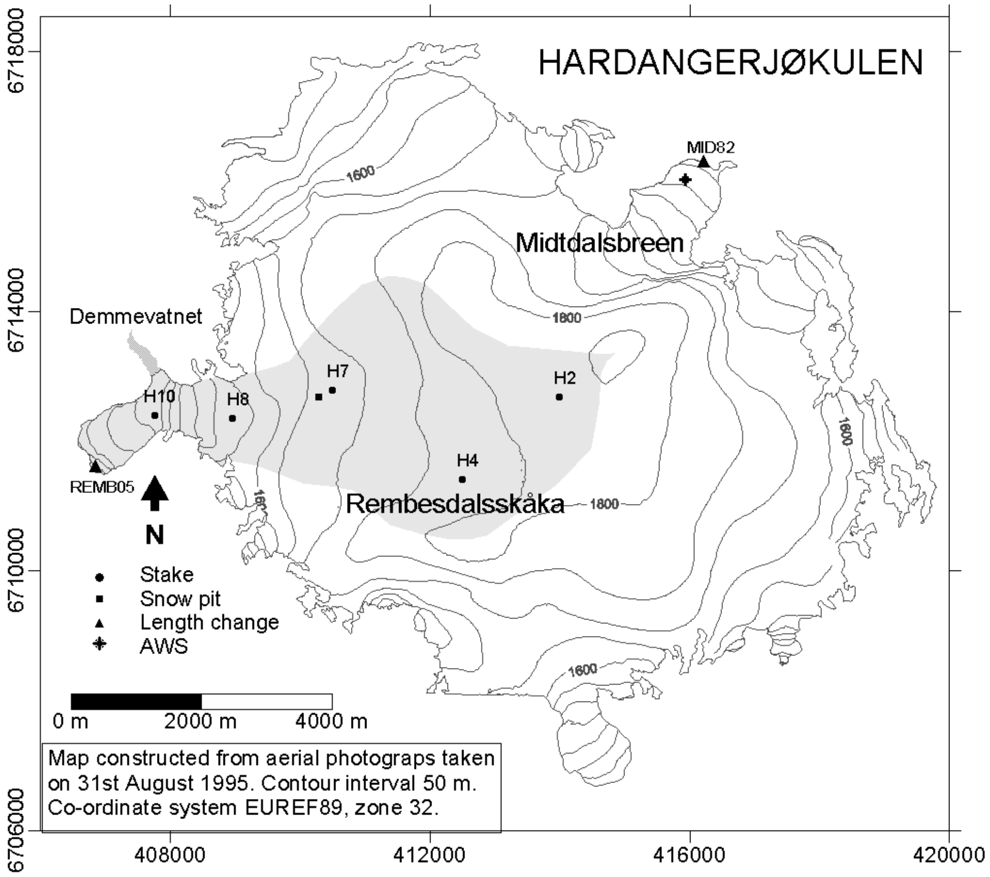


Figure 6-1
Location of stakes at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and an automatic weather station (AWS) at Midtdalsbreen.

Figure 6-2
Coring at H8 (1510 m a.s.l.) at Hardangerjøkulen on 29th May 2009. The snow depth was 2.8 metres. Photo: Hallgeir Elvehøy.

6.1 Mass balance at Rembesdalsskåka in 2009

Fieldwork

The stake network was checked on 5th December 2008, 15th January and 19th March 2009. Stakes were maintained throughout the winter in three positions. Snow depth sounding and stake measurements at stake H10 on 29th May 2009 showed there was no melting after the autumn measurements on 30th October 2008.

The winter balance measurements were carried out on 29th May. The calculation of winter balance is based on the following data (see fig. 6-1 for locations):

- Snow depth measurements at stakes H10 (1260 m a.s.l.), H4 (1775 m a.s.l.) and H2 (1830 m a.s.l.), showing snow depths of 1.65 – 5.65 and 5.15 metres, respectively.
- Snow density down to last years summer surface (SS) at 4.6 m depth at location H7 (1660 m a.s.l.). The mean snow density was 490 kg/m^3.
- Snow depth soundings. The measurements have been changed from fixed profiles to a 500 x 500 metre regular grid in order to assess the spatial variations better. Due to unfavourable weather conditions only 19 of the 54 grid points were measured. In addition, the locations of three snow-covered stakes were sounded. The snow depth

was 2.8 to 4.2 metres between 1500 and 1650 m a.s.l. The snow depth was 4.5 to 5.7 metres between 1650 and 1830 m a.s.l.

The glacier was not visited during the summer and stakes H10 and H8 melted out.

Summer and net balance were measured on 14th October. The glacier was covered with new snow, and measurements at the stakes showed between 0.35 and 0.85 m of new snow. The snow line altitude immediately prior to snow accumulation could not be detected due to the new snow cover, but stake readings indicate that the TSL altitude was about 1650 m a.s.l., close to stake H7. The remaining stakes above 1650 m a.s.l. showed 3.5 to 4.0 m of snow melting during summer. At stakes H2 and H4, 2.0 and 1.5 m of snow remained, and up to 0.2 m of snow remained at three stakes at location H7.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive "summer surfaces", excluding snow accumulation before 14th October 2009. The calculations are based on a map from 1995.

Winter balance

The winter balance was calculated from the snow depth and snow density measurements on 29th May.

Stake measurements and snow depth sounding at stake H10 on 29th May 2009 showed no ice melting had occurred after 30th October 2008.

A snow depth-water equivalent profile was calculated based on snow density measurements at location H7 (1660 m a.s.l.) on 29th May. Using the calculated profile, the mean density of 5 m of snow was 500 kg/m^3. The snow depth measurements were transformed to water equivalent values using this profile. From the calculated water equivalent values, averages for 50 m elevation bands were calculated and plotted against altitude. An altitudinal winter balance curve was drawn from these averages (Fig. 6-3). Below 1500 m a.s.l. the winter balance curve was extrapolated from the measurements at stakes H8 (1510 m a.s.l.) and H10 (1260 m a.s.l.). A mean value for each 50 m elevation was then determined from this curve.

The resulting winter balance was 2.4 ±0.2 m w.e. or 40 ±3 mill. m^3 water. This is 106 % of the 1971-2000 normal of 2.24 m w.e., and 105 % of the 2004-2008 average of 2.26 m w.e. The altitudinal distribution of the winter balance is shown in Figure 6-4 and Table 6-1.

Based on the snow depth measurements the spatial distribution of the winter balance was extrapolated using the Inverse distance to power method (IDP). The distributed winter balance is shown in Figure 6-3, and the mean winter balance was 2.5 m w.e.

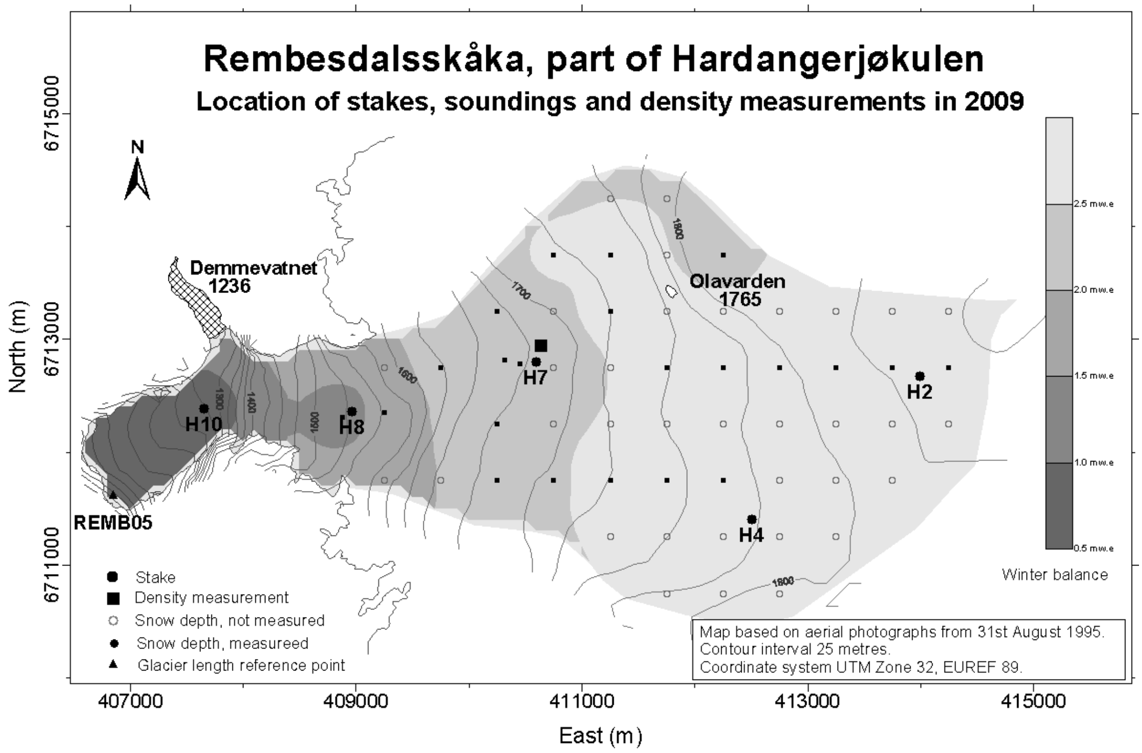


Figure 6-3
Winter balance at Rembesdalsskåka interpolated from 23 measurements (•) of snow depth.

Summer balance

The summer balance was calculated directly at three locations between 1660 and 1830 m a.s.l. The density of the remaining snow at locations H7, H4 and H2 was set as 600 kg/m^3.

The snow and ice melting at locations H10 and H8 had to be estimated. A Positive Degree Day model (PDD-model) calibrated with stake measurements was used. Meteorological data came from Meteorological Institute's station 49800 Fet in Eidfjord, at 735 m a.s.l. and 15 km SSW of Rembesdalsskåka. Precipitation has been measured here since 1953 and air temperature measurements began in 2005. The PDD-model is calibrated with stake measurements at H10 and H8 between 22nd September 2006 and 29th May 2009. Snow accumulation is calibrated by tuning the catch deficit for snow and rain, and the vertical lapse rate for precipitation. Ablation is calibrated using degree-day factors for snow and ice. The calibration performance is evaluated by minimising the RMS of the differences between measured and modelled values for different periods. The resulting summer balance at location H10 was −4.9 m w.e. (1.65 m of snow and 4.65 m of ice). At H8 the summer balance was −3.3 m w.e. (2.8 m of snow and 2.2 m of ice).

The summer balance curve in Figure 6-4 was drawn from three measured and two modelled point values. The summer balance was calculated as −2.2 ±0.2 m w.e., corresponding to −38 ±3 mill. m^3 of water. This is 115 % of the 1971-2000 normal average, which is −1.92 m w.e., and 100 % of the 2004-2008 average of −2.22 m w.e.

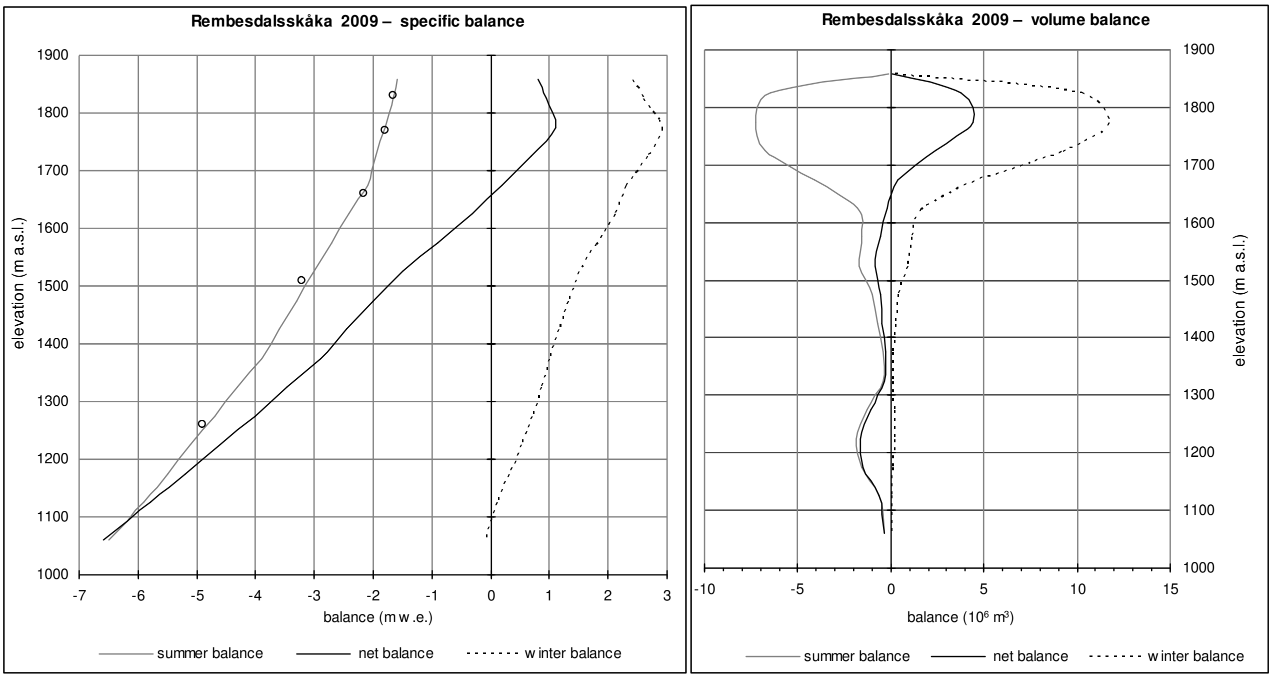


Figure 6-4
Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2009. Specific summer balance at five stakes is shown (○).

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka in 2009.

Mass balance Rembesdalsskåka2008/09 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 29th May 2009		Measured 14th Oct 2009		Summer surface 2008 - 2009	
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	2.40	0.2	-1.60	-0.1	0.80	0.1
1800 - 1850	3.93	2.60	10.2	-1.65	-6.5	0.95	3.7
1750 - 1800	4.03	2.90	11.7	-1.80	-7.3	1.10	4.4
1700 - 1750	3.46	2.65	9.2	-1.95	-6.7	0.70	2.4
1650 - 1700	1.94	2.30	4.5	-2.10	-4.1	0.20	0.4
1600 - 1650	0.75	2.10	1.6	-2.40	-1.8	-0.30	-0.2
1550 - 1600	0.59	1.80	1.1	-2.70	-1.6	-0.90	-0.5
1500 - 1550	0.57	1.50	0.9	-3.00	-1.7	-1.50	-0.9
1450 - 1500	0.29	1.30	0.4	-3.30	-1.0	-2.00	-0.6
1400 - 1450	0.19	1.15	0.2	-3.60	-0.7	-2.45	-0.5
1350 - 1400	0.10	1.00	0.1	-3.90	-0.4	-2.90	-0.3
1300 - 1350	0.10	0.85	0.1	-4.30	-0.4	-3.45	-0.3
1250 - 1300	0.27	0.70	0.2	-4.70	-1.3	-4.00	-1.1
1200 - 1250	0.36	0.50	0.2	-5.10	-1.9	-4.60	-1.7
1150 - 1200	0.28	0.30	0.1	-5.50	-1.6	-5.20	-1.5
1100 - 1150	0.11	0.10	0.0	-5.90	-0.6	-5.80	-0.6
1020 - 1100	0.05	-0.10	0.0	-6.50	-0.3	-6.60	-0.3
1020 - 1865	**17.12**	**2.37**	**40.5**	**-2.21**	**-37.9**	**0.15**	**2.6**

Net balance

The net balance at Rembesdalsskåka was calculated as +0.2 ±0.3 m w.e. or +3 ±5 mill. m^3 water. The 1971-2000 normal value is +0.32 m w.e., and the 2004-2008 average is +0.04 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 1655 m a.s.l. from the net balance curve in Figure 6-3. The corresponding accumulation area ratio (AAR) was 77 %. Results from 1963-2009 are shown in Figure 6-4. The cumulative net balance is +87 mill. m^3 w.e. This mass gain occurred between 1989 and 1993. Since 2000 the glacier has had a mass deficit of –44 mill. m^3 w.e.

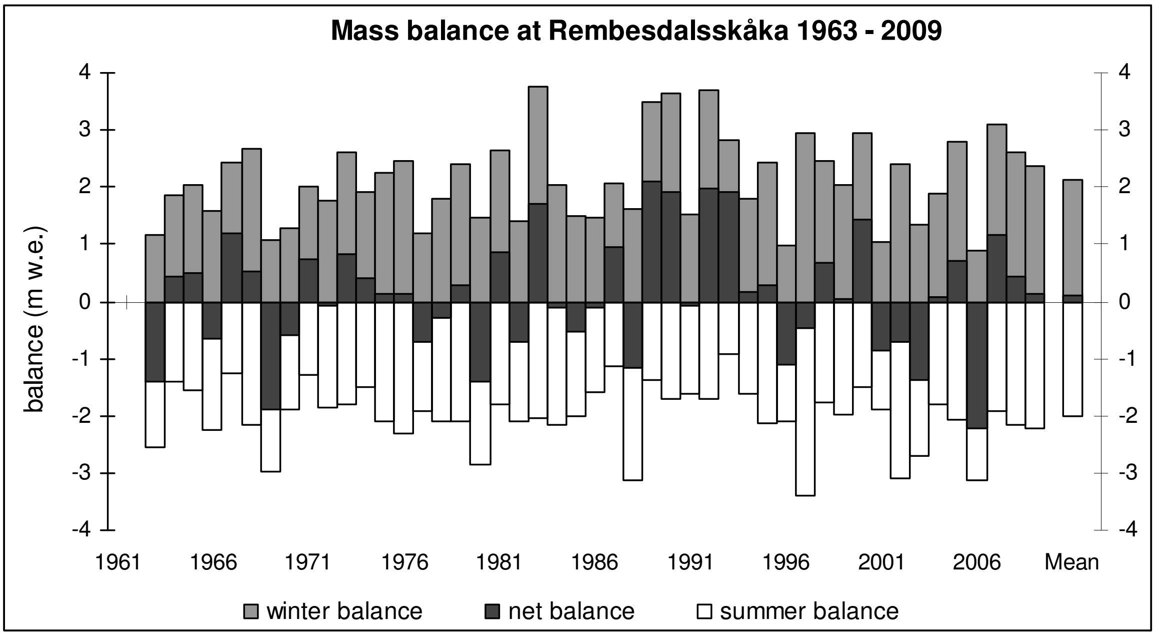


Figure 6-5
Winter-, summer- and net balances at Hardangerjøkulen during the period 1963-2009. Mean values (1963-2009) are b_w=2.12 m, b_s=–2.01 m and b_n=+0.11 m water equivalent.

6.2 Meteorological measurements on Midtdalsbreen

(Rianne H. Giesen, Utrecht University)

An automatic weather station (AWS) has operated in the ablation area of Midtdalsbreen, a north-eastern outlet glacier of Hardangerjøkulen, since October 2000. The station (Fig. 1) is owned and maintained by the Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: J.Oerlemans@uu.nl). The station records air temperature, relative humidity, wind speed and direction, distance to the surface, shortwave and long wave 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 29th August 2008 and 24th August 2009.

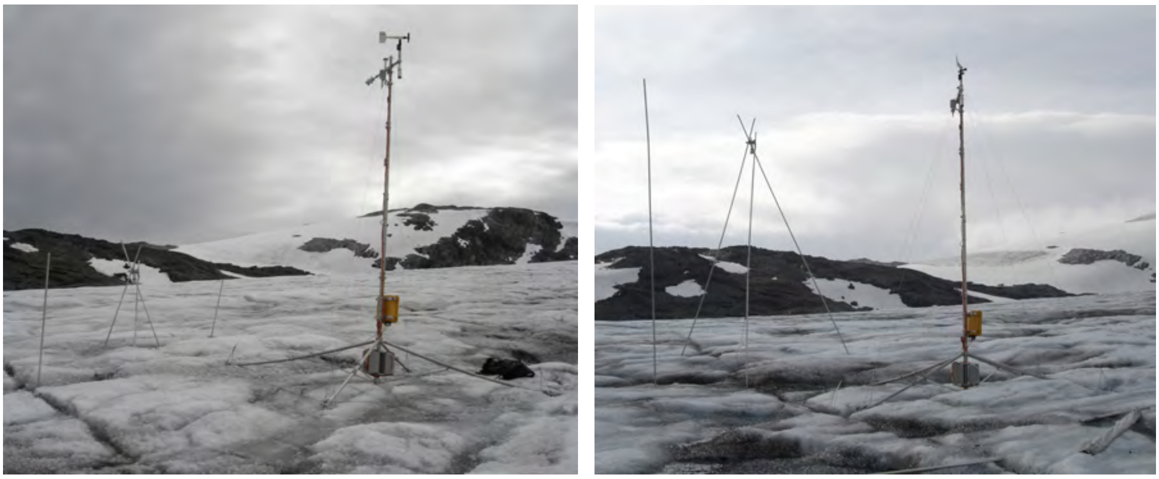


Figure 6-6
The AWS site on Midtdalsbreen after the maintenance on 29th August 2008 (left) and upon arrival on 24th August 2009 (right). The ice surface sank 3.4 m during this period. Photo: Rianne H. Giesen.

Net ice ablation

The mast with the instruments is standing on the ice surface and sinks with the surface as it melts. In this way, the distance of the instruments to the surface remains constant (5.7 m), as long as there is no snow. The tripod with a sonic ranger is drilled into the ice and the measured distance to the surface changes constantly. During the maintenance visit on 29th August 2008, the sonic ranger on the tripod was positioned at 1.6 m above the surface (Fig. 6-6). One year later, the sonic ranger was almost as high above the surface as the instruments in the mast. The record from the sonic ranger contained large data gaps, probably due to a damaged cable. Since the sonic ranger did measure at both the beginning and the end of the period, we could determine the net ice ablation at the AWS site, amounting to 3.40 m of ice. This value is smaller than the ablation measured at the stake (3.75 m). The difference is probably caused by the uneven surface under the sonic ranger; the shortest distance to the surface is then recorded. For most of the nine years since the installation in 2000, net ice ablation at the AWS site ranged between 3 and 4 m. However, in 2002 and 2006 the melt was significantly larger.

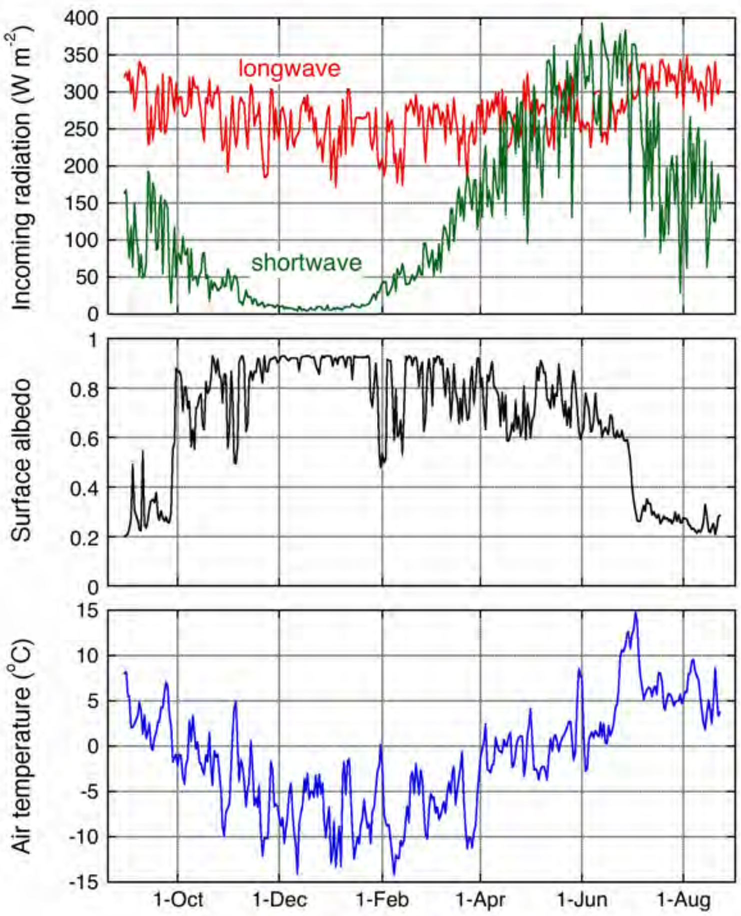


Figure 6-7
Daily mean values of incoming shortwave and long wave radiation, surface albedo and air temperature for the period 29th August 2008 to 24th August 2009.

Incoming radiation, surface albedo and air temperature

Daily mean values of incoming shortwave (solar) and long wave radiation, surface albedo and air temperature are shown in Figure 6-7. The daily surface albedo was computed by dividing the daily sums of reflected and incoming solar radiation. The increase in albedo on 28th September indicates the start of the snow accumulation. Daily temperatures higher than the melting point occurred regularly after this date, lowering the surface albedo again. The low snow albedos computed for November and February may not be realistic, but caused by the lower accuracy of the radiation sensor for small solar elevation angles. In December and January, the sun does not rise above the surrounding terrain and only diffuse sunlight reaches the AWS site. Daily mean air temperatures fluctuated continuously around the melting point in April and May, while the incoming solar and long wave radiation records indicate alternating periods with cloudy and clear-sky conditions. June was a sunny month divided into a cold period at the beginning and very warm days at the end of the month. In early July, the last snow disappeared at the AWS site, exposing the underlying ice with a lower albedo. Almost simultaneously, temperatures dropped and cloudy conditions prevailed for the remainder of the summer.

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Jotunheimen mountain massif in central southern Norway. Mass balance measurements began in 1949 and 2009 is the 61st year of continuous measurements.

In autumn 2009 the glacier was surveyed by laser scanning and aerial photography (Fig. 7-1). A new digital terrain model (DTM) and a new glacier outline have been derived from these data. According to the new dataset from 2009 Storbreen has a total area of 5.1 km^2 and ranges in altitude from 1400 to 2102 m a.s.l. The glacier terminus has retreated markedly and the glacier area has been reduced by about 0.2 km^2 since 1997 (Fig. 7-1).

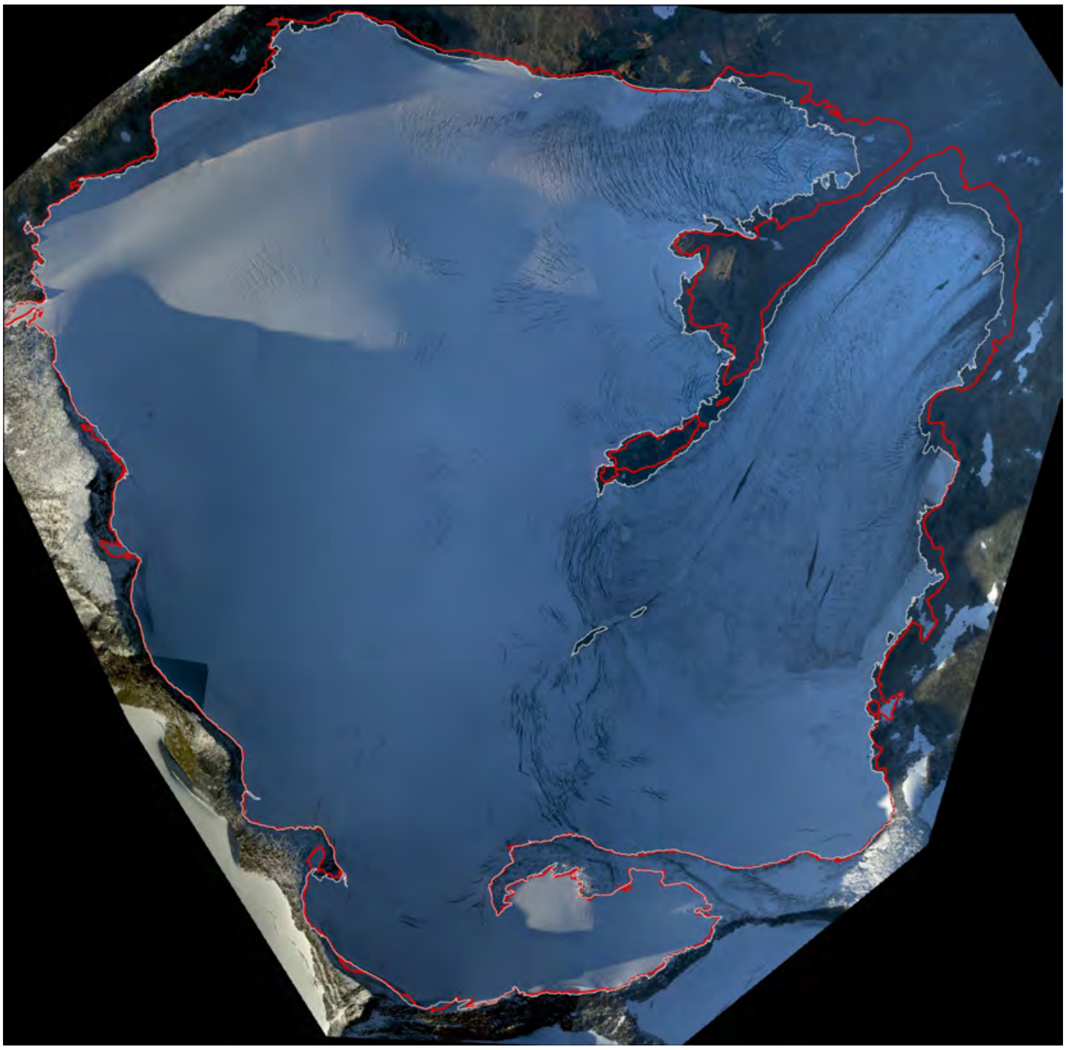


Figure 7-1
Orthophoto (orthorectified aerial photograph) of Storbreen taken on 14th September. Red line shows the glacier extent in 1997, grey line shows the glacier extent in 2009. Orthophoto produced by Blom Geomatics AS.

7.1 Mass balance 2009

Fieldwork

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

- Measurements of stakes in 6 different positions. The stake readings showed 0-20 cm of additional surface melting below 1715 m a.s.l. after the ablation measurements in the previous mass balance year (1st September 2008).
- Soundings of snow depth in 174 positions between 1427 and 1984 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was relatively easy to identify over the whole glacier, except for a small area in the uppermost part of the glacier. The snow depth varied between 1.08 and 6.10 m, the mean being 3.34 m.
- Snow density was measured at stake 4 at 1715 m a.s.l.

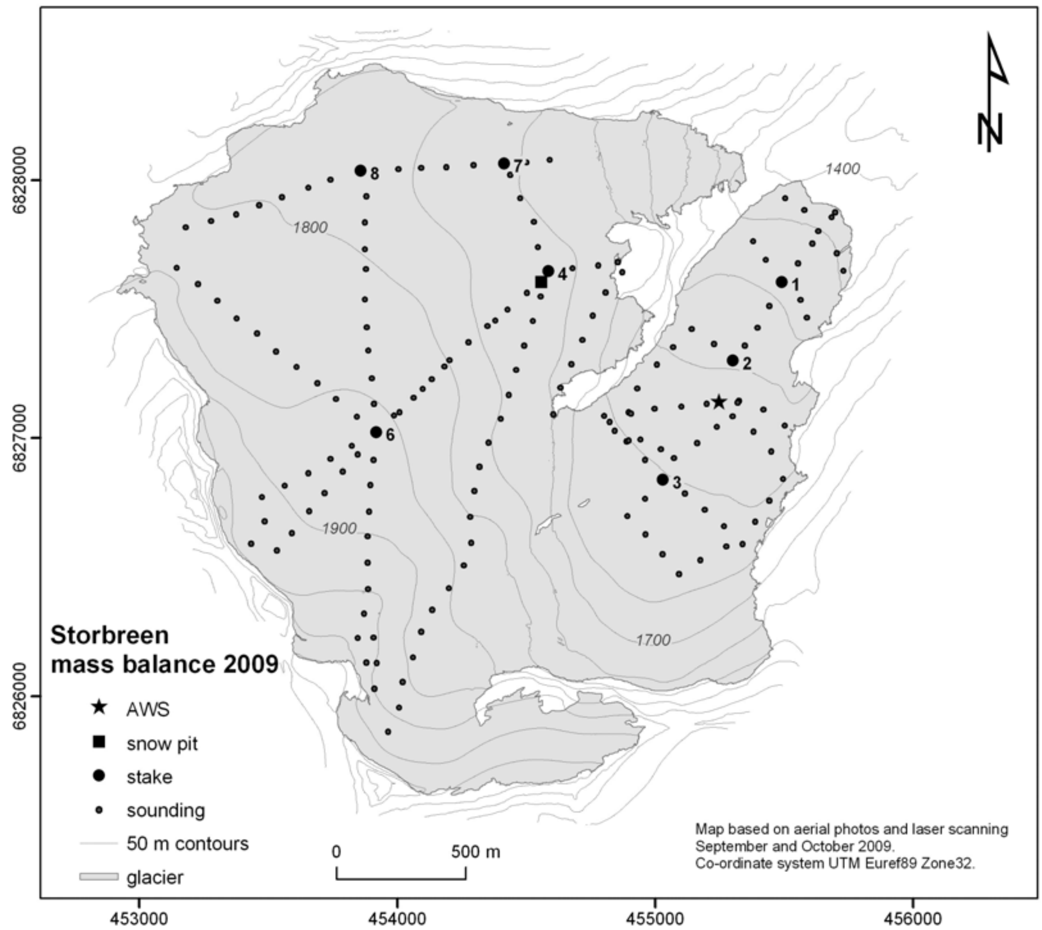


Figure 7-2
Location of stakes, density pits and the automatic weather station (AWS) at Storbreen in 2009.

Ablation measurements were performed on 17th and 18th September on stakes in most positions. The highest stake (6 at 1860 m a.s.l.) was not measured due to snow and weather conditions.

The locations of stakes, density pits and soundings are shown in Figure 7-2.

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 441 kg/m^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The specific winter balance was calculated to be 1.60 ± 0.2 m w.e. This is 130 % of the mean for 1971-2000.

Summer balance

Summer balance was calculated directly from stakes at 7 locations (1, 2, AWS, 3, 4, 7 and 8). The density of the remaining snow was assumed to be 600 kg/m^3. The density of the melted ice was assumed to be 900 kg/m^3. The lack of ablation stake reading at the highest stake (6) makes the summer balance (and thus net balance) curve more uncertain above 1800 m a.s.l. The summer balance was calculated to be −1.8 ±0.3 m w.e., which is 112 % of the mean for 1971-2000.

Net balance

The net balance of Storbreen was negative in 2009, −0.22 ±0.3 m w.e., which is equivalent to a volume of −1.15±1.54 mill. m^3 of water. The ELA calculated from the net balance diagram (Fig. 7-3) was 1760 m a.s.l. and the accumulation area ratio (AAR) was 53 %. The cumulative balance over 1949-2009 is −17.4 m w.e., the mean annual net balance over the 61 years of measurements is −0.29 m w.e. (Fig. 7-4).

Mass balance Storbreen 2008/09 – traditional method

		Winter balance Measured 12-14 May 2009		Summer balance Measured 17-18 Sep 2009		Net balance Summer surfaces 2008 - 2009	
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)
2050 - 2102	0.00	3.00	0.01	-0.20	0.00	2.80	0.01
2000 - 2050	0.09	2.85	0.27	-0.30	-0.03	2.55	0.24
1950 - 2000	0.18	2.73	0.49	-0.40	-0.07	2.33	0.42
1900 - 1950	0.29	2.68	0.78	-0.50	-0.15	2.18	0.63
1850 - 1900	0.34	2.03	0.70	-0.65	-0.22	1.38	0.47
1800 - 1850	0.75	1.54	1.16	-0.80	-0.60	0.74	0.56
1750 - 1800	0.87	1.51	1.31	-1.20	-1.04	0.31	0.27
1700 - 1750	0.68	1.41	0.96	-2.30	-1.57	-0.89	-0.61
1650 - 1700	0.55	1.44	0.79	-2.60	-1.42	-1.16	-0.63
1600 - 1650	0.31	1.56	0.49	-2.80	-0.87	-1.24	-0.39
1550 - 1600	0.49	1.35	0.67	-3.00	-1.48	-1.65	-0.82
1500 - 1550	0.26	1.14	0.30	-3.20	-0.84	-2.06	-0.54
1450 - 1500	0.18	0.96	0.17	-3.40	-0.60	-2.44	-0.43
1400 - 1450	0.13	1.09	0.15	-3.60	-0.48	-2.51	-0.34
1400 - 2102	**5.14**	**1.60**	**8.23**	**-1.83**	**-9.38**	**-0.22**	**-1.15**

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2009.

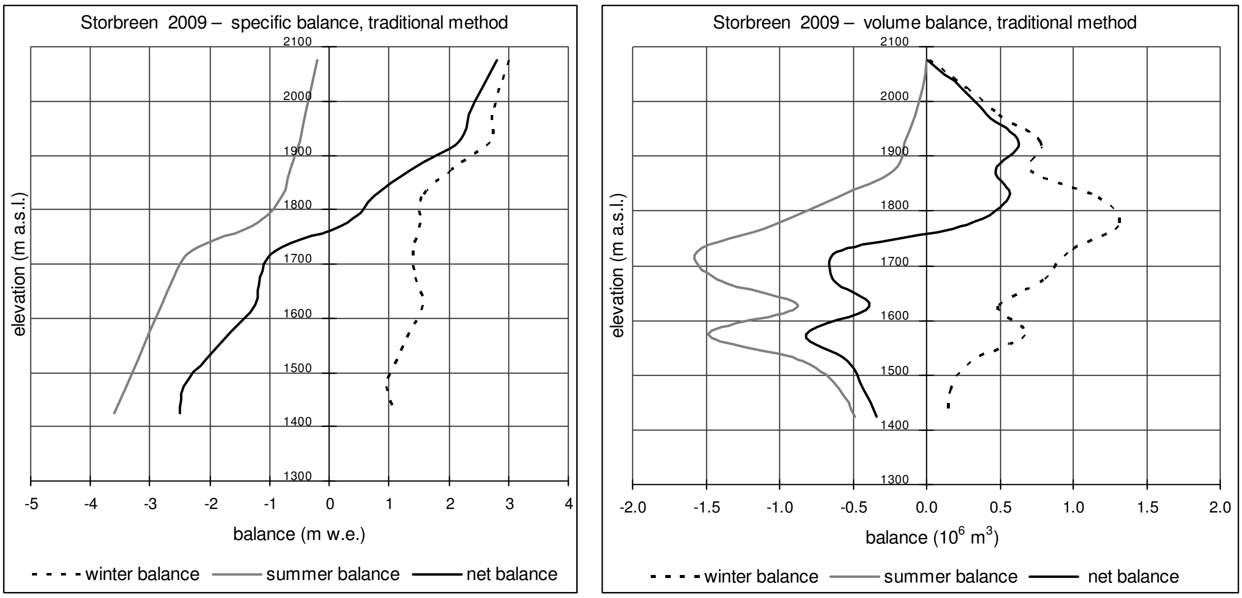


Figure 7-3
Mass balance diagram for Storbreen 2009, showing specific balance on the left and volume balance on the right.

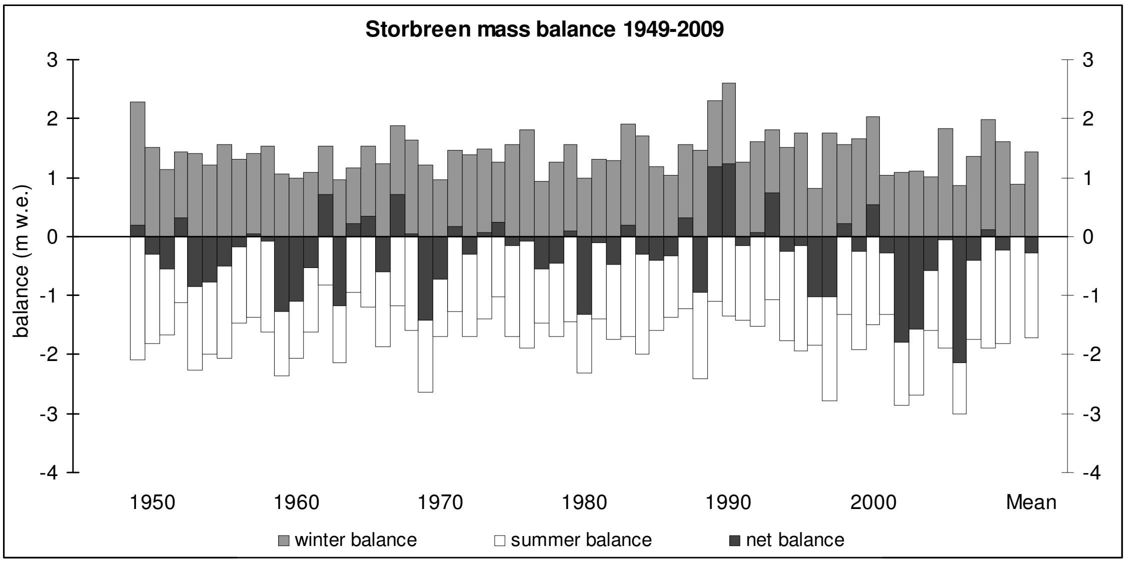


Figure 7-4
Winter, summer and net balance at Storbreen for the period 1949-2009.

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@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 analysis of the data from the first five years (2001-2006) are found in Andreassen et al. (2008). Results from the AWS have also been used to calibrate a mass balance model for Storbreen (Andreassen and Oerlemans, 2009) and have been compared with data from an AWS at Midtdalsbreen (Giesen et al., 2009).

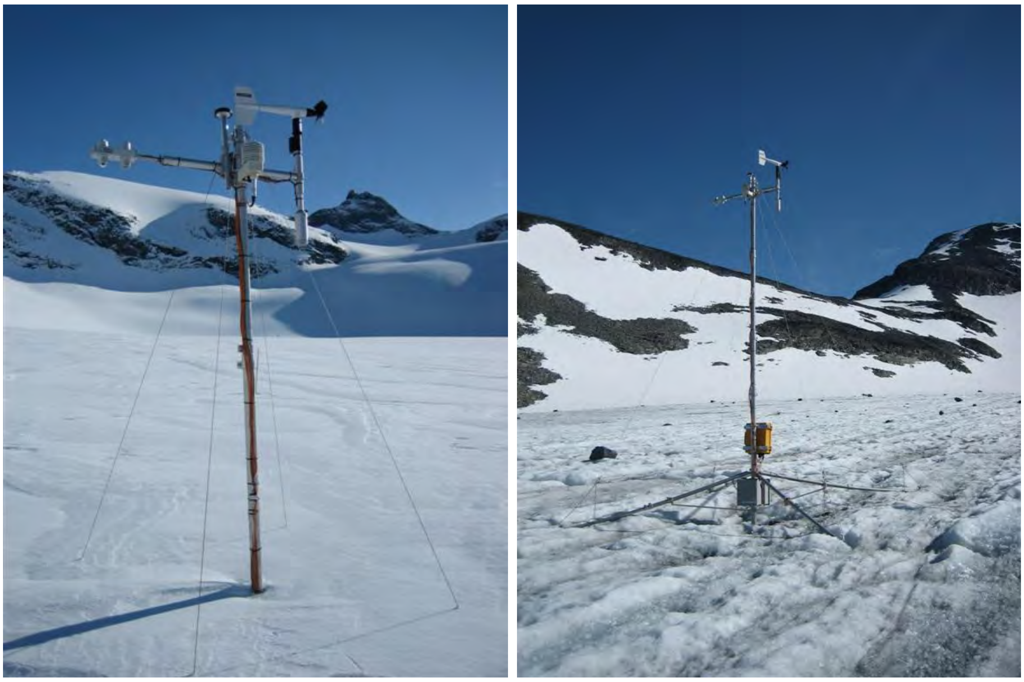
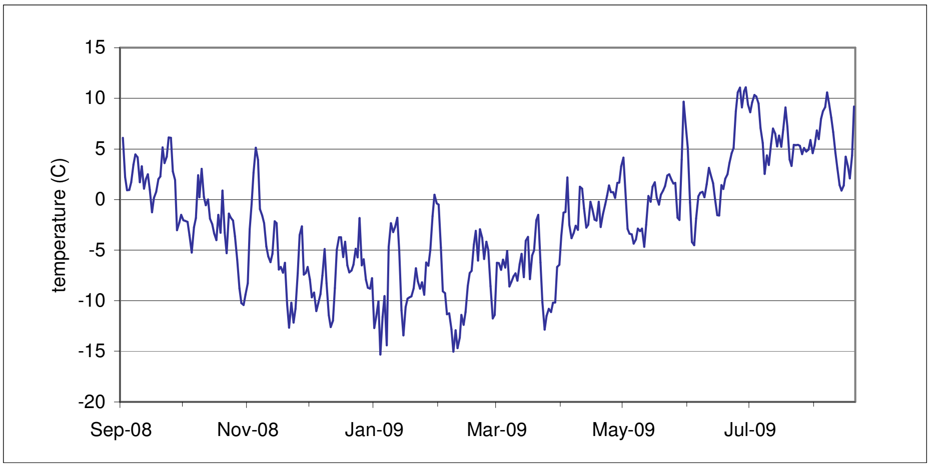


Figure 7-5
The AWS at Storbreen on 12th May 2009 (to the left) and 5th August 2009 (to the right). The snow depth at the AWS was 2.8 m in May and all the snow had melted by August. Photos: Liss M. Andreassen.

Temperature, wind and shortwave radiation

Mean daily temperature, wind speed and shortwave incoming and outgoing radiation for the period 1st September 2008 to 20th August are shown in Figures 7-6 and 7-7. Mean daily temperature varied between −15.3 (4th Jan) and 11.1 °C (29th June), the mean being −2.1 °C. The mean wind speed was 3.8 m/s, and daily mean values varied between 0.77 and 9.9 m/s. The shortwave incoming and outgoing radiation show the typical annual cycle in shortwave radiation, but also large variability from day to day (Fig. 7-7). Comparing incoming shortwave radiation with top of atmosphere (TOA) radiation indicates higher transmissivity and thus more clear-sky weather in spring and early summer than late summer. Calculation of albedo, α, by diving shortwave outgoing with incoming radiation, indicates that the glacier surface at the AWS location became snow free on 31st July.



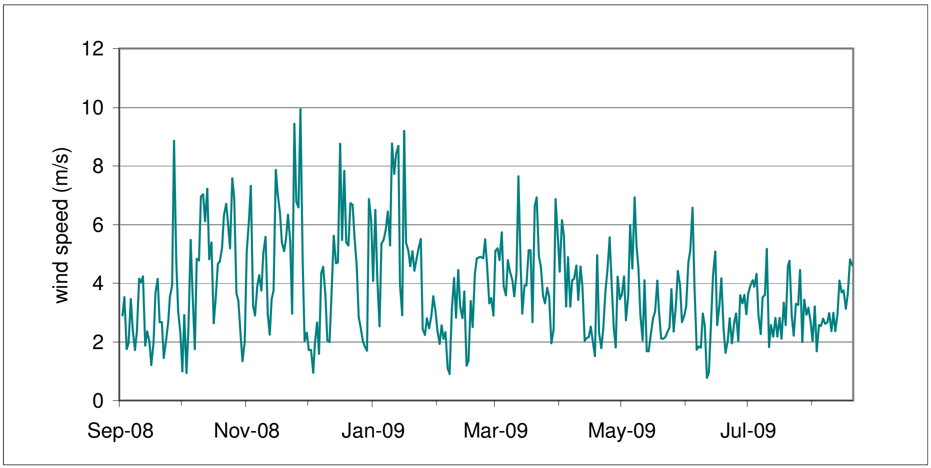


Figure 7-6
Daily mean temperature in degrees Celsius (upper figure) and wind speed (lower figure) at Storbreen AWS from 1st September 2008 to 20th August 2009.

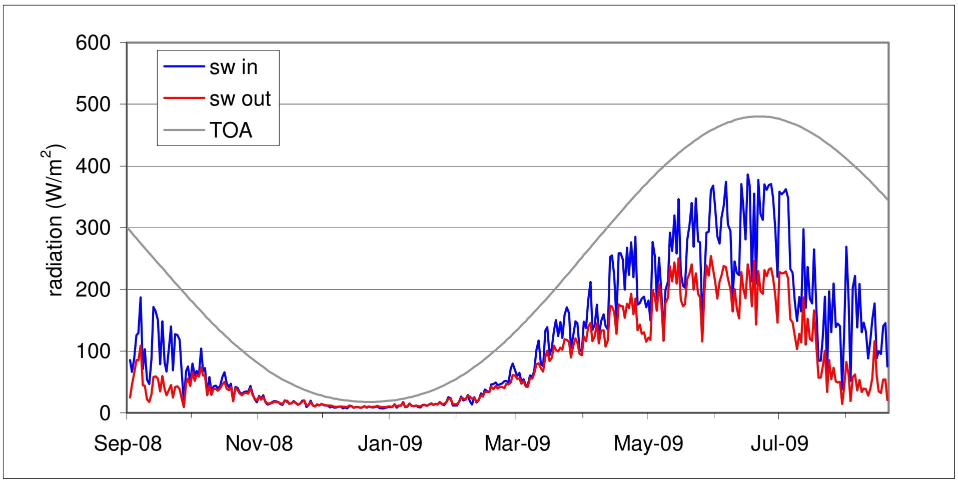


Figure 7-7
Daily mean incoming (sw in) and outgoing (sw out) shortwave radiation and top of atmosphere (TOA) radiation at Storbreen AWS from 1st September 2008 to 20th August 2009.

8. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen. The glacier shares border with vestre Memurubre glacier. Aerial photos (Fig. 8-1) and a new laser digital terrain model (DTM) for the glacier were acquired in 2009. The new DTM reveals that Hellstugubreen ranges in elevation from 1482 to 2229 m a.s.l. and has an area of 2.9 km^2 (reduced by 0.1 km^2 since 1997). The glacier terminus has retreated about 100 m from 1997 to 2009. Annual mass balance measurements began in 1962 and 2009 was the 48th year of continuous measurements at Hellstugubreen.

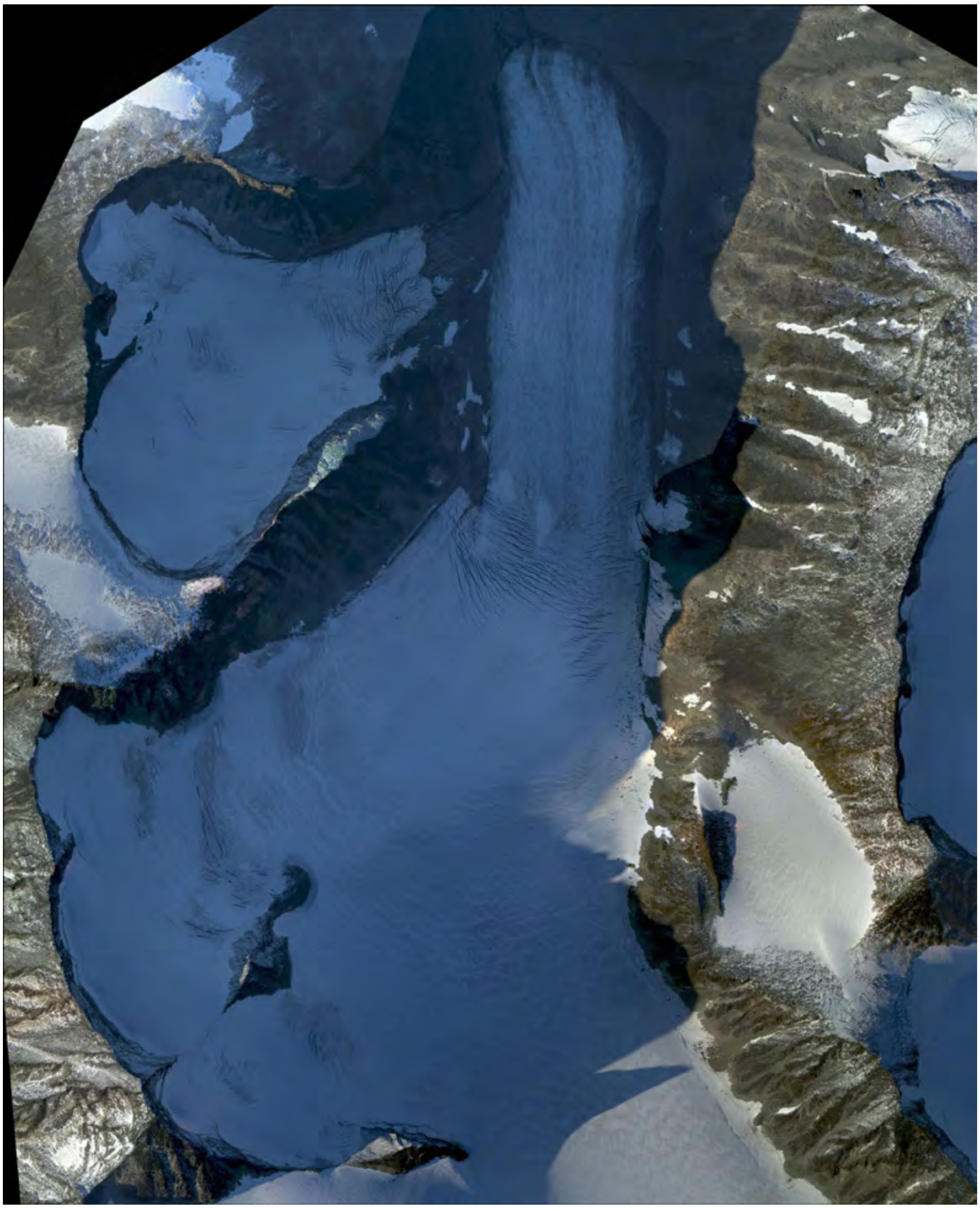


Figure 8-1
Orthophoto (orthorectified aerial photograph) of Hellststugubreen taken on 14th September 2009. The orthophoto was produced by Blom Geomatics AS.

8.1 Mass balance 2009

Fieldwork

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

- Measurements of stakes in 10 different positions. Stake readings indicated that at the lowest stake location only (stake 4, 1533 m a.s.l.) there had been additional melting after the ablation measurements on 18th September 2008.
- Soundings of snow depth in 105 positions between 1533 and 2126 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 1.11 and 4.54 m, the mean being 2.7 m.
- The snow density was measured by sampling in a pit at 1960 m a.s.l. where the total snow depth was 2.8 m.

Ablation measurements were carried out on 16th September at all visible stakes (Fig. 8-2). The location of stakes, density pit and sounding profiles are shown in Figure 8-3.

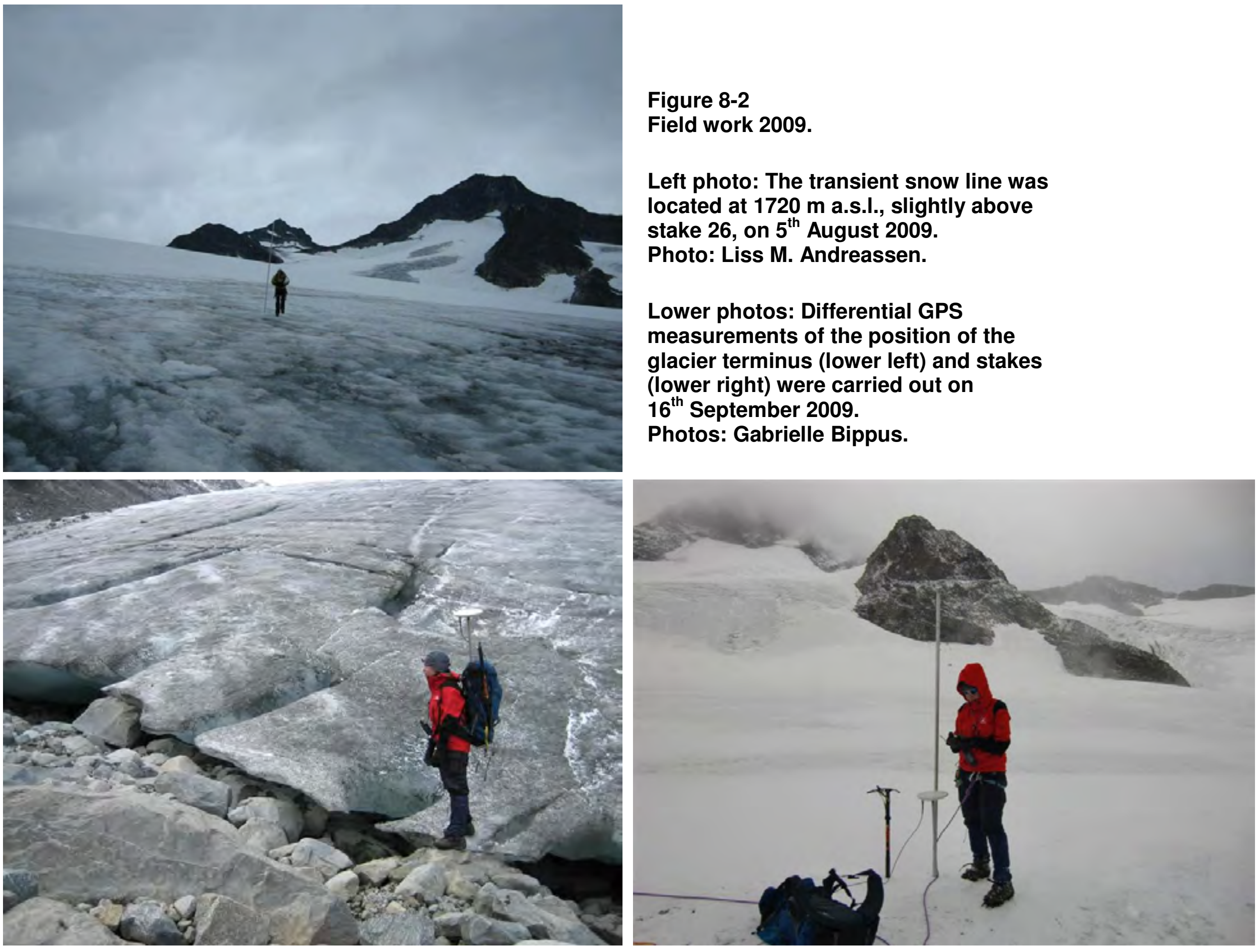


Figure 8-2
Field work 2009.

Left photo: The transient snow line was located at 1720 m a.s.l., slightly above stake 26, on 5th August 2009. Photo: Liss M. Andreassen.

Lower photos: Differential GPS measurements of the position of the glacier terminus (lower left) and stakes (lower right) were carried out on 16th September 2009. Photos: Gabrielle Bippus.

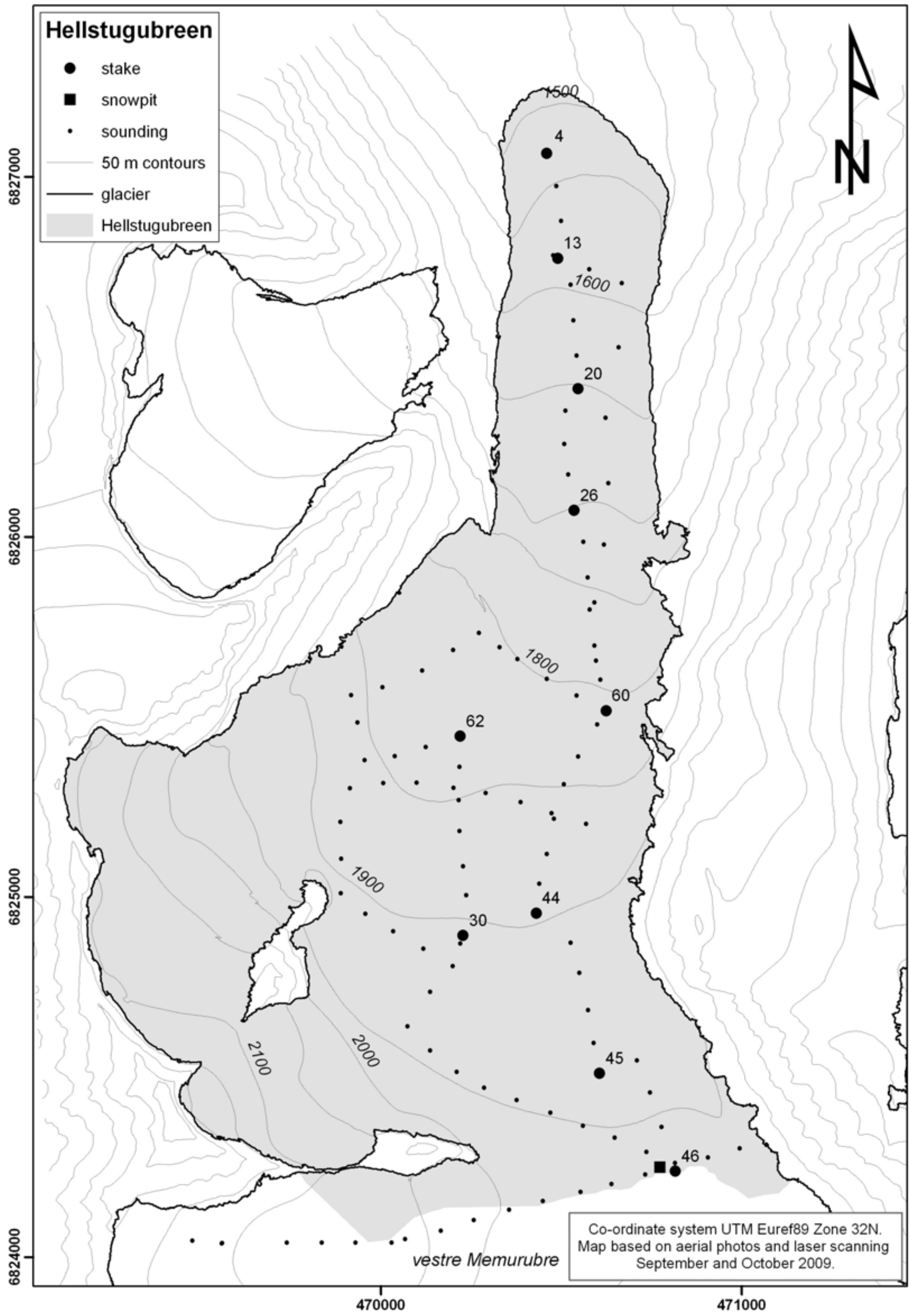


Figure 8-3
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2009. The glacier outline was derived from aerial photography taken on 14th September 2009 and the glacier surface map is derived from laser scanning carried out on 17th October.

Results

The mass balance results of 2009 are presented in Table 8-1 and Figure 8-4.

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 440 kg/m^3. The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.3 ±0.2 m w.e. This is 113 % of the mean for the period 1971-2000.

Summer balance

Direct summer balance was calculated from stakes in 6 locations. The density of the melted ice was assumed to be 900 kg/m^3 and the density of remaining snow to be 600 kg/m^3. The summer balance was calculated to be –1.53 ±0.3 m w.e., which is 107 % of the mean value for the period 1971-2000.

Net balance

The net balance of Hellstugubreen in 2009 was slightly negative, –0.23 ±0.3 m w.e., which amounts to a volume loss of –0.68 ±0.9 mill. m^3 water. The equilibrium line altitude (ELA) (calculated from Figure 8-4) was 1920 m a.s.l. resulting in an accumulation area ratio (AAR) of 42 %. The cumulative net balance since 1962 is –17.7 m w.e., giving a mean annual deficit of 0.37 m w.e. per year (Fig. 8-5). The calculated annual net balance for Hellstugubreen has been negative every year since 2001. The cumulative deficit amounts to 7.4 m w.e. for the period 2001-2009.

Mass balance Hellstugubreen 2008/09 – traditional method

		Winter balance Measured 12th May 2009		Summer balance Measured 16th Sep 2009		Net balance Summer surfaces 2008 - 2009	
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 - 2229	0.02	1.60	0.03	-0.30	-0.01	1.30	0.03
2100 - 2150	0.08	1.44	0.12	-0.50	-0.04	0.94	0.08
2050 - 2150	0.29	1.73	0.50	-0.60	-0.17	1.13	0.33
2000 - 2050	0.18	1.65	0.30	-0.92	-0.17	0.73	0.13
1950 - 2000	0.31	1.42	0.44	-1.18	-0.36	0.24	0.07
1900 - 1950	0.60	1.38	0.83	-1.35	-0.81	0.03	0.02
1850 - 1900	0.37	1.26	0.47	-1.50	-0.56	-0.24	-0.09
1800 - 1850	0.33	1.20	0.40	-1.70	-0.56	-0.50	-0.16
1750 - 1800	0.16	0.99	0.16	-1.90	-0.30	-0.91	-0.14
1700 - 1750	0.09	1.25	0.11	-2.05	-0.18	-0.80	-0.07
1650 - 1700	0.14	0.98	0.14	-2.25	-0.31	-1.27	-0.18
1600 - 1650	0.11	1.17	0.13	-2.60	-0.30	-1.43	-0.16
1550 - 1600	0.12	0.76	0.09	-3.00	-0.37	-2.24	-0.28
1500 - 1550	0.08	0.64	0.05	-3.25	-0.27	-2.61	-0.22
1482 - 1500	0.01	0.50	0.01	-3.40	-0.04	-2.90	-0.03
1482 - 2229	**2.90**	**1.30**	**3.78**	**-1.53**	**-4.46**	**-0.23**	**-0.68**

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2009.

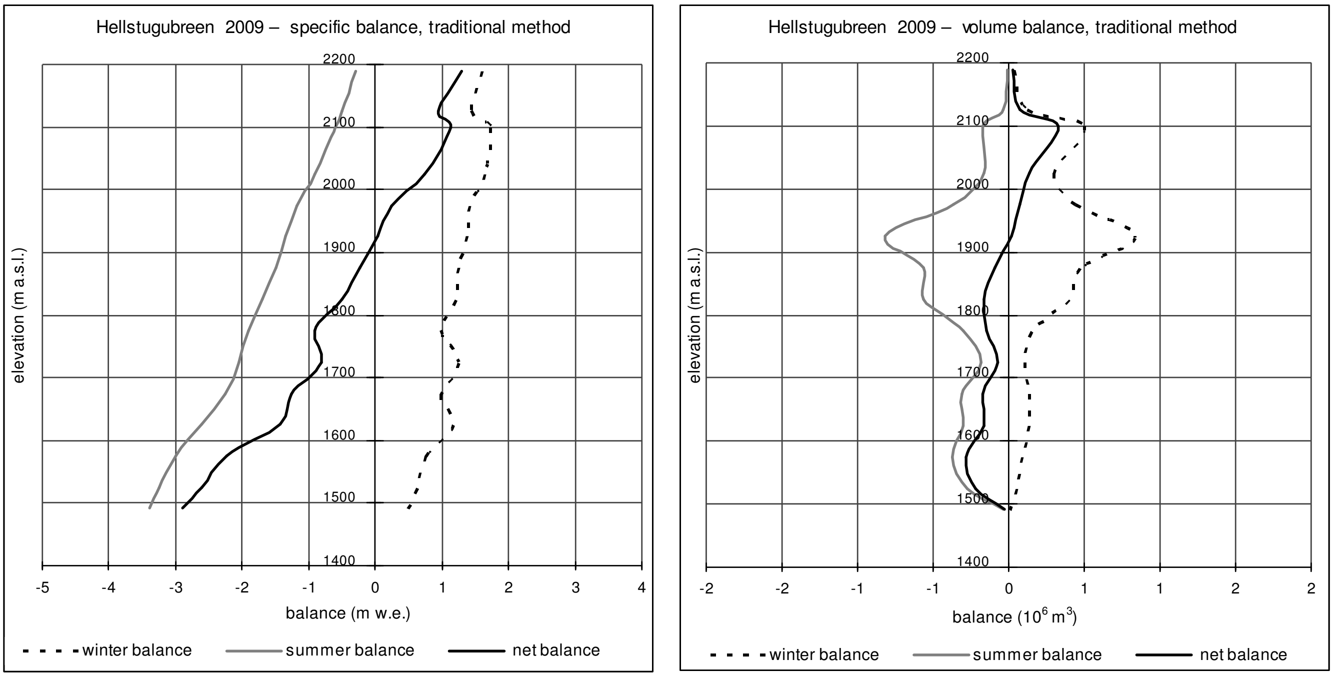


Figure 8-4
Mass balance diagram for Hellstugubreen in 2009, showing specific balance on the left and volume balance on the right.

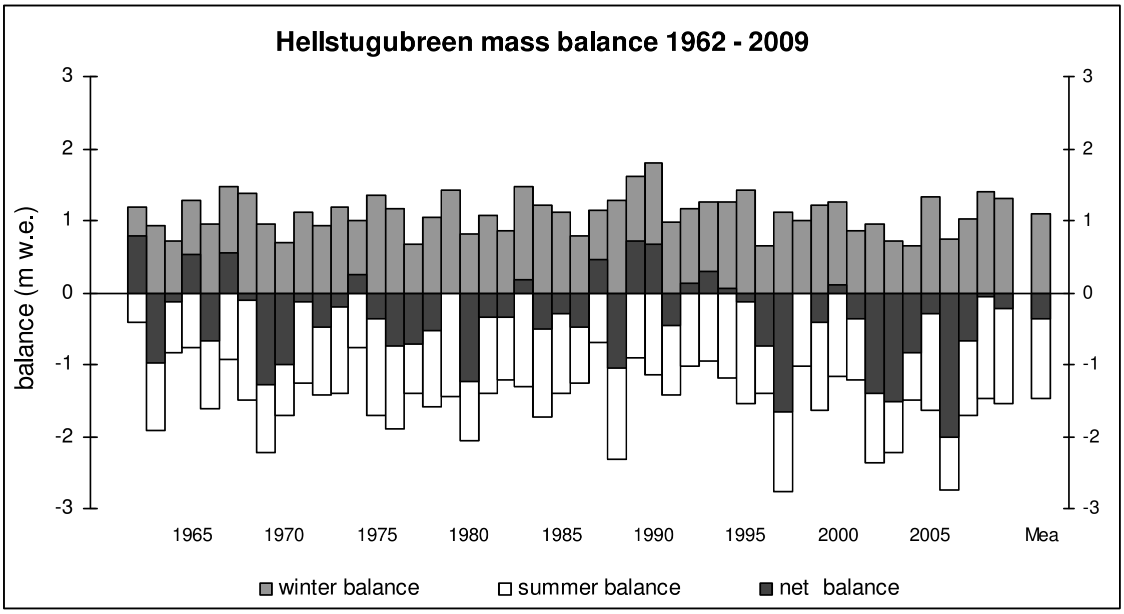


Figure 8-5
Winter, summer and net balance at Hellstugubreen for the period 1962-2009.

9. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is a small, polythermal glacier located in the eastern part of the Jotunheimen mountain area in southern Norway. Superimposed ice occurs in the central parts of the glacier where snowdrift causes a relatively thin snow pack. Mass balance investigations have been carried out annually since 1962 and 2009 was the 48th year of continuous measurements.

In 2009 the glacier surface was measured by laser scanning on 17th October to construct a new high resolution digital terrain model (DTM) of the glacier. A new glacier outline was constructed from orthophotos made from aerial photographs taken of the glacier on 14th September 2009 (Fig. 9-1). The new DTM and glacier outline have been used to calculate a new area-altitude distribution of the glacier which is used as basis for the mass balance calculations for 2009. The new mapping shows that the glacier presently covers an area of 2.12 km^2 and ranges in elevation from 1833 to 2283 m a.s.l. (Fig. 9-2). In 1997, the glacier had an area of 2.25 km^2 and the elevation range was 1830-2290 m a.s.l.

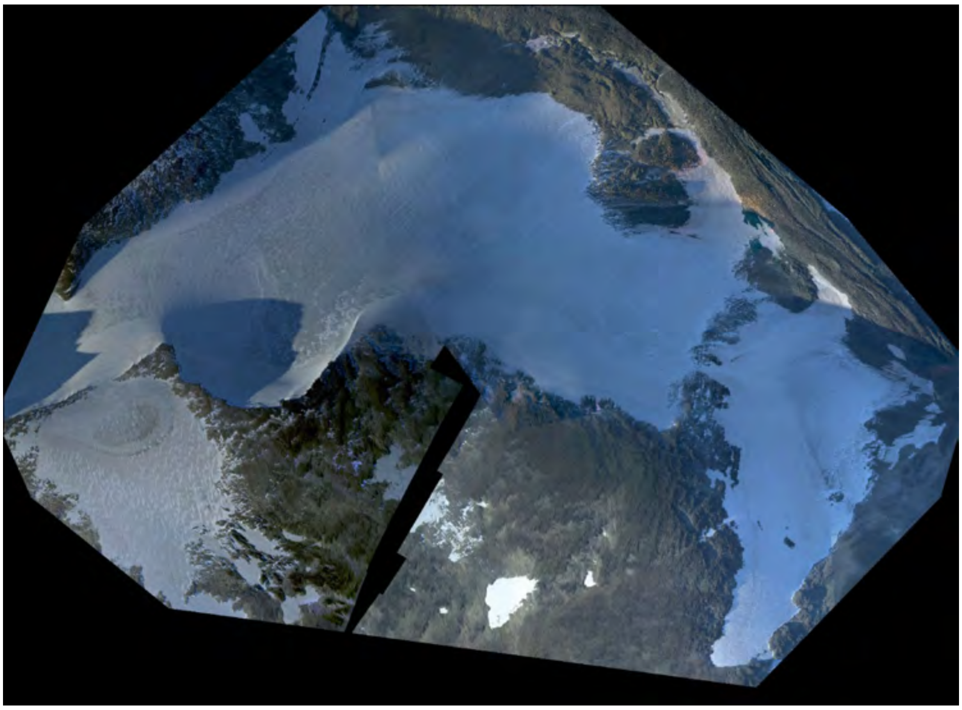


Figure 9-1
Orthophoto (orthorectified aerial photograph) of Gråsubreen taken on 14th September 2009. The orthophoto was produced by Blom Geomatics AS.

9.1 Mass balance 2009

Fieldwork

Accumulation measurements were performed on 15th and 16th June 2009. The calculation of winter balance is based on:

- Measurements of stakes in 13 different positions.

- Soundings of snow depth in 104 positions between 1838 and 2243 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 0.48 and 3.23 m, the mean snow depth was 1.90 m.
- The snow density was measured by sampling in a pit near stake 8 (elevation 2144 m a.s.l.) where the total snow depth was 1.7 m.

Ablation measurements were carried out on 14th and 15th September, when stakes in all locations were measured. A thin layer of 5-10 cm of fresh snow covered most of the glacier at the time of the ablation measurements (Fig. 9-1, Fig. 9-3).

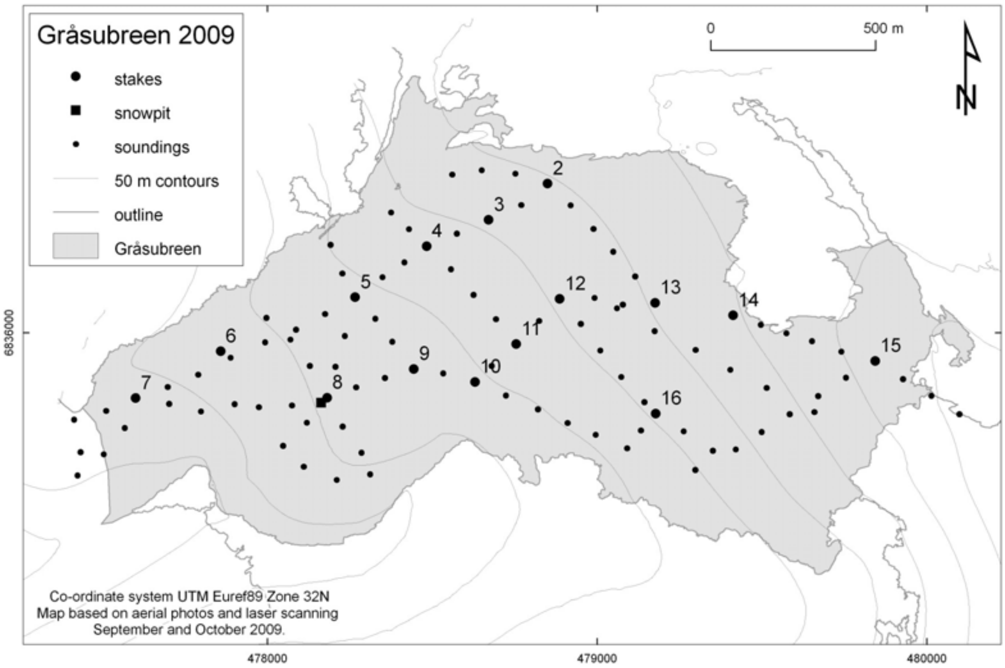


Figure 9-2
Map of Gråsubreen (shaded in grey) showing the location of stakes, snowpit and soundings in 2009.

Figure 9-3
Ablation measurements on stake 5 on 15th September 2009.
Photo: Gabrielle Bippus.

Results

The mass balance results are presented in Table 9-1 and Figure 9-4.

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 410 kg/m^3. The stake recordings showed neither significant additional melting nor any significant formation of superimposed ice after the previous year's ablation measurements (on 16th September 2008).

The winter balance was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter balance of 0.81 ±0.2 m w.e., which is 103 % of the mean winter balance for the period 1971-2000.

Summer balance

Summer balance was calculated from direct measurements of stakes in twelve locations. There was no remaining snow at any of the stakes at ablation measurements in 2009. The density of melted firn was estimated to be 700 kg/m^3 and melted ice was estimated to be 900 kg/m^3. The resulting summer balance was −1.08 ±0.3 m w.e. The specific summer balance is 101% of the mean for the period 1971-2000.

Net balance

The net balance of Gråsubreen was negative in 2009, −0.28 ±0.3 m w.e. The equilibrium line altitude (ELA) was estimated to be 2235 m a.s.l. and the resulting accumulation area ratio (AAR) was 7 %.

The cumulative mass balance of Gråsubreen amounts to −16.4 m w.e. since measurements began in 1962. Of the total 48 years of measurements, 34 had a negative mass balance (Fig. 9-5). The average annual balance is thus −0.35 m w.e. per year. Since 2001 the glacier has had a cumulative balance of −6.7 m w.e.

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2009.

Mass balance Gråsubreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 15 Jun 2009 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 15 Sep 2009 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2008 - 2009 Specific (m w.e.)	Net balance Volume (10^6 m^3)
2250 - 2283	0.03	0.70	0.02	-0.52	-0.02	0.18	0.01
2200 - 2250	0.15	0.66	0.10	-0.70	-0.11	-0.04	-0.01
2150 - 2200	0.26	0.84	0.21	-0.90	-0.23	-0.06	-0.02
2100 - 2150	0.35	0.57	0.20	-0.98	-0.35	-0.41	-0.14
2050 - 2100	0.36	0.71	0.26	-1.22	-0.44	-0.51	-0.19
2000 - 2050	0.41	0.81	0.33	-1.15	-0.47	-0.34	-0.14
1950 - 2000	0.32	0.98	0.32	-1.15	-0.37	-0.17	-0.05
1900 - 1950	0.13	1.09	0.14	-1.26	-0.16	-0.17	-0.02
1833 - 1900	0.11	1.15	0.13	-1.40	-0.16	-0.25	-0.03
1833 - 2283	**2.12**	**0.81**	**1.71**	**-1.08**	**-2.29**	**-0.28**	**-0.59**

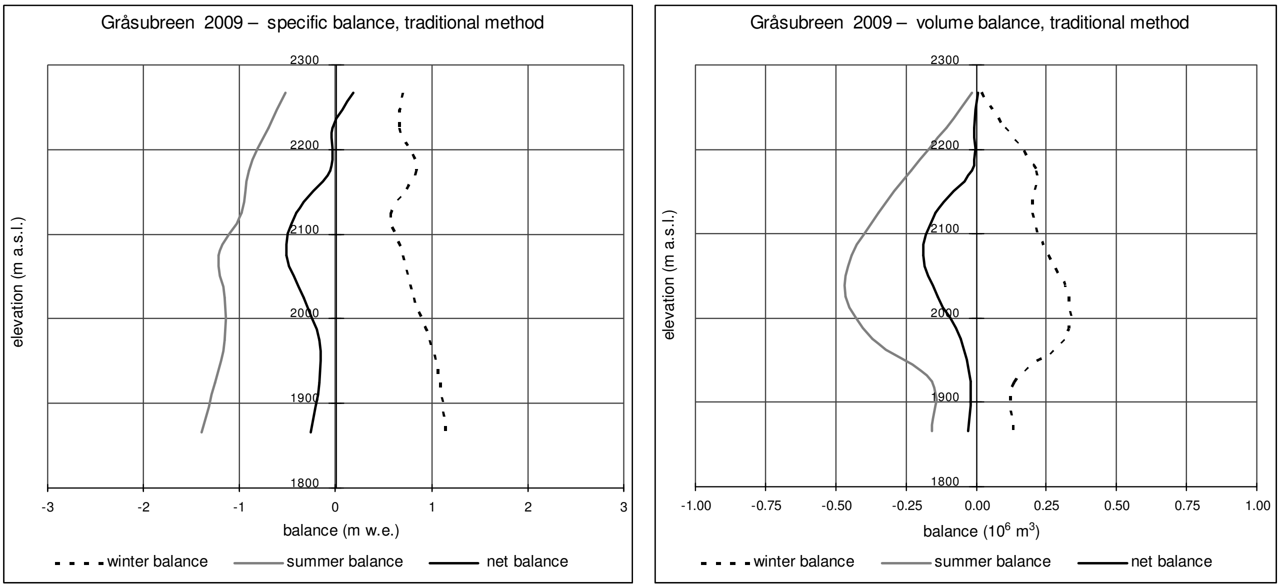


Figure 9-4
Mass balance diagram for Gråsubreen in 2009, showing specific balance on the left and volume balance on the right.

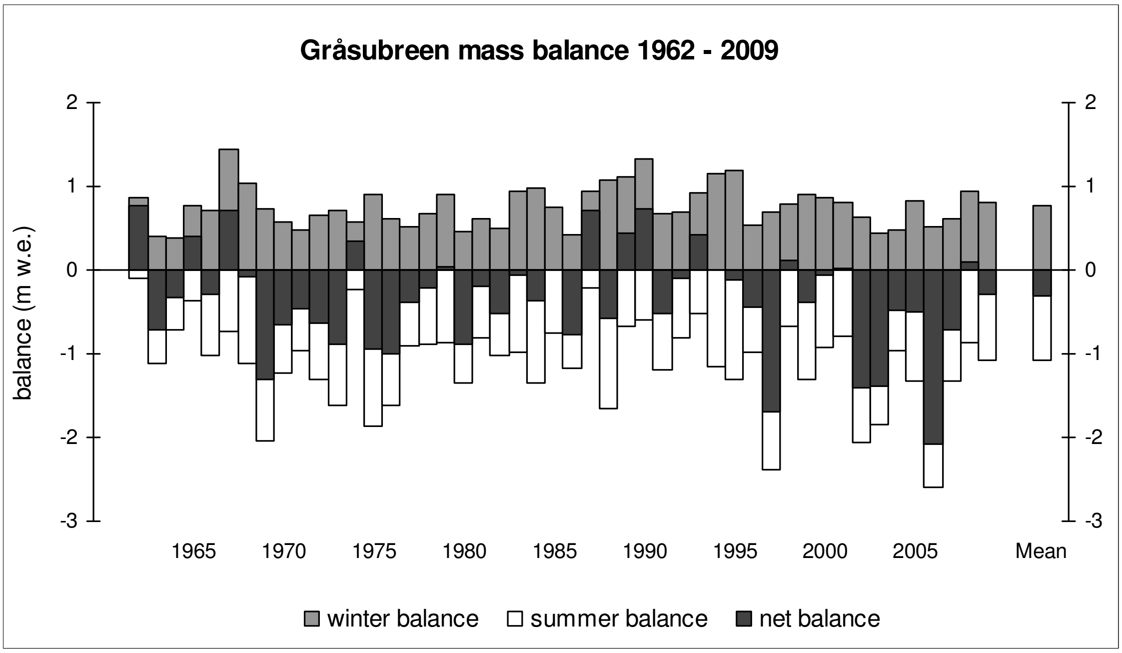


Figure 9-5
Winter, summer and net balance at Gråsubreen during the period 1962-2009.

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). A meteorological station has been operated at the nunatak Skjæret (1364 m a.s.l.) since 1995 (chap. 10-2).

Data from pressure sensor records from the Svartisen Subglacial Laboratory under Engabreen are presented in chapter 10-3. Results from other research performed at the subglacial laboratory in 2009 will be published elsewhere. A workshop on subglacial processes took place at the subglacial laboratory in March 2009 and was well attended by 29 researchers from ten countries.

Figure 10-1
Engabreen on 4th August 2009. The entrance to Svartisen Subglacial Laboratory is located at 520 m a.s.l. east of the glacier tongue (white circle). Photo: Hallgeir Elvehøy.

10.1 Mass balance 2009

Fieldwork

The glacier was visited on 25th March. Stakes in positions E105 and E101 were measured. The snow depth at the stakes was 6.5 metres.

The locations of stakes and towers, the density pit and the sounding profile are shown in Figure 10-2. The calculation of the winter balance is based on the following measurements on 14th May:

- Direct measurement of snow depth at locations E105 (7.55 m) and E101 (7.0 m).
- Snow depth from coring at stake E38, showing 6.1 m of snow.

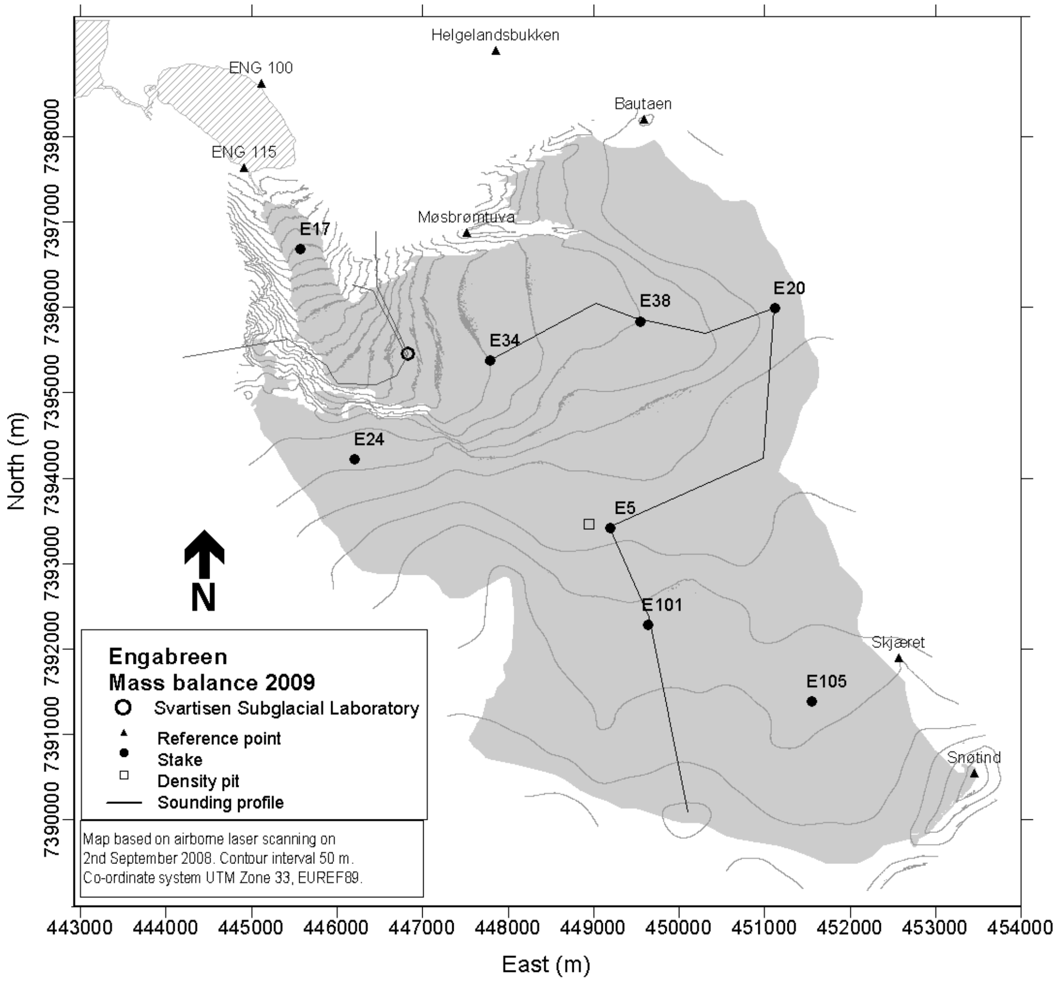


Figure 10-2
Location of stakes, density pit and sounding profiles on Engabreen in 2009. The tunnel system under Engabreen and the location of Svartisen Subglacial Laboratory is shown.

- Snow depth sounding at 51 locations on an 11 km long profile. The snow depth was between 7 and 8 m above 1300 m a.s.l., and mainly between 5 and 7 m between 1000 and 1300 m a.s.l. Around stake E34 the snow depth was about 4 metres.
- Direct measurement of 1.25 m of ice melt at location E17 between 3rd October 2008 and 14th May 2009.
- Snow density measured down to the summer surface (SS) at 6.2 m depth at stake E5. The mean snow density was 480 kg/m^3.

The stake in position E17 at the tongue melted out near the end of July, and was replaced on 4th August. More than 6 m of ice melted before 4th August, and 3.8 m ice melted between 4th August and 20th October. At the plateau, between 2.8 and 4.1 m of snow melted between 14th May and 4th August. After 4th August up to 2.3 m snow melted before the winter snow accumulation started.

The net and summer balance measurements were carried out on 20th October. There was up to 1.6 m of new snow on the glacier plateau. Nine stakes were found in eight locations (E17, E34, E38, E20, E24, E5, E101 and E105). From stake measurements the TSL altitude was between 960 and 1050 m a.s.l. At stake E34 all the snow and 1.35 m of ice had melted during the summer. At the stakes above the TSL up to 2.75 m of snow remained.

Results

The mass balance is calculated using the stratigraphic method, which reports the balance between two successive "summer surfaces", excluding snow accumulation before the date of net balance measurements but also excluding ablation after net balance measurements. The mass balance calculations are based on a map from 2008.

Winter balance

The temperature record at Skjæret (see Fig. 10-2 for location) shows that the air temperature on the glacier plateau was at or below zero after 25th September 2008. This implies that no significant late autumn melting occurred.

The calculation of the winter balance was based on point measurements of snow depth (stake readings, coring and snow depth soundings) and on snow density measurements. A water equivalent profile was modelled from the snow density measured at stake E5 (1230 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. 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 2.9 ±0.2 m w.e., which corresponds to a volume of 111 ±8 mill. m^3 of water. This is 94 % of the mean value for the normal period 1971-2000 (3.04 m w.e.), but 101 % of the mean value for the 5-year period 2004-2008 (2.85 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 E34, E38, E20, E24 and E5. At location E17 some of the summer melting had to be estimated. An altitudinal distribution curve was drawn based on the calculated summer balance in eight locations between 300 and 1340 m a.s.l. (Fig. 10-3). The summer balance was calculated as −2.9 ±0.2 m w.e., which equals a volume of −112 ±8 mill. m^3 water. This is 131 % of the average for the normal period 1971-2000 (−2.22 m w.e.), but 117 % of the average for the 5-year period 2004-2008 (−2.48 m w.e.).

Net balance

The net balance of Engabreen for 2009 was calculated as 0.0 ±0.3 m w.e., which means the glacier mass was unchanged in 2009. The mean value for the normal period 1971-2000 is +0.82 m w.e., and +0.37 m w.e. for 2004-2008. The equilibrium line altitude (ELA) was determined as 1170 m a.s.l. from the net balance curve in Figure 10-3. This corresponds to an accumulation area ratio (AAR) of 63 %. The mass balance results are shown in Figure 10-3 and Table 10-1. The results from 2009 are compared with mass balance results for the period 1970-2008 in Figure 10-4.

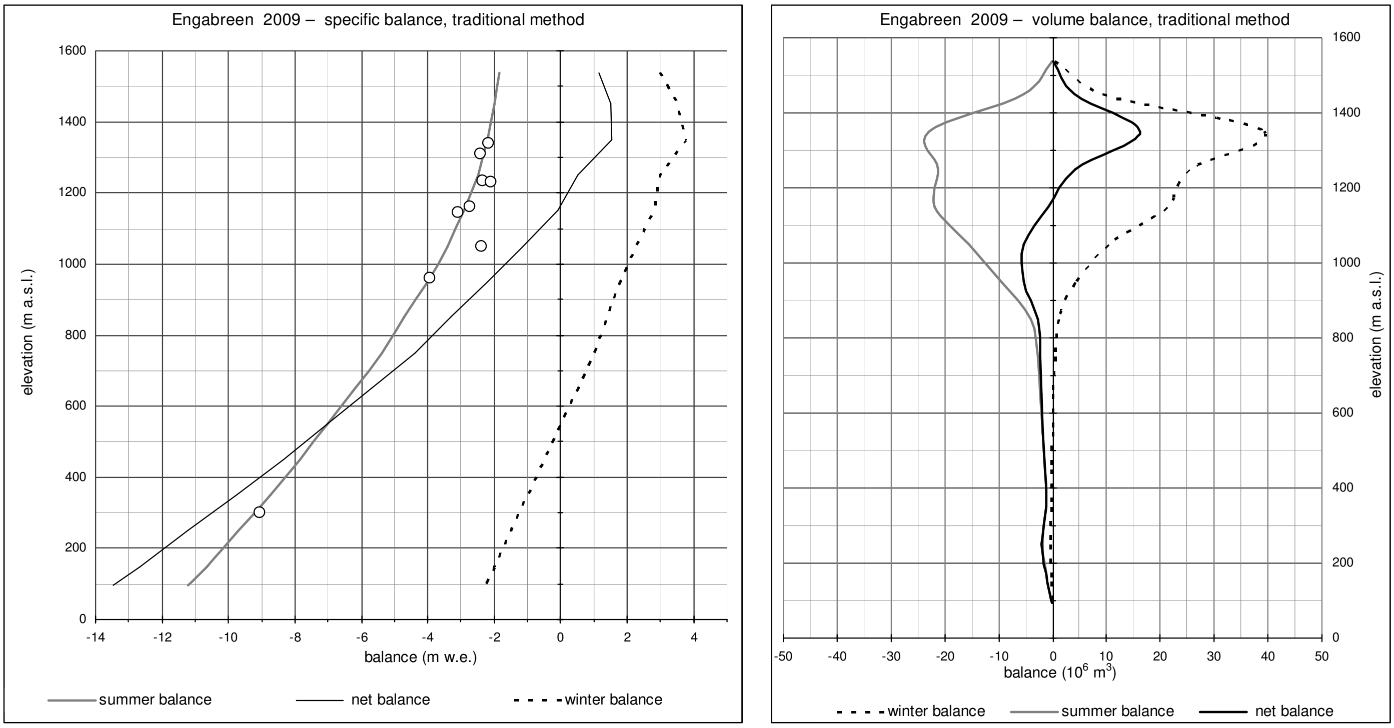


Figure 10-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2009. Summer balance at stake locations is shown as circles (○).

Table 10-1
Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2009.

Mass balance Engabreen 2008/09 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 14th May 2009		Summer balance Measured 20th Oct 2009		Net balance Summer surface 2008 - 2009	
		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)
1500 - 1574	0.10	3.00	0.3	-1.85	-0.2	1.15	0.1
1400 - 1500	2.65	3.50	9.3	-2.00	-5.3	1.50	4.0
1300 - 1400	10.49	3.75	39.3	-2.20	-23.1	1.55	16.3
1200 - 1300	8.46	3.00	25.4	-2.50	-21.1	0.50	4.2
1100 - 1200	7.56	2.80	21.2	-2.90	-21.9	-0.10	-0.8
1000 - 1100	4.57	2.25	10.3	-3.40	-15.5	-1.15	-5.3
900 - 1000	2.38	1.80	4.3	-4.00	-9.5	-2.20	-5.2
800 - 900	0.84	1.40	1.2	-4.70	-3.9	-3.30	-2.8
700 - 800	0.51	1.00	0.5	-5.40	-2.7	-4.40	-2.2
600 - 700	0.35	0.50	0.2	-6.20	-2.2	-5.70	-2.0
500 - 600	0.26	0.00	0.0	-7.00	-1.8	-7.00	-1.8
400 - 500	0.17	-0.50	-0.1	-7.85	-1.4	-8.35	-1.4
300 - 400	0.13	-1.00	-0.1	-8.75	-1.1	-9.75	-1.2
200 - 300	0.18	-1.50	-0.3	-9.70	-1.7	-11.20	-2.0
100 - 200	0.086	-2.00	-0.2	-10.65	-0.9	-12.65	-1.1
89 - 100	0.001	-2.27	0.0	-11.20	0.0	-13.47	0.0
89 - 1574	**38.74**	**2.87**	**111.2**	**-2.90**	**-112.5**	**-0.03**	**-1.3**

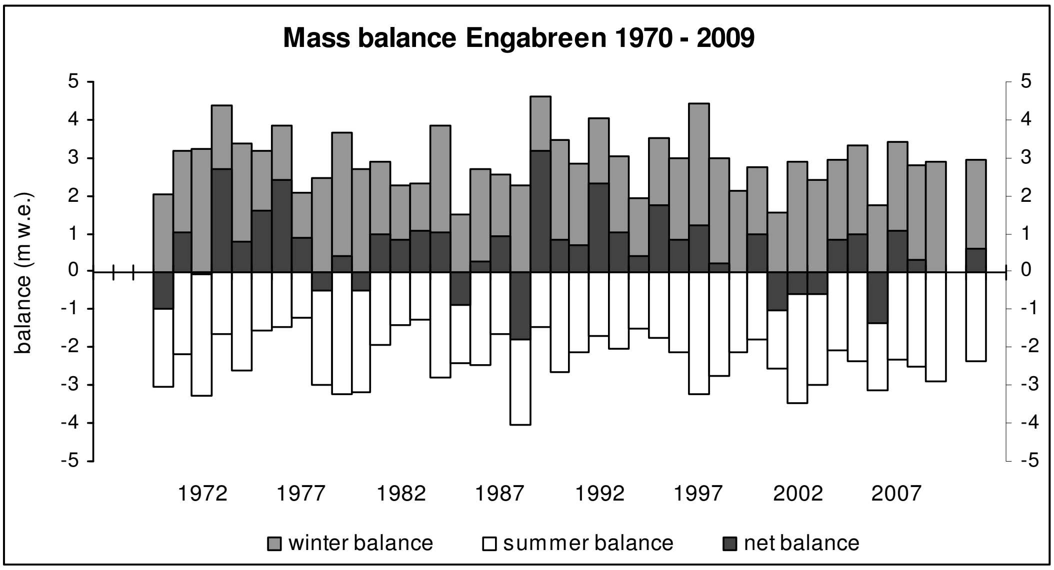


Figure 10-4
Mass balance at Engabreen during the period 1970-2009. The average winter and summer balances are b_w =2.93 m w.e. and b_s =–2.35 m w.e.

10.2 Meteorological observations

A meteorological station recording air temperature, global radiation, relative humidity and wind speed and direction at 3 metre level is located on the nunatak Skjæret (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig. 10-2). 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. The precipitation station 80740 Reipå (9 m a.s.l.) has been operated by the Norwegian Meteorological Institute (DNMI) since 1995. In July 2009 the station was upgraded to a full meteorological station. This station is located 28 km north of Engabreen and 19 km north-west of Glomfjord.

In 2009, there was a gap in the data record between 6th and 25th January. This gap has been filled using temperature measured in Glomfjord and the mean temperature lapse rate between Glomfjord and Skjæret (−0.73 °C/100m) (Fig. 10-5). When the autumn measurements were carried out on 3rd October 2008 up to 1.6 metres of snow had accumulated on the glacier plateau. The air temperature was mainly close to or above freezing until 26th September. Very little melting seems to have occurred on the plateau after this date. The coldest period this winter was around 7th February when the daily mean temperature was −16.2 °C. The first period in spring with daily temperatures above 0 °C was 30th April to 2nd May. The temperature was then below 0 °C until 14th May when snow measurements were performed. The warm period from 14th to 20th May marks the end of the winter accumulation season. Except for cold periods between 14th and 17th June, 17th and 18th July, 15th and 19th August and 16th to 17th September, the air temperature was at or above 0 °C between 9th June and 22nd September. The maximum daily temperature was measured on 26th June and 7th August (11.9 °C). At Skjæret, the summer mean temperature (1st June – 30th September) was 3.1 °C which is 1.0 °C lower than in the warm summers of 2002 and 2006, but 0.4 °C higher than in 2007 and 2008.

In Glomfjord the mean annual temperature in 2009 was 6.0 °C, which is 1.0 °C above the 1961-90 average. The summer temperature in Glomfjord (1st June – 30th September, 12.3 °C) was 1.2 °C higher than the 1961-90 average.

At the meteorological station 80740 Reipå (9 m a.s.l) the recorded winter precipitation (1st October – 31st May) in 2009 was 859 mm, which is similar to 2004 and 2008. 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 to 2002 indicates that Reipå gets 67 % of the winter precipitation in Glomfjord. This suggests that the winter precipitation in Glomfjord in 2009 was about 1300 mm which is approximately 87 % of the 1971-2000 average. The winter balance at Engabreen was 94 % of the 1971-2000 average.

The subglacial river discharge under Engabreen at Svartisen Subglacial Laboratory is shown in figure 10-5 (Figure 10-2 for location). The discharge peak on 3rd – 4th August is caused by high temperatures, while the four discharge peaks in September are related to peaks in precipitation.

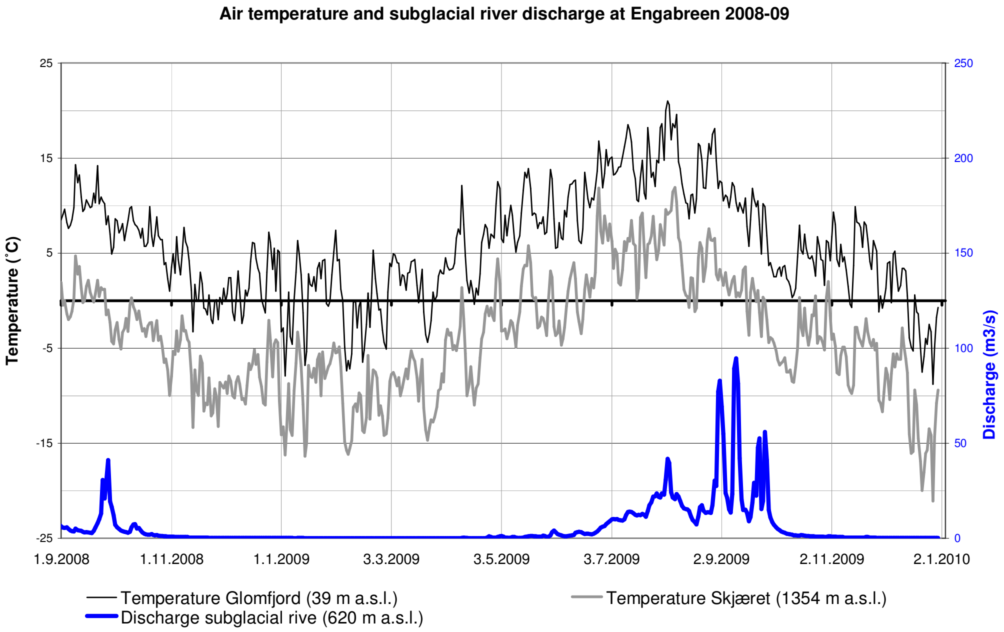


Figure 10-5
Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700), and discharge in the subglacial river intake beneath Engabreen between 1st September 2008 and 31st December 2009.

10.3 Svartisen Subglacial Laboratory

Svartisen Subglacial Laboratory is a unique facility situated under Engabreen. Laboratory buildings and research shaft are about 1.5 km along a tunnel that is part of a large hydropower development (Fig 10-6). At the research shaft there is direct access to the bed of the glacier for the purposes of measuring subglacial 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).

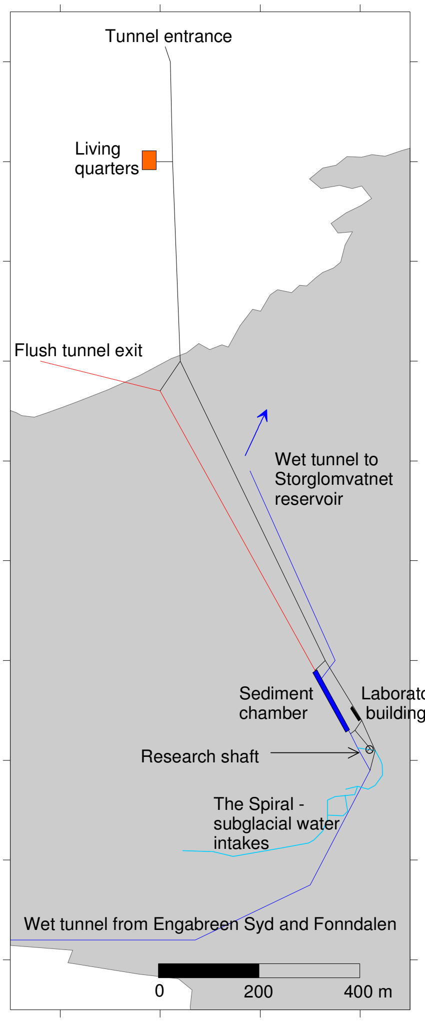


Figure 10-6
Map of tunnel system under Engabreen, showing research shaft and other facilities.

Pressure measurements

Six load cells were installed at the bed of the glacier next to the research shaft in December 1992 in order to measure variations in subglacial pressure (Fig 10-7). 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). Two new loads cells were installed in November 1997. Of these eight load cells, six of them are still recording, although two of them (1e and 97-1) record somewhat intermittently. Note that the graphs of load cell pressure have different axes.

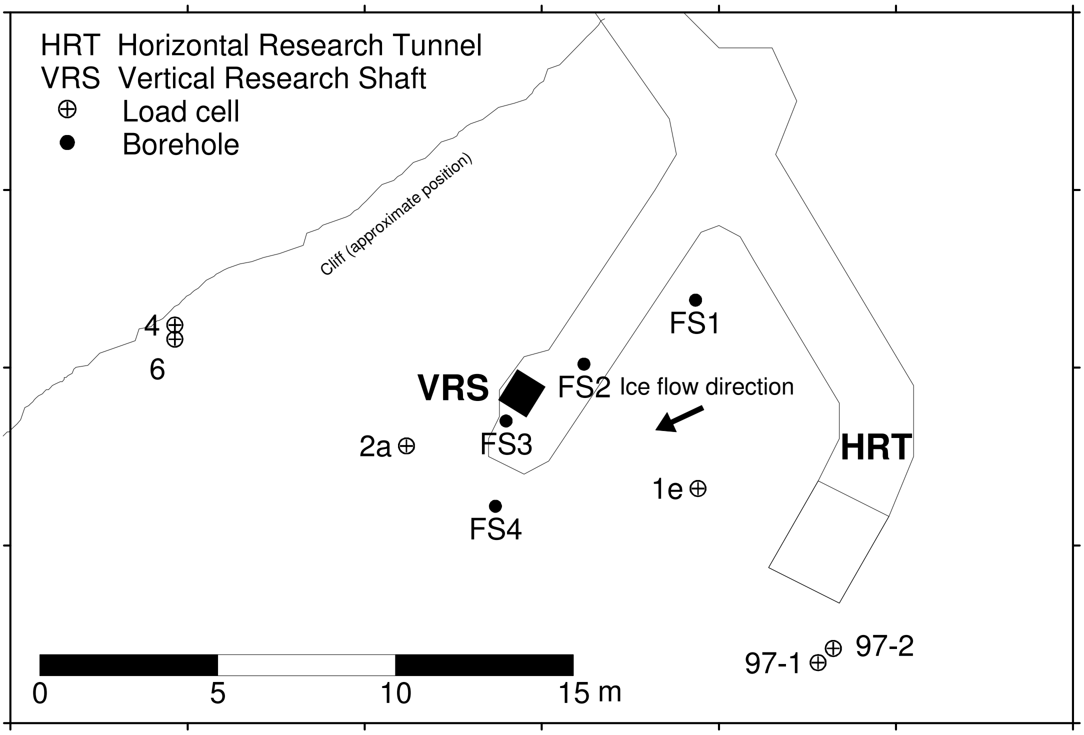


Figure 10-7
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 97-1 and 97-2 and boreholes, marked FS.

Pressure sensor records for winter 2009 from 5th February to 31st March are shown in Figure 10-8. Data are missing for the first 5 weeks of 2009 due to datalogger malfunction. Data are shown in two figures - for all six load cells, and also for load cells 4 and 6 only, as these load cells are not as exposed with ensuing noisy records as the others and are generally a more reliable indicator of when significant changes are occurring at the glacier base. Records for load cells 4 and 6 are generally typical for the winter period - relatively quiet and stable, corresponding with very low discharge measured in the subglacial tunnel. There are two distinct events in March, on days 61 and 72 which correspond with increases in the subglacial discharge. The absolute values of subglacial discharge are small and not discernible in Figure 10-5, but mark the first increases in discharge after the very low flow of the winter. A large precipitation event in the second half of March caused an even greater increase in discharge, but was apparently not registered at the glacier bed. However, during this time there was research activity in the laboratory and the ice tunnel was melted out several times, thus explaining the somewhat noisier records in mid- to late-March.

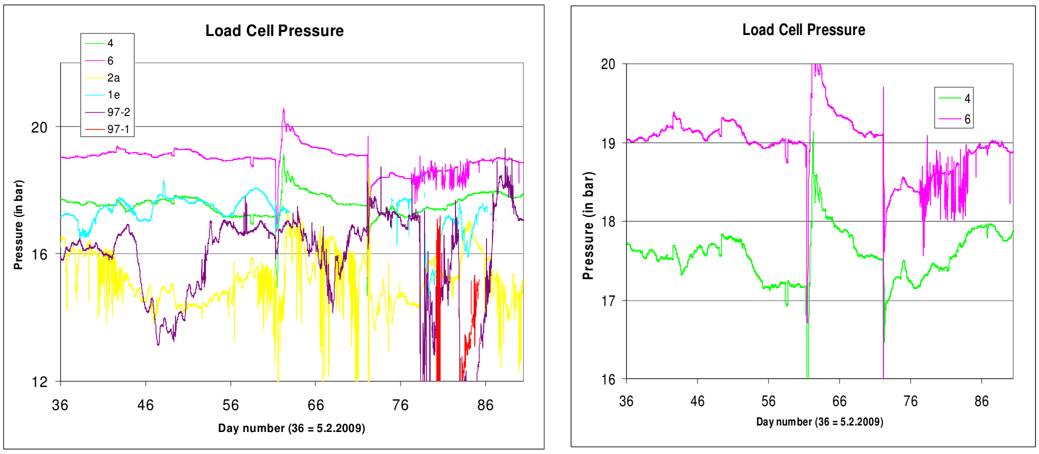


Figure 10-8
Pressure records for 5th February to 31st March.

Pressure sensor records for the late-spring and early- summer, from 1st April to 30th June, are shown in Figure 10-9. Load cells 4 and 6 show typical records for this period in terms of level and amount of activity. Load cell 6 has consistently higher values than 4, as is usual, although this was reversed for much of 2008. The first obvious event on day 102, 12th April, is unusual in that there is an initial drop, but values then recover to slightly less than they were before the event, rather increasing about 2 bars above the mean, as is usual. This event is linked to a slight, but marked increase in subglacial discharge. The most obvious event is on day 140, 20th May, and is recorded on all load cells but appears unrelated to any obvious change in subglacial discharge or meteorological event. Note that around 20th May is usually the start of the melt season.

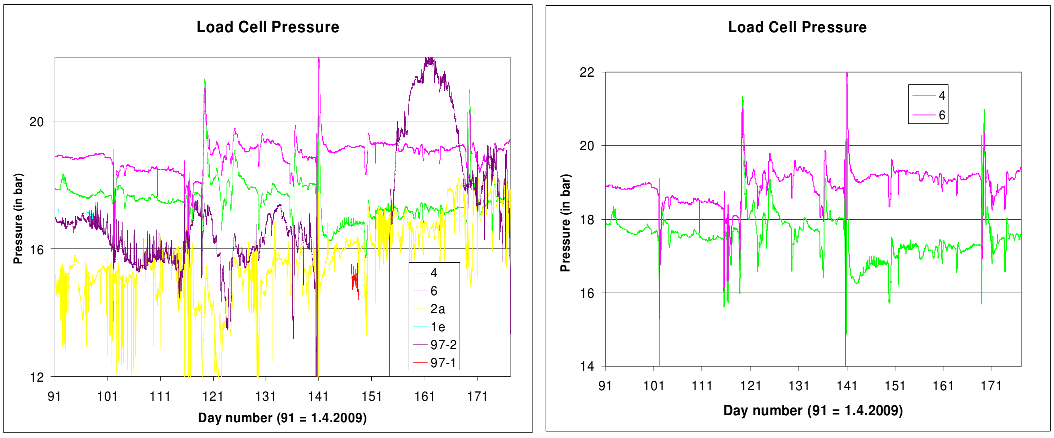


Figure 10-9
Pressure records for 1st April to 30th June.

Pressure sensor records for the summer and autumn, from 1st July to 30th September, are shown in Figure 10-10. These are rather quieter than normal, although subglacial discharge for this period was higher than in 2008. There are several distinct peaks in the recorded pressure and these are all related to peaks in subglacial discharge, which in turn are related to precipitation events. September 2009 was especially rainy with over 330 m of rain recorded at Reipå, 28 km from Engabreen, and rain almost every day of the month. In the warm, quiet period in July it is possible to see the diurnal signal at load cells 4 and 6 due to the daily peak in glacier melt.

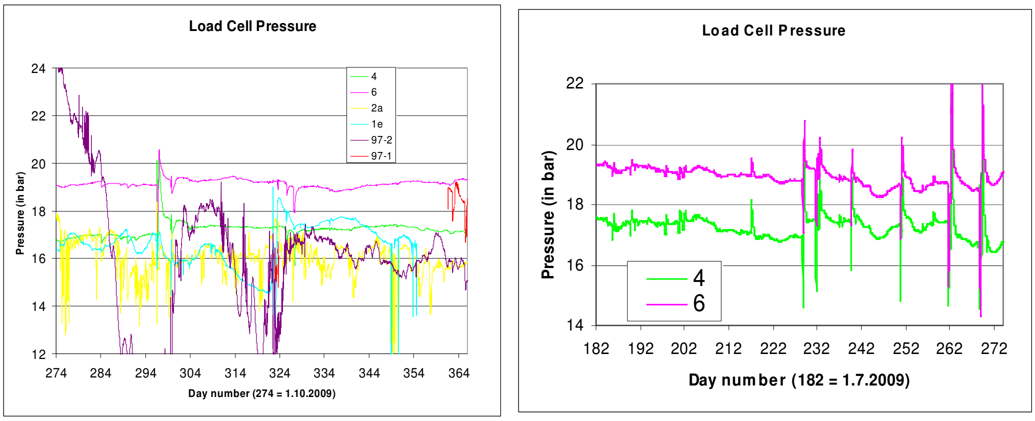


Figure 10-10
Pressure records for 1st July to 30th September.

Figure 10-11 shows the pressure records for late autumn/early winter, from 1st October to 31st December. These are generally quiet, although a distinct event on day 296, 23rd October, is recorded at all load cells. It is not related to a peak in subglacial discharge, which was then very low.

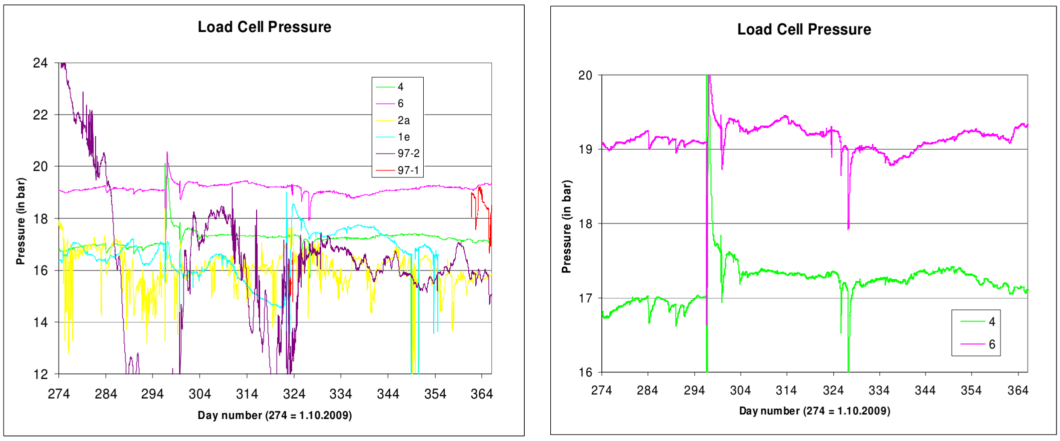


Figure 10-11
Pressure records for 1st October to 31st December.

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 7.7 km^2 (2008), and of this 3.2 km^2 drains eastward. The investigations are performed on this east-facing part, ranging from 302 to 1050 m a.s.l.

The glaciological investigations in 2009 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 2009

Fieldwork

Snow accumulation measurements

Snow accumulation was measured on 7th May and the calculation of winter balance is based on (Fig. 11-2):

- Uninterrupted measurements of stakes in positions 10 (500 m a.s.l.) and 30 (884 m a.s.l.). It was also possible to make use of measurements of substitute stakes drilled in May 2009 and older stakes that appeared during the melt season in positions 20 (633 m a.s.l.) and 25 (726 m a.s.l.). The stake measurements showed snow depths between 2.7 and 4.0 m.
- 66 snow depth soundings between 333 and 1048 m elevation. The sounding conditions were good over the whole glacier and the summer surface could easily be detected. The snow depth varied between 2 and 6 m.
- Snow density was measured down to SS at 3.0 m depth at stake position 25.

Figure 11-1
The outlet of Langfjordjøkelen photographed on 5th August 2009. Photo: Heidi B. Stranden.

Ablation measurements

Ablation was measured on 7th October. The net balance was measured at seven stakes in all five locations between 495 and 1050 m a.s.l. Since the snow measurements in May the stakes had increased in length between 4.7 m (pos. 30) and 6.6 m (pos. 10). At the time of measurements up to 90 cm of fresh snow had fallen.

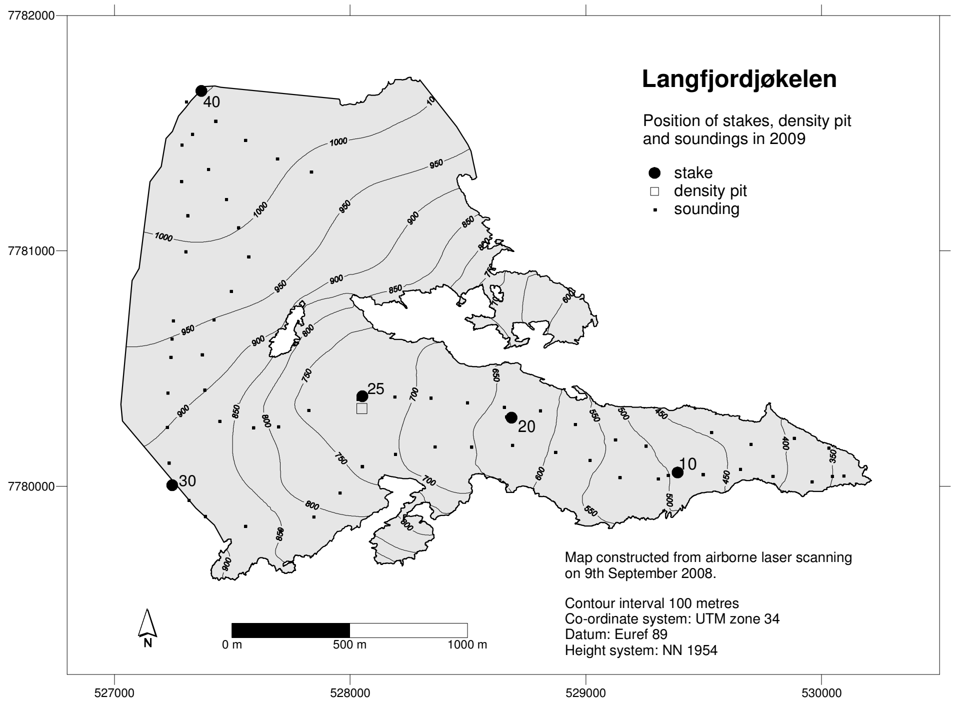


Figure 11-2
Location of stakes, soundings and snow pit at Langfjordjøkelen in 2009.

Results

The calculations are based on a Digital Elevation Model from 2008.

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 2008. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measurement at 727 m altitude. The mean density of 3.0 m snow was 460 kg/m^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 50 m height interval was estimated (Tab. 11-1).

The winter balance was calculated as 1.9 ±0.2 m w.e., corresponding to a water volume of 6 ±1 mill. m^3. The result is 89 % of the mean value for the periods 1989-1993 and 1996-2008.

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 11-3). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. The result obtained using this gridding method was also 1.9 m w.e.

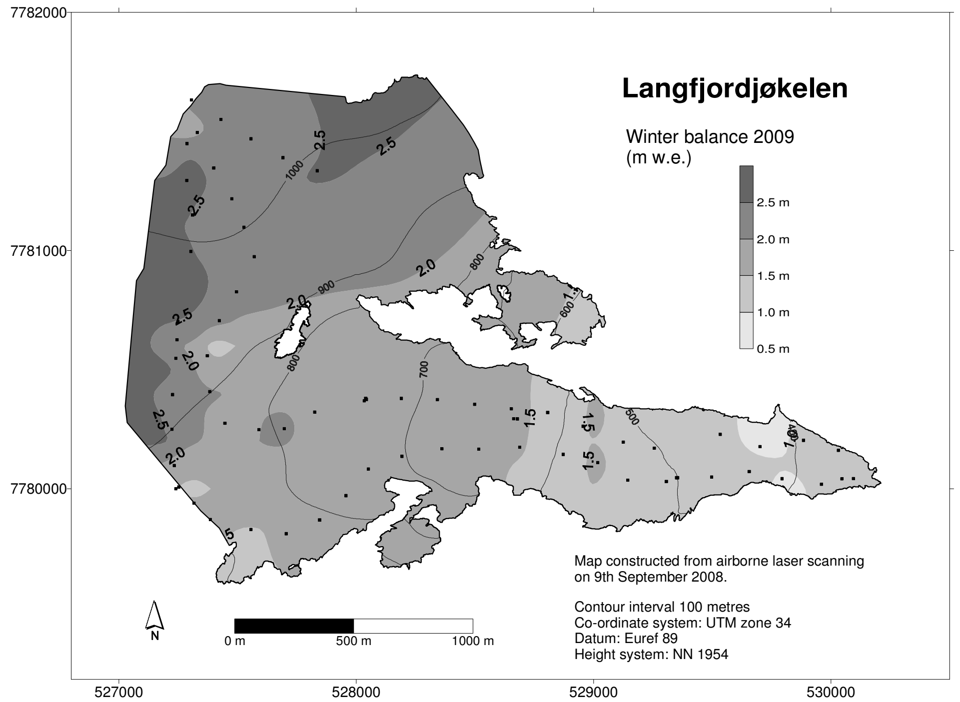


Figure 11-3
Winter balance at Langfjordjøkelen in 2009 interpolated from 70 snow depth measurements (•).

Summer balance

When calculating the summer balance the density of melted firn was estimated as 650 kg/m^3, while the density of melted ice was taken as 900 kg/m^3.

The summer balance was calculated at all five locations. The summer balance increased from −2.5 m w.e. at position 40 (1049 m a.s.l.) to −4.8 m w.e. at position 10 (495 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −3.2 ±0.3 m w.e., which is −10 ±1 mill. m^3 of water. The result is 106 % of the average for the periods 1989-1993 and 1996-2008.

Net balance

The net balance at Langfjordjøkelen for 2009 was −1.3 ±0.3 m w.e., which equals a volume loss of −4 ±1 mill. m^3 of water (Tab. 11-1). The mean value for the measurement periods 1989-93 and 1996-2008 is −0.91 m w.e. (Fig. 11-5), while the average over the 10-year period 1999-2008 is −1.38 m w.e.

Based on Figure 11-4, the Equilibrium Line Altitude (ELA) lies above the summit. Accordingly, the Accumulation Area Ratio (AAR) is 0 %.

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.

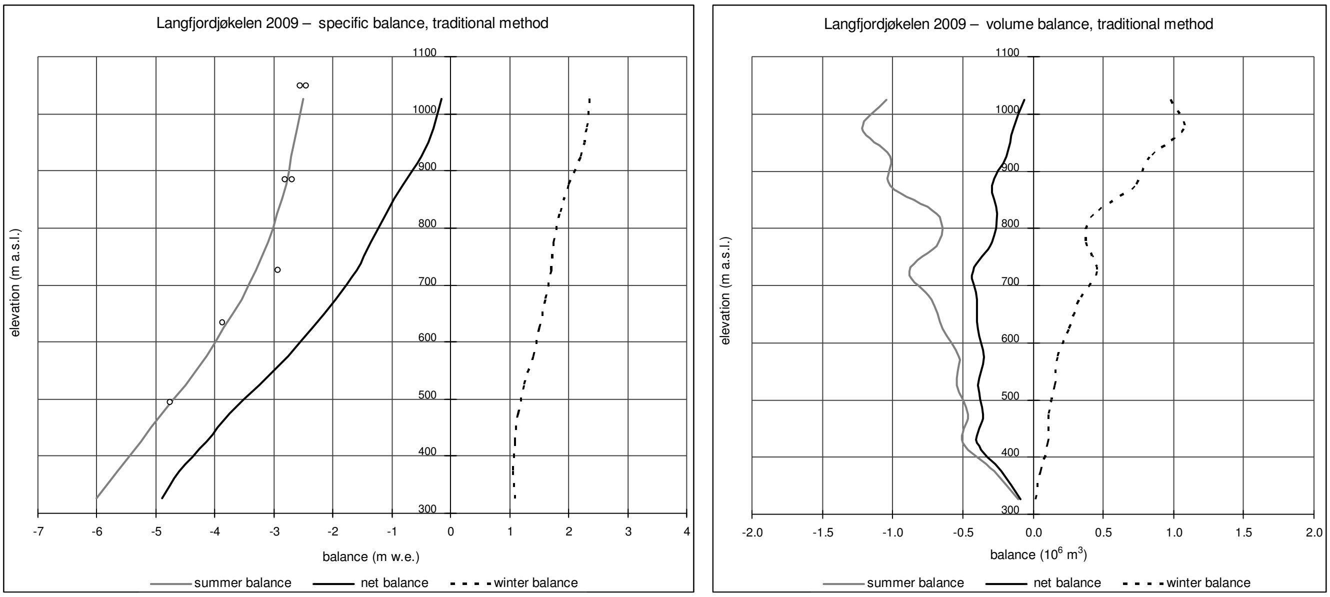


Figure 11-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2009. Summer balance for seven stakes is shown (o).

Table 11-1
Winter, summer and net balance for Langfjordjøkelen in 2009. Mean values for the periods 1989-93 and 1996-2008 are b_w = 2,11 m, b_s = –3,02 m and b_n = –0,91 m w.e.

Mass balance Langfjordjøkelen2008/09 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 7th May 2009		Measured 7th Oct 2009		Summer surface 2008 - 2009	
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	0.42	2.35	1.0	-2.50	-1.0	-0.15	-0.1
950 - 1000	0.47	2.30	1.1	-2.60	-1.2	-0.30	-0.1
900 - 950	0.38	2.20	0.8	-2.70	-1.0	-0.50	-0.2
850 - 900	0.36	2.00	0.7	-2.80	-1.0	-0.80	-0.3
800 - 850	0.23	1.85	0.4	-2.95	-0.7	-1.10	-0.3
750 - 800	0.22	1.75	0.4	-3.10	-0.7	-1.35	-0.3
700 - 750	0.27	1.70	0.5	-3.30	-0.9	-1.60	-0.4
650 - 700	0.20	1.60	0.3	-3.55	-0.7	-1.95	-0.4
600 - 650	0.17	1.50	0.3	-3.85	-0.6	-2.35	-0.4
550 - 600	0.13	1.40	0.2	-4.15	-0.5	-2.75	-0.4
500 - 550	0.12	1.25	0.2	-4.50	-0.5	-3.25	-0.4
450 - 500	0.10	1.15	0.1	-4.90	-0.5	-3.75	-0.4
400 - 450	0.10	1.10	0.1	-5.25	-0.5	-4.15	-0.4
350 - 400	0.05	1.05	0.1	-5.65	-0.3	-4.60	-0.2
302 - 350	0.02	1.10	0.0	-6.00	-0.1	-4.90	-0.1
302 - 1050	**3.21**	**1.88**	**6.1**	**-3.21**	**-10.3**	**-1.32**	**-4.3**

The balance year 2008/2009 is the thirteenth successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2009 (estimated values for 1994 and 1995 included) is −18 m w.e.

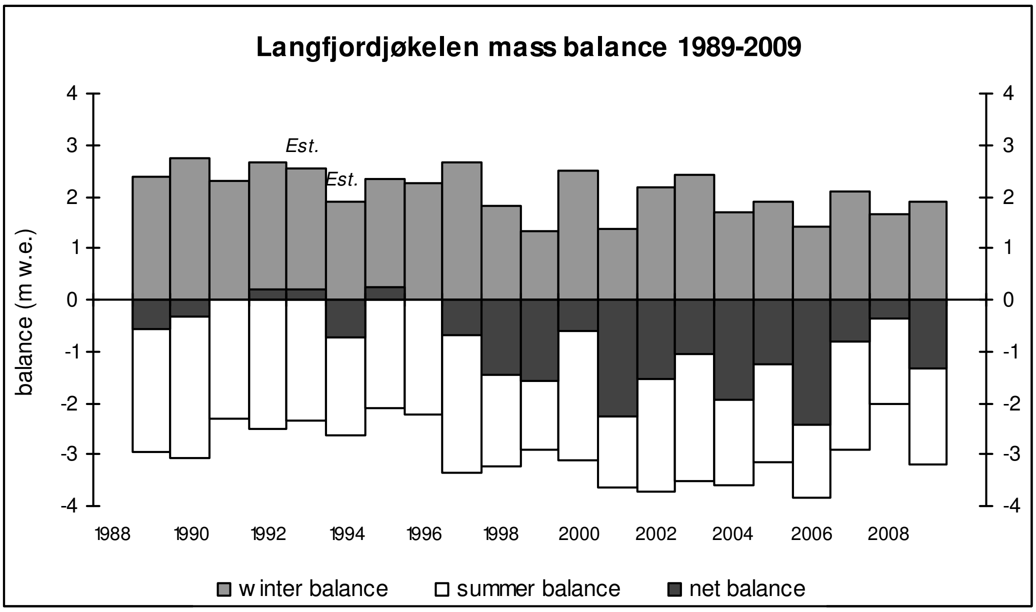


Figure 11-5
Mass balance at Langfjordjøkelen during the period 1989-2009. The total accumulated deficit over 1989-2009 is 18 m w.e. (includes estimated values for 1994 and 1995).

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 2009, glacier length change was measured at 27 glaciers - 22 in southern Norway and five glaciers in northern Norway (Fig. 12-1). Several glaciers were not measured due to an early start of the accumulation season.

Up to and including 2009, glacier length change has been measured at 64 glaciers since 1899. The total number of observations is 2373, and the median observation period is 27.5 years. At Briksdalsbreen, the glacier length change has been measured every year

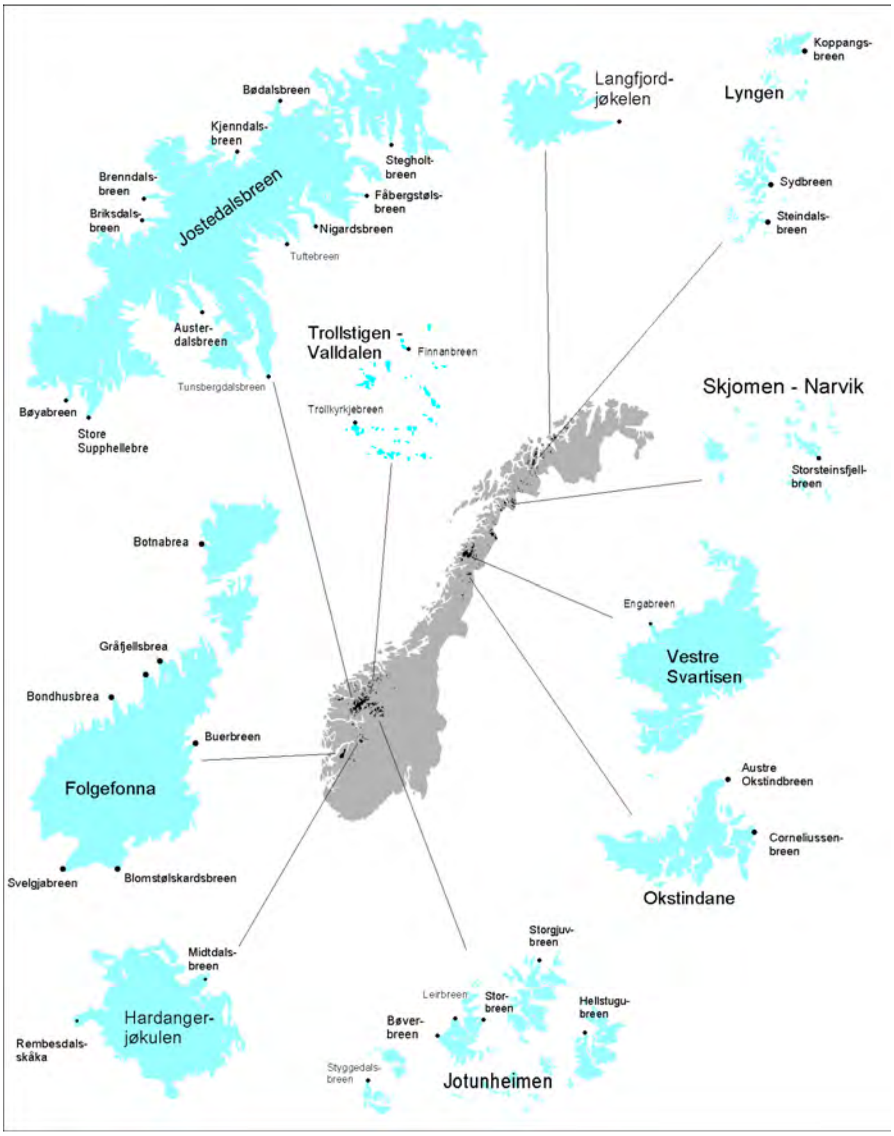


Figure 12-1
Location map showing glaciers where length change observations were performed in 2009. Note that the different glacier areas are not to the same scale.

since 1900, resulting in 109 observations. Stegholtbreen and Fåbergstølsbreen have more than 100 observations, too. A total of 19 glaciers have more than 50 observations, and another 11 glaciers have more than 30 observations.

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. The representativeness for the glacier tongue of the annual length change calculated from measurements from one reference point can be questionable. However, when longer time periods are considered the measurements give valuable information about glacier fluctuations, as well as regional tendencies and variations (Andreassen et al., 2005).

Results 2009

Twenty-seven glaciers were measured, five in northern Norway and 22 glaciers in southern Norway. Twenty-two glaciers retreated, three glaciers had minor changes, and two glaciers had an advance. The measured glaciers constitute around 14 % of the glacier area in Norway. The glacier length changes at the observed glaciers are listed in Table 12-1.

At Jostedalsbreen, seven out of eleven glaciers retreated more than 20 metres. Kjenndalsbreen and Bødalsbreen in Stryn and Fåbergstølsbreen in Luster retreated 93, 52 and 59 metres respectively. Kjenndalsbreen has retreated almost 600 metres since 2000.

At Folgefonna, three of five measured glaciers have retreated. Bondhusbrea in Kvinnherad retreated 10 metres in 2009 and has retreated 300 metres since 1996 when the most recent advance culminated. Buerbreen in Odda retreated five metres, and the tongue seems to have stabilised in the same area as prior to the most recent advance. The glacier has retreated 227 metres since 1998. Gråfjellsbrea in Kvinnherad retreated 19 metres and has retreated 228 metres since measurements started in 2002. A pro-glacial lake has been uncovered since the 1950s and is now almost 900 metres long. At Hardangerjøkulen, Rembesdalsskåka in Eidfjord melted back 10 metres. The tongue has retreated 327 metres since 1997. Measurements at Midtdalsbreen at Finse in Ulvik show an advance of six metres, but this is probably a local adaption after extensive retreat in 2007 and 2008. The glacier has retreated 109 metres since 2001.

In Jotunheimen the annual changes are smaller compared with the changes at the coastal outlet glaciers. Four glaciers melted back between 5 and 10 metres. Hellstugubreen and Storbreen have been measured since 1901 and 1902, and each has retreated almost 1100 metres in this period.

In Nordland, a northern outlet from Svartisen, Engabreen, has melted back eight metres in 2009, and 255 metres since 1999.

Three glaciers in Lyngen in Troms have melted back 10 to 20 metres. Steindalsbreen and Koppangsbreen have retreated approximately 200 metres since observations started in 1998. An eastern outlet from Langfjordjøkelen in Loppa in West Finnmark melted back 53 metres. The glacier has retreated 372 metres since 1998 and 1166 metres since 1965.

Table 12-1
Glacier length change between autumn 2008 and autumn 2009. See Figure 12-1 for locations.

Region	Glacier	2008-09 (m)	Observer	Period(s) of length change measurements	Number of obs	Length change 2004-09
Jostedalsbreen	Austerdalsbreen	-5	NVE	1905-20, 1933-	89	-75
	Brenndalsbreen	-29	SW	1900-62, 1996-	74	-385
	Briksdalsbreen	-22	NVE/AN	1900-	109	-259
	Bødalsbreen	-52	SW	1900-53, 1996-	59	-174
	Fåbergstølsbreen	-59	NVE	1899-	104	-161
	Kjenndalsbreen	-93	SW	1900-52, 1996-	56	-446
	Nigardsbreen	-24	NVE	1899-	98	-69
	Stegholtbreen	1	NVE	1903-	103	-61
	Tuftebreen	-12	NVE	2007-	2	
	Tunsbergdalsbreen	NM	NB	1900-1960, 2008-	62	
	Bøyabreen	-29	NB	1899-1953, 2003-	59	-117
	Store Supphellebreen	5	NB	1899-1958, 1977-83, 1992-	76	5
Folgefonna	Bondhusbrea	-10	S	1901-86, 1996-	75	-161
	Botnabrea	-1	GK	1996-	11	-30
	Blomstølskardsbreen	NM	SKL	1994-	11	
	Buerbreen	-5	NVE	1900-80, 1995-	61	-63
	Gråfjellsbrea	-19	S	2002-	7	-202
	Svelgjabreen	1	SKL	2007-	2	
Hardanger-jøkulen	Midtdalsbreen	6	AN	1982-	27	-63
	Rembesdalsskåka	-10	S	1918-41, 1968-83, 1995-	32	-161
Jotunheimen	Bøverbreen	-7	SW	1903-12, 1936-63, 1997-	39	-18
	Hellstugubreen	-10	NVE	1901-	69	-39
	Leirbreen	NM	NVE	1909-	48	
	Storbreen	-5	NVE	1902-	77	-29
	Storgjuvbreen	-8	SW	1901-12, 1933-63, 1997-	50	-21
	Styggedalsbreen	NM	NVE	1901-	88	
Møre & Romsdal	Trollkyrkjebreen	NM	NVE	1944-74, 2008-	28	
	Finnanbreen	NM	NVE	1950-74, 2008-	19	
Okstindane	Austre Okstindbreen	NM	NVE	1909-44, 2006-	19	
	Corneliussenbreen	NM	NVE	2006-	2	
Svartisen	Engabreen	-8	S	1903-	76	-132
Skjomen	Storsteinsfjellbreen	NM	NVE	2006-	2	
Lyngen	Koppangsbreen	-20	NVE	1998-	9	-118
	Sydbreen	-10	NVE	2007-	2	
	Steindalsbreen	-10	NVE	1998-	8	-130
Finnmark	Langfjordjøkelen	-53	NVE	1998-	11	-180

NM: not measured in 2009
Observers – other than NVE:
AN: Prof. Atle. Nesje, University of Bergen
GK: Geir Knudsen, Tyssedal
NB: Norwegian glacier museum, Fjærland
S: Statkraft
SKL: Sunnhordland Kraftlag
SW: Dr. Stefan Winkler, Germany

Figure 12-2
Fåbergstølsbreen on 20th September 2009. Glacier length change observations were initiated in 1899. Fåbergstølsbreen advanced 190 metres between 1992 and 2000. Since 2000, the glacier has retreated 224 metres. This is the most retreated terminus position since The Little Ice age (ca. 1600-1900 AD). Photo: Kristen Åsen.

12.2 Jøkulhlaup at Blåmannsisen

A new jøkulhlaup (outburst flood) occurred on 6th-7th September 2009 from Blåmannsisen in northern Norway, the fourth in the last ten years (Engeset et al, 2005; Kjøllmoen et al, 2008). In this most recent event 20 million cubic metres of water drained from a glacier-dammed lake and under the glacier.

The first known event occurred on 5th-7th September 2001. The glacier-dammed lake (Øvre Messingmalmvatn) drained under the outlet glacier Rundvassbreen, and the 40 million cubic metres of water discharged raised the level downstream in Sisovatnet reservoir by 2.5 m in only 36 hours. Previously the water had drained in the opposite direction, over a rock sill and into Sweden. Three years later the glacier-dammed lake was again at its previous level, but another year elapsed before the next event occurred. This happened on 27th-29th August 2005 when 35 million m^3 drained under the glacier and thence to Sisovatnet. The third event occurred on 29th August 2007, only two years after the previous episode, and when the lake level was still 9 m under the rock threshold. Only twenty million m^3 of water drained to Sisovatnet during this event. This latest event is somewhat similar. It occurred before Øvre Messingmalmvatn was completely full, 11.6 m under its full level. Again, it happened only two years after the previous event and a similar volume of water, 20 million m^3, was released.

The jøkulhlaups have occurred due to thinning of the glacier, such that the ice dam is no longer thick enough to retain the water in Øvre Messingmalmvatn. The glacier thickness in the ice dam region decreased by 15 – 26 m between 1961 and 2001 (Engeset et al, 2005). The ice thickness has now decreased even more, such that the glacier-dammed lake is now able to drain under the glacier before it is completely full. The change in thickness in the seven-year period from 2002 to 2009 is about 10 m (see table 12-2 and figure 12-4).

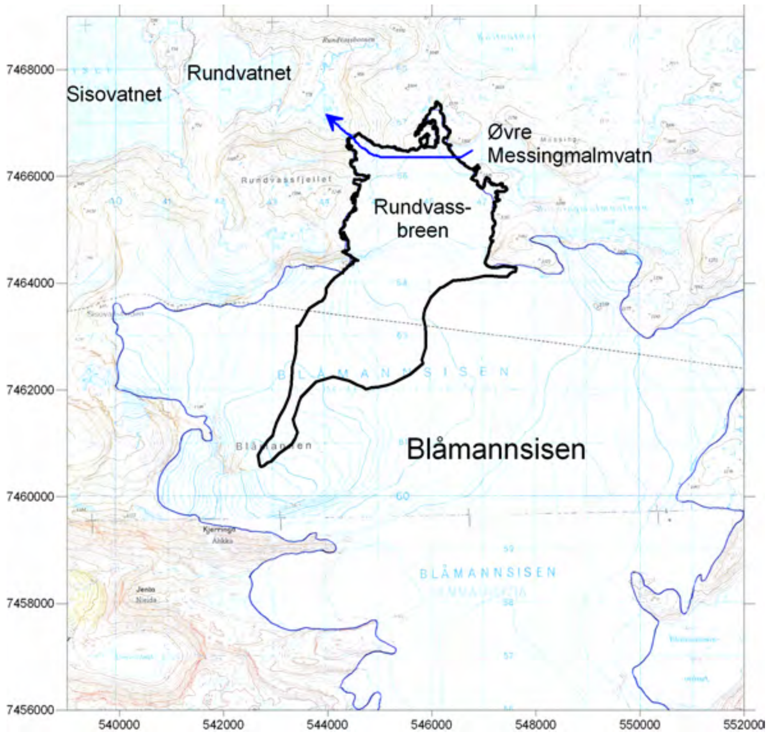


Figure 12-3
Map of Blåmannsisen showing outlet glacier Rundvassbreen, lakes named in the text and approximate direction of water flow under the glacier (blue arrow).

Table 12-2
Thickness changes since 2002 and since 2004 at six points in the ice dam area

Location	Height (m a.s.l.) in 2009	Change (m) 2004-09	Change (m) 2002-09
S101	1 101.20	-6.2	-10.2
S102	1 097.36	-5.6	-9.1
S104	1 093.07	-	-10.0
BP5	1 097.39	-7.8	-12.0
BP6	1 087.16	-10.3	-15.4
BMIPT	1 085.78	-5.2	-9.3

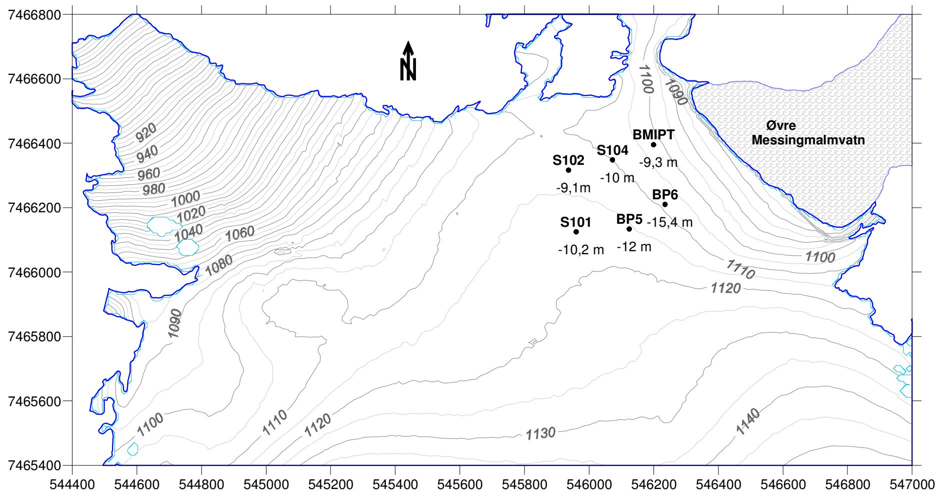


Figure 12-4
Position thickness measurements in ice-dam area adjacent to Øvre Messingmalmvatn. Changes in thickness between 2002 and 2009 are shown for each point.

13. References

Andreassen, L.M., H. Elvehøy, B. Kjøllmoen., R. Engeset & N. Haakensen
2005: Glacier mass balance and length variation in Norway. *Annals of Glaciology, 42,* p. 317-325.

Andreassen, L.M. & J. Oerlemans
2009: Modelling long-term summer and winter balances and the climate sensitivity of Storbreen, Norway. *Geografiska Annaler, 91(4),* p. 233-251.

Andreassen, L.M., M.R. van den Broeke, R.H. Giesen & J. Oerlemans
2008: A five-year record of surface energy and mass balance from the ablation zone of Storbreen, Norway. *Journal of Glaciology, 54 (185)*, p. 245-258.

Engeset, R.V., T.V. Schuler & M. Jackson
2005: Analysis of the first jökulhlaup at Blåmannsisen in northern Norway and implications for future events. *Annals of Glaciology, 42*, p. 35-41.

Giesen, R.H., L.M. Andreassen, M.R. van den Broeke & J. Oerlemans
2009: Comparison of meteorology and surface energy balance at Storbreen, and Midtdalsbreen, two glaciers in southern Norway. *The Cryosphere, 3*, p. 57-74.

Golden Software, Inc.
1999: Surfer User's Guide, Contouring and 3D, Surface Mapping for Scientists and Engineers, 619 pp.

Jackson, M.
2000: Svartisen Subglacial Laboratory. *NVE Document 14 2000*, 27 pp.

Kjøllmoen, B. (Ed.), L.M. Andreassen, H. Elvehøy, M. Jackson, R.H. Giesen & S. Winkler
2008: Glaciological investigations in Norway in 2007. *NVE Report 3 2008*, 91 pp.

Pytte, R. (Ed.)
1969: Glasiologiske undersøkelser i Norge 1969. *NVE Rapport 5 1970*, p. 17-25.

Tvede, A.M. (Ed.)
1973: Glasiologiske undersøkelser i Norge i 1971. *NVE Rapport 2 1973*, p. 18-20.

Wold, B & J.O. Hagen (Ed.)
1977: Glasiologiske undersøkelser i Norge 1975. *NVE Rapport 2 1977*, p. 13-15.

Østrem, G. & M. Brugman
1991: Glacier mass-balance measurements. A manual for field and office work. National Hydrology Research Institute, *Scientific Report, No. 4.* Environment Canada, N.H.R.I., Saskatoon and Norwegian Water Resources and Energy Directorate, Oslo, 224 pp.

Appendix A

Publications published in 2009

Andreassen, L.M.
Storbreen blir mindre. *Klima No. 4*, p. 18-19.

Andreassen, L.M. & J. Oerlemans
Modelling long-term summer and winter balances and the climate sensitivity of Storbreen, Norway. *Geografiska Annaler, 91(4)*, p. 233-251.

Baumann, S., S. Winkler & L.M. Andreassen
Mapping glaciers in Jotunheimen, South-Norway, during the 'Little Ice Age' maximum. *The Cryosphere, 3*, p. 231-243.

Elvehøy, H., M. Jackson & L.M. Andreassen
The influence of drainage boundaries on specific mass balance results, a case study of Engabreen, Norway. *Annals of Glaciology, 50*, p. 135-140.

Giesen, R.H., L.M. Andreassen, M.R. van den Broeke & J. Oerlemans
Comparison of meteorology and surface energy balance at Storbreen and Midtdalsbreen, two glaciers in southern Norway. *The Cryosphere 3*, p. 57-74.

Haug, T., C. Rolstad, H. Elvehøy, M. Jackson & I. Maalen-Johansen
Geodetic mass balance of the western Svartisen ice cap, Norway, in the periods 1968–1985 and 1985–2002. *Annals of Glaciology, 50*, p. 119-125.

Hausberg, J.E. & L.M. Andreassen
Satellittbasert brekartlegging i Lyngen. *NVE Rapport 7 2009*, 19 pp.

Kjøllmoen, B. (Ed.)
Glaciological investigations in Norway in 2008. *NVE Report 2 2009*, 80 pp.

Paul, F. & L.M. Andreassen
A new glacier inventory for the Svartisen region (Norway) from Landsat ETM+ data: Challenges and change assessment. *Journal of Glaciology, 55 (192)*, p. 607-618.

Winkler, S., H. Elvehøy & A. Nesje
Glacier fluctuations of Jostedalsbreen, western Norway, during the past 20 years: the sensitive response of maritime mountain glaciers. *The Holocene vol. 19, No. 3*, p. 395-414.

Appendix B

Mass balance measurements in Norway – an overview

Mass balance measurements were carried out at 42 Norwegian glaciers during the period 1949-2009. The table below shows important data for the individual glaciers.

Area/ No. Glacier	Area (km^2)	Altitude (m a.s.l.)	Mapping year	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	4.5	903-1382	1997	1963-	47
2 Hansebreen	3.1	930-1327	1997	1986-	24
Folgefonna					
3 Blomsterskardsbreen	45.7	850-1640	1959	1971-77	7
3a Svelgjabreen*	22.5	832-1636	2007	2007-	3
3b Blomstølskardsbreen*	22.8	1013-1636	2007	2007-	3
4 Bondhusbrea	10.7	480-1635	1979	1977-81	5
5 Breidablikkbrea	3.4	1234-1651	2007	1963-68, 2003-	13
6 Gråfjellsbrea	8.4	1049-1651	2007	64-68, 74-75, 2003-	14
7 Blåbreen and Ruklebreen	4.5	1065-1610	1959	1963-68	6
8 Midtre Folgefonna	8.7	1100-1570	1959	1970-71	2
Jostedalsbreen					
9 Jostefonn	3.8	960-1622	1993	1996-2000	5
10 Vesledalsbreen	4.2	1130-1730	1966	1967-72	6
11 Tunsbergdalsbreen	50.1	540-1930	1964	1966-72	7
12 Nigardsbreen	47.2	315-1957	2009	1962-	48
13 Store Supphellebreen	12.0	80-300/ 720-1740	1966	1964-67, 73-75, 79-82	11
14 Austdalsbreen	10.5	1200-1747	2009	1988-	22
15 Spørteggbreen	27.9	1260-1770	1988	1988-91	4
16 Harbardsbreen	13.2	1250-1960	1996	1997-2001	5
Hardangerjøkulen					
17 Rembesdalsskåka	17.1	1020-1865	1995	1963-	47
18 Midtdalsbreen	6.7	1380-1862	1995	2000-2001	2
19 Omnsbreen	1.5	1460-1570	1969	1966-70	5
Jotunheimen					
20 Tverråbreen	5.9	1415-2200		1962-63	2
21 Blåbreen	3.6	1550-2150	1961	1962-63	2
22 Storbreen	5.1	1400-2102	2009	1949-	61
23 Vestre Memurubre	9.0	1570-2230	1966	1968-72	5
24 Austre Memurubre	8.7	1630-2250	1966	1968-72	5
25 Hellstugubreen	2.9	1482-2229	2009	1962-	48
26 Gråsubreen	2.1	1833-2283	2009	1962-	48
Okstindbreene					
27 Charles Rabot Bre	1.1	1090-1760	1965	1970-73	4
28 Austre Okstindbre	14.0	730-1750	1962	1987-96	10
Svartisen					
29 Høgtuvbreen	2.6	590-1170	1972	1971-77	7
30 Svartisheibreen	5.5	770-1420	1985	1988-94	7
31 Engabreen	38.7	89-1574	2008	1970-	40
32 Storglombreen	59.2 62.4	520-1580 520-1580	1968	1985-88 2000-05	10
33 Tretten-null-tobreen	4.3	580-1260	1968	1985-86	2
34 Glombreen	2.2	870-1110	1953	1954-56	3
35 Kjølbreen	3.9	850-1250	1953	1954-56	3
36 Trollbergdalsbreen	1.8 1.6	900-1375 900-1300	1968 1985	1970-75 1990-94	11
Blåmannsisen					
37 Rundvassbreen	11.6	788-1537	1998	2002-04	3
Skjomen					
38 Blåisen	2.2	850-1200	1960	1963-68	6
39 Storsteinsfjellbreen	6.1 5.9	920-1850 970-1850	1960 1993	1964-68 1991-95	10
40 Cainhavarre	0.7	1210-1540	1960	1965-68	4
Vest-Finnmark					
41 Svartfjelljøkelen	2.7	500-1080	1966	1978-79	2
42 Langfjordjøkelen	3.7 3.2	280-1050 302-1050	1994 2008	1989-93, 1996-	19

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 598 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 each year at every 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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	2.49	-3.59	-1.09	-1.09	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	-0.66	950
6	68	4.55	-3.60	0.95	0.29	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	3.82	-3.70	0.12	-2.06	1195
11	73	4.67	-2.49	2.18	0.13	<870
12	74	3.57	-2.54	1.03	1.15	1065
13	75	4.64	-3.43	1.21	2.37	1050
14	76	4.40	-2.87	1.53	3.89	<870
15	77	2.33	-2.89	-0.56	3.33	1280
16	78	2.56	-3.07	-0.51	2.82	1290
17	79	3.28	-3.41	-0.13	2.70	1240
18	1980	2.51	-3.30	-0.79	1.90	1275
19	81	4.04	-3.82	0.22	2.12	1210
20	82	3.35	-3.48	-0.13	1.99	1240
21	83	4.79	-3.19	1.60	3.60	1010
22	84	4.09	-2.77	1.32	4.92	1050
23	85	2.44	-3.00	-0.56	4.36	1290
24	86	2.35	-2.76	-0.41	3.95	1255
25	87	4.29	-2.22	2.07	6.02	<870
26	88	2.73	-5.21	-2.48	3.54	>1380
27	89	5.20	-2.93	2.27	5.81	1030
28	1990	5.98	-4.19	1.79	7.61	995
29	91	4.09	-3.30	0.79	8.40	1035
30	92	5.48	-3.19	2.29	10.69	1050
31	93	4.81	-2.74	2.07	12.76	<870
32	94	3.71	-2.92	0.79	13.54	925
33	95	5.10	-3.90	1.20	14.75	1120
34	96	1.83	-3.71	-1.88	12.87	>1380
35	97	4.22	-4.14	0.08	12.95	1200
36	98	3.66	-3.55	0.11	13.06	1240
37	99	4.61	-4.55	0.06	13.11	1245
38	2000	5.57	-3.58	1.99	15.10	1025
39	01	1.86	-3.95	-2.09	13.01	>1382
40	02	3.78	-5.31	-1.53	11.48	>1382
41	03	2.52	-5.03	-2.50	8.98	>1382
42	04	3.32	-3.42	-0.10	8.88	1225
43	05	4.99	-4.32	0.67	9.55	1135
44	06	2.69	-5.88	-3.19	6.36	>1382
45	07	4.49	-3.22	1.27	7.63	1000
46	08	4.04	-3.35	0.68	8.31	1130
47	09	3.84	-4.00	-0.17	8.14	1240
Mean 1963-2009		3.73	-3.56	0.17		

2 Hansebreen - 3.1 km^2 (1997)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1986	2.28	-2.87	-0.58	-0.58	1200
2	87	3.76	-2.63	1.13	0.54	1100
3	88	2.50	-5.25	-2.75	-2.21	>1320
4	89	4.13	-3.71	0.42	-1.79	1140
5	1990	4.42	-4.10	0.32	-1.47	1140
6	91	3.37	-3.11	0.26	-1.21	1125
7	92	4.41	-3.43	0.97	-0.23	1125
8	93	4.23	-3.15	1.08	0.85	<925
9	94	3.39	-2.97	0.43	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	0.86	0.26	1075
16	01	1.71	-4.43	-2.72	-2.46	>1327
17	02	3.51	-5.44	-1.93	-4.39	>1327
18	03	2.45	-5.12	-2.67	-7.06	>1327
19	04	2.87	-3.38	-0.50	-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	0.85	-10.79	1042
23	08	3.90	-3.65	0.26	-10.53	1125
24	09	3.45	-4.42	-0.97	-11.50	>1327
Mean 1986-2009		3.48	-3.96	-0.48		

3 Blomsterskardsbreen - 45.7 km^2 (1959)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1970			0.00	0.00	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	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2007	3.89	-2.54	1.35	1.35	1205
2	08	3.38	-2.65	0.72	2.07	1235
3	09	3.33	-2.97	0.36	2.43	1310
Mean 2007-09		3.53	-2.72	0.81		

3b Blomstølskardsbreen - 22.8 km^2 (2007)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2007	4.17	-2.30	1.88	1.88	1230
2	08	3.44	-2.14	1.30	3.18	1265
3	09	3.59	-2.52	1.07	4.24	1290
Mean 2007-09		3.73	-2.32	1.41		

4 Bondhusbrea - 10.7 km^2 (1979)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	1.11	-2.32	-1.21	-1.21	1635
2	64	1.918	-1.68	0.23	-0.98	1450
3	65	1.72	-2.28	-0.56	-1.54	1525
4	66	1.52	-3.17	-1.65	-3.19	>1660
5	67	3.40	-2.23	1.17	-2.02	1355
6	68	3.55	-2.68	0.87	-1.15	1360
7	2003	2.12	-4.38	-2.26	-2.26	>1659
8	04	2.25	-3.12	-0.87	-3.13	1595
9	05	3.04	-3.37	-0.33	-3.45	1510
10	06	1.49	-4.44	-2.95	-6.40	>1659
11	07	3.42	-3.07	0.36	-6.05	1410
12	08	2.66	-2.96	-0.30	-6.34	1515
13	09	2.47	-2.98	-0.52	-6.86	1565
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-09		2.49	-3.47	-0.98		

6 Gråfjellsbrea - 8.4 km² (2007)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	1.31	0.00	1355
5	68	3.39	-2.82	0.57	0.57	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	1.91	-4.09	-2.18	-2.18	>1659
9	04	2.05	-2.82	-0.76	-2.95	1565
10	05	3.15	-3.13	0.02	-2.93	1460
11	06	1.40	-4.55	-3.15	-6.07	>1659
12	07	3.60	-2.85	0.75	-5.32	1395
13	08	2.66	-2.80	-0.14	-5.46	1490
14	09	2.34	-2.88	-0.54	-6.00	1540
Mean 1964-68		2.48	-2.36	0.11		
Mean 1974-75		2.32	-1.90	0.41		
Mean 2003-09		2.44	-3.30	-0.86		

7 Blåbreen and Ruklebreen - 4.5 km² (1959)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 - 47.2 km² (2009)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	2.88	-0.63	2.25	2.25	1260
2	63	1.87	-2.09	-0.23	2.02	1550
3	64	2.13	-1.18	0.95	2.97	1400
4	65	2.29	-1.38	0.90	3.87	1395
5	66	1.76	-2.68	-0.92	2.95	1700
6	67	3.40	-1.24	2.16	5.11	1310
7	68	2.72	-2.50	0.22	5.33	1550
8	69	1.95	-3.26	-1.31	4.02	1850
9	1970	1.73	-2.29	-0.56	3.46	1650
10	71	2.11	-1.29	0.82	4.28	1400
11	72	1.88	-2.02	-0.14	4.14	1570
12	73	2.40	-1.30	1.11	5.25	1410
13	74	2.06	-1.58	0.48	5.73	1490
14	75	2.50	-2.23	0.27	6.00	1450
15	76	2.88	-2.48	0.40	6.40	1540
16	77	1.52	-2.29	-0.77	5.63	1650
17	78	2.12	-2.25	-0.13	5.50	1590
18	79	2.75	-2.04	0.71	6.21	1500
19	1980	1.77	-2.99	-1.22	4.99	1730
20	81	2.19	-1.88	0.32	5.31	1560
21	82	1.93	-2.35	-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	-0.90	6.70	1660
28	89	4.05	-0.85	3.20	9.90	1175
29	1990	3.52	-1.75	1.76	11.66	1430
30	91	1.95	-1.75	0.20	11.86	1520
31	92	3.16	-1.56	1.60	13.46	1360
32	93	3.13	-1.28	1.85	15.31	1300
33	94	2.28	-1.72	0.57	15.88	1400
34	95	3.16	-1.97	1.19	17.07	1320
35	96	1.40	-1.81	-0.41	16.66	1660
36	97	2.66	-2.62	0.04	16.69	1500
37	98	2.50	-1.53	0.97	17.67	1350
38	99	2.38	-2.21	0.17	17.84	1470
39	2000	3.38	-1.66	1.72	19.56	1250
40	01	1.75	-1.97	-0.22	19.34	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	17.25	1530
44	05	2.80	-1.70	1.10	18.35	1395
45	06	1.75	-3.15	-1.40	16.95	1850
46	07	3.09	-2.05	1.05	18.00	1320
47	08	3.01	-1.92	1.10	19.10	1325
48	09	2.20	-1.96	0.24	19.34	1465
Mean 1962-2009		2.39	-1.99	0.40		

13 Store Supphellebreen - 12.0 km^2 (1966)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 - 10.5 km^2 (2009)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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
21	08	2.55	-2.62	-0.07	-5.71	1420
22	09	1.92	-2.62	-0.70	-6.41	1475
Mean 1988-2009		2.20	-2.50	-0.29		

15 Spørteggbreen - 27.9 km^2 (1988)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	1.15	-2.55	-1.40	-1.40	>1860
2	64	1.85	-1.41	0.44	-0.96	1620
3	65	2.05	-1.54	0.51	-0.45	1620
4	66	1.60	-2.24	-0.64	-1.09	1750
5	67	2.44	-1.25	1.19	0.10	1540
6	68	2.68	-2.15	0.53	0.63	1600
7	69	1.07	-2.97	-1.90	-1.27	>1860
8	1970	1.29	-1.89	-0.60	-1.87	1780
9	71	2.02	-1.28	0.74	-1.13	1600
10	72	1.78	-1.86	-0.08	-1.21	1650
11	73	2.62	-1.79	0.83	-0.38	1570
12	74	1.91	-1.50	0.41	0.03	1615
13	75	2.25	-2.10	0.15	0.18	1620
14	76	2.45	-2.30	0.15	0.33	1620
15	77	1.20	-1.92	-0.72	-0.39	>1860
16	78	1.80	-2.10	-0.30	-0.69	
17	79	2.40	-2.10	0.30	-0.39	
18	1980	1.45	-2.85	-1.40	-1.79	>1860
19	81	2.65	-1.80	0.85	-0.94	1590
20	82	1.40	-2.10	-0.70	-1.64	1800
21	83	3.75	-2.05	1.70	0.06	1450
22	84	2.05	-2.15	-0.10	-0.04	1675
23	85	1.48	-2.00	-0.52	-0.56	1715
24	86	1.47	-1.57	-0.10	-0.66	1670
25	87	2.08	-1.14	0.94	0.28	1535
26	88	1.61	-3.13	-1.52	-1.24	1860
27	89	3.48	-1.37	2.11	0.87	1420
28	1990	3.65	-1.72	1.93	2.80	1450
29	91	1.52	-1.61	-0.09	2.71	1660
30	92	3.71	-1.72	1.99	4.70	1525
31	93	2.82	-0.91	1.91	6.61	1450
32	94	1.79	-1.63	0.16	6.77	1600
33	95	2.44	-2.14	0.30	7.07	1575
34	96	0.99	-2.10	-1.11	5.96	>1860
35	97	2.94	-3.41	-0.47	5.49	1700
36	98	2.47	-1.78	0.69	6.18	1585
37	99	2.04	-1.99	0.05	6.23	1685
38	2000	2.93	-1.50	1.43	7.66	1425
39	01	1.03	-1.88	-0.85	6.81	1760
40	02	2.39	-3.10	-0.71	6.10	1750
41	03	1.33	-2.69	-1.36	4.74	>1860
42	04	1.89	-1.81	0.08	4.82	1670
43	05	2.79	-2.07	0.72	5.54	1590
44	06	0.90	-3.12	-2.22	3.32	>1860
45	07	3.10	-1.93	1.17	4.49	1570
46	08	2.61	-2.16	0.45	4.94	1610
47	09	2.37	-2.21	0.15	5.09	1655
Mean 1963-2009		2.12	-2.01	0.11		

18 Midtdalsbreen - 6.7 km^2 (1995)

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

20 Tverråbreen - 5.9 km^2 ()

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

21 Blåbreen - 3.6 km^2 (1961)

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

22 Storbreen - 5.1 km^2 (2009)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	49	2.28	-2.08	0.20	0.20	1650
2	1950	1.52	-1.81	-0.29	-0.09	1750
3	51	1.13	-1.67	-0.54	-0.63	1770
4	52	1.44	-1.13	0.31	-0.32	1630
5	53	1.40	-2.25	-0.85	-1.17	1850
6	54	1.21	-1.98	-0.77	-1.94	1830
7	55	1.57	-2.06	-0.49	-2.43	1800
8	56	1.31	-1.48	-0.17	-2.60	1705
9	57	1.42	-1.37	0.05	-2.55	1680
10	58	1.54	-1.62	-0.08	-2.63	1700
11	59	1.07	-2.35	-1.28	-3.91	1930
12	1960	0.98	-2.07	-1.09	-5.00	1910
13	61	1.10	-1.62	-0.52	-5.52	1820
14	62	1.54	-0.82	0.72	-4.80	1510
15	63	0.96	-2.14	-1.18	-5.98	1900
16	64	1.16	-0.95	0.21	-5.77	1655
17	65	1.54	-1.20	0.34	-5.43	1650
18	66	1.25	-1.86	-0.61	-6.04	1815
19	67	1.89	-1.17	0.72	-5.32	1570
20	68	1.64	-1.59	0.05	-5.27	1700
21	69	1.22	-2.64	-1.42	-6.69	2020
22	1970	0.97	-1.69	-0.72	-7.41	1840
23	71	1.46	-1.28	0.18	-7.23	1690
24	72	1.39	-1.70	-0.31	-7.54	1770
25	73	1.48	-1.40	0.08	-7.46	1705
26	74	1.26	-1.02	0.24	-7.22	1630
27	75	1.55	-1.70	-0.15	-7.37	1760
28	76	1.81	-1.90	-0.09	-7.46	1740
29	77	0.94	-1.48	-0.54	-8.00	1840
30	78	1.26	-1.70	-0.44	-8.44	1815
31	79	1.55	-1.45	0.10	-8.34	1700
32	1980	0.99	-2.30	-1.31	-9.65	1975
33	81	1.30	-1.40	-0.10	-9.75	1730
34	82	1.28	-1.75	-0.47	-10.22	1785
35	83	1.90	-1.70	0.20	-10.02	1625
36	84	1.70	-2.00	-0.30	-10.32	1765
37	85	1.20	-1.60	-0.40	-10.72	1790
38	86	1.05	-1.37	-0.32	-11.04	1770
39	87	1.55	-1.23	0.32	-10.72	1570
40	88	1.45	-2.40	-0.95	-11.67	1970
41	89	2.30	-1.10	1.20	-10.47	1550
42	1990	2.60	-1.35	1.25	-9.22	1530
43	91	1.26	-1.41	-0.15	-9.37	1740
44	92	1.61	-1.53	0.08	-9.29	1715
45	93	1.81	-1.06	0.75	-8.54	1605
46	94	1.52	-1.77	-0.25	-8.79	1800
47	95	1.77	-1.93	-0.16	-8.95	1810
48	96	0.81	-1.84	-1.03	-9.98	1890
49	97	1.75	-2.78	-1.03	-11.01	1875
50	98	1.55	-1.33	0.22	-10.79	1680
51	99	1.67	-1.91	-0.24	-11.03	1830
52	2000	2.04	-1.49	0.55	-10.48	1650
53	01	1.05	-1.32	-0.27	-10.75	1845
54	02	1.09	-2.87	-1.78	-12.53	2075
55	03	1.11	-2.68	-1.57	-14.10	2025
56	04	1.01	-1.59	-0.58	-14.68	1855
57	05	1.83	-1.89	-0.06	-14.74	1795
58	06	0.86	-3.01	-2.15	-16.89	>2100
59	07	1.35	-1.74	-0.39	-17.28	1835
60	08	1.99	-1.88	0.11	-17.17	1770
61	09	1.60	-1.83	-0.22	-17.39	1760
Mean 1949-2009		1.44	-1.73	-0.29		

23 Vestre Memurubre - 9.0 km^2 (1966)

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

24 Austre Memurubre - 8.7 km^2 (1966)

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

25 Hellstugubreen - 2.9 km^2 (2009)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1962	1.18	-0.40	0.78	0.78	
2	63	0.94	-1.92	-0.98	-0.20	2020
3	64	0.71	-0.83	-0.12	-0.32	1900
4	65	1.29	-0.77	0.52	0.20	1690
5	66	0.95	-1.62	-0.67	-0.47	1940
6	67	1.48	-0.93	0.55	0.08	1800
7	68	1.38	-1.49	-0.11	-0.03	1875
8	69	0.95	-2.23	-1.28	-1.31	2130
9	1970	0.70	-1.70	-1.00	-2.31	2020
10	71	1.12	-1.25	-0.13	-2.44	1860
11	72	0.94	-1.43	-0.49	-2.93	1950
12	73	1.20	-1.41	-0.21	-3.14	1880
13	74	1.00	-0.76	0.24	-2.90	1785
14	75	1.35	-1.71	-0.36	-3.26	1950
15	76	1.16	-1.89	-0.73	-3.99	1970
16	77	0.68	-1.40	-0.72	-4.71	2075
17	78	1.05	-1.59	-0.54	-5.25	1890
18	79	1.43	-1.45	-0.02	-5.27	1820
19	1980	0.81	-2.05	-1.24	-6.51	2050
20	81	1.06	-1.39	-0.33	-6.84	1950
21	82	0.85	-1.20	-0.35	-7.19	1920
22	83	1.47	-1.30	0.17	-7.02	1820
23	84	1.22	-1.73	-0.51	-7.53	1965
24	85	1.11	-1.40	-0.29	-7.82	1880
25	86	0.78	-1.27	-0.49	-8.31	1940
26	87	1.15	-0.70	0.45	-7.86	1690
27	88	1.28	-2.32	-1.04	-8.90	2025
28	89	1.62	-0.90	0.72	-8.18	1660
29	1990	1.81	-1.15	0.66	-7.52	1640
30	91	0.98	-1.43	-0.45	-7.97	1950
31	92	1.17	-1.03	0.14	-7.83	1850
32	93	1.25	-0.95	0.30	-7.53	1670
33	94	1.26	-1.19	0.07	-7.46	1850
34	95	1.42	-1.54	-0.12	-7.58	1885
35	96	0.65	-1.39	-0.74	-8.32	1955
36	97	1.12	-2.77	-1.65	-9.97	2200
37	98	1.00	-1.02	-0.02	-9.99	1870
38	99	1.22	-1.64	-0.42	-10.41	1930
39	2000	1.26	-1.16	0.10	-10.31	1840
40	01	0.85	-1.21	-0.36	-10.67	1910
41	02	0.96	-2.37	-1.41	-12.08	2080
42	03	0.71	-2.23	-1.52	-13.60	2200
43	04	0.65	-1.49	-0.84	-14.44	1980
44	05	1.34	-1.63	-0.29	-14.73	1930
45	06	0.73	-2.74	-2.01	-16.74	>2210
46	07	1.03	-1.70	-0.67	-17.41	1975
47	08	1.41	-1.47	-0.06	-17.47	1880
48	09	1.30	-1.53	-0.23	-17.70	1920
Mean 1962-2009		1.10	-1.47	-0.37		

26 Gråsubreen - 2.1 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(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	Undef.
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
47	08	0.95	-0.86	0.08	-16.36	Undef.
48	09	0.81	-1.08	-0.28	-16.64	2235
Mean 1962-2009		0.76	-1.11	-0.35		

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

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(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 years	Year	bw	bs	bn	Cum. bn	ELA
		(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 years	Year	bw	bs	bn	Cum. bn	ELA
		(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 years	Year	bw	bs	bn	Cum. bn	ELA
		(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 - 38.7 km^2 (2008)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(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	1.76	-3.12	-1.36	21.82	1325
38	07	3.40	-2.30	1.10	22.92	1035
39	08	2.81	-2.50	0.31	23.23	1093
40	09	2.87	-2.90	-0.03	23.20	1170
Mean 1970-2009		2.92	-2.34	0.58		

32 Storglombreen - 62.4 km^2 (1968)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(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 - 3.2 km^2 (2008)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	89	2.40	-2.96	-0.55	-0.55	870
2	1990	2.74	-3.06	-0.32	-0.88	780
3	91	2.31	-2.31	0.00	-0.87	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	-1.57	-3.68	970
10	2000	2.51	-3.12	-0.61	-4.29	860
11	01	1.36	-3.64	-2.28	-6.57	>1050
12	02	2.19	-3.73	-1.54	-8.12	>1050
13	03	2.44	-3.51	-1.07	-9.18	>1050
14	04	1.69	-3.61	-1.92	-11.10	>1050
15	05	1.88	-3.14	-1.25	-12.35	935
16	06	1.42	-3.83	-2.41	-14.77	>1050
17	07	2.09	-2.90	-0.81	-15.58	870
18	08	1.67	-2.02	-0.35	-15.93	835
19	09	1.88	-3.21	-1.32	-17.25	>1050
Mean 1989-93		2.54	-2.63	-0.10		
Mean 1996-2009		1.94	-3.17	-1.23		

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