Glaciological investigations in Norway in 2008

Bjarne Kjøllmoen (Ed.)

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REPORT

Glaciological investigations in Norway in 2008

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Glaciological investigations in Norway in 2008

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Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2008 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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Contents

Preface **4**

Summary **5**

Sammendrag **6**

1. Glacier investigations in Norway in 2008 **7**

2. Ålfotbreen **14**

3. Folgefonna **20**

4. Nigardsbreen **33**

5. Austdalsbreen **38**

6. Hardangerjøkulen **45**

7. Storbreen **52**

8. Hellstugubreen **55**

9. Gråsubreen **58**

10. Engabreen **61**

11. Langfjordjøkelen **69**

12. Glacier length change **74**

13. References **79**

Appendix A (Publications published in 2008) **i**

Appendix B (Mass balance measurements in Norway - an overview) **ii**

Appendix C (Mass balance measurements in Norway - annual results) **iii**

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 and Environmental Hydrology during 2008. The chapters are written by different authors with different objectives, but are presented in a uniform format. The individual authors hold the professional responsibility for the contents of each chapter. The fieldwork and the calculations are mainly the result of co-operative work amongst the personnel at NVE.

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

Oslo, April 2009

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Summary

Mass balance

Mass balance investigations were performed on fourteen glaciers in Norway in 2008. Twelve of these glaciers are in southern Norway and two are in northern Norway.

The winter balance was greater than average for all measured glaciers in southern Norway. In northern Norway the winter balance was lower than average on both Engabreen and Langfjordjøkelen.

The summer balance was approximately average at the glaciers in southern Norway. In northern Norway, Langfjordjøkelen had the lowest summer balance since measurements started in 1989.

In southern Norway the net balance was positive for eight of twelve measured glaciers. Blomstølskardsbreen (+1.3 m) and Nigardsbreen (+1.1 m) had the greatest surplus. In northern Norway, Langfjordjøkelen had the twelfth successive year of deficit.

Glacier length change

Glacier length changes were measured at 24 glaciers in southern Norway and eight glaciers in northern Norway in 2008. Twenty four of the glacier outlets had a retreat in length, five were unchanged and three outlets had an advance. Fåbergstølsbreen and Brenndalsbreen, both outlets from Jostedalsbreen, showed retreats of between 50 and 60 metres. Bondhusbrea, an outlet from Folgefonna, had a retreat of 50 metres.

Sammendrag

Massebalanse

I 2008 ble det utført massebalansemålinger på 14 breer i Norge – tolv i Sør-Norge og to i Nord-Norge.

Vinterbalansen ble større enn gjennomsnittet på samtlige målte breer i Sør-Norge. I Nord-Norge ble vinterbalansen mindre enn gjennomsnittet på både Engabreen og Langfjordjøkelen.

Sommerbalansen ble omtrent som gjennomsnittet for breene i Sør-Norge. I Nord-Norge fikk Langfjordjøkelen den minste sommerbalansen som er målt siden målingene startet i 1989.

I Sør-Norge ble det positiv nettobalanse på åtte av tolv målte breer. Størst overskudd fikk Blomstølskardsbreen (1,3 m) og Nigardsbreen (1,1 m). I Nord-Norge fikk Langfjordjøkelen underskudd for tolvte året på rad.

Lengdeendringer

Lengdeendringer ble målt på 24 breer i Sør-Norge og åtte breer i Nord-Norge i 2008. Tjuefire av breutløperne hadde tilbakegang, fem var uendret og tre hadde framgang. Fåbergstølsbreen og Brenndalsbreen, begge utløpere fra Jostedalsbreen, hadde tilbakegang på mellom 50 og 60 m. Bondhusbrea, en utløper fra Folgefonna, smeltet tilbake 50 m.

1. Glacier investigations in Norway in 2008

1.1 Mass balance

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

Method

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

Winter balance

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

Summer and net balance

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

Figure 1-1
Ice-covered tower at Engabreen, Svartisen in March 2008. Photo: Hallgeir Elvehøy.

Stratigraphic method

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

Accuracy

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

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

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

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

Mass balance program

In 2008 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 46 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 60 years of measurements, while Engabreen at Svartisen has the longest series (39 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 2008 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.

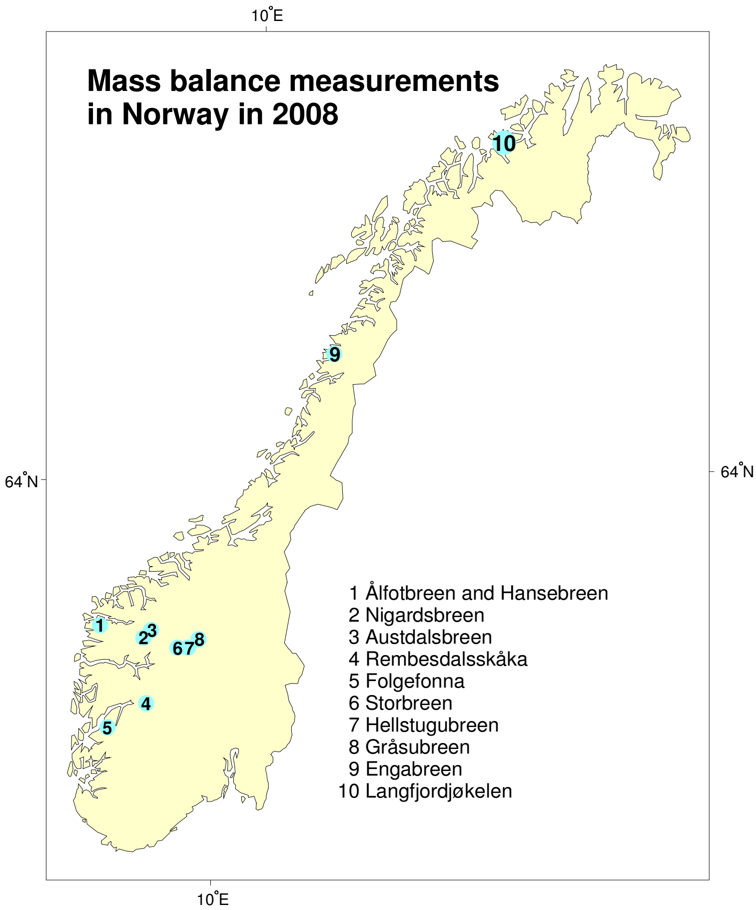


Figure 1-2
Location of the glaciers at which mass balance studies were performed in 2008.

Weather conditions and mass balance results

Wintry weather

The 2007/2008 winter season was mild and snow-rich in southern Norway. In northern Norway the winter was also mild, but snow conditions were normal. However, the winter season in southern Norway started with a dry October and November, but the following winter months were snow-rich, particularly January and February. Some parts of northern Norway had heavy snowfall in December and February.

Snow accumulation and winter balance

The winter balance was greater than average at all measured glaciers in southern Norway. The long-term (20 years of measurements or more) glaciers in western Norway had results of 108 to 126 % of their average winter balance. Nigardsbreen had the greatest relative winter balance with 126 % (3.0 m w.e.). The glaciers in Jotunheimen had between 125 and 139 % of average. In northern Norway, Engabreen had 96 % of average, and Langfjordjøkelen in western Finnmark had the fourth lowest winter balance (78 %) since measurements started in 1989.

Summer weather

The summer season in 2008 was slightly warmer than normal in southern Norway. June was rather cool, but July and August were warmer than normal. In northern Norway, the summer was cooler than normal in the northernmost parts.

Ablation and summer balance

The summer balance was about average at the glaciers in southern Norway. The long-term glaciers in western Norway had summer balances between 92 and 108 % of their average. The glaciers in Jotunheimen had between 77 and 109 % of their average. In northern Norway, Engabreen had summer balance slightly above average, while Langfjordjøkelen had the lowest summer balance ever measured.

Net balance

In southern Norway net balance was positive for eight of twelve measured glaciers in 2008. The greatest surplus was measured at Blomstølskardsbreen (+1.3 m w.e.) and Nigardsbreen (+1.1 m w.e.). The three measured glaciers in Jotunheimen were all approximately in balance. In northern Norway, Engabreen had a slight surplus, while Langfjordjøkelen had the twelfth successive year with deficit.

The results from the mass balance measurements in Norway in 2008 are shown in Table 1-1. Winter ($\mathbf{b_w}$,), summer ($\mathbf{b_s}$) and net balance ($\mathbf{b_n}$) are given in metres water equivalent (m w.e.) smoothly distributed over the entire glacier surface. The figures in the **% of average** column show the current results in percent of the average for the previous years (minimum eight years of measurements). The net balance results are compared with the mean net balance in the same way. **ELA** is the equilibrium line altitude (m a.s.l.) and **AAR** is the accumulation area ratio (%).

Table 1-1
Review of the results from mass balance measurements performed in Norway in 2008. The glaciers in southern Norway are listed from west to east.

Glacier	*Period*	*Area (km^2)*	*Altitude (m a.s.l.)*	b_w *(m)*	*% of average*	b_s *(m)*	*% of average*	b_n *(m)*	b_n *middle*	*ELA*	*AAR %*
Ålfotbreen	1963-08	4.5	903-1382	4.04	108	−3.35	94	0.69	0.17	1130	79
Hansebreen	1986-08	3.1	930-1327	3.90	113	−3.65	92	0.25	−0.49	1125	64
Svelgjabreen	2007-08	22.5	832-1636	3.65	-	−2.88	-	0.77	-	1225	75
Blomstølskardsbreen	2007-08	22.8	1013-1636	3.69	-	−2.36	-	1.33	-	1260	86
Breidablikkbrea	1963-68 2003-08	3.9 3.4	1219-1660 1234-1651	2.71	[1] 117	−2.96	[1] 99	−0.25	−0.19 [1] −0.65	1505	46
Gråfjellsbrea	1964-68 1974-75 2003-08	9.4 8.4	1039-1660 1049-1651	2.72	[2] 112	−2.80	[2] 102	−0.08	0.20 [2] −0.33	1580	59
Nigardsbreen	1962-08	47.8	320-1960	3.01	126	−1.92	96	1.09	0.39	1325	91
Austdalsbreen	1988-08	11.8	1200-1757	2.55	116	[3] −2.62	105	−0.07	−0.28	1420	71
Rembesdalsskåka	1963-08	17.1	1020-1865	2.61	124	−2.16	108	0.45	0.10	1610	82
Storbreen	1949-08	5.4	1390-2100	1.99	139	−1.88	109	0.11	−0.29	1770	51
Hellstugubreen	1962-08	3.0	1480-2210	1.41	129	−1.47	100	−0.06	−0.38	1880	57
Gråsubreen	1962-08	2.3	1830-2290	0.95	125	−0.86	77	0.09	−0.36	Undef.	-
Engabreen	1970-08	38.7	89-1574	2.81	96	−2.50	107	0.31	0.60	1093	77
Langfjordjøkelen	1989-93 1996-08	3.2	280-1050	1.67	[4] 77	−2.02	[4] 67	−0.35	[4] −0.87	835	53

[1] *Calculated for the measured periods 1963-68 and 2003-07*
[2] *Calculated for the measured periods 1964-68, 1974-75 and 2003-07*
[3] *Contribution from calving amounts to 0.31 m for b_s*
[4] *Calculated for the measured periods 1989-93 and 1996-2007*

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2008. The west-east gradient is evident for both winter and summer balances.

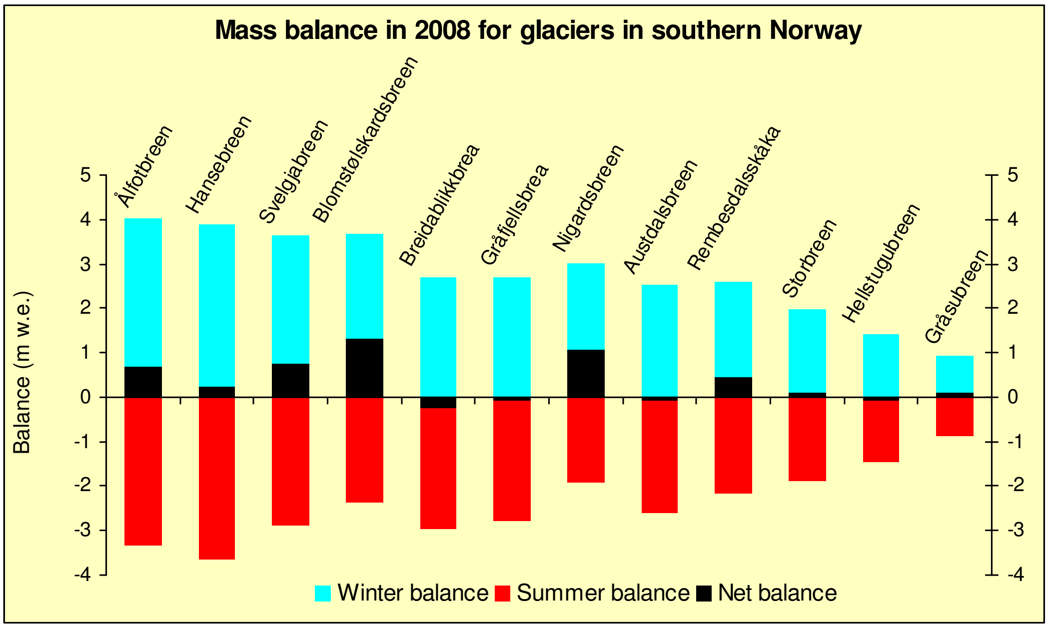


Figure 1-3
Mass balance 2008 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-time series during the period 1963-2008 is shown in Figure 1-4. The maritime glaciers – Ålfotbreen, Nigardsbreen and Rembesdalsskåka showed a marked increase in volume during the period 1989-95. The surplus was mainly the result of several winters with heavy snowfall. The results for 2008 also show a positive net balance for seven of twelve measured glaciers in southern Norway.

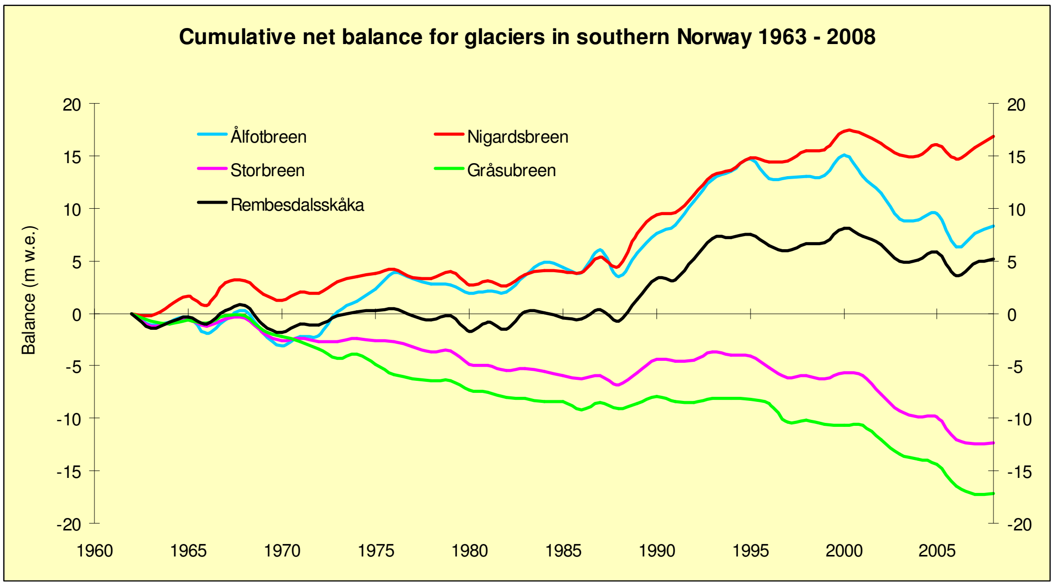


Figure 1-4
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka (Hardangerjøkulen), Storbreen and Gråsubreen during the period 1963-2008.

1.2 Other investigations

Glacier length change measurements were performed at 32 glaciers in Norway in 2008. 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 2008.

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

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 Ålfotbreen. The adjacent glacier to the east of Ålfotbreen has been given the name Hansebreen, and has been measured since 1986. None of the outlet glaciers from the icecap are given names on the official maps. Ålfotbreen, including its component parts and surroundings, is shown in Figure 2-1.

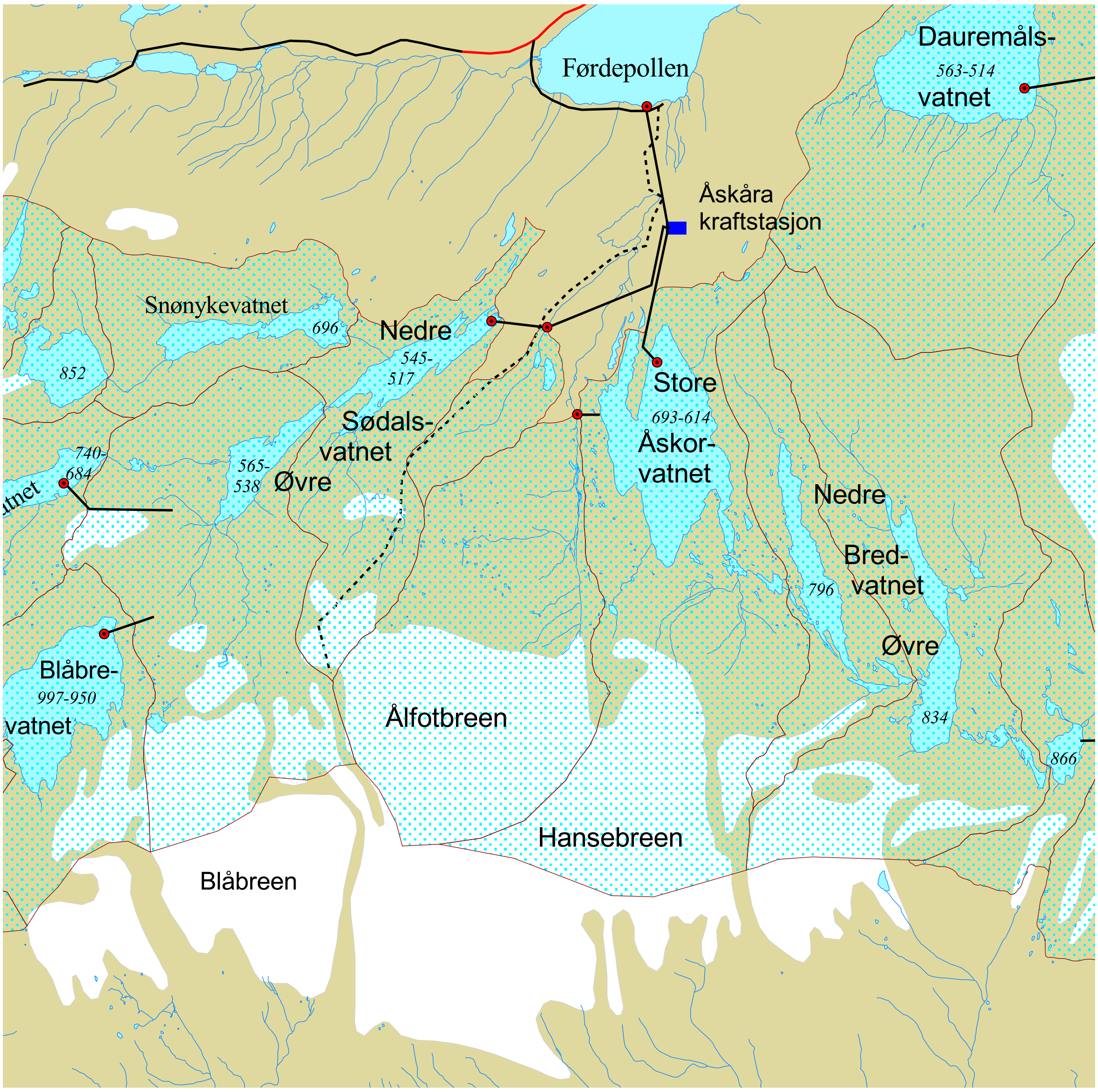


Figure 2-1
Ålfotbreen ice cap and surrounding area, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed.

2.1 Mass balance 2008

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 21st and 22nd April. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Measurements of stake replacements and older stakes that appeared during the melt season at positions 12 (960 m a.s.l.), 13 (1100 m a.s.l.), 45 (1180 m a.s.l.), 37 (1225 m a.s.l.) and 28 (1240 m a.s.l.) on Ålfotbreen. Measurements of stake replacements and older stakes that appeared during the melt season in positions 50 (1020 m a.s.l.), 60 (1070 m a.s.l.) and 80 (1125 m a.s.l.) on Hansebreen.
- 46 snow depth soundings between 930 and 1380 m elevation on Ålfotbreen, and 43 snow depth soundings between 955 and 1310 m elevation on Hansebreen. The snow depth at Ålfotbreen was generally between 8 and 10 m, while measurements at Hansebreen showed snow depths between 7 and 10 m. In spite of deep snow the summer surface (SS) could be identified easily on both glaciers.
- Snow density was measured down to 6.2 m depth (SS at 7.8 m) at stake position 37.

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

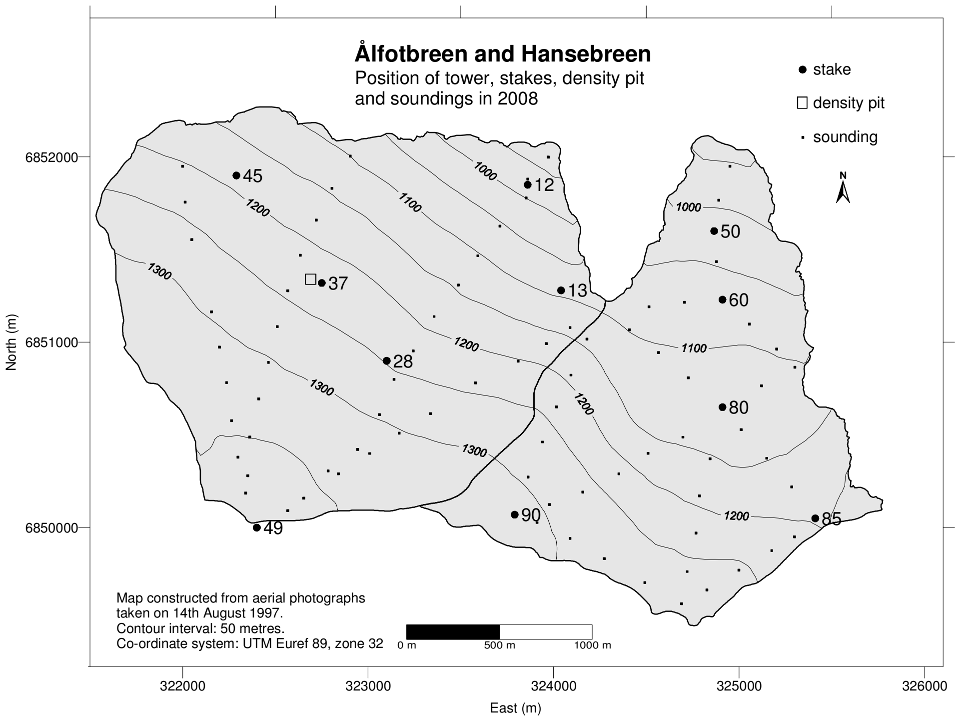


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen (left) and Hansebreen (right) in 2008.

Ablation measurements

Ablation was measured on 31st October. The net balance was measured directly at stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was between 2 and 3 m of snow remaining in the upper areas of the glacier. At the time of the ablation measurements between 1 and 1.5 m of fresh snow had fallen.

Figure 2-3
Measurement and maintenance of stake 49 on Ålfotbreen in August. 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 2007.

A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 7.8 m snow was 0.48 g/cm^3. The density model was assumed to be representative for both Ålfotbreen and Hansebreen, and all snow depths were converted to water equivalents using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalents) in a diagram. A curve was drawn based on a visual evaluation (Fig. 2-5) and a mean value for each 50 m height interval was estimated (Tab. 2-1).

Winter balance at Ålfotbreen in 2008 was 4.0 ±0.2 m w.e., corresponding to a volume of 18 ±1 mill. m^3 of water. The result is 108 % of the mean winter balance for 1963-2007, and 102 % of the mean for 1986-2007 (same measurement period as Hansebreen).

The winter balance at Hansebreen was 3.9 ±0.2 m w.e., corresponding to a volume of 12 ±1 mill. m^3 of water. The result is 113 % of the mean value.

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 summarised. Using this method, which is a control of the traditional method, gave 4.0 m w.e. for Ålfotbreen and 3.8 m w.e. for Hansebreen.

Summer balance

The density of remaining snow was estimated as 0.60 g/cm^3. The density of one year old melted firn was estimated as 0.65 g/cm^3, while the density of ice was taken as 0.90 g/cm^3.

The summer balance at Ålfotbreen was measured and calculated directly at stakes in six different positions. The calculated values increased from 2.3 m w.e. at the glacier summit (1380 m a.s.l.) to 5.2 m on the tongue (960 m a.s.l.). Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −3.4 ±0.3 m w.e., corresponding to −15 ±1 mill. m^3 of water. This result is 94 % of the average between 1963 and 2007, and 88 % of the average between 1986 and 2007.

The summer balance for Hansebreen was measured and calculated at stakes in five different positions. It increased from −2.8 m w.e. at 1310 m elevation to −4.9 m w.e. at 1020 m elevation. Based on the stake measurements and the estimated density, the summer balance was calculated as −3.6 ±0.3 m w.e. or −11 ±1 mill. m^3 of water. The result is 92 % of the mean value.

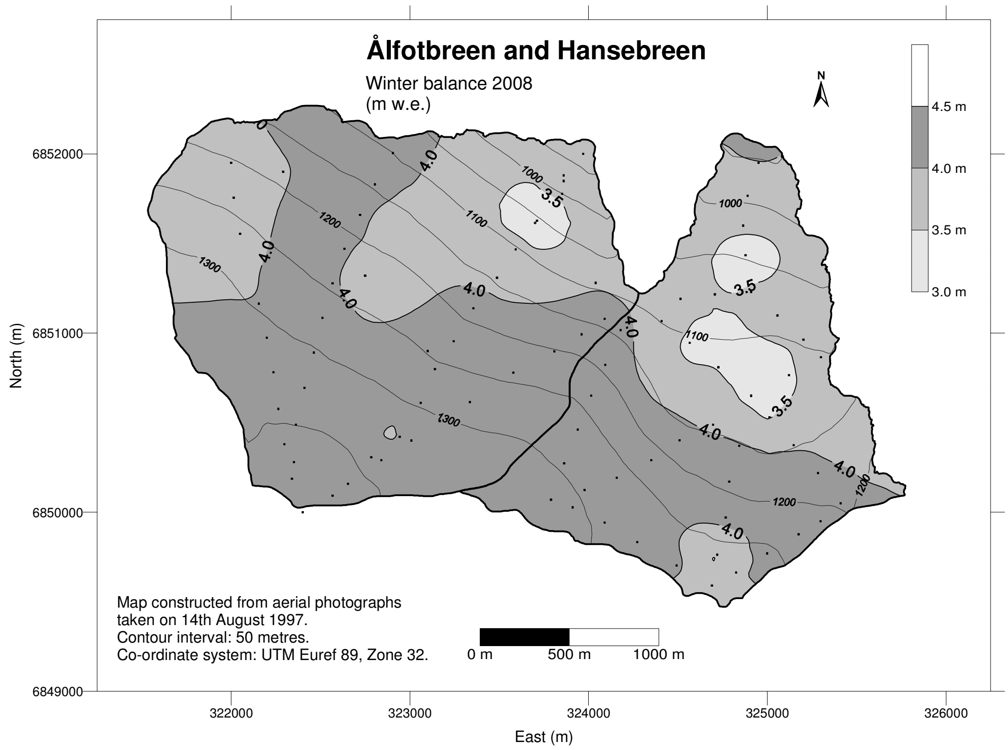


Figure 2-4
Winter balance at Ålfotbreen and Hansebreen in 2008 interpolated from 98 snow depth measurements, shown by (·).

Net balance

The net balance at Ålfotbreen for 2008 was positive, at +0.7 ±0.4 m w.e., or a surplus of 3 ±2 mill. m^3 of water. The mean net balance between 1963 and 2007 is +0.17 m w.e., and +0.15 m w.e. during 1986-2007. Since measurements started at Ålfotbreen in 1963 the cumulative net balance is +8.3 m w.e. Since 1996, however, the net balance shows a deficit of −6.4 m w.e.

The net balance at Hansebreen was calculated as +0.3 ±0.4 m w.e., or a surplus of 1 ±1 mill. m^3 of water. The mean value for the period 1986-2007 is −0.49 m w.e. After six successive years with negative net balance this is the second year with surplus on Hansebreen since 2000. Since measurements began in 1986 the cumulative net balance is −10.5 m w.e.

According to Figure 2-5 the Equilibrium Line Altitude (ELA) lies at 1130 m a.s.l. on Ålfotbreen and at 1125 m a.s.l. on Hansebreen. Consequently, the AAR is 79 % and 64 % 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.

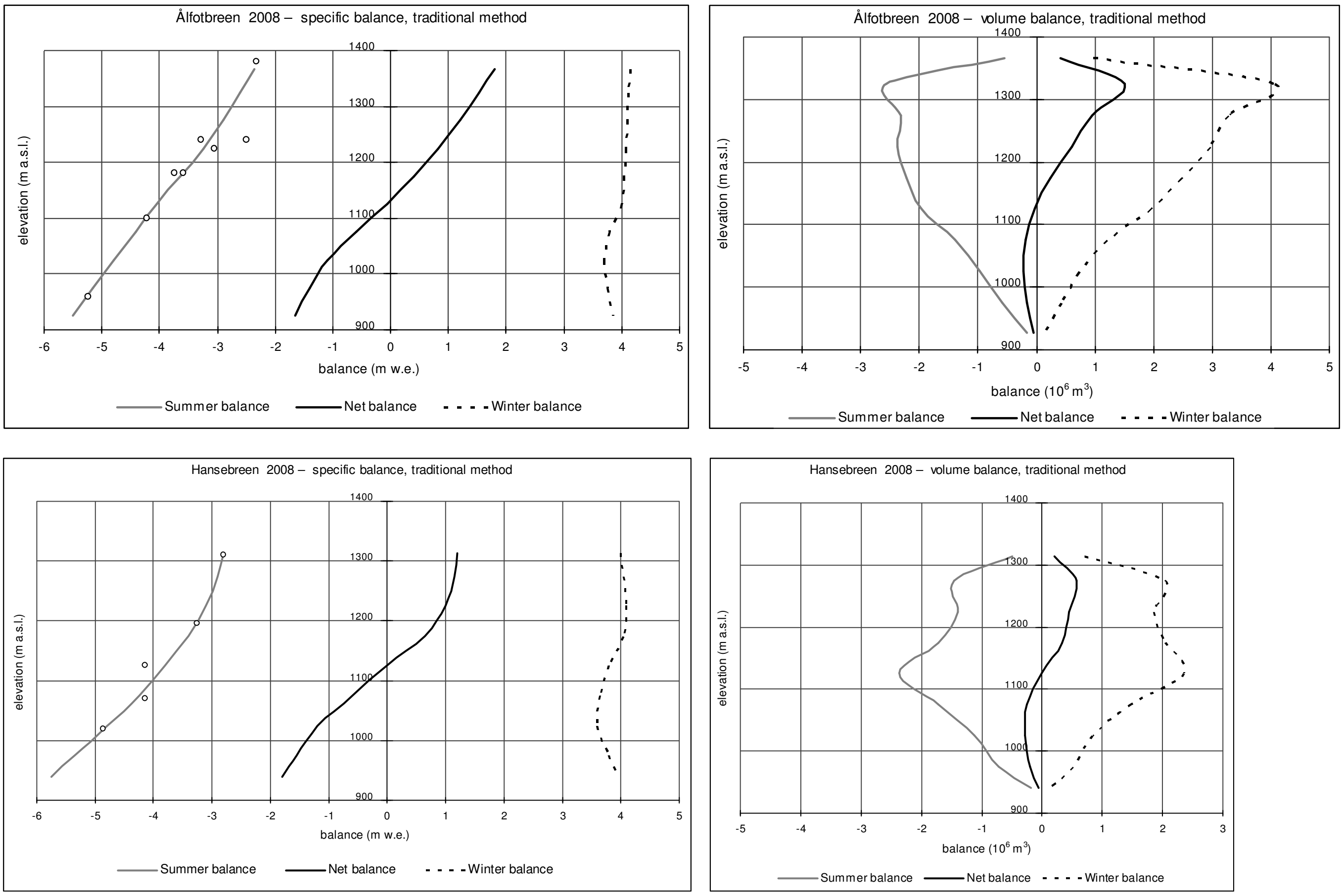


Figure 2-5
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2008 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).

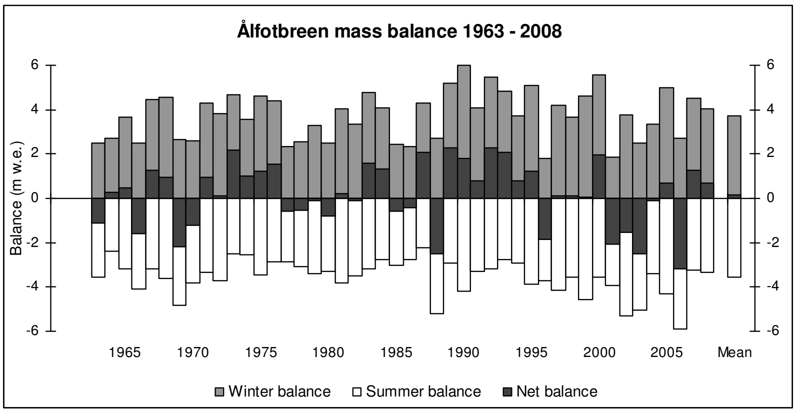
Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2008.

Mass balance Ålfotbreen 2007/08 – traditional method

		Winter balance Measured 21st Apr 2008		Summer balance Measured 31st Oct 2008		Net balance Summer surfaces 2007 - 2008	
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)
1350 - 1382	0.23	4.15	1.0	-2.35	-0.5	1.80	0.4
1300 - 1350	0.98	4.13	4.1	-2.60	-2.6	1.53	1.5
1250 - 1300	0.80	4.10	3.3	-2.90	-2.3	1.20	1.0
1200 - 1250	0.73	4.08	3.0	-3.25	-2.4	0.83	0.6
1150 - 1200	0.61	4.05	2.5	-3.65	-2.2	0.40	0.2
1100 - 1150	0.49	4.00	1.9	-4.05	-2.0	-0.05	0.0
1050 - 1100	0.32	3.80	1.2	-4.40	-1.4	-0.60	-0.2
1000 - 1050	0.20	3.70	0.7	-4.80	-1.0	-1.10	-0.2
950 - 1000	0.11	3.75	0.4	-5.15	-0.6	-1.40	-0.2
903 - 950	0.03	3.85	0.1	-5.50	-0.2	-1.65	-0.1
903 - 1382	**4.50**	**4.04**	**18.2**	**-3.35**	**-15.1**	**0.68**	**3.1**

Mass balance Hansebreen 2007/08 – traditional method

		Winter balance Measured 21st Apr 2008		Summer balance Measured 31st Oct 2008		Net balance Summer surface 2007 - 2008	
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)
1300 - 1327	0.18	4.00	0.71	-2.80	-0.49	1.20	0.21
1250 - 1300	0.50	4.05	2.03	-2.90	-1.45	1.15	0.58
1200 - 1250	0.45	4.10	1.85	-3.10	-1.40	1.00	0.45
1150 - 1200	0.51	4.05	2.05	-3.40	-1.72	0.65	0.33
1100 - 1150	0.62	3.80	2.36	-3.80	-2.36	0.00	0.00
1050 - 1100	0.40	3.65	1.47	-4.25	-1.71	-0.60	-0.24
1000 - 1050	0.23	3.60	0.84	-4.80	-1.12	-1.20	-0.28
950 - 1000	0.13	3.80	0.51	-5.35	-0.71	-1.55	-0.21
930 - 950	0.03	3.95	0.13	-5.75	-0.19	-1.80	-0.06
930 - 1327	**3.06**	**3.90**	**11.9**	**-3.65**	**-11.2**	**0.26**	**0.8**



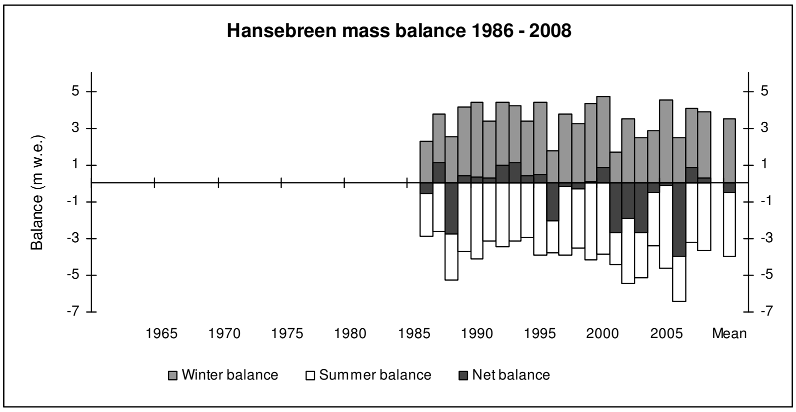


Figure 2-6
Mass balance at Ålfotbreen (upper) 1963-2008 and Hansebreen (lower) 1986-2008.

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 northwestward-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 southward-facing glaciers Svelgjabreen (22.5 km^2) and Blomstølskardsbreen (22.8 km^2).

Mass balance measurements were previously carried out at Breidablikkbrea during 1963-68 (Pytte, 1969) and at Gråfjellsbrea during the periods 1964-68 and 1974-75 (Wold and Hagen, 1977). The historical results are presented in Figure 3-4. Mass balance measurements were also carried out at Svelgjabreen/Blomstølskardsbreen (then called Blomsterskardsbreen) in 1971 (Tvede, 1973), and net balance only was measured in the period 1972-77.

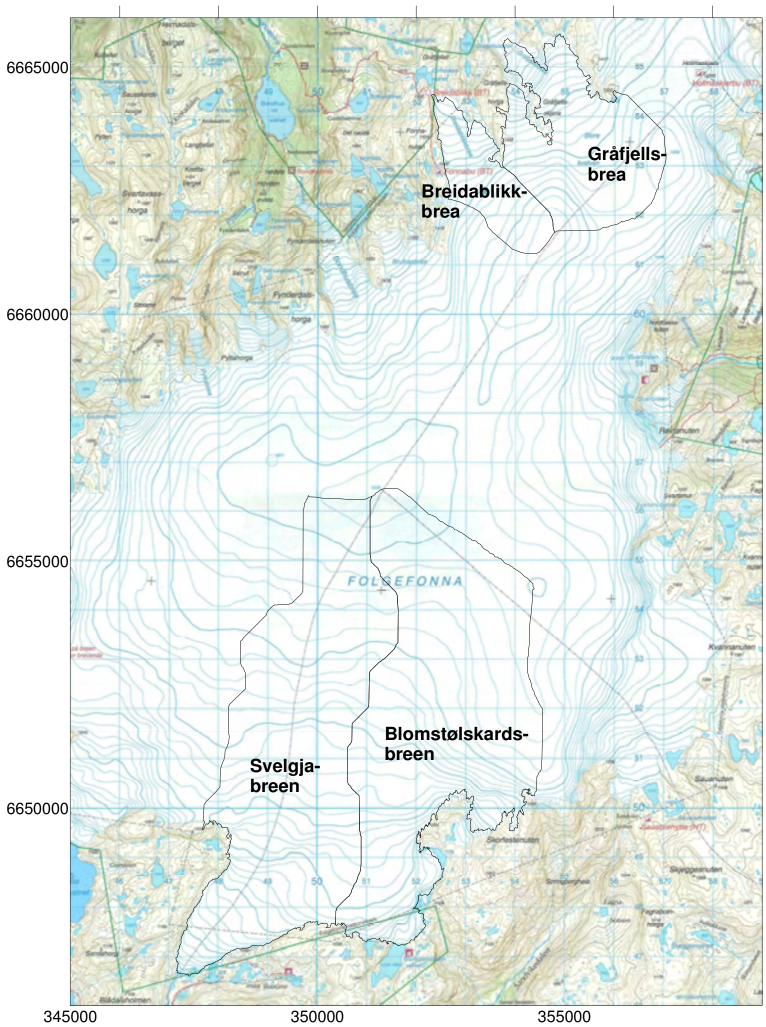


Figure 3-1
Southern Folgefonna with Breidablikkbrea and Gråfjellsbrea in the northwest and Svelgjabreen and Blomstølskardsbreen in the south.

3.1 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2008

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 22nd and 23rd April. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-2):

- Measurement of stakes at positions 40 (1247 m a.s.l.), 47 (1420 m a.s.l.) and T60 (1641 m a.s.l.) on Breidablikkbrea and measurement of a stake in position 10 (1073 m a.s.l.), 15 (1267 m a.s.l.), 20 (1345 m a.s.l.), 25 (1474 m a.s.l.), 30 (1546 m a.s.l.) and T60 on Gråfjellsbrea. Measurements of stake replacements and older stakes that appeared during the melt season at position 55 and 56 (both 1564 m a.s.l.) on Breidablikkbrea.
- 48 snow depth soundings between 1247 and 1645 m a.s.l. on Breidablikkbrea, and 66 snow depth soundings between 1260 and 1641 m a.s.l. on Gråfjellsbrea. The sounding conditions were reasonable on both glaciers. However, the snow depth may be some uncertain in areas with snow remaining from winter 2007. Generally, the snow depth varied between 5 and 6 m.
- A core sample and snow density was measured down to the summer surface (5.4 m) at position 25 at Gråfjellsbrea.

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

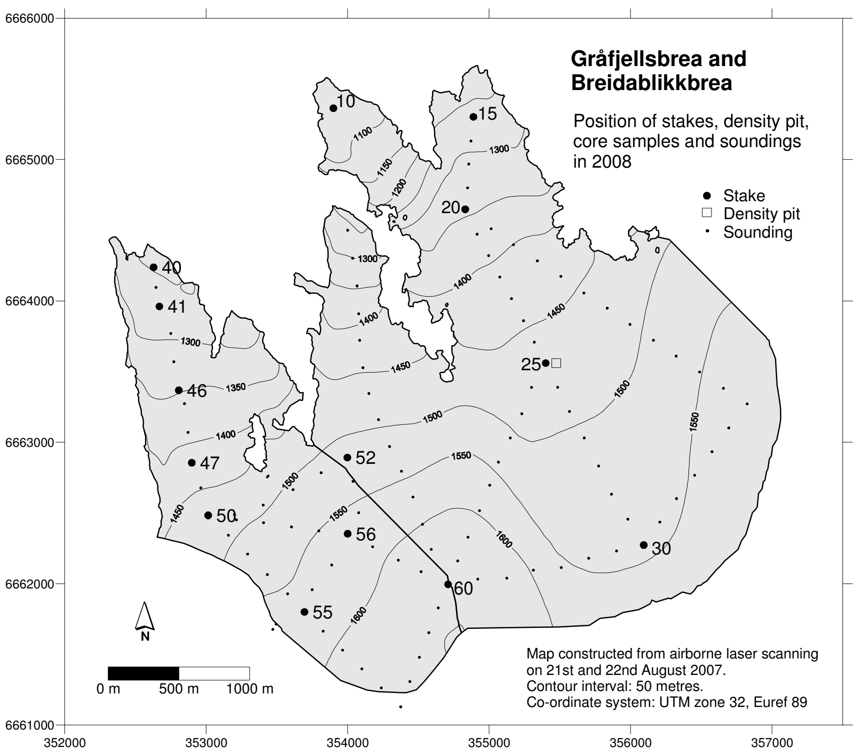


Figure 3-2 Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2008.

Ablation measurements

Ablation was measured on 23rd September (Fig. 3-3). The net balance was measured at stakes in nine different positions on Breidablikkbrea and seven positions on Gråfjellsbrea. There was about 1 m of snow remaining in the upper areas of the glacier. No fresh snow had fallen at the time of the ablation measurements.

The glacier was visited again on 4th December. Some of the stakes were extended and the fresh snow layer was sounded. A comparison of the stake measurements and the probings showed that some melting had occurred after the ablation measurements in September. Between 5 and 20 cm melting had occurred at the stakes below 1350 m a.s.l.

Figure 3-3
Gråfjellsbrea photographed on 23rd September 2008.
Photo: Geir Johan Knudsen.

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 measurements in December 2007 indicated some melting after the final measurements in September 2007. This melting was included in the 2007 summer balance.

A density profile was modelled from the snow density measured at 1474 m a.s.l. The mean snow density of 5.4 m snow was 0.49 g/cm^3. The density model was assumed to be representative for both Breidablikkbrea and Gråfjellsbrea, and all snow depths were converted to water equivalent using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 3-5) and a mean value for each 50 m height interval was estimated (Tab. 3-1).

Winter balance at Breidablikkbrea in 2008 was 2.7 ±0.2 m w.e., corresponding to a volume of 9 ±1 mill. m^3 of water. The result is 117 % of the average for the periods 1963-68 and 2003-07.

The winter balance at Gråfjellsbrea was 2.7 ±0.2 m w.e., corresponding to a volume of 23 ±1 mill. m^3 of water. This result is 112 % of the average for 1964-68, 1974-75 and 2003-07.

As verification, the winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 3-4). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. This method gave results of 2.6 m w.e. for Breidablikkbrea and 2.7 m w.e. for Gråfjellsbrea.

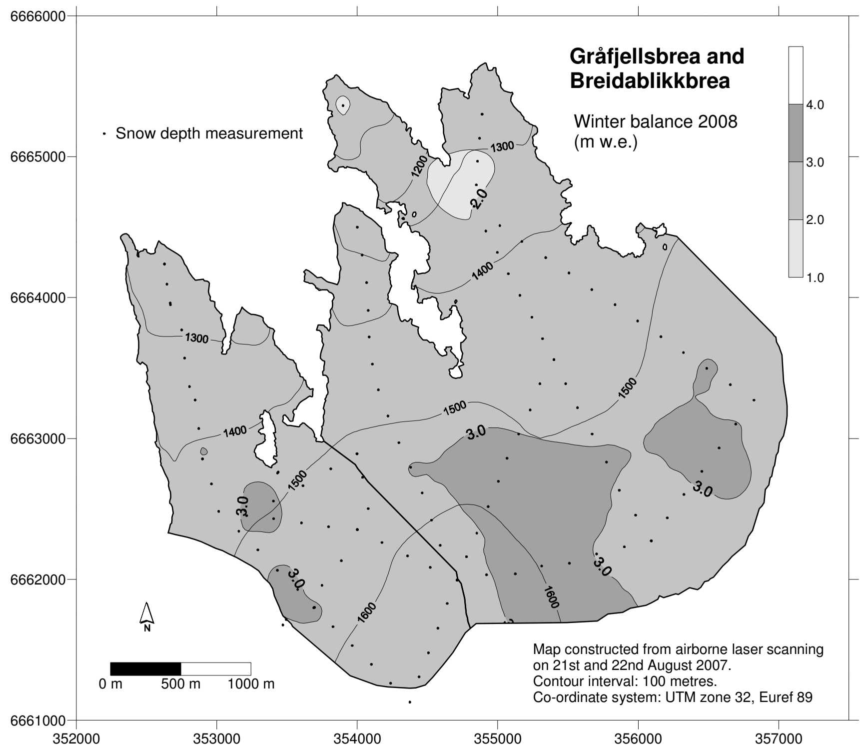


Figure 3-4 Winter balance at Breidablikkbrea and Gråfjellsbrea in 2008 interpolated from 125 snow depth measurements (·).

Summer balance

When calculating the summer balance the density of remaining snow was estimated as 0.60 g/cm^3. The density of melted firn was estimated as 0.65 g/cm^3, and the density of melted ice was assumed to be 0.90 g/cm^3.

The melting that occurred after the ablation measurement at the end of September 2008 is included in the summer balance for 2008. The additional melting is calculated to be 0.05-0.20 m w.e. at the elevation interval from 1347 to 1073 m a.s.l.

The summer balance at Breidablikkbrea was measured and calculated at nine stakes. The stake values increased from 2.0 m w.e. at the topmost stake to 4.3 m w.e. at the lowest stake position. 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 99 % of the mean value for 1963-68 and 2003-07.

The summer balance for Gråfjellsbrea was measured and calculated at seven stakes. The stake values increased from 2.0 m w.e. at the topmost stake to 5.1 m w.e. at the lowest stake position. Based on the seven stakes and the estimated density the summer balance was calculated as –2.8 ±0.3 m w.e. or –24 ±1 mill. m^3 of water. This is 102 % of the mean value for 1964-68, 1974-75 and 2003-07.

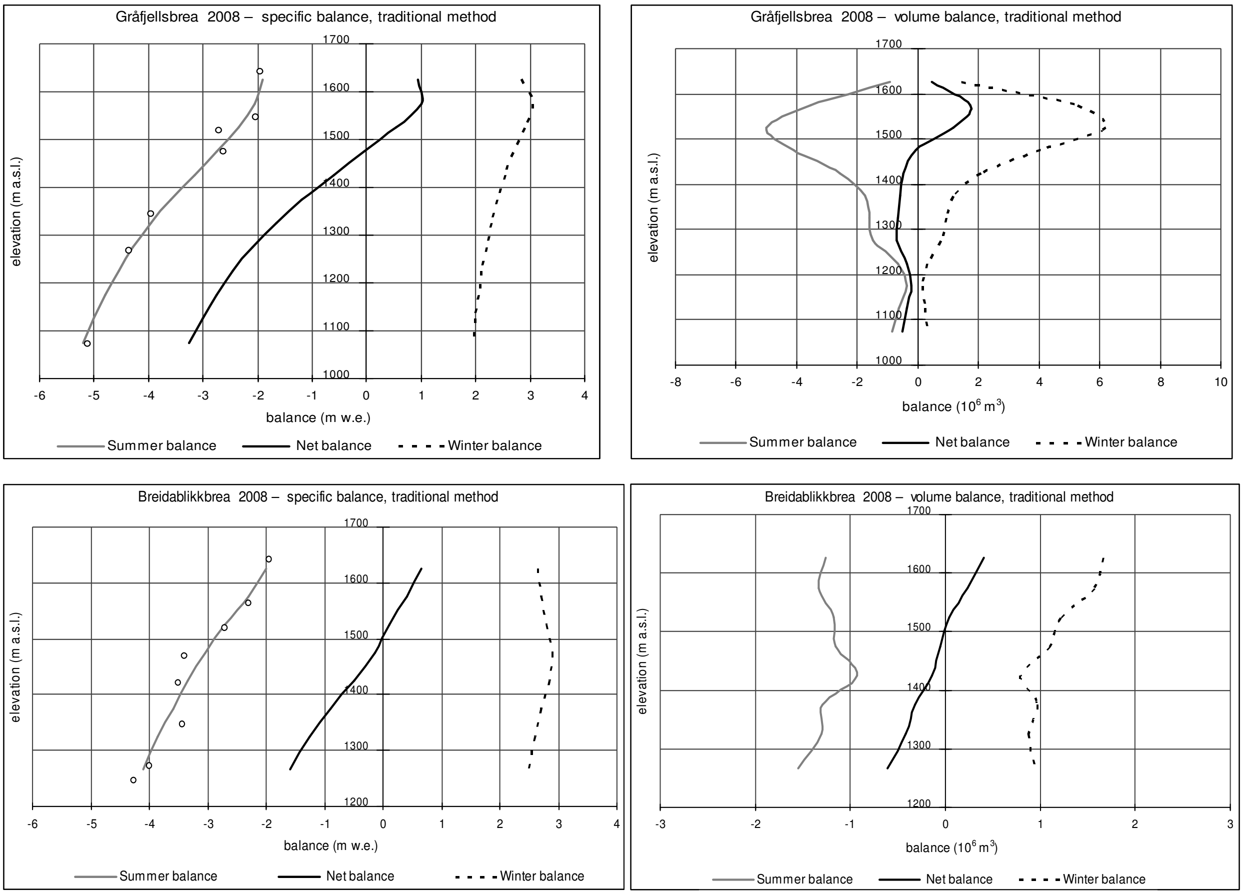


Figure 3-5
Mass balance diagram for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2008 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○). Melting after the ablation measurements on 23rd September is included in the summer balance for 2008.

Net balance

The net balance at Breidablikkbrea for 2008 was calculated as –0.3 ±0.4 m w.e. or a deficit of –1 ±2 mill. m^3 of water. The mean net balance for 1963-68 and 2003-07 is –0.65 m w.e.

The net balance at Gråfjellsbrea was calculated as –0.1 ±0.4 m w.e. or a deficit of –1 ±2 mill. m^3 of water. The mean value for the years 1964-68, 1974-75 and 2003-07 is –0.33 m w.e.

As shown in Figure 3-5, the Equilibrium Line Altitude (ELA) lies at 1505 m a.s.l. on Breidablikkbrea and 1480 m a.s.l. on Gråfjellsbrea. Consequently, the Accumulation Area Ratio (AAR) is 46 % and 59 % respectively.

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

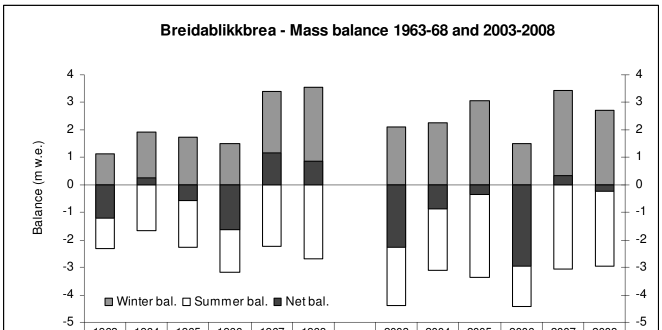
Table 3-1
Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2008.

Mass balance Breidablikkbrea 2007/08 – traditional method

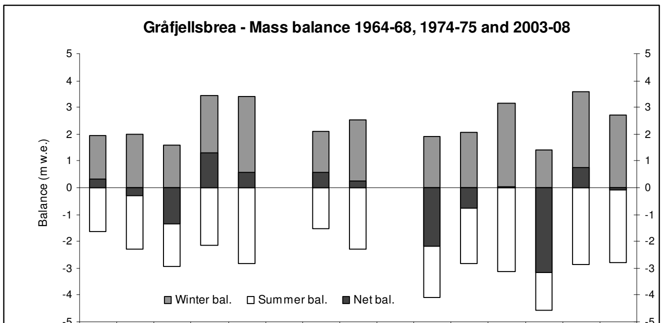
		Winter balance		Summer balance		Net balance	
		Measured 22nd April 2008		Measured 23rd Sep 2008		Summer surfaces 2007 - 2008	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1651	0.63	2.65	1.7	-2.00	-1.3	0.65	0.4
1550 - 1600	0.58	2.70	1.6	-2.30	-1.3	0.40	0.2
1500 - 1550	0.43	2.80	1.2	-2.70	-1.2	0.10	0.0
1450 - 1500	0.38	2.90	1.1	-3.05	-1.2	-0.15	-0.1
1400 - 1450	0.28	2.85	0.8	-3.35	-0.9	-0.50	-0.1
1350 - 1400	0.36	2.70	1.0	-3.60	-1.3	-0.90	-0.3
1300 - 1350	0.34	2.60	0.9	-3.85	-1.3	-1.25	-0.4
1234 - 1300	0.38	2.50	0.9	-4.10	-1.6	-1.60	-0.6
1234 - 1651	**3.37**	**2.71**	**9.1**	**-2.96**	**-10.0**	**-0.26**	**-0.9**

Mass balance Gråfjellsbrea 2007/08 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 22nd April 2008		Measured 23rd Sep 2008		Summer surfaces 2007 - 2008	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1651	0.50	2.85	1.4	-1.90	-0.9	0.95	0.5
1550 - 1600	1.72	3.05	5.3	-2.05	-3.5	1.00	1.7
1500 - 1550	2.13	2.90	6.2	-2.35	-5.0	0.55	1.2
1450 - 1500	1.49	2.70	4.0	-2.75	-4.1	-0.05	-0.1
1400 - 1450	0.81	2.55	2.1	-3.15	-2.6	-0.60	-0.5
1350 - 1400	0.49	2.40	1.2	-3.60	-1.8	-1.20	-0.6
1300 - 1350	0.41	2.30	0.9	-3.95	-1.6	-1.65	-0.7
1250 - 1300	0.34	2.20	0.8	-4.30	-1.5	-2.10	-0.7
1200 - 1250	0.15	2.10	0.3	-4.55	-0.7	-2.45	-0.4
1150 - 1200	0.08	2.05	0.2	-4.80	-0.4	-2.75	-0.2
1100 - 1150	0.12	2.00	0.2	-5.00	-0.6	-3.00	-0.4
1049 - 1100	0.16	1.95	0.3	-5.20	-0.8	-3.25	-0.5
1049 - 1651	**8.41**	**2.72**	**22.9**	**-2.80**	**-23.5**	**-0.08**	**-0.7**



	1963	1964	1965	1966	1967	1968		2003	2004	2005	2006	2007	2008
Winter bal.	1.11	1.92	1.72	1.52	3.40	3.55		2.12	2.25	3.04	1.49	3.42	2.71
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
Net bal.	-1.21	0.24	-0.56	-1.65	1.17	0.87		-2.26	-0.87	-0.33	-2.95	0.35	-0.25



	1964	1965	1966	1967	1968		1974	1975		2003	2004	2005	2006	2007	2008
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	2.72
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
Net bal.	0.32	-0.28	-1.35	1.32	0.57		0.58	0.25		-2.18	-0.77	0.02	-3.15	0.75	-0.08

Figure 3-6
Winter, summer and net balance at Breidablikkbrea for the periods 1963-68 and 2003-08 (upper figure), and at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-08 (lower figure).

3.2 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2008

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 21st and 22nd April. The calculation of winter balance at Svelgjabreen and Blomstølskardsbreen is based on (Fig. 3-7):

- Measurement of stakes at positions 10 (978 m a.s.l.), 20 (1156 m a.s.l.) and 30 (1245 m a.s.l.) on Svelgjabreen and measurement of stakes at positions 25 (1232 m a.s.l.) and 45 (1428 m a.s.l.) on Blomstølskardsbreen. Measurements of stake replacements and older stakes that appeared during the melt season at position 40 (1363 m a.s.l.) on Svelgjabreen and positions 35 (1351 m a.s.l.) and 75 (1585 m a.s.l.).
- 26 snow depth soundings between 920 and 1628 m a.s.l. on Svelgjabreen, and 48 snow depth soundings between 1082 and 1624 m a.s.l. on Blomstølskardsbreen. In the lower areas the summer surface (SS) was easy to define. In the upper areas the SS was rather difficult to determine. However, by taking a couple of core samples, the SS was easily defined in these areas too. The snow depth varied between 4 and 9 m at Svelgjabreen, and between 6 and 9 m at Blomstølskardsbreen.
- Snow density was measured down to 7.7 m (SS) at stake position 65 (1530 m a.s.l.) (1530 m a.s.l.) at Blomstølskardsbreen.

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

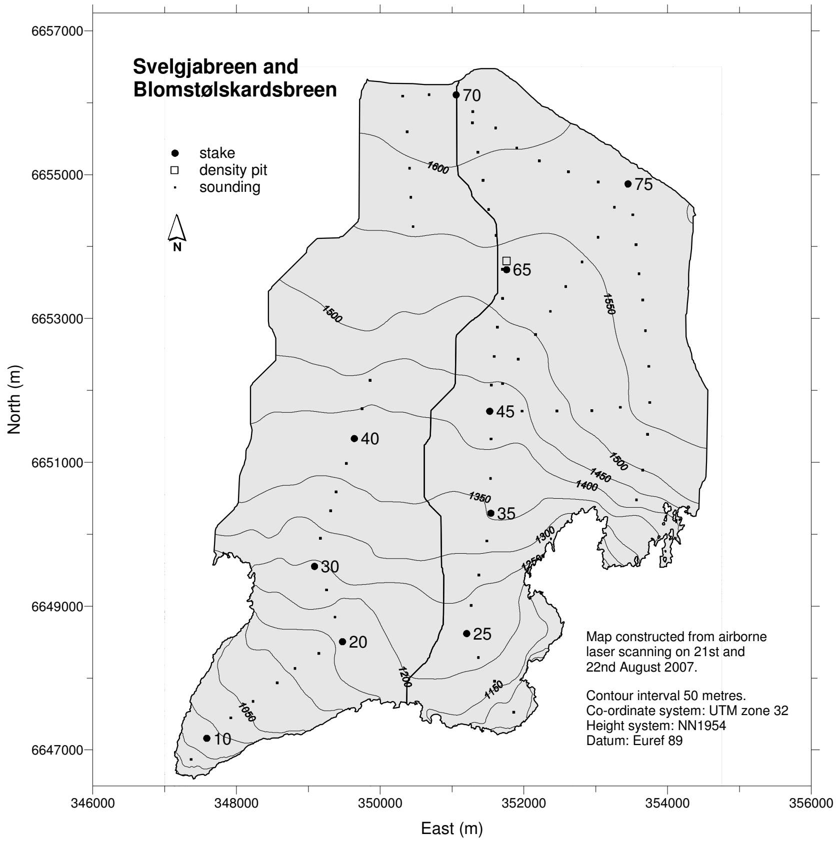


Figure 3-7 Location of stakes, soundings and density pit at Svelgjabreen and Blomstølskardsbreen in 2008.

Ablation measurements

Ablation was measured on 23rd September. The net balance was measured at stakes in ten different positions on the two glaciers. There was up to 4.5 m of snow remaining in the upper areas of the glacier. No fresh snow had fallen at the time of the ablation measurements.

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 1530 m a.s.l. The mean snow density of 7.7 m snow was 0.50 g/cm^3. The density model was assumed to be representative for both Svelgjabreen and Blomstølskardsbreen, and all snow depths were converted to water equivalent using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 3-9) and a mean value for each 50 m height interval was estimated (Tab. 3-2).

Winter balance at Svelgjabreen in 2008 was 3.6 ±0.2 m w.e., corresponding to a volume of 82 ±4 mill. m^3 of water. The winter balance at Blomstølskardsbreen was 3.7 ±0.2 m w.e., corresponding to a volume of 84 ±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 summarised. This method gave the same results: 3.6 and 3.7 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 0.60 g/cm^3. The density of melted ice was assumed to be 0.90 g/cm^3.

The summer balance at Svelgjabreen was measured at six stakes. The stake values increased from 1.3 m w.e. (1632 m a.s.l.) to 5.0 m w.e. (978 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated as −2.9 ±0.3 m w.e. corresponding to −65 ±6 mill. m^3 of water.

The summer balance for Blomstølskardsbreen was measured and calculated at six stakes. The stake values increased from 1.3 m w.e. (1632 m a.s.l.) to 2.9 m w.e. (1232 m a.s.l.). Based on the six stakes and the estimated density the summer balance was calculated as −2.4 ±0.3 m w.e. or −54 ±6 mill. m^3 of water.

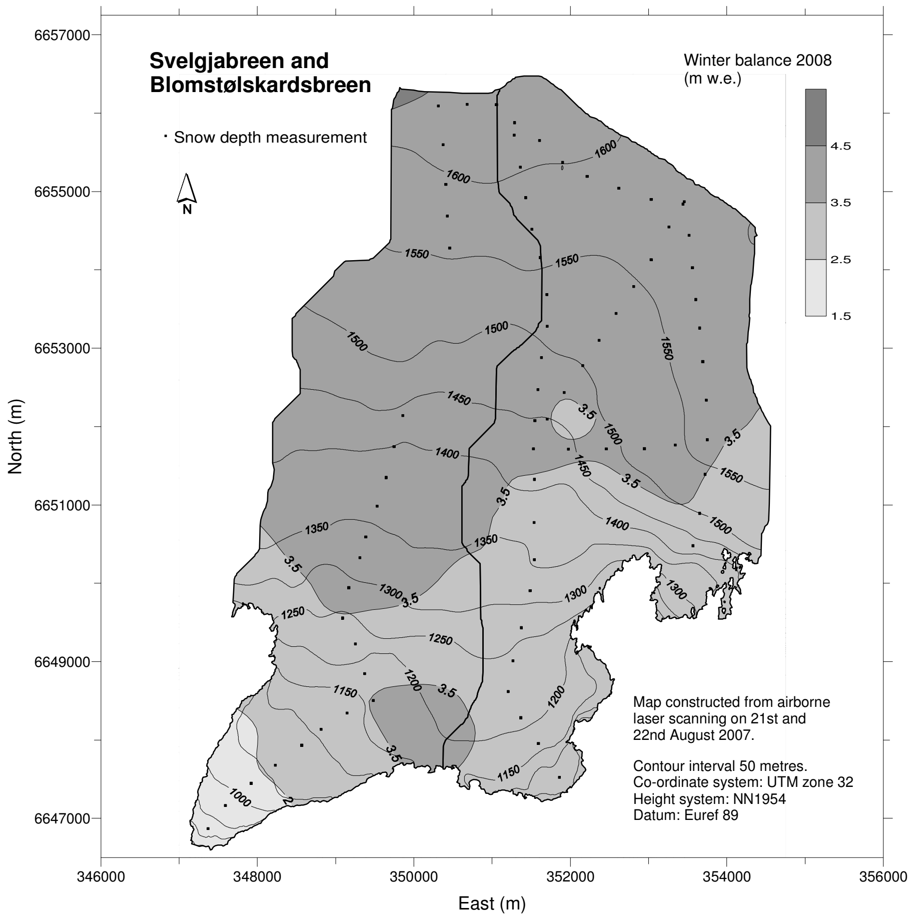


Figure 3-8
Winter balance at Svelgjabreen and Blomstølskardsbreen in 2008 interpolated from 85 snow depth measurements (·).

Net balance

The net balance at Svelgjabreen for 2008 was calculated as +0.8 ±0.4 m w.e. or a surplus of 17 ±9 mill. m^3 of water.

The net balance at Blomstølskardsbreen was calculated as +1.3 ±0.4 m w.e. or a surplus of 30 ±9 mill. m^3 of water.

As shown in Figure 3-9, the equilibrium line altitude (ELA) lies at 1225 m a.s.l. on Svelgjabreen and 1260 m a.s.l. on Blomstølskardsbreen. Consequently, the Accumulation Area Ratio (AAR) is 75 % and 86 % 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.

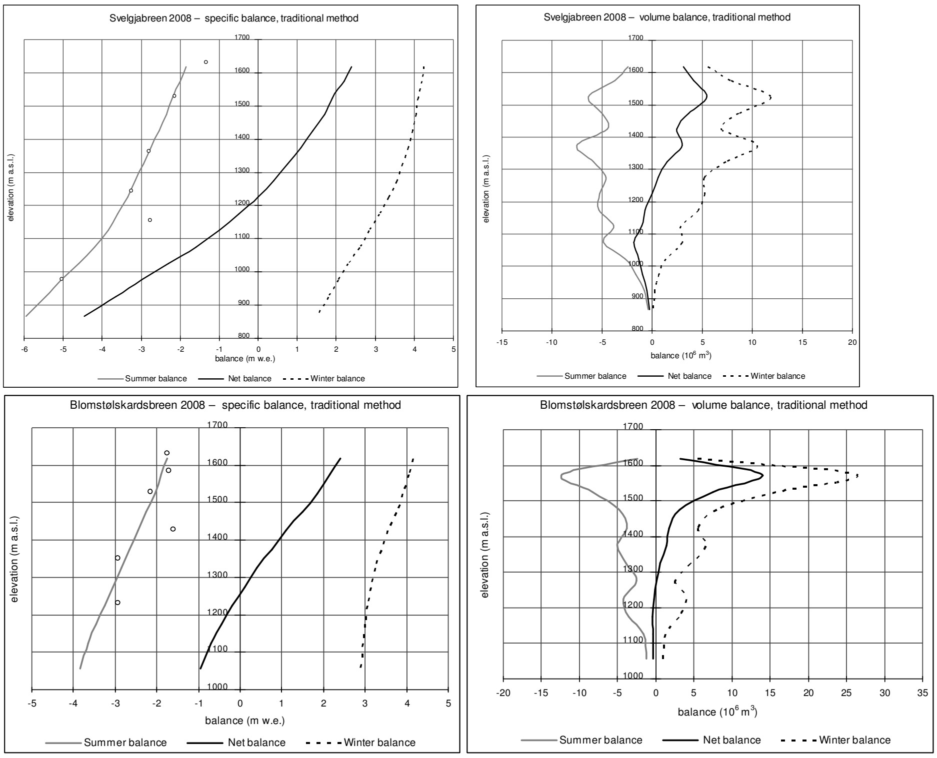


Figure 3-9
Mass balance diagram for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2008 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).

Table 3-2
Winter, summer and net balances for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2008.

Mass balance Svelgjabreen 2007/08 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 21st Apr 2008		Measured 23rd Sep 2008		Summer surface 2007 - 2008	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1636	1.30	4.25	5.5	-1.85	-2.4	2.40	3.1
1550 - 1600	1.87	4.20	7.8	-2.00	-3.7	2.20	4.1
1500 - 1550	2.89	4.10	11.8	-2.20	-6.4	1.90	5.5
1450 - 1500	2.13	4.05	8.6	-2.35	-5.0	1.70	3.6
1400 - 1450	1.75	3.95	6.9	-2.55	-4.5	1.40	2.4
1350 - 1400	2.73	3.85	10.5	-2.75	-7.5	1.10	3.0
1300 - 1350	1.99	3.70	7.4	-2.95	-5.9	0.75	1.5
1250 - 1300	1.47	3.55	5.2	-3.15	-4.6	0.40	0.6
1200 - 1250	1.57	3.35	5.3	-3.35	-5.3	0.00	0.0
1150 - 1200	1.47	3.10	4.6	-3.60	-5.3	-0.50	-0.7
1100 - 1150	1.00	2.85	2.9	-3.85	-3.9	-1.00	-1.0
1050 - 1100	1.16	2.60	3.0	-4.20	-4.9	-1.60	-1.9
1000 - 1050	0.59	2.30	1.4	-4.60	-2.7	-2.30	-1.4
950 - 1000	0.32	2.05	0.7	-5.05	-1.6	-3.00	-1.0
900 - 950	0.14	1.80	0.3	-5.45	-0.8	-3.65	-0.5
832 - 900	0.06	1.50	0.1	-5.95	-0.4	-4.45	-0.3
832 - 1636	**22.45**	**3.65**	**81.9**	**-2.88**	**-64.8**	**0.76**	**17.1**

Mass balance Blomstølskardsbreen 2007/08 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 21st April 2008		Measured 23rd Sep 2008		Summer surfaces 2007 - 2008	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1636	1.35	4.15	5.6	-1.75	-2.4	2.40	3.2
1550 - 1600	6.49	4.05	26.3	-1.90	-12.3	2.15	14.0
1500 - 1550	4.04	3.90	15.8	-2.05	-8.3	1.85	7.5
1450 - 1500	2.11	3.75	7.9	-2.25	-4.8	1.50	3.2
1400 - 1450	1.56	3.55	5.5	-2.45	-3.8	1.10	1.7
1350 - 1400	1.92	3.40	6.5	-2.65	-5.1	0.75	1.4
1300 - 1350	1.37	3.25	4.5	-2.85	-3.9	0.40	0.5
1250 - 1300	0.81	3.15	2.6	-3.05	-2.5	0.10	0.1
1200 - 1250	1.31	3.05	4.0	-3.25	-4.3	-0.20	-0.3
1150 - 1200	1.02	3.00	3.0	-3.45	-3.5	-0.45	-0.5
1100 - 1150	0.45	2.95	1.3	-3.65	-1.6	-0.70	-0.3
1013 - 1100	0.33	2.90	1.0	-3.85	-1.3	-0.95	-0.3
1013 - 1636	**22.77**	**3.69**	**84.0**	**-2.36**	**-53.7**	**1.33**	**30.3**

3.3 The changes in areas of the Folgefonna glaciers during historical times (Arve M. Tvede)

Introduction

The Folgefonna glaciers, situated on the Folgefonna Peninsula about 70 km southeast of Bergen, consist of three separate ice caps called Northern, Middle and Southern Folgefonna. The Southern icecap is by far the largest and is ranked as third largest in Scandinavia in terms of area. There are also several small glaciers in the mountains surrounding the ice caps. In connection with an article published by the author in the book “Folgefonna og fjordbygdene” (Folgefonna and the fjord district) (Brekke, 2008), a calculation of the areas of the glaciers was carried out, based on the newest air photos. The results are presented here and will be compared with earlier calculations of the area of the Folgefonna glaciers.

Data and methodology

The area values from August 1981 and July 2006 were found by applying the planimeter tool to the maps and the air photos at www.Zett.no. The air photos from July 2006 were taken during a summer with extreme negative mass balance (see Kjøllmoen, 2007). The photos expose glacier ice along nearly all the edges of the ice caps, so it is straight forward to draw the correct line for the actual glacier border. The areas of the nunataks are subtracted. The corresponding borders from 1981 are from the official M711 maps which were constructed from air photos taken in August 1981. Glacier area values for 1928-53 and 1959 are taken from Liestøl (1962) and Østrem & Ziegler (1969) respectively. Liestøl used the maps available at that time. The publication years vary between 1928 and 1953, and only the southernmost are based on air photos. It is thus assumed that the quality of the maps is quite variable. The Østrem & Ziegler (1969) values are all from excellent air photos taken in 1959, also a summer with little snow on the glaciers in August.

The values for the areas at the largest historical extent are taken from the University thesis of the author (Tvede), see also Figure 3-11. The glacier borders were mapped using a combination of field studies of moraines, lichen growth and scouring marks on rocks in combination with studies of the air photos from 1959. It must be pointed out that the maximum extent was not synchronous at all the Folgefonna glaciers. Field studies revealed that the maximum extent probably was around 1750 at the northern parts of Søndre Folgefonna, around 1890 at Bondhusbrea and Buerbreen and as late as 1940 at Blomstølskardsbreen and Svelgjabreen (Tvede & Liestøl, 1977).

Results

The results from this and previous studies are presented in table 3-3. It should also be mentioned that the values in the NVE publication “Atlas over breer i Sør-Norge” from 1988, are not included in the table. The area values of Folgefonna in that publication was also based on the air photos from 1981. The value for Southern Folgefonna was presented as 185 km^2. Evidently some mistakes were made as there is no reason to believe that the glacier had increased its size by 13 km^2 since 1959.

Table 3-3
Glacier areas in km^2.

Glacier name	*Largest in historical time (Tvede, 1972)*	*From maps surveyed 1928-53 (Liestøl, 1962)*	*Air photos August 1959 (*NVE, 1969)*	*Air photos August 1981 (Tvede, 2008)*	*Air photos July 2006 (Tvede, 2008)*
Northern Folgefonna	35.4	31.1	27.0	27.3	26.5
Middle Folgefonna	19.8	13.5	12.8	12.0	11.4
Southern Folgefonna	189.2	180.6	171.7	167.8	166.5
Total for the ice caps		225.1	211.5	207.1	204.3
Sum small glaciers	**Estimated 5.0	4.5	1.5	4.8	3.2
Total for all glaciers	Estimated 250	229.6	212.2	211.9	207.5

**Østrem, G & T. Ziegler*

***Not surveyed*

Some comments should be made about the small glaciers. In the survey published in 1962 (Liestøl, 1962) and in 1969 (Østrem & Ziegler, 1969), only 6 "small glaciers" are presented. The survey in 2006 found a total of 68 small glaciers on the air photos. These glaciers ranged in size from 0.01 km^2 to 0.4 km^2. A typical "small glacier" is shown in Figure 3-10. It is evident that the number must have been higher than actually reported also in 1961 and in 1969. The number of small glaciers has, however, probably grown because larger units have been divided into several units due to downmelting. Some units were also previously connected to the main ice caps. This was the case with the small glacier on Figure 3-10 for example. The number and areas of the small glaciers at the historical maximum is not surveyed, because this will require closer field studies.

Figure 3-10
Photo of an unnamed, small glacier north of the mountain Hundsøyra on 5th September 2003. That summer all the glaciers had a strong negative mass balance and only the glacier ice was left. Field studies indicate that this glacier was connected to the main ice cap (seen in the background) at the maximum historical glacier extent. Photo: Arve M. Tvede.

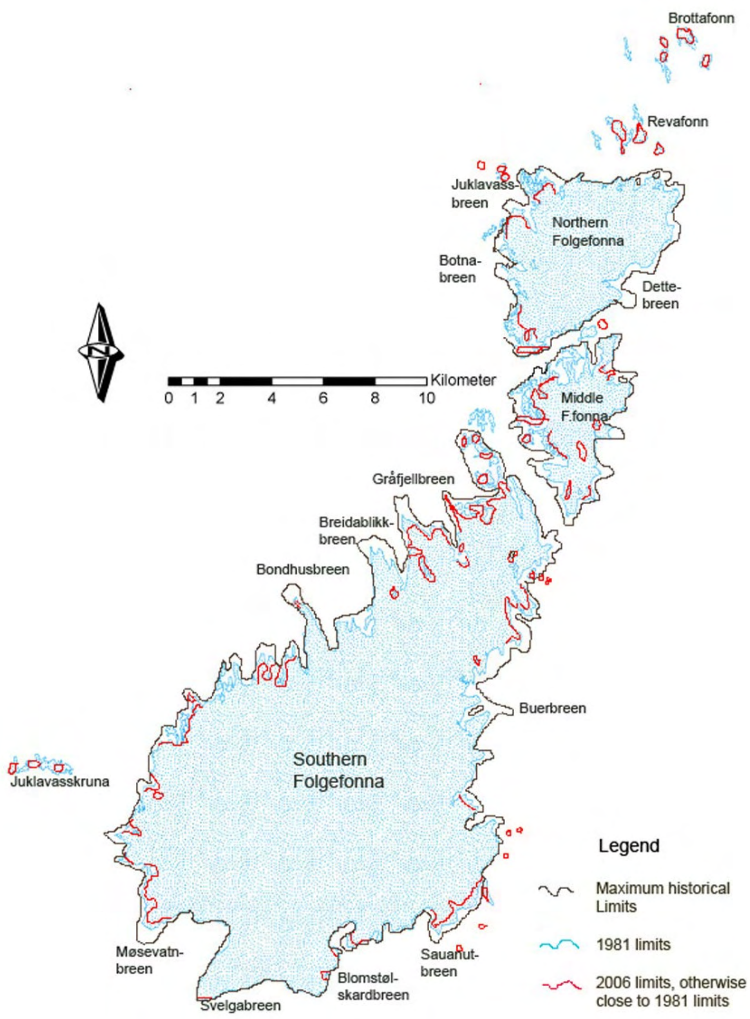


Figure 3-11
Map showing the Folgefonna ice caps at the maximum historical limits, the limits in 1981 and the limits in 2006 for the areas where they differ from the 1981-limits. The maximum historical limits are not mapped for the small isolated glaciers. Map source: Norge digitalt.

Discussion

The glaciers on the Folgefonna peninsula today cover 83 % of their maximum historical extent, giving a mean area loss of 17 %. If one assume that the glaciers were close to this size as late as 1890, it means that the mean reduction rate has been 0.16 % per. year between 1890 and 2006. A similar calculation for the period 1981-2006 gives only 0.08 % per. year. However, it should be mentioned that the western glaciers in southern Norway all had mainly positive mass balances between 1981 and 1995 and most glacier tongues had a net advance. Nearly all the area reduction between 1981 and 2006 probably took place in the last part of this period.

The reduction rate is, however, not uniform as can clearly be seen from Table 3-3 and Figure 3-11. The Southern Folgefonna has lost only 12 % and most of this loss is found on the northern third of that ice cap. Middle Folgefonna has lost 38 % and Northern Folgefonna has lost 25 % of its maximum size.

The volume changes of the glaciers are not dealt with in this study. Some earlier papers have documented recent volume changes within certain drainage basins of Folgefonna, (Østrem & Tvede, 1986), (Smith-Meyer & Tvede, 1996) and (Kjøllmoen, 2008).

4. Nigardsbreen (Bjarne Kjøllmoen)

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

Glaciological investigations in 2008 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The outlet of Nigardsbreen photographed on 30th October 2008. Photo: Miriam Jackson.

4.1 Mass balance 2008

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 7th and 8th May and the calculation of winter balance (Fig. 4-2) is based on:

- Uninterrupted measurement of stakes and towers in positions 600 (580 m a.s.l.), 1000 (960 m a.s.l.), T95 (1688 m a.s.l.) and T56 (1799 m a.s.l.). It was also possible to make use of measurements of a substitute stake drilled in May 2008 and an older stake that appeared during the melt season in position 54 (1613 m a.s.l.). The stake measurements on the plateau showed snow depth between 6.8 (54) and 7.8 m (T95). Measured snow depth at position 1000 was 3.7 m and 1.4 m at position 600. Stake readings did not show any indication of melting after the final measurements in September 2007.
- Core sample at position 94 (1705 m a.s.l.) showing snow depth of 6.7 m.

* 124 snow depth soundings on the plateau between 1315 and 1966 m a.s.l. Some few probings at the tongue at 580 and 995 m elevation. Due to hard-packed snow it was relatively difficult to define the snow depth on the plateau. The snow depth soundings on the plateau gave a snow thickness between 6.5 and 7.5 m. Down on the tongue the snow depth was 3.6 m (995 m a.s.l.) and 1.4 m (580 m a.s.l.).
* Snow density was measured down to 6.6 m depth (SS at 6.7 m) at position 94 (Fig. 4-2).

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

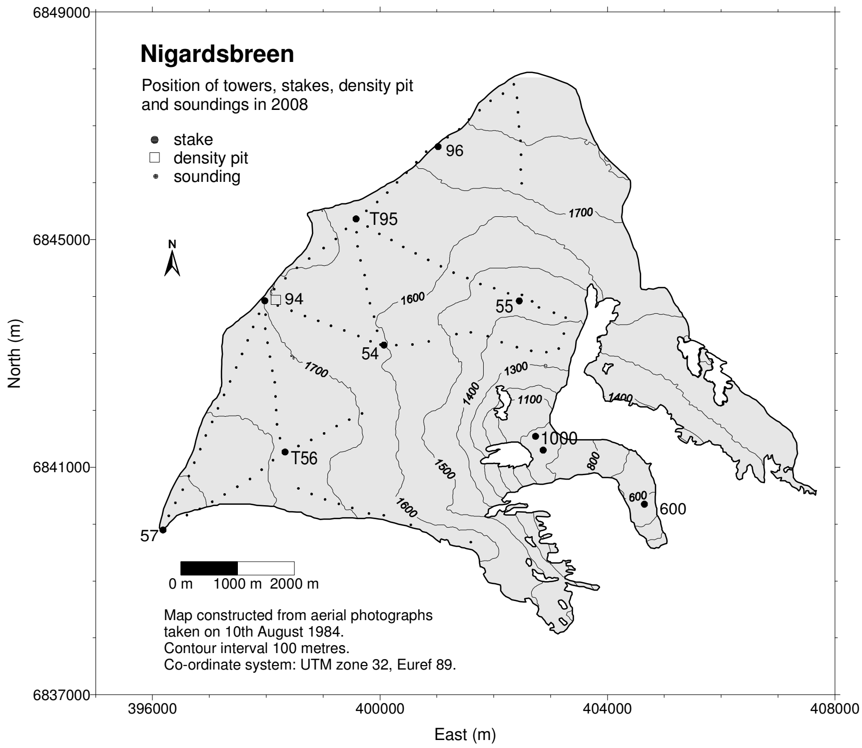


Figure 4-2 Location of towers and stakes, snow pit and soundings on Nigardsbreen in 2008.

Ablation measurements

Ablation measurements were carried out on 30th October. Measurements were made at four stakes and two towers in six different positions. Since snow measurements in May the stakes on the plateau had increased in length between 3.7 and 4.0 m. Hence, there was between 2.5 and 4.0 m of snow remaining from winter 2007/2008. At the time of measurement, approximately 2 m of fresh snow had fallen in the upper areas above 1600 m elevation.

Results

The calculations are based on a glacier map from 1984.

Winter balance

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

There was no melting after the final measurements in September 2007. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1705 m altitude (6.6 m depth). Using this model gave a snow density of 0.46 g/cm^3. This model was used for all snow depth measurements.

The winter balance calculation was performed by plotting measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 4-4), and a mean value for each 100 m height interval estimated (Tab. 4-1). The elevations above 1320 m a.s.l. were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 995, 960 and 580 m altitude.

These calculations give a winter balance of 3.0 ±0.2 m w.e., corresponding to a water volume of 144 ±10 mill. m^3. This is 126 % of the average for 1962-2007. Nine years have shown a greater winter balance on Nigardsbreen; the greatest was in 1989 with 4.0 m w.e.

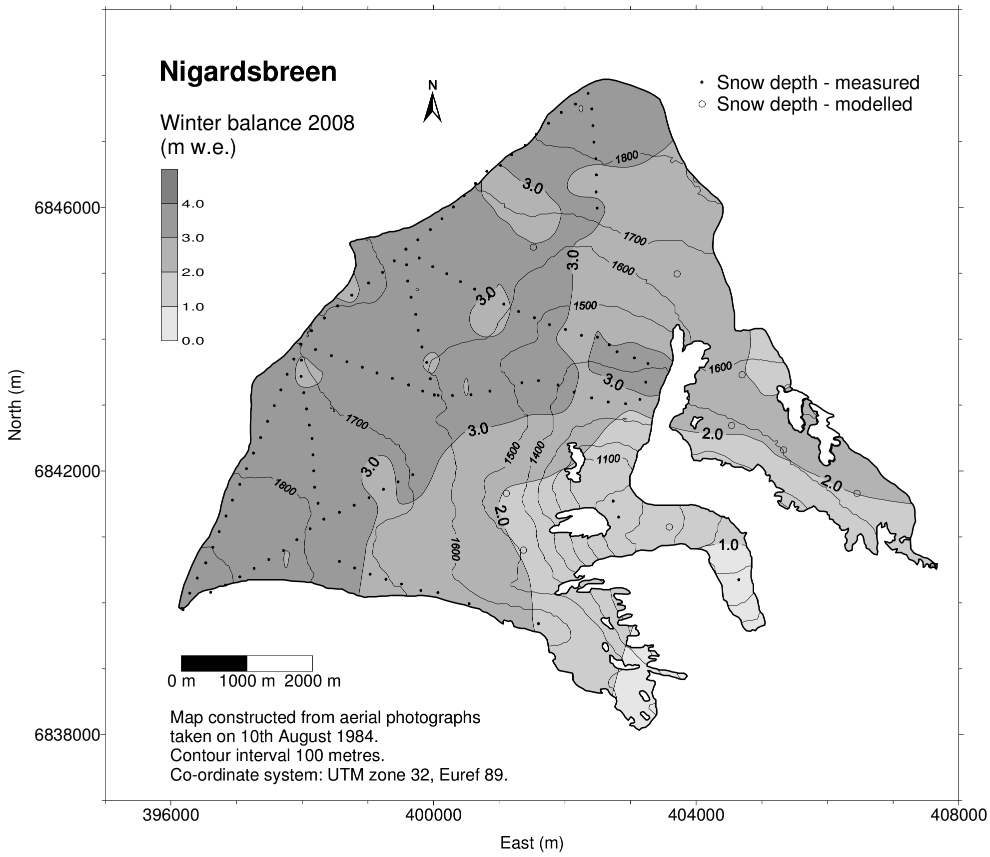


Figure 4-3
Winter balance at Nigardsbreen in 2008 interpolated from 139 measurements (·) of snow depth. In areas with few or no measurements nine extrapolated points (○) are added.

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 4-3). In areas with insufficient measurements some (nine) simulated points were extracted. These point values were calculated based on measurements from the period 1975-81, years with extensive measurements. Water equivalents for each cell in a 250 x 250 m grid were calculated and summarised. The result obtained using this gridding method was 2.7 m w.e.

Summer balance

When calculating the summer balance the density of the remaining snow was estimated as 0.60 g/cm^3. The density of melted firn was assumed to be 0.65 g/cm^3, while the density of ice was taken as 0.90 g/cm^3.

The summer balance was calculated at stakes and towers at seven different elevations. For stakes 57 (1966 m a.s.l.) and 1000 the measurements were supplemented with estimated values based on correlation with other stakes. The summer balance increased (in absolute value) from −1.0 m w.e. at the glacier summit (1966 m a.s.l.) to −8.8 m down on the tongue (580 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −1.9 ±0.3 m w.e., which is −92 ±15 mill. m^3 of water. This is 96 % of the average for 1962-2007.

Net balance

The net balance for 2008 was calculated at stakes and towers in eight different positions. The result was a surplus of +1.1 m ±0.3 m w.e., which means a volume increase of 52 ±15 mill.m^3 water. The mean value for the period 1962-2007 is +0.39 m w.e. (Fig. 4-5), while the average for 1996-2007 is +0.01 m w.e.

Based on Figure 4-4, the Equilibrium Line Altitude (ELA) was 1325 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 91 %.

The mass balance for Nigardsbreen in 2008 is shown in Table 4-1 and the corresponding curves are shown in Figure 4-4. The historical mass balance results are presented in Figure 4-5.

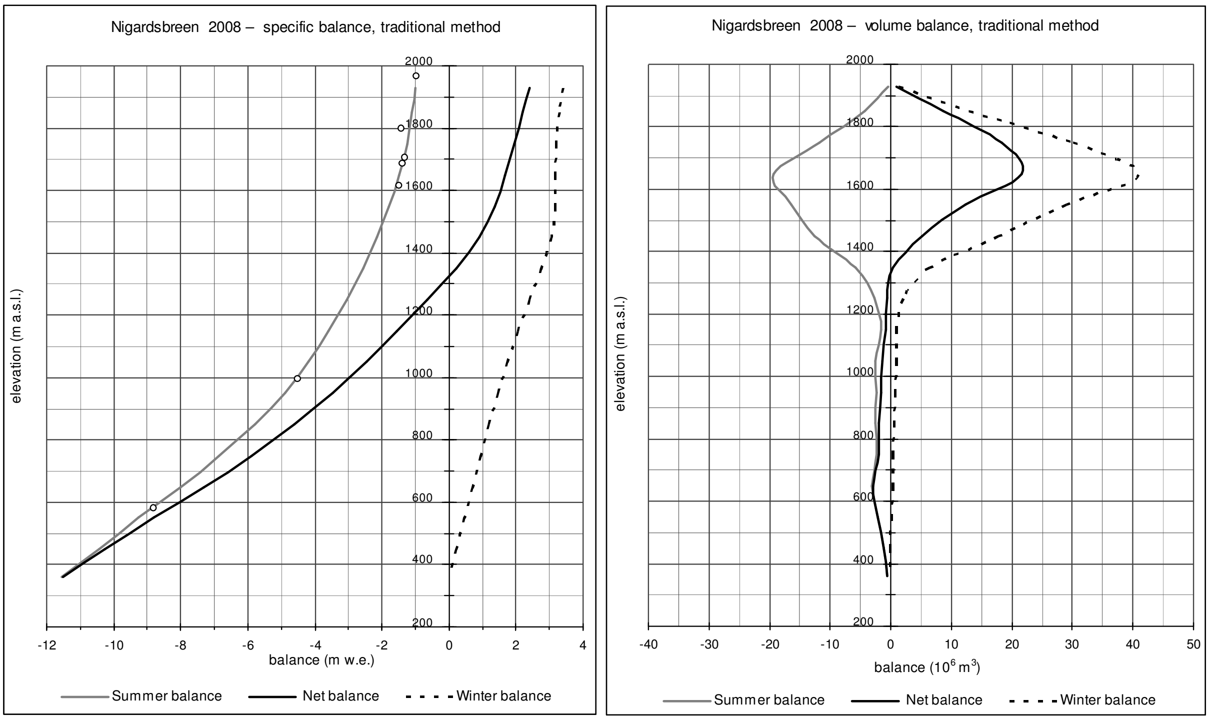


Figure 4-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2008. Specific summer balance at seven stake positions is shown as dots (o). The net balance curve intersects the y-axis and defines the ELA as 1325 m a.s.l. Thus the AAR was 91 %.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2008. Mean values for the period 1962-2007 are 2.38 (b_s), −1.99 m (b_s) and +0.39 m (b_n) water equivalent.

Mass balance Nigardsbreen 2007/08 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 8th May 2008		Summer balance Measured 30th Oct 2008		Net balance Summer surface 2007 - 2008	
		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 - 1960	0.38	3.40	1.3	-1.00	-0.4	2.40	0.9
1800 - 1900	3.92	3.30	12.9	-1.10	-4.3	2.20	8.6
1700 - 1800	9.39	3.20	30.0	-1.25	-11.7	1.95	18.3
1600 - 1700	12.88	3.18	40.9	-1.50	-19.3	1.68	21.6
1500 - 1600	9.18	3.15	28.9	-1.80	-16.5	1.35	12.4
1400 - 1500	5.82	3.05	17.8	-2.15	-12.5	0.90	5.2
1300 - 1400	2.28	2.75	6.3	-2.55	-5.8	0.20	0.5
1200 - 1300	0.90	2.40	2.2	-3.05	-2.7	-0.65	-0.6
1100 - 1200	0.45	2.05	0.9	-3.60	-1.6	-1.55	-0.7
1000 - 1100	0.58	1.75	1.0	-4.20	-2.4	-2.45	-1.4
900 - 1000	0.47	1.45	0.7	-4.90	-2.3	-3.45	-1.6
800 - 900	0.44	1.20	0.5	-5.80	-2.6	-4.60	-2.0
700 - 800	0.33	0.95	0.3	-6.85	-2.3	-5.90	-1.9
600 - 700	0.39	0.70	0.3	-8.00	-3.1	-7.30	-2.8
500 - 600	0.24	0.45	0.1	-9.25	-2.2	-8.80	-2.1
400 - 500	0.12	0.20	0.0	-10.45	-1.3	-10.25	-1.2
320 - 400	0.05	0.05	0.0	-11.55	-0.6	-11.50	-0.6
320 - 1960	**47.82**	**3.01**	**144.1**	**-1.92**	**-91.7**	**1.10**	**52.4**

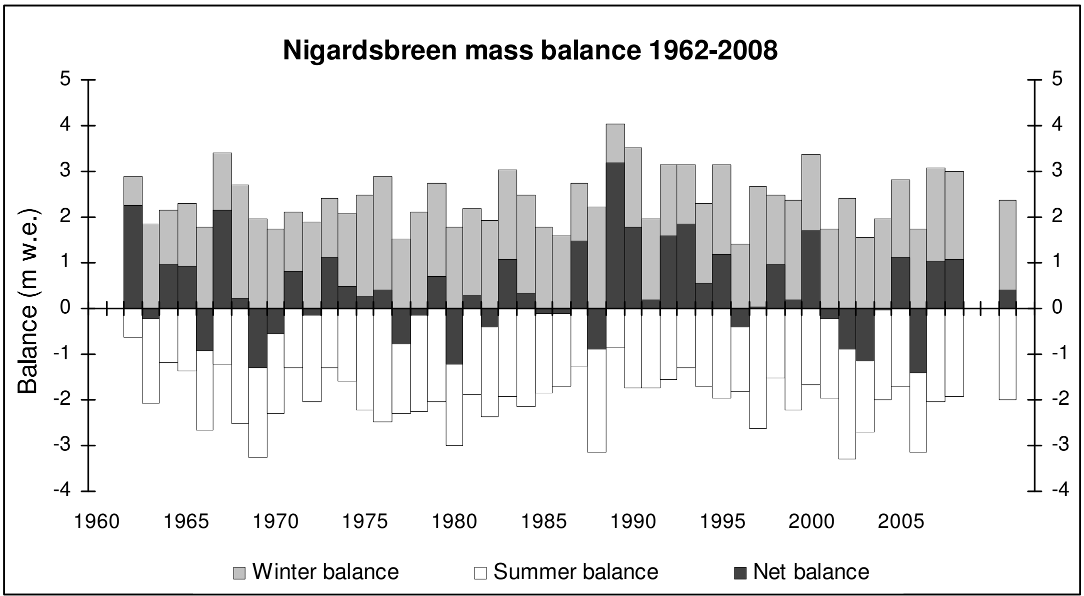


Figure 4-5
Annual mass balance at Nigardsbreen during the period 1962-2008.

5. Austdalsbreen (Hallgeir Elvehøy)

Austdalsbreen (61°45'N, 7°20'E) is an eastern outlet of the northern part of Jostedalsbreen, ranging in altitude from 1200 to 1757 m a.s.l. The glacier terminates in Austdalsvatnet, which has been part of the hydropower reservoir Styggevatnet since 1988. Glaciological investigations at Austdalsbreen started in 1986 in connection with the construction of the hydropower reservoir.

The glaciological investigations in 2008 included mass balance, front position change and glacier velocity. Mass balance has been measured at Austdalsbreen since 1988.

Figure 5-1
Austdalsbreen seen from AUS100 (see Fig. 5-2 for location) on 30th October 2008. The lake level was close to 1200 m a.s.l. which is the highest possible regulated lake level. Photo: Miriam Jackson.

5.1 Mass balance 2008

Fieldwork

Four mass balance stakes were maintained through out the winter.

The winter balance was measured on 22nd May. The calculation of winter balance was based on the following data (Fig. 5-2):

- Snow depth at stakes A5 (1.15 m), A90 (3.85 m), A24 (4.75 m) and T70 (5.50 m).
- Snow density down to the previous summer surface at 5.0 m depth at stake A60 (1490 m a.s.l.). The mean snow density was 0.53 g/cm^3.
- 87 snow depth measurements along 16 km of profiles. At Austdalsnuten above 1600 m a.s.l. the snow depth was 3 to 5 m. Between 1400 and 1600 m a.s.l. the snow was 4 to 6 m deep. Below 1400 m a.s.l. the snow depth was between 3 and 4.5 m at most locations. The summer surface (SS) from 2007 was difficult to detect in the upper areas. A transition to coarser snow was found to correspond with the summer surface at stakes A24, A60 and A70, and this transition was used as the summer surface.

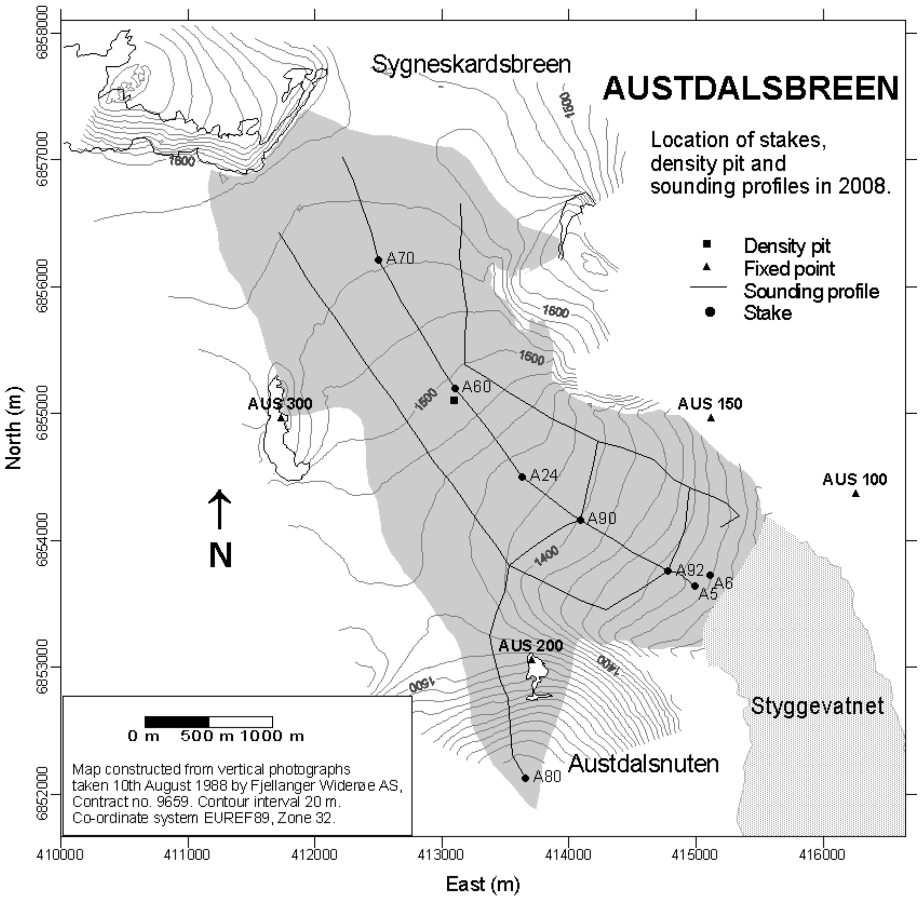


Figure 5-2
Location of stakes, density pit and sounding profiles at Austdalsbreen in 2008.

On 19th August the transient snow line was 1370 m a.s.l.

Summer and net balance measurements were carried out on 30th October. The glacier was covered with up to 1.7 m of new snow. Based on the stake measurements the temporary snow line (TSL) at the end of the summer season was about 1420 m a.s.l. At stakes above 1420 m a.s.l. 3 to 4 m of snow had melted and 1 to 2 m of snow remained. At the TSL around 4 m of snow had melted. At the stakes close to the terminus 4.5 m of ice had melted.

Results

The mass balance was calculated according to the stratigraphic method (see chap.1). The calculations are based on a map from 10th August 1988 reduced for the areas below the highest regulated lake level (below 1200 m a.s.l., 0.11 km^2). However, the actual glacier area based on front position measurements (chap. 5-2) has been reduced by 0.44 km^2, and the surface elevation has been reduced accordingly on the lower part of the glacier.

Winter balance

There is no evidence for significant melting after the stake measurements on 27th September 2007.

The winter balance was calculated from snow depth and snow density measurements on 22nd 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 30 ±2 mill. m^3 water or 2.6 ±0.2 m w.e., which is 116 % of the 1988-2007 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 2.7 m w.e.

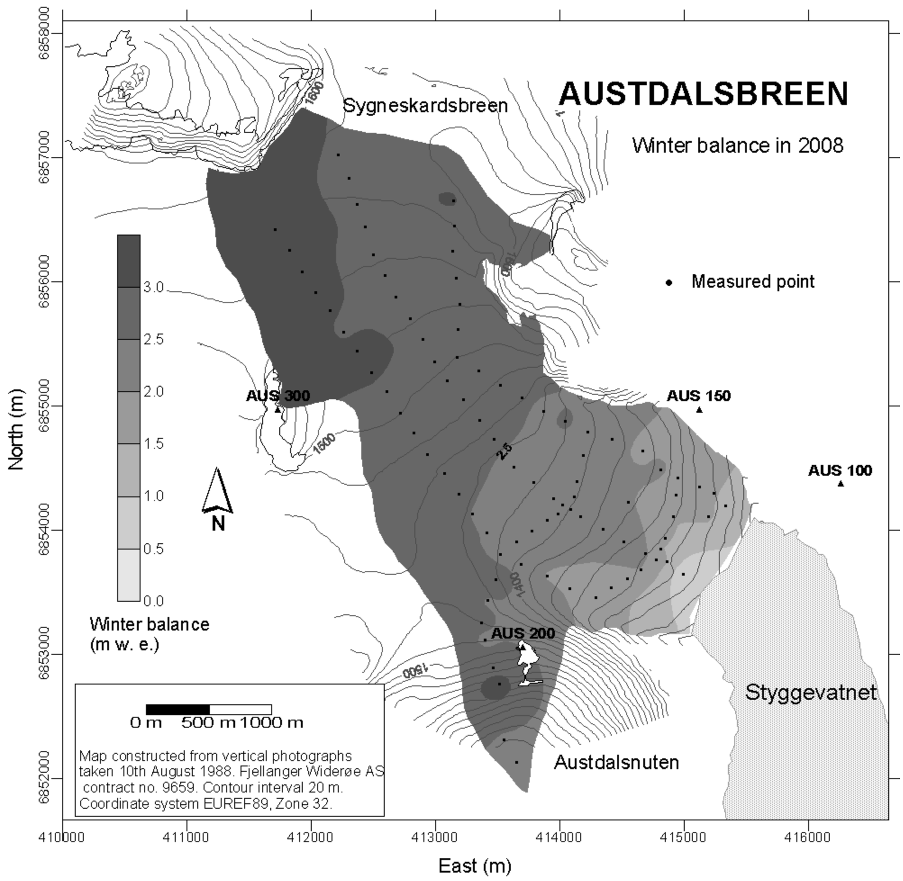


Figure 5-3
Winter balance at Austdalsbreen in 2008 from 92 water equivalent values calculated from snow depth measurements.

Summer balance

The summer balance was calculated for nine stakes in eight positions between 1250 and 1730 m a.s.l. Stake A90 was lost between 19th August and 30th October, and the amount of melted ice was estimated from stakes A92 and A24. The summer balance curve was drawn from these values (Fig. 5-4).

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

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

where ρ_{ice} is 0.9 g/cm^3, u_{ice} is annual glacier velocity (60 ±10 m/a, chap. 5.3), u_f is front position change averaged across the terminus (−33 ±5 m/a, chap. 5.2), W is terminus width (1010 ±20 m) and H is mean ice thickness at the terminus (43 ±5 m). The mean ice thickness was calculated from mean surface altitudes along the calving terminus surveyed on 27th September 2007 (1211 m a.s.l.) and 30th October 2008 (1223 m a.s.l.), and mean bottom elevation along the terminus in September 2007 (1173 m a.s.l.) and October 2008 (1174 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 4 ±1 mill. m^3 water or 0.3 ±0.1 m w.e. averaged over the glacier area (11.8 km^2).

The summer balance, including calving, was calculated as −2.6 ±0.3 m w.e., which corresponds to −31 ±3 mill. m^3 of water. The result is 105 % of the 1988-2007 average (−2.48 m w.e.). The calving volume was 13 % of the summer balance.

Net balance

The net balance at Austdalsbreen was calculated as −0.1 ±0.3 m w.e., corresponding to −1 ±3 mill. m^3 water. The 1988-2007 average is −0.28 m w.e. The equilibrium line altitude (ELA) was 1420 m a.s.l. Correspondingly, the Accumulation Area Ratio (AAR) was 71 % in 2008. The altitudinal distribution of winter, summer and net balances is shown in Figure 5-4 and Table 5-1. Results from 1988-2008 are shown in Figure 5-5.

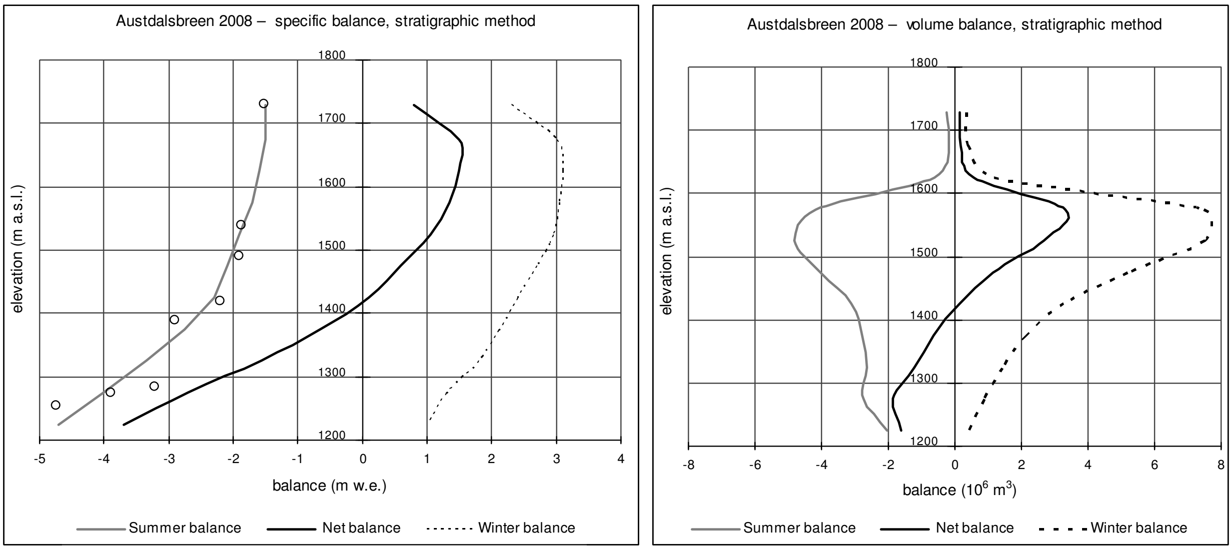


Figure 5-4
Altitudinal distribution of winter, summer and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2008. Specific summer balance at eight stake locations is shown (○).

Table 5-1
Altitudinal distribution of winter, summer and net balances at Austdalsbreen in 2008.

Mass balance Austdalsbreen 2007/08 – stratigraphic method

		Winter balance Measured 22nd May 2008		Summer balance Measured 30th Oct 2008		Net balance Summer surface 2007 - 2008	
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)
1700 - 1757	0.16	2.30	0.36	-1.50	-0.24	0.80	0.13
1650 - 1700	0.13	3.00	0.38	-1.50	-0.19	1.50	0.19
1600 - 1650	0.38	3.10	1.17	-1.60	-0.60	1.50	0.56
1550 - 1600	2.45	3.05	7.47	-1.70	-4.16	1.35	3.30
1500 - 1550	2.54	2.95	7.49	-1.90	-4.82	1.05	2.67
1450 - 1500	1.92	2.70	5.19	-2.10	-4.04	0.60	1.15
1400 - 1450	1.36	2.40	3.25	-2.30	-3.12	0.10	0.14
1350 - 1400	1.01	2.10	2.12	-2.75	-2.78	-0.65	-0.66
1300 - 1350	0.79	1.80	1.42	-3.35	-2.64	-1.55	-1.22
1250 - 1300	0.69	1.30	0.89	-4.00	-2.75	-2.70	-1.85
1200 - 1250	0.44	1.00	0.44	-4.70	-2.04	-3.70	-1.61
Calving					-3.6		-3.6
1200 - 1757	**11.84**	**2.55**	**30.2**	**-2.62**	**-31.0**	**-0.07**	**-0.8**

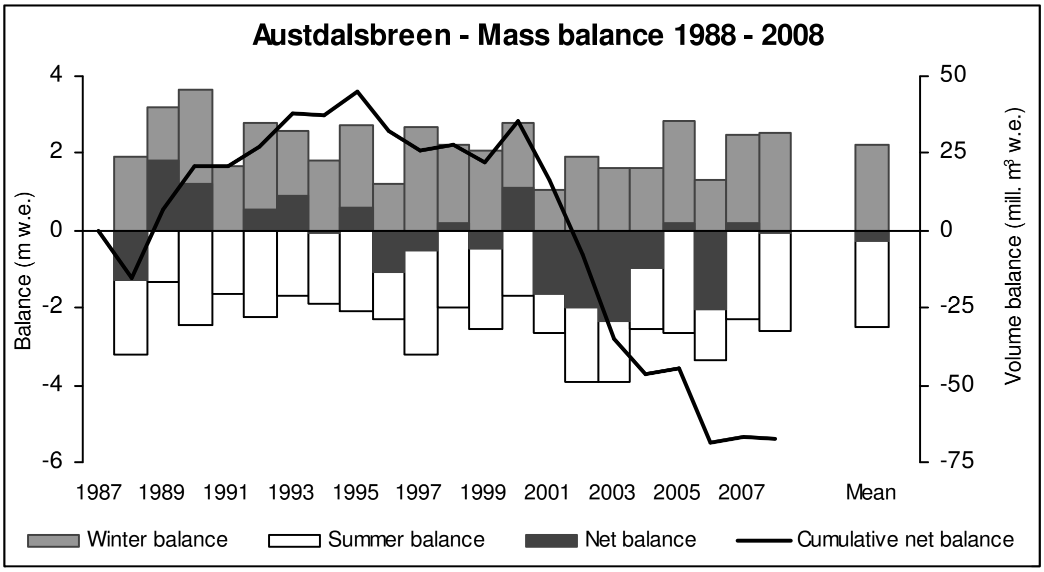


Figure 5-5
Winter, summer and net balances at Austdalsbreen during the period 1988-2008. Mean winter, summer and net balance is 2.22, –2.49 and –0.27 m w.e., respectively.

5.2 Front position change

Eight points along the calving terminus were surveyed on 30th October 2008. The mean front position change was −33 ±5 m (Fig. 5-6) between 27th September 2007 and 30th October 2008. The width of the calving terminus was 1010 ±20 metres. Since 1988 the glacier terminus has retreated 459 metres, whilst the glacier area has decreased by approximately 0.48 km^2 (Fig. 5-6).

The terminus position was surveyed on 19th August 2008. A comparison of surveyed front positions and stake positions at stakes A5 and A6 shows that in front of these stakes the ice cliff calved 30 metres between 27th September 2007 and 19th August 2008, and 50 metres between 19th August and 30th October 2008.

Due to large variations in calving, the variation in front position throughout the year is large compared with the net change from year to year. Figure 5-7 illustrates how the front position at a central flow line has varied over the last 20 years. As a consequence of lake regulation it was expected that the glacier terminus would retreat. Modelling predicted a future change in front position that is shown as a broken line in Figure 5-7. The mean annual net balance used in the model was −0.47 m w.e., whilst the measured mean net balance has been −0.27 m w.e. (1988-2008).

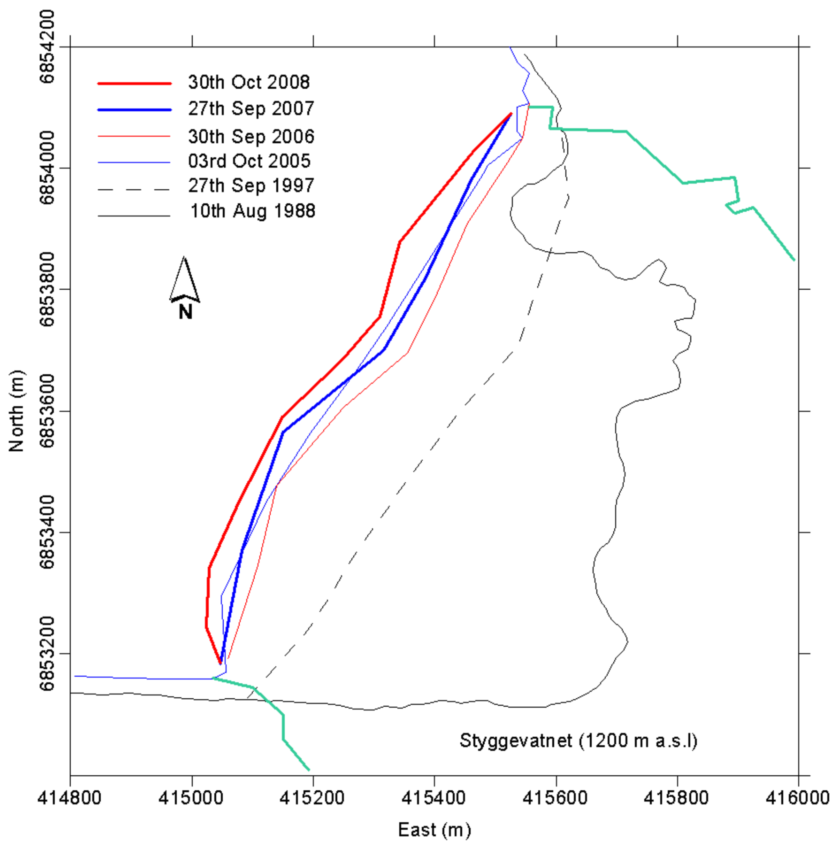


Figure 5-6
Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, in 1997, and in 2005-2008. The mean front position change between 27th September 2007 and 30th October 2008 was −33 metres.

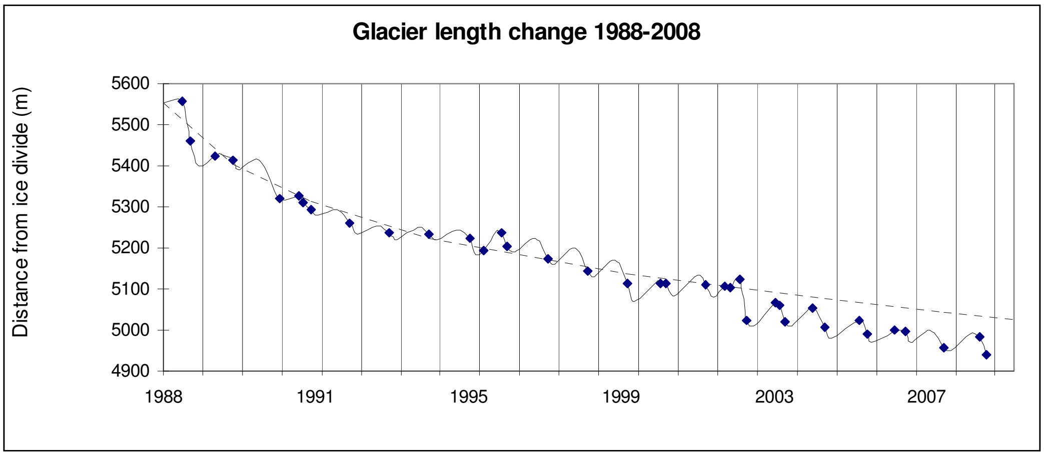


Figure 5-7
Surveyed glacier front position along a central flow line, shown as change in glacier length along this flow line (dots). The solid line indicates annual variation in front position. The glacier terminus advances from December to July when the lake is frozen, and retreats during July-December due to calving. Lake Austdalsvatnet/Styggevatnet was regulated as a reservoir for the first time in 1988. The dashed line shows predicted glacier length change based on expected annual lake level variations due to regulation and an annual net balance of –0.47 m w.e. (Laumann & Wold, 1992).

5.3 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 27th September 2007, and 22nd May, 19th August and 30th October 2008.

Annual velocities were calculated for five stake locations based on surveys on 27th September and 19th August (327 days). The annual velocities at stake locations A5, A6, A92, A90, and A24 were 69 m/a, 63 m/a, 50 m/a, 33 m/a and 23 m/a, respectively. This is similar to velocities calculated for 2006/2007.

The glacier velocity averaged across the front width and thickness must be estimated in order to calculate the calving volume (chap. 5.1). The surface centre line velocity at the terminus was calculated from summer measurements at stake A5 (70 m/a), average distance from the stake to terminus (170 m), and an average strain rate from previous years (0.1 a^{-1}) as 87 m/a. The glacier velocity averaged over the cross-section is estimated to be 70 % of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed. The resulting terminus cross-sectional averaged glacier velocity for 2007/2008 is 60 ±10 m/a.

6. Hardangerjøkulen (Hallgeir Elvehøy)

Hardangerjøkulen (60°32'N, 7°22'E) is the sixth largest (73 km^2) glacier in Norway. The glacier is situated on the main water divide between Hardangerfjorden and Hallingdalen valley. In 1963 the Norwegian Polar Institute began mass balance measurements on the south-western outlet glacier Rembesdalsskåka (17 km^2), which drains towards Simadalen valley and Hardangerfjorden. In the past Simadalen has been flooded by jökulhlaups (outburst floods) from the glacier-dammed lake Demmevatnet, the most recent occurring in 1937 and 1938.

The Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalsskåka since 1985. The investigated basin covers the altitudinal range between 1020 and 1865 m a.s.l. At Rembesdalsskåka, glacier length observations were initiated in 1917 by Johan Rekstad at Bergen Museum. Observations were conducted in several periods during the 20th century. Statkraft Energy AS re-initiated the observations at Rembesdalsskåka in 1995. At Midtdalsbreen, glacier length observations were started by Prof. Atle Nesje at the University of Bergen in 1982. Glacier length observations are described in chapter 12. The University of Utrecht, Netherlands, operates an automatic weather station (AWS) close to the terminus of Midtdalsbreen (chap. 6-2).

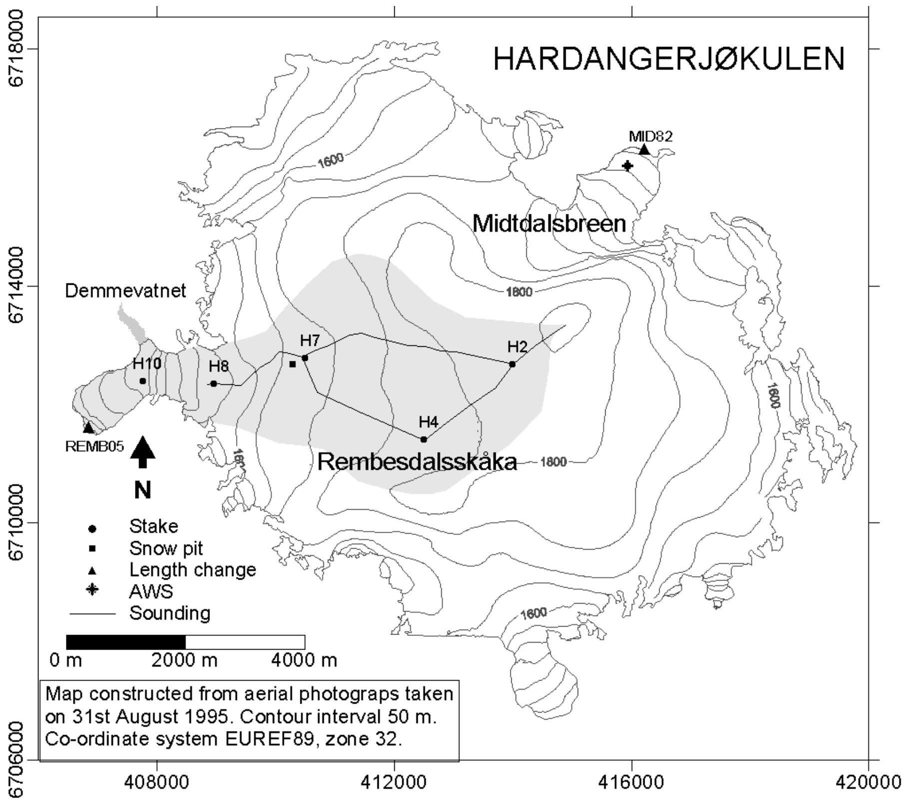


Figure 6-1
Location of sounding profiles, stakes and snow pit at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and an automatic weather station (AWS) at Midtdalsbreen.

Figure 6-2
Stake H4 (1775 m a.s.l.) at Hardangerjøkulen on 14th February 2008. The snow depth was 4.35 metres. Photo: Hallgeir Elvehøy.

6.1 Mass balance at Rembesdalsskåka in 2008

Fieldwork

The stake network was checked on 11th December 2007, 14th February, 3rd April and 16th April 2008. Stakes were maintained throughout the winter in four positions. Snow depth soundings and stake measurements on 11th December 2007 showed that 0.15 m of ice had melted at stakes H10 after the autumn measurements on 3rd October 2007.

The winter balance measurements were carried out on 21st May with supplementary measurements from 16th April. The calculation of winter balance is based on the following data (see fig. 6-1 for locations):

<u>16th April</u>:

- Snow depth measurements at stakes H8 (1515 m a.s.l.), H706 (1660 m a.s.l.) and H4 (1775 m a.s.l.), showing snow depths of 3.4 – 5.0 and 5.9 m, respectively.
- Snow depth coring at location H4 (1770 m a.s.l.) and H2 (1830 m a.s.l.) showing snow depths of 5.7 and 6.4 m, respectively.
- Snow density down to last years summer surface (SS) at 5.0 m depth at location H7 (1660 m a.s.l.). There was firn below the SS.
- Snow density down to last years summer surface (SS) at 5.3 m depth at location H2 (1830 m a.s.l.). New stake H208. Below the SS there was firn.
- Snow depth soundings along profiles H7 – H4 – H2 and H7 – H2. The snow depth was between 5 and 6 metres.

21st May:

- Snow depth measurements at stakes H10 (1270 m a.s.l.), H8 (1515 m a.s.l.), stake H706 (1660 m a.s.l.), H4 (1775 m a.s.l.) and H208 (1830 m a.s.l.), showing snow depths of 1.9 – 2.85 – 4.65 – 5.85 and 5.2 metres, respectively.
- Snow density down to last years summer surface (SS) at 4.65 m depth at location H7 (1660 m a.s.l.).
- Snow density down to a reference surface from 16th April at 0.48 m depth at location H2 (1830 m a.s.l.).
- Snow depth soundings along profiles H8 – H7 and H2 – summit, plus some additional points between 1650 and 1700 m a.s.l. Between 1500 and 1650 m a.s.l. and above 1830 m a.s.l. the snow depth was 4 to 5 metres. Between 1650 and 1830 m a.s.l. the snow depth was 5 to 6 metres. The SS was difficult to detect. It was defined by a transition to coarse snow.

On 15th August the temporary snow line (TSL) altitude was about 1525 m a.s.l. At the stakes above the TSL, 2.6 to 3.1 m of snow had melted. Below the TSL all the snow and about 0.75 and 2.95 m of ice had melted.

Summer and net balance were measured on 30th and 31st October. Measurements at the stakes showed up to 2 m of new snow at the stakes. The TSL could not be detected due to the new snow cover, but stake readings indicate that the TSL altitude was about 1600 m a.s.l. After 15th August 0.4 to 0.7 m of snow had melted at the stakes above the TSL, while up to 2 m of ice had melted at the stakes below the TSL. The accumulation of new snow probably started late in September. Up to 2.5 m of snow remained from winter 2008 at the plateau. At stake H10 on the glacier tongue more than 5 m of ice had melted.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive “summer surfaces”, but including melting after 3rd October 2007 and excluding snow accumulation before 30th October 2008. 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 21st May and the snow depth measurements on 16th April corrected for snow depth change as interpolated from stake measurements at stake H7, H4 and H2.

Stake measurements and snow depth soundings on 11th December 2007 showed that ice melting had occurred after 3rd October 2007 at stake H10 but not at stake H8. As the winter balance curve below 1500 m a.s.l. is inter- and extrapolated based on the winter balance at stake H10, this was calculated as the sum of late autumn melting and snow accumulation at the stake. The density of melted ice was set as 0.90 g/cm^3. The late autumn melt was estimated as 0.13 m w.e.

Between 16th April and 21st May the snow depth at stakes H7, H4 and H2 was reduced by 0.35, 0.1 and 0.0 m in a combination of snow compaction and snow accumulation. The snow depth soundings on 16th April were reduced accordingly based on elevation.

A snow depth-water equivalent profile was calculated based on snow density measurements at location H7 (1660 m a.s.l.) on 21st May. Using the calculated profile, the mean density of 5 m of snow was 0.54 g/cm^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 8 and 10. a mean value for each 50 m elevation interval was then determined from this curve.

The resulting winter balance was 2.6 ±0.2 m w.e. or 45 ±3 mill. m^3 water. This is 124 % of the 1963-2007 average of 2.10 m w.e., and 130 % of the 2003-2007 average of 2.00 m w.e. The altitudinal distribution of the winter balance is shown in Figure 6-3 and Table 6-1.

Summer balance

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

The summer balance curve in Figure 6-2 was drawn from these five point values. The summer balance was calculated as −2.2 ±0.2 m w.e., corresponding to −37 ±3 mill. m^3 of water. This is 108 % of the 1963-2007 average, which is −2.00 m w.e., and 93 % of the 2003-2007 average of −2.32 m w.e.

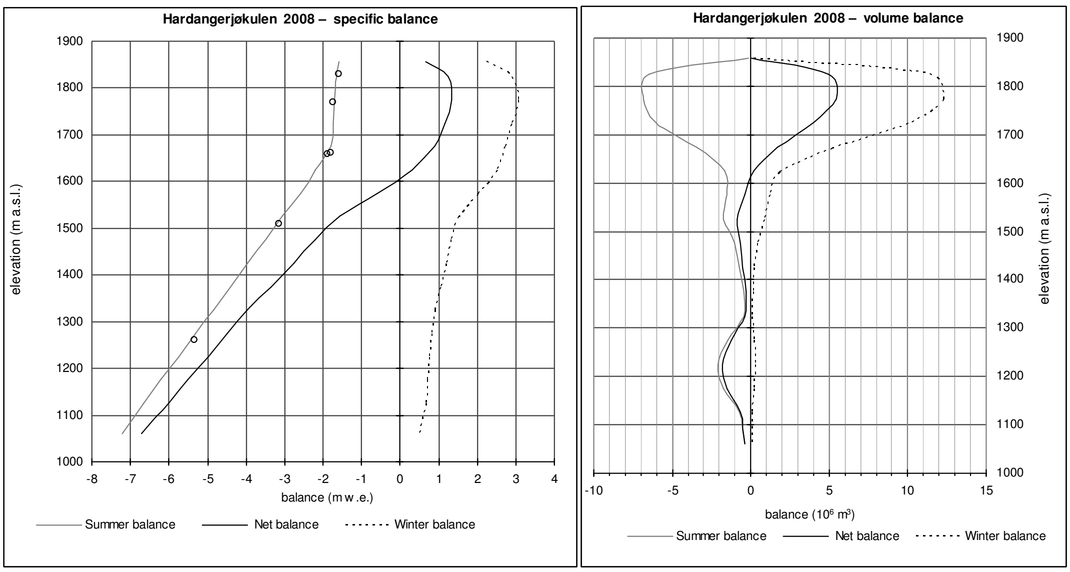


Figure 6-3
Altitudinal distribution of winter-, summer- and net balance shown as specific balance (left) and volume balance (right) at Rembesdalsskåka, Hardangerjøkulen in 2008. Specific summer balance at six stakes is shown (○).

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka in 2008.

Mass balance Hardangerjøkulen 2007/08 – traditional method							
		Winter balance Measured 21st May 2008		Summer balance Measured 30th Oct 2008		Net balance Summer surface 2007 - 2008	
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	2.25	0.2	-1.60	-0.1	0.65	0.1
1800 - 1850	3.93	2.90	11.4	-1.65	-6.5	1.25	4.9
1750 - 1800	4.03	3.05	12.3	-1.70	-6.9	1.35	5.4
1700 - 1750	3.46	2.90	10.0	-1.75	-6.1	1.15	4.0
1650 - 1700	1.94	2.70	5.2	-1.80	-3.5	0.90	1.7
1600 - 1650	0.75	2.50	1.9	-2.20	-1.6	0.30	0.2
1550 - 1600	0.59	2.00	1.2	-2.60	-1.5	-0.60	-0.4
1500 - 1550	0.57	1.50	0.9	-3.05	-1.7	-1.55	-0.9
1450 - 1500	0.29	1.30	0.4	-3.50	-1.0	-2.20	-0.6
1400 - 1450	0.19	1.20	0.2	-3.95	-0.7	-2.75	-0.5
1350 - 1400	0.10	1.05	0.1	-4.40	-0.4	-3.35	-0.3
1300 - 1350	0.10	0.90	0.1	-4.85	-0.5	-3.95	-0.4
1250 - 1300	0.27	0.80	0.2	-5.30	-1.4	-4.50	-1.2
1200 - 1250	0.36	0.75	0.3	-5.75	-2.1	-5.00	-1.8
1150 - 1200	0.28	0.70	0.2	-6.20	-1.7	-5.50	-1.6
1100 - 1150	0.11	0.65	0.1	-6.65	-0.7	-6.00	-0.6
1020 - 1100	0.05	0.50	0.0	-7.20	-0.4	-6.70	-0.4
1020 - 1865	**17.1**	**2.61**	**44.7**	**-2.16**	**-37.0**	**0.45**	**7.7**

Net balance

The net balance at Rembesdalsskåka was calculated as +0.5 ±0.3 m w.e. or +8 ±5 mill. m^3 water. The 1963-2007 average is +0.10 m w.e., and the 2003-2007 average is −0.32 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 1610 m a.s.l. from the net balance curve in Figure 6-3. The corresponding accumulation area ratio (AAR) was 82 %. Results from 1963-2008 are shown in Figure 6-4. The cumulative net balance is +5.1 m w.e.

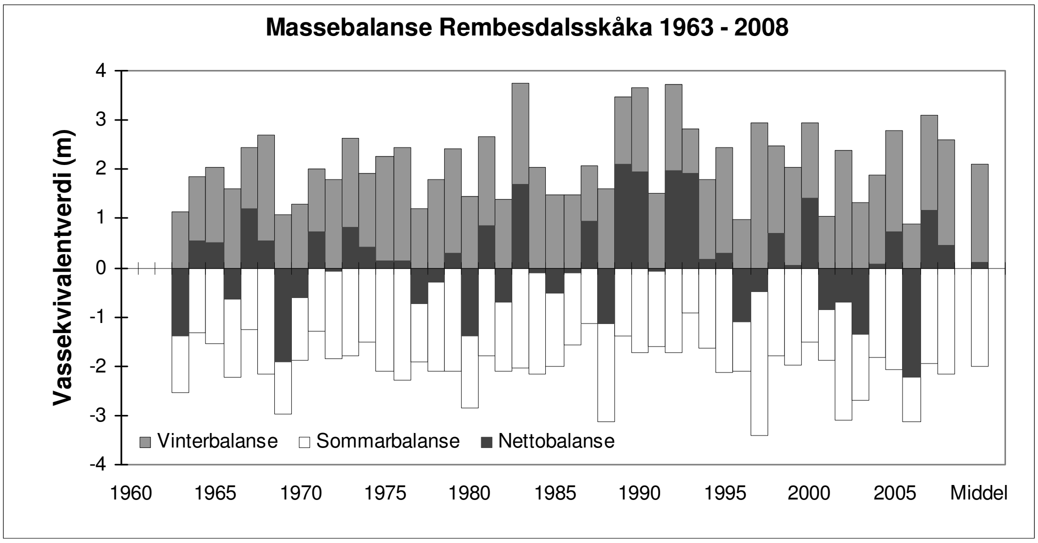


Figure 6-4
Winter-, summer- and net balances at Hardangerjøkulen during the period 1963-2008. Mean values for the period are b_w=2.12 m, b_s=−2.01 m and b_n=+0.12 m water equivalent.

6.2 Meteorological measurements on Midtdalsbreen

(Rianne H. Giesen, Utrecht University)

Since October 2000, an automatic weather station (AWS) has been operating in the ablation area on Midtdalsbreen, a north-easterly outlet glacier of Hardangerjøkulen (Fig. 6-1 for location). The station (Fig. 6-5) is owned and maintained by the Institute of 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 and validate a mass balance model for the glacier. Here, we present the surface energy balance calculated from AWS data collected between 16th September 2007 and 27th August 2008.

The surface energy balance

The surface energy balance at a glacier's surface can be described by:

$$Q = S_{\mathrm{net}} + L_{\mathrm{net}} + H_{\mathrm{sen}} + H_{\mathrm{lat}} + G,$$

where Snet and Lnet are the net shortwave and long wave radiation, Hsen and Hlat the turbulent fluxes of sensible and latent heat, G the subsurface heat flux and Q the energy available for melt. The shortwave and long wave radiation fluxes are directly measured; the remaining fluxes have been calculated from the AWS measurements with an energy balance model. A description of the model and additional results can be found in Giesen et al., 2008.

Figure 6-5
The AWS site on Midtdalsbreen on 29th August 2008. The sonic ranger measuring the changing distance to the ice surface is to the right. Photo: Rianne H. Giesen.

Daily mean values of the energy fluxes during the period considered here are shown in Figure 6-6. Snet has the largest seasonal cycle of the radiative and turbulent fluxes. From late November to late January, Snet is practically zero, because the AWS site does not receive any direct sunlight and the surface albedo is high. The winter snowpack at the AWS site disappeared around 1st July. The associated decrease in surface albedo is leading to a large increase in Snet. Changes in cloudiness cause the large fluctuations in

Snet and Lnet, which have opposite signs because clouds reduce Snet and enhance Lnet. In winter, net radiation (Snet + Lnet) is negative; between May and September, Snet dominates net radiation. In mid-summer Lnet can become positive on cloudy days with air temperatures well above 0 °C.

The contribution of Hsen to the energy balance is almost continuously positive; in summer a significant part of the melt energy is supplied by Hsen. High values of Hsen in summer occur on days with high air temperatures, while in autumn and winter, peaks in Hsen are the combined result of relative high air temperatures and high wind speeds. Hlat is small compared to Hsen. It is mainly negative in spring, but contributes positively to the surface energy balance in summer, when the air is relatively warm and humid compared to the air just above the glacier surface. Daily mean values of G fluctuate around zero, values are generally positive in spring, when the entire snowpack is at the melting point temperature and cannot be heat further. The calculated melt energy *Q* shows that some melting occurred until November on days with large turbulent fluxes. After melting started again in the middle of April, the surface was almost continuously melting except for a short cold period in May. The large variations in *Q* are due to coinciding periods with both high S_{net} and large turbulent fluxes.

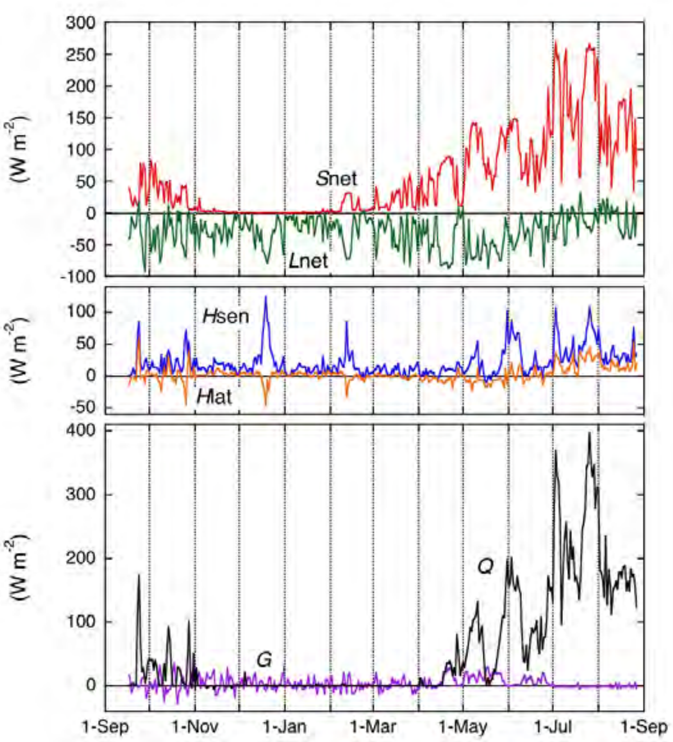


Figure 6-6
Daily mean surface energy fluxes at the AWS site on Midtdalsbreen. Q is the energy available for melt.

During the 347-day period considered here, the surface was melting 33 % of the time, which is similar to earlier years (2001-2005, Giesen et al., 2008). However, the mean *Q* during melt is almost 10 % higher than in the same period in earlier years. The primary reason is a larger S_{net} (22 % increase) because the spring and summer of 2008 were sunnier than in the other years. Furthermore, a melt water stream under the AWS mast (Fig. 6-5) lowered the surface albedo, also increasing S_{net}. For the 347-day period, 85 % of the melt energy was supplied by S_{net}, 21 % by H_{sen} and 6 % by H_{lat}, while L_{net} and *G* were energy sinks of 11 % and 2 %, respectively.

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Jotunheimen mountain massif in central southern Norway (Fig. 7-1). The glacier has a total area of 5.4 km^2 and ranges in altitude from 1390 to 2100 m a.s.l. (Fig. 7-1). Mass balance measurements began in 1949 and 2008 is the 60th year of continuous measurements.

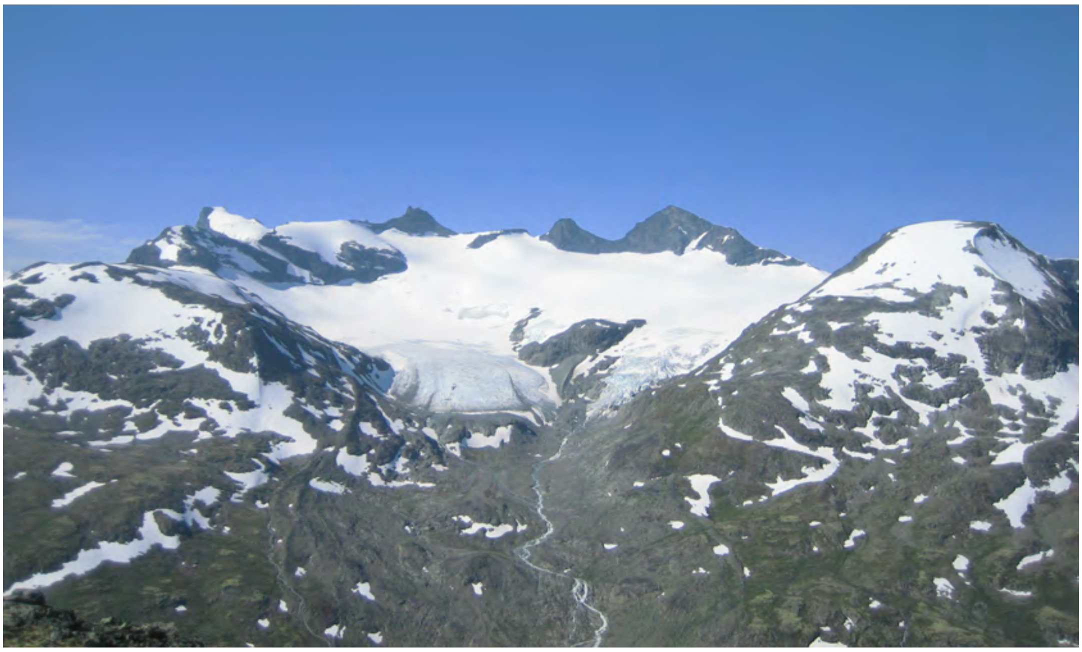


Figure 7-1
View of Storbreen taken from northeast (from Sauhøi) on 29th July 2008. Photo: Liss M. Andreassen.

7.1 Mass balance 2008

Fieldwork

Accumulation measurements were performed on 6-7th May and the calculation of winter balance is based on:

- Measurements of stakes in 6 different positions. The stake readings did not indicate any significant additional surface melting after the ablation measurements in the previous mass balance year (19th September 2007).
- Soundings of snow depth in 143 positions between 1458 and 1955 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was easy to identify over the whole glacier. The snow depth varied between 1.52 and 6.35 m, the mean being 3.84 m.
- Snow density was measured at two positions, at the automatic weather station (AWS) on the glacier at 1570 m a.s.l. and at stake 4 at 1725 m a.s.l.
- Ablation measurements were performed on 1st September on stakes in all positions. The locations of stakes, density pits and soundings are shown in Figure 7-2.

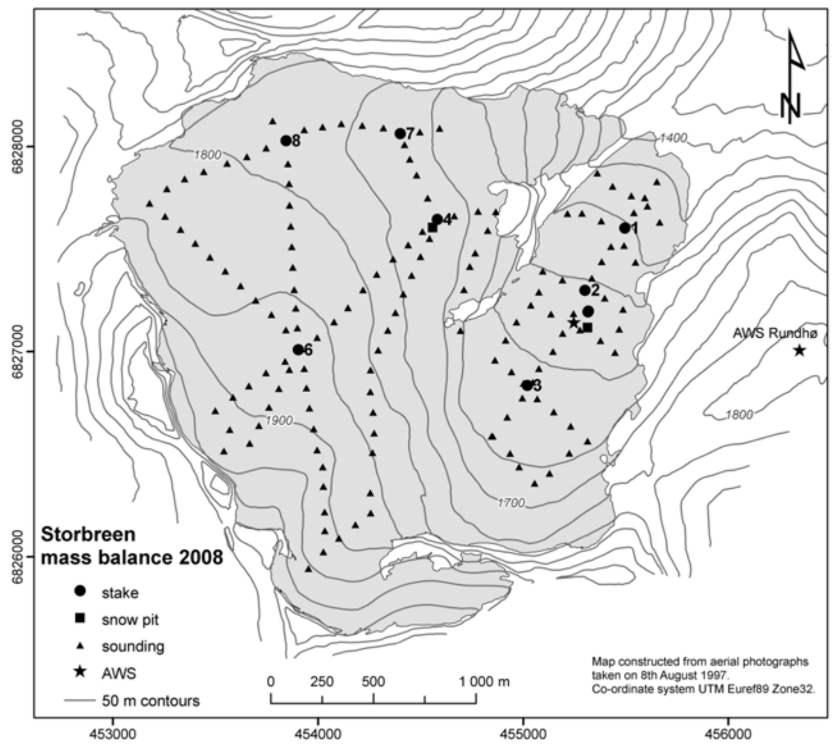


Figure 7-2
Location of stakes, density pits and the automatic weather stations (AWS) at Storbreen in 2008.

Results

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

Winter balance

Winter accumulation was calculated from soundings and the snow density measurements. The mean measured snow density was 0.495 g/cm^3 (0.51 g/cm^3 at the AWS and 0.48 g/cm^3 at stake 4). The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The specific winter balance was calculated to be 2.0 ±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, 6 and 7). The density of the remaining snow was assumed to be 0.6 g/cm^3. The density of the melted ice was assumed to be 0.9 g/cm^3. The summer balance was calculated to be −1.9 ±0.3 m w.e., which is 115 % of the mean for 1971-2000.

Net balance

The net balance of Storbreen was slightly positive in 2008, 0.1 ±0.3 m w.e., which is equivalent to a volume of ±0.59 mill. m^3 of water. The ELA calculated from the net balance diagram (Fig. 7-3) was 1770 m a.s.l. and the accumulation area ratio (AAR) was 51 %. The cumulative balance since 1949 is −17.2 m w.e., giving a mean annual net balance of −0.29 m w.e. over the 60 years of measurements (Fig. 7-4).

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2008.

Mass balance Storbreen 2007/08 – traditional method

		Winter balance Measured 7 May 2008		Summer balance Measured 1 Sep 2008		Net balance Summer surfaces 2007 - 2008	
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 - 2100	0.04	2.60	0.10	-0.50	-0.02	2.10	0.08
2000 - 2050	0.15	2.67	0.40	-0.65	-0.10	2.02	0.30
1950 - 2000	0.23	2.75	0.63	-0.80	-0.18	1.95	0.45
1900 - 1950	0.36	2.83	1.02	-1.00	-0.36	1.83	0.66
1850 - 1900	0.57	2.45	1.40	-1.25	-0.71	1.20	0.69
1800 - 1850	0.92	2.03	1.87	-1.65	-1.52	0.38	0.35
1750 - 1800	0.75	1.97	1.47	-1.90	-1.43	0.07	0.05
1700 - 1750	0.64	1.72	1.10	-2.20	-1.41	-0.48	-0.31
1650 - 1700	0.40	2.00	0.80	-2.30	-0.92	-0.30	-0.12
1600 - 1650	0.49	1.77	0.87	-2.38	-1.17	-0.61	-0.30
1550 - 1600	0.35	1.40	0.49	-2.55	-0.89	-1.15	-0.40
1500 - 1550	0.21	1.08	0.23	-2.80	-0.59	-1.72	-0.36
1450 - 1500	0.18	1.10	0.20	-3.10	-0.56	-2.00	-0.36
1390 - 1450	0.06	1.09	0.07	-3.39	-0.20	-2.30	-0.14
1390 - 2100	**5.35**	**1.99**	**10.64**	**-1.88**	**-10.05**	**0.11**	**0.59**

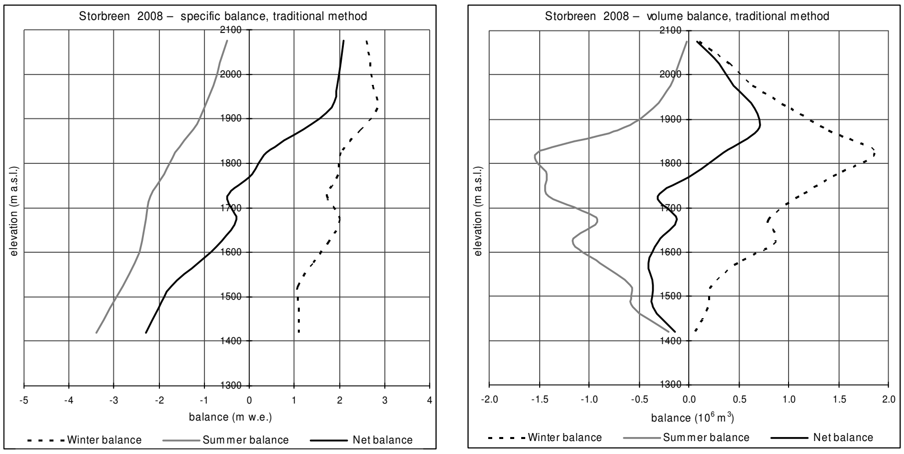


Figure 7-3
Mass balance diagram for Storbreen 2008, showing specific balance on the left and volume balance on the right.

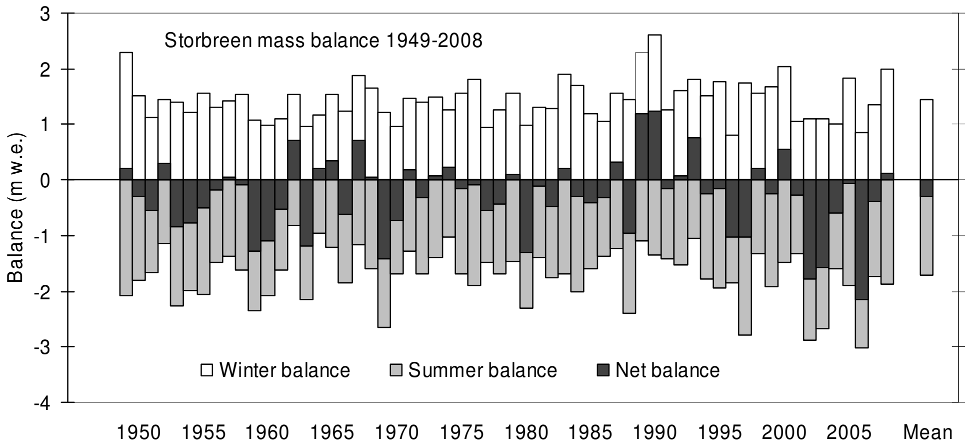


Figure 7-4
Winter, summer and net balance at Storbreen for the period 1949-2008.

8. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 8-1). The glacier shares a border with Vestre Memurubre and ranges in elevation from 1480 to 2210 m a.s.l. It had an area of 3.0 km^2 in 1997, and the glacier terminus retreated about 100 m from 1997 to 2007 (Fig. 8-2). Annual mass balance measurements began in 1962 and have continued annually since then.

Figure 8-1
Photograph of Hellstugubreen on 30th July 2008. The temporary snow line was then located at about 1680 m a.s.l. Photo: Liss M. Andreassen.

8.1 Mass balance 2008

Fieldwork

Accumulation measurements were performed on 6th May and the calculation of winter balance is based on:

- Measurements of stakes in 11 different positions. Stake readings indicated that only at the two lowest stakes there had been additional melting after the ablation measurements on 11th September 2007.
- Soundings of snow depth in 100 positions between 1533 and 2145 m a.s.l. covering most of the altitudinal range of the glacier (Fig. 8-2). The snow depth varied between 1.15 and 5.00 m, the mean being 3.2 m.
- The snow density was measured by sampling in a pit at 1960 m a.s.l. where the total snow depth was 3.5 m.

Ablation measurements were carried out on 18th September on all visible stakes. The location of stakes, density pit and sounding profiles are shown in Figure 8-2.

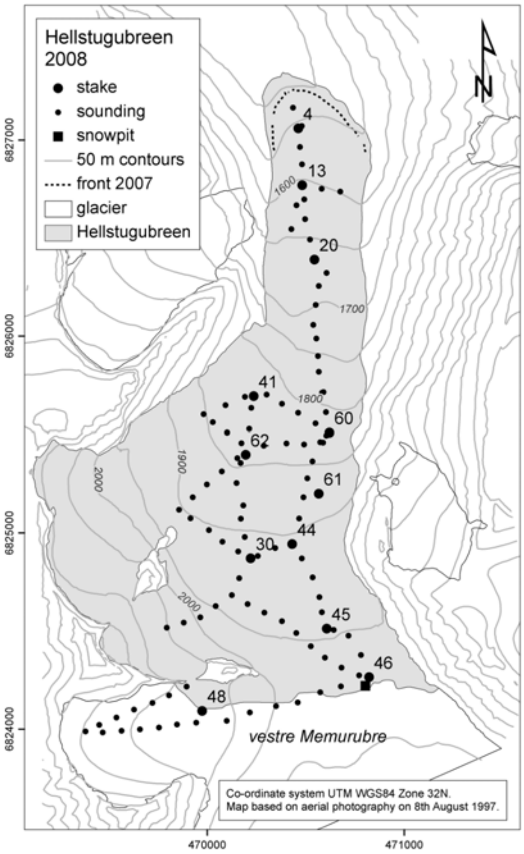


Figure 8-2
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2008. The position of the glacier front in 2007 (measured by handheld GPS) is also indicated.

Results

The mass balance results of 2008 are presented in Table 8-1 and Figure 8-3.

Winter balance

The winter balance was calculated from the soundings and the snow density measurement, which was considered to be representative for the whole glacier. The density in the snow pit was 0.45 g/cm^3. The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.4 ±0.2 m w.e. This is 123 % of the mean for the period 1971-2000.

Summer balance

Direct summer balance was calculated from stakes in 9 locations. The density of the melted ice was assumed to be 0.9 g/cm^3 and the density of remaining snow to be 0.6 g/cm^3. The summer balance was calculated to be −1.5 ±0.3 m w.e., which is 104 % of the mean value for the period 1971-2000.

Net balance

The net balance of Hellstugubreen in 2008 was almost in balance, but slightly negative, -0.1 ±0.3 m w.e., which amounts to a volume loss of −0.17 ±0.9 mill. m^3 water. The equilibrium line altitude (ELA) (calculated from Figure 8-3) was 1880 m a.s.l. resulting in an accumulation area ratio (AAR) of 57 %. The cumulative net balance since 1962 is −17.5 m w.e., giving a mean annual deficit of 0.37 m w.e. per year (Fig. 8-4). The calculated annual net balance for Hellstugubreen has been negative every year since 2001. The cumulative deficit amounts to 7.2 m w.e. for the period 2001-2008.

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2008.

Mass balance Hellstugubreen 2007/08 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance, Measured 6 May 2008: Specific (m w.e.)	Winter balance: Volume (10^6 m^3)	Summer balance, Measured 18 Sep 2008: Specific (m w.e.)	Summer balance: Volume (10^6 m^3)	Net balance, Summer surfaces 2007 - 2008: Specific (m w.e.)	Net balance: Volume (10^6 m^3)
2150 - 2210	0.02	1.80	0.04	-0.20	0.00	1.60	0.03
2100 - 2150	0.09	1.72	0.16	-0.41	-0.04	1.31	0.12
2050 - 2150	0.28	1.89	0.53	-0.50	-0.14	1.39	0.39
2000 - 2050	0.18	1.95	0.36	-0.76	-0.14	1.19	0.22
1950 - 2000	0.38	1.57	0.59	-0.98	-0.37	0.59	0.22
1900 - 1950	0.61	1.57	0.96	-1.20	-0.73	0.37	0.23
1850 - 1900	0.35	1.36	0.47	-1.44	-0.50	-0.08	-0.03
1800 - 1850	0.33	1.36	0.45	-1.70	-0.56	-0.34	-0.11
1750 - 1800	0.13	1.24	0.16	-1.94	-0.26	-0.70	-0.09
1700 - 1750	0.10	1.09	0.11	-2.16	-0.23	-1.07	-0.11
1650 - 1700	0.17	1.05	0.18	-2.35	-0.40	-1.30	-0.22
1600 - 1650	0.13	0.90	0.11	-2.60	-0.33	-1.70	-0.21
1550 - 1600	0.16	0.63	0.10	-2.85	-0.45	-2.22	-0.35
1500 - 1550	0.08	0.49	0.04	-3.13	-0.24	-2.64	-0.21
1480 - 1500	0.02	0.43	0.01	-3.30	-0.06	-2.87	-0.05
1480 - 2210	**3.03**	**1.41**	**4.28**	**-1.47**	**-4.45**	**-0.06**	**-0.17**

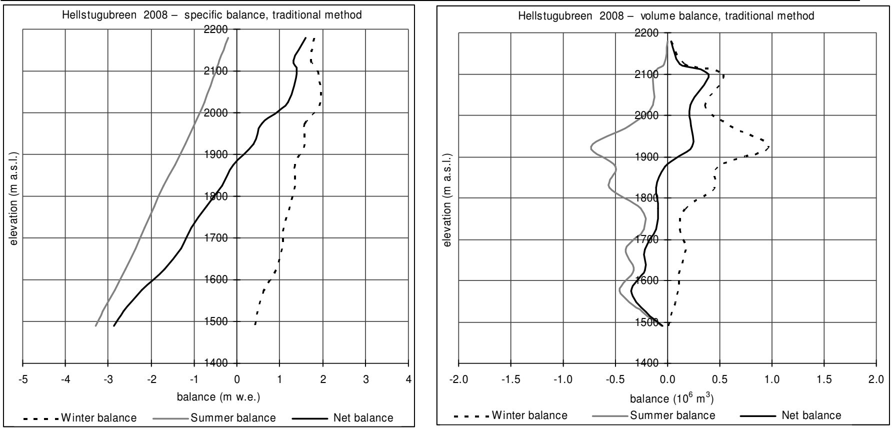


Figure 8-3
Mass balance diagram for Hellstugubreen in 2008, showing specific balance on the left and volume balance on the right.

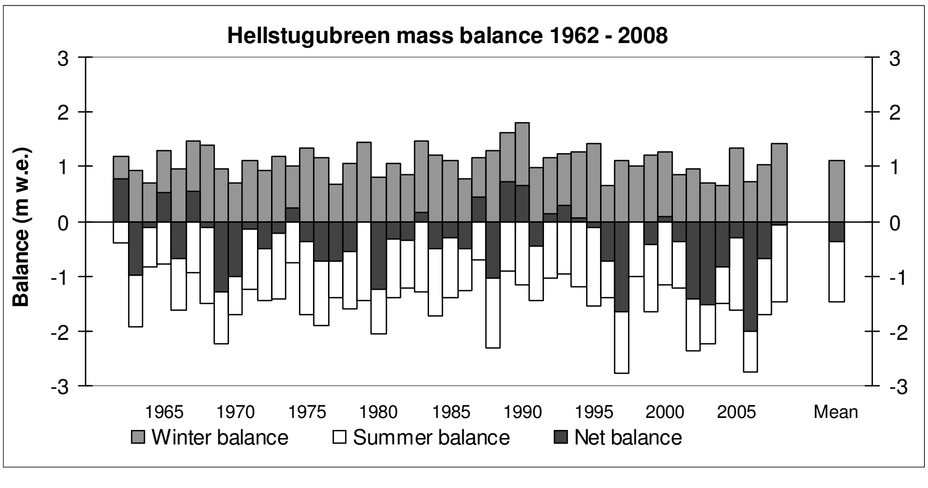


Figure 8-4
Winter, summer and net balance at Hellstugubreen for the period 1962-2008.

9. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is located in the eastern part of the Jotunheimen mountain area in southern Norway. The glacier covers an area of 2.2 km^2 and ranges in elevation from 1830 to 2290 m a.s.l. (Fig. 9-1). Mass balance investigations have been carried out annually since 1962 and 2008 is the 47th year of continuous measurements.

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

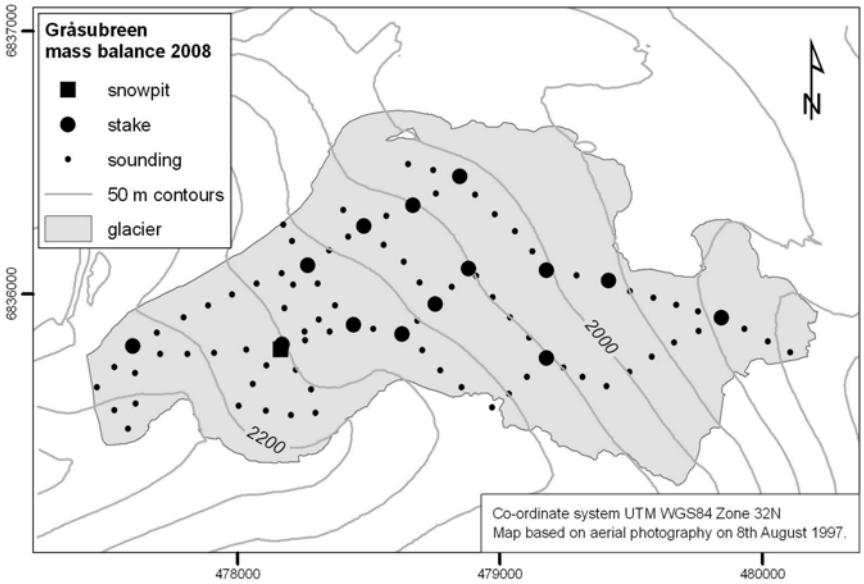


Figure 9-1
Map of Gråsubreen (shaded in grey) showing the location of stakes, snow pit and soundings in 2008.

9.1 Mass balance 2008

Fieldwork

Accumulation measurements were performed on 5th - 6th June 2008. The calculation of winter balance is based on:

- Measurements of stakes in 12 different positions.
- Soundings of snow depth in 93 positions between 1845 and 2275 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was easy to identify over the whole glacier. The snow depth varied between 0.36 and 3.2 m, the mean being 1.74 m.
- The snow density was measured by sampling in a pit near stake 8 at 2150 m a.s.l. where the total snow depth was 1.9 m.

Ablation measurements were carried out on 16th-17th September, when stakes in all locations were measured. A thin layer of new snow covered most of the glacier at the time of the ablation measurements (Fig. 9-2).

Figure 9-2
Field work at Gråsubreen in September 2008. A fresh layer of snow covered the glacier. View towards southwest to Glittertind. Photo: Jon Endre Hausberg.

Results

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

Winter balance

Winter accumulation was calculated from the soundings and the snow density measurement, which was considered representative for the whole glacier. The mean measured snow density was 0.51 g/cm^3. The stake recordings showed neither significant additional melting nor any significant formation of superimposed ice after the previous year's ablation measurements (on 12th September 2007).

The winter balance was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter balance of 1.0 ±0.2 m w.e., which is 121 % of the mean winter balance for the period 1971-2000.

Summer balance

Summer balance was calculated from direct measurements of stakes in eleven locations. The density of the remaining snow was estimated to be 0.60 g/cm^3 and melted ice was estimated to be 0.90 g/cm^3. The resulting summer balance was –0.9 ±0.3 m w.e. The specific summer balance is 80 % of the mean for the period 1971-2000.

Net balance

The net balance of Gråsubreen in 2008 was slightly positive, 0.1 ±0.3 m w.e. The mass balance diagram shows that the net balance curve intersects the y-axis at two elevations, at about 2100 and 1985 m a.s.l. due to the low accumulation in the central part of the glacier (Fig. 9-3). The equilibrium line altitude (ELA) and accumulation area ratio (AAR) were therefore not determined in 2008.

Gråsubreen has had a cumulative mass loss of –16.4 m w.e. since 1962, which is an average of –0.35 m w.e. per year. Most of this mass loss occurred in the 1970s and 1980s, and since 2001.

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2008.

Mass balance Gråsubreen 2007/08 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 5 June 2008		Measured 16 Sep 2008		Summer surfaces 2007 - 2008	
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)
2250 - 2290	0.04	0.85	0.04	-0.30	-0.01	0.55	0.02
2200 - 2250	0.17	0.69	0.11	-0.43	-0.07	0.26	0.04
2150 - 2200	0.26	1.01	0.27	-0.56	-0.15	0.45	0.12
2100 - 2150	0.34	0.79	0.27	-0.67	-0.23	0.12	0.04
2050 - 2100	0.37	0.73	0.27	-0.80	-0.30	-0.07	-0.03
2000 - 2050	0.42	0.86	0.36	-0.97	-0.41	-0.11	-0.04
1950 - 2000	0.36	1.16	0.41	-1.13	-0.40	0.03	0.01
1900 - 1950	0.14	1.36	0.19	-1.23	-0.18	0.13	0.02
1830 - 1900	0.15	1.37	0.21	-1.35	-0.21	0.02	0.00
1830 - 2290	**2.25**	**0.95**	**2.13**	**-0.86**	**-1.95**	**0.08**	**0.19**

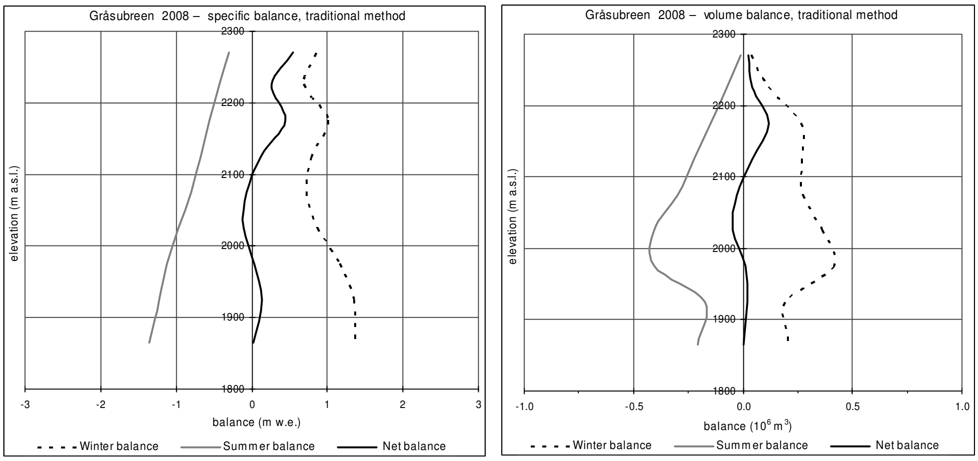


Figure 9-3
Mass balance diagram for Gråsubreen in 2008, showing specific balance on the left and volume balance on the right.

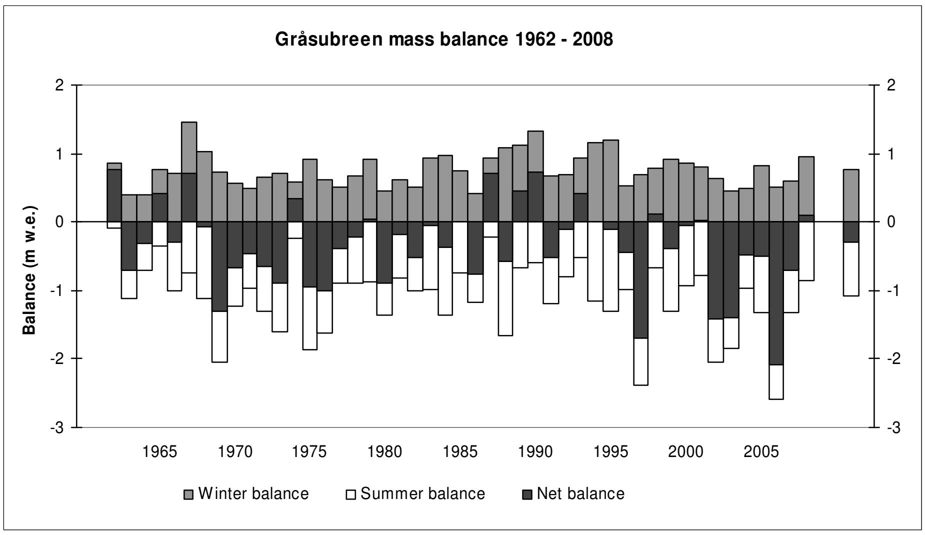


Figure 9-4
Winter, summer and net balance at Gråsubreen during the period 1962-2008.

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. In September 2008 this station was upgraded and measures wind speed, wind direction, global radiation, relative humidity and air temperature. In 2008 both Engabreen and Storglombreen was mapped using airborne laser altimetry (Lidar).

10.1 New map of Engabreen

As part of the International Polar Year (IPY) project Glaciodyn a large part of Vestisen (western Svartisen) was mapped on 2nd September 2008 (Blom Geomatics AS, Oslo, Norway). The point density varies between 2.6 and 6 points square metre. A homogeneity check investigating elevation deviations between neighbouring flight lines gave a total RM-error of 0.175 m. The highest deviations are found in steep terrain, as expected. Based on the point elevation data a 5 x 5 m DEM covering Engabreen, Litlebreen and Storglom-breen was constructed. A second quality check was carried out comparing the 5 x 5 m DEM with 438 point elevations measured with differential GPS (dGPS) on the glacier plateau on the same day as the ALS data collection. The dGPS reference station was Holandsfjord, 5 km north of the surveyed area. The difference between dGPS and ALS elevations was less than 0.2 m at 96.5 % of the dGPS points.

The glacier outline was mapped using a combination of laser intensity values and terrain relief. The drainage basin for calculation of the mass balance at Engabreen was updated using the new glacier outline.

The elevation distribution was calculated by counting grid cells within 100 metre elevation bins, each grid cell representing 25 m^2. The elevation and volume changes will be discussed elsewhere.

10.2 Mass balance 2008

Fieldwork

The glacier was visited on 7th March. Stakes in positions E105, E101 and E17 were measured. The snow depth at the stakes on the plateau was 5.5 to 6 metres.

The locations of stakes and towers, the density pit and the sounding profile are shown in Figure 10-1. The calculation of the winter balance is based on the following measurements on 15th May:

- Direct measurement of snow depth at locations E105 (6.15 m) and E101 (5.75 m).
- Snow depth from coring at stake E5, E38 and E34, showing 6.35, 5.55 and 2.4 m of snow, respectively.

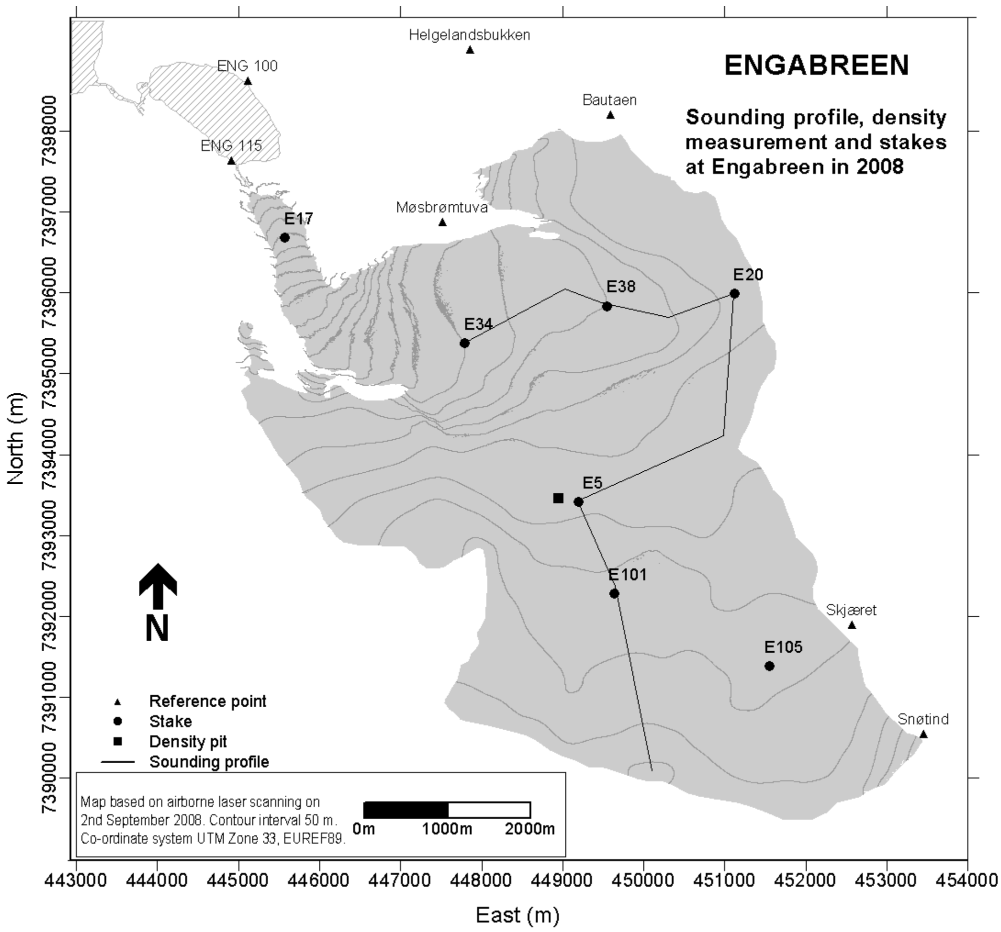


Figure 10-1
Location of stakes, density pit and sounding profiles on Engabreen in 2008.

- Snow depth sounding at 49 locations on a 11 km long profile and 5 extra locations. The snow depth was about 6 m at most of the locations above 1200 m a.s.l., and mainly between 2 and 6 m between 950 and 1200 m a.s.l.
- Direct measurement of 0.5 m of ice melt at location E17.
- Snow density measured down to the summer surface (SS) at 5.55 m depth at stake E5. The mean snow density was 0.54 g/cm^3.

The stake in position E17 at the tongue melted out around 29th July, and it was replaced on 5th August. About 6 m of ice melted before 5th August, and 2.7 m ice melted between 5th August and 3rd October. At the plateau, between 3.5 and 5 m of snow melted between 15th May and 2nd September. After 2nd September up to 0.7 m snow melted before the winter snow accumulation started.

The net and summer balance measurements were carried out on 3rd October. There was up to 0.5 m of new snow on the glacier plateau. Stakes were found in seven locations (E17, E34, E38, E20, 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 3 m of ice had melted during summer. At the stakes above the TSL 1 to 2.5 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 (Fig. 10-1 for location) shows that the air temperature on the glacier plateau was at or below zero for most of the period between 25th August and 13th November 2007. This implies that no significant late autumn melting occurred. The winter maximum snow-water-equivalent (SWE) occurred around the date of the snow measurements 15th May 2008. At stake E34 the maximum SWE occurred a little earlier, around 1st May, and at the glacier tongue melting probably occurred in periods through the entire winter season. This run-off volume has not been calculated.

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 (1240 m a.s.l.). This model was then used to calculate the water equivalent value of the snow depth measurements.

Point values of the snow water equivalent (SWE) were plotted against altitude, and a curve was drawn based on visual evaluation (Fig. 10-2). Below 960 m a.s.l. the winter balance curve was interpolated based on the observed snow depth at stake E34 and the observed negative winter balance at stake E17. Based on this altitudinal distribution curve, the winter balance was calculated as 2.8 ±0.2 m w.e., which corresponds to a volume of 109 ±8 mill. m^3 of water. This is 96 % of the mean value for the period 1970-2007 (2.94 m w.e.), and 102 % of the mean value for the 5-year period 2003-2007 (2.77 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 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 seven locations between 300 and 1350 m a.s.l. (Fig. 10-2). The summer balance was calculated as −2.5 ±0.2 m w.e., which equals a volume of −97 ±8 mill. m^3 water. This is 107 % of the average for the period 1970-2007 (−2.33 m w.e.), but 97 % of the average for the 5-year period 2003-2007 (−2.58 m w.e.).

Net balance

The net balance of Engabreen for 2008 was calculated as 0.3 ±0.3 m w.e., which corresponds to a mass gain of 10 ±10 mill. m^3 water. The mean value for the period 1970-2007 is +0.60 m w.e., but +0.19 m w.e for 2003-2007. The equilibrium line altitude (ELA) was determined as 1093 m a.s.l. from the net balance curve in Figure 10-2. This corresponds to an accumulation area ratio (AAR) of 77 %. The mass balance results are shown in Figure 10-2 and Table 10-1. The results from 2008 are compared with mass balance results for the period 1970-2007 in Figure 10-3.

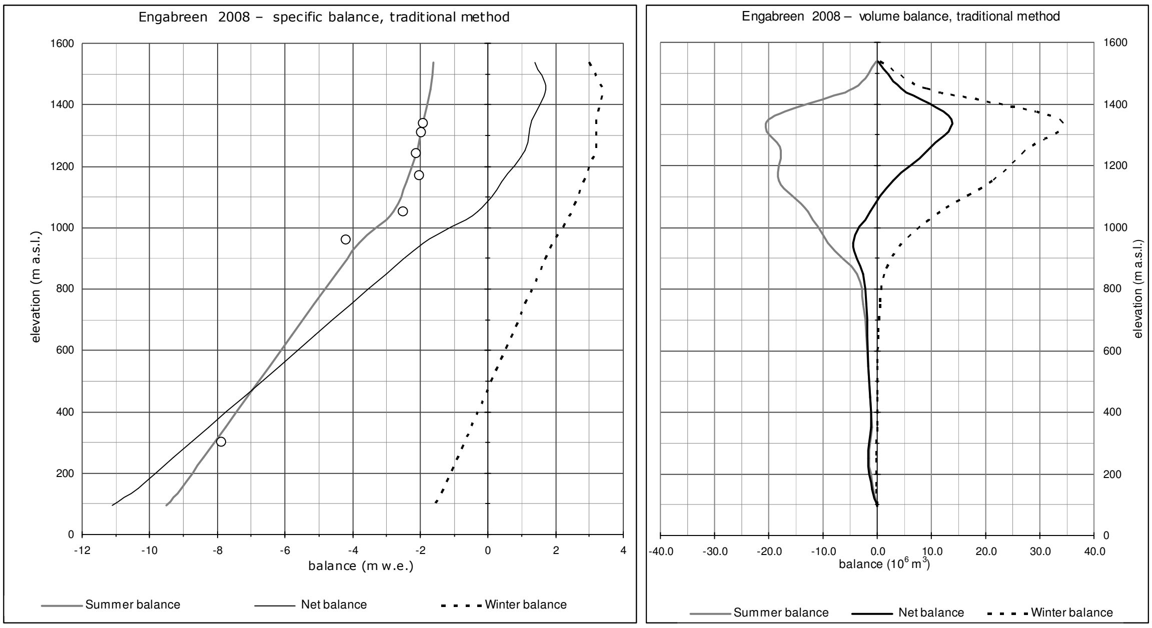


Figure 10-2
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2008. Summer balance at stakes and towers is shown as circles (o).

Table 10-1
Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2008, using the map from 2008.

Mass balance Engabreen 2007/08 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 15th May 2008		Measured 3rd Oct 2008		Summer surface 2007 - 2008	
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)
1500 - 1574	0.10	3.00	0.3	-1.60	-0.2	1.40	0.1
1400 - 1500	2.65	3.40	9.0	-1.70	-4.5	1.70	4.5
1300 - 1400	10.49	3.20	33.6	-1.90	-19.9	1.30	13.6
1200 - 1300	8.46	3.20	27.1	-2.10	-17.8	1.10	9.3
1100 - 1200	7.56	2.80	21.2	-2.40	-18.1	0.40	3.0
1000 - 1100	4.57	2.50	11.4	-2.80	-12.8	-0.30	-1.4
900 - 1000	2.38	1.90	4.5	-3.80	-9.1	-1.90	-4.5
800 - 900	0.84	1.50	1.3	-4.50	-3.8	-3.00	-2.5
700 - 800	0.51	1.10	0.6	-5.15	-2.6	-4.05	-2.1
600 - 700	0.35	0.70	0.2	-5.80	-2.0	-5.10	-1.8
500 - 600	0.26	0.30	0.1	-6.45	-1.7	-6.15	-1.6
400 - 500	0.17	-0.10	0.0	-7.10	-1.2	-7.20	-1.2
300 - 400	0.13	-0.50	-0.1	-7.75	-1.0	-8.25	-1.0
200 - 300	0.18	-0.90	-0.2	-8.40	-1.5	-9.30	-1.7
100 - 200	0.09	-1.30	-0.1	-9.05	-0.8	-10.35	-0.9
89 - 100	0.00	-1.60	0.0	-9.50	0.0	-11.10	0.0
85 - 1574	**38.74**	**2.81**	**108.9**	**-2.50**	**-97.0**	**0.31**	**11.9**

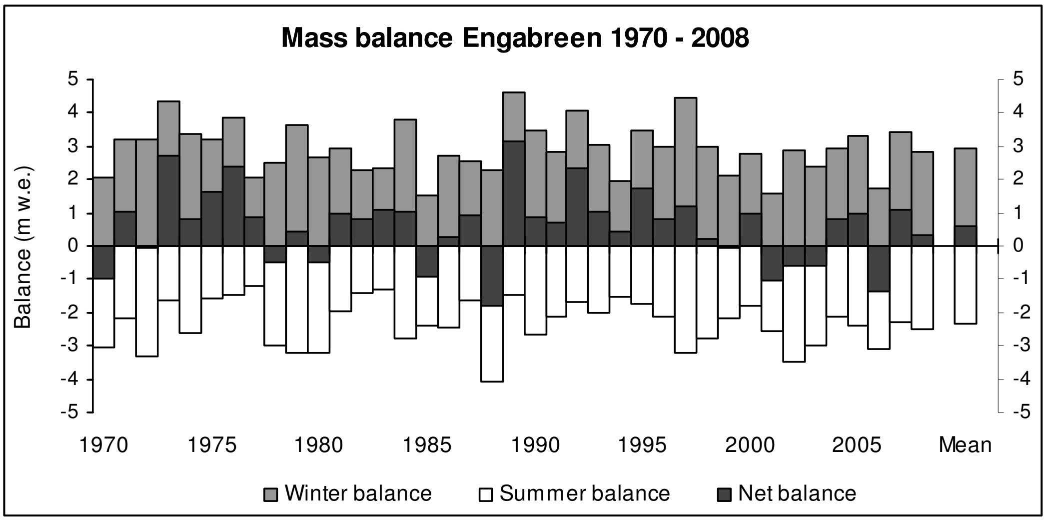


Figure 10-3
Mass balance at Engabreen during the period 1970-2008. The average winter, summer and net balances are b_w =2.93 m w.e., b_s =–2.34 m w.e., and b_n =0.59 m w.e.

10.3 Meteorological observations

A meteorological station recording air temperature and global radiation is located on the nunatak Skjæret (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig. 10-1). The station has recorded data since 1995 with some gaps. In September the station was upgraded to include humidity, wind direction and wind speed. 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. This station is located 28 km north of Engabreen and 19 km north-west of Glomfjord.

In 2008, data was collected at Skjæret with no gaps (Fig. 10-4). When the autumn measurements were carried out on 13th November 2007 up to 2 metres of snow had accumulated on the glacier plateau. The air temperature was mainly close to or above freezing during the first half of October. The coldest period this winter was around 21st March when the daily mean temperature was –17.7 °C. The first period in spring with daily temperatures above 0 °C was 29th April to 3rd May. The temperature was then mainly below 0 °C until 29th May. The snow measurements were performed on 15th May. The temperature stayed above 0 °C even at night from 29th May until 8th June. The maximum daily temperature was measured on 28th July (13.1 °C). Except for cold periods between 9th and 13th June and from 24th to 27th June the air temperature was at or above 0 °C until 26th September. At Skjæret the summer mean temperature was 2.7 °C which is 1.4 °C lower than in the warm summers of 2002 and 2006 but similar to 2001, 2005 and 2007.

In Glomfjord the mean annual temperature in 2008 was 6.1 °C, which is 1.1 °C above the 1961-90 average. The summer temperature in Glomfjord (1st June -30th September, 11.9 °C) was 0.8 °C higher than the 1961-90 average.

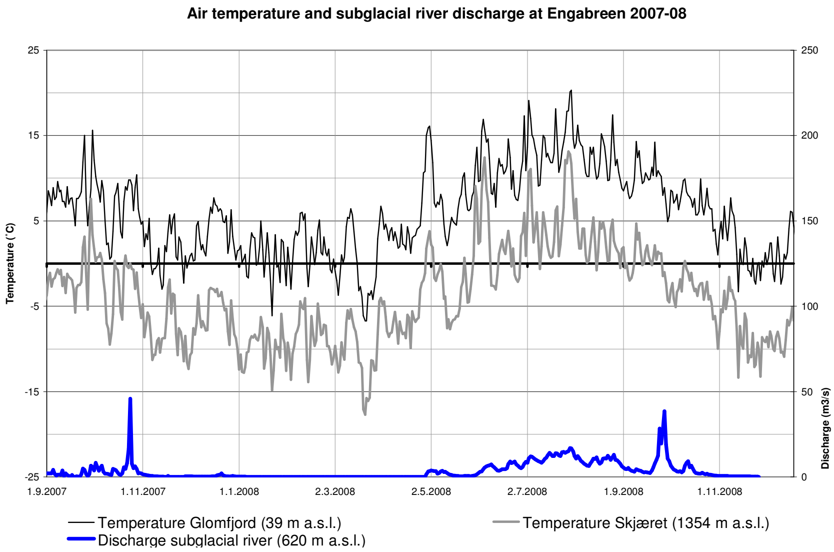


Figure 10-4
Daily mean air temperature at Skjæret (159.20) and Glomfjord (80700), and discharge in the subglacial river intake beneath Engabreen between 1st September 2007 and 31st December 2008.

At the precipitation station Reipå the recorded winter precipitation in 2008 was 877 mm, which is more than in 2001 and 2003, but comparable to 2004. 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 2008 was a little less than the 1961-1990 average.

10.4 Svartisen subglacial laboratory

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

Pressure measurements

Six load cells were installed at the bed of the glacier in December 1992 in order to measure variations in subglacial pressure. The load cells are Geonor P-105 Earth Pressure Cells. Readings are recorded from the load cells at 15 minute intervals (more frequently when experiments are being performed). Four of these load cells were still functioning at the beginning of 2008. A further two load cells were installed in November 1997 and were also still operating into 2008 (Fig. 10-5). One load cell (1e) recorded very little data from mid-March to June, but showed reliable values from July onwards. Another load cell (97-1) registered only error (or nonsense) values for much of August and September. On 11th October the Campbell datalogger suddenly started registering only error values for all load cells. This was due to an electronics problem and has now been fixed, but there were no more data recorded in 2008. There is a break in the data in mid-May, as this was during a field campaign and data was recorded at a different data interval, so is not presented here. A seventh load cell (number 7, Fig 10-5), has recorded intermittently since installation in November 2003, and showed error values for much of 2008, hence these results are not included here. Note that the graphs of load cell pressure variations have different axes.

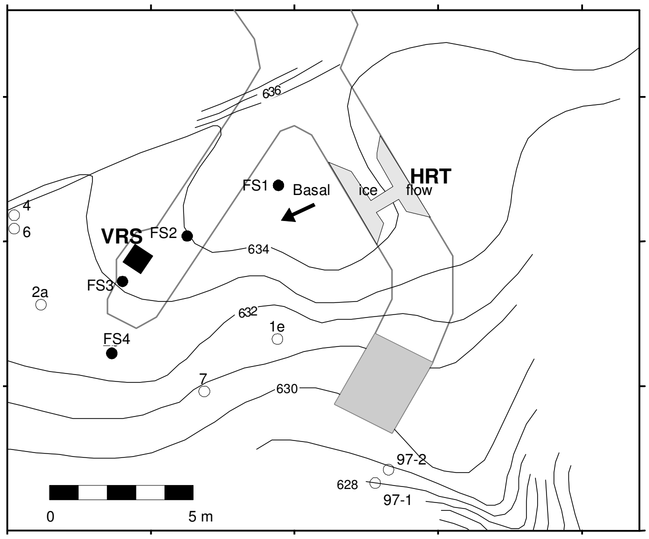


Figure 10-5
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 97-1 and 97-2 and boreholes, marked FS.

Pressure sensor records for winter 2008 from 1st January to 31st March are shown in Figure 10-6. The records are generally typical for the winter period - relatively quiet and stable, corresponding with very low discharge measured in the subglacial tunnel, although somewhat noisier than is usual. Temperatures as measured at the meteorological station (Fig. 10-4) at Skjæret were low (between about −18° C and −4° C) and discharge in the subglacial tunnels was correspondingly low. Values measured at the pressure sensors were generally similar, although 97-1 was noticeably lower (by 2-3 bars) compared with the same period in 2007.

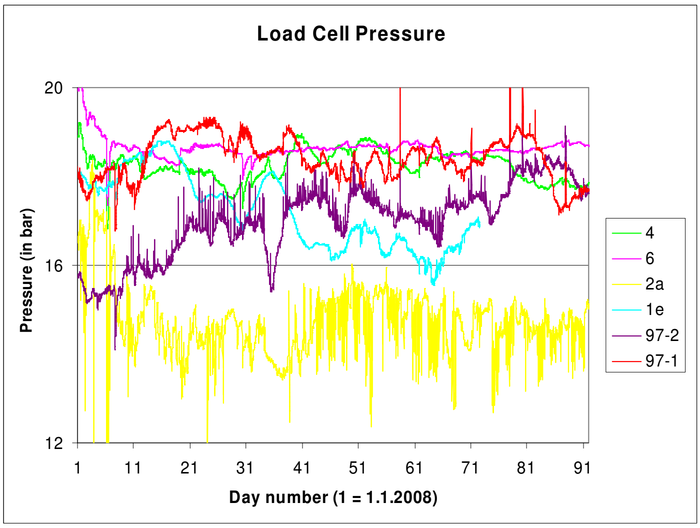


Figure 10-6
Pressure records for 1st January to 31st March.

Pressure sensor records for the late-spring and early- summer, from 1st April to 30th June, are shown in Figure 10-7. There are no data presented here for the period between 9:46 on 9th May and 7:01 on 14th May, because this was during a measurement campaign on the glacier surface and a different recording interval was used at this time. This period is represented by a break in the graph. The first major melting event occurred between 29th April and 3rd May when temperatures were unseasonably high. Discharge in the subglacial system rose rapidly, and this was quickly reflected at all load cells, which first dropped in value then sharply rose again as there was extensive meltwater under the glacier.

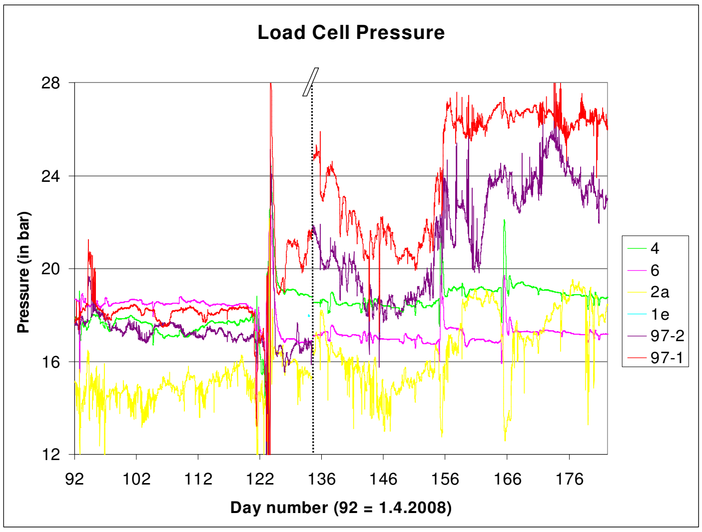


Figure 10-7
Pressure records for 1st April to 30th June. Note the gap in data between 9:46 on 9th May and 7:01 on 14th May.

Pressure sensor records for the summer and autumn, from 1st July to 11th October, are shown in Figure 10-8. These are fairly typical for the summer period. Changes in pressure recorded at the sensors are for the most part well-correlated with each other, although 97-2, shows some unusual variations. There was an unusually high amount of subglacial meltwater at the end of September that corresponds with a rainy period between 19th and 30th September, when there was probably more than 100 mm rain between 25th and 30th September. This is reflected in the pressure records especially at load cells 4 and 6, and also at 2a and 1e.

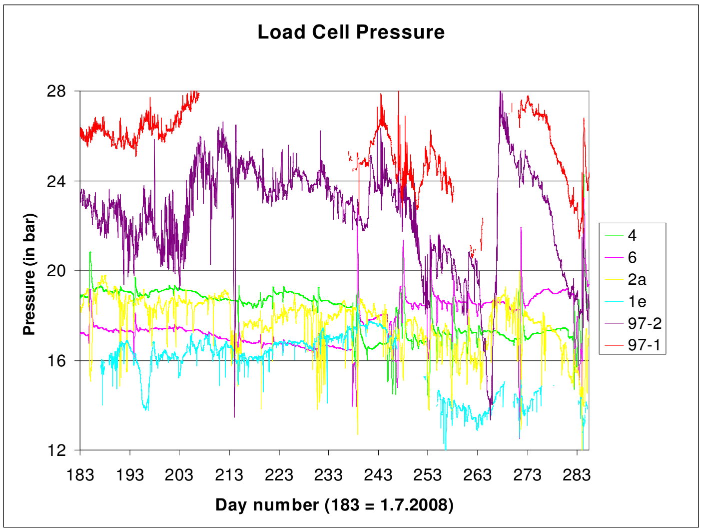


Figure 10-8
Pressure records for 1st July to 11th October.

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 2008 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 2008

New mapping of Langfjordjøkelen

The mass balance of Langfjordjøkelen was previously calculated using a map constructed from aerial photographs taken on 1st August 1994. As part of Glaciodyn, an International Polar Year project, NVE has constructed a new Digital Elevation Model (DEM) from airborne laser scanning acquired on 9th September 2008 (Blom Geomatics AS, Norway). This DEM is now used in the mass balance calculations.

Figure 11-1
The outlet of Langfjordjøkelen photographed on 26th May 2008 (left) and 5th August 2008 (right). Photo: Kjetil Melvold (left) and Bjarne Kjøllmoen (right).

Fieldwork

Snow accumulation measurements

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

- Measurements of stakes in positions 10 (470 m a.s.l.), 20 (634 m a.s.l.) and 25 (724 m a.s.l.) showing snow depths of 2.1, 3.2 and 3.7 m respectively.
- 78 snow depth soundings between 309 and 1050 m elevation. Generally, the sounding conditions were reasonable over the whole glacier. However, the summer surface was

more difficult to detect in the upper areas. In general the snow depth varied between 2 and 5 m.

- Snow density was measured down to SS at 3.5 m depth at stake position 30.

Ablation measurements

Ablation was measured on 16th October. The net balance was measured at seven stakes in all five locations between 502 and 1050 m a.s.l. Since the snow measurements in May the stakes had increased in length between 4.2 m (724 m a.s.l.) and 4.8 m (634 m a.s.l.). There was about 1 m of snow remaining at the top of the glacier from the winter season 2007/2008. At the time of measurements up to 15 cm of fresh snow had fallen.

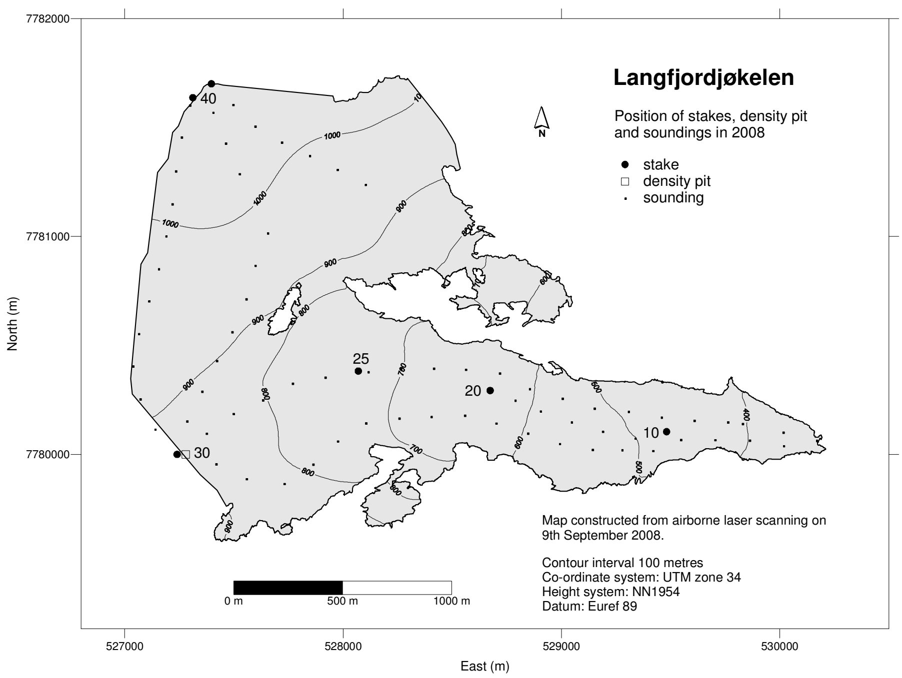


Figure 11-2
Location of stakes, soundings and snow pit at Langfjordjøkelen in 2008.

Results

The calculations are based on a glacier map 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 November 2007. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measurement at 884 m altitude. The mean density of 3.4 m snow was 0.46 g/cm^3. The density model was used to convert all measured snow depths to water equivalent.

The winter balance calculations were performed by plotting the measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 11-4) and a mean value for each 50 m height interval was estimated (Tab. 11-1).

The winter balance was calculated as 1.7 ±0.2 m w.e., corresponding to a water volume of 5 ±1 mill. m^3. The result is 77 % of the mean value for the periods 1989-1993 and 1996-2007. Only three years (2006, 2001 and 1999) have shown a lower winter balance since the measurements began in 1989.

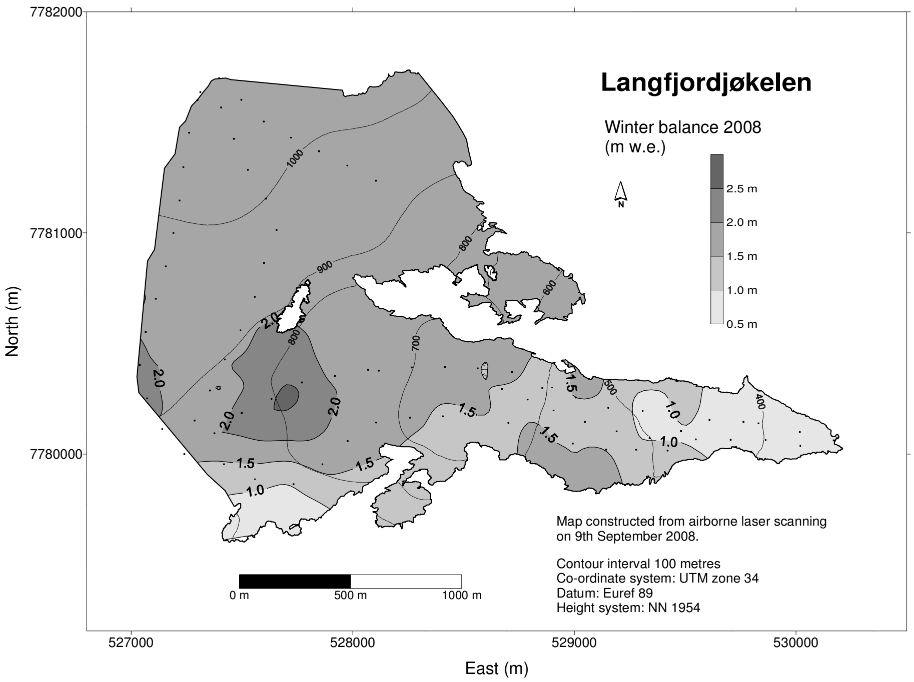


Figure 11-3
Winter balance at Langfjordjøkelen in 2008 interpolated from 82 snow depth measurements (•).

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 1.6 m w.e.

Summer balance

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

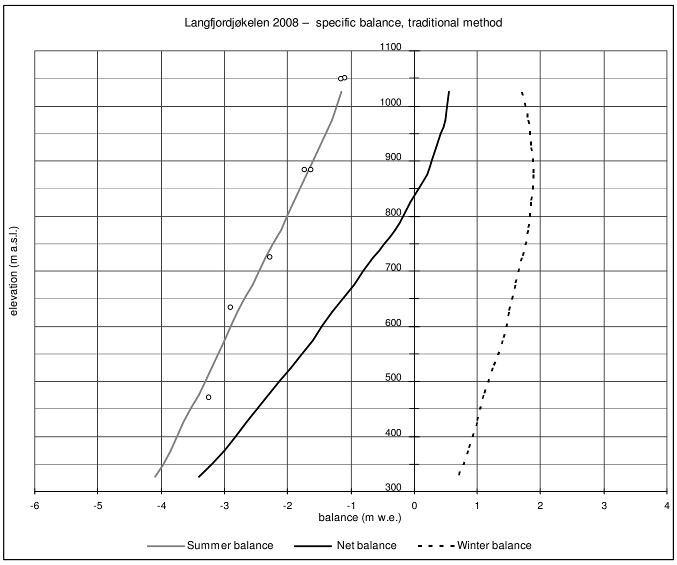
The summer balance was calculated at all five locations. The summer balance increased from −1.1 m w.e. at position 40 (1050 m a.s.l.) to −3.2 m w.e. at position 10 (470 m a.s.l.). Based on estimated density and stake measurements, the summer balance was calculated to be −2.0 ±0.3 m w.e., which is −6 ±1 mill. m^3 of water. The result is 67 % of the average for the periods 1989-1993 and 1996-2007. This is the lowest summer balance measured at Langfjordjøkelen.

Net balance

The net balance at Langfjordjøkelen for 2008 was −0.3 ±0.3 m w.e., which equals a volume loss of −1 ±1 mill. m^3 of water (Tab. 11-1). The mean value for the measurement periods 1989-93 and 1996-2007 is −0.87 m w.e. (Fig. 11-5), while the average over the 5-year period 2003-2007 is −1.3 m w.e.

Based on Figure 11-4, the Equilibrium Line Altitude (ELA) lies at 835 m a.s.l. Accordingly, the Accumulation Area Ratio is 53 %.

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.



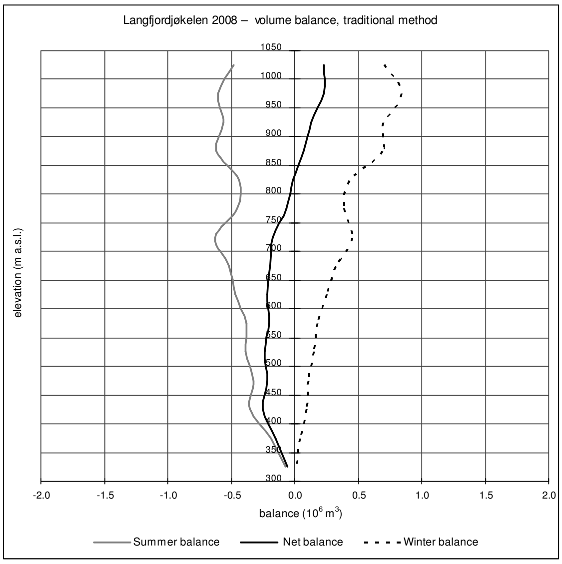


Figure 11-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2008. Summer balance for seven stakes is shown (o).

Table 11-1
Winter, summer and net balance for Langfjordjøkelen in 2008. Mean values for the periods 1989-93 and 1996-2007 are b_w = 2,16 m, b_s = –3,03 m and b_n = –0,87 m w.e.

Mass balance Langfjordjøkelen2007/08 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 22nd May 2008 Specific (m w.e.)	Volume (10^6 m^3)	Summer balance Measured 16th Oct 2008 Specific (m w.e.)	Volume (10^6 m^3)	Net balance Summer surface 2007 - 2008 Specific (m w.e.)	Volume (10^6 m^3)
1000 - 1050	0.42	1.70	0.7	-1.15	-0.5	0.55	0.2
950 - 1000	0.47	1.80	0.8	-1.30	-0.6	0.50	0.2
900 - 950	0.38	1.85	0.7	-1.50	-0.6	0.35	0.1
850 - 900	0.36	1.90	0.7	-1.70	-0.6	0.20	0.1
800 - 850	0.23	1.85	0.4	-1.90	-0.4	-0.05	0.0
750 - 800	0.22	1.80	0.4	-2.10	-0.5	-0.30	-0.1
700 - 750	0.27	1.70	0.5	-2.35	-0.6	-0.65	-0.2
650 - 700	0.20	1.60	0.3	-2.55	-0.5	-0.95	-0.2
600 - 650	0.17	1.50	0.3	-2.80	-0.5	-1.30	-0.2
550 - 600	0.13	1.40	0.2	-3.00	-0.4	-1.60	-0.2
500 - 550	0.12	1.25	0.2	-3.20	-0.4	-1.95	-0.2
450 - 500	0.10	1.10	0.1	-3.40	-0.3	-2.30	-0.2
400 - 450	0.10	1.00	0.1	-3.65	-0.3	-2.65	-0.3
350 - 400	0.05	0.85	0.0	-3.85	-0.2	-3.00	-0.1
302 - 350	0.02	0.70	0.0	-4.10	-0.1	-3.40	-0.1
302 - 1050	**3.21**	**1.67**	**5.4**	**-2.02**	**-6.5**	**-0.35**	**-1.1**

The balance year 2007/2008 is the twelfth successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2008 (estimated values for 1994 and 1995 included) is −16 m w.e.

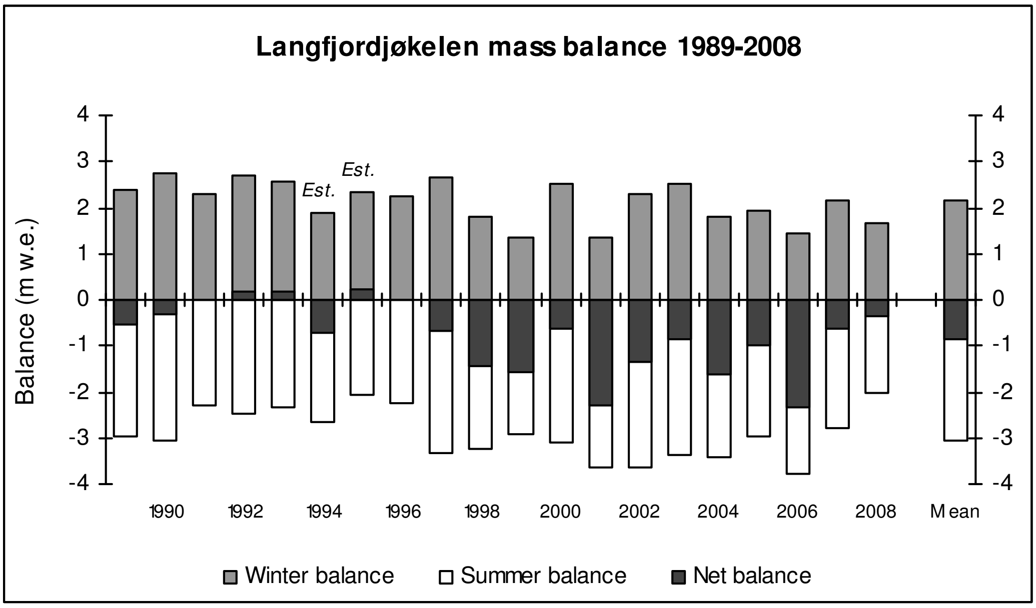


Figure 11-5
Mass balance at Langfjordjøkelen during the period 1989-2008. The total accumulated deficit over 1989-2008 is 15.7 m w.e. (includes estimated values for 1994 and 1995).

12. Glacier length change (Hallgeir Elvehøy)

Observations of glacier length change at Norwegian glaciers started around 1900. In 2008, glacier length change was measured for 32 glaciers - 24 in southern Norway and eight glaciers in northern Norway (Fig. 12-1). Length change measurements have been resumed at Tunsbergdalsbreen, an outlet glacier from Jostedalsbreen (Fig. 12-2), and at Trollkyrkjebreen (Fig. 12-3) and Finnanbreen, two valley/cirque glaciers in Møre & Romsdal.

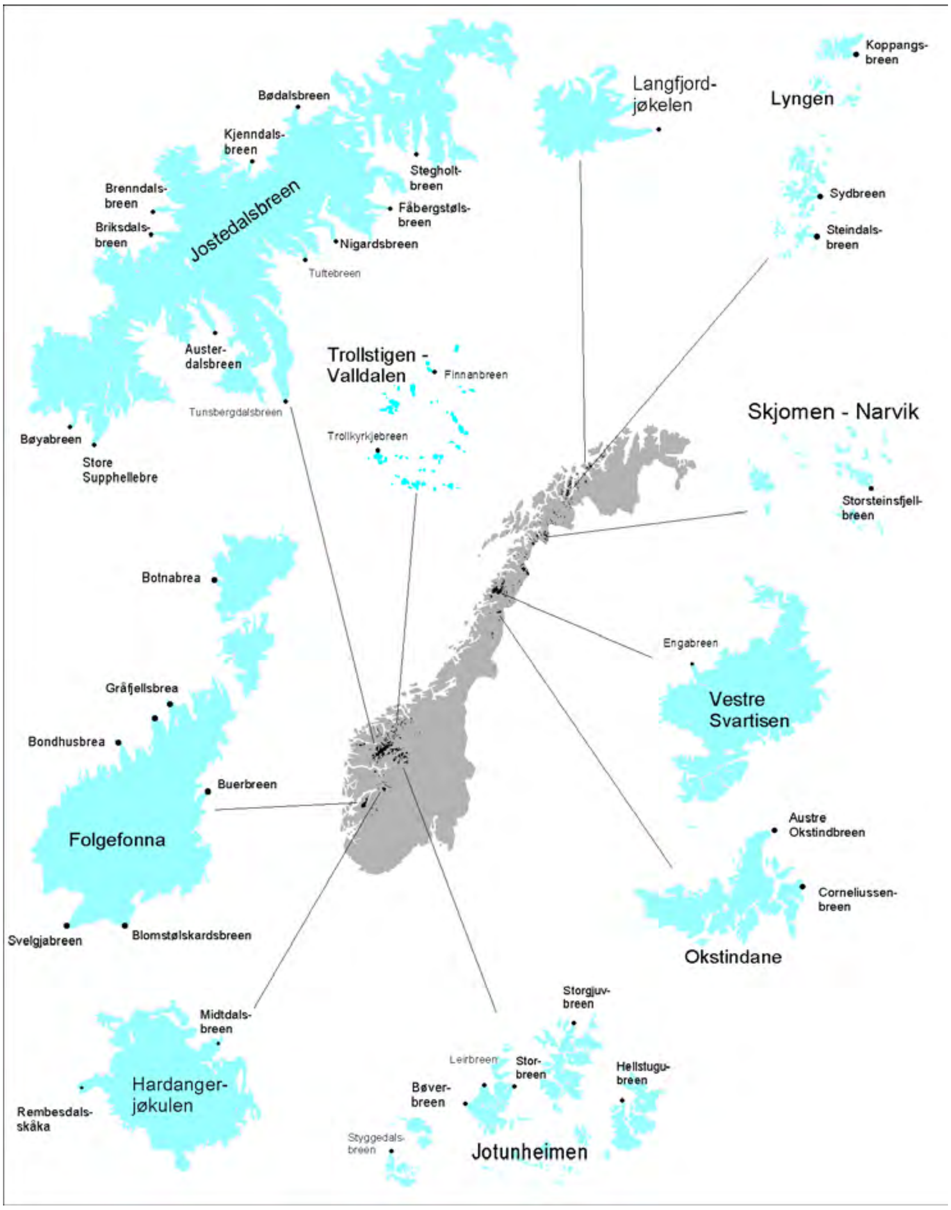


Figure 12-1
Location map showing glaciers where length change observations were performed in 2008. Note that the different glacier areas are not to the same scale.

Figure 12-2
Tunsbergdalsbreen was photographed on 5th July 2007. Glacier length change measurements were initiated in 1900. At that time the glacier terminus was located on the sandur in the lower central part of the photo. The glacier retreated 980 m between 1900 and 1960. Glacier length change measurements were resumed by Norsk bremuseum (Norwegian glacier museum) in 2008 when fixed points were established on the left bank of the proglacial lake. Photo: Miriam Jackson.

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 representativity 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 2008

In 2008, 32 glaciers were measured, eight in northern Norway and 24 glaciers in southern Norway. The glacier length changes at the observed glaciers are listed in Table 12-1.

At Jostedalsbreen, Fåbergstølsbreen retreated 60 m, and has retreated a total of 166 m since 2000. Brenndalsbreen retreated 56 m, and has retreated 444 m since 2000. The average retreat of eleven outlet glaciers from Jostedalsbreen was 16 metres.

At Folgefonna, Bondhusbrea retreated 50 metres, and has retreated 287 m since 1996 when measurements resumed. At Hardangerjøkulen, Rembesdalsskåka retreated 35 metres, and has retreated 319 m since 1997.

In Jotunheimen, the length change rates are generally slow. Styggedalsbreen, Bøverbreen and Storgjuvbreen advanced slightly in the second half of the 1990s, and at Storbreen and Hellstugubreen the retreat rates were lower than in previous and following periods. After 2000 the rate of retreat has increased, but it is considerably lower than in the 1940s, 1950s and 1960s.

In Nordland, Engabreen retreated 29 m and has retreated 247 m since the last advance ended in 1999. Corneliussenbreen advanced during the 1970s, -80s and -90s, but has retreated 240 metres from its most recent end moraine which was formed late in the 1990s. Austre Okstindbreen has not changed significantly during the last two years, but has retreated from fresh end moraines probably formed in the 1990s, located on the shore of the pro–glacial lake Bretjørna, and terminates completely in this lake. Storsteinsfjellbreen in Skjomen retreated 470 m between 1963 and 2006 (−11 m/a), but retreated only 12 metres during the last two years. The glacier terminus is at present on a rock threshold.

In Troms and Finnmark the retreat at Koppangsbreen has decreased probably because the retreating terminus has reached a narrowing part of the valley. The mean retreat of four glaciers is 14 metres.

Figure 12-3
Photograph showing the terminus of Trollkyrkjebreen, a north-facing valley glacier in Valldalen, Møre & Romsdal, on 24th September 2008. The glacier area was 1.5 km^2 and covered the altitudinal interval between 1180 and 1570 m a.s.l. Glacier length change measurements were carried out between 1944 and 1974, and was re-initiated in 2008. The length change is measured on the western (right) side of the river. Photo: Tore Klokk.

Table 12-1
Glacier length change between autumn 2007 and autumn 2008. See Figure 12-1 for locations.

Region	Glacier	2007-08 (m)	Observer	Period(s) of length change measurements	Number of obs.	Change since	Length change
Jostedalsbreen	Austerdalsbreen	-20	NVE	1905-20, 1933-	88	1933	-1386
	Brenndalsbreen	-56	SW	1900-62, 1996-	72	1900	-1591
	Briksdalsbreen	-12	NVE/AN	1900-	108	1900	-863
	Bødalsbreen	-22	SW	1900-53, 1996-	57	1900	-831
	Fåbergstølsbreen	-60	NVE	1899-	103	1899	-2435
	Kjenndalsbreen	-4	SW	1900-52, 1996-	55	1996	-505
	Nigardsbreen	-1	NVE	1899-	97	1899	-2365
	Stegholtbreen	-30	NVE	1903-	102	1903	-1800
	Tuftebreen	-12	NVE	2007-	1		
	Tunsbergdalsbreen	X	NB	1900-1960, 2008-	55		
	Bøyabreen	32	NB	1899-1953, 2003-	52	2003	-106
	Store Supphellebreen	9	NB	1899-1958, 1977-83, 1992-	74	1992	-46
Folgefonna	Bondhusbrea	-50	S	1901-86, 1996-	75	1996	-287
	Botnabrea	-9[1]	GK	1996-	10	1996	-31
	Blomstølskardsbreen	0	SKL	1994-	11	1994	-6
	Buerbreen	3	NVE	1900-80, 1995-	60	1900	-741
	Gråfjellsbrea	-19	S	2002-	9	1959	-864
	Svelgjabreen	-1	SKL	2007-	1		
Hardanger-jøkulen	Midtdalsbreen	-31	AN	1982-	26	1982	-80
	Rembesdalsskåka	-35	S	1918-41, 1968-83, 1995-	30	1918	-1123
Jotunheimen	Bøverbreen	-2	SW	1903-12, 1936-63, 1997-	35	1997	-19
	Hellstugubreen	0	NVE	1901-	68	1901	-1071
	Leirbreen	NM	NVE	1909-	50	1909	-713
	Storbreen	-7	NVE	1902-	77	1902	-1088
	Storgjuvbreen	-4	SW	1901-12, 1933-63, 1997-	78	1997	+9
	Styggedalsbreen	9	NVE	1901-	87	1901	-492
Møre & Romsdal	Trollkyrkjebreen	X	NVE	1944-74, 2008-	28	1944	-289
	Finnanbreen	X	NVE	1950-74, 2008-	20	1950	-190
Okstindane	Austre Okstindbreen	2	NVE	1909-44, 2006-	22	2006	+3
	Corneliussenbreen	-24	NVE	2006-	2	2006	-66
Svartisen	Engabreen	-29	S	1903-	74	1903	-2191
Skjomen	Storsteinsfjellbreen	-9	NVE	2006-	2	2006	-12
Lyngen	Koppangsbreen	-4	NVE	1998-	8	1998	-167
	Sydbreen	-14	NVE	2007-	1		
	Steindalsbreen	-24	NVE	1998-	7	1998	-196
Finnmark	Langfjordjøkelen	-18	NVE	1998-	10	1966	-1119

X: measurements started or resumed in 2008
NM: not measured in 2008
[1]Since 2006 (the terminus of Botnabrea was snow-covered in 2007)
Observers:
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

Changes since 1982

In the 1980s, most of the observed glaciers retreated slowly (Fig. 12-4). Many outlet glaciers from coastal ice caps started to advance late in the 1980s. This advance ended before the turn of the century. At Stegholtbreen the advance didn't begin until 1996 and lasted four years. After 2000 the steep outlet glaciers have retreated quickly. At Nigardsbreen the retreating phase has been much less dramatic than at most other outlet glaciers. The more continental glaciers such as Hellstugubreen have been retreating slowly for decades.

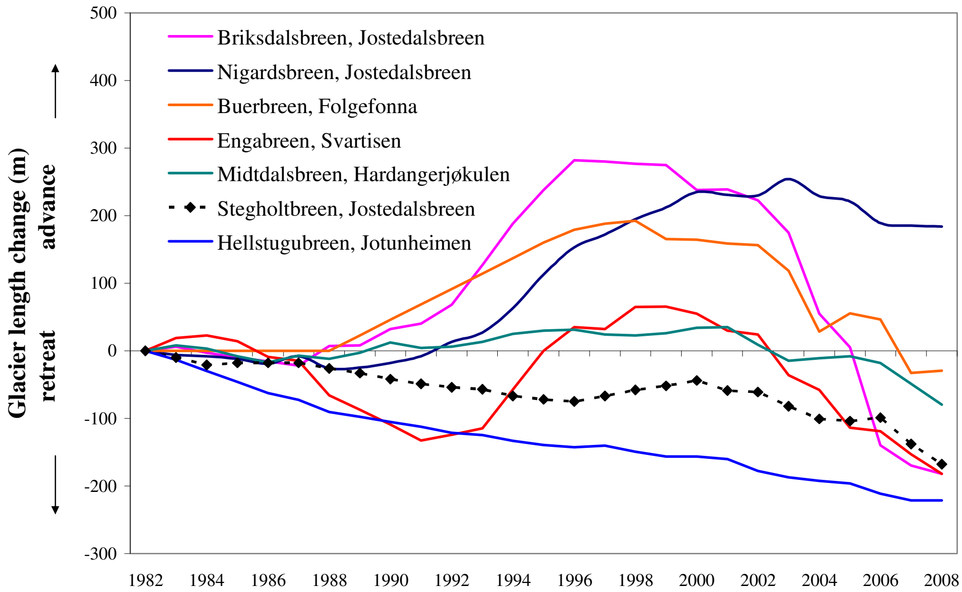


Figure 12-4
Cumulative glacier length change since 1982 at seven glaciers. See Figure 12-1 for locations.

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Appendix A

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Landsat-derived glacier inventory for Jotunheimen, Norway, and deduced glacier changes since the 1930s. *The Cryosphere, Vol. 2, No. 3*, p 131-145.

Andreassen, L.M., M.R. van den Broeke, R. Giesen & J. Oerlemans
A 5 year record of surface energy and mass balance from the ablation zone of Storbreen, Norway. *Journal of Glaciology, Vol. 54, No. 185*, p 245-258.

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Appendix B

Mass balance measurements in Norway – an overview

During the period 1949-2008 there are carried out mass balance measurements at 42 Norwegian glaciers. The table below shows some characteristic data for the individual glaciers.

Area/ No. Glacier	Area (km^2)	Altitude (m a.s.l.)	Mapping year	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	4.5	903-1382	1997	1963-	46
2 Hansebreen	3.1	930-1327	1997	1986-	23
Folgefonna					
3 Blomsterskardsbreen	45.7	850-1640	1959	1970-77	8
3a Svelgjabreen*	22.5	832-1636	2007	2007-	2
3b Blomstølskardsbreen*	22.8	1013-1636	2007	2007-	2
4 Bondhusbrea	10.7	480-1635	1979	1977-81	5
5 Breidablikkbrea	3.4	1234-1651	2007	1963-68, 2003-	12
6 Gråfjellsbrea	8.4	1049-1651	2007	64-68, 74-75, 2003-	13
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	47.8	320-1960	1984	1962-	47
13 Store Supphellebreen	12.0	80-300/ 720-1740	1966	1964-67, 73-75, 79-82	11
14 Austdalsbreen	11.8	1200-1757	1988	1988-	21
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-	46
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	5.4	1390-2100	1997	1949-	60
23 Vestre Memurubre	9.0	1570-2230	1966	1968-72	5
24 Austre Memurubre	8.7	1630-2250	1966	1968-72	5
25 Hellstugubreen	3.0	1480-2210	1997	1962-	47
26 Gråsubreen	2.3	1830-2290	1997	1962-	47
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-	39
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-	18

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 585 years of measurements at Norwegian glaciers. The following tables show winter (bw), summer (bs) and net balance (bn) together with cumulative net balance (Cum. bn) and equilibrium line altitude (ELA) for every single year at each glacier. In front of each table there is a heading containing the name and the area of the glacier. The reported year (in brackets) corresponds to the given area.

1 Ålfotbreen - 4.5 km^2 (1997)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1963	2.48	-3.58	-1.10	-1.10	1300
2	64	2.69	-2.41	0.28	-0.82	1140
3	65	3.64	-3.16	0.48	-0.34	1150
4	66	2.47	-4.08	-1.61	-1.95	>1380
5	67	4.46	-3.18	1.28	-0.67	950
6	68	4.55	-3.60	0.95	0.28	1075
7	69	2.66	-4.83	-2.17	-1.89	>1380
8	1970	2.60	-3.83	-1.23	-3.12	>1380
9	71	4.29	-3.35	0.94	-2.18	1140
10	72	3.81	-3.70	0.11	-2.07	1195
11	73	4.67	-2.49	2.18	0.11	<870
12	74	3.57	-2.54	1.03	1.14	1065
13	75	4.64	-3.43	1.21	2.35	1050
14	76	4.40	-2.87	1.53	3.88	<870
15	77	2.33	-2.89	-0.56	3.32	1280
16	78	2.56	-3.07	-0.51	2.81	1290
17	79	3.28	-3.41	-0.13	2.68	1240
18	1980	2.51	-3.30	-0.79	1.89	1275
19	81	4.04	-3.82	0.22	2.11	1210
20	82	3.35	-3.48	-0.13	1.98	1240
21	83	4.79	-3.19	1.60	3.58	1010
22	84	4.09	-2.77	1.32	4.90	1050
23	85	2.44	-3.00	-0.56	4.34	1290
24	86	2.35	-2.76	-0.41	3.93	1255
25	87	4.29	-2.22	2.07	6.00	<870
26	88	2.73	-5.21	-2.48	3.52	>1380
27	89	5.20	-2.93	2.27	5.79	1030
28	1990	5.98	-4.19	1.79	7.58	995
29	91	4.09	-3.30	0.79	8.37	1035
30	92	5.48	-3.19	2.29	10.66	1050
31	93	4.81	-2.74	2.07	12.73	<870
32	94	3.71	-2.92	0.79	13.52	925
33	95	5.10	-3.90	1.20	14.72	1120
34	96	1.83	-3.71	-1.88	12.84	>1380
35	97	4.22	-4.14	0.08	12.92	1200
36	98	3.66	-3.55	0.11	13.03	1240
37	99	4.61	-4.55	0.06	13.09	1245
38	2000	5.57	-3.58	1.99	15.08	1025
39	01	1.86	-3.95	-2.09	12.99	>1382
40	02	3.78	-5.31	-1.53	11.46	>1382
41	03	2.52	-5.03	-2.51	8.95	>1382
42	04	3.32	-3.42	-0.10	8.85	1225
43	05	4.99	-4.32	0.67	9.52	1135
44	06	2.69	-5.88	-3.19	6.33	>1382
45	07	4.49	-3.22	1.27	7.60	1000
46	08	4.04	-3.35	0.69	8.29	1130
Mean 1963-2008		3.73	-3.55	0.18		

2 Hansebreen - 3.1 km^2 (1997)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1986	2.28	-2.87	-0.59	-0.59	1200
2	87	3.76	-2.63	1.13	0.54	1100
3	88	2.50	-5.24	-2.74	-2.20	>1320
4	89	4.13	-3.71	0.42	-1.78	1140
5	1990	4.42	-4.10	0.32	-1.46	1140
6	91	3.37	-3.11	0.26	-1.20	1125
7	92	4.41	-3.43	0.98	-0.22	1125
8	93	4.23	-3.15	1.08	0.86	<925
9	94	3.39	-2.97	0.42	1.28	1120
10	95	4.38	-3.90	0.48	1.76	1140
11	96	1.74	-3.76	-2.02	-0.26	>1320
12	97	3.77	-3.92	-0.15	-0.41	1160
13	98	3.21	-3.51	-0.30	-0.71	1170
14	99	4.30	-4.19	0.11	-0.60	1155
15	2000	4.69	-3.82	0.87	0.27	1075
16	01	1.71	-4.43	-2.72	-2.45	>1327
17	02	3.51	-5.44	-1.93	-4.38	>1327
18	03	2.45	-5.12	-2.67	-7.05	>1327
19	04	2.87	-3.38	-0.51	-7.56	1220
20	05	4.52	-4.61	-0.09	-7.65	1150
21	06	2.45	-6.43	-3.98	-11.63	>1327
22	07	4.07	-3.23	0.84	-10.79	1042
23	08	3.90	-3.65	0.25	-10.54	1125
Mean 1986-2008		3.48	-3.94	-0.46		

3 Blomsterskardsbreen - 45.7 km^2 (1959)

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

3a Svelgjabreen - 22.5 km^2 (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	2007	3.89	-2.54	1.35	1.35	1205
2	08	3.65	-2.88	0.77	2.12	1225
Mean 2007-08		3.77	-2.71	1.06		

3b Blomstølskardsbreen - 22.8 km^2 (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	2007	4.17	-2.30	1.87	1.87	1230
2	08	3.69	-2.36	1.33	3.20	1260
Mean 2007-08		3.93	-2.33	1.60		

4 Bondhusbrea - 10.7 km^2 (1979)

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

5 Breidablikkbrea - 3.4 km² (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1963	1.11	-2.32	-1.21	-1.21	1635
2	64	1.92	-1.68	0.24	-0.97	1450
3	65	1.72	-2.28	-0.56	-1.53	1525
4	66	1.52	-3.17	-1.65	-3.18	>1660
5	67	3.40	-2.23	1.17	-2.01	1355
6	68	3.55	-2.68	0.87	-1.14	1360
7	2003	2.12	-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	-3.46	1510
10	06	1.49	-4.44	-2.95	-6.41	>1659
11	07	3.42	-3.07	0.35	-6.06	1410
12	08	2.71	-2.96	-0.25	-6.31	1505
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-08		2.51	-3.56	-1.05		

6 Gråfjellsbrea - 8.4 km² (2007)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1964	1.94	-1.62	0.32	0.32	1385
2	65	2.01	-2.29	-0.28	0.04	1490
3	66	1.58	-2.93	-1.35	-1.31	>1660
4	67	3.46	-2.14	1.32	0.01	1355
5	68	3.39	-2.82	0.57	0.58	1380
6	1974	2.11	-1.53	0.58	0.58	1370
7	75	2.53	-2.28	0.25	0.83	1420
8	2003	1.91	-4.09	-2.18	-2.18	>1659
9	04	2.05	-2.82	-0.77	-2.95	1565
10	05	3.15	-3.13	0.02	-2.93	1460
11	06	1.40	-4.55	-3.15	-6.08	>1659
12	07	3.60	-2.85	0.75	-5.33	1395
13	08	2.72	-2.80	-0.08	-5.41	1580
Mean 1964-68		2.48	-2.36	0.12		
Mean 1974-75		2.32	-1.91	0.42		
Mean 2003-08		2.47	-3.37	-0.90		

7 Blåbreen and Ruklebreen - 4.5 km² (1959)

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

[1)] Blåbreen only

8 Midtre Folgefonna - 8.7 km² (1959)

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

9 Jostefonn - 3.8 km² (1993)

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

10 Vesledalsbreen - 4.2 km² (1966)

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

11 Tunsbergdalsbreen - 50.1 km² (1964)

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

12 Nigardsbreen - 47.8 km² (1984)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1962	2.88	-0.63	2.25	2.25	1260
2	63	1.87	-2.09	-0.22	2.03	1550
3	64	2.13	-1.18	0.95	2.98	1400
4	65	2.29	-1.38	0.91	3.89	1395
5	66	1.76	-2.68	-0.92	2.97	1700
6	67	3.40	-1.24	2.16	5.13	1310
7	68	2.72	-2.50	0.22	5.35	1550
8	69	1.95	-3.26	-1.31	4.04	1850
9	1970	1.73	-2.29	-0.56	3.48	1650
10	71	2.11	-1.29	0.82	4.30	1400
11	72	1.88	-2.02	-0.14	4.16	1570
12	73	2.40	-1.30	1.10	5.26	1410
13	74	2.06	-1.58	0.48	5.74	1490
14	75	2.50	-2.23	0.27	6.01	1450
15	76	2.88	-2.48	0.40	6.41	1540
16	77	1.52	-2.29	-0.77	5.64	1650
17	78	2.12	-2.25	-0.13	5.51	1590
18	79	2.75	-2.04	0.71	6.22	1500
19	1980	1.77	-2.99	-1.22	5.00	1730
20	81	2.19	-1.88	0.31	5.31	1560
21	82	1.94	-2.36	-0.42	4.89	1600
22	83	3.02	-1.93	1.09	5.98	1445
23	84	2.49	-2.15	0.34	6.32	1500
24	85	1.77	-1.87	-0.10	6.22	1590
25	86	1.61	-1.71	-0.10	6.12	1590
26	87	2.73	-1.25	1.48	7.60	1350
27	88	2.24	-3.13	-0.89	6.71	1660
28	89	4.05	-0.85	3.20	9.91	1175
29	1990	3.52	-1.75	1.77	11.68	1430
30	91	1.95	-1.75	0.20	11.88	1520
31	92	3.16	-1.56	1.60	13.48	1360
32	93	3.13	-1.28	1.85	15.33	1300
33	94	2.28	-1.72	0.56	15.89	1400
34	95	3.16	-1.97	1.19	17.08	1320
35	96	1.40	-1.81	-0.41	16.67	1660
36	97	2.66	-2.62	0.04	16.71	1500
37	98	2.50	-1.53	0.97	17.68	1350
38	99	2.38	-2.21	0.17	17.85	1470
39	2000	3.38	-1.66	1.72	19.57	1250
40	01	1.75	-1.97	-0.22	19.35	1560
41	02	2.41	-3.30	-0.89	18.46	1715
42	03	1.56	-2.72	-1.16	17.30	>1960
43	04	1.97	-2.01	-0.04	17.26	1530
44	05	2.80	-1.70	1.10	18.36	1395
45	06	1.75	-3.15	-1.40	16.96	1850
46	07	3.09	-2.05	1.04	18.00	1320
47	08	3.01	-1.92	1.09	19.09	1325
Mean 1962-2008		2.40	-1.99	0.41		

13 Store Supphellebreen - 12.0 km^2 (1966)

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

14 Austdalsbreen - 11.8 km^2 (1988)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1988	1.94	-3.22	-1.28	-1.28	1570
2	89	3.18	-1.34	1.84	0.56	1275
3	1990	3.65	-2.45	1.20	1.76	1310
4	91	1.64	-1.64	0.00	1.76	1435
5	92	2.80	-2.26	0.54	2.30	1375
6	93	2.60	-1.69	0.91	3.21	1320
7	94	1.81	-1.88	-0.07	3.14	1425
8	95	2.72	-2.10	0.62	3.76	1360
9	96	1.20	-2.27	-1.07	2.69	1565
10	97	2.67	-3.20	-0.53	2.16	1450
11	98	2.20	-2.01	0.19	2.35	1420
12	99	2.08	-2.56	-0.48	1.87	1435
13	2000	2.77	-1.66	1.11	2.98	1315
14	01	1.04	-2.66	-1.62	1.36	>1757
15	02	1.91	-3.92	-2.01	-0.65	>1757
16	03	1.60	-3.94	-2.34	-2.99	>1757
17	04	1.60	-2.56	-0.96	-3.95	1495
18	05	2.85	-2.66	0.19	-3.76	1385
19	06	1.32	-3.38	-2.06	-5.82	>1757
20	07	2.46	-2.28	0.18	-5.64	1405
21	08	2.55	-2.62	-0.07	-5.71	1420
Mean 1988-2008		2.22	-2.49	-0.27		

15 Spørteggbreen - 27.9 km^2 (1988)

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

16 Harbardsbreen - 13.2 km^2 (1996)

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

17 Rembesdalsskåka - 17.1 km^2 (1995)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1963	1.15	-2.55	-1.40	-1.40	>1860
2	64	1.85	-1.31	0.54	-0.86	1620
3	65	2.05	-1.54	0.51	-0.35	1620
4	66	1.60	-2.24	-0.64	-0.99	1750
5	67	2.44	-1.25	1.19	0.20	1540
6	68	2.68	-2.15	0.53	0.73	1600
7	69	1.07	-2.97	-1.90	-1.17	>1860
8	1970	1.29	-1.89	-0.60	-1.77	1780
9	71	2.02	-1.28	0.74	-1.03	1600
10	72	1.78	-1.86	-0.08	-1.11	1650
11	73	2.62	-1.79	0.83	-0.28	1570
12	74	1.91	-1.50	0.41	0.13	1615
13	75	2.25	-2.10	0.15	0.28	1620
14	76	2.45	-2.30	0.15	0.43	1620
15	77	1.20	-1.92	-0.72	-0.29	>1860
16	78	1.80	-2.10	-0.30	-0.59	
17	79	2.40	-2.10	0.30	-0.29	
18	1980	1.45	-2.85	-1.40	-1.69	>1860
19	81	2.65	-1.80	0.85	-0.84	1590
20	82	1.40	-2.10	-0.70	-1.54	1800
21	83	3.75	-2.05	1.70	0.16	1450
22	84	2.05	-2.15	-0.10	0.06	1675
23	85	1.48	-2.00	-0.52	-0.46	1715
24	86	1.47	-1.57	-0.10	-0.56	1670
25	87	2.08	-1.14	0.94	0.38	1535
26	88	1.61	-3.13	-1.52	-1.14	1860
27	89	3.48	-1.37	2.11	0.97	1420
28	1990	3.65	-1.72	1.93	2.90	1450
29	91	1.52	-1.61	-0.09	2.81	1660
30	92	3.71	-1.72	1.99	4.80	1525
31	93	2.82	-0.91	1.91	6.71	1450
32	94	1.79	-1.63	0.16	6.87	1600
33	95	2.44	-2.14	0.30	7.17	1575
34	96	0.99	-2.10	-1.11	6.06	>1860
35	97	2.94	-3.41	-0.47	5.59	1700
36	98	2.47	-1.78	0.69	6.28	1585
37	99	2.04	-1.99	0.05	6.33	1685
38	2000	2.93	-1.50	1.43	7.76	1425
39	01	1.03	-1.88	-0.85	6.91	1760
40	02	2.39	-3.10	-0.71	6.20	1750
41	03	1.33	-2.69	-1.36	4.84	>1860
42	04	1.89	-1.81	0.08	4.92	1670
43	05	2.79	-2.07	0.72	5.64	1590
44	06	0.90	-3.12	-2.22	3.42	>1860
45	07	3.10	-1.93	1.17	4.59	1570
46	08	2.61	-2.16	0.45	5.04	1610
Mean 1963-2008		2.12	-2.01	0.11		

18 Midtdalsbreen - 6.7 km^2 (1995)

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

19 Omnsbreen - 1.5 km^2 (1969)

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

20 Tverråbreen - 5.9 km^2 ()

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

21 Blåbreen - 3.6 km^2 (1961)

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

22 Storbreen - 5.4 km^2 (1997)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	49	2.28	-2.08	0.20	0.20	1650
2	1950	1.52	-1.81	-0.29	-0.09	1750
3	51	1.13	-1.67	-0.54	-0.63	1770
4	52	1.44	-1.13	0.31	-0.32	1630
5	53	1.40	-2.25	-0.85	-1.17	1850
6	54	1.21	-1.98	-0.77	-1.94	1830
7	55	1.57	-2.06	-0.49	-2.43	1800
8	56	1.31	-1.48	-0.17	-2.60	1705
9	57	1.42	-1.37	0.05	-2.55	1680
10	58	1.54	-1.62	-0.08	-2.63	1700
11	59	1.07	-2.35	-1.28	-3.91	1930
12	1960	0.98	-2.07	-1.09	-5.00	1910
13	61	1.10	-1.62	-0.52	-5.52	1820
14	62	1.54	-0.82	0.72	-4.80	1510
15	63	0.96	-2.14	-1.18	-5.98	1900
16	64	1.16	-0.95	0.21	-5.77	1655
17	65	1.54	-1.20	0.34	-5.43	1650
18	66	1.25	-1.86	-0.61	-6.04	1815
19	67	1.89	-1.17	0.72	-5.32	1570
20	68	1.64	-1.59	0.05	-5.27	1700
21	69	1.22	-2.64	-1.42	-6.69	2020
22	1970	0.97	-1.69	-0.72	-7.41	1840
23	71	1.46	-1.28	0.18	-7.23	1690
24	72	1.39	-1.70	-0.31	-7.54	1770
25	73	1.48	-1.40	0.08	-7.46	1705
26	74	1.26	-1.02	0.24	-7.22	1630
27	75	1.55	-1.70	-0.15	-7.37	1760
28	76	1.81	-1.90	-0.09	-7.46	1740
29	77	0.94	-1.48	-0.54	-8.00	1840
30	78	1.26	-1.70	-0.44	-8.44	1815
31	79	1.55	-1.45	0.10	-8.34	1700
32	1980	0.99	-2.30	-1.31	-9.65	1975
33	81	1.30	-1.40	-0.10	-9.75	1730
34	82	1.28	-1.75	-0.47	-10.22	1785
35	83	1.90	-1.70	0.20	-10.02	1625
36	84	1.70	-2.00	-0.30	-10.32	1765
37	85	1.20	-1.60	-0.40	-10.72	1790
38	86	1.05	-1.37	-0.32	-11.04	1770
39	87	1.55	-1.23	0.32	-10.72	1570
40	88	1.45	-2.40	-0.95	-11.67	1970
41	89	2.30	-1.10	1.20	-10.47	1550
42	1990	2.60	-1.35	1.25	-9.22	1530
43	91	1.26	-1.41	-0.15	-9.37	1740
44	92	1.61	-1.53	0.08	-9.29	1715
45	93	1.81	-1.06	0.75	-8.54	1605
46	94	1.52	-1.77	-0.25	-8.79	1800
47	95	1.77	-1.93	-0.16	-8.95	1810
48	96	0.81	-1.84	-1.03	-9.98	1890
49	97	1.75	-2.78	-1.03	-11.01	1875
50	98	1.55	-1.33	0.22	-10.79	1680
51	99	1.67	-1.91	-0.24	-11.03	1830
52	2000	2.04	-1.49	0.55	-10.48	1650
53	01	1.05	-1.32	-0.27	-10.75	1845
54	02	1.09	-2.87	-1.78	-12.53	2075
55	03	1.11	-2.68	-1.57	-14.10	2025
56	04	1.01	-1.59	-0.58	-14.68	1855
57	05	1.83	-1.89	-0.06	-14.74	1795
58	06	0.86	-3.01	-2.15	-16.89	>2100
59	07	1.35	-1.74	-0.39	-17.28	1835
60	08	1.99	-1.88	0.11	-17.17	1770
Mean 1949-2008		1.44	-1.72	-0.29		

23 Vestre Memurubre - 9.0 km^2 (1966)

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

25 Hellstugubreen - 3.0 km^2 (1997)

No. of	Year	bw	bs	bn	Cum. bn	ELA
years		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	1.18	-0.40	0.78	0.78	
2	63	0.94	-1.92	-0.98	-0.20	2020
3	64	0.71	-0.83	-0.12	-0.32	1900
4	65	1.29	-0.77	0.52	0.20	1690
5	66	0.95	-1.62	-0.67	-0.47	1940
6	67	1.48	-0.93	0.55	0.08	1800
7	68	1.38	-1.49	-0.11	-0.03	1875
8	69	0.95	-2.23	-1.28	-1.31	2130
9	1970	0.70	-1.70	-1.00	-2.31	2020
10	71	1.12	-1.25	-0.13	-2.44	1860
11	72	0.94	-1.43	-0.49	-2.93	1950
12	73	1.20	-1.41	-0.21	-3.14	1880
13	74	1.00	-0.76	0.24	-2.90	1785
14	75	1.35	-1.71	-0.36	-3.26	1950
15	76	1.16	-1.89	-0.73	-3.99	1970
16	77	0.68	-1.40	-0.72	-4.71	2075
17	78	1.05	-1.59	-0.54	-5.25	1890
18	79	1.43	-1.45	-0.02	-5.27	1820
19	1980	0.81	-2.05	-1.24	-6.51	2050
20	81	1.06	-1.39	-0.33	-6.84	1950
21	82	0.85	-1.20	-0.35	-7.19	1920
22	83	1.47	-1.30	0.17	-7.02	1820
23	84	1.22	-1.73	-0.51	-7.53	1965
24	85	1.11	-1.40	-0.29	-7.82	1880
25	86	0.78	-1.27	-0.49	-8.31	1940
26	87	1.15	-0.70	0.45	-7.86	1690
27	88	1.28	-2.32	-1.04	-8.90	2025
28	89	1.62	-0.90	0.72	-8.18	1660
29	1990	1.81	-1.15	0.66	-7.52	1640
30	91	0.98	-1.43	-0.45	-7.97	1950
31	92	1.17	-1.03	0.14	-7.83	1850
32	93	1.25	-0.95	0.30	-7.53	1670
33	94	1.26	-1.19	0.07	-7.46	1850
34	95	1.42	-1.54	-0.12	-7.58	1885
35	96	0.65	-1.39	-0.74	-8.32	1955
36	97	1.12	-2.77	-1.65	-9.97	2200
37	98	1.00	-1.02	-0.02	-9.99	1870
38	99	1.22	-1.64	-0.42	-10.41	1930
39	2000	1.26	-1.16	0.10	-10.31	1840
40	01	0.85	-1.21	-0.36	-10.67	1910
41	02	0.96	-2.37	-1.41	-12.08	2080
42	03	0.71	-2.23	-1.52	-13.60	2200
43	04	0.65	-1.49	-0.84	-14.44	1980
44	05	1.34	-1.63	-0.29	-14.73	1930
45	06	0.73	-2.74	-2.01	-16.74	>2210
46	07	1.03	-1.7	-0.67	-17.41	1975
47	08	1.41	-1.47	-0.06	-17.47	1880
Mean 1962-2008		1.10	-1.47	-0.37		

26 Gråsubreen - 2.3 km^2 (1997)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1962	0.86	-0.09	0.77	0.77	1870
2	63	0.40	-1.11	-0.71	0.06	2275
3	64	0.39	-0.71	-0.32	-0.26	2160
4	65	0.77	-0.36	0.41	0.15	1900
5	66	0.72	-1.01	-0.29	-0.14	2150
6	67	1.45	-0.74	0.71	0.57	1870
7	68	1.03	-1.11	-0.08	0.49	2140
8	69	0.74	-2.04	-1.30	-0.81	2275
9	1970	0.57	-1.23	-0.66	-1.47	2200
10	71	0.49	-0.96	-0.47	-1.94	2200
11	72	0.66	-1.30	-0.64	-2.58	2240
12	73	0.72	-1.61	-0.89	-3.47	2275
13	74	0.58	-0.24	0.34	-3.13	1870
14	75	0.91	-1.86	-0.95	-4.08	2275
15	76	0.62	-1.62	-1.00	-5.08	2275
16	77	0.51	-0.90	-0.39	-5.47	2275
17	78	0.67	-0.89	-0.22	-5.69	2140
18	79	0.91	-0.87	0.04	-5.65	2025
19	1980	0.46	-1.35	-0.89	-6.54	2225
20	81	0.62	-0.81	-0.19	-6.73	2180
21	82	0.50	-1.01	-0.51	-7.24	2275
22	83	0.94	-0.99	-0.05	-7.29	2090
23	84	0.98	-1.35	-0.37	-7.66	2275
24	85	0.75	-0.75	0.00	-7.66	2100
25	86	0.42	-1.18	-0.76	-8.42	2275
26	87	0.94	-0.22	0.72	-7.70	1870
27	88	1.08	-1.66	-0.58	-8.28	2195
28	89	1.12	-0.67	0.45	-7.83	1870
29	1990	1.33	-0.60	0.73	-7.10	1870
30	91	0.67	-1.19	-0.52	-7.62	1950
31	92	0.70	-0.80	-0.10	-7.72	
32	93	0.93	-0.51	0.42	-7.30	<1850
33	94	1.16	-1.16	0.00	-7.30	2075
34	95	1.19	-1.30	-0.11	-7.41	2180
35	96	0.53	-0.98	-0.45	-7.86	2205
36	97	0.70	-2.39	-1.69	-9.55	>2290
37	98	0.78	-0.67	0.11	-9.44	Undef.
38	99	0.91	-1.30	-0.39	-9.83	2210
39	2000	0.87	-0.92	-0.05	-9.88	Undef.
40	01	0.80	-0.78	0.02	-9.86	2070
41	02	0.63	-2.05	-1.42	-11.28	>2290
42	03	0.45	-1.84	-1.39	-12.67	>2290
43	04	0.48	-0.97	-0.49	-13.16	2210
44	05	0.83	-1.33	-0.50	-13.66	2180
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	0.09	-16.36	Undef.
Mean 1962-2008		0.76	-1.11	-0.35		

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

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

28 Austre Okstindbre - 14.0 km^2 (1962)

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

29 Høgtuvbreen - 2.6 km^2 (1972)

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

30 Svartisheibreen - 5.5 km^2 (1985)

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

31 Engabreen - 38.7 km^2 (2008)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1970	2.05	-3.04	-0.99	-0.99	1280
2	71	3.20	-2.19	1.01	0.02	1070
3	72	3.22	-3.29	-0.07	-0.05	1150
4	73	4.37	-1.65	2.72	2.67	830
5	74	3.39	-2.59	0.80	3.47	1030
6	75	3.18	-1.57	1.61	5.08	960
7	76	3.86	-1.45	2.41	7.49	910
8	77	2.08	-1.20	0.88	8.37	1000
9	78	2.48	-2.99	-0.51	7.86	1250
10	79	3.64	-3.22	0.42	8.28	1130
11	1980	2.68	-3.18	-0.50	7.78	1270
12	81	2.91	-1.93	0.98	8.76	965
13	82	2.27	-1.43	0.84	9.60	1030
14	83	2.34	-1.28	1.06	10.66	1020
15	84	3.83	-2.78	1.05	11.71	1000
16	85	1.50	-2.40	-0.90	10.81	1375
17	86	2.70	-2.45	0.25	11.06	1170
18	87	2.57	-1.63	0.94	12.00	1000
19	88	2.26	-4.05	-1.79	10.21	1400
20	89	4.62	-1.45	3.17	13.38	890
21	1990	3.49	-2.64	0.85	14.23	1035
22	91	2.83	-2.14	0.69	14.92	1090
23	92	4.05	-1.71	2.34	17.26	875
24	93	3.06	-2.02	1.04	18.30	985
25	94	1.95	-1.53	0.42	18.72	1050
26	95	3.50	-1.76	1.74	20.46	940
27	96	2.97	-2.14	0.83	21.29	970
28	97	4.44	-3.22	1.22	22.51	1010
29	98	2.98	-2.77	0.21	22.72	1100
30	99	2.12	-2.15	-0.03	22.69	1215
31	2000	2.76	-1.27	1.49	24.18	970
32	01	1.05	-2.58	-1.53	22.65	>1594
33	02	2.89	-3.48	-0.59	22.06	1200
34	03	2.41	-3.00	-0.59	21.47	1195
35	04	2.92	-2.10	0.82	22.29	1040
36	05	3.31	-2.42	0.89	23.18	1060
37	06	1.73	-3.16	-1.43	21.75	1325
38	07	3.37	-2.83	0.54	22.29	1100
39	08	2.81	-2.50	0.31	22.60	1093
Mean 1970-2008		2.92	-2.34	0.58		

32 Storglombreen - 62.4 km^2 (1968)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	1985	1.40	-2.59	-1.19	-1.19	1300
2	86	2.45	-2.87	-0.42	-1.61	1100
3	87	2.32	-1.87	0.45	-1.16	1020
4	88	2.06	-3.88	-1.82	-2.98	1350
5	2000	2.66	-1.55	1.11	1.11	1000
6	01	1.15	-2.91	-1.76	-0.65	>1580
7	02	2.33	-3.58	-1.25	-1.90	>1580
8	03	2.18	-3.28	-1.10	-3.00	>1580
9	04	2.26	-2.14	0.12	-2.88	1075
10	05	2.74	-2.41	0.33	-2.55	1060
Mean 1985-88		2.06	-2.80	-0.75		
Mean 2000-05		2.22	-2.65	-0.43		

33 Tretten-null-tobreen - 4.9 km^2 (1968)

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

34 Glombreen - 2.2 km^2 (1953)

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

35 Kjølbreen - 3.9 km^2 (1953)

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

36 Trollbergdalsbreen - 1.6 km^2 (1985)

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

37 Rundvassbreen - 11.6 km^2 (1998)

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

38 Blåisen - 2.2 km^2 (1960)

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

39 Storsteinsfjellbreen - 5.9 km^2 (1993)

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

40 Cainhavarre - 0.7 km^2 (1960)

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

41 Svartfjelljøkelen - 2.7 km^2 (1966)

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

42 Langfjordjøkelen - 3.2 km^2 (2008)

No. of years	Year	bw (m w.e.)	bs	bn (m w.e.)	Cum. bn	ELA (m a.s.l.)
1	89	2.40	-2.96	-0.56	-0.56	870
2	1990	2.74	-3.06	-0.32	-0.88	780
3	91	2.31	-2.31	0.00	-0.88	710
4	92	2.68	-2.49	0.19	-0.69	700
5	93	2.55	-2.35	0.20	-0.49	740
6	96	2.25	-2.23	0.02	0.02	700
7	97	2.65	-3.34	-0.69	-0.67	820
8	98	1.80	-3.24	-1.44	-2.11	>1050
9	99	1.33	-2.91	-1.58	-3.69	970
10	2000	2.51	-3.12	-0.61	-4.30	860
11	01	1.36	-3.64	-2.28	-6.58	>1050
12	02	2.19	-3.73	-1.54	-8.12	>1050
13	03	2.44	-3.51	-1.07	-9.19	>1050
14	04	1.69	-3.61	-1.92	-11.11	>1050
15	05	1.88	-3.14	-1.26	-12.37	940
16	06	1.42	-3.83	-2.41	-14.78	>1050
17	07	2.09	-2.90	-0.81	-15.59	870
18	08	1.67	-2.02	-0.35	-15.94	835
Mean 1989-93		2.54	-2.63	-0.10		
Mean 1996-2008		1.94	-3.17	-1.23		

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