Glaciological investigations in Norway in 2010

Bjarne Kjøllmoen (Ed.)

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Glaciological investigations in Norway in 2010

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Glaciological investigations in Norway in 2010

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Frontpage photo: Part of Rundvassbreen, a northern outlet of Blåmannsisen in North Norway. In September 2010 there was an outburst from the glacier-dammed lake in front of the glacier. This was the fifth such event from Rundvassbreen. The photo was taken before the outburst, on 19th August 2010 by Hans Martin Hjemaas, Siso Energi AS.
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Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2010 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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Preface

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

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

The report is published in English with a summary in Norwegian. The purpose of this report is to provide a joint presentation of the investigations and calculations made mainly by NVE's Section for Glaciers, Snow and Ice during 2010. 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, July 2011

Morten Johnsrud
Director,
Hydrology Department

Rune V. Engeset
Head of section,
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Summary

Mass balance

Mass balance investigations were performed on fifteen glaciers in Norway in 2010. Thirteen of these glaciers are in southern Norway and two are in northern Norway.

The winter balance for the long-term glaciers was lower than average of the reference period 1971-2000. In southern Norway, Storbreen had the lowest winter balance since the measurements started in 1949 and Ålfotbreen had the third lowest winter balance since 1963. Engabreen in northern Norway had the fifth lowest since measurements started in 1970.

The summer balance was greater than the 1971-2000 average for all the long-term glaciers. Storbreen and Gråsubreen, both in Jotunheimen, had the greatest relative summer balance with 157 % and 150 % of the reference period.

Consequently, the net balance was negative for all fifteen measured glaciers. For the long-term glaciers Ålfotbreen and Storbreen had the greatest deficit with −1.9 m and −1.8 m water equivalent, respectively.

Glacier length change

Glacier length changes were measured at 23 glaciers in southern Norway and eight glaciers in northern Norway in 2010. Twenty seven of the glacier outlets had a decrease in length, one was unchanged and three outlets had a small advance. The greatest retreats were observed at Bødalsbreen and Nigardsbreen, both outlets from Jostedalsbreen, and at Steindalsbreen in Lyngen, northern Norway, with 65, 39 and 40 metres, respectively.

Sammendrag

Massebalanse

I 2010 ble det utført massebalansemålinger på 15 breer i Norge – tretten i Sør-Norge og to i Nord-Norge.

For de breene som har langtids måleserier ble vinterbalansen mindre enn gjennomsnittet for referanseperioden 1971-2000. I Sør-Norge hadde Storbreen den minste vinterbalansen siden målingene startet i 1949 og Ålfotbreen hadde den tredje minste vinterbalansen siden 1963. I Nord-Norge hadde Engabreen femte minste vinterbalansen siden målingene startet i 1970.

Sommerbalansen ble større enn gjennomsnittet for 1971-2000 for alle breene med langtids måleserier. Storbreen og Gråsubreen, begge i Jotunheimen, hadde relativt størst sommerbalanse med hhv. 157 % og 150 % av referanseperioden.

Det ble negativ nettobalanse på samtlige av de femten målte breene. For breene med langtids måleserier hadde Ålfotbreen og Storbreen størst underskudd med hhv. −1.9 m og −1.8 m vannekvivalenter.

Lengdeendringer

Lengdeendringer ble målt på 23 breer i Sør-Norge og åtte breer i Nord-Norge i 2010. Tjuesju av breutløperne hadde tilbakegang, én var uendret og tre hadde litt framgang. Størst tilbakegang ble målt på Bødalsbreen og Nigardsbreen, begge utløpere fra Jostedalsbreen, og Steindalsbreen i Lyngen med hhv. 65, 39 og 40 meter.

1. Glacier investigations in Norway in 2010

1.1 Mass balance

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

Method

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

Winter balance

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

Figure 1-1
Snow density is usually measured by using a sampling cylinder in a snow pit down to 1.5 m depth (to the left) and completed with a coring auger down to required depth, preferably S.S. (to the right). Photo: Ragnar Ekker (left) and Hallgeir Elvehøy (right).

Summer and net balance

Summer and net balances are obtained from stake measurements, usually performed in September or October. Below the glacier's equilibrium line the net balance is negative, meaning that more snow and ice melts during a given summer than accumulates during the winter. Above the equilibrium line, in the accumulation area, the net balance is positive. Based on past experience, snow density of the remaining snow in the accumulation area is typically assumed to be 600 kg/m^3. After especially cold summers, or if there is more snow than usual remaining at the end of the summer, snow density is either measured using snow-cores or is assumed to be 650 kg/m^3. The density of melted firn is, depending on the age, assumed to be between 650 and 800 kg/m^3. The density of melted ice is taken as 900 kg/m^3.

Stratigraphic method

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

Accuracy

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

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

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

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

Mass balance program

In 2010 mass balance measurements were performed on 15 glaciers in Norway - 13 in southern Norway and 2 in northern Norway. In southern Norway, 6 of the glaciers have been measured for 48 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 62 years of measurements, while Engabreen at Svartisen has the longest series (41 years) in northern Norway. In 2010 mass balance measurements were started on Juvfonne, a small glacier in Jotunheimen. 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 2010 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.

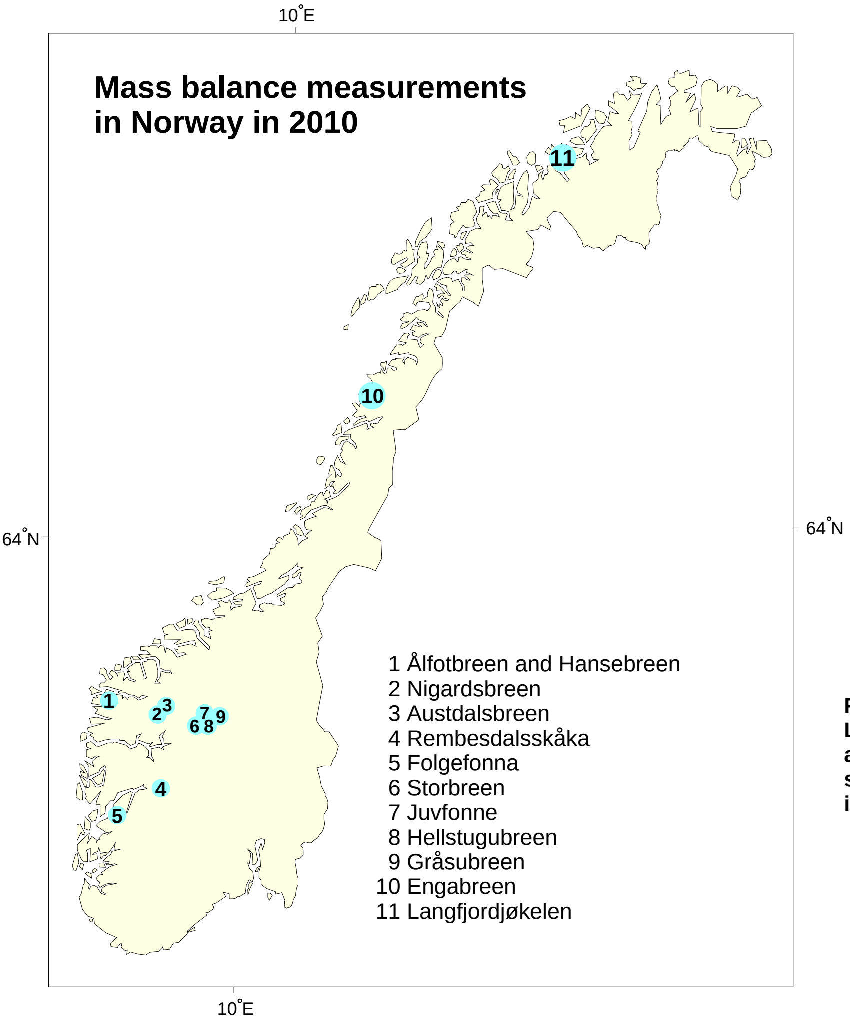


Figure 1-2
Location of the glaciers at which mass balance studies were performed in 2010.

Weather conditions and mass balance results

Winter weather

In general the 2009/2010 winter season was cold and dry over the whole country, especially in October, December and February. However, November 2009 was rather mild with normal precipitation in the mountain areas in southern Norway. At the end of the winter season March was snow-rich in the north and April was snow-rich in western Norway.

Snow accumulation and winter balance

The winter balance for the long-term glaciers (measurements started in 1971 or earlier) was lower than the average of the reference period 1971-2000. Storbreen (52 % of 1971-2000 mean) had the lowest winter balance since measurements started in 1949. The three long-term glaciers in western Norway, Ålfotbreen, Nigardsbreen and Rembesdalsskåka, had results of 55, 60 and 57 % of the 1971-2000 average winter balance. In northern Norway, Engabreen (67 % of 1971-2000 mean) had the fifth lowest winter balance since 1970.

Summer weather

The summer season in 2010 was warmer than normal in southern Norway and cooler than normal in northern Norway. July and particularly August were warmer than normal in the south. In the north July was approximately normal while August and particularly June were cool.

Ablation and summer balance

The summer balance was greater than the 1971-2000 average at all the long-term glaciers. The long-term glaciers in western Norway had results of 121 % (Ålfotbreen), 119 % (Nigardsbreen) and 144 % (Rembesdalsskåka) of the 1971-2000 average. The long-term glaciers in Jotunheimen had 157 % (Storbreen), 147 % (Hellstugubreen) and 150 % (Gråsubreen) of the reference period average. Langfjordjøkelen in western Finnmark, however, had lower summer balance than the average for the measurement period.

Net balance

Net balance was negative for all fifteen measured glaciers in 2010. For the long-term glaciers the greatest deficit was measured at Ålfotbreen (−1.9 m w.e.) and Storbreen (−1.8 m w.e.), and are the seventh and third greatest mass loss since measurements started in 1963 and 1949, respectively. In northern Norway, Langfjordjøkelen had negative net balance (−0.8 m w.e.) for the fifteenth successive year.

The results from the mass balance measurements in Norway in 2010 are shown in Table 1-1. Winter ($\mathbf{b_w}$), summer ($\mathbf{b_s}$) and net balance ($\mathbf{b_n}$) are given in metres water equivalent (m w.e.) smoothly distributed over the entire glacier surface. The figures in the **% of ref.** column show the current results as a percentage of the average for the period 1971-2000. The net balance results are compared with the mean net balance in the same way. **ELA** is the equilibrium line altitude (m a.s.l.) and **AAR** is the accumulation area ratio (%).

Table 1-1
Review of the results from mass balance measurements performed in Norway in 2010. The glaciers in southern Norway are listed from west to east. The figures in the *% of ref.* column show the current results as a percentage of the average for the period 1971-2000.

Glacier	*Period*	*Area* *(km^2)*	*Altitude* *(m a.s.l.)*	*b_w* *(m)*	*% of ref.*	*b_s* *(m)*	*% of ref.*	*b_n* *(m)*	*b_n ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-10	4.0	890-1368	2.19	55	−4.03	121	−1.84	0.61	>1382	0
Hansebreen	1986-10	2.8	927-1310	2.10	[1]60	−4.31	[1]109	−2.22	[1]−0.48	>1327	0
Svelgjabreen	2007-10	22.5	832-1636	1.65	-	−3.29	-	−1.64	-	>1636	0
Blomstølskardsbreen	2007-10	22.8	1013-1636	1.85	-	−3.07	-	−1.23	-	>1636	0
Breidablikkbrea	1963-68	3.9	1219-1660						−0.19		
	2003-10	3.4	1234-1651	1.60	[2]64	−3.53	[2]102	−1.94	[2]−0.98	>1651	0
Gråfjellsbrea	1964-68 1974-75	9.4	1039-1660						0.20		
	2003-10	8.4	1049-1651	1.51	[2]62	−3.35	[2]101	−1.84	[2]−0.86	>1651	0
Nigardsbreen	1962-10	47.2	315-1957	1.47	60	−2.27	119	−0.80	0.54	1770	14
Austdalsbreen	1988-10	10.6	1200-1747	1.03	[3]47	[4]−3.03	[3]121	−2.00	[3]−0.29	>1747	0
Rembesdalsskåka	1963-10	17.3	1066-1854	1.28	57	−2.78	144	−1.49	0.32	>1854	0
Storbreen	1949-10	5.1	1400-2102	0.79	52	−2.55	157	−1.76	−0.10	1990	4
Juvfonne	2010-	0.2	1840-1998	0.67	-	−3.91	-	−3.24	-	<1998	0
Hellstugubreen	1962-10	2.9	1482-2229	0.75	65	−2.09	147	−1.34	−0.27	2230	0
Gråsubreen	1962-10	2.1	1833-2283	0.54	69	−1.60	150	−1.06	−0.28	2250	4
Engabreen	1970-10	38.7	89-1574	2.04	67	−2.56	115	−0.52	0.82	1240	47
Langfjordjøkelen	1989-93	3.7	280-1050								
	1996-10	3.2	302-1050	1.89	[5]90	−2.65	[5]87	−0.76	[5]−0.93	1005	12

[1] *Calculated for the measured period 1986-2009*
[2] *Calculated for the measured period 2003-2009*
[3] *Calculated for the measured period 1988-2009*
[4] *Contribution from calving amounts to 0.25 m for b_s*
[5] *Calculated for the measured periods 1989-93 and 1996-2009*

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2010. The west-east gradient is evident for both winter and summer balances. The results for 2010 show negative net balance for all fifteen measured glaciers in Norway.

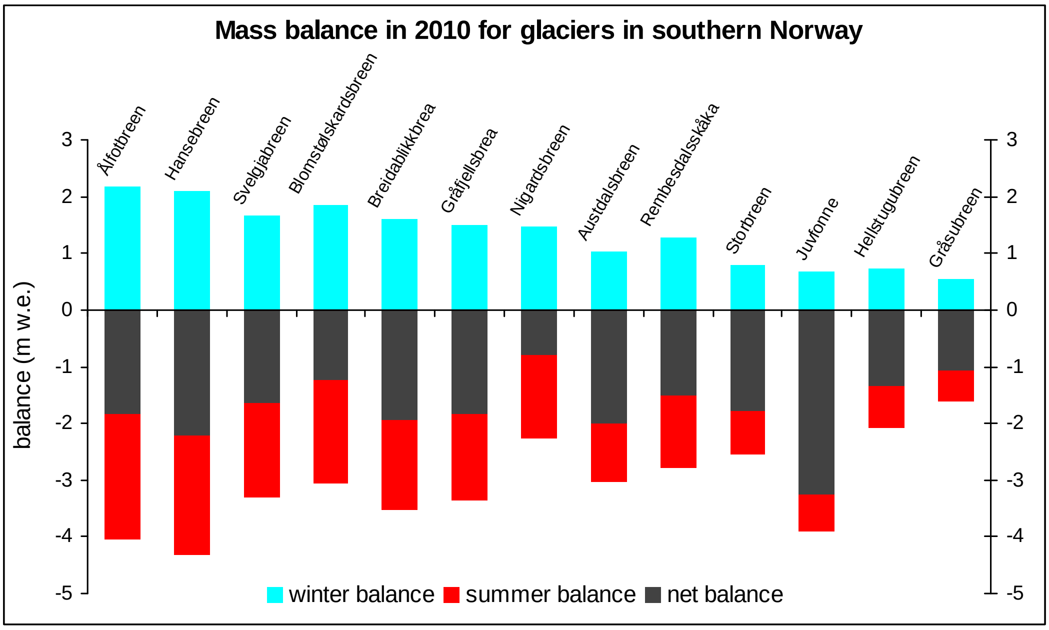


Figure 1-3
Mass balance 2010 in southern Norway. The glaciers are listed from west to east.

The cumulative net balance for glaciers in southern Norway with long-term series for the period 1963-2010 is shown in Figure 1-4. The maritime glaciers, Ålfotbreen, Nigardsbreen and Rembesdalsskåka, showed a marked increase in volume during the period 1989-95. The surplus was mainly the result of several winters with heavy snowfall.

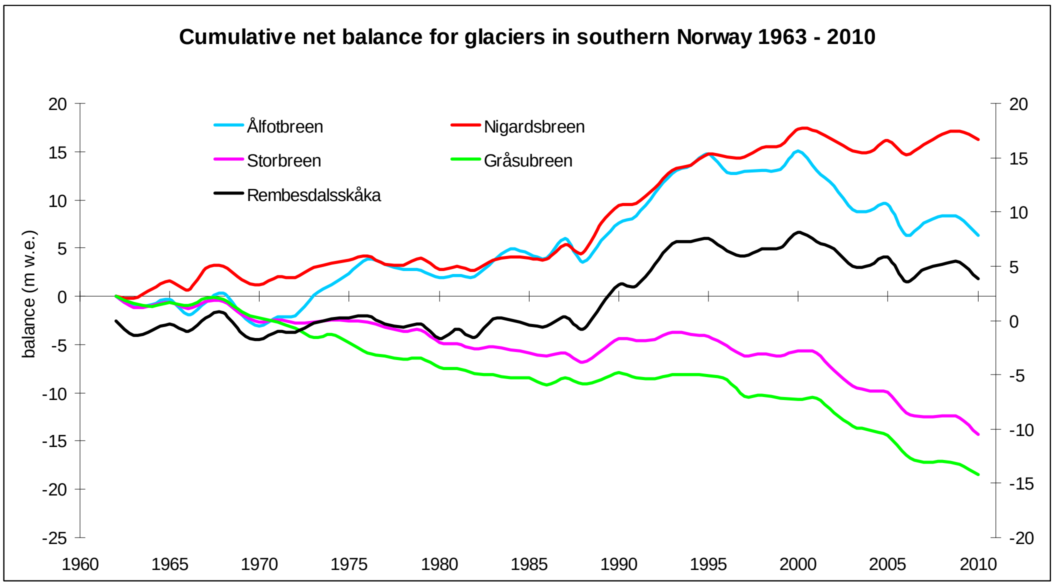


Figure 1-4
Cumulative net balance for Ålfotbreen, Nigardsbreen, Rembesdalsskåka (Hardangerjøkulen), Storbreen and Gråsubreen for the period 1963-2010.

1.2 Other investigations

Glacier length change measurements were performed at 31 glaciers in Norway in 2010. Some of the glaciers have a measurement series going back to about 1900. The length changes are described in a separate chapter (chap. 13).

Glacier dynamics (velocity) have been studied at Austdalsbreen since 1987 (chap. 5). The measurements continued in 2010.

Meteorological observations have been performed at Hardangerjøkulen (chap. 6), Storbreen (chap. 7), Engabreen (chap. 11) and Langfjordjøkelen (chap. 12).

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 11.

Several jökulhlaups have occurred in 2010. The first was at Harbardsbreen, a small ice cap located in Breheimen between Jostedalsbreen and Jotunheimen, in August. Two more jökulhlaups were observed in September at Koppangsbreen and Blåmannsisen, both situated in northern Norway (chap. 13).

2. Ålfotbreen (Bjarne Kjøllmoen)

Ålfotbreen ice cap (61°45’N, 5°40’E) has an area of 10.6 km^2 (2010) and is, together with Blåbreen, the westernmost and the most maritime glacier in Norway. Mass balance studies have been carried out on two adjacent north-facing outlet glaciers - Ålfotbreen (4.0 km^2,) and Hansebreen (2.8 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 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 ice cap, including its component parts and surroundings, is shown in Figure 2-1.

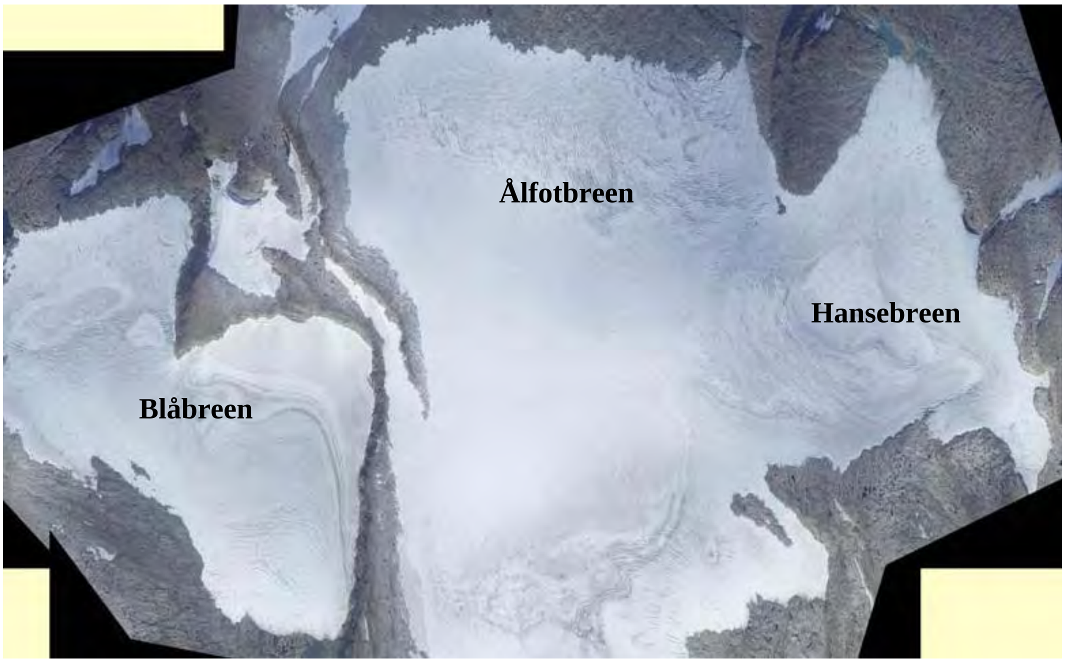


Figure 2-1
Orthophoto of Ålfotbreen ice cap, showing the two north-facing glaciers Ålfotbreen and Hansebreen at which mass balance studies are performed. Blåbreen to the left is separate from Ålfotbreen.

2.1 Mapping

A new mapping of Ålfotbreen and Hansebreen was performed in 2010. The glacier surface was mapped by aerial photographs and airborne laser scanning on 2nd September.

A Digital Elevation Model (DEM) is processed based on the laser scanning data. The glacier boundary is determined from an orthophoto composed of the air photos. The ice divides between the different glaciers are processed using a GIS, and a revised height-area distribution for Ålfotbreen and Hansebreen is calculated. Since the previous mapping in 1997 the glacier area of Ålfotbreen has decreased from 4.5 to 4.0 km^2 (12 %) and the area of Hansebreen from 3.1 to 2.8 km^2 (10 %).

2.2 Mass balance 2010

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 6th and 7th May. The calculation of winter balance at Ålfotbreen and Hansebreen is based on (Fig. 2-2):

- Uninterrupted measurements of stakes at positions 12 (955 m a.s.l.), 45 (1168 m a.s.l.) and 37 (1203 m a.s.l.) on Ålfotbreen and in positions 50 (999 m a.s.l.), 80 (1099 m a.s.l.), 85 (1172 m a.s.l.) and 90 (1295 m a.s.l.) on Hansebreen. Two stakes in position 13 (1064 m a.s.l.) on Ålfotbreen and 60 (1043 m a.s.l.) on Hansebreen were excluded as they had tilted too much to give reliable values.
- Snow depth probings performed in a grid of 250 x 250 metres. Snow depth is sounded at 79 grid points on Ålfotbreen, and at 54 grid points on Hansebreen. The snow depth was generally between 4 and 5 m. The sounding conditions were good and the summer surface (S.S.) could easily be detected.
- Snow density was measured down to 4.2 m (S.S. at 4.5 m) at stake position 28 (1225 m a.s.l.).

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

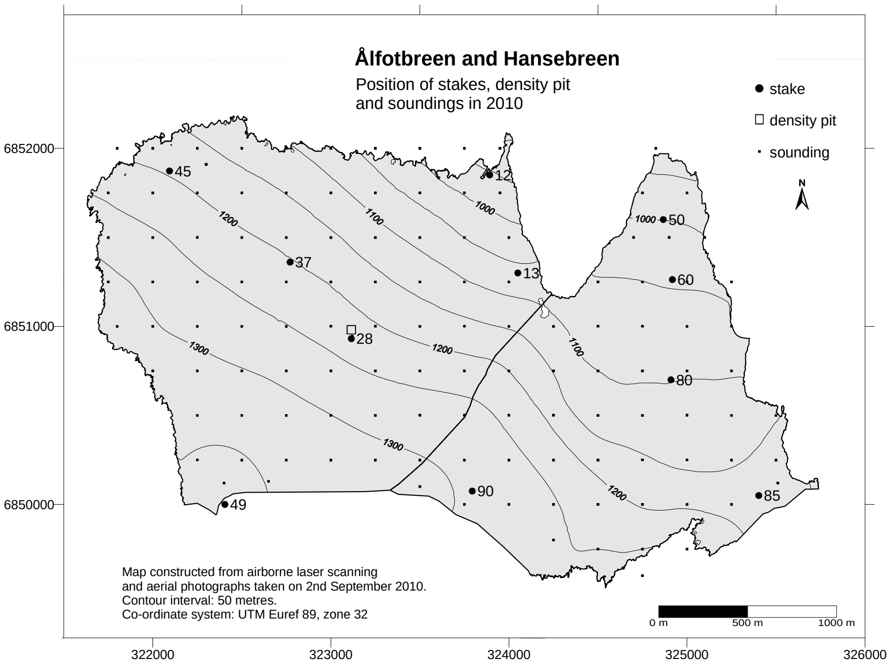


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen (left) and Hansebreen (right) in 2010.

Ablation measurements

Ablation was measured on 28th September (Fig. 2-3). The net balance was measured directly at stakes in six different positions on Ålfotbreen and five positions on Hansebreen. There was no snow remaining on the two glaciers from the winter season 2009/10. At the time of the ablation measurements up to 10 cm of fresh snow had fallen.

Figure 2-3
Measurement of stake 37 at Ålfotbreen on 28th September 2010. Photo: Ånund S. Kvambekk.

Results

The calculations are based on the new glacier map from 2010.

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 2009.

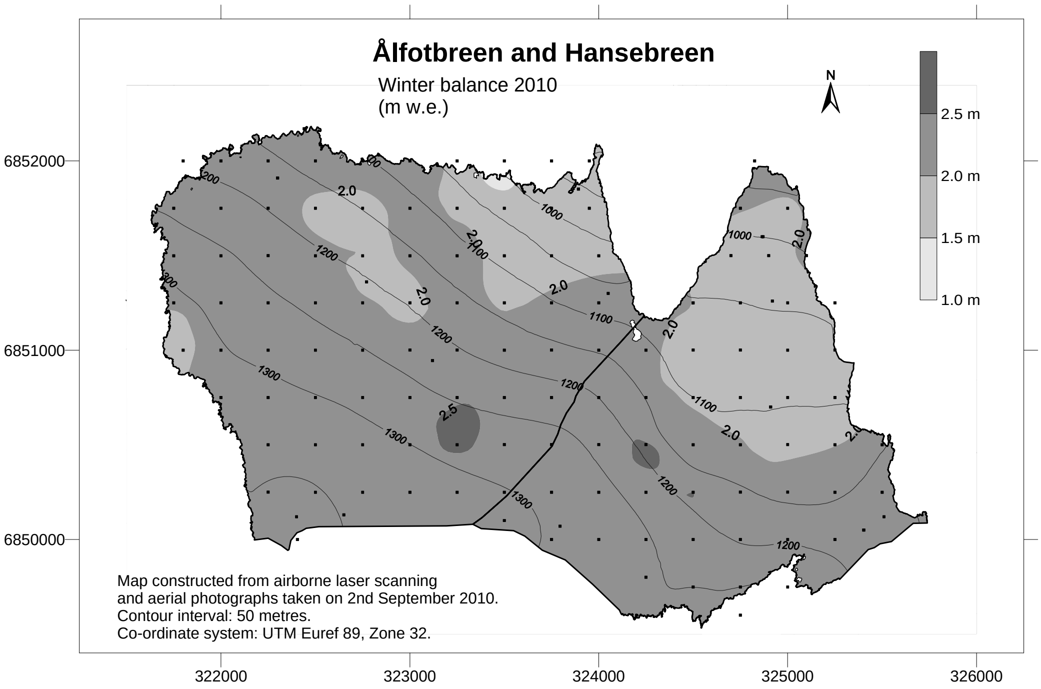
A density profile was modelled from the snow density measured at 1225 m a.s.l. The mean snow density of 4.2 m snow was 466 kg/m^3. The density model was assumed to be representative for both Ålfotbreen and Hansebreen, and all snow depths were converted to water equivalents using this model.

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

Winter balance at Ålfotbreen in 2010 was 2.2 ±0.2 m w.e., corresponding to a volume of 9 ±1 mill. m^3 of water. The result is 55 % of the mean winter balance for the reference period 1971-2000. This is the third lowest winter balance since measurements started in 1963, the lowest being 1.8 m w.e. in 1996.

The winter balance at Hansebreen was 2.1 ±0.2 m w.e., corresponding to a volume of 6 ±1 mill. m^3 of water. The result is 60 % of the mean winter balance for the measurement period 1986-2009. This is the third lowest winter balance since measurements started in 1986, the lowest being 1.7 m w.e. in 2001.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 2-4). Water equivalents for each cell in a 100 x 100 m grid were calculated and summed. Using this method, which is a control of the traditional method, gave 2.2 m w.e. for Ålfotbreen and 2.1 m w.e. for Hansebreen.



Map constructed from airborne laser scanning
and aerial photographs taken on 2nd September 2010.
Contour interval: 50 metres.
Co-ordinate system: UTM Euref 89, Zone 32.

Figure 2-4
Winter balance at Ålfotbreen and Hansebreen in 2010 interpolated from 132 snow depth measurements, shown by (·).

Summer balance

The density of melted firn was estimated as 650-800 kg/m^3, depending on the age of the firn. The density of melted ice was taken as 900 kg/m^3.

The summer balance at Ålfotbreen was measured and calculated directly at stakes in six different positions (Fig 2-5). The calculated values increased from 3.4 m w.e. at the glacier summit (1368 m a.s.l.) to 4.9 m on the tongue (955 m a.s.l.). Based on estimated density and stake measurements the summer balance for Ålfotbreen was calculated as −4.0 ±0.3 m w.e., corresponding to −16 ±1 mill. m^3 of water. This result is 121 % of the mean summer balance for the reference period 1971-2000.

The summer balance for Hansebreen was measured and calculated at stakes in five different positions (Fig. 2-5). The lowest summer balance value was, as usual, measured at the topmost stake (pos. 90, 1295 m a.s.l.) with 3.8 m w.e. The greatest value, however, was measured at stake 85 (1172 m a.s.l.) with 4.8 m w.e. Normally the summer balance increases with decreasing altitude. This correlation between summer balance and altitude is not quite evident for Hansebreen in 2010. Besides, the difference between the greatest and the lowest measured summer balance value is unusual small, only 1.0 m w.e. Similar measuring results were recorded in 2006 and 2009. Based on the stake measurements and the estimated density, the summer balance was calculated as −4.3 ±0.3 m w.e. or −12 ±1 mill. m^3 of water. The result is 109 % of the mean summer balance for the measurement period 1986-2009.

Net balance

The net balance at Ålfotbreen for 2010 was negative, at −1.8 ±0.4 m w.e., or a mass loss of −7 ±2 mill. m^3 of water. The mean net balance for the reference period 1971-2000 is +0.61 m w.e. Over the last ten years (2001-2010), however, the annual mean net balance is −0.88 m w.e. Seven of these years show a negative net balance.

The net balance at Hansebreen was calculated as −2.2 ±0.4 m w.e., or a mass loss of −6 ±1 mill. m^3 of water. The mean value for the measurement period 1986-2009 is −0.48 m w.e. Since measurements began in 1986 the cumulative net balance is −13.7 m w.e. Over the last ten years the deficit is −14.0 m w.e.

According to Figure 2-5 the Equilibrium Line Altitude (ELA) lies *above* the highest summit on both glaciers. Consequently, the AAR is 0 %.

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.

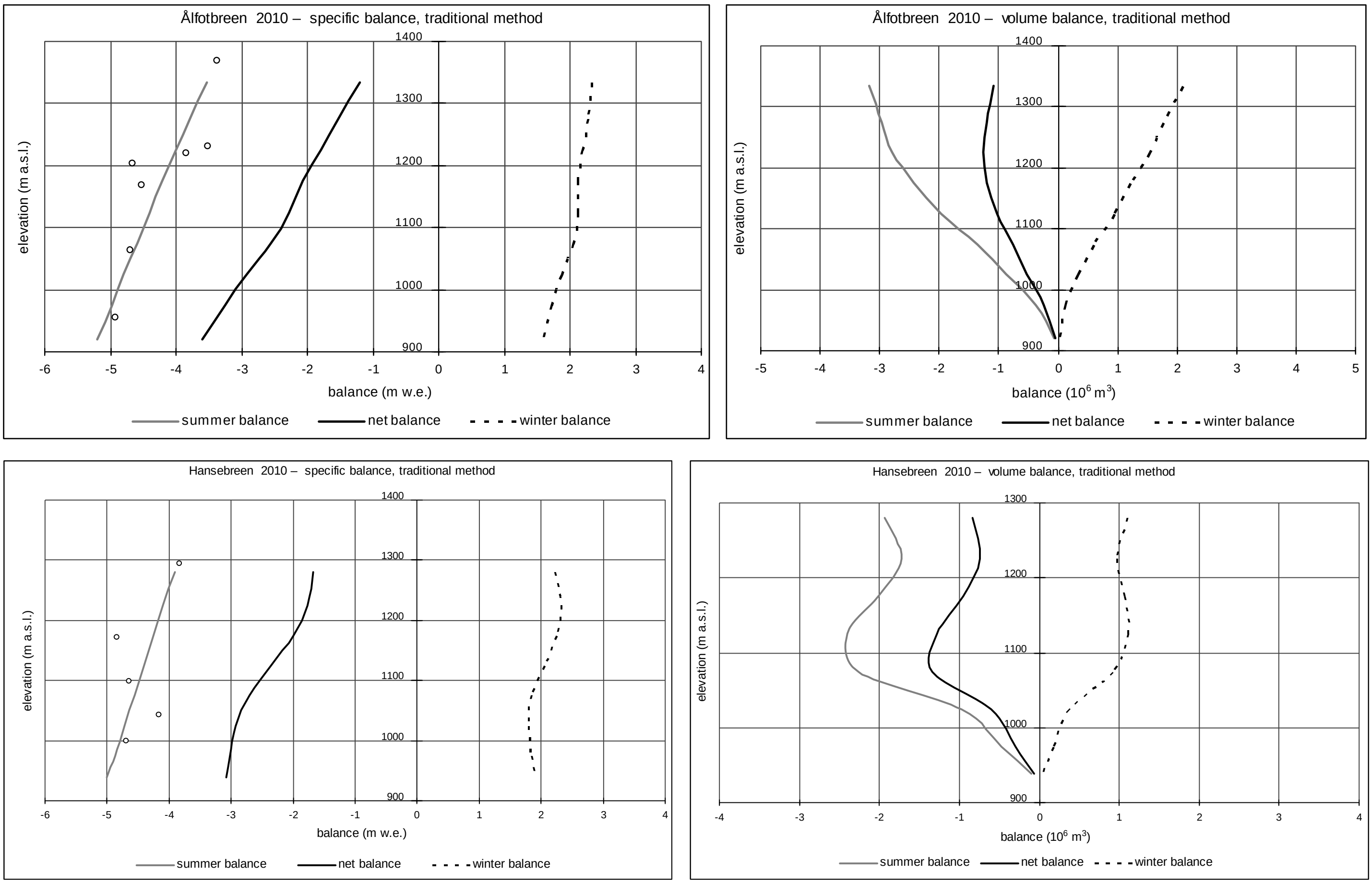


Figure 2-5
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2010 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○).

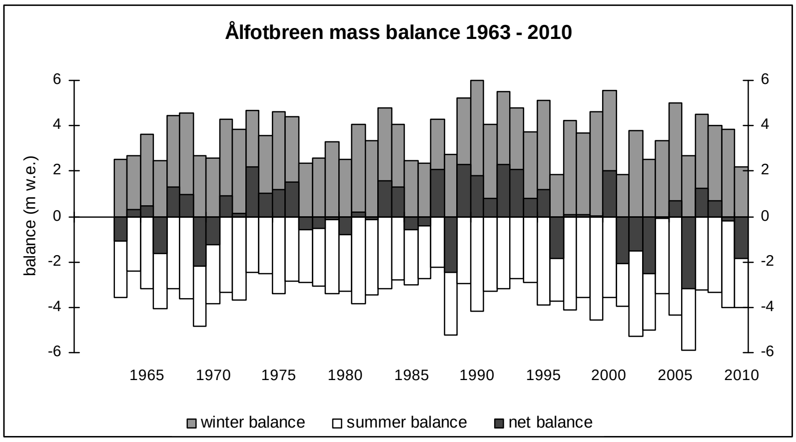
Table 2-1
Winter, summer and net balances for Ålfotbreen (upper) and Hansebreen (lower) in 2010.

Mass balance Ålfotbreen 2009/10 – traditional method

		Winter balance Measured 6th May 2010		Summer balance Measured 28th Sep 2010		Net balance Summer surfaces 2009 - 2010	
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 - 1368	0,90	2,33	2,1	-3,53	-3,2	-1,20	-1,1
1250 - 1300	0,78	2,28	1,8	-3,80	-3,0	-1,53	-1,2
1200 - 1250	0,70	2,20	1,5	-4,00	-2,8	-1,80	-1,3
1150 - 1200	0,58	2,13	1,2	-4,20	-2,4	-2,08	-1,2
1100 - 1150	0,45	2,13	1,0	-4,40	-2,0	-2,28	-1,0
1050 - 1100	0,30	2,05	0,6	-4,60	-1,4	-2,55	-0,8
1000 - 1050	0,18	1,88	0,3	-4,80	-0,9	-2,93	-0,5
950 - 1000	0,07	1,73	0,1	-4,98	-0,4	-3,25	-0,2
890 - 950	0,01	1,60	0,0	-5,20	-0,1	-3,60	-0,1
890 - 1368	**3,98**	**2,19**	**8,7**	**-4,03**	**-16,0**	**-1,84**	**-7,3**

Mass balance Hansebreen 2009/10 – traditional method

		Winter balance Measured 6th May 2010		Summer balance Measured 28th Sep 2010		Net balance Summer surface 2009 - 2010	
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)
1250 - 1310	0,50	2,23	1,10	-3,90	-1,93	-1,68	-0,83
1200 - 1250	0,42	2,33	0,97	-4,10	-1,72	-1,78	-0,74
1150 - 1200	0,47	2,25	1,07	-4,25	-2,02	-2,00	-0,95
1100 - 1150	0,54	2,05	1,12	-4,40	-2,40	-2,35	-1,28
1050 - 1100	0,50	1,85	0,92	-4,55	-2,26	-2,70	-1,34
1000 - 1050	0,21	1,80	0,37	-4,73	-0,97	-2,93	-0,60
950 - 1000	0,10	1,85	0,18	-4,88	-0,48	-3,03	-0,30
927 - 950	0,02	1,93	0,04	-5,00	-0,10	-3,08	-0,06
927 - 1310	**2,75**	**2,10**	**5,8**	**-4,31**	**-11,9**	**-2,22**	**-6,1**



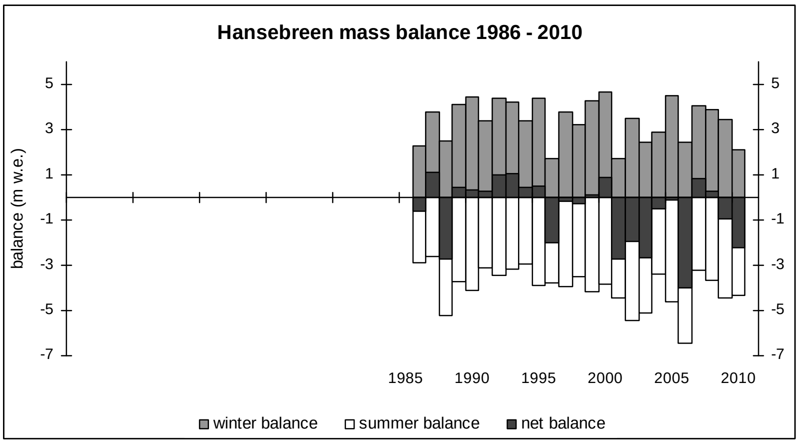


Figure 2-6
Mass balance at Ålfotbreen (upper) 1963-2010 and Hansebreen (lower) 1986-2010.

3. Folgefonna

(Bjarne Kjøllmoen)

Folgefonna is situated in the south-western part of Norway between Hardangerfjorden to the west and the mountain plateau Hardangervidda to the east. It is divided into three separate ice caps - Northern, Middle and Southern Folgefonna. Southern Folgefonna is the third largest (161 km^2 in 2007) ice cap in Norway. In 2003 mass balance measurements began on two adjacent northwest-facing outlet glaciers of Southern Folgefonna (60°4'N, 6°24'E) – Breidablikkbrea (3.4 km^2) and Gråfjellsbrea (8.4 km^2) (Fig. 3-1). In 2007 mass balance measurements began on two more outlet glaciers of Southern Folgefonna – the two adjacent south-facing glaciers Svelgjabreen (22.5 km^2) and Blomstølskardsbreen (22.8 km^2).

Mass balance measurements were previously carried out at Breidablikkbrea during 1963-68 (Pytte, 1969) and at Gråfjellsbrea during the periods 1964-68 and 1974-75 (Wold and Hagen, 1977). The historical results are presented in Figure 3-6. 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.

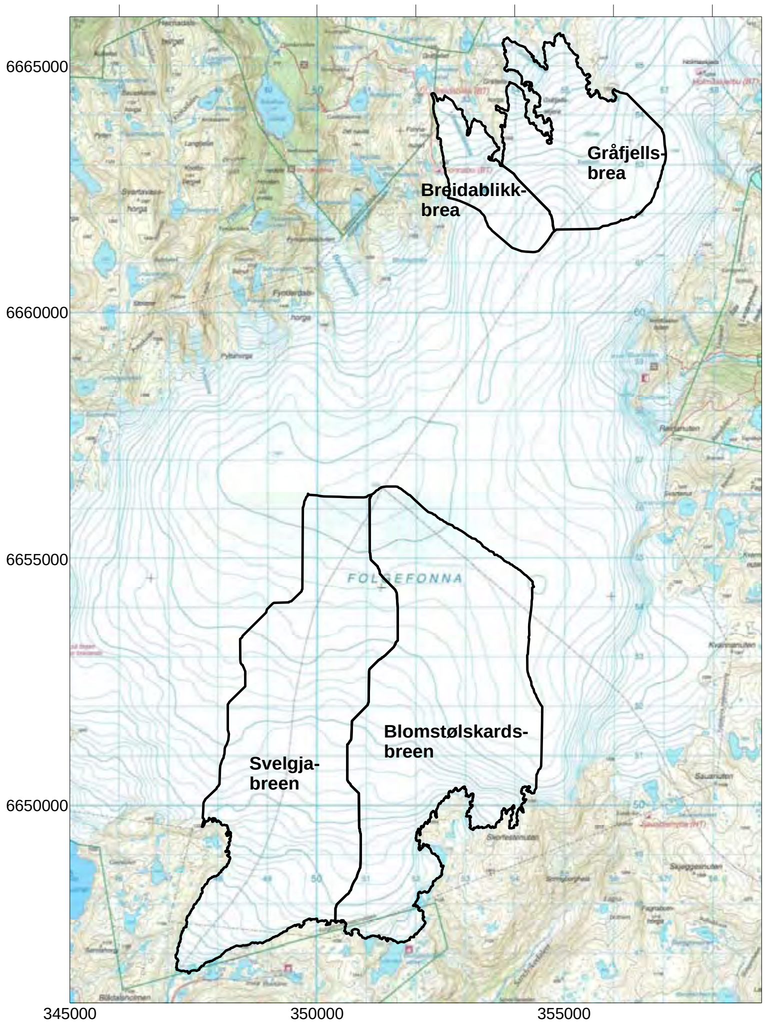


Figure 3-1
Southern Folgefonna with Breidablikkbrea and Gråfjellsbrea in the northwest and Svelgjabreen and Blomstølskardsbreen in the south.

3.1 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2010

Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 5th May. The calculation of winter balance at Breidablikkbrea and Gråfjellsbrea is based on (Fig. 3-2):

- Measurement of stakes at positions 40 (1248 m a.s.l.), 41 (1272 m a.s.l.), 46 (1345 m a.s.l.), 47 (1419 m a.s.l.), 152 (1523 m a.s.l.), 55 (1564 m a.s.l.) and T60 (1640 m a.s.l.) on Breidablikkbrea. The stake readings showed snow depths between 3.2 and 4.6 m. Measurement of stakes at positions 10 (1117 m a.s.l.), 15 (1266 m a.s.l.), 20 (1339 m a.s.l.), 25 (1471 m a.s.l.), 30 (1546 m a.s.l.) and T60 on Gråfjellsbrea. Stake readings showed snow depths between 2.0 and 4.2 m.
- Snow depth probings performed in a regular grid with a spacing of approximately 330 metres between measurements. Snow depth is sounded at 43 grid points on Breidablikkbrea, and at 81 grid points on Gråfjellsbrea. The sounding conditions were good and the summer surface (S.S.) could be detected easily on both glaciers. The snow depth varied between 2.1 and 4.3 m on Breidablikkbrea and between 1.9 and 4.7 m on Gråfjellsbrea.
- Snow density measured down to S.S. at 3.4 m at position 25 on Gråfjellsbrea.

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

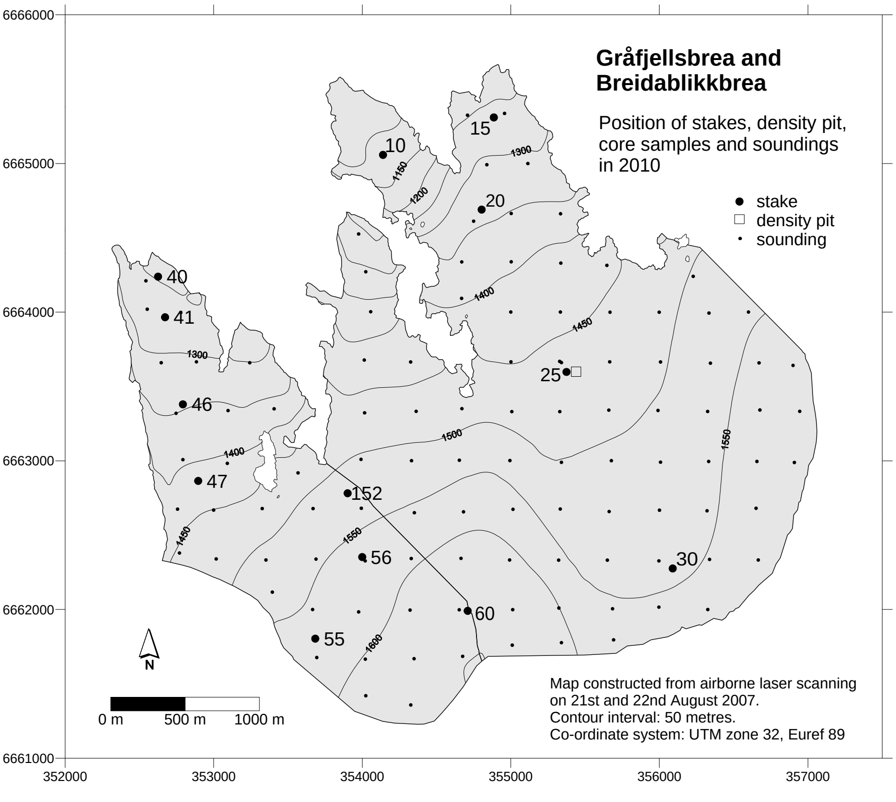


Figure 3-2 Location of stakes, soundings and density pit at Breidablikkbrea and Gråfjellsbrea in 2010.

Ablation measurements

Ablation was measured on 28th September. The net balance was measured at stakes in eight different positions on Breidablikkbrea and five positions on Gråfjellsbrea. Due to some risky crevasses the length of stake 25 was estimated from the helicopter. All snow from the previous winter had disappeared. At the time of the ablation measurements up to 0.7 m of fresh snow had fallen.

Figure 3-3
The two outlets from Gråfjellsbrea photographed on 28th September 2010. Photo: Geir 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.

A density profile was modelled from the snow density measured at 1471 m a.s.l. The mean snow density of 3.4 m snow was 463 kg/m^3. The density model was assumed to be representative for both Breidablikkbrea and Gråfjellsbrea, and all snow depths were converted to water equivalent using this model.

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

Winter balance at Breidablikkbrea in 2010 was 1.6 ±0.2 m w.e., corresponding to a volume of 5 ±1 mill. m^3 of water. The result is 64 % of the average for the period 2003-09.

The winter balance at Gråfjellsbrea was 1.5 ±0.2 m w.e., corresponding to a volume of 13 ±1 mill. m^3 of water. This result is 62 % of the average for 2003-09.

As verification, the winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 3-4). Water equivalents for each cell in a 100 x 100 m grid were calculated and summed. This method gave 1.6 m w.e. for both glaciers.

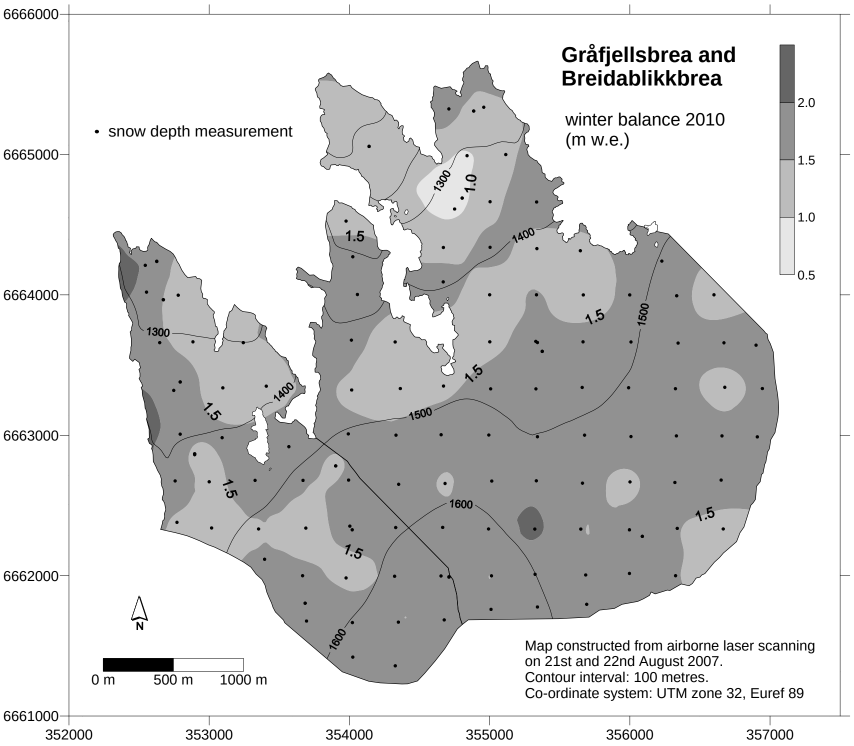


Figure 3-4
Winter balance at Breidablikkbrea and Gråfjellsbrea in 2010 interpolated from 137 snow depth measurements (•).

Summer balance

When calculating the summer balance the density of melted firn was estimated as 650-800 kg/m^3. The density of melted ice was assumed to be 900 kg/m^3.

The summer balance at Breidablikkbrea was measured and calculated at stakes in eight different positions (Fig. 3-5). The stake values increased from 3.1 m w.e. at position 55 (1564 m a.s.l.) to 4.0 m w.e. at position 40 (1248 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated as −3.5 ±0.3 m w.e., corresponding to −12 ±1 mill. m^3 of water. This is 102 % of the mean value for 2003-09.

The summer balance for Gråfjellsbrea was measured and calculated at stakes in six different positions (Fig. 3-5). The stake values increased from 2.8 m w.e. at position 25 (1471 m a.s.l.) to 4.7 m w.e. at position 15 (1266 m a.s.l.). Based on the six stakes and the estimated density, the summer balance was calculated as −3.3 ±0.3 m w.e. or −28 ±1 mill. m^3 of water. This is 101 % of the mean value for 2003-09.

Usually the summer balance increases with decreasing altitude. This correlation between summer balance and altitude doesn't quite hold for Gråfjellsbrea in 2010 for the summer balance values at the uppermost (pos. 60) and the lowestmost (pos. 10) stakes. Hence, the summer and net balance curves for Gråfjellsbrea are somewhat uncertain above 1600 m a.s.l. and below 1200 m a.s.l. The same trend has occurred in previous years, but is even more apparent this year.

Net balance

The net balance at Breidablikkbrea for 2010 was calculated as −1.9 ±0.4 m w.e. or a deficit of −7 ±2 mill. m^3 of water. The mean net balance for 2003-2009 is −0.98 m w.e.

The net balance at Gråfjellsbrea was calculated as −1.8 ±0.4 m w.e. or a deficit of −15 ±2 mill. m^3 of water. The mean value for 2003-2009 is −0.86 m w.e.

As shown in Figure 3-5, the Equilibrium Line Altitude (ELA) lies above the highest summit (>1651 m a.s.l.) on both glaciers. Consequently, the Accumulation Area Ratios (AAR) are 0 %.

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. For the period 2002-2010 there is only one year (2007) with significant positive net balance at Gråfjellsbrea and Breidablikkbrea.

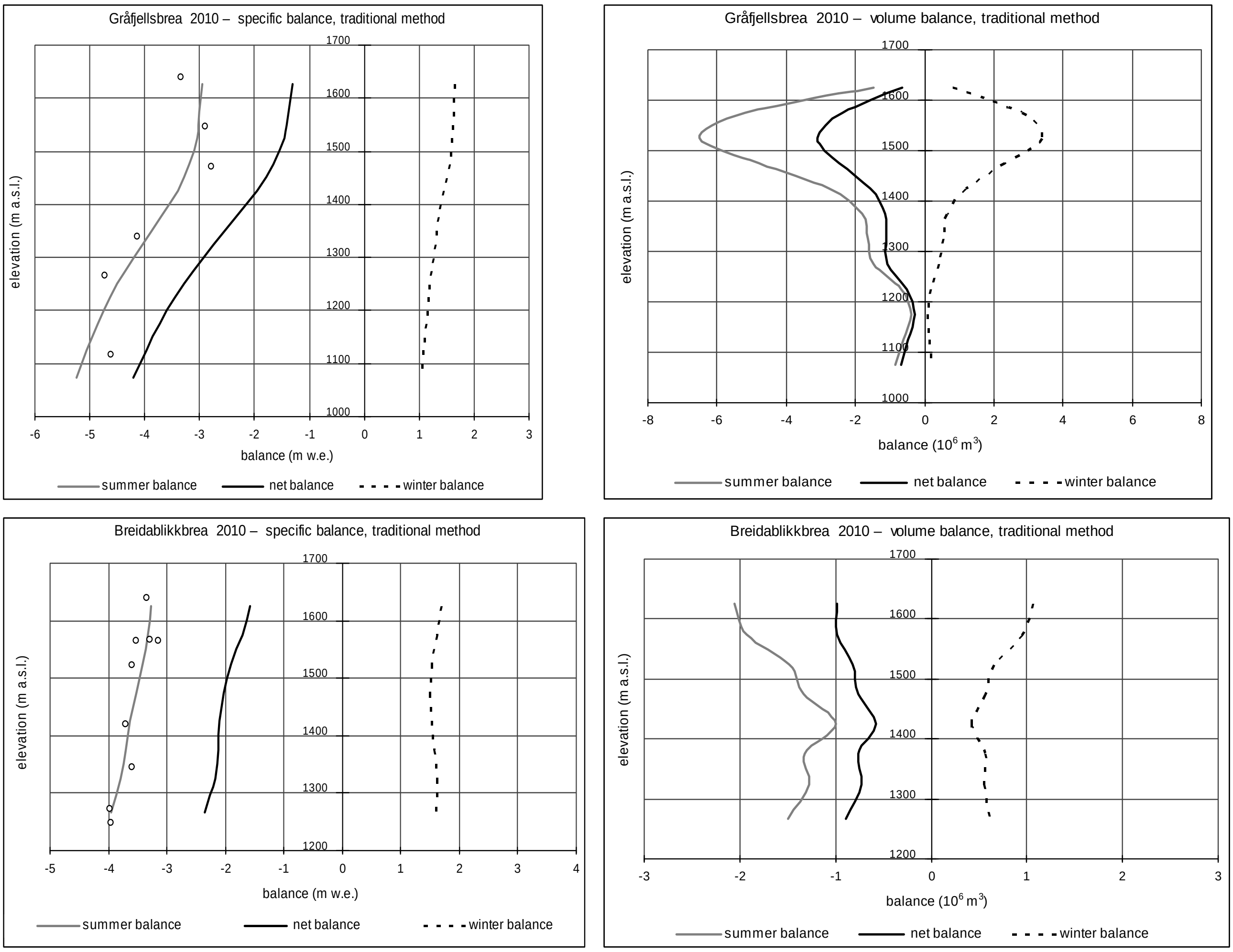


Figure 3-5
Mass balance diagram for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2010 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and net balance. Specific summer balance at each stake is shown (○). Note that the measured summer balance values at the uppermost (1640 m a.s.l.) and lowermost (1117 m a.s.l.) stakes do not follow the usual altitudinal relationship (upper left diagram). Thus the summer and net balance curves for Gråfjellsbrea are somewhat uncertain below 1200 m a.s.l.

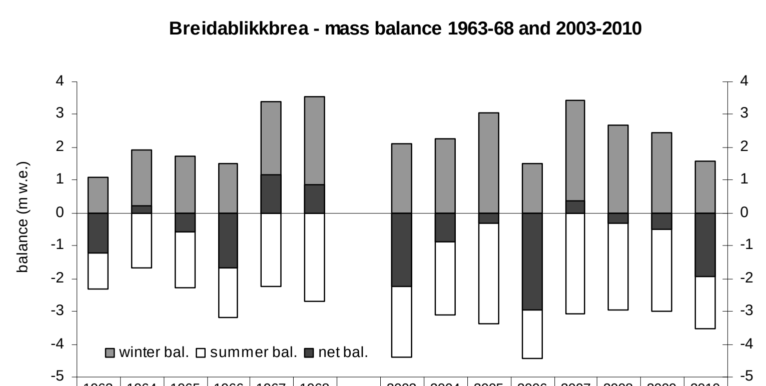
Table 3-1
Winter, summer and net balances for Breidablikkbrea (upper) and Gråfjellsbrea (lower) in 2010.

Mass balance Breidablikkbrea 2009/10 – traditional method

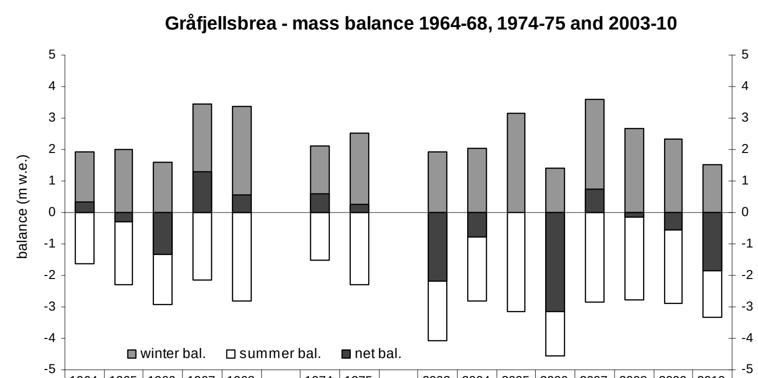
Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 5th May 2010 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 28th Sep 2010 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2009 - 2010 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1600 - 1651	0.63	1.70	1.1	-3.28	-2.1	-1.58	-1.0
1550 - 1600	0.58	1.63	0.9	-3.33	-1.9	-1.70	-1.0
1500 - 1550	0.43	1.53	0.7	-3.43	-1.5	-1.90	-0.8
1450 - 1500	0.38	1.50	0.6	-3.53	-1.3	-2.03	-0.8
1400 - 1450	0.28	1.53	0.4	-3.63	-1.0	-2.10	-0.6
1350 - 1400	0.36	1.58	0.6	-3.70	-1.3	-2.13	-0.8
1300 - 1350	0.34	1.63	0.5	-3.80	-1.3	-2.18	-0.7
1234 - 1300	0.38	1.60	0.6	-3.95	-1.5	-2.35	-0.9
1234 - 1651	**3.37**	**1.60**	**5.4**	**-3.53**	**-11.9**	**-1.94**	**-6.5**

Mass balance Gråfjellsbrea 2009/10 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 5th May 2010 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 28th Sep 2010 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surfaces 2009 - 2010 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1600 - 1651	0.50	1.65	0.8	-2.95	-1.5	-1.30	-0.6
1550 - 1600	1.72	1.63	2.8	-3.00	-5.2	-1.38	-2.4
1500 - 1550	2.13	1.60	3.4	-3.05	-6.5	-1.45	-3.1
1450 - 1500	1.49	1.55	2.3	-3.20	-4.8	-1.65	-2.5
1400 - 1450	0.81	1.45	1.2	-3.40	-2.8	-1.95	-1.6
1350 - 1400	0.49	1.35	0.7	-3.70	-1.8	-2.35	-1.2
1300 - 1350	0.41	1.30	0.5	-4.05	-1.7	-2.75	-1.1
1250 - 1300	0.34	1.23	0.4	-4.35	-1.5	-3.13	-1.1
1200 - 1250	0.15	1.18	0.2	-4.63	-0.7	-3.45	-0.5
1150 - 1200	0.08	1.13	0.1	-4.85	-0.4	-3.73	-0.3
1100 - 1150	0.12	1.08	0.1	-5.05	-0.6	-3.98	-0.5
1049 - 1100	0.16	1.05	0.2	-5.25	-0.9	-4.20	-0.7
1049 - 1651	**8.41**	**1.51**	**12.7**	**-3.35**	**-28.2**	**-1.84**	**-15.5**



	1963	1964	1965	1966	1967	1968		2003	2004	2005	2006	2007	2008	2009	2010
▨ winter bal.	1.11	1.92	1.72	1.52	3.40	3.55		2.12	2.25	3.04	1.49	3.42	2.66	2.47	1.60
☐ summer bal.	-2.32	-1.68	-2.28	-3.17	-2.23	-2.68		-4.38	-3.12	-3.37	-4.44	-3.07	-2.96	-2.98	-3.53
■ net bal.	-1.21	0.23	-0.56	-1.65	1.17	0.87		-2.26	-0.87	-0.33	-2.95	0.36	-0.30	-0.52	-1.94



	1964	1965	1966	1967	1968		1974	1975		2003	2004	2005	2006	2007	2008	2009	2010
▨ winter bal.	1.94	2.01	1.58	3.46	3.39		2.11	2.53		1.91	2.05	3.15	1.40	3.60	2.66	2.34	1.51
☐ summer bal.	-1.62	-2.29	-2.93	-2.14	-2.82		-1.53	-2.28		-4.09	-2.82	-3.13	-4.55	-2.85	-2.80	-2.88	-3.35
■ net bal.	0.32	-0.28	-1.35	1.31	0.57		0.58	0.25		-2.18	-0.76	0.02	-3.15	0.75	-0.14	-0.54	-1.84

Figure 3-6
Winter, summer and net balance at Breidablikkbrea for the periods 1963-68 and 2003-09 (upper figure), and at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-10 (lower figure).

3.2 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2010

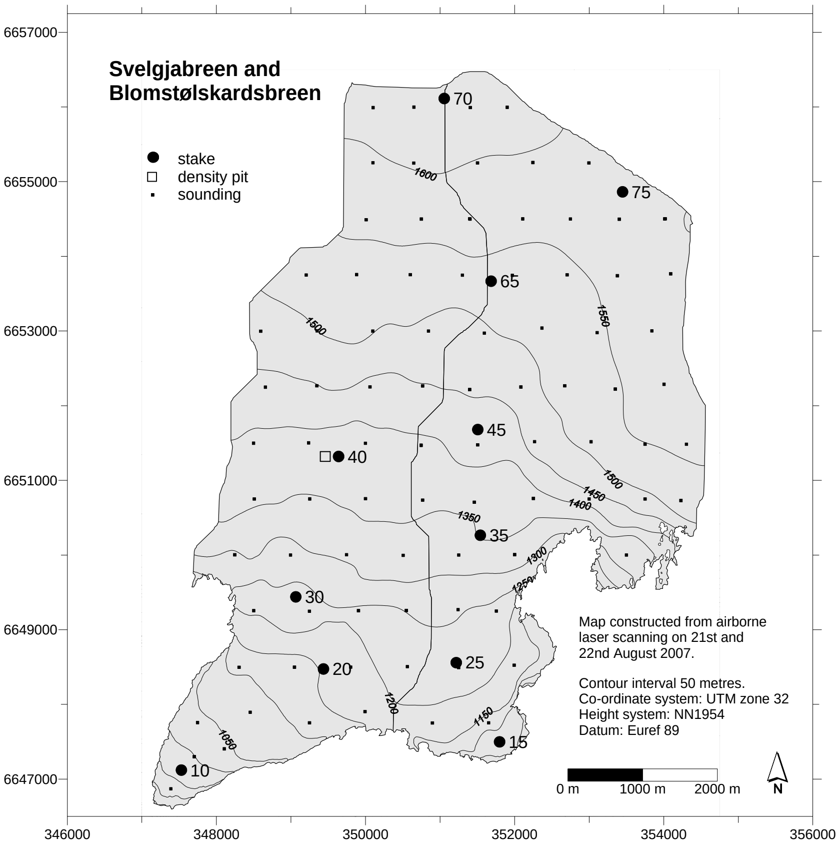
Fieldwork

Snow accumulation measurements

Snow accumulation measurements were performed on 4th May. The calculation of winter balance at Svelgjabreen and Blomstølskardsbreen is based on (Fig. 3-7):

- Measurement of stakes at positions 10 (970 m a.s.l.), 20 (1154 m a.s.l.), 30 (1238 m a.s.l.), 65 (1530 m a.s.l.) and 70 (1632 m a.s.l.) on Svelgjabreen and measurement of stakes at positions 15 (1082 m a.s.l.), 25 (1229 m a.s.l.), 45 (1430 m a.s.l.), 65, 75 (1584 m a.s.l.) and 70 on Blomstølskardsbreen.
- Snow depth probings performed in an approximately regular grid of spacing 750 x 750 m. Snow depth is sounded at 51 grid points on Svelgjabreen and at 53 grid points on Blomstølskardsbreen. The summer surface (S.S.) was fairly easy to detect except in the areas above 1500 m elevation where the S.S. was somewhat difficult to define. Generally, the snow depth varied from 3.5 m to 4.5 m at Svelgjabreen, and from 4.0 m to 5.0 m at Blomstølskardsbreen. Average snow depth was 3.8 m and 4.3 m, respectively.
- Snow density was measured down to S.S. at 4.5 m at stake position 40 (1364 m a.s.l.) at Svelgjabreen.

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



Map constructed from airborne laser scanning on 21st and 22nd August 2007.

Contour interval 50 metres.
Co-ordinate system: UTM zone 32
Height system: NN1954
Datum: Euref 89

**Figure 3-7
Location of stakes, soundings and density pit at Svelgjabreen and Blomstølskardsbreen in 2010.**

Ablation measurements

Ablation was measured on 28th September. The net balance was measured at stakes in all eleven positions on the two glaciers. There was no snow remaining on the glacier surface from the winter season 2009/2010. At the time of the ablation measurement between 0.2 and 0.3 m of fresh snow had fallen in the areas above 1300 m elevation.

Results

The calculations are based on the Digital Elevation Model 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.

There was no melting after the final measurements in October 2009. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1364 m a.s.l. The mean snow density of 4.45 m snow was 431 kg/m^3. The density model was assumed to be representative for both Svelgjabreen and Blomstølskardsbreen, and all snow depths were converted to water equivalent using this model.

The calculation of winter balance was performed by plotting the point measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation (Fig. 3-9) and a mean value for each 50 m height interval was estimated (Tab. 3-2). All height intervals are well-represented with point measurements at both glaciers except the very lowest interval (832-900 m a.s.l.) at Svelgjabreen.

Winter balance at Svelgjabreen in 2010 was 1.7 ±0.2 m w.e., corresponding to a volume of 37 ±4 mill. m^3 of water. The winter balance at Blomstølskardsbreen was 1.8 ±0.2 m w.e., corresponding to a volume of 42 ±4 mill. m^3 of water.

As verification, the winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 3-8). Water equivalents for each cell in a 400 x 400 m grid were calculated and summed. This method gave 1.6 m w.e. for Svelgjabreen and 1.8 m w.e. for Blomstølskardsbreen.

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 melted firn was estimated as 650-725 kg/m^3. The density of melted ice was assumed to be 900 kg/m^3.

The summer balance at Svelgjabreen was measured at seven stakes. The stake values increased from 2.5 m w.e. (1632 m a.s.l.) to 4.4 m w.e. (970 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated as −3.3 ±0.3 m w.e. corresponding to −74 ±6 mill. m^3 of water.

The summer balance for Blomstølskardsbreen was measured and calculated at seven stakes. The stake values increased from 2.5 m w.e. (1632 m a.s.l.) to 4.1 m w.e. (1229 m a.s.l.). The measured summer balance at stake 15 (1082 m a.s.l.) was 0.9 m w.e. *lower* than measured at the stake that is next highest in elevation (25, 1229 m a.s.l.). This anomalous measurement may be due to geometry and the position being somewhat protected from melting, or it may be erroneous. Regardless, the summer balance curve is drawn irrespective of stake 15. Based on the other six stakes and the estimated density the summer balance was calculated as −3.1 ±0.3 m w.e. or −70 ±6 mill. m^3 of water.

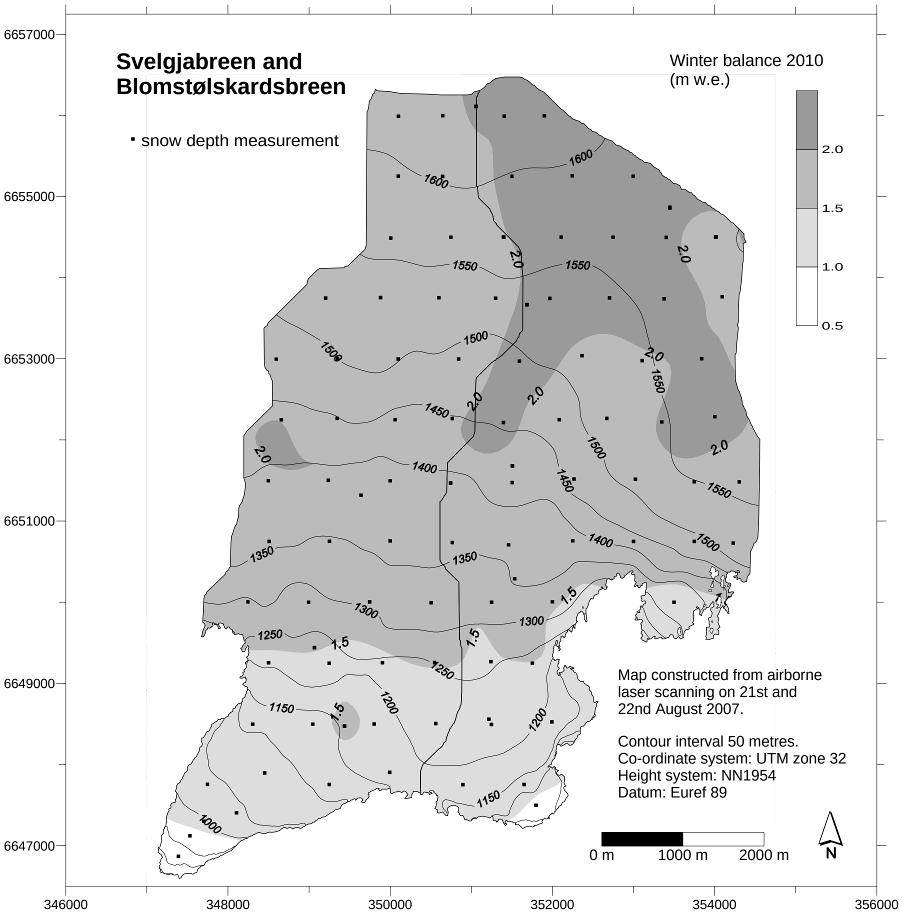


Figure 3-8
Winter balance at Svelgjabreen and Blomstølskardsbreen in 2010 interpolated from 115 snow depth measurements (•).

Net balance

The net balance at Svelgjabreen for 2010 was calculated as −1.6 ±0.4 m w.e. or a mass loss of 37 ±9 mill. m^3 of water.

The net balance at Blomstølskardsbreen was calculated as −1.2 ±0.4 m w.e. or a mass loss of 28 ±9 mill. m^3 of water.

As shown in Figure 3-9, the equilibrium line altitude (ELA) lies above the highest summit (1636 m a.s.l.) on both glaciers. Consequently, the Accumulation Area Ratios (AAR) are 0 %.

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

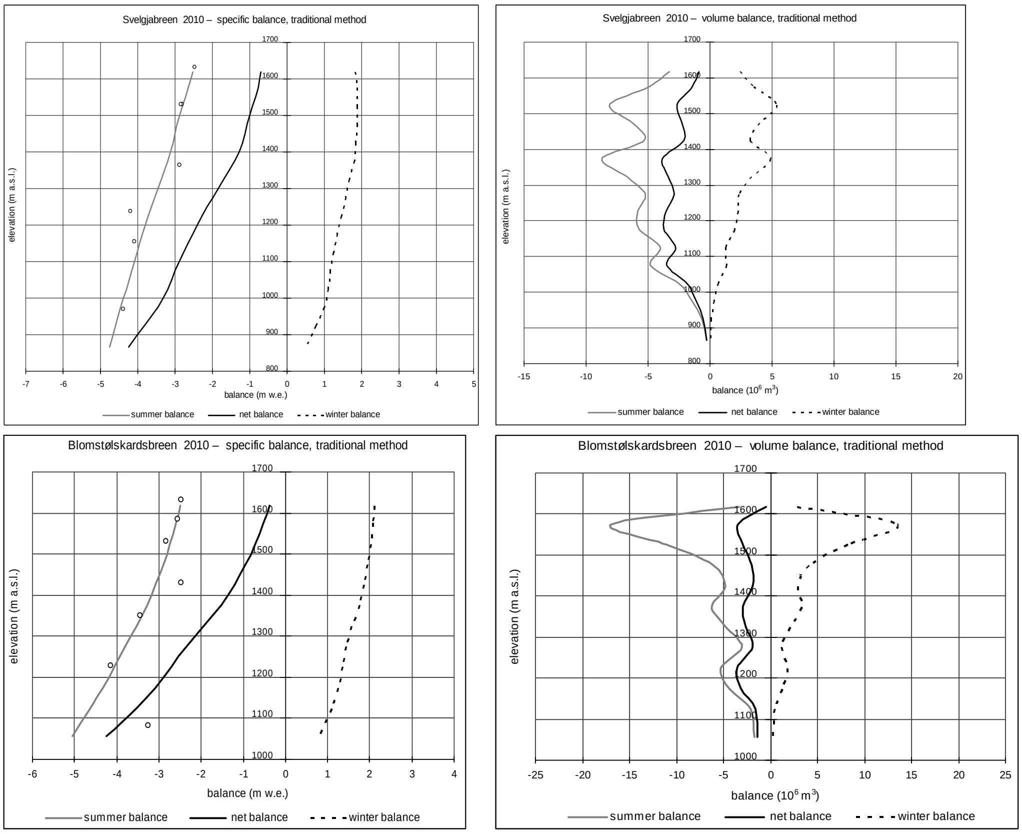


Figure 3-9
Mass balance diagram for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2010.

Table 3-2
Winter, summer and net balances for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2010.

Mass balance Svelgjabreen 2009/10 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 4th May 2010		Measured 28th Sep 2010		Summer surface 2009 - 2010	
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	1.83	2.4	-2.53	-3.3	-0.70	-0.9
1550 - 1600	1.87	1.88	3.5	-2.65	-4.9	-0.78	-1.4
1500 - 1550	2.89	1.88	5.4	-2.80	-8.1	-0.93	-2.7
1450 - 1500	2.13	1.88	4.0	-2.95	-6.3	-1.08	-2.3
1400 - 1450	1.75	1.85	3.2	-3.05	-5.3	-1.20	-2.1
1350 - 1400	2.73	1.80	4.9	-3.20	-8.7	-1.40	-3.8
1300 - 1350	1.99	1.68	3.3	-3.38	-6.7	-1.70	-3.4
1250 - 1300	1.47	1.58	2.3	-3.55	-5.2	-1.98	-2.9
1200 - 1250	1.57	1.45	2.3	-3.73	-5.8	-2.28	-3.6
1150 - 1200	1.47	1.35	2.0	-3.88	-5.7	-2.53	-3.7
1100 - 1150	1.00	1.25	1.3	-4.03	-4.0	-2.78	-2.8
1050 - 1100	1.16	1.15	1.3	-4.15	-4.8	-3.00	-3.5
1000 - 1050	0.59	1.10	0.7	-4.30	-2.5	-3.20	-1.9
950 - 1000	0.32	1.00	0.3	-4.45	-1.4	-3.45	-1.1
900 - 950	0.14	0.78	0.1	-4.60	-0.7	-3.83	-0.5
832 - 900	0.06	0.50	0.0	-4.75	-0.3	-4.25	-0.3
832 - 1636	**22.45**	**1.65**	**37.1**	**-3.29**	**-74.0**	**-1.64**	**-36.9**

Mass balance Blomstølskardsbreen 2009/10 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 4th May 2010		Measured 28th Sep 2010		Summer surfaces 2009 - 2010	
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	2.13	2.9	-2.50	-3.4	-0.38	-0.5
1550 - 1600	6.49	2.08	13.5	-2.60	-16.9	-0.53	-3.4
1500 - 1550	4.04	2.03	8.2	-2.75	-11.1	-0.73	-2.9
1450 - 1500	2.11	1.95	4.1	-2.90	-6.1	-0.95	-2.0
1400 - 1450	1.56	1.88	2.9	-3.08	-4.8	-1.20	-1.9
1350 - 1400	1.92	1.75	3.4	-3.28	-6.3	-1.53	-2.9
1300 - 1350	1.37	1.58	2.2	-3.53	-4.8	-1.95	-2.7
1250 - 1300	0.81	1.45	1.2	-3.80	-3.1	-2.35	-1.9
1200 - 1250	1.31	1.35	1.8	-4.05	-5.3	-2.70	-3.5
1150 - 1200	1.02	1.25	1.3	-4.33	-4.4	-3.08	-3.1
1100 - 1150	0.45	1.10	0.5	-4.63	-2.1	-3.53	-1.6
1013 - 1100	0.33	0.80	0.3	-5.05	-1.7	-4.25	-1.4
1013 - 1636	**22.77**	**1.85**	**42.1**	**-3.07**	**-70.0**	**-1.23**	**-27.9**

4. Nigardsbreen (Bjarne Kjøllmoen)

Nigardsbreen (61°42'N, 7°08'E) is one of the largest and best known outlet glaciers from Jostedalsbreen. It has an area of 47.2 km^2 (2009) and flows south-east from the centre of the ice cap. Nigardsbreen accounts for approximately 10 % of the total area of Jostedalsbreen, and extends from 1957 m a.s.l. down to 315 m a.s.l.

Glaciological investigations in 2010 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962.

4.1 Mass balance 2010

Fieldwork

Snow accumulation measurements

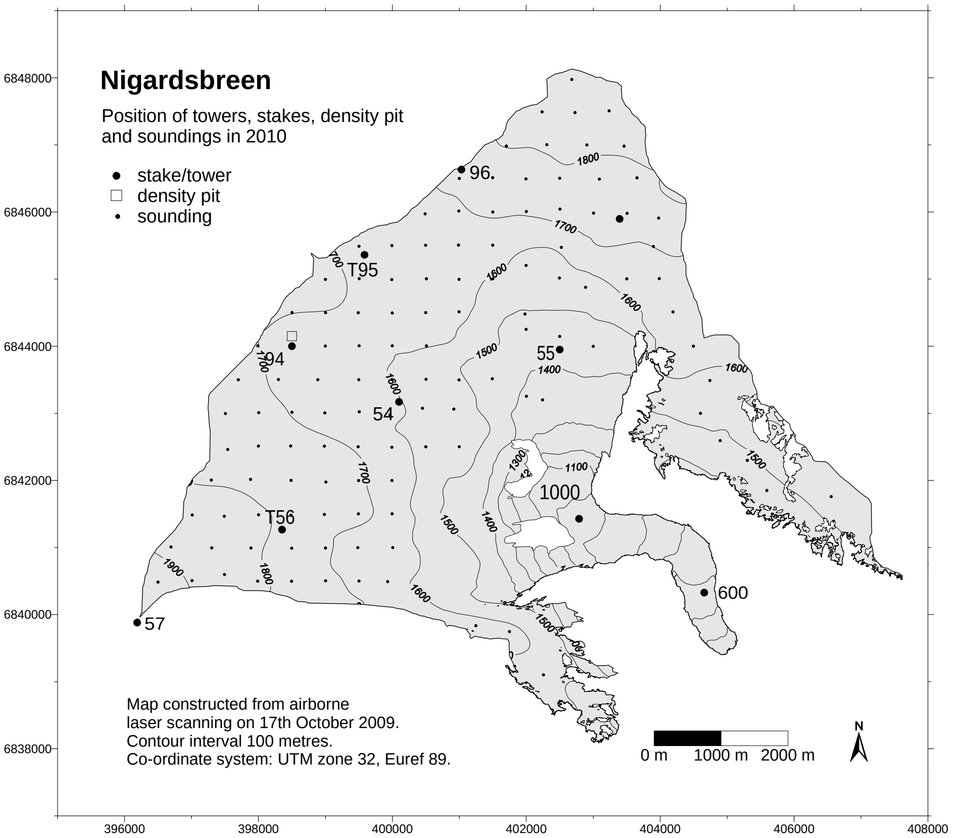
Snow accumulation measurements were performed on 19th and 20th May and the calculation of winter balance (Fig. 4-1) is based on:

- Uninterrupted measurement of stakes and towers in positions 600 (575 m a.s.l.), 1000 (965 m a.s.l.), 55 (1460 m a.s.l.), 54 (1602 m a.s.l.), T95 (1678 m a.s.l.), 96 (1753 m a.s.l.) and T56 (1792 m a.s.l.). It was also possible to make use of measurements of a substitute stake drilled in May 2010 and an older stake that appeared during the melt season in position 57 (1957 m a.s.l.). The stake measurements on the plateau showed snow depths between 3.25 and 3.75 m. Measurement of stake 600 indicated 0.3 m of melting after the final measurement on 13th October 2009. Based on temperature data from adjacent meteorological stations this melting most probably occurred in spring before snow accumulation measurements in May 2010. Hence, it is assumed that there was no melting in late autumn after the final measurements in October 2009.
- Snow depth probings performed in an approximately regular grid of 500 x 500 m. Snow depth is sounded in 129 grid points on the plateau between 1357 and 1957 m a.s.l. The sounding conditions were good and the summer surface (S.S.) was easy to detect. The snow depth varied between 3 and 4 metres.
- Snow density measured down to 3.25 m depth (S.S. at 3.45 m) at position 94 (1687 m a.s.l.). (Fig. 4-1).

Location of stakes, towers, snow pit, core samples and soundings are shown in Figure 4-1.

Ablation measurements

Ablation measurements were carried out on 29th September. Measurements were made at nine stakes and two towers at nine different locations. Since snow measurements in May the stakes on the plateau had increased in length between 3.1 and 4.1 m. Hence, there was 0.3 m of snow remaining from winter 2009/2010 on the glacier summit (1957 m a.s.l.). At the time of measurement, between 0.15 and 0.45 m of fresh snow had fallen in the areas above 1450 m elevation.


Nigardsbreen

Position of towers, stakes, density pit and soundings in 2010

Map constructed from airborne laser scanning on 17th October 2009. Contour interval 100 metres. Co-ordinate system: UTM zone 32, Euref 89.

Figure 4-1
Location of towers and stakes, snow pit and soundings on Nigardsbreen in 2010.

Results

The calculations are based on a Digital Elevation Model from 2009.

Winter balance

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

There was no melting after the final measurements in October 2009. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measured at 1687 m altitude (3.25 m depth). Using this model gave a mean snow density of 468 kg/m^3. This model was used for all snow depth measurements.

The winter balance calculation was performed by plotting measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation, and a mean value for each 100 m height interval estimated (Tab. 4-1). The elevations above 1350 m a.s.l., which cover ca. 90 % of the catchment area, were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 965 and 575 m altitude.

These calculations give a winter balance of 1.5 ±0.2 m w.e., corresponding to a water volume of 69 ±10 mill. m^3. This is the second lowest winter balance measured at Nigardsbreen since measurements started in 1962. The lowest was measured in 1996 (1.4 m w.e.). The result is 60 % of the mean for the reference period 1971-2000.

The winter balance was also calculated using a gridding method based on the aerial distribution of the snow depth measurements (Fig. 4-2). Water equivalents for each cell in a 250 x 250 m grid were calculated and summed. The result obtained using this gridding method was also 1.5 m w.e.

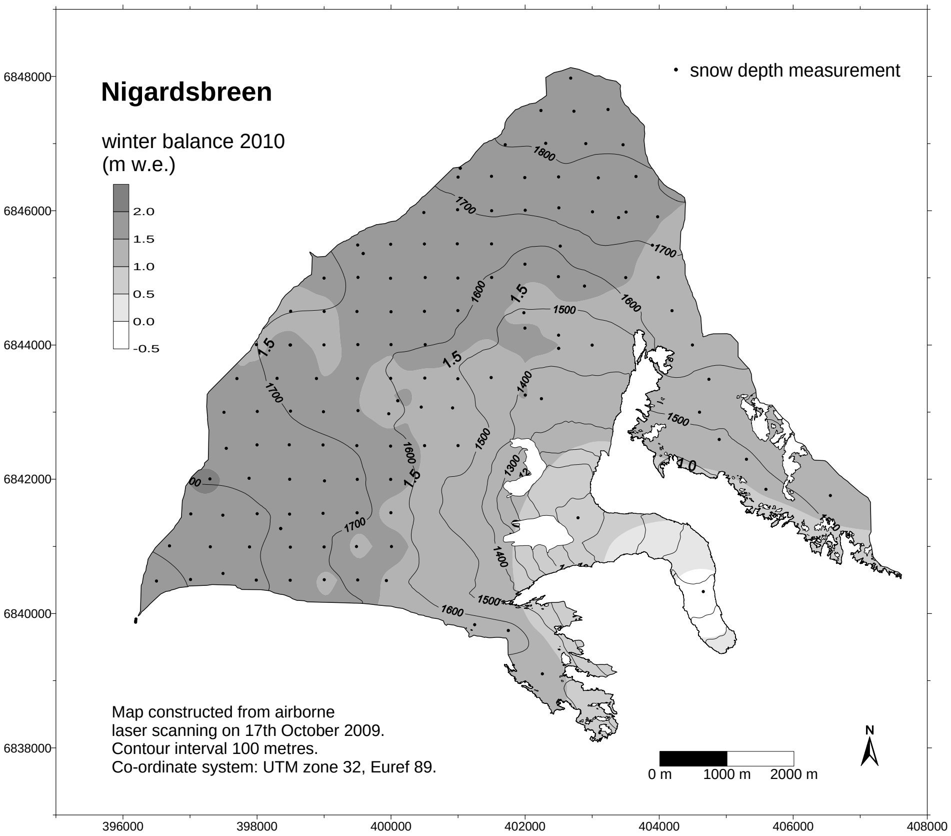


Figure 4-2
Winter balance at Nigardsbreen in 2010 interpolated from 138 measurements (•) of snow depth.

Summer balance

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

The summer balance was calculated at stakes and towers at ten different elevations (Fig. 4-3). For stake 1000 the melting is estimated for the period 19th May to 18th August. The melting is also estimated for stake 94 for the period 18th August to 29th September. The measured summer and net balance values for stake 55 (1460 m a.s.l.) are very different from the other stakes. Thus, values for stake 55 are not considered in the summer and net balance calculations. The summer balance increased (in absolute value) from −1.4 m w.e. at the glacier summit (1957 m a.s.l.) to −6.5 m on the tongue (575 m a.s.l.). Based on estimated density and stake measurements the summer balance was calculated to be −2.3 ±0.3 m w.e., which is −107 ±15 mill. m^3 of water. This is 119 % of the mean for the reference period 1971-2000.

Net balance

The net balance was calculated at stakes and towers in ten different positions. The result was a deficit of −0.8 m ±0.3 m w.e., which means a mass loss of −38 ±15 mill.m^3 water. The mean value for the reference period 1971-2000 is +0.54 m w.e., while the average for last ten years (2000-2009) is +0.15 m w.e.

Based on Figure 4-3, the Equilibrium Line Altitude (ELA) was 1770 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 14 %.

The mass balance for Nigardsbreen in 2010 is shown in Table 4-1 and the corresponding curves are shown in Figure 4-3. The historical mass balance results are presented in Figure 4-4.

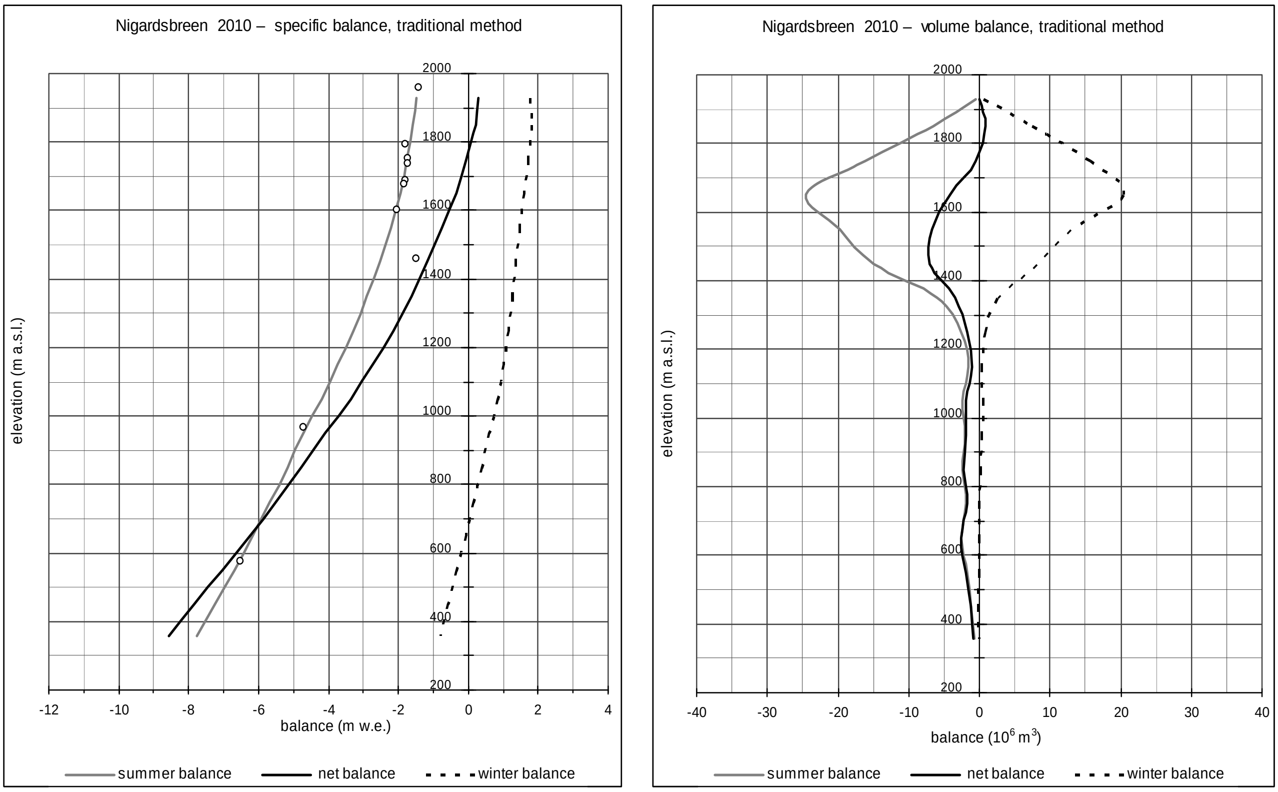


Figure 4-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2010. Specific summer balance at ten stake positions is shown as dots (○). The net balance curve intersects the y-axis and defines the ELA as 1770 m a.s.l. Thus the AAR was 14 %.

Table 4-1
Winter, summer and net balance for Nigardsbreen in 2010. Mean values for the reference period 1971-2000 are 2.45 (b_w), −1.92 m (b_s) and +0.54 m (b_n) water equivalent.

Mass balance Nigardsbreen 2009/10 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 19th May 2010		Measured 29th Sep 2010		Summer surface 2009 - 2010	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1900 - 1957	0.31	1.78	0.5	-1.50	-0.5	0.28	0.1
1800 - 1900	4.06	1.80	7.3	-1.60	-6.5	0.20	0.8
1700 - 1800	9.19	1.70	15.6	-1.75	-16.1	-0.05	-0.5
1600 - 1700	12.74	1.60	20.4	-1.93	-24.5	-0.33	-4.1
1500 - 1600	8.94	1.45	13.0	-2.20	-19.7	-0.75	-6.7
1400 - 1500	5.92	1.35	8.0	-2.53	-15.0	-1.18	-7.0
1300 - 1400	2.08	1.28	2.7	-2.90	-6.0	-1.63	-3.4
1200 - 1300	0.79	1.15	0.9	-3.30	-2.6	-2.15	-1.7
1100 - 1200	0.39	1.00	0.4	-3.75	-1.5	-2.75	-1.1
1000 - 1100	0.58	0.83	0.5	-4.20	-2.4	-3.38	-2.0
900 - 1000	0.46	0.60	0.3	-4.70	-2.1	-4.10	-1.9
800 - 900	0.47	0.40	0.2	-5.18	-2.4	-4.78	-2.3
700 - 800	0.32	0.15	0.0	-5.68	-1.8	-5.53	-1.8
600 - 700	0.41	-0.08	0.0	-6.18	-2.5	-6.25	-2.5
500 - 600	0.26	-0.33	-0.1	-6.70	-1.7	-7.03	-1.8
400 - 500	0.16	-0.58	-0.1	-7.25	-1.1	-7.83	-1.2
315 - 400	0.09	-0.80	-0.1	-7.78	-0.7	-8.58	-0.8
315 - 1957	**47.16**	**1.47**	**69.5**	**-2.27**	**-107.2**	**-0.80**	**-37.7**

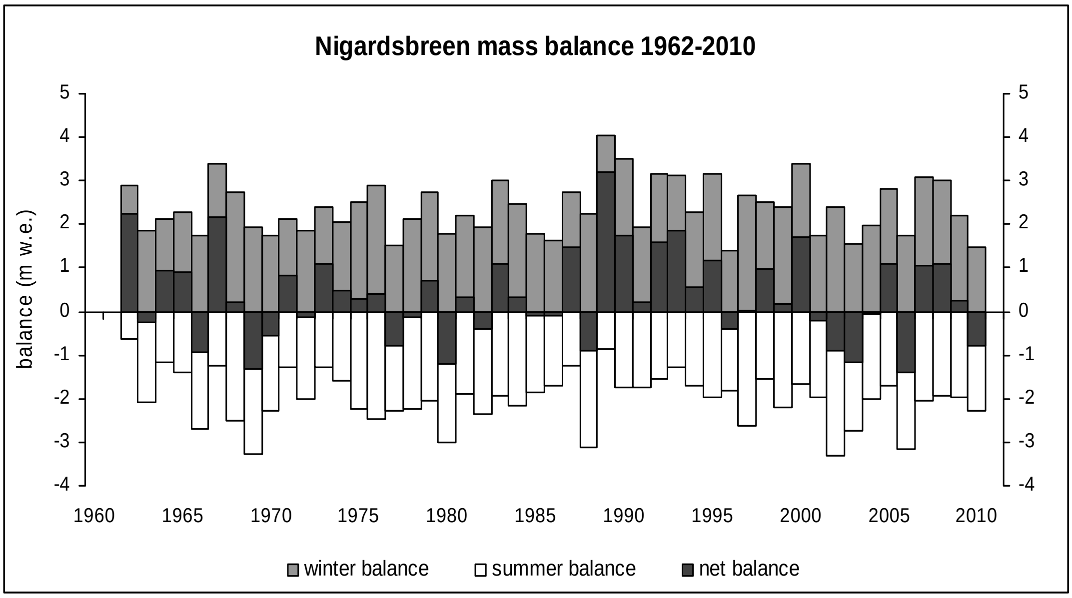


Figure 4-4
Annual mass balance at Nigardsbreen over the period 1962-2010.

5. Austdalsbreen (Hallgeir Elvehøy)

Austdalsbreen (61°45'N, 7°20'E) is an eastern outlet of the northern part of Jostedalsbreen, ranging in altitude from 1200 to 1747 m a.s.l. The glacier terminates in Austdalsvatnet, which has been part of the hydropower reservoir Styggevatnet since 1988. Glaciological investigations at Austdalsbreen started in 1986 in connection with the construction of the hydropower reservoir.

The glaciological investigations in 2010 included mass balance, front position change and glacier velocity. The mass balance has been measured at Austdalsbreen since 1988.

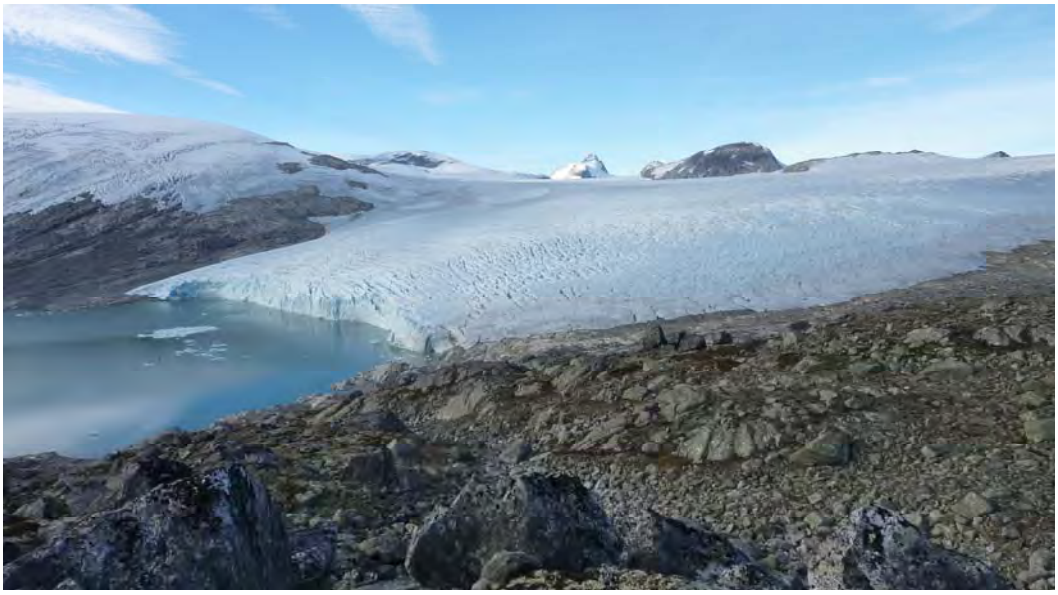


Figure 5-1
Austdalsbreen on 9th October 2010 as seen from AUS100 (Fig. 5-3). The lake level was 1189.5 m a.s.l. which is 10.5 m below the highest regulated lake level. Photo: Hallgeir Elvehøy.

5.1 Mass balance 2010

Fieldwork

Stakes were maintained throughout the winter in seven of eight stake locations.

The winter balance was measured on 1st June. The calculation of winter balance was based on the following data (Fig. 5-2):

- Snow depth at stakes A92 (1.25 m), A90 (1.25 m), A24 (2.10 m), A60 (2.25 m) and A70 (2.55 m). At stakes A5 and A6 there was no snow remaining and 0.2 m ice had melted.
- Stakes were re-established at locations A5 and A6. Snow depth at the new stake positions showed snow depths of 1.0 and 1.05 m snow.
- Snow density down to the previous summer surface at 2.53 m depth at stake A60 (1490 m a.s.l.). The mean snow density was 480 kg/m^3.

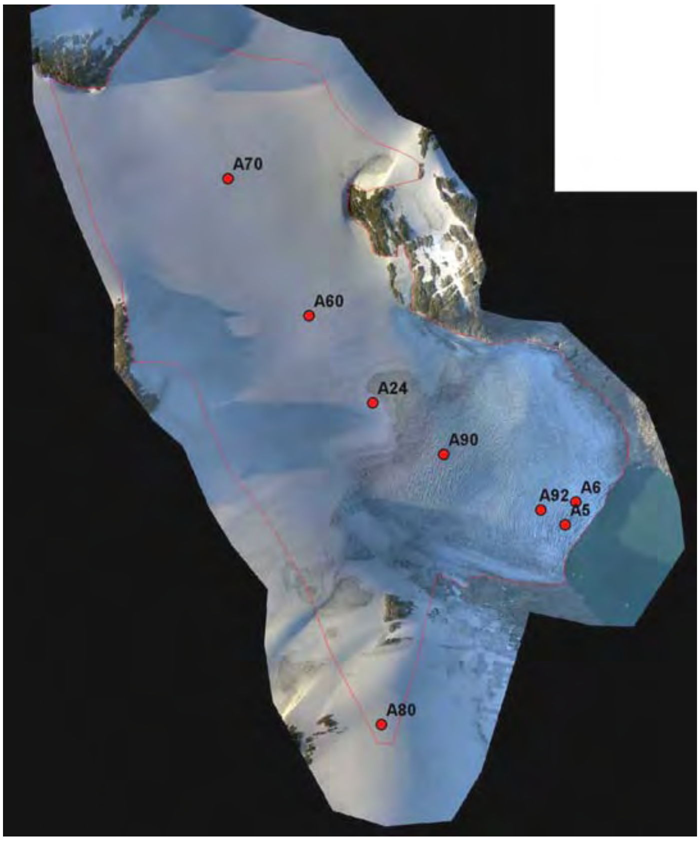


Figure 5-2
Location of stakes at Austdalsbreen in 2010.

- 37 snow depth measurements in a 500 x 500 m grid. At Austdalsnuten above 1600 m a.s.l. the snow depth was about 2 m. Between 1400 and 1600 m a.s.l. the snow depth was 2 to 3 metres. Below 1400 m a.s.l. the snow depth was between 1 and 2 metres.

On 18th August the winter snow at Austdalsbreen had melted. The stakes had become 3 to 4 metres longer since 1st June.

Summer and net balance measurements were carried out on 9th October. In the area around A80 there was new snow on the glacier. Eight stakes in seven locations were found. Stake A5 was not found. The stakes were 0.5 to 1.5 m longer than in August.

Results

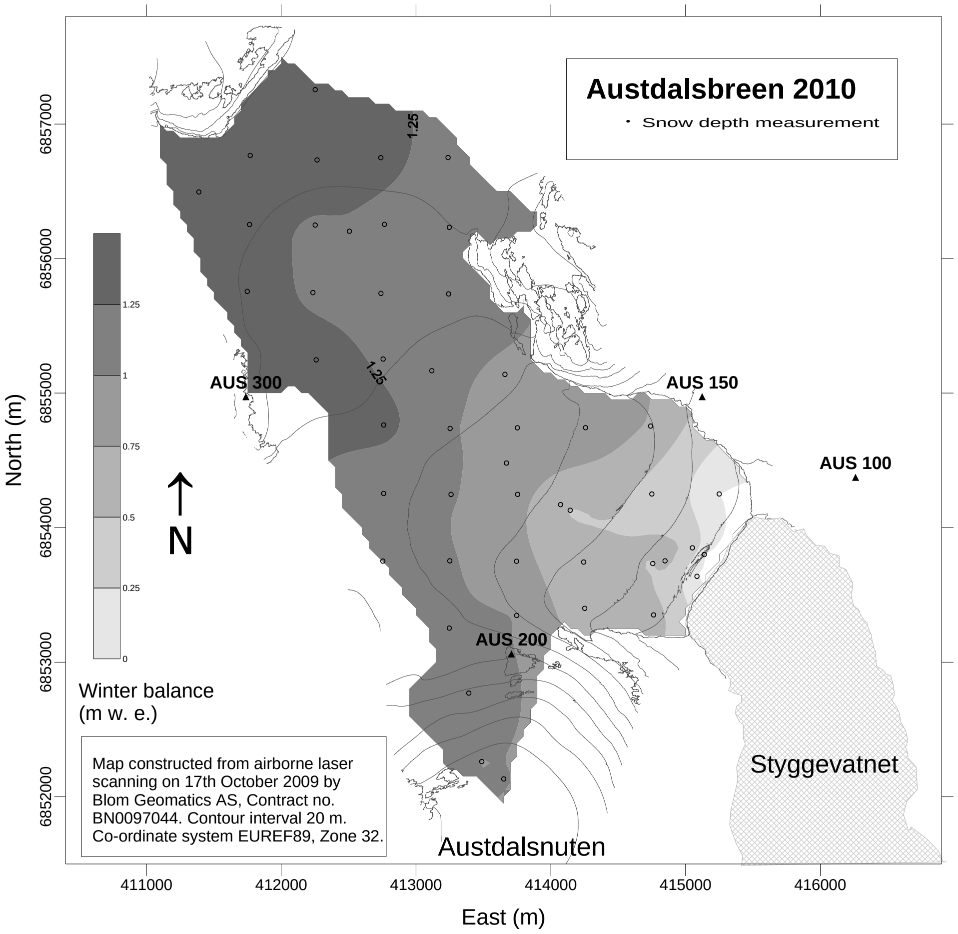
The mass balance was calculated according to the stratigraphic method (see chap.1). The calculations are based on a new DTM from 17th October 2009.

Winter balance

The winter balance was calculated from snow depth and snow density measurements on 1st June. 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 11 ±2 mill. m^3 water or 1.0 ±0.2 m w.e., which is 47 % of the 1988-2009 average (2.20 m w.e.).

The winter balance was calculated using a gridding method also, based on the spatial distribution of the snow depth measurements (Fig. 5-3). Water equivalents for each cell in a 50 x 50 m grid were calculated and summarised. The result based on this method, which is a control of the traditional method, showed a winter balance of 1.1 m w.e.



Map constructed from airborne laser scanning on 17th October 2009 by Blom Geomatics AS, Contract no. BN0097044. Contour interval 20 m. Co-ordinate system EUREF89, Zone 32.

Figure 5-3
Winter balance at Austdalsbreen in 2010 from 48 water equivalent values calculated from snow depth measurements.

Summer balance

The summer balance was calculated directly for stakes in six locations between 1250 and 1550 m a.s.l. Stake A80 was missing in June, but the snow depth was measured by sounding. The summer balance curve was drawn from these seven point values (Fig. 5-4).

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

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

where ρ_{ice} is 900 kg/m^3, u_{ice} is annual glacier velocity (25 ±10 m/a, chap. 5.3), u_f is front position change averaged across the terminus (−34 ±5 m/a, chap. 5.2), W is terminus width (990 ±20 m) and H is mean ice thickness at the terminus (51 ±5 m). The mean ice thickness was calculated from mean surface altitudes along the calving terminus surveyed on 13th October 2009 (1223 m a.s.l.) and 9th October 2010 (1228 m a.s.l.), and mean bottom elevation along the terminus in October 2009 (1176 m a.s.l.) and October 2010 (1173 m a.s.l.) calculated from a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989). The resulting calving volume was 3 ±1 mill. m^3.

The summer balance, including calving, was calculated as −3.0 ±0.3 m w.e., which corresponds to −32 ±3 mill. m^3 of water. The result is 121 % of the 1988-2009 average (−2.50 m w.e.). The calving volume was 8 % of the summer balance.

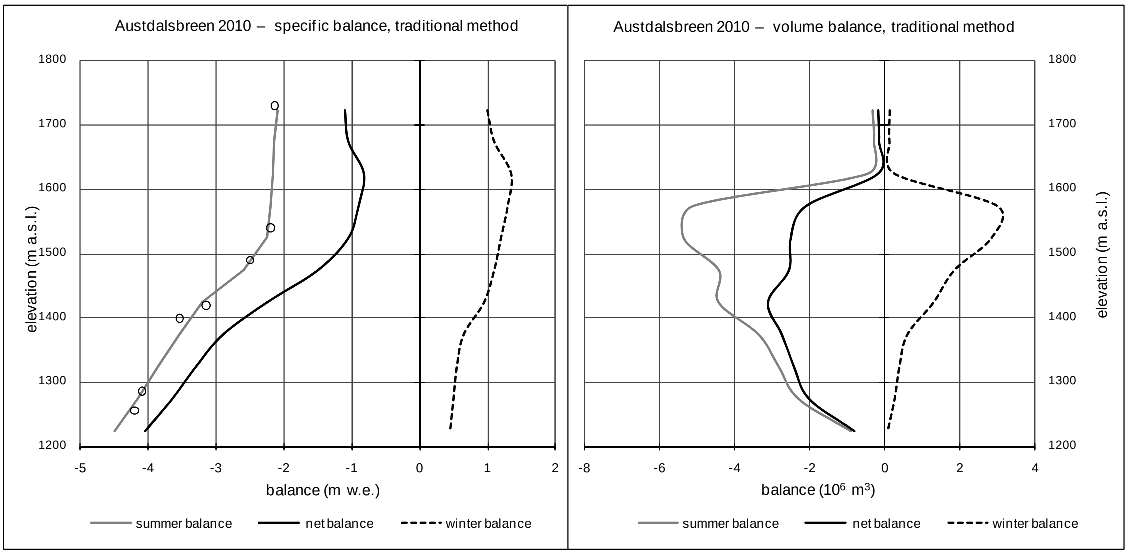


Figure 5-4
Altitudinal distribution of winter, summer and net balances is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2010. Specific summer balance at seven stake locations is shown (○).

Table 5-1
Altitudinal distribution of winter, summer and net balances at Austdalsbreen in 2010.

Mass balance Austdalsbreen 2009/10 – traditional method

Altitude (m a.s.l.)	Area (km²)	Winter balance		Summer balance		Net balance	
		Measured 1st June 2010		Measured 9th Oct 2010		Summer surface 2009 - 2010	
		Specific (m w.e.)	Volume (10⁶ m³)	Specific (m w.e.)	Volume (10⁶ m³)	Specific (m w.e.)	Volume (10⁶ m³)
1700 - 1747	0,14	1,00	0,14	-2,10	-0,30	-1,10	-0,16
1650 - 1700	0,13	1,10	0,14	-2,15	-0,27	-1,05	-0,13
1600 - 1650	0,20	1,35	0,27	-2,17	-0,44	-0,82	-0,16
1550 - 1600	2,31	1,30	3,00	-2,20	-5,08	-0,90	-2,08
1500 - 1550	2,37	1,20	2,85	-2,25	-5,34	-1,05	-2,49
1450 - 1500	1,69	1,10	1,86	-2,60	-4,40	-1,50	-2,54
1400 - 1450	1,38	0,95	1,31	-3,20	-4,41	-2,25	-3,10
1350 - 1400	0,94	0,65	0,61	-3,55	-3,34	-2,90	-2,73
1300 - 1350	0,73	0,55	0,40	-3,85	-2,80	-3,30	-2,40
1250 - 1300	0,55	0,50	0,27	-4,15	-2,27	-3,65	-2,00
1200 - 1250	0,20	0,45	0,09	-4,50	-0,88	-4,05	-0,79
Calving					-2,7		-2,7
1200 - 1747	**10,63**	**1,03**	**10,9**	**-3,03**	**-32,2**	**-2,00**	**-21,3**

Net balance

The net balance at Austdalsbreen was calculated as −2.0 ±0.3 m w.e., corresponding to −21 ±3 mill. m^3 water. The 1988-2009 average is −0.29 m w.e. The equilibrium line altitude (ELA) in 2010 was above the top of the glacier. Correspondingly, the Accumulation Area Ratio (AAR) is 0 %. The altitudinal distribution of winter, summer and net balances is shown in Figure 5-4 and Table 5-1. Results from 1988-2010 are shown in Figure 5-5.

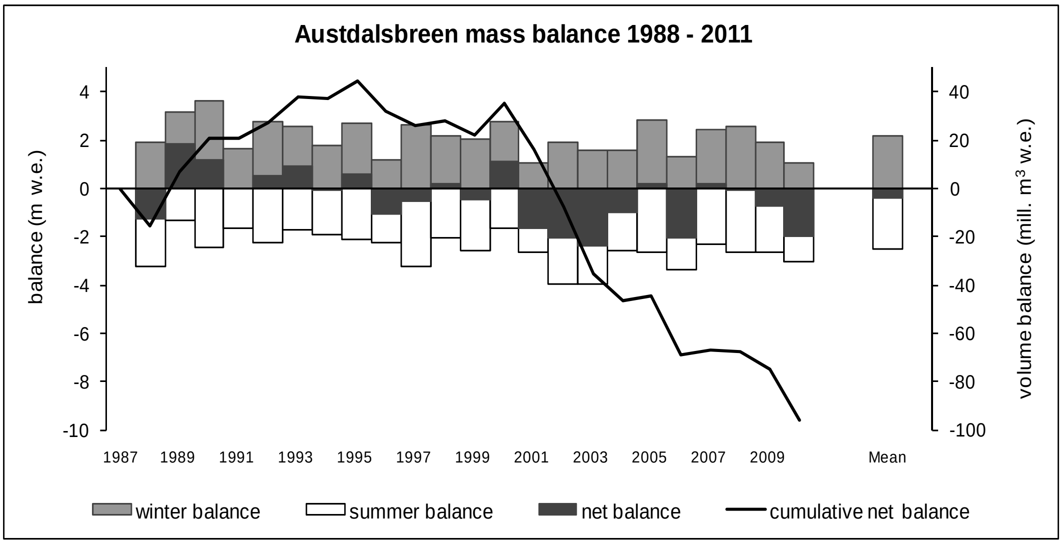


Figure 5-5
Winter, summer and net balances at Austdalsbreen during the period 1988-2010. Mean winter and summer balance is 2.15 and −2.52 m w.e., respectively. The cumulative net balance is −96 mill. m^3 water equivalent.

5.2 Front position change

Eight points along the calving terminus were surveyed on 9th October 2010. The mean front position change was −34 ±5 m (Fig. 5-6) between 13th October 2009 and 9th October 2010. The width of the calving terminus was 990 ±20 metres. Since 1988 the glacier terminus has retreated 511 metres, whilst the glacier area has decreased by approximately 0.53 km^2 (Fig. 5-6).

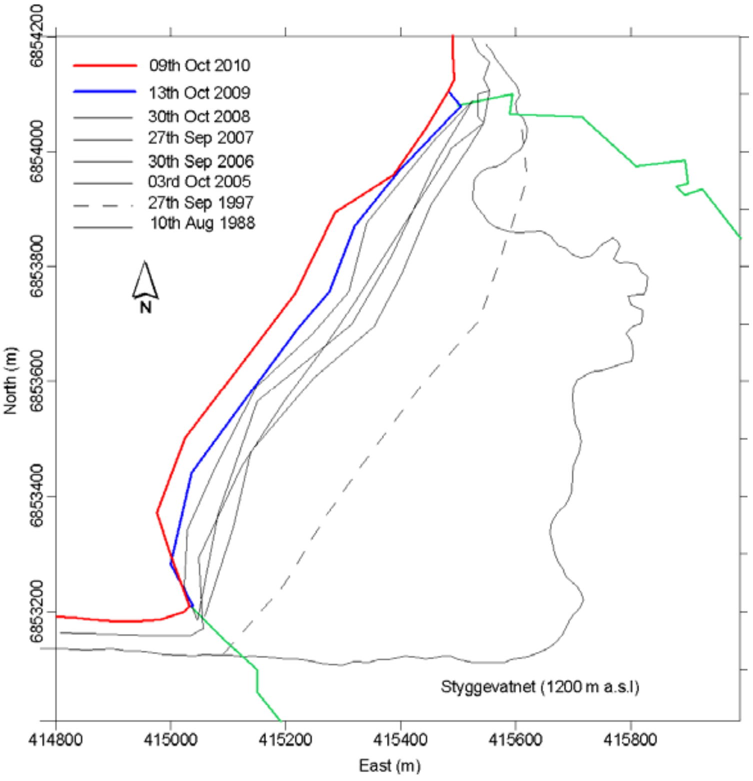


Figure 5-6
Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, in 1997, and in 2005-2010. The mean front position change between 13th October 2009 and 9th October 2010 was −35 metres.

5.3 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 13th October 2009, and 1st June, 18th August and 09th October 2010. Annual velocities were calculated for six stake locations for the period 13th October 2009 – 9th October 2010 (361 days). The annual velocities at stake locations were 36 $m.a^{-1}$ at A6 (80 $m.a^{-1}$ in 2009), 35 $m.a^{-1}$ at A92 (49 $m.a^{-1}$ in 2009), 30 $m.a^{-1}$ at A90 (33 $m.a^{-1}$ in 2009), 24 $m.a^{-1}$ at A24, 20 $m.a^{-1}$ at A6098, and 6 $m.a^{-1}$ at A70. This is considerably less than in previous years at the lower part of the glacier, and is mainly due to the hydro-power reservoir Austdalsbreen calves into having a lower than average lake level in 2010.

The glacier velocity averaged across the front width and thickness must be estimated in order to calculate the calving volume (chap. 5.1). Due to similar calculated velocities at stakes A6 and A92, the expected velocity increase towards the calving front is neglected, and A6 is assumed to be representative for the centre line surface velocity. The glacier velocity averaged over the cross-section is estimated to be 70 % of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed. The resulting glacier velocity averaged across the terminus for 2009/2010 is 25 ±10 $m.a^{-1}$.

6. Hardangerjøkulen (Hallgeir Elvehøy)

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

The Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations at Rembesdalsskåka since 1985. The investigated basin covers the altitudinal range between 1066 and 1854 m a.s.l. At Rembesdalsskåka, glacier length observations were initiated in 1917 by John Bernhard 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
Lower part of Rembesdalsskåka on 2nd September 2010. The glacier terminus has retreated 343 m since 1997 when the most recent glacier advance culminated. Photo: Hallgeir Elvehøy.

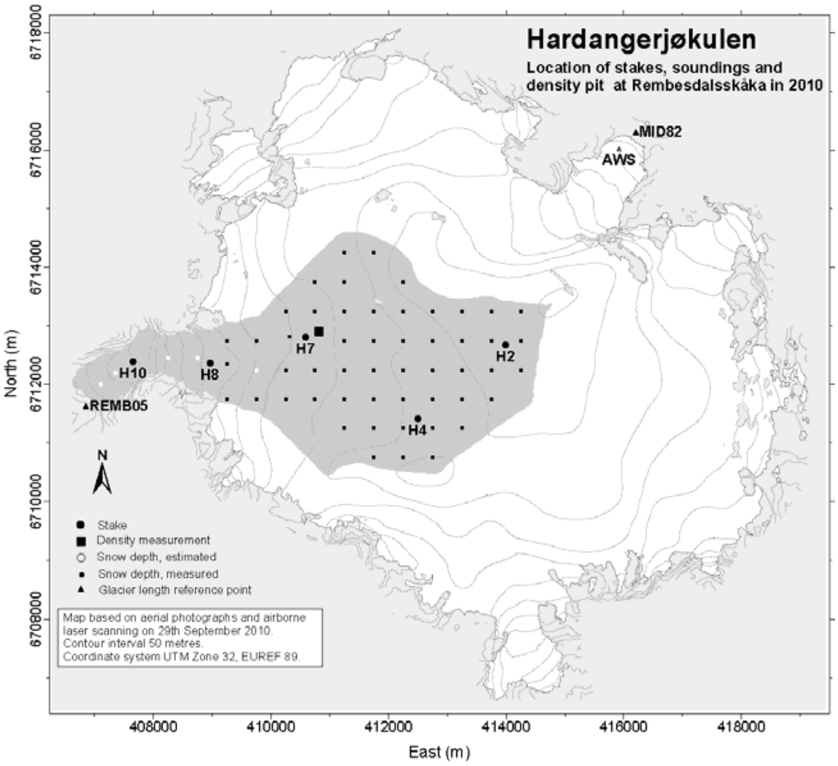


Figure 6-2
Location of stakes at Rembesdalsskåka (shaded), glacier length observations at Rembesdalsskåka and Midtdalsbreen, and an automatic weather station (AWS) at Midtdalsbreen.

6.1 New map over Hardangerjøkulen

Hardangerjøkulen was mapped on 29th September 2010. Aerial photographs were taken and airborne laser scanning was carried out (Terratec AS, contract 10063 Hardangerjøkulen). The mean point density was 0.55 points per m^2 (1.83 m^2 pr. point), and the expected point accuracy was 0.4 metres.

A 10 x 10 m Digital Elevation Model (DEM) was processed based on the laser scanning data. The glacier boundary was determined mainly from the air photos. Drainage divides were determined based on surface flow directions calculated from the DEM.

6.2 Mass balance at Rembesdalsskåka in 2010

Fieldwork

The stake network was checked on 11th December 2009, 12th February and 14th April 2010. Stakes were maintained throughout the winter in all five positions. Snow depth sounding and stake measurements at stake H10 on 1st June 2010 showed there was no melting after the autumn measurements on 14th October 2009.

The winter balance measurements were carried out on 1st June. The calculation of winter balance is based on the following data (see fig. 6-2 for locations):

- Snow depth measurements at stakes H10 (1250 m a.s.l.), H8 (1510 moh.), H7 (1655 m a.s.l.), H4 (1765 m a.s.l.) and H2 (1825 m a.s.l.) showing 0.70, 0.90, 2.15, 2.9 and 3.25 metres, respectively.

- Snow density down to last years summer surface (SS) at 2.14 m depth at location H7 (1655 m a.s.l.). The mean snow density was 530 kg/m^3. The summer surface was firn.
- Snow depth soundings at 51 locations in a regular grid of spacing 500 x 500 metres. In addition, snow depth was sounded at the locations of three buried stakes. The snow depth was 1 to 2 metres between 1500 and 1650 m a.s.l. The snow depth was 2 to 3 metres between 1650 and 1830 m a.s.l.

Stakes H10 and H8 were re-drilled on 2nd September. At that time all the winter snow had melted.

Summer and net balance were measured on 8th October. There was some new snow on the glacier above 1650 m a.s.l. At stakes H4 and H2 the new snow depth was 5 and 20 cm, respectively. At stakes H7, H4 and H2 all the winter snow and 1 to 3 metres of firn had melted. At stakes H8 and H10, 3.65 and 5.15 metres of ice melted during the summer season.

Results

The mass balance is calculated according to a stratigraphic method relating the net balance to the difference between two successive “summer surfaces”, excluding snow accumulation before 8th October 2010. The calculations are based on the new DTM from 2010.

Winter balance

The winter balance was calculated from the snow depth and snow density measurements on 1st June. Snow depth sounding and stake measurements at stake H10 on 1st June 2010 showed there was no melting after the autumn measurements on 14th October 2009.

A snow depth-water equivalent profile was calculated based on snow density measurements at location H7 (1655 m a.s.l.) on 1st June. Calculated snow densities between 1.68 and 2.14 m depth were unrealistically high, and were excluded from the results. Using the calculated profile, the mean density of 3.5 m of snow was 518 kg/m^3. The snow depth measurements were transformed to water equivalent values using this profile. From the calculated water equivalent values, averages for 50 m elevation bands were calculated and plotted against altitude. An altitudinal winter balance curve was drawn from these averages (Fig. 6-3). Below 1500 m a.s.l. the winter balance curve was extrapolated from the measurements at stakes H8 (1510 m a.s.l.) and H10 (1250 m a.s.l.). A mean value for each 50 m elevation was then determined from this curve.

The resulting winter balance was 1.3 ±0.2 m w.e. or 22 ±3 mill. m^3 water. This is 57 % of the 1971-2000 normal of 2.24 m w.e., and 54 % of the 2005-2009 average of 2.35 m w.e. The altitudinal distribution of the winter balance is shown in Figure 6-4 and Table 6-1.

Based on the snow depth measurements the spatial distribution of the winter balance was interpolated using the Inverse distance to power method (IDP). Five points in the icefall and on the glacier tongue were estimated. The distributed winter balance is shown in Figure 6-3, and the mean winter balance was 1.3 m w.e.

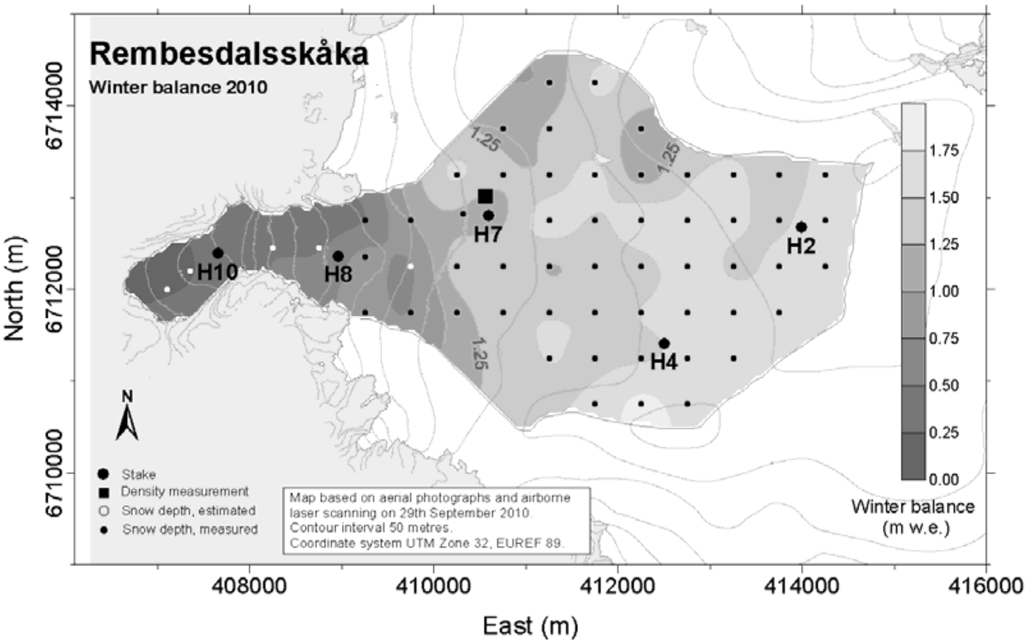


Figure 6-3
Winter balance at Rembesdalsskåka interpolated from 54 measurements (•) of snow depth and five estimated points.

Summer balance

The summer balance was calculated directly at all five locations. The density of the melted firn from 2009 at stake H2 and H4 was set as 700 kg/m³. At H7, the density of firn from 2007 and 2008 was set as 750 kg/m³. The density of ice was set as 900 kg/m³.

The summer balance curve in Figure 6-4 was drawn from five point values. The summer balance was calculated as −2.8 ±0.2 m w.e., corresponding to −48 ±3 mill. m^3 of water. This is 144 % of the 1971-2000 normal average, which is −1.92 m w.e., and 121 % of the 2005-2009 average of −2.30 m w.e.

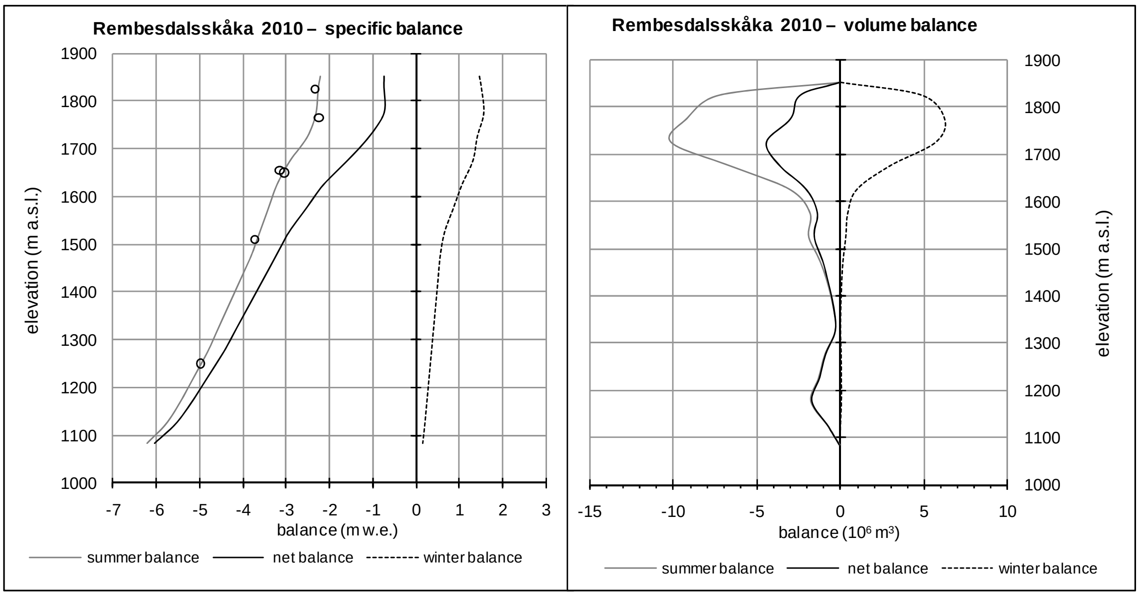


Figure 6-4
Altitudinal distribution of winter, summer and net balance is shown as specific balance (left) and volume balance (right). Specific summer balance at six stakes is shown (○).

Table 6-1
Altitudinal distribution of winter, summer and net balance at Rembesdalsskåka in 2010.

Mass balance Rembesdalsskåka2009/10 – traditional method

		Winter balance Measured 1st Jun 2010		Summer balance Measured 8th Oct 2010		Net balance Summer surface 2009 - 2010	
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 - 1854	0,03	1,45	0,0	-2,20	-0,1	-0,75	0,0
1800 - 1850	3,21	1,50	4,8	-2,25	-7,2	-0,75	-2,4
1750 - 1800	3,99	1,55	6,2	-2,30	-9,2	-0,75	-3,0
1700 - 1750	4,05	1,40	5,7	-2,50	-10,1	-1,10	-4,5
1650 - 1700	2,28	1,30	3,0	-2,90	-6,6	-1,60	-3,7
1600 - 1650	0,96	1,05	1,0	-3,20	-3,1	-2,15	-2,1
1550 - 1600	0,55	0,85	0,5	-3,40	-1,9	-2,55	-1,4
1500 - 1550	0,53	0,65	0,3	-3,60	-1,9	-2,95	-1,6
1450 - 1500	0,34	0,55	0,2	-3,80	-1,3	-3,25	-1,1
1400 - 1450	0,20	0,50	0,1	-4,05	-0,8	-3,55	-0,7
1350 - 1400	0,11	0,45	0,0	-4,30	-0,5	-3,85	-0,4
1300 - 1350	0,07	0,40	0,0	-4,55	-0,3	-4,15	-0,3
1250 - 1300	0,20	0,35	0,1	-4,80	-1,0	-4,45	-0,9
1200 - 1250	0,26	0,30	0,1	-5,10	-1,3	-4,80	-1,3
1150 - 1200	0,33	0,25	0,1	-5,40	-1,8	-5,15	-1,7
1100 - 1150	0,14	0,20	0,0	-5,75	-0,8	-5,55	-0,8
1066 - 1100	0,01	0,15	0,0	-6,20	-0,1	-6,05	-0,1
1066 - 1854	**17,26**	**1,28**	**22,1**	**-2,78**	**-47,9**	**-1,49**	**-25,8**

Net balance

The net balance at Rembesdalsskåka was calculated as −1.5 ±0.3 m w.e. or −26 ±5 mill. m^3 water. The 1971-2000 normal value is +0.32 m w.e., and the 2005-2009 average is +0.06 m w.e. The altitudinal distribution of winter, summer and net balances is shown in Figure 6-4 and Table 6-1.The equilibrium line altitude (ELA) was higher than the top of the glacier (1854 m a.s.l.), and the corresponding accumulation area ratio (AAR) was 0 %. Results from 1963-2010 are shown in Figure 6-5. The cumulative net balance is +61 mill. m^3 w.e. Since 2000 the glacier has had a mass deficit of −69 mill. m^3 w.e.

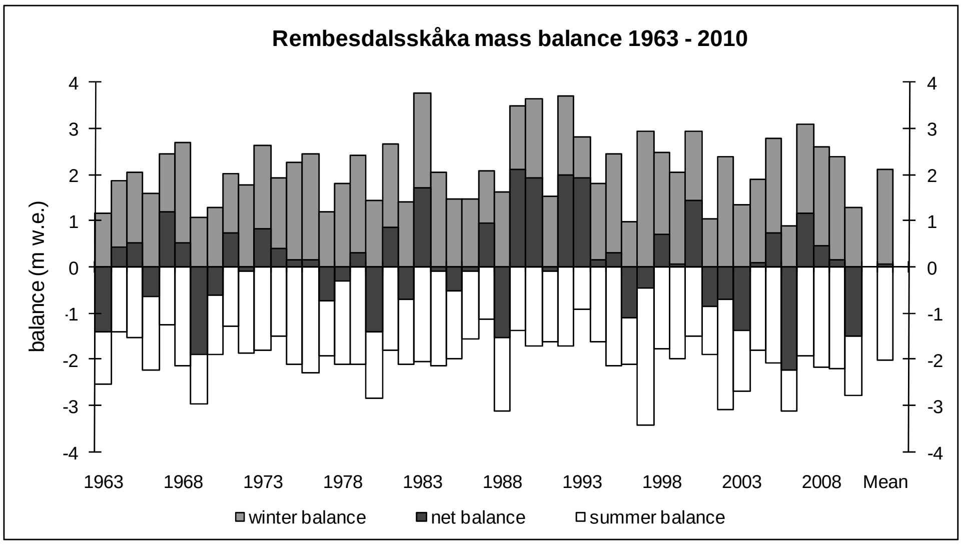


Figure 6-5
Winter, summer and net balances at Rembesdalsskåka during the period 1963-2010. Mean values (1963-2010) are b_w=2.10 m. b_s=−2.03 m and b_n=+0.08 m water equivalent.

6.3 Meteorological measurements on Midtdalsbreen

(Rianne H. Giesen)

An automatic weather station (AWS) has been operating in the ablation area on Midtdalsbreen, a north-easterly outlet glacier of Hardangerjøkulen (Fig. 6-2), since October 2000. The station (Fig. 6-6) is owned and maintained by the Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: J.Oerlemans@uu.nl). The station records incoming and outgoing short wave and long wave radiation, air temperature, relative humidity, wind speed and direction, air pressure and distance to the surface. Sampling is done every few minutes (depending on the sensor) and 30-minute averages are stored. The record from this AWS span almost ten years (1st October 2000 to 24th August 2010) with only two data gaps; data is missing for 39 days in summer 2005 and 55 days in spring 2007.

Figure 6-6
The AWS site on Midtdalsbreen after maintenance on 24th August 2009. Photo: Rianne H. Giesen.

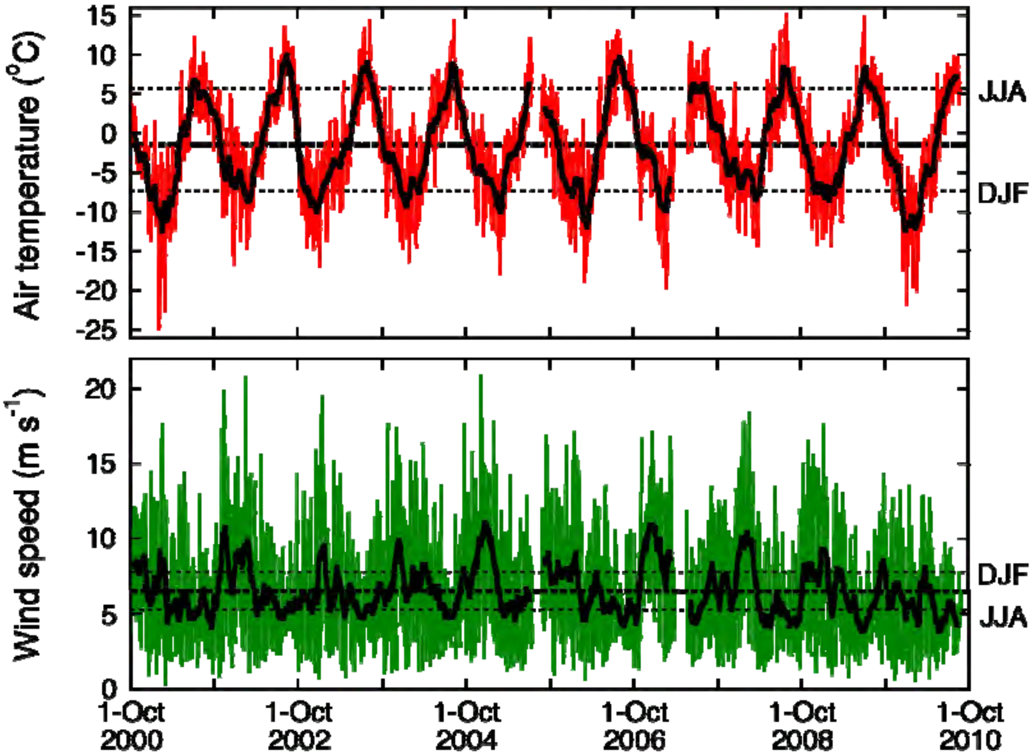


Figure 6-7
Daily mean values of air temperature and wind speed for the ten-year period (coloured lines) and the moving average over 31 days (thick solid lines). In both panels, the thick dashed line is the average of all daily mean values, the upper and lower thin dashed lines indicate the mean winter (December-February) and summer (June-August) values.

Air temperature and wind speed

Figure 6-7 shows daily mean air temperature and wind speed over the ten-year period. The mean air temperature over this period (excluding data gaps) was −1.5 °C, with mean summer and winter temperatures of 5.7 °C and 7.2 °C, respectively. The warmest summers were 2002 and 2006; the highest monthly temperature was 9.2 °C, recorded in August 2002. The mean summer temperature of 2010 (5.6 °C until 24th August) was close to the 10-year average. The winter of 2009/2010 was the coldest in the record, with mean monthly temperatures of −11.7 and −11.8 °C in January and February 2010.

The mean wind speed over the ten-year period was 6.5 m s^{-1}, with much higher variability in winter than in summer. Whilst the average winter wind speed was 7.7 m s^{-1}, the highest December to February average was recorded in 2005 (9.2 m s^{-1}) and the lowest in the winter of 2009/2010 (5.4 m s^{-1}).

Surface height change

For all ten years, the variation in surface height resulting from accumulation and ablation is shown in Figure 6-8. The records from the sonic rangers measuring the distance to the surface have more data gaps than the other records, due to melt out of the tripod or burial of the sensor in the snowpack. The maximum snow height was usually reached in April or May, ranging between less than 2 m of snow in 2002 and 2006 and more than 3 m in 2005. Depending primarily on the maximum winter snow depth, the underlying ice surfaced again between early June (in 2002) and middle July (2005). The melt rate in summer is related to the summer air temperature (Fig. 6-7), with the lowest melt rates in 2001, 2005 and 2007 and the highest in 2002 and 2006. The record from 2010 had many gaps caused by a damaged cable, but estimated maximum snow depth (2.0 m) and net ablation on 24th August (−2.7 m ice) indicate that the year 2009/2010 was an average year within this ten-year period.

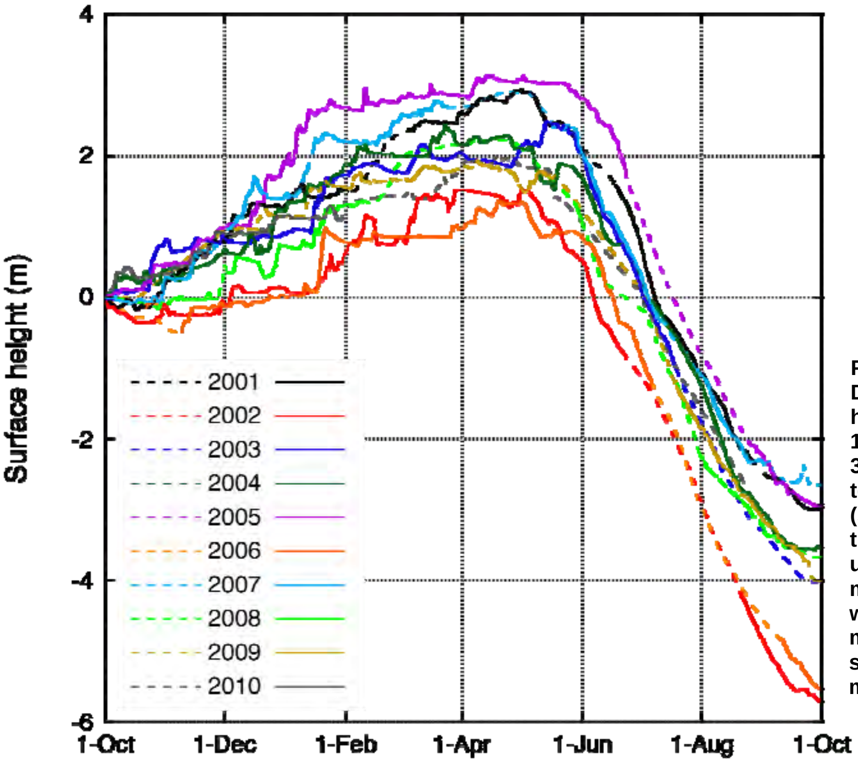


Figure 6-8
Daily mean surface height over the period 1st October to 30th September for the ten years in the record (solid lines). Gaps in the record were filled using precipitation measured at a nearby weather station and melt computed with a surface energy balance model (dashed lines).

7. Storbreen

(Liss M. Andreassen)

Storbreen (61°34' N, 8°8' E) is situated in the Jotunheimen mountain massif in central southern Norway. The glacier has relatively well-defined borders and is surrounded by high peaks (Fig. 7-1). Mass balance has been measured since 1949.

Storbreen has a total area of 5.1 km^2 and ranges in altitude from 1400 to 2102 m a.s.l. (map of 2009, Fig. 7-2).

Figure 7-1
The upper part of Storbreen viewed from the east on 5th May 2010. To the left Sokse (2189 m a.s.l.) and to the right Kniven (2133 m a.s.l.) and part of Store Smørstabbtinden (2208 m a.s.l.).
Photo: Liss M. Andreassen.

7.1 Mass balance 2010

Fieldwork

Accumulation measurements were performed on 5th and 6th May and the calculation of winter balance is based on:

- Measurements of stakes in 7 different positions. The stake readings showed 12-26 cm of additional surface melting below 1800 m a.s.l. after the ablation measurements in the previous mass balance year (17th September 2009).
- Soundings of snow depth in 322 points between 1435 and 2004 m a.s.l., covering most of the altitudinal range of the glacier. The summer surface was relatively easy to identify over the whole glacier, except for a small area in the uppermost part of the glacier. The snow depth varied between 1.00 and 4.10 m, the mean being 2.39 m.
- Snow density was measured at stake 4 at 1715 m a.s.l. and at the AWS at 1563 m a.s.l. The snow depth was 2.0 m at both sites.

Ablation measurements were performed on 28th September on stakes in all positions. A layer of fresh snow covered most of the glacier and the snow depth varied between 2 and 33 cm at the stakes.

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

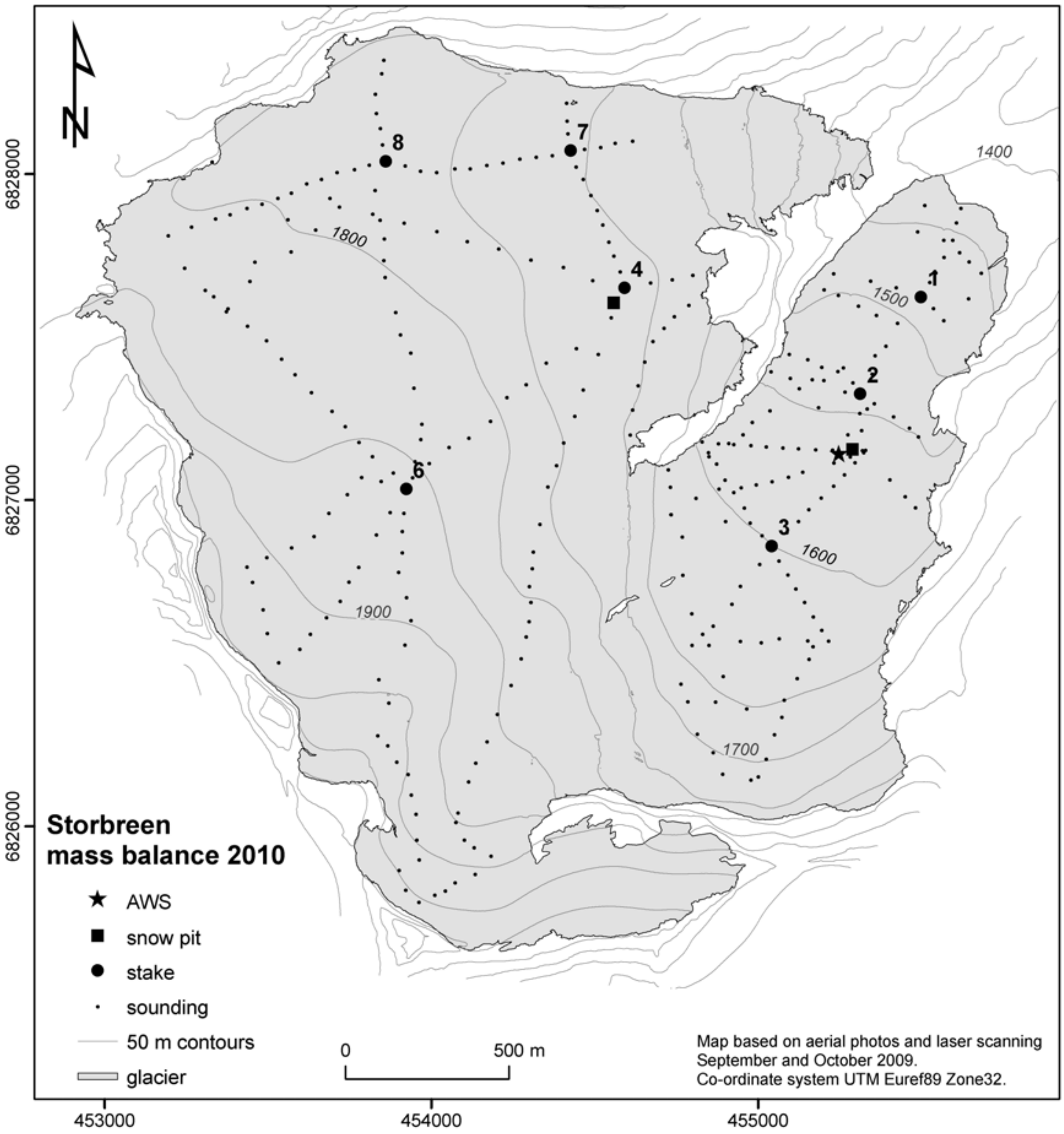


Figure 7-2
Location of stakes, density pits and the automatic weather station (AWS) at Storbreen in 2010.

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 381 kg/m^3 at the AWS and 344 kg/m^3 at stake 4. A polynomial density function was fitted to each density measurement, and the function fitted for the AWS pit was used for soundings below 1650 m a.s.l. and the function from stake 4 pit was used for soundings above 1650 m a.s.l. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The specific winter accumulation was calculated to be 0.9 ± 0.2 m w.e.

To account for the additional summer melt after the ablation measurements in the previous year, the winter balance was calculated as winter accumulation subtracted by additional melt for altitude intervals below 1850 m a.s.l. This gave a winter balance of 0.8 ±0.2 m w.e. This is 52 % of the mean for 1971-2000, and the lowest winter balance value measured for Storbreen.

Summer balance

Summer balance was calculated directly from stakes at seven locations (1, 2, 3, 4, 6, 7 and 8). The density of the melted ice was assumed to be 900 kg/m^3. The density of melted firn was assumed to be 700-800 kg/m^3. The summer balance was calculated to be −2.6 ±0.3 m w.e., which is 157 % of the mean for 1971-2000.

Net balance

The net balance of Storbreen was negative in 2010, −1.8 ±0.3 m w.e., which is equivalent to a volume of −9.1 ±1.5 mill. m^3 of water. The ELA calculated from the net balance diagram (Fig. 7-3) was calculated to be ~1990 m a.s.l. resulting in an accumulation area ratio (AAR) of 4 %. The cumulative balance over 1949-2010 is −19.2 m w.e.; the mean annual net balance over the 62 years of measurements is thus −0.29 m w.e. (Fig. 7-4).

Table 7-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Storbreen in 2010.

Mass balance Storbreen 2009/10 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 5th May 2010		Measured 28th Sep 2010		Summer surfaces 2009 - 2010	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
2050 - 2102	0.00	1.70	0.01	-1.10	0.00	0.60	0.00
2000 - 2050	0.09	1.46	0.14	-1.20	-0.11	0.26	0.02
1950 - 2000	0.18	1.22	0.22	-1.35	-0.24	-0.13	-0.02
1900 - 1950	0.29	1.31	0.38	-1.50	-0.44	-0.19	-0.05
1850 - 1900	0.34	1.09	0.37	-1.70	-0.59	-0.61	-0.21
1800 - 1850	0.75	0.81	0.61	-2.05	-1.54	-1.24	-0.93
1750 - 1800	0.87	0.75	0.65	-2.42	-2.09	-1.67	-1.44
1700 - 1750	0.68	0.68	0.47	-2.60	-1.77	-1.92	-1.30
1650 - 1700	0.55	0.72	0.40	-2.80	-1.53	-2.08	-1.14
1600 - 1650	0.31	0.76	0.24	-3.10	-0.97	-2.34	-0.73
1550 - 1600	0.49	0.64	0.32	-3.35	-1.66	-2.71	-1.34
1500 - 1550	0.26	0.54	0.14	-3.55	-0.93	-3.01	-0.79
1450 - 1500	0.18	0.39	0.07	-3.85	-0.68	-3.46	-0.61
1400 - 1450	0.13	0.37	0.05	-4.20	-0.57	-3.83	-0.52
1400 - 2102	**5.14**	**0.79**	**4.05**	**-2.55**	**-13.13**	**-1.76**	**-9.07**

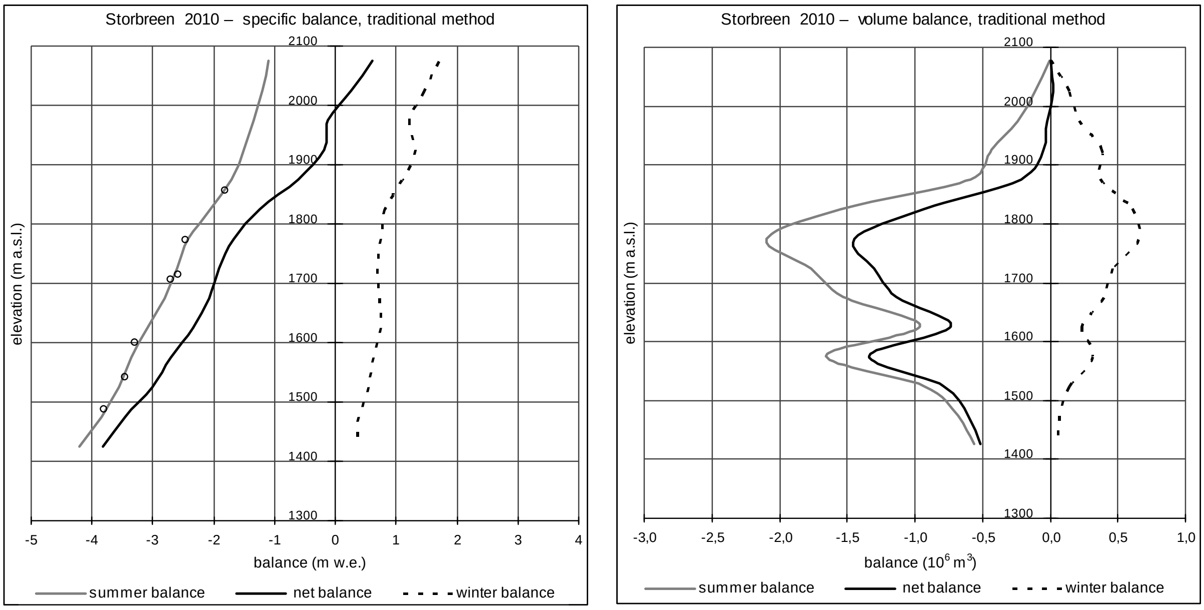


Figure 7-3
Mass balance diagram for Storbreen 2010, showing specific balance on the left and volume balance on the right. Summer balance at seven stakes is shown (○).

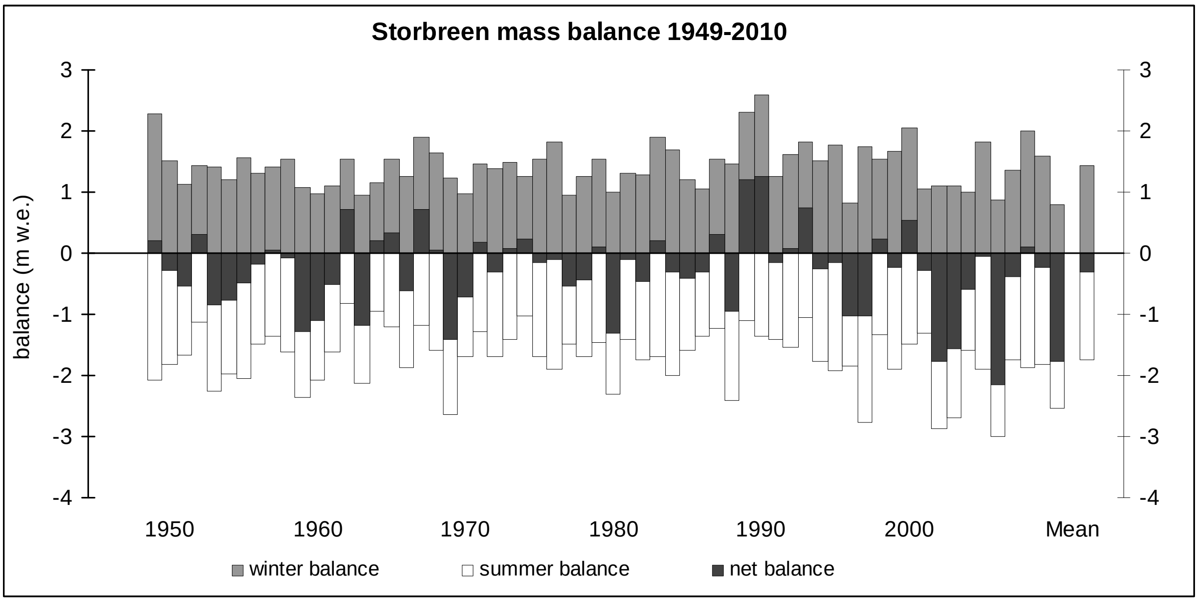


Figure 7-4
Winter, summer and net balance at Storbreen for the period 1949-2010.

7.2 Meteorological measurements

(Liss M. Andreassen and Rianne H. Giesen)

An automatic weather station (AWS) has been operating in the ablation zone of Storbreen, at about 1570 m a.s.l. (Figs. 7-2 and 7-5), since September 2001. The station is part of the Institute of Marine and Atmospheric Research (IMAU) network of AWS on glaciers (contact: J.Oerlemans@uu.nl). The AWS stands freely on the ice and sinks with the melting surface. The station records air temperature, wind speed, wind direction, shortwave and longwave radiation, humidity, pressure and height above to the surface.

The data have been used to study the local microclimate (Andreassen et al., 2008; Giesen et al., 2009) and to calibrate a mass balance model for Storbreen (Andreassen and Oerlemans, 2009). The data from the station are downloaded once a year at the maintenance visit. Due to a memory card error data from the 2009/2010 season were lost for the period 21th August 2009 to 14th July 2010. Here we show a few results from the available data for the summer of 2010.

Figure 7-5
The AWS at Storbreen on 5th May 2010. The snow depth was 2.0 m. Photo: Liss M. Andreassen.

Albedo

Daily surface albedo is calculated as the ratio between the outgoing and incoming shortwave radiation. The daily albedo values of Storbreen were close to 0.30 from 15th July 2010 revealing that the surface at the AWS was already snow free (Fig. 7-6). Albedo shows a peak on 28-29th of August due to a late summer snow fall. Albedo drops as the snow melts away, but a new snow fall covers the surface from 14th September.

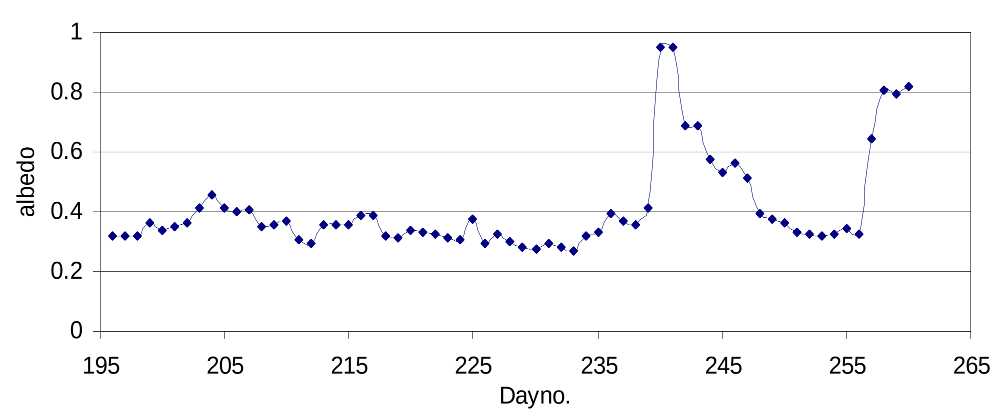


Figure 7-6
Daily surface albedo from 15th July (Day no. 195) to 17th September 2010 (Day no. 260).

Daily cycles

Daily cycles of selected variables from 20th to 23rd July 2010 (days 202-205) are shown in Figure 7-7. On the first day (202) relative humidity was close to 100 %, incoming (SWin) and outgoing (SWout) shortwave radiation were small compared with the top of atmosphere radiation (TOA) and air temperature had a weak daily signal, indicating cloudy conditions. Over the next few days relative humidity decreased, while air pressure, SWin and SWout increased. On day 204 a clear daily cycle in air temperature and high SWin and SWout values reveal clear-sky conditions. The day of 204 is not typical for Storbreen in summer; values recorded in 2010 show that only ~1in 10 days had similar clear-sky conditions.

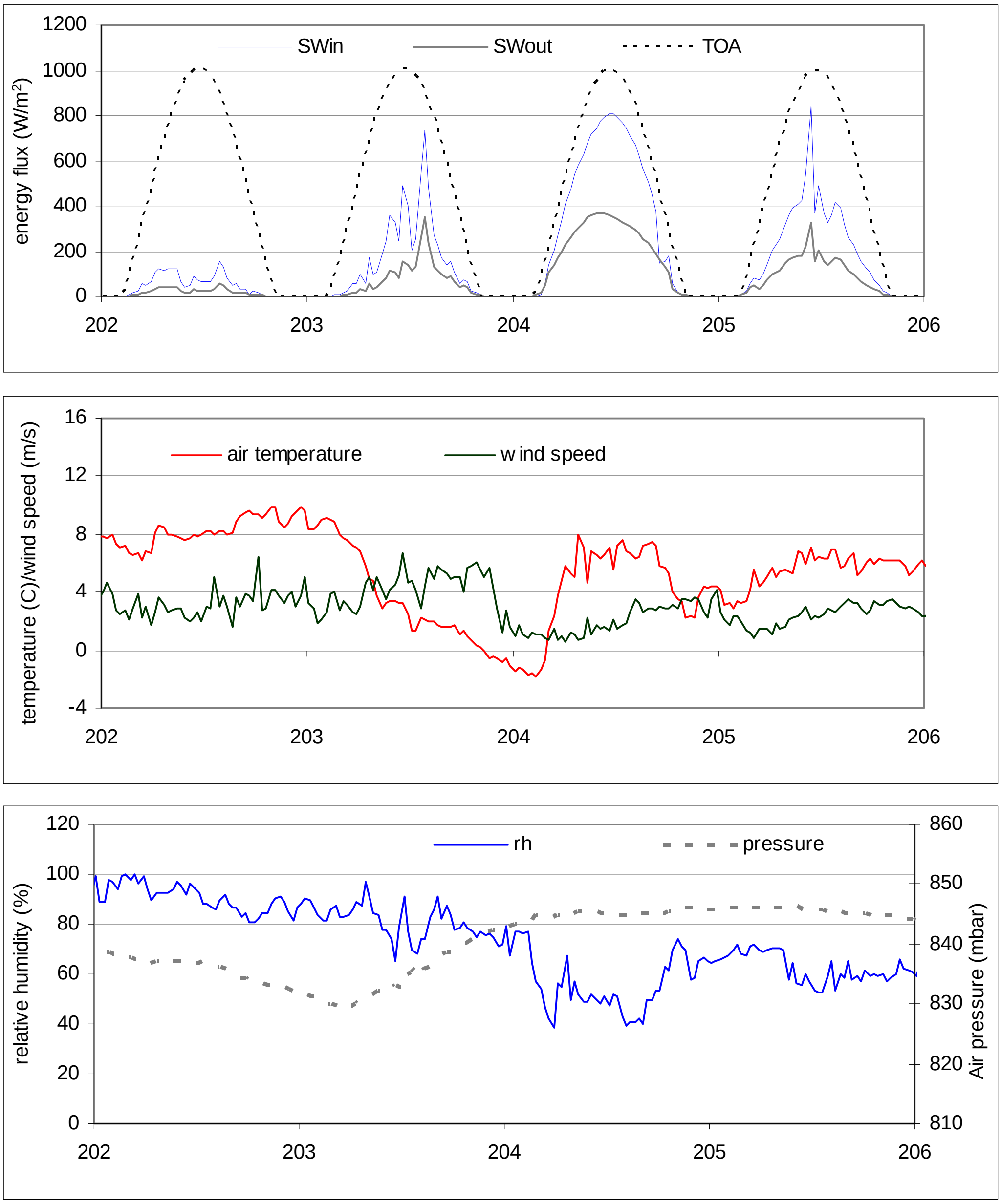


Figure 7-7
Daily cycles of relative humidity (rh), air pressure, air temperature, wind speed, and shortwave incoming (SWin), outgoing (SWout) and top of atmosphere (TOA) radiation from 20th to 23rd July 2010 (days 202-205).

8. Juvfonne (Liss M. Andreassen)

Juvfonne (61°40' N, 8°21' E) is a small ice patch situated in the Jotunheimen mountain massif in central southern Norway (Fig. 8-1). Mass balance measurements began in May 2010, thus 2009/10 is the first year of measurements. The extent of Juvfonne and positions of stakes were measured by differential Global Navigation Satellite System (GNSS) measurements on 25th August 2010. The measurements on Juvfonne were started as a contribution to 'Klimapark 2469' – a forum for research and dissemination activities in the alpine region around Galdhøpiggen, the highest mountain peak in Norway (2469 m a.s.l.).

No detailed glacier map of Juvfonne exists. Therefore, the 1:50 000 map with 20 m contours from the Norwegian mapping authorities, constructed from air photos from 2004, was used for calculating the area-altitudinal distribution. According to this map Juvfonne has an area of 0.17 km^2 and ranges in altitude from 1840 to 1998 m a.s.l. The extent was also mapped from point measurements of GNSS on the ice patch on 25th August 2010 (Fig. 8-2). According to the GNSS measurements, Juvfonne has a total area of 0.15 km^2 and ranges in altitude from 1839 to 1993 m a.s.l. Front measurements at one location revealed that the glacier terminus retreated 18 m from 13th August 2009 to 13th August 2010 (Atle Nesje, pers. comm.).

Figure 8-1
Juvfonne on 5th August 2010. Photo: Liss M. Andreassen.

8.1 Mass balance 2010

Fieldwork

Accumulation measurements were performed on 19th May and the calculation of winter balance is based on:

- Soundings of snow depth in 37 positions between 1842 and 1998 m a.s.l., covering the whole altitudinal range of Juvfonne. The summer surface was relatively easy to identify over the whole ice patch. The snow depth varied between 0.95 and 2.05 m, the mean being 1.5 m.
- Snow density measured at stake J2 at 1887 m a.s.l. to the previous summer surface, total snow depth was 1.5 m.
- Measurements at three stakes, J1-J3 (Fig. 8-2).

Ablation measurements were performed on 9th October at all stakes. The surface of Juvfonne was then ice with no remaining snow from the previous winter. A late summer snow fall observed at the end of August had melted away by the time of the ablation measurements.

The location of stakes, soundings and density pit are shown in Figure 8-2.

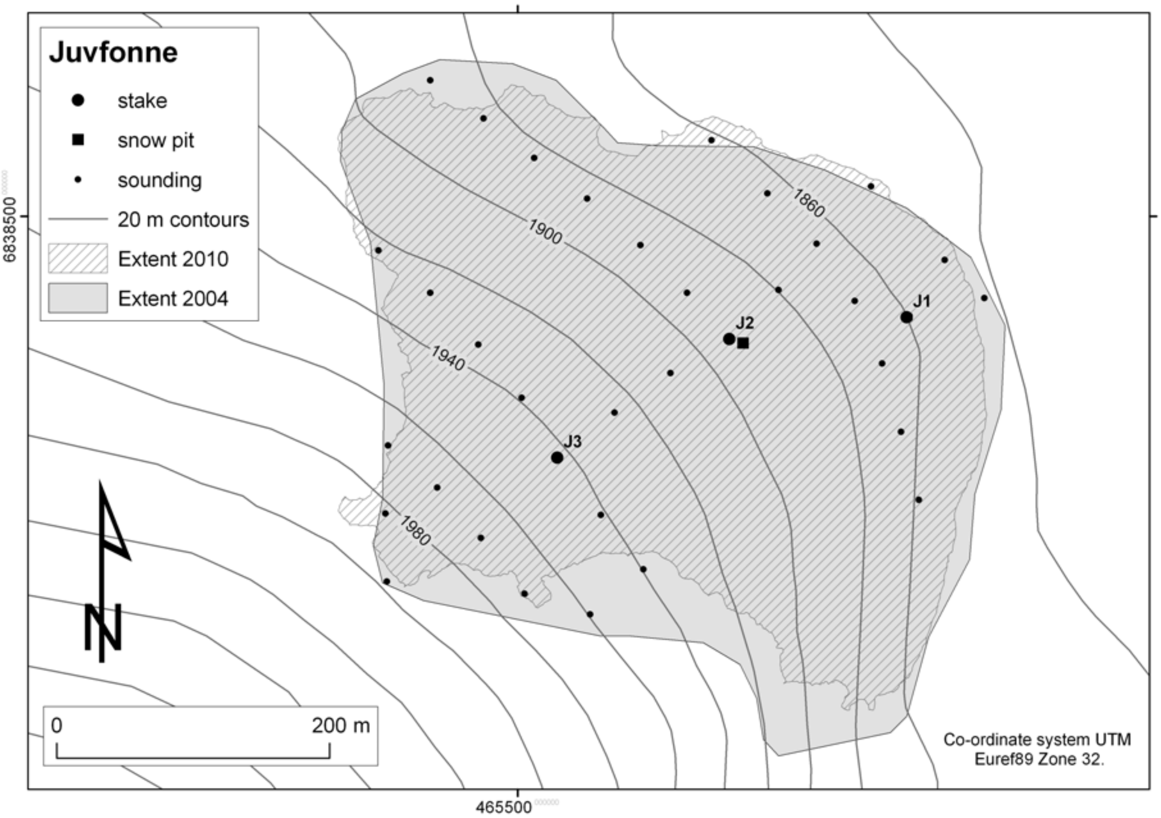


Figure 8-2
Location of stakes, soundings and density pit at Juvfonne in 2010. The extent from 2004 is from the Norwegian mapping authorities 1:50 000 map series. The extent from 2010 is based on GNSS measurements on the ice patch.

Figure 8-3
Field work: density pit at Juvfonne on 19th May 2010 (left) and mapping the extent using GNSS measurements on the ice patch on 25th August 2010 (right). Photos: Atle Nesje and Trine Fjeldstad.

Results

The mass balance results are shown in Table 8-1 and Figure 8-4.

Winter balance

Winter accumulation was calculated from soundings and snow density measurements. The mean measured snow density was 456 kg/m^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The specific winter balance was calculated to be 0.7 ±0.2 m w.e. Measurements revealed that Juvfonne has an atypical snow distribution, with decreasing snow depths with elevation, probably an effect of wind drift and leeward deposition.

Summer balance

Summer balance was calculated directly from stakes J1-J3. The density of the melted ice was assumed to be 900 kg/m^3. The summer balance was calculated to be −3.9 ±0.3 m w.e.

Net balance

The net balance of Juvfonne was negative in 2010, −3.2 ±0.3 m w.e., which is equivalent to a volume of −0.55 ± 0.05 mill. m^3 of water. The observed ELA, as well as the ELA calculated from the net balance diagram (Fig. 8-4), was above the highest point of the Juvfonne (>1998 m a.s.l.) and the accumulation area ratio (AAR) was therefore 0 %.

Table 8-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Juvfonne in 2010.

Mass balance Juvfonne 2009/10 – traditional method

		Winter balance		Summer balance		Net balance	
		Measured 19 May 2010		Measured 9 Oct 2010		Summer surfaces 2009 - 2010	
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)
1950 - 1998	0,020	0,57	0,01	-3,20	-0,07	-2,63	-0,05
1900 - 1950	0,063	0,60	0,04	-3,80	-0,24	-3,20	-0,20
1850 - 1900	0,082	0,73	0,06	-4,16	-0,34	-3,43	-0,28
1840 - 1850	0,006	0,84	0,00	-4,17	-0,02	-3,33	-0,02
1840 - 1998	**0,171**	**0,67**	**0,11**	**-3,91**	**-0,67**	**-3,24**	**-0,55**

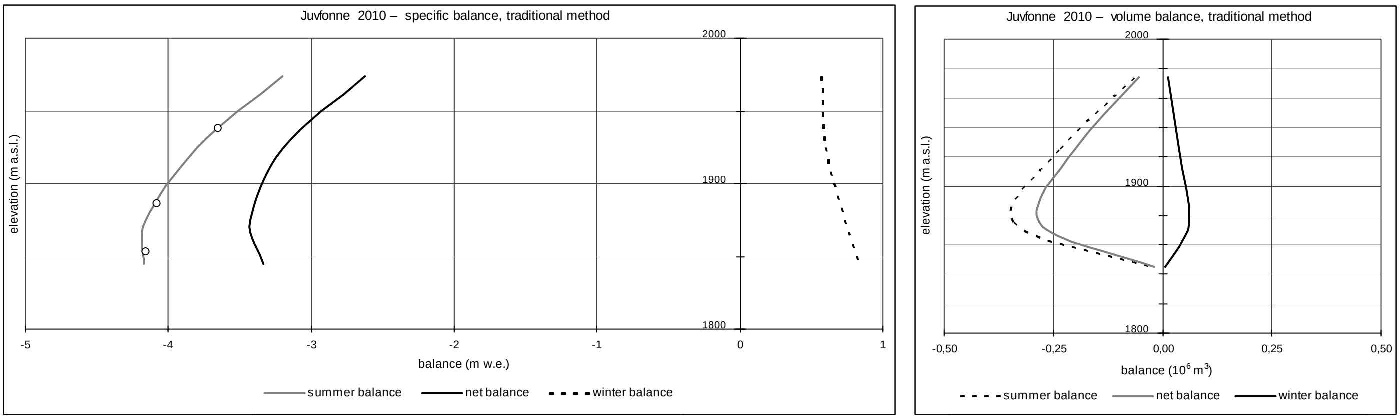
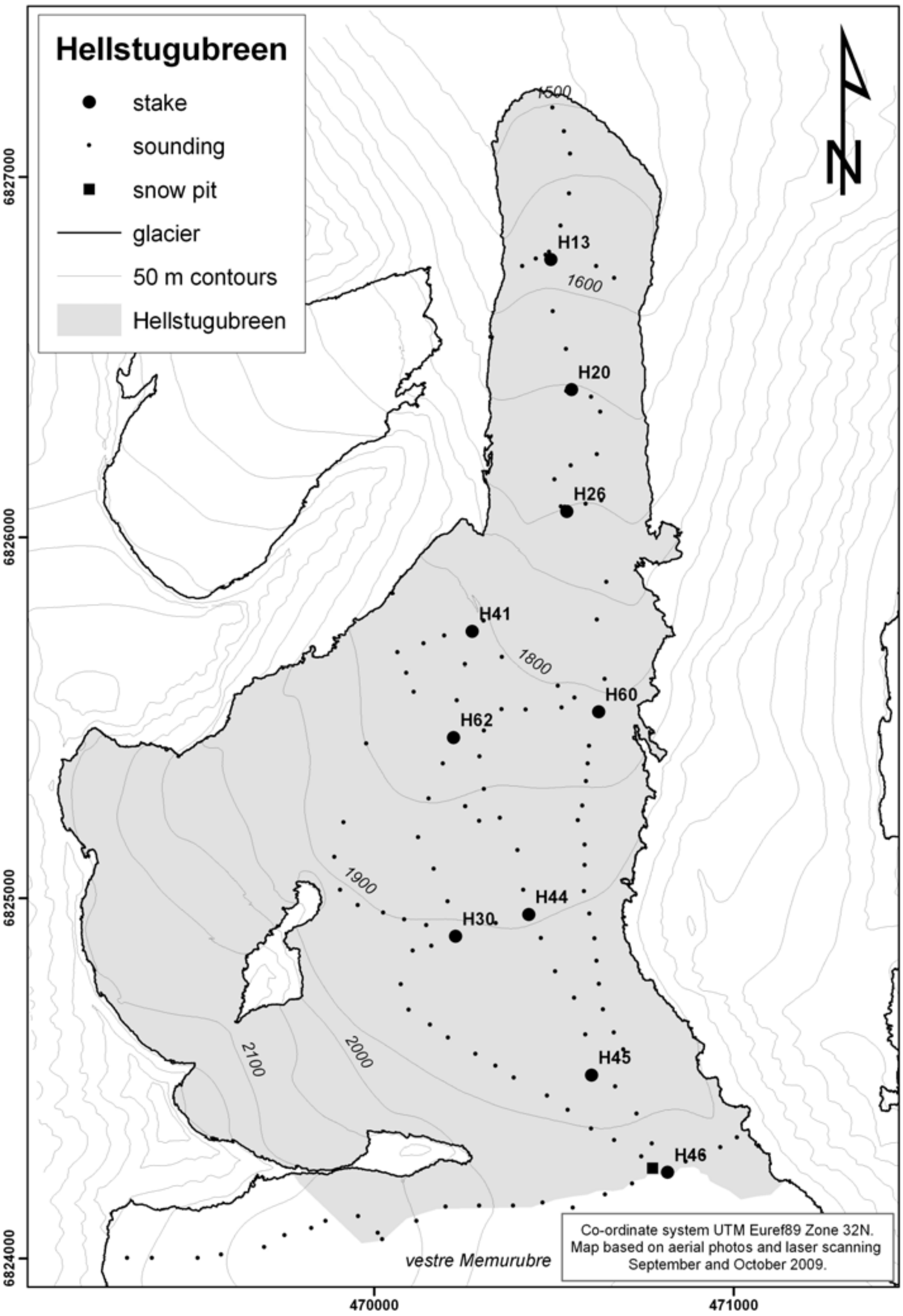


Figure 8-4
Mass balance diagram for Juvfonne 2010, showing specific balance, summer balance at stakes and winter balance from soundings to the left and volume balance to the right.

9. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61º34`N, 8º 26`E) is a north-facing valley glacier situated in central Jotunheimen (Fig. 9-1). The glacier a shares border with vestre Memurubre glacier. Hellstugubreen ranges in elevation from 1482 to 2229 m a.s.l. and has an area of 2.9 km^2. Annual mass balance measurements began in 1962 and 2010 was the 49th year of continuous measurements at Hellstugubreen.



Co-ordinate system UTM Euref89 Zone 32N.
Map based on aerial photos and laser scanning September and October 2009.

Figure 9-1
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pit in 2010. The glacier outline is derived from aerial photography taken on 14th September 2009 and the glacier surface map is derived from laser scanning carried out on 17th October 2009.

9.1 Mass balance 2010

Fieldwork

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

- Stake measurements in 10 different positions. Stake readings indicated that at stakes below 1900 m a.s.l. there had been 10-20 cm of additional melting after the ablation measurements on 16th September 2009.
- Snow depth soundings in 138 positions between 1503 and 2258 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 1.04 and 4.02 m, with a mean of 2.06 m.
- Snow density measured by sampling in a pit at 1954 m a.s.l. The total snow depth was 2.3 m (Fig. 9-2).

Ablation measurements were carried out on 28th September at all visible stakes (Fig. 9-2). The location of stakes, density pit and sounding profiles are shown in Figure 9-1.

Figure 9-2
Field work 2010. Left: density measurement in a snow pit on 7th May. Right: Ablation and position measurement on 28th September. Photos: Liss M. Andreassen and Solveig H. Winsvold.

Results

The mass balance results of 2010 are presented in Table 9-1 and Figure 9-3.

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 374 kg/m^3. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 0.78 ±0.2 m w.e. To account for the additional summer melt after the previous year's ablation measurement in the cumulative balance, the winter balance was calculated as winter accumulation subtracted by additional melt for altitude intervals below 1900 m a.s.l. This gave a winter balance of 0.7 ±0.2 m w.e. This is 65 % of the mean for the reference period 1971-2000.

Summer balance

Direct summer balance was calculated from stakes in 6 locations. The density of the melted ice was assumed to be 900 kg/m^3 and the density of firn to be 830 kg/m^3. The summer balance was calculated to be −2.1 ±0.3 m w.e., which is 147 % of the mean value for the period 1971-2000.

Net balance

The net balance of Hellstugubreen in 2010 was negative, −1.3 ±0.3 m w.e., which amounts to a volume loss of −4 ±1 mill. m^3 water. The equilibrium line altitude (ELA) was calculated to be at about the highest point of the glacier, ~2230 m a.s.l., resulting in an accumulation area ratio (AAR) of 0 %. The cumulative net balance since 1962 amounts to −19 m w.e., giving a mean annual deficit of 0.37 m w.e. per year (Fig. 9-4).

Table 9-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Hellstugubreen in 2010.

Mass balance Hellstugubreen 2009/10 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 7th May 2010		Summer balance Measured 28th Sep 2010		Net balance Summer surfaces 2009 - 2010	
		Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
2150 - 2229	0,02	0,92	0,02	-0,95	-0,02	-0,03	0,00
2100 - 2150	0,08	0,85	0,07	-1,15	-0,09	-0,30	-0,02
2050 - 2100	0,29	1,09	0,32	-1,25	-0,36	-0,16	-0,05
2000 - 2050	0,18	1,10	0,20	-1,55	-0,28	-0,45	-0,08
1950 - 2000	0,31	0,84	0,26	-1,75	-0,54	-0,91	-0,28
1900 - 1950	0,60	0,81	0,49	-1,90	-1,15	-1,09	-0,66
1850 - 1900	0,37	0,74	0,28	-2,10	-0,78	-1,36	-0,51
1800 - 1850	0,33	0,69	0,23	-2,25	-0,75	-1,56	-0,52
1750 - 1800	0,16	0,39	0,06	-2,40	-0,38	-2,01	-0,32
1700 - 1750	0,09	0,43	0,04	-2,55	-0,22	-2,12	-0,19
1650 - 1700	0,14	0,58	0,08	-2,80	-0,39	-2,22	-0,31
1600 - 1650	0,11	0,39	0,04	-3,06	-0,35	-2,67	-0,30
1550 - 1600	0,12	0,33	0,04	-3,30	-0,41	-2,97	-0,37
1500 - 1550	0,08	0,52	0,04	-3,55	-0,30	-3,03	-0,25
1482 - 1500	0,01	0,30	0,00	-3,80	-0,04	-3,50	-0,04
1482 - 2229	**2,90**	**0,75**	**2,17**	**-2,09**	**-6,05**	**-1,34**	**-3,89**

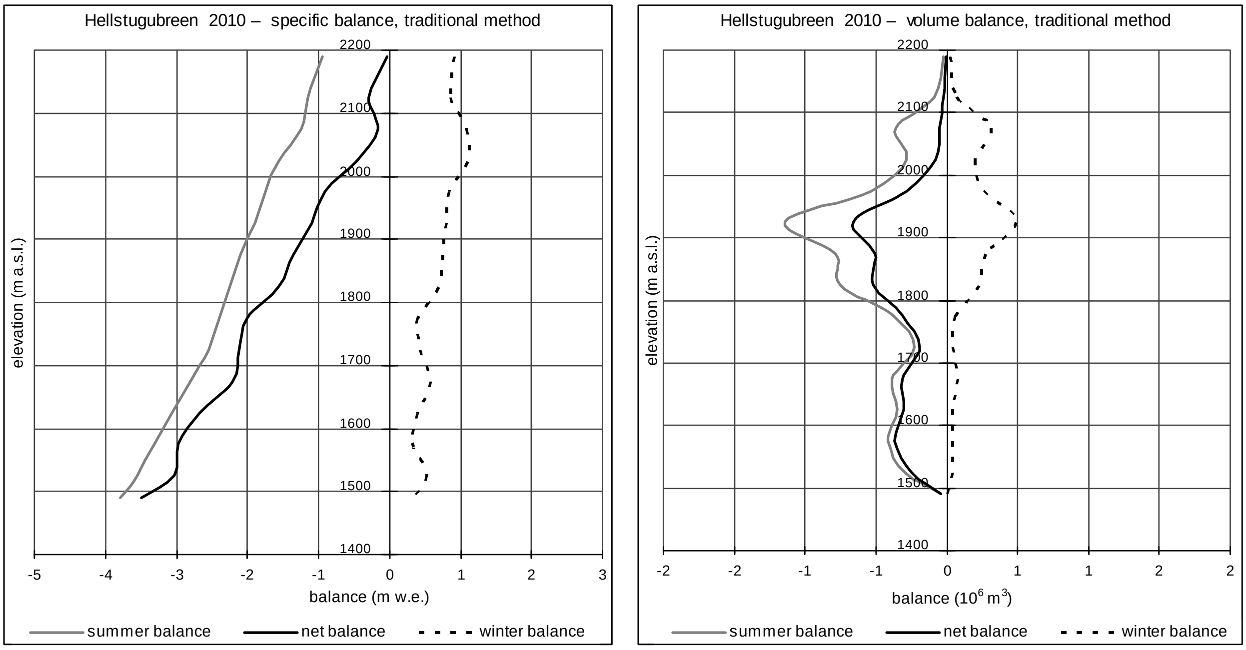


Figure 9-3
Mass balance diagram for Hellstugubreen in 2010, showing specific balance on the left and volume balance on the right.

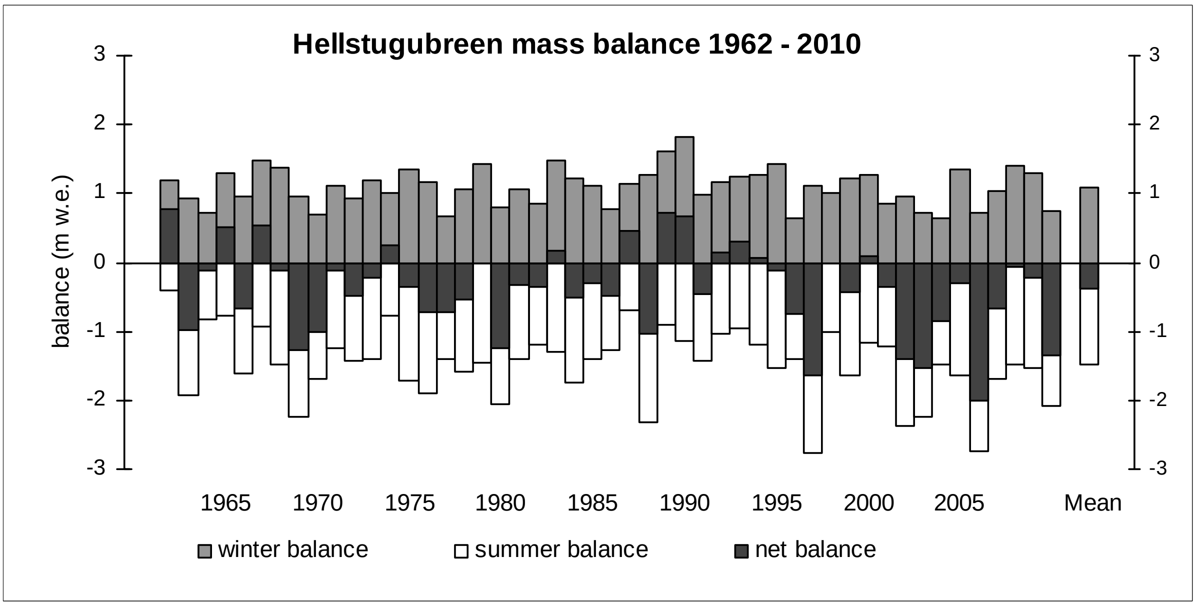


Figure 9-4
Winter, summer and net balance at Hellstugubreen for the period 1962-2010.

10. Gråsubreen

(Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is a small, polythermal glacier located in the eastern part of the Jotunheimen mountain area in southern Norway. Superimposed ice occurs in the central parts of the glacier where snowdrift causes a relatively thin snow pack. Gråsubreen covers an area of 2.12 km^2 and ranges in elevation from 1833 to 2283 m a.s.l. (map from 2009, Fig. 10-1). Mass balance investigations have been carried out annually since 1962, and 2010 was the 49th year of continuous measurements.

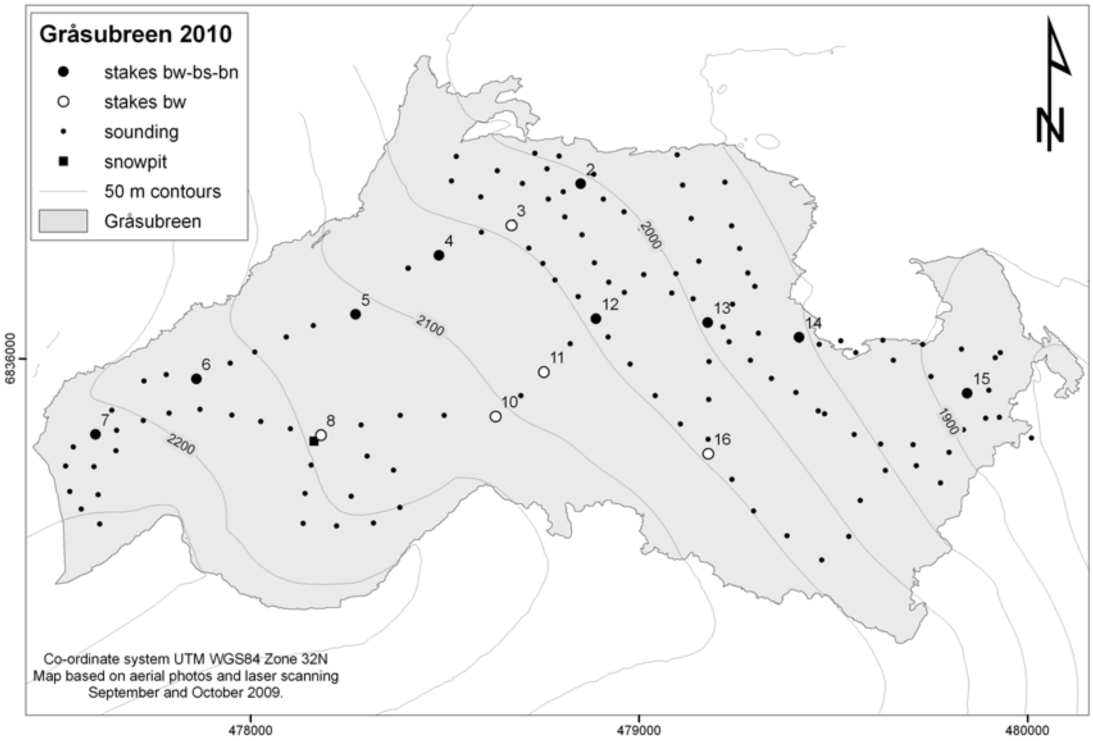


Figure 10-1
Map of Gråsubreen showing the location of stakes, snowpit and soundings in 2010.

10.1 Mass balance 2010

Fieldwork

Accumulation measurements were performed on 4th May 2010. The calculation of winter balance is based on:

- Stake measurements in 14 different positions.
- Snow depth soundings in 153 positions between 1854 and 2256 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 0.80 and 2.75 m, with a mean snow depth of 1.57 m.
- The snow density was measured by sampling in a pit near stake 8 (elevation 2156 m a.s.l.) where the total snow depth was 1.3 m.

Ablation measurements were carried out on 27th and 28th September, when all visible stakes were measured. The calculation of summer balance was based on stakes in nine different positions. An unusually thick layer of 30-80 cm of fresh snow covered the glacier. The location of stakes, snow pit and soundings are shown in Figure 10-1.

Figure 10-2
Left: Density measurement in snowpit on 4th May 2010. The snow depth was 1.3 m. Right: Stake 2 at Gråsubreen on 27th September 2010. Nearly 50 cm of fresh snow covered the surface.
Photos: Liss M. Andreassen.

Results

The mass balance results are presented in Table 10-1 and Figure 10-3.

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 410 kg/m^3. The stake recordings showed a small amount (up to 11 cm) of additional melting after the previous year's ablation measurements (on 15th September 2009), but no notable formation of superimposed ice.

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter accumulation of 0.60 ±0.2 m w.e., which is 76 % of the mean winter balance for the period 1971-2000. To account for the additional summer melt in the cumulative balance, the winter balance was calculated as winter accumulation subtracted by additional melt for altitudinal intervals below 2150 m a.s.l. This gave a winter balance of 0.5 ±0.2 m w.e. This is 69 % of the mean for the reference 1971-2000.

Summer balance

Summer balance was calculated from direct measurements of stakes in nine locations. There was no remaining snow at any of the stakes when ablation was measured in 2010. The density of melted ice was estimated to be 900 kg/m^3. The resulting summer balance was −1.6 ±0.3 m w.e. The specific summer balance was 150 % of the mean for the period 1971-2000.

Net balance

The net balance of Gråsubreen was negative in 2010, −1.1 ±0.3 m w.e. The equilibrium line altitude (ELA) was estimated to be 2250 m a.s.l. and the resulting accumulation area ratio (AAR) was 4 %.

The cumulative mass balance of Gråsubreen amounts to −17.7 m w.e. since measurements began in 1962. The average annual balance is thus −0.36 m w.e. per year. Except for a small surplus in 2001 and 2008, the glacier has had a negative mass balance every year since 1999. The total deficit for 1999-2010 is −8.25 m w.e. or −0.69 m w.e. per year.

Table 10-1
The distribution of winter, summer and net balance in 50 m altitudinal intervals for Gråsubreen in 2010.

Mass balance Gråsubreen 2009/10 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance		Summer balance		Net balance	
		Measured 4 May 2010		Measured 27 Sep 2010		Summer surfaces 2009 - 2010	
		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 - 2283	0.03	1.19	0.04	-0.90	-0.03	0.29	0.01
2200 - 2250	0.15	0.68	0.10	-1.00	-0.15	-0.32	-0.05
2150 - 2200	0.26	0.57	0.15	-1.15	-0.29	-0.58	-0.15
2100 - 2150	0.35	0.48	0.17	-1.30	-0.46	-0.82	-0.29
2050 - 2100	0.36	0.41	0.15	-1.50	-0.54	-1.09	-0.39
2000 - 2050	0.41	0.50	0.20	-1.75	-0.71	-1.25	-0.51
1950 - 2000	0.32	0.59	0.19	-2.00	-0.64	-1.41	-0.45
1900 - 1950	0.13	0.60	0.08	-2.25	-0.29	-1.65	-0.21
1833 - 1900	0.11	0.65	0.07	-2.50	-0.28	-1.85	-0.21
1833 - 2283	**2.12**	**0.54**	**1.15**	**-1.60**	**-3.39**	**-1.06**	**-2.24**

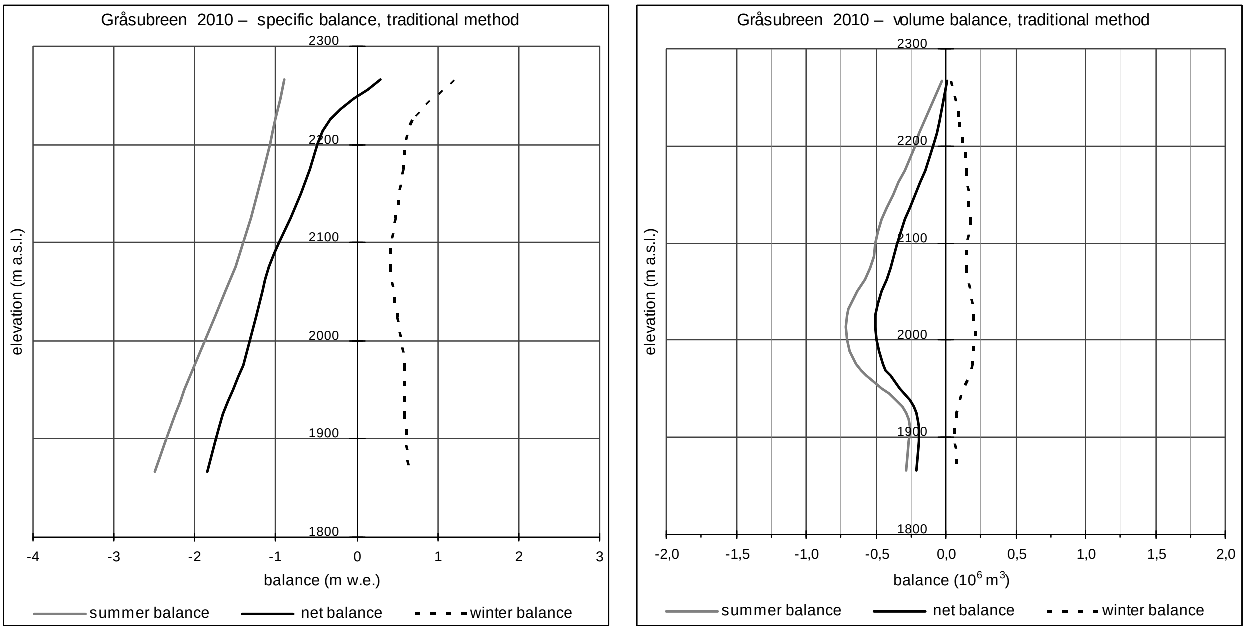


Figure 10-3
Mass balance diagram for Gråsubreen in 2010, showing specific balance on the left and volume balance on the right.

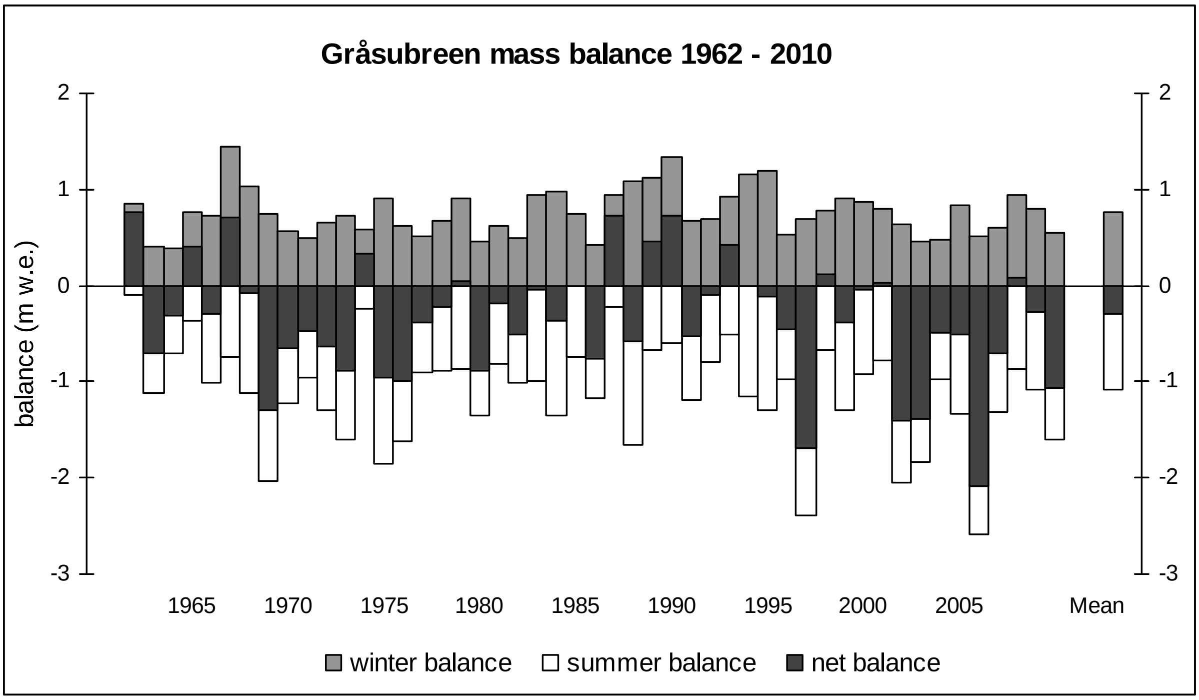


Figure 10-4
Winter, summer and net balance at Gråsubreen for the period 1962-2010.

11. 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 1574 m a.s.l. (at Snøtind) down to 89 m a.s.l. (at Engabrevatnet), as shown in Figure 11-1. Mass balance measurements have been performed annually since 1970, and length change observations started in 1903 (chap. 13-1). A meteorological station has been operated at the nunatak Skjæret (1364 m a.s.l.) since 1995 (chap. 11-2).

Data from pressure sensor records from the Svartisen Subglacial Laboratory under Engabreen are presented in chapter 11-3. Results from other research performed at the subglacial laboratory in 2010 will be published elsewhere.

Figure 11-1
Engabreen on 4th August 2010. The entrance to Svartisen Subglacial Laboratory is located east of the glacier tongue at 520 m a.s.l. (white circle). Photo: Hallgeir Elvehøy.

11.1 Mass balance 2010

Fieldwork

The glacier was visited on 24th March. Stakes in positions E105 and E101 were measured. The snow depth at the stakes was around 3 metres.

The locations of stakes and towers, the density pit and the sounding profile are shown in Figure 11-2. The calculation of the winter balance is based on the following measurements on 27th May:

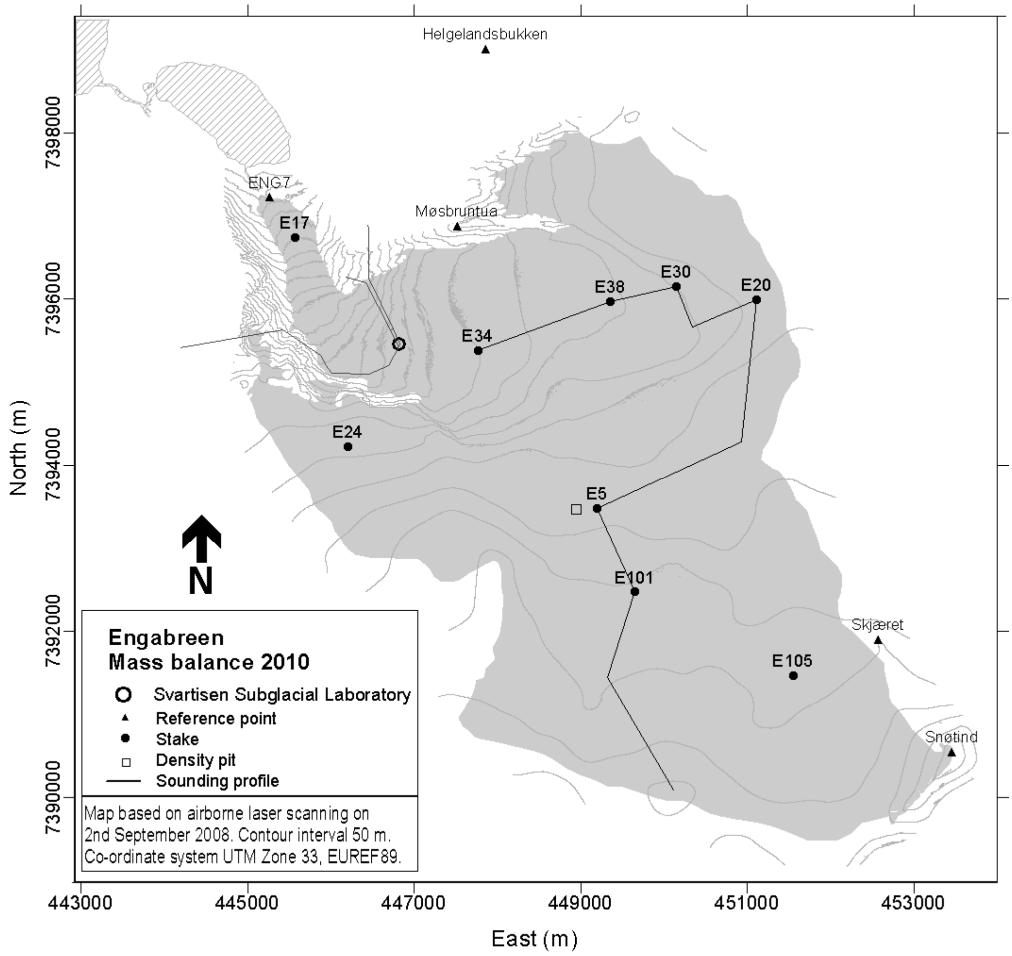


Figure 11-2
Location of stakes, density pit and sounding profiles on Engabreen in 2010. The tunnel system under Engabreen and the location of Svartisen Subglacial Laboratory is shown.

- Snow depth sounding at 45 locations on an 11 km long profile. The snow depth was between 4 and 4.5 m above 1200 m a.s.l., and between 2 and 4 m between 950 and 1200 m a.s.l.
- Direct measurement of 0.8 m of ice melt at location E17 between 20th October 2009 and 27th May 2010.
- Snow density measured down to 3.90 m depth at stake E5. The mean snow density was 567 kg/m^3. The summer surface (SS) was at 4.15 m depth.

At the glacier tongue, stake measurements showed that 4.5 m of ice melted between 27th May and 3rd August, and 3.05 m ice melted between 3rd August and 28th September. At the plateau, between 2.3 and 3.4 m of snow and ice melted between 27th May and 3rd August. After 3rd August between 1.2 and 1.9 m of snow, firn and ice melted before the winter snow accumulation started.

The net and summer balance measurements were carried out on 28th September. There was up to 0.15 m of new snow on the glacier plateau. Ten stakes were found in nine locations. From stake measurements the Transient Snow Line (TSL) altitude was about 1230 m a.s.l. At stakes E34, E30 and E24 all the snow and 2.75, 1.3 and 1.95 m of ice, respectively, melted during the summer. At the stakes above the TSL up to 0.65 m of snow remained.

Results

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

Winter balance

The temperature record at Skjæret (see Fig. 11-2 for location) shows that the air temperature on the glacier plateau was mainly below zero after 22nd September 2009. This implies that no significant late autumn melting occurred. Comparison of stake length and snow depth sounding at stake E34 show no ice melting at this location after 20th October. The snow depth at E34 was 0.8 metres on this date.

The calculation of the winter balance was based on point measurements of snow depth (stake readings, coring and snow depth soundings) and on snow density measurements. A water equivalent profile was modelled from the snow density measured at stake E5 (1230 m a.s.l.). This model was then used to calculate the water equivalent value of the snow depth measurements.

Point values of the snow water equivalent (SWE) were plotted against altitude, and a curve was drawn based on visual evaluation. Below 950 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 2.0 ±0.2 m w.e., which corresponds to a volume of 79 ±8 mill. m^3 of water. This is 67 % of the mean value for the normal period 1971-2000 (3.04 m w.e.), and 72 % of the mean value for the 5-year period 2005-2009 (2.84 m w.e.).

Summer balance

The summer balance was measured directly at stakes E17, E34, E38, E101 and E105. It was calculated from snow depth sounding and stake measurements at stakes E30, E24, E20 and E5. An altitudinal distribution curve was drawn based on the calculated summer balance in nine locations between 300 and 1340 m a.s.l. (Fig. 11-3). The summer balance was calculated as −2.6 ±0.2 m w.e., which equals a volume of −99 ±8 mill. m^3 water. This is 115 % of the average for the normal period 1971-2000 (−2.22 m w.e.), but 97 % of the average for the 5-year period 2005-2009 (−2.64 m w.e.).

Net balance

The net balance of Engabreen for 2010 was calculated as −0.5 ±0.3 m w.e., which corresponds to a volume of −20 ±8 mill. m^3 water. The mean value for the normal period 1971-2000 is +0.82 m w.e., and +0.20 m w.e. for 2005-2009. The equilibrium line altitude (ELA) was determined as 1240 m a.s.l. from the net balance curve in Figure 11-3. This corresponds to an accumulation area ratio (AAR) of 47 %. The mass balance results are shown in Figure 11-3 and Table 11-1. The results from 2010 are compared with mass balance results for the period 1970-2009 in Figure 11-4.

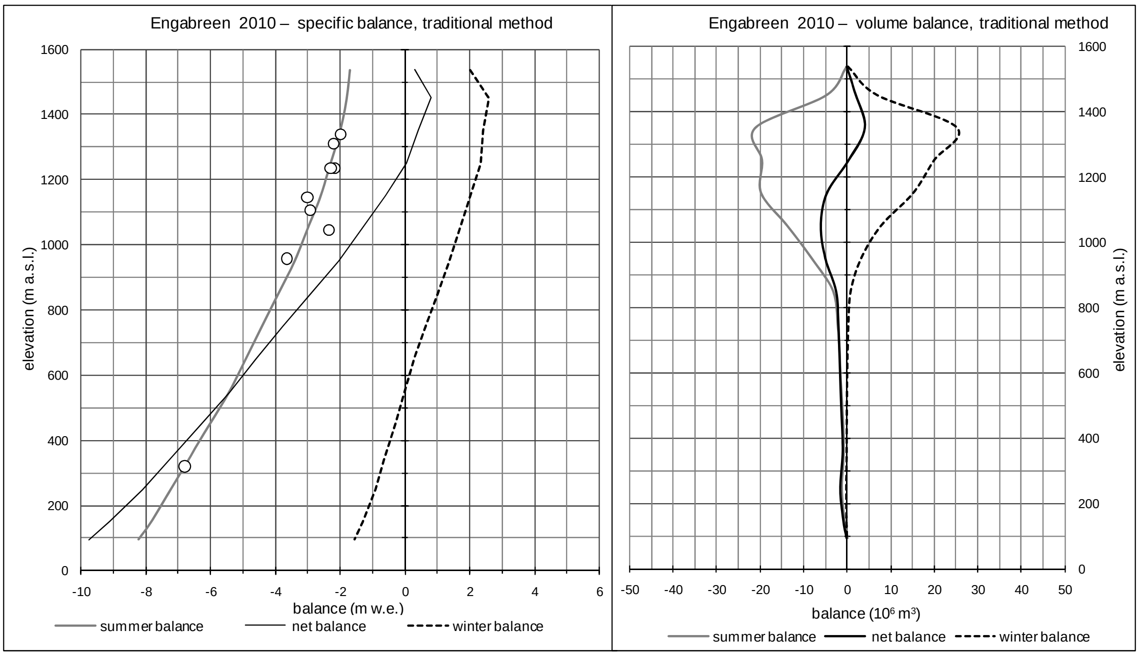


Figure 11-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2010. Summer balance at stake locations is shown as circles.

Table 11-1
Specific and volume winter, summer and net balance calculated for 100 m elevation intervals at Engabreen in 2010.

Mass balance Engabreen 2009/10 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 27th May 2010 Specific (m w.e.)	Winter balance Volume (10^6 m^3)	Summer balance Measured 28th Sep 2010 Specific (m w.e.)	Summer balance Volume (10^6 m^3)	Net balance Summer surface 2009 - 2010 Specific (m w.e.)	Net balance Volume (10^6 m^3)
1500 - 1574	0,10	2,00	0,2	-1,70	-0,2	0,30	0,0
1400 - 1500	2,65	2,60	6,9	-1,80	-4,8	0,80	2,1
1300 - 1400	10,49	2,40	25,2	-2,00	-21,0	0,40	4,2
1200 - 1300	8,46	2,35	19,9	-2,30	-19,5	0,05	0,4
1100 - 1200	7,56	2,00	15,1	-2,60	-19,7	-0,60	-4,5
1000 - 1100	4,57	1,70	7,8	-3,00	-13,7	-1,30	-5,9
900 - 1000	2,38	1,35	3,2	-3,40	-8,1	-2,05	-4,9
800 - 900	0,84	1,00	0,8	-3,90	-3,3	-2,90	-2,4
700 - 800	0,51	0,65	0,3	-4,40	-2,2	-3,75	-1,9
600 - 700	0,35	0,30	0,1	-4,90	-1,7	-4,60	-1,6
500 - 600	0,26	0,00	0,0	-5,40	-1,4	-5,40	-1,4
400 - 500	0,17	-0,30	-0,1	-6,00	-1,0	-6,30	-1,1
300 - 400	0,13	-0,60	-0,1	-6,60	-0,8	-7,20	-0,9
200 - 300	0,18	-0,90	-0,2	-7,20	-1,3	-8,10	-1,5
100 - 200	0,09	-1,30	-0,1	-7,80	-0,7	-9,10	-0,8
89 - 100	0,001	-1,55	0,0	-8,20	0,0	-9,75	0,0
89 - 1574	**38,74**	**2,04**	**79,1**	**-2,56**	**-99,3**	**-0,52**	**-20,2**

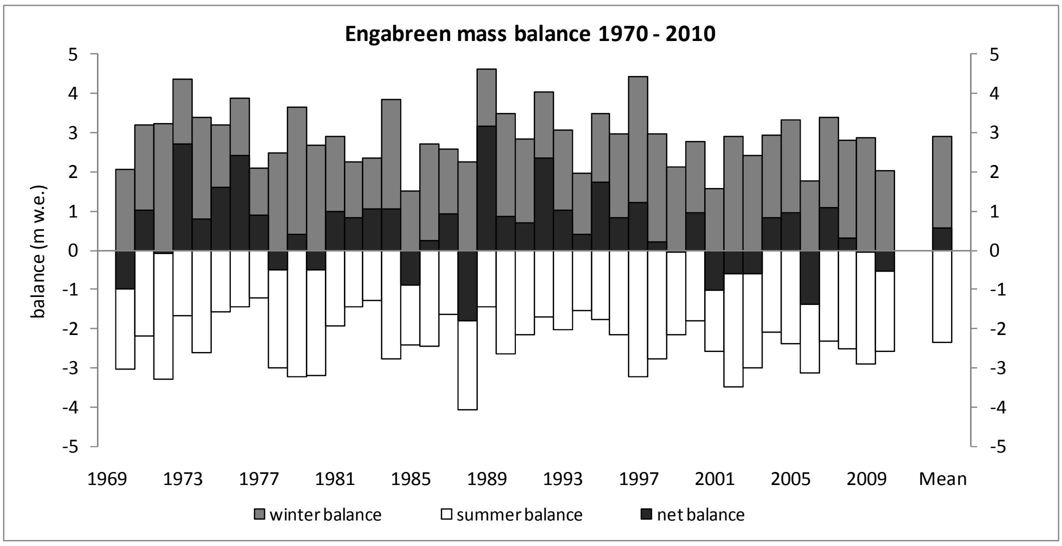


Figure 11-4
Mass balance at Engabreen during the period 1970-2010. The average winter and summer balances are b_w =2.91 m w.e. and b_s =−2.35 m w.e.

11.2 Meteorological observations

A meteorological station recording air temperature, global radiation and relative humidity at 3 metre level is located on the nunatak Skjæret (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig. 11-2). The station has recorded data since 1995 with some gaps.

In the mass balance year 2009/10, there were no gaps in the temperature record at Skjæret (Fig. 11-5). The air temperature was mainly close to or above freezing until 26th September 2009. Very little melting seems to have occurred on the plateau after this date. The coldest period this winter was around 22nd February when the daily mean temperature was −23.6 °C. The first period in spring with daily temperatures above 0 °C was 14th to 21st May when the air temperature peaked at 10 °C on 16th May. Between 22nd May and 23rd June the air temperature varied above and below zero, and there were several snowfalls. Except for short, cold periods around 23rd July and 15th August, the air temperature was at or above 0 °C between 24th June and 24th August. The maximum daily temperature was measured on 7th September (11.5 °C). The daily mean temperature remained positive until 9th October except around 1st and 24th September when there was some snow accumulation. When net balance measurements were performed on 29th September up to 15 cm of new snow covered the glacier above 1200 m a.s.l.

At Skjæret, the summer mean temperature (1st June – 30th September) was 2.7 °C which is 1.4 °C lower than in the warm summers of 2002 and 2006, but similar to the 2005-09 average (2.8 °C). The 2010 summer balance at Engabreen was 97 % of the 2005-09 summer balance average.

The nearest meteorological station to Engabreen is 80740 Reipå (9 m a.s.l., 28 km NNW of Engabreen) which has been operated by the Norwegian Meteorological Institute (DNMI) as a precipitation station since 1995. The station was upgraded to a meteorological station in July 2009. The meteorological station 80700 Glomfjord (39 m a.s.l., 19 km NNE of Engabreen) was operated by the Norwegian Meteorological

Institute (DNMI) between 1916 and 2010. The precipitation record is incomplete after 2004, and the temperature record ended in March 2010.

At 80740 Reipå the recorded winter precipitation sum (1st October – 31st May) in 2010 was 689 mm which is 60 % of the 2005-09 average. Correspondingly, the winter balance at Engabreen was 72 % of the 2005-09 average.

The subglacial river discharge under Engabreen at Svartisen Subglacial Laboratory is shown in figure 11-5 (Fig. 11-2 for location). The peaks in discharge on 15th August and 10th October are caused mainly by precipitation events, while the discharge peaks in May, July and September are related mainly to peaks in temperature.

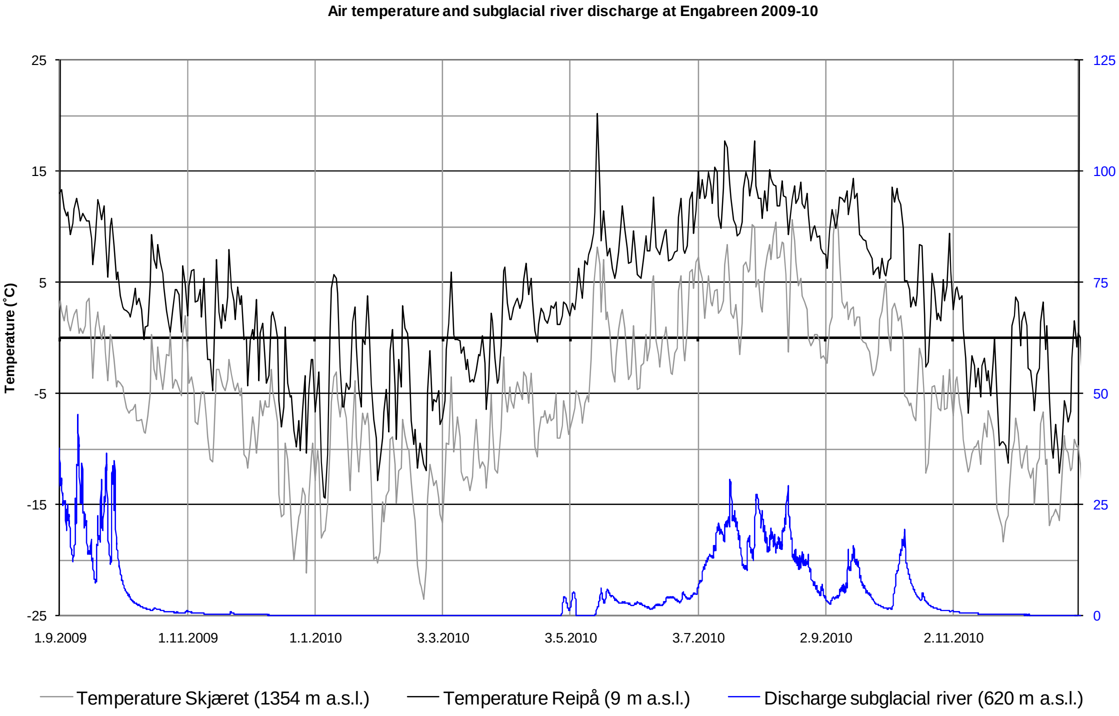


Figure 11-5
Daily mean air temperature at Skjæret (159.20) and Reipå (80740), and discharge in the subglacial river intake beneath Engabreen between 1st September 2009 and 31st December 2010.

11.3 Svartisen Subglacial Laboratory

Svartisen Subglacial Laboratory is a unique facility situated under Engabreen. Laboratory buildings and research shaft are located about 1.5 km along a tunnel that is part of a large hydropower development (Fig 11-6). At the research shaft there is direct access to the bed of the glacier that is used for measuring subglacial parameters, extracting samples and performing experiments. Further general information about the laboratory is available in report number 14 in NVE's document series for 2000, entitled 'Svartisen Subglacial Laboratory' (Jackson, 2000).

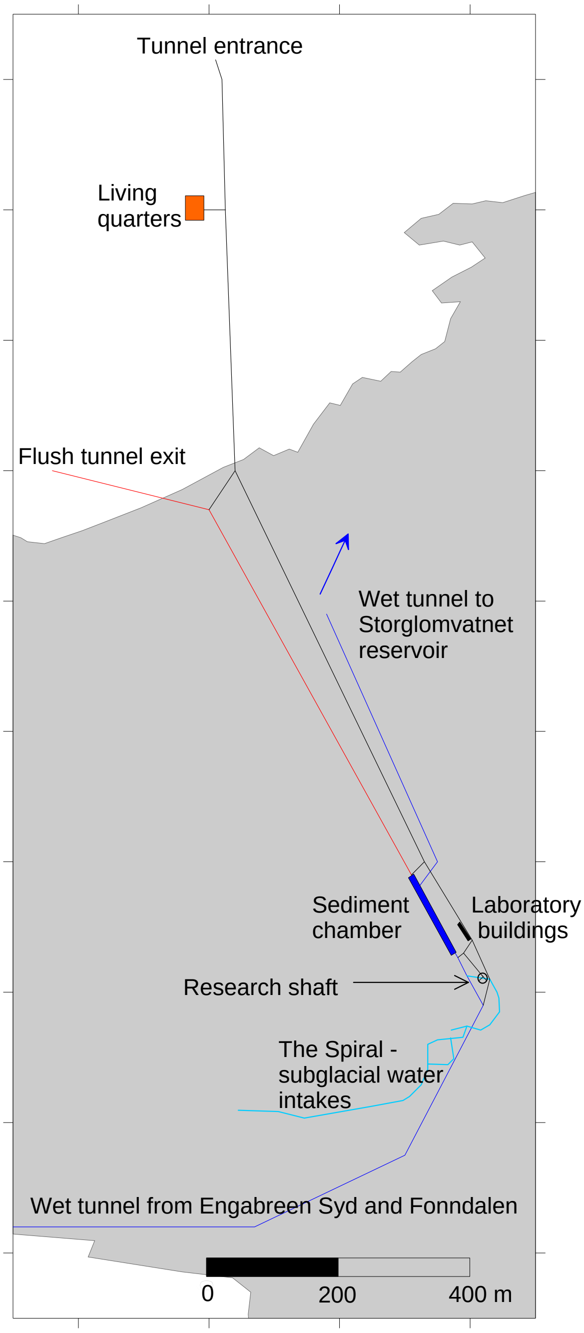


Figure 11-6
Map of tunnel system under Engabreen, showing research shaft and other facilities.

Pressure measurements

Six load cells were installed at the bed of the glacier next to the research shaft in December 1992 in order to measure variations in subglacial pressure (Fig 11-7). The load cells are Geonor P-105 Earth Pressure Cells. Readings are recorded from the load cells at 15 minute intervals (more frequently between mid-March and mid-June). Two new loads cells were installed in November 1997. Of these eight load cells, six of them are still recording, although two of them (1e and 97-1) record somewhat intermittently. There are no data from mid-July for the rest of the year in 2011 due to equipment problems. Note that the graphs of load cell pressure have different axes.

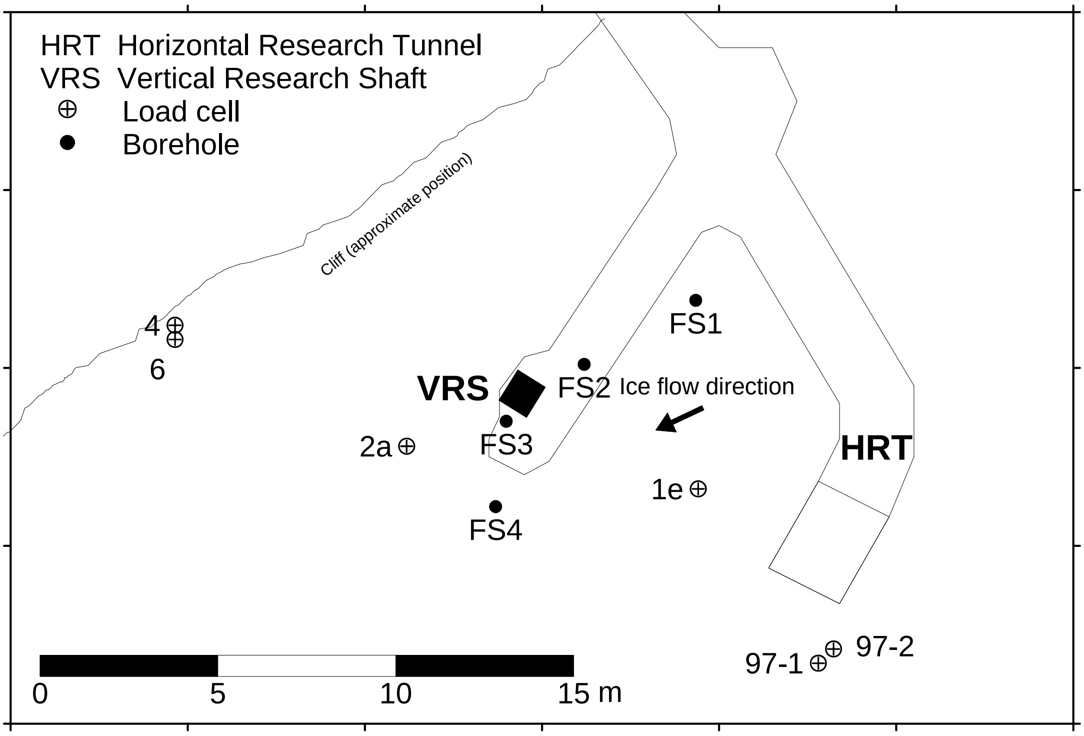


Figure 11-7
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 97-1 and 97-2 and boreholes, marked FS.

Pressure sensor records for winter 2010 from 1st January to 13th March are shown in Figure 11-8. Data from both 1e and 97-1 are lacking for much of this period due to erroneous values recorded, which are then deleted from the figures. The remaining data are shown in two figures - for all six load cells, and for load cells 4 and 6 only. These two load cells are not as exposed as the others with the ensuing noisy records and are generally a more reliable indicator of when significant changes are occurring at the glacier base. The records are generally typical for the winter period – relatively quiet and stable, corresponding with very low discharge measured in the subglacial tunnel (see Figure 11-5). The pressure values measured are significantly lower than normal for this time of the year at load cells 4 and 1e, but slightly higher at 6 and 2a. The suddenly noisy record at the end of this period corresponds to research activity and melting out of an ice tunnel at this time.

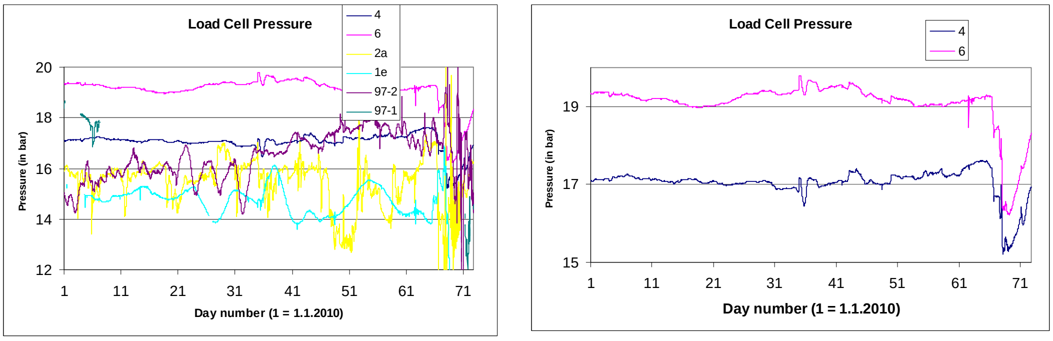
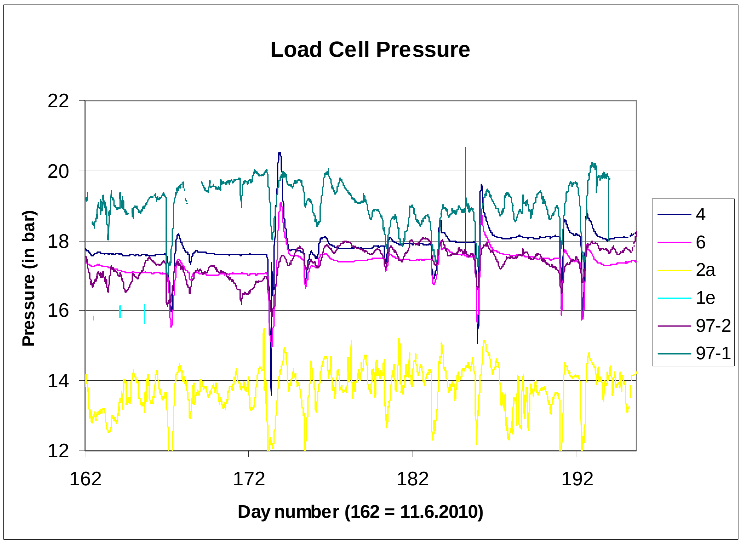
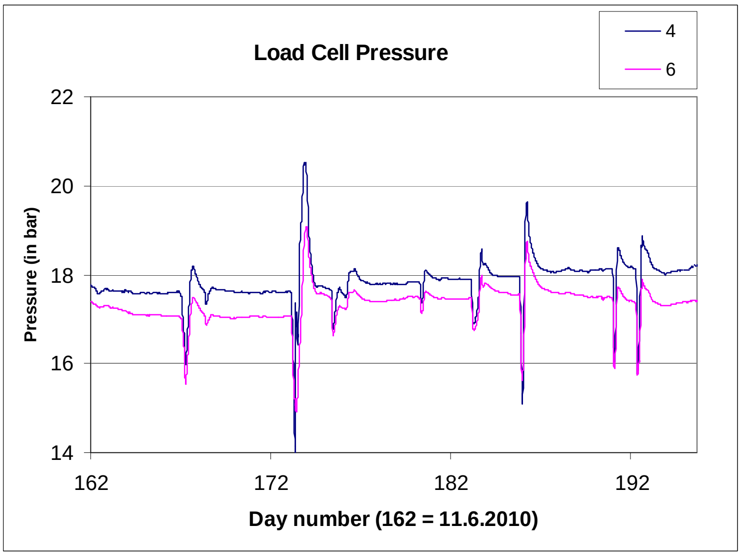


Figure 11-8
Pressure records for 1st January to 13th March.

Pressure sensor records for the period from 13th March to 11th June were measured at a much shorter time interval, generally two minutes. The early part of this period includes much research activity, so the records do not reflect the natural variations. There is also a data gap from 14th April to 24th April. Hence, the data are not presented here.





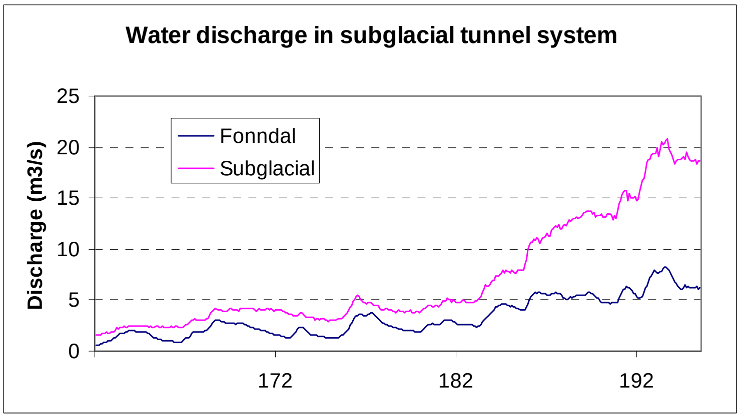


Figure 11-9
Pressure records for 11th June to 15th July (for all six load cells at top, and for two load cells in middle) and discharge in the subglacial tunnel system (bottom). Fonndal is discharge measured in a tunnel that is also fed by subaerial intakes and subglacial is the discharge component from the 'Spiral' tunnel (Fig 11-6) and is wholly from subglacial intakes.

Pressure sensor records for the early summer, from 11th June to 15th July, are shown in Figure 11-9, and were recorded at the standard 15 minute interval. There were no data recorded after this due to equipment problems. The records are fairly typical for the early summer period. The records from load cells 4 and 6 are generally quiet with distinct events every few days that are characterised by a sudden drop in a pressure, an abrupt rise to a pressure higher than before the event, and then a more gradual decrease back to the original pressure. The timing of these events corresponds very well to the timing of water flux events (lowermost figure in 11.9).

12. Langfjordjøkelen

(Bjarne Kjøllmoen)

Langfjordjøkelen (70º10'N, 21º45'E) is a plateau glacier situated on the border of Troms and Finnmark counties, approximately 60 km northwest of the city of Alta. It has an area of about 7.7 km^2 (2008), and of this 3.2 km^2 drains eastward. The investigations are performed on this east-facing part (Fig. 12-1), ranging from 302 to 1050 m a.s.l.

The glaciological investigations in 2010 include mass balance and change in glacier length (chap. 13). Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

12.1 Mass balance 2010

Fieldwork

Snow accumulation measurements

Snow accumulation was measured on 19th May and the calculation of winter balance is based on (Fig. 12-2):

- Uninterrupted measurements of stakes in positions 10 (468 m a.s.l.), 20 (629 m a.s.l.), 25 (724 m a.s.l.) and 30 (884 m a.s.l.). The stake measurements showed snow depths between 2.1 and 3.6 m.
- 71 snow depth soundings between 328 and 1049 m elevation. Identification of the summer surface (S.S.) was easy below 950 m elevation. Above this level several ice layers made it more difficult to detect the S.S. The snow depth varied between 1.7 and 5.0 m.
- Snow density was measured down to 2.0 m depth (S.S. at 3.2 m) at stake position 30.

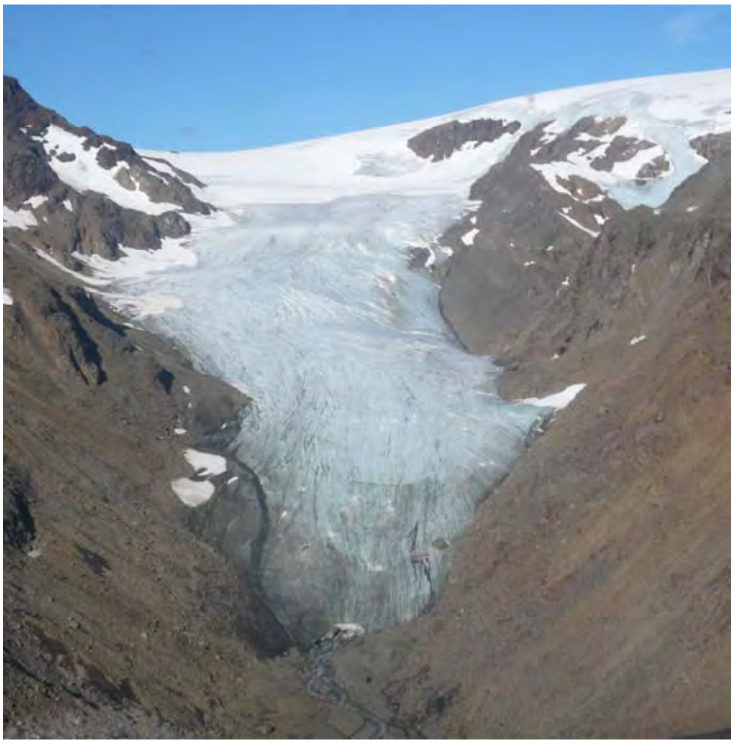


Figure 12-1
The east-facing outlet of Langfjordjøkelen photographed on 6th August 2010. Photo: Bjarne Kjøllmoen.

Ablation measurements

Ablation was measured on 23rd September. The net balance was measured at seven stakes in four locations between 468 and 1049 m a.s.l. Due to fog on the glacier stake 20 could not be reached by the helicopter and thus was not measured. Since the snow measurements in May the stakes had increased in length between 3.8 m (pos. 30) and 5.0 m (pos. 10). At the time of measurements the glacier surface was relatively featureless and solid in the uppermost area (pos. 40). Thus, it was rather difficult to determine whether the surface was covered by a thin layer of frozen fresh snow, or remaining snow from the previous winter. It is assumed to be either a negligible layer of fresh snow (<10 cm), or remaining snow.

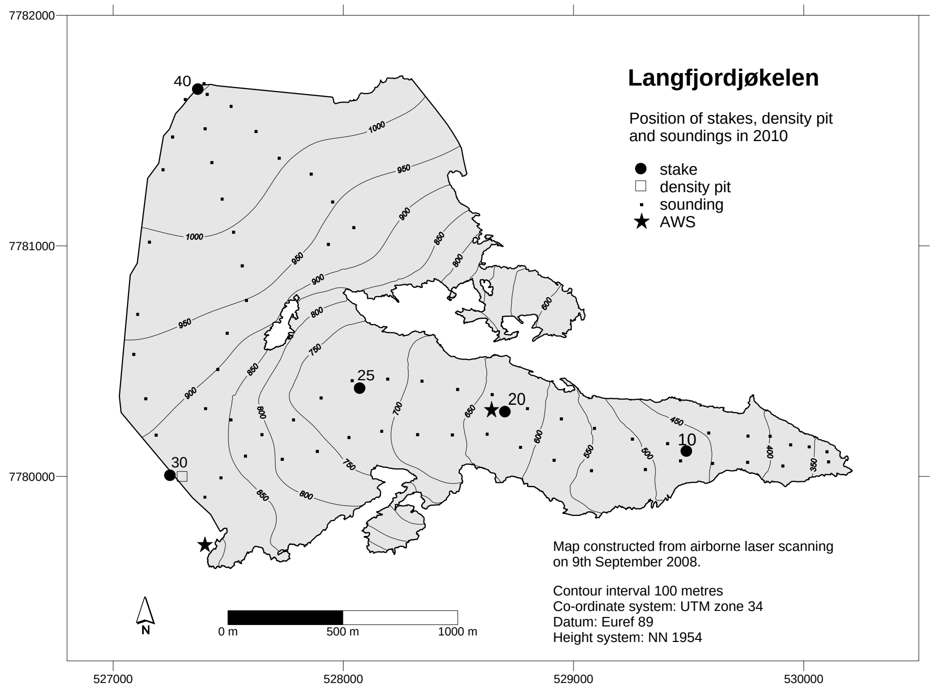


Figure 12-2
Location of stakes, soundings, snow pit and automatic weather stations (AWS) at Langfjordjøkelen in 2010.

Results

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

Winter balance

The calculations of winter balance are based on 76 point measurements of snow depth (stakes and soundings) and on one snow density measurement.

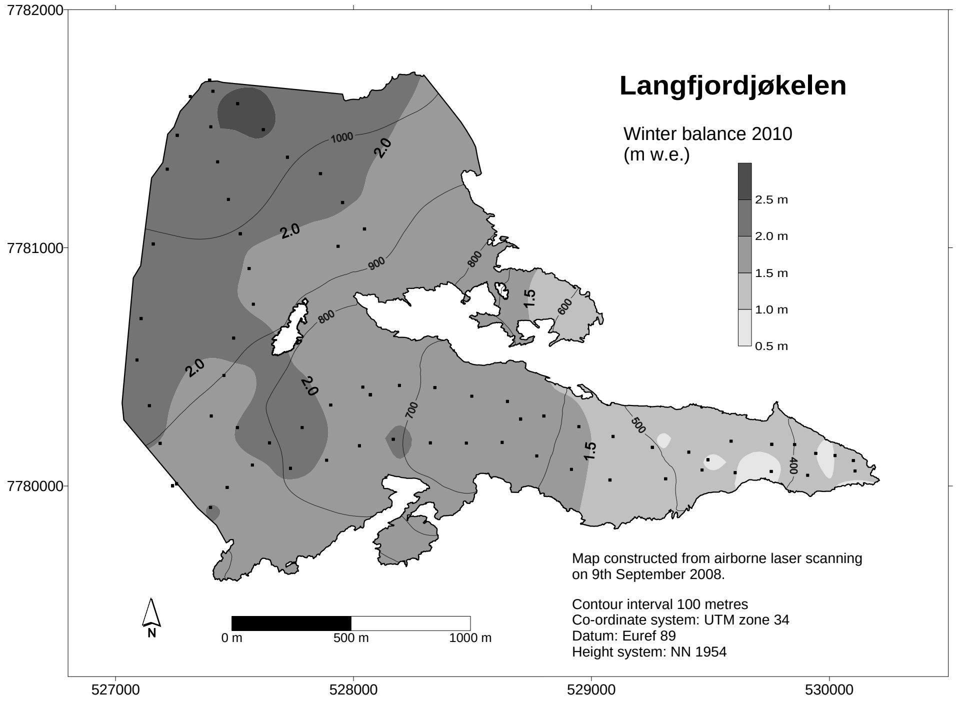
There was no melting after the final measurements in October 2009. Consequently, winter *accumulation* and winter *balance* are equal.

A density profile was modelled from the snow density measurement at 884 m altitude. The mean density of 3.2 m snow was 522 kg/m^3. The density model was used to convert all measured snow depths to water equivalent.

The winter balance calculations were performed by plotting the measurements (water equivalent) in a diagram. A curve was drawn based on visual evaluation and a mean value for each 50 m height interval was estimated (Tab. 12-1).

The winter balance was calculated as 1.9 ±0.2 m w.e., corresponding to a water volume of 6 ±1 mill. m^3. The result is 90 % of the mean value for the periods 1989-1993 and 1996-2009.

The winter balance was also calculated using a gridding method (Kriging) based on the aerial distribution of the snow depth measurements (Fig. 12-3). Water equivalents for each cell in a 100 x 100 m grid were calculated and summarised. The result obtained using this gridding method was 1.8 m w.e.



Map constructed from airborne laser scanning on 9th September 2008.

Contour interval 100 metres
Co-ordinate system: UTM zone 34
Datum: Euref 89
Height system: NN 1954

Figure 12-3
Winter balance at Langfjordjøkelen in 2010 interpolated from 76 snow depth measurements (•).

Summer balance

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

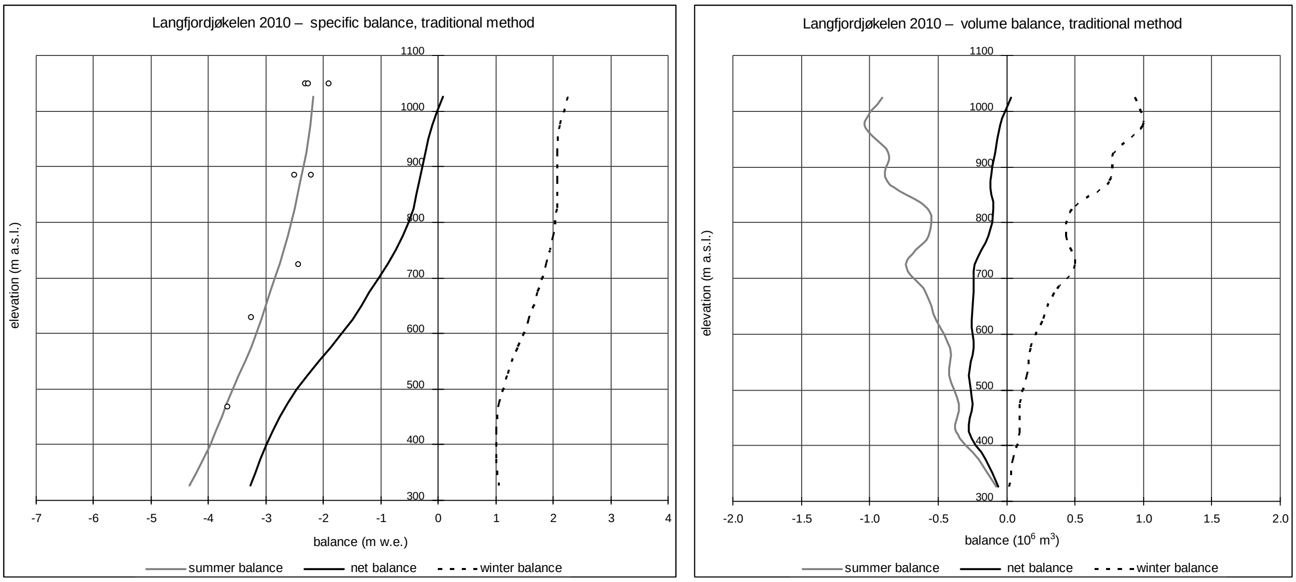
The summer balance was calculated at stakes in all five locations (Fig. 12-4). For stake 20 the melting is estimated for the period 6th August to 23rd September. The summer balance increased from −2.2 m w.e. at position 40 (average of three stakes) to −3.7 m w.e. at position 10. Based on estimated density and stake measurements, the summer balance was calculated to be −2.6 ±0.3 m w.e., which is −9 ±1 mill. m^3 of water. The result is 87 % of the average for the periods 1989-1993 and 1996-2009.

Net balance

The net balance at Langfjordjøkelen for 2010 was −0.8 ±0.3 m w.e., which equals a volume loss of −2 ±1 mill. m^3 of water (Tab. 12-1). The mean value for the measurement periods 1989-93 and 1996-2009 is −0.93 m w.e. (Fig. 12-5), while the average over the 10-year period 2000-2009 is −1.36 m w.e.

Based on Figure 12-4, the Equilibrium Line Altitude (ELA) lies at 1005 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) is 12 %.

The mass balance results are shown in Table 12-1. The corresponding curves for specific and volume balance are shown in Figure 12-4. The historical mass balance results are presented in Figure 12-5.


Langfjordjøkelen 2010 – specific balance, traditional method

Langfjordjøkelen 2010 – volume balance, traditional method

Figure 12-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2010. Summer balance for seven stakes is shown (○).

Table 12-1
Winter, summer and net balance for Langfjordjøkelen in 2010. Mean values for the periods 1989-93 and 1996-2009 are b_w = 2,10 m, b_s = −3,03 m and b_n = −0,93 m w.e.

Mass balance Langfjordjøkelen2009/10 – traditional method

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 19th May 2010		Summer balance Measured 23rd Sep 2010		Net balance Summer surface 2009 - 2010	
		Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1000 - 1050	0.42	2.25	0.9	-2.18	-0.9	0.08	0.0
950 - 1000	0.47	2.13	1.0	-2.23	-1.0	-0.10	0.0
900 - 950	0.38	2.08	0.8	-2.30	-0.9	-0.23	-0.1
850 - 900	0.36	2.08	0.8	-2.40	-0.9	-0.33	-0.1
800 - 850	0.23	2.08	0.5	-2.50	-0.6	-0.43	-0.1
750 - 800	0.22	2.00	0.4	-2.63	-0.6	-0.63	-0.1
700 - 750	0.27	1.88	0.5	-2.75	-0.7	-0.88	-0.2
650 - 700	0.20	1.73	0.3	-2.93	-0.6	-1.20	-0.2
600 - 650	0.17	1.58	0.3	-3.08	-0.5	-1.50	-0.3
550 - 600	0.13	1.38	0.2	-3.25	-0.4	-1.88	-0.2
500 - 550	0.12	1.20	0.1	-3.48	-0.4	-2.28	-0.3
450 - 500	0.10	1.05	0.1	-3.68	-0.4	-2.63	-0.3
400 - 450	0.10	1.00	0.1	-3.88	-0.4	-2.88	-0.3
350 - 400	0.05	1.00	0.0	-4.10	-0.2	-3.10	-0.2
302 - 350	0.02	1.05	0.0	-4.33	-0.1	-3.28	-0.1
302 - 1050	**3.21**	**1.89**	**6.1**	**-2.65**	**-8.5**	**-0.76**	**-2.4**

The balance year 2009/2010 is the fourteenth successive year with significant negative net balance at Langfjordjøkelen. The cumulative net balance for the period 1989-2009 (estimated values for 1994 and 1995 included) is −19 m w.e.

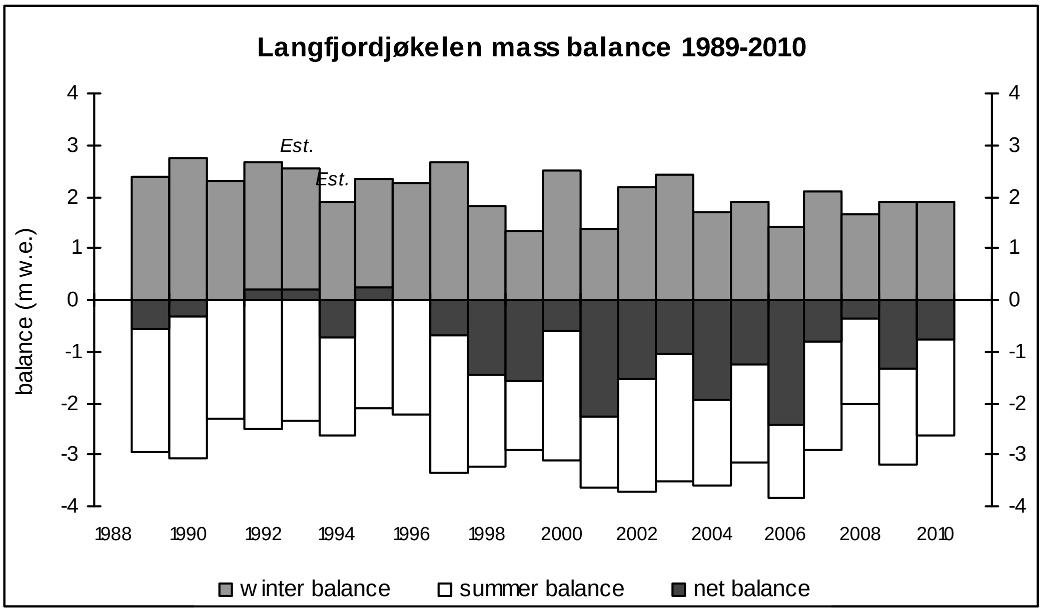


Figure 12-5
Mass balance at Langfjordjøkelen during the period 1989-2010. The total accumulated mass loss over 1989-2010 is 19 m w.e. (includes estimated values for 1994 and 1995).

12.2 Meteorological measurements

(Rianne H. Giesen and Liss M. Andreassen)

From September 2007 until August 2010, an automatic weather station (AWS) has been operating at 650 m a.s.l. in the ablation area of Langfjordjøkelen (Fig. 12-2), as a contribution to the International Polar Year (Glaciodyn). The station (Fig. 12-6) was owned and maintained by the Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: J.Oerlemans@uu.nl). The station recorded shortwave and longwave radiation (incoming and outgoing), air temperature, relative humidity, wind speed and direction, air pressure and distance to the surface. Sampling was done every few minutes (depending on the sensor) and 30-minute averages were stored. The measurements will be used to study the local microclimate at Langfjordjøkelen and to calibrate a mass balance model for the ice cap. Here, we present a selection of the data collected over the three-year period.

Figure 12-6
The AWS site on Langfjordjøkelen on 26th August, 2008. A second sonic ranger, measuring the distance to the surface, is on the tripod to the left of the mast. Photo: Rianne H. Giesen.

Surface height change and albedo

For the major part of the three-year period, the surface at the AWS consisted of snow (Fig. 12-7). The underlying ice generally surfaced in the last days of July and the winter snowpack started to build up again between the end of September and the end of October. Maximum winter snow depth was approximately 3.5 m in all three winters. Over the three-year period, almost 6 m of ice melted at the AWS location, which corresponds well to the mass balance measurements at the nearby NVE stake.

The surface albedo was calculated from measured incoming and reflected solar radiation. Between early November and early February, no or very little incoming solar radiation reached the sensor and albedo could not be calculated. Surface albedo was high in winter, when frequent snowfalls occurred. When the snow surface started to melt, surface albedo decreased to values around 0.7. During the short periods with bare ice at the surface, the albedo at the AWS location varied between 0.25 and 0.30.

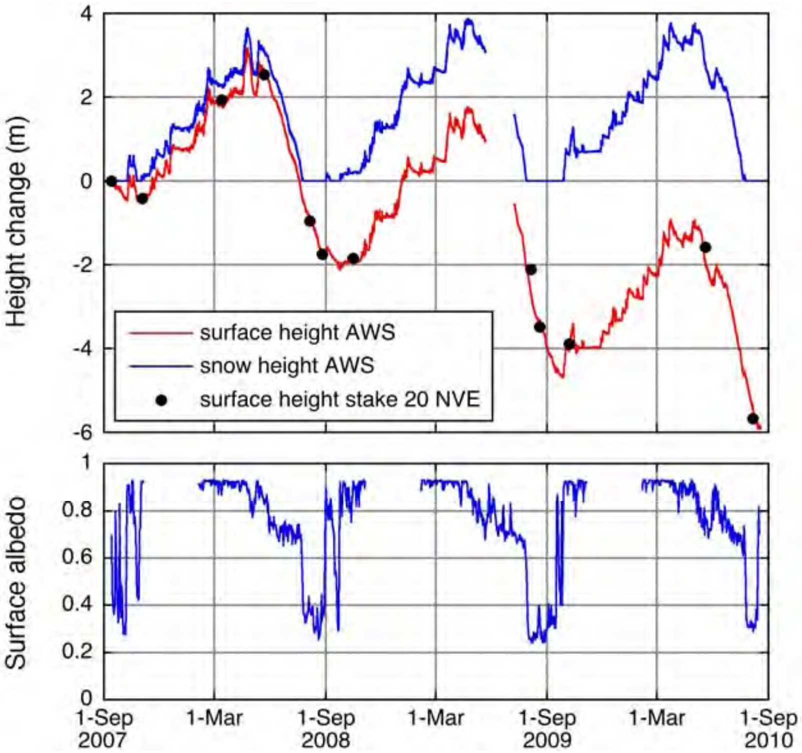


Figure 12-7
Daily mean values of surface height (AWS and nearest NVE mass balance stake) and snow height (upper), and surface albedo (lower) for the period September 2007 to September 2010.

Air temperature

Figure 12-8 shows daily mean air temperature together with a two-year record from a second AWS, which is operated by NVE and is situated on a rock surface above the glacier at an altitude of 910 m a.s.l. (Fig. 12-2). The mean air temperature at the IMAU AWS was −1.0 °C. For the period with data from both AWSs, the mean temperatures at the IMAU and NVE AWSs were −0.7 °C and −2.3 °C, respectively. The highest temperatures over the three-year period were recorded in the summer of 2009, while the lowest temperatures were measured in the first months of 2010. Even in mid-winter, daily mean air temperatures were occasionally higher than 0 °C.

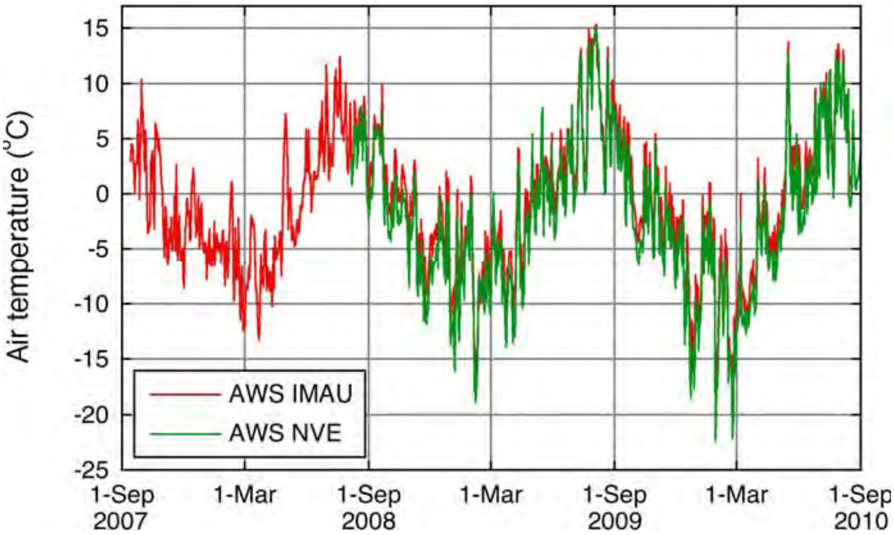


Figure 12-8
Daily mean air temperature at the AWSs operated by IMAU and NVE for the period September 2007 to September 2010.

13. Glacier monitoring

(Hallgeir Elvehøy and Miriam Jackson)

13.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started around 1900. In 2010, glacier length change was measured at 31 glaciers - 23 in southern Norway and eight glaciers in northern Norway (Fig. 13-1).

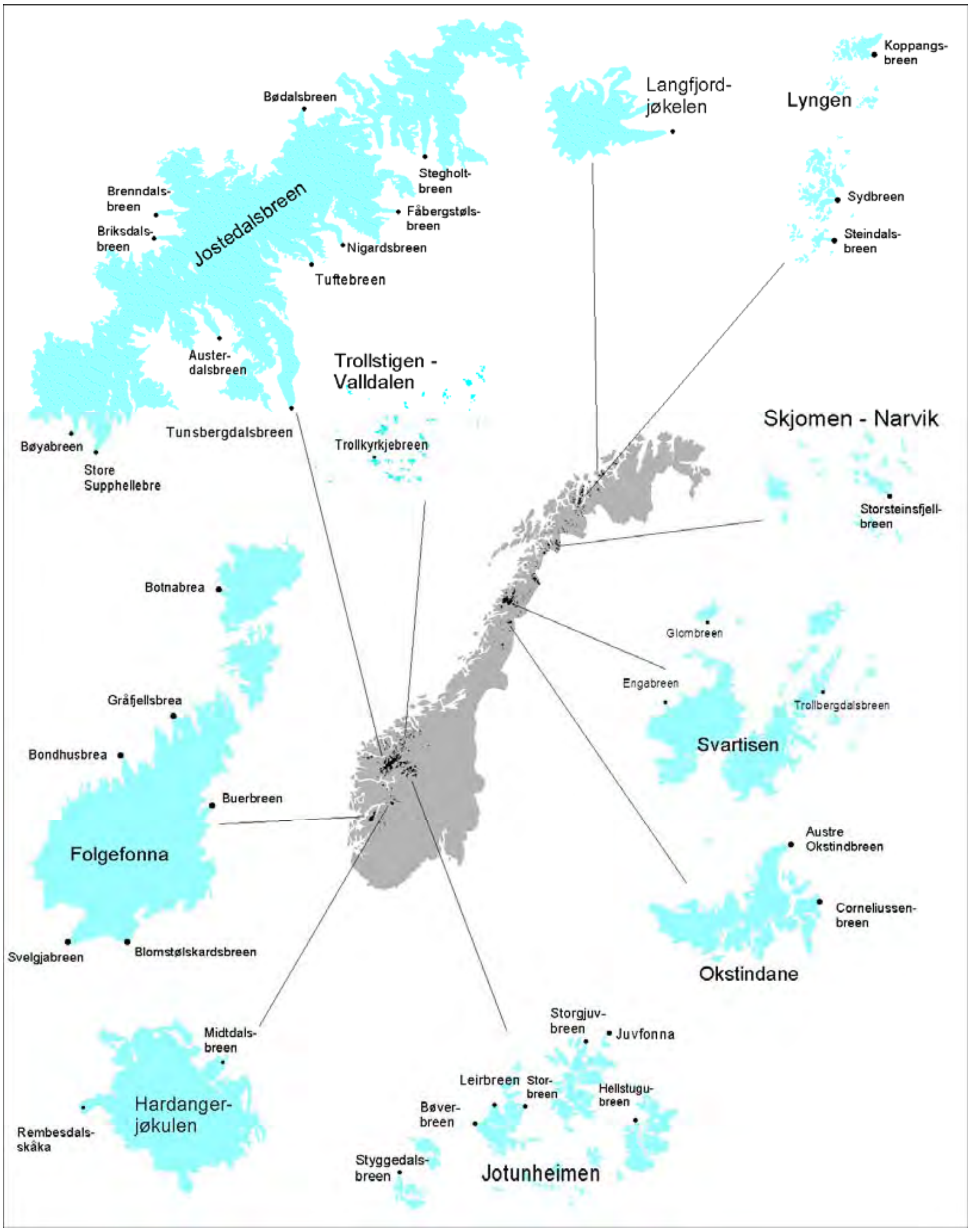


Figure 13-1
Location map showing glaciers where length change observations were performed in 2010. Note that the different glacier areas are not to the same scale.

Up to and including 2010, glacier length change has been measured at 64 glaciers since 1899. The total number of observations is 2404, and the median number of observations is 27 glaciers pr. year. At Briksdalsbreen, the glacier length change has been measured every year since 1900, resulting in 110 observations. Stegholtbreen and Fåbergstølsbreen have more than 100 observations, too. A total of 20 glaciers have more than 50 observations, and another 10 glaciers have more than 30 observations. This year measurements were initiated at Juvfonna in Jotunheimen (Fig. 8-1), and at Glombreen (Fig. 13-2) and Trollbergdalsbreen in the Svartisen area. New reference points were established at Tunsbergdalsbreen. Measurements at Bøverbreen and Storjuvbreen in Jotunheimen, and Brenndalsbreen and Bødalsbreen from Jostedalsbreen have been conducted by Dr. Stefan Winkler since 1996/97. The responsibility for these measurements has now been transferred to NVE. The measurements at Kjenndalsbreen were ended due to increasingly difficult access to the glacier tongue.

Methods

The distance to the glacier terminus is measured from one or several fixed points in defined directions, usually in September or October each year. The change in distance gives a rough estimate of the length change of the glacier. The representativeness for the glacier tongue of the annual length change calculated from measurements from one reference point can be questionable. However, when longer time periods are considered the measurements give valuable information about glacier fluctuations, as well as regional tendencies and variations (Andreassen et al., 2005).

Results 2010

Thirty-one glaciers were measured, eight in northern Norway and 23 glaciers in southern Norway. Twenty-seven glaciers retreated, one glacier had minor changes, and three glaciers had an advance. The measured glaciers constitute around 14 % of the glacier area in Norway. The glacier length changes at the observed glaciers are listed in Table 13-1.

At Jostedalsbreen, three out of nine glaciers retreated more than 20 metres. Bødalsbreen in Stryn retreated 65 metres, and has retreated almost 300 metres since 2000. Briksdalsbreen showed a small advance – this may imply that the rapid retreat since 1999 has come to an end.

At Folgefonna, four of five measured glaciers retreated. Bondhusbrea in Kvinnherad and Buerbreen in Odda both retreated 28 metres in 2010 and have retreated 270 and 230 metres respectively since 2000. At Hardangerjøkulen, Rembesdalsskåka in Eidfjord retreated 14 metres. The tongue has retreated 343 metres since 1997. Measurements at Midtdalsbreen showed a retreat of 34 metres. The glacier has retreated 143 metres since 2001.

In Jotunheimen the annual changes are smaller compared with the changes at the coastal outlet glaciers. Six glaciers retreated between 5 and 20 metres. The large retreat at Leirbreen is due to calving into a pro-glacial lake.

Four glaciers have been measured in Nordland. Engabreen, a northern outlet from Svartisen, retreated eleven metres in 2010, and a total of 266 metres since 1999. Storsteinsfjellbreen in Skjomen retreated 22 metres in two years, and Austre

Okstindbreen in Rana retreated 32 metres in two years. This glacier is now calving into a lake.

In Lyngen in Troms, Steindalsbreen retreated 40 metres. Sydbreen and Koppangsbreen retreated 10 and 18 metres, respectively. Steindalsbreen and Koppangsbreen have retreated approximately 200 metres since observations began in 1998. An eastern outlet from Langfjordjøkelen in Loppa in West Finnmark melted back 15 metres. The glacier has retreated 387 metres since 1998 and 1181 metres since 1965.

Figure 13-2
Glombreen on 2nd September 2008 from the south-east. Glacier length change observations were initiated in 2010 on the south-western part of the glacier complex. This glacier covers the elevation interval between about 850 and 1130 m a.s.l., and the area is approximately 1.5 km².
Photo: Hallgeir Elvehøy.

Table 13-1
Glacier length change between autumn 2009 and autumn 2010. See Figure 13-1 for locations.

Region	Glacier	**2009-10 (m)**	Observer	Period(s) of length change measurements	Number of obs.	Length change 2005-2010	Length change 2000-2010
Jostedalsbreen	Austerdalsbreen	**-12**	NVE	1905-20, 1933-	90	-78	-107
	Brenndalsbreen	**NM**	NVE	1900-62, 1996-	74		
	Briksdalsbreen	**8**	NVE/AN	1900-	110	-201	-434
	Bødalsbreen	**-65**	NVE	1900-53, 1996-	60	-224	-291
	Fåbergstølsbreen	**-10**	NVE	1899-	105	-189	-234
	Nigardsbreen	**-39**	NVE	1899-	99	-100	-114
	Stegholtbreen	**-6**	NVE	1903-	104	-69	-129
	Tuftebreen	**-15**	NVE	2007-	3		
	Tunsbergdalsbreen	**NEW**	NB	1900-1960, 2010-	62		
	Bøyabreen	**-32**	NB	1899-1953, 2003-	60	-140	
	Store Supphellebreen	**16**	NB	1899-1958, 1977-83, 1992-	77	2	-75
Folgefonna	Bondhusbrea	**-28**	S	1901-86, 1996-	76	-185	-271
	Botnabrea	**-10**	GK	1996-	12	-42	-68
	Blomstølskardsbreen	**-8**	SKL	1994-	12	-9	-16
	Buerbreen	**-28**	NVE	1900-80, 1995-	62	-118	-227
	Gråfjellsbrea	**NM**	S	2002-	7		
	Svelgjabreen	**1**	SKL	2007-	3		
Hardanger-jøkulen	Midtdalsbreen	**-34**	AN	1982-	28	-100	-142
	Rembesdalsskåka	**-14**	S	1918-41, 1968-83, 1995-	33	-115	-321
Jotunheimen	Bøverbreen	**-14**	NVE	1903-12, 1936-63, 1997-	40	-28	-47
	Hellstugubreen	**-5**	NVE	1901-	70	-40	-80
	Juvfonna	**NEW**	NVE	2010-			
	Leirbreen	**-50***	NVE	1909-	50	-27	-70
	Storbreen	**-14**	NVE	1902-	78	-35	-80
	Storjuvbreen	**-18**	NVE	1901-12, 1933-63, 1997-	51	-41	-35
	Styggedalsbreen	**-27***	NVE	1901-	89	-45	-74
Møre & Romsdal	Trollkyrkjebreen	**-16***	NVE	1944-74, 2008-	29		
Okstindane	Austre Okstindbreen	**-32***	NVE	1909-44, 2006-	20		
	Corneliussenbreen	**7***	NVE	2006-	3		
Svartisen	Engabreen	**-8**	S	1903-	77	-87	-256
	Glombreen	**NEW**	NVE	2010-			
	Trollbergdalsbreen	**NEW**	NVE	2010-			
Skjomen	Storsteinsfjellbreen	**-22***	NVE	2006-	3		
Lyngen	Koppangsbreen	**-18**	NVE	1998-	10	-92	-168
	Sydbreen	**-10**	NVE	2007-	3		
	Steindalsbreen	**-40**	NVE	1998-	9	-138	-221
Finnmark	Langfjordjøkelen	**-15**	NVE	1998-	12	-166	-336

NM: not measured in 2010 NEW: Start of new series in 2010 *: two years – not measured in 2009

Observers – other than NVE:

AN: Prof. Atle. Nesje, University of Bergen
GK: Geir Knudsen, Tyssedal
NB: Norwegian glacier museum, Fjærland
S: Statkraft
SKL: Sunnhordland Kraftlag

13.2 Jøkulhlaups

Blåmannsisen

There were several jøkulhlaups or Glacier Lake Outburst Floods (GLOFs) in Norway in 2010. One of these jøkulhlaups was from Blåmannsisen in Nordland and was the fifth such event from this glacier. It occurred over a period of several days from 8th to 17th September. The first known event from Blåmannsisen happened in September 2001 when 40 million cubic metres of water from a glacier-dammed lake suddenly streamed under the glacier and subsequently to the hydropower reservoir Sisovatnet. Previously the water had drained over a rock sill and flowed into a river in Sweden. The glacier-dammed lake was full again three years later in 2004, but the next event didn't occur until the following year in late August 2005 (Tab. 13-2). The next event occurred after an interval of only two years, in late August 2007. This time, the glacier-dammed lake was only partially full (9 m below water level when full) and approximately 20 million cubic metres of water drained under the glacier. The following event was also after an interval of two years, in early September 2009 and with a similar volume of water, about 20 million cubic metres. This latest event differed from previous events in that the water volume was much less, only 11 million cubic metres, the event occurred over a longer period and that it happened only a year after the previous event. Measurements of the glacier surface adjacent to the glacier-dammed lake in 2002, 2004 and 2009 showed a significant decrease in thickness of 11m in just seven years (from 2002 to 2009) (Kjøllmoen et al, 2010). Presumably the glacier has continued to decrease in thickness and the water is now able to escape at a lower water level than previously.

Table 13-2
Dates and volumes of jøkulhlaups from Blåmannsisen.

Year	Approximate dates	Water volume	Water level before event
2001	5th – 7th September	40 mill. m^3	full
2005	27th – 29th August	35 mill. m^3	full
2007	29th August	20 mill. m^3	~ half-full
2009	6th – 7th September	20 mill. m^3	~ half-full
2010	8th – 17th September	11 mill. m^3	less than half-full

Harbardsbreen

There was also a jøkulhlaup from Harbardsbreen (Fig. 13-3) in Luster in Sogn and Fjordane county between 4th and 6th August. Harbardsbreen is a plateau glacier in the Breheimen area of Norway with an area of about 25 km^2. The central part drains eastward to the river Steindalselvi, into Fivlemyrane reservoir and then into the river Fortundalselvi. The total water volume was about 5.5 million m^3. Smaller events have occurred here previously but this time the flood caused the hydropower reservoir downstream from the glacier to overflow and evacuation along the river in the valley Fortunsdalen was considered but turned out to be unnecessary. NVE performed mass balance measurements on the part of Harbardsbreen that drains eastward between 1997 and 2001.

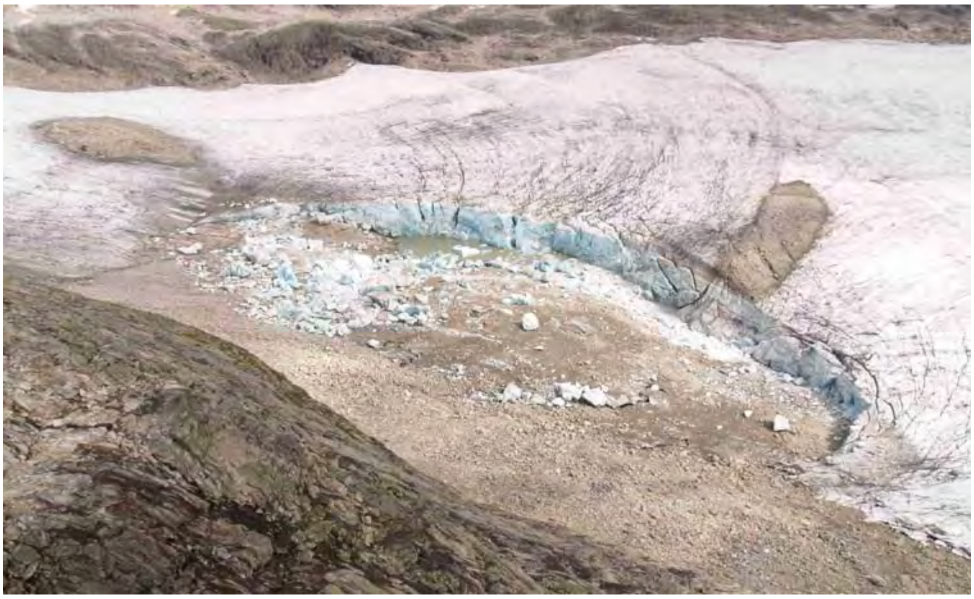
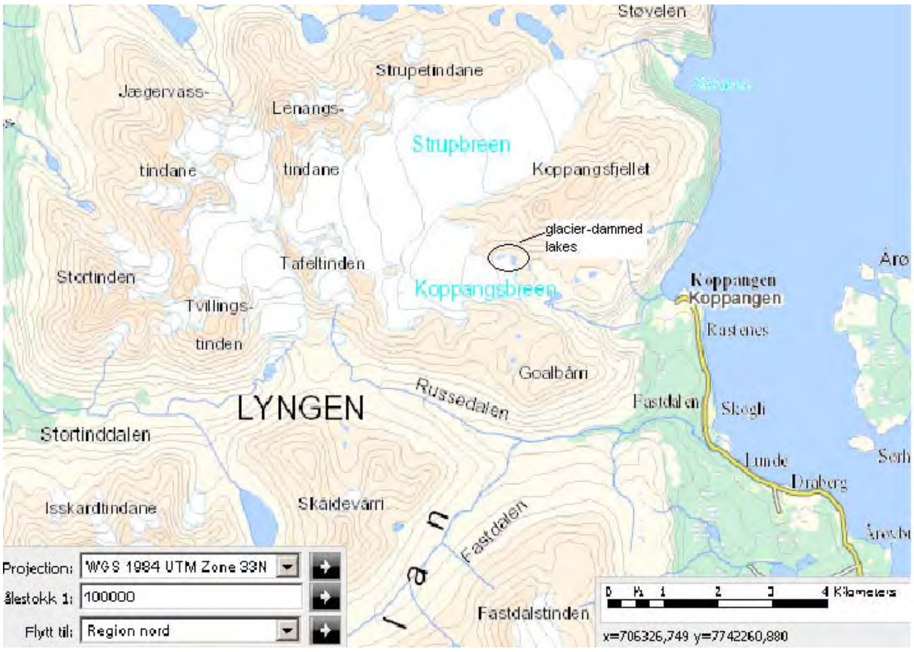


Figure 13-3
The site of the glacier-dammed lake that discharged under Harbardsbreen in August. Photo: Rune Engeset.

Koppangsbreen

On 6th September there was an unexpected flood in the river Koppangselva on Lyngen in Troms county. The river consequently took a new course, such that a house at Koppangen became cut-off and was in danger of being flooded. The flood came from a glacier-dammed lake (Fig. 13-4) beside the glacier Koppangsbreen. The glacier front has melted back more than 200 m since 1998 as the glacier has become smaller, and the glacier-dammed lake has grown correspondingly.



Projection: WGS 1984 UTM Zone 33N
ålestokk 1: 100000
Flytt til: Region nord
x=706326,749 y=7742260,880

Figure 13-4
Map showing Koppangsbreen in Lyngen, Troms county in northern Norway.

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Appendix A

Publications published in 2010

Andreassen, L.M., B. Kjøllmoen, K. Melvold, S.H. Winsvold, Ø. Nordli & A. Rasmussen
Stor nedsmelting av breene i Finnmark. *Klima 6/2010*, p. 4-5.

Kjøllmoen, B. (Ed.)
Glaciological investigations in Norway in 2009. *NVE Report 2 2009*, 85 pp.

Rasmussen, L.A., L.M. Andreassen, S. Baumann & H. Conway
Little Ice Age precipitation in Jotunheimen, southern Norway. *The Holocene vol. 20, No. 7*, p. 1039-1045.

Appendix B

Mass balance measurements in Norway – an overview

Mass balance measurements were carried out at 43 Norwegian glaciers during the period 1949-2010. The table below shows important data for the individual glaciers.

Area/ No. Glacier	Area (km^2)	Altitude (m a.s.l.)	Mapping year	Period	No. of years
Ålfotbreen					
1 Ålfotbreen	4.0	890-1368	2010	1963-	48
2 Hansebreen	2,8	927-1310	2010	1986-	25
Folgefonna					
3 Blomsterskardsbreen	45.7	850-1640	1959	1971-77	7
3a Svelgjabreen*	22.5	832-1636	2007	2007-	4
3b Blomstølskardsbreen*	22.8	1013-1636	2007	2007-	4
4 Bondhusbrea	10.7	480-1635	1979	1977-81	5
5 Breidablikkbrea	3.4	1234-1651	2007	1963-68, 2003-	14
6 Gråfjellsbrea	8.4	1049-1651	2007	64-68, 74-75, 2003-	15
7 Blåbreen and Ruklebreen	4.5	1065-1610	1959	1963-68	6
8 Midtre Folgefonna	8.7	1100-1570	1959	1970-71	2
Jostedalsbreen					
9 Jostefonn	3.8	960-1622	1993	1996-2000	5
10 Vesledalsbreen	4.2	1130-1730	1966	1967-72	6
11 Tunsbergdalsbreen	50.1	540-1930	1964	1966-72	7
12 Nigardsbreen	47.2	315-1957	2009	1962-	49
13 Store Supphellebreen	12.0	80-300/ 720-1740	1966	1964-67, 73-75, 79-82	11
14 Austdalsbreen	10.5	1200-1747	2009	1988-	23
15 Spørteggbreen	27.9	1260-1770	1988	1988-91	4
16 Harbardsbreen	13.2	1250-1960	1996	1997-2001	5
Hardangerjøkulen					
17 Rembesdalsskåka	17.3	1066-1854	2010	1963-	48
18 Midtdalsbreen	6.7	1380-1862	1995	2000-2001	2
19 Omnsbreen	1.5	1460-1570	1969	1966-70	5
Jotunheimen					
20 Tverråbreen	5.9	1415-2200		1962-63	2
21 Blåbreen	3.6	1550-2150	1961	1962-63	2
22 Storbreen	5.1	1400-2102	2009	1949-	62
23 Vestre Memurubre	9.0	1570-2230	1966	1968-72	5
24 Austre Memurubre	8.7	1630-2250	1966	1968-72	5
25 Juvfonne	0.2	1840-1998	2004	2010-	1
26 Hellstugubreen	2.9	1482-2229	2009	1962-	49
27 Gråsubreen	2.1	1833-2283	2009	1962-	49
Okstindbreene					
28 Charles Rabot Bre	1.1	1090-1760	1965	1970-73	4
29 Austre Okstindbre	14.0	730-1750	1962	1987-96	10
Svartisen					
30 Høgtuvbreen	2.6	590-1170	1972	1971-77	7
31 Svartisheibreen	5.5	770-1420	1985	1988-94	7
32 Engabreen	38.7	89-1574	2008	1970-	41
33 Storglombreen	59.2 62.4	520-1580 520-1580	1968	1985-88 2000-05	10
34 Tretten-null-tobreen	4.3	580-1260	1968	1985-86	2
35 Glombreen	2.2	870-1110	1953	1954-56	3
36 Kjølbreen	3.9	850-1250	1953	1954-56	3
37 Trollbergdalsbreen	1.8 1.6	900-1375 900-1300	1968 1985	1970-75 1990-94	11
Blåmannsisen					
38 Rundvassbreen	11.6	788-1537	1998	2002-04	3
Skjomen					
39 Blåisen	2.2	850-1200	1960	1963-68	6
40 Storsteinsfjellbreen	6.1 5.9	920-1850 970-1850	1960 1993	1964-68 1991-95	10
41 Cainhavarre	0.7	1210-1540	1960	1965-68	4
Vest-Finnmark					
42 Svartfjelljøkelen	2.7	500-1080	1966	1978-79	2
43 Langfjordjøkelen	3.7 3.2	280-1050 302-1050	1994 2008	1989-93, 1996-	20

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 613 years of measurements at Norwegian glaciers. The following tables show winter (bw), summer (bs) and net balance (bn) together with cumulative net balance (Cum. bn) and equilibrium line altitude (ELA) for each year at every glacier. In front of each table there is a heading containing the name and the area of the glacier. The reported year (in brackets) corresponds to the given area.

1 Ålfotbreen - 4.0 km^2 (2010)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	2,49	-3,59	-1,09	-1,09	1300
2	64	2,69	-2,41	0,28	-0,82	1140
3	65	3,64	-3,16	0,48	-0,34	1150
4	66	2,47	-4,08	-1,61	-1,95	>1380
5	67	4,46	-3,18	1,28	-0,66	950
6	68	4,55	-3,60	0,95	0,29	1075
7	69	2,66	-4,83	-2,17	-1,89	>1380
8	1970	2,60	-3,83	-1,23	-3,12	>1380
9	71	4,29	-3,35	0,94	-2,18	1140
10	72	3,82	-3,70	0,12	-2,06	1195
11	73	4,67	-2,49	2,18	0,13	<870
12	74	3,57	-2,54	1,03	1,15	1065
13	75	4,64	-3,43	1,21	2,37	1050
14	76	4,40	-2,87	1,53	3,89	<870
15	77	2,33	-2,89	-0,56	3,33	1280
16	78	2,56	-3,07	-0,51	2,82	1290
17	79	3,28	-3,41	-0,13	2,70	1240
18	1980	2,51	-3,30	-0,79	1,90	1275
19	81	4,04	-3,82	0,22	2,12	1210
20	82	3,35	-3,48	-0,13	1,99	1240
21	83	4,79	-3,19	1,60	3,60	1010
22	84	4,09	-2,77	1,32	4,92	1050
23	85	2,44	-3,00	-0,56	4,36	1290
24	86	2,35	-2,76	-0,41	3,95	1255
25	87	4,29	-2,22	2,07	6,02	<870
26	88	2,73	-5,21	-2,48	3,54	>1380
27	89	5,20	-2,93	2,27	5,81	1030
28	1990	5,98	-4,19	1,79	7,61	995
29	91	4,09	-3,30	0,79	8,40	1035
30	92	5,48	-3,19	2,29	10,69	1050
31	93	4,81	-2,74	2,07	12,76	<870
32	94	3,71	-2,92	0,79	13,54	925
33	95	5,10	-3,90	1,20	14,75	1120
34	96	1,83	-3,71	-1,88	12,87	>1380
35	97	4,22	-4,14	0,08	12,95	1200
36	98	3,66	-3,55	0,11	13,06	1240
37	99	4,61	-4,55	0,06	13,11	1245
38	2000	5,57	-3,58	1,99	15,10	1025
39	01	1,86	-3,95	-2,09	13,01	>1382
40	02	3,78	-5,31	-1,53	11,48	>1382
41	03	2,52	-5,03	-2,50	8,98	>1382
42	04	3,32	-3,42	-0,10	8,88	1225
43	05	4,99	-4,32	0,67	9,55	1135
44	06	2,69	-5,88	-3,19	6,36	>1382
45	07	4,49	-3,22	1,27	7,63	1000
46	08	4,04	-3,35	0,68	8,31	1130
47	09	3,84	-4,00	-0,17	8,14	1240
48	2010	2,19	-4,03	-1,84	6,30	>1368
Mean 1963-2010		3,70	-3,57	0,13		

2 Hansebreen - 2.8 km^2 (2010)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1986	2,28	-2,87	-0,58	-0,58	1200
2	87	3,76	-2,63	1,13	0,54	1100
3	88	2,50	-5,25	-2,75	-2,21	>1320
4	89	4,13	-3,71	0,42	-1,79	1140
5	1990	4,42	-4,10	0,32	-1,47	1140
6	91	3,37	-3,11	0,26	-1,21	1125
7	92	4,41	-3,43	0,97	-0,23	1125
8	93	4,23	-3,15	1,08	0,85	<925
9	94	3,39	-2,97	0,43	1,28	1120
10	95	4,38	-3,90	0,48	1,76	1140
11	96	1,74	-3,76	-2,02	-0,26	>1320
12	97	3,77	-3,92	-0,15	-0,41	1160
13	98	3,21	-3,51	-0,30	-0,71	1170
14	99	4,30	-4,19	0,11	-0,60	1155
15	2000	4,69	-3,82	0,86	0,26	1075
16	01	1,71	-4,43	-2,72	-2,46	>1327
17	02	3,51	-5,44	-1,93	-4,39	>1327
18	03	2,45	-5,12	-2,67	-7,06	>1327
19	04	2,87	-3,38	-0,50	-7,56	1220
20	05	4,52	-4,61	-0,09	-7,65	1150
21	06	2,45	-6,43	-3,98	-11,63	>1327
22	07	4,07	-3,23	0,85	-10,79	1042
23	08	3,90	-3,65	0,26	-10,53	1125
24	09	3,45	-4,42	-0,97	-11,50	>1327
25	2010	2,10	-4,31	-2,22	-13,71	>1310
Mean 1986-2010		3,42	-3,97	-0,55		

3 Blomsterskardsbreen - 45.7 km^2 (1959)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1970			0,00	0,00	1370
2	71	2,85	-1,87	0,98	0,98	1240
3	72			0,32	1,30	1340
4	73			1,57	2,87	1180
5	74			0,51	3,38	1325
6	75			1,70	5,08	1170
7	76			1,40	6,48	1210
8	77			-1,40	5,08	>1640
Mean 1971-77				0,73		

3a Svelgjabreen - 22.5 km^2 (2007)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2007	3,89	-2,54	1,35	1,35	1205
2	08	3,38	-2,65	0,72	2,07	1235
3	09	3,33	-2,97	0,36	2,43	1310
4	2010	1,65	-3,29	-1,64	0,78	>1636
Mean 2007-10		3,06	-2,87	0,20		

3b Blomstølskardsbreen - 22.8 km^2 (2007)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2007	4,17	-2,30	1,88	1,88	1230
2	08	3,44	-2,14	1,30	3,18	1265
3	09	3,59	-2,52	1,07	4,24	1290
4	2010	1,85	-3,07	-1,23	3,02	>1636
Mean 2007-10		3,26	-2,51	0,75		

4 Bondhusbrea - 10.7 km^2 (1979)

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

5 Breidablikkbrea - 3.4 km^2 (2007)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	1.11	-2.32	-1.21	-1.21	1635
2	64	1.918	-1.68	0.23	-0.98	1450
3	65	1.72	-2.28	-0.56	-1.54	1525
4	66	1.52	-3.17	-1.65	-3.19	>1660
5	67	3.40	-2.23	1.17	-2.02	1355
6	68	3.55	-2.68	0.87	-1.15	1360
7	2003	2.12	-4.38	-2.26	-2.26	>1651
8	04	2.25	-3.12	-0.87	-3.13	1595
9	05	3.04	-3.37	-0.33	-3.45	1510
10	06	1.49	-4.44	-2.95	-6.40	>1651
11	07	3.42	-3.07	0.36	-6.05	1410
12	08	2.66	-2.96	-0.30	-6.34	1515
13	09	2.47	-2.98	-0.52	-6.86	1565
14	2010	1.60	-3.53	-1.94	-8.80	>1651
Mean 1963-68		2.20	-2.39	-0.19		
Mean 2003-10		2.38	-3.48	-1.10		

6 Gråfjellsbrea - 8.4 km^2 (2007)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1964	1.94	-1.62	0.32	0.32	1385
2	65	2.01	-2.29	-0.28	0.04	1490
3	66	1.58	-2.93	-1.35	-1.31	>1660
4	67	3.46	-2.14	1.31	0.00	1355
5	68	3.39	-2.82	0.57	0.57	1380
6	1974	2.11	-1.53	0.58	0.58	1370
7	75	2.53	-2.28	0.25	0.83	1420
8	2003	1.91	-4.09	-2.18	-2.18	>1651
9	04	2.05	-2.82	-0.76	-2.95	1565
10	05	3.15	-3.13	0.02	-2.93	1460
11	06	1.40	-4.55	-3.15	-6.07	>1651
12	07	3.60	-2.85	0.75	-5.32	1395
13	08	2.66	-2.80	-0.14	-5.46	1490
14	09	2.34	-2.88	-0.54	-6.00	1540
15	2010	1.51	-3.35	-1.84	-7.84	>1651
Mean 1964-68		2.48	-2.36	0.11		
Mean 1974-75		2.32	-1.90	0.41		
Mean 2003-10		2.33	-3.31	-0.98		

7 Blåbreen and Ruklebreen - 4.5 km^2 (1959)

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

$^{1)}$ Blåbreen only

8 Midtre Folgefonna - 8.7 km^2 (1959)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1970	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 km^2 (1993)

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

10 Vesledalsbreen - 4.2 km^2 (1966)

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

11 Tunsbergdalsbreen - 50.1 km^2 (1964)

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

12 Nigardsbreen - 47.2 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	2.88	-0.63	2.25	2.25	1260
2	63	1.87	-2.09	-0.23	2.02	1550
3	64	2.13	-1.18	0.95	2.97	1400
4	65	2.29	-1.38	0.90	3.87	1395
5	66	1.76	-2.68	-0.92	2.95	1700
6	67	3.40	-1.24	2.16	5.11	1310
7	68	2.72	-2.50	0.22	5.33	1550
8	69	1.95	-3.26	-1.31	4.02	1850
9	1970	1.73	-2.29	-0.56	3.46	1650
10	71	2.11	-1.29	0.82	4.28	1400
11	72	1.88	-2.02	-0.14	4.14	1570
12	73	2.40	-1.30	1.11	5.25	1410
13	74	2.06	-1.58	0.48	5.73	1490
14	75	2.50	-2.23	0.27	6.00	1450
15	76	2.88	-2.48	0.40	6.40	1540
16	77	1.52	-2.29	-0.77	5.63	1650
17	78	2.12	-2.25	-0.13	5.50	1590
18	79	2.75	-2.04	0.71	6.21	1500
19	1980	1.77	-2.99	-1.22	4.99	1730
20	81	2.19	-1.88	0.32	5.31	1560
21	82	1.93	-2.35	-0.42	4.89	1600
22	83	3.02	-1.93	1.09	5.98	1445
23	84	2.49	-2.15	0.34	6.32	1500
24	85	1.77	-1.87	-0.10	6.22	1590
25	86	1.61	-1.71	-0.10	6.12	1590
26	87	2.73	-1.25	1.48	7.60	1350
27	88	2.24	-3.13	-0.90	6.70	1660
28	89	4.05	-0.85	3.20	9.90	1175
29	1990	3.52	-1.75	1.76	11.66	1430
30	91	1.95	-1.75	0.20	11.86	1520
31	92	3.16	-1.56	1.60	13.46	1360
32	93	3.13	-1.28	1.85	15.31	1300
33	94	2.28	-1.72	0.57	15.88	1400
34	95	3.16	-1.97	1.19	17.07	1320
35	96	1.40	-1.81	-0.41	16.66	1660
36	97	2.66	-2.62	0.04	16.69	1500
37	98	2.50	-1.53	0.97	17.67	1350
38	99	2.38	-2.21	0.17	17.84	1470
39	2000	3.38	-1.66	1.72	19.56	1250
40	01	1.75	-1.97	-0.22	19.34	1560
41	02	2.41	-3.30	-0.89	18.46	1715
42	03	1.56	-2.72	-1.16	17.30	>1960
43	04	1.97	-2.01	-0.04	17.25	1530
44	05	2.80	-1.70	1.10	18.35	1395
45	06	1.75	-3.15	-1.40	16.95	1850
46	07	3.09	-2.05	1.05	18.00	1320
47	08	3.01	-1.92	1.10	19.10	1325
48	09	2.20	-1.96	0.24	19.34	1465
49	2010	1.47	-2.27	-0.80	18.54	1770
Mean 1962-2010		2.37	-2.00	0.38		

13 Store Supphellebreen - 12.0 km^2 (1966)

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

14 Austdalsbreen - 10.6 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1988	1,94	-3,22	-1,28	-1,28	1570
2	89	3,18	-1,34	1,84	0,56	1275
3	1990	3,65	-2,45	1,20	1,76	1310
4	91	1,64	-1,64	0,00	1,76	1435
5	92	2,80	-2,26	0,54	2,30	1375
6	93	2,60	-1,69	0,91	3,21	1320
7	94	1,81	-1,88	-0,07	3,14	1425
8	95	2,72	-2,10	0,62	3,76	1360
9	96	1,20	-2,27	-1,07	2,69	1565
10	97	2,67	-3,20	-0,53	2,16	1450
11	98	2,20	-2,01	0,19	2,35	1420
12	99	2,08	-2,56	-0,48	1,87	1435
13	2000	2,77	-1,66	1,11	2,98	1315
14	01	1,04	-2,66	-1,62	1,36	>1757
15	02	1,91	-3,92	-2,01	-0,65	>1757
16	03	1,60	-3,94	-2,34	-2,99	>1757
17	04	1,60	-2,56	-0,96	-3,95	1495
18	05	2,85	-2,66	0,19	-3,76	1385
19	06	1,32	-3,38	-2,06	-5,82	>1757
20	07	2,46	-2,28	0,18	-5,64	1405
21	08	2,55	-2,62	-0,07	-5,71	1420
22	09	1,92	-2,62	-0,70	-6,41	1475
23	2010	1,03	-3,03	-2,00	-8,41	<1747
Mean 1988-2010		2,15	-2,52	-0,37		

15 Spørteggbreen - 27.9 km^2 (1988)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1988	1,61	-3,15	-1,54	-1,54	>1770
2	89	2,76	-1,62	1,14	-0,40	1410
3	1990	3,34	-2,33	1,01	0,61	1390
4	91	1,40	-1,37	0,03	0,64	1540
Mean 1988-91		2,28	-2,12	0,16		

16 Harbardsbreen - 13.2 km^2 (1996)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1997	2,17	-2,72	-0,55	-0,55	>1960
2	98	1,66	-1,60	0,06	-0,49	1500
3	99	1,81	-2,15	-0,34	-0,83	>1960
4	2000	2,30	-1,52	0,78	-0,05	1250
5	01	0,88	-1,99	-1,11	-1,16	>1960
Mean 1997-2001		1,76	-2,00	-0,23		

17 Rembesdalsskåka - 17.3 km^2 (2010)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1963	1,15	-2,55	-1,40	-1,40	>1860
2	64	1,85	-1,41	0,44	-0,96	1620
3	65	2,05	-1,54	0,51	-0,45	1620
4	66	1,60	-2,24	-0,64	-1,09	1750
5	67	2,44	-1,25	1,19	0,10	1540
6	68	2,68	-2,15	0,53	0,63	1600
7	69	1,07	-2,97	-1,90	-1,27	>1860
8	1970	1,29	-1,89	-0,60	-1,87	1780
9	71	2,02	-1,28	0,74	-1,13	1600
10	72	1,78	-1,86	-0,08	-1,21	1650
11	73	2,62	-1,79	0,83	-0,38	1570
12	74	1,91	-1,50	0,41	0,03	1615
13	75	2,25	-2,10	0,15	0,18	1620
14	76	2,45	-2,30	0,15	0,33	1620
15	77	1,20	-1,92	-0,72	-0,39	>1860
16	78	1,80	-2,10	-0,30	-0,69	
17	79	2,40	-2,10	0,30	-0,39	
18	1980	1,45	-2,85	-1,40	-1,79	>1860
19	81	2,65	-1,80	0,85	-0,94	1590
20	82	1,40	-2,10	-0,70	-1,64	1800
21	83	3,75	-2,05	1,70	0,06	1450
22	84	2,05	-2,15	-0,10	-0,04	1675
23	85	1,48	-2,00	-0,52	-0,56	1715
24	86	1,47	-1,57	-0,10	-0,66	1670
25	87	2,08	-1,14	0,94	0,28	1535
26	88	1,61	-3,13	-1,52	-1,24	1860
27	89	3,48	-1,37	2,11	0,87	1420
28	1990	3,65	-1,72	1,93	2,80	1450
29	91	1,52	-1,61	-0,09	2,71	1660
30	92	3,71	-1,72	1,99	4,70	1525
31	93	2,82	-0,91	1,91	6,61	1450
32	94	1,79	-1,63	0,16	6,77	1600
33	95	2,44	-2,14	0,30	7,07	1575
34	96	0,99	-2,10	-1,11	5,96	>1860
35	97	2,94	-3,41	-0,47	5,49	1700
36	98	2,47	-1,78	0,69	6,18	1585
37	99	2,04	-1,99	0,05	6,23	1685
38	2000	2,93	-1,50	1,43	7,66	1425
39	01	1,03	-1,88	-0,85	6,81	1760
40	02	2,39	-3,10	-0,71	6,10	1750
41	03	1,33	-2,69	-1,36	4,74	>1860
42	04	1,89	-1,81	0,08	4,82	1670
43	05	2,79	-2,07	0,72	5,54	1590
44	06	0,90	-3,12	-2,22	3,32	>1860
45	07	3,10	-1,93	1,17	4,49	1570
46	08	2,61	-2,16	0,45	4,94	1610
47	09	2,37	-2,21	0,15	5,09	1655
48	2010	1,28	-2,78	-1,50	3,59	<1854
Mean 1963-2010		2,10	-2,03	0,07		

18 Midtdalsbreen - 6.7 km^2 (1995)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2000	2,89	-1,57	1,32	1,32	1500
2	01	1,26	-1,90	-0,64	0,68	1785
Mean 2000-2001		2,08	-1,74	0,34		

19 Omnsbreen - 1.5 km^2 (1969)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1966	1,44	-2,28	-0,84	-0,84	
2	67	2,21	-1,72	0,49	-0,35	
3	68	2,20	-2,38	-0,18	-0,53	1520
4	69	1,09	-3,68	-2,59	-3,12	
5	1970	1,12	-2,62	-1,50	-4,62	
Mean 1966-70		1,61	-2,54	-0,92		

20 Tverråbreen - 5.9 km^2

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	2,03	-1,28	0,75	0,75	
2	63	1,24	-2,46	-1,22	-0,47	
Mean 1962-63		1,64	-1,87	-0,24		

21 Blåbreen - 3.6 km^2 (1961)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	1,15	-0,35	0,80	0,80	<1550
2	63	0,85	-1,71	-0,86	-0,06	1970
Mean 1962-63		1,00	-1,03	-0,03		

22 Storbreen - 5.1 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	49	2,28	-2,08	0,20	0,20	1650
2	1950	1,52	-1,81	-0,29	-0,09	1750
3	51	1,13	-1,67	-0,54	-0,63	1770
4	52	1,44	-1,13	0,31	-0,32	1630
5	53	1,40	-2,25	-0,85	-1,17	1850
6	54	1,21	-1,98	-0,77	-1,94	1830
7	55	1,57	-2,06	-0,49	-2,43	1800
8	56	1,31	-1,48	-0,17	-2,60	1705
9	57	1,42	-1,37	0,05	-2,55	1680
10	58	1,54	-1,62	-0,08	-2,63	1700
11	59	1,07	-2,35	-1,28	-3,91	1930
12	1960	0,98	-2,07	-1,09	-5,00	1910
13	61	1,10	-1,62	-0,52	-5,52	1820
14	62	1,54	-0,82	0,72	-4,80	1510
15	63	0,96	-2,14	-1,18	-5,98	1900
16	64	1,16	-0,95	0,21	-5,77	1655
17	65	1,54	-1,20	0,34	-5,43	1650
18	66	1,25	-1,86	-0,61	-6,04	1815
19	67	1,89	-1,17	0,72	-5,32	1570
20	68	1,64	-1,59	0,05	-5,27	1700
21	69	1,22	-2,64	-1,42	-6,69	2020
22	1970	0,97	-1,69	-0,72	-7,41	1840
23	71	1,46	-1,28	0,18	-7,23	1690
24	72	1,39	-1,70	-0,31	-7,54	1770
25	73	1,48	-1,40	0,08	-7,46	1705
26	74	1,26	-1,02	0,24	-7,22	1630
27	75	1,55	-1,70	-0,15	-7,37	1760
28	76	1,81	-1,90	-0,09	-7,46	1740
29	77	0,94	-1,48	-0,54	-8,00	1840
30	78	1,26	-1,70	-0,44	-8,44	1815
31	79	1,55	-1,45	0,10	-8,34	1700
32	1980	0,99	-2,30	-1,31	-9,65	1975
33	81	1,30	-1,40	-0,10	-9,75	1730
34	82	1,28	-1,75	-0,47	-10,22	1785
35	83	1,90	-1,70	0,20	-10,02	1625
36	84	1,70	-2,00	-0,30	-10,32	1765
37	85	1,20	-1,60	-0,40	-10,72	1790
38	86	1,05	-1,37	-0,32	-11,04	1770
39	87	1,55	-1,23	0,32	-10,72	1570
40	88	1,45	-2,40	-0,95	-11,67	1970
41	89	2,30	-1,10	1,20	-10,47	1550
42	1990	2,60	-1,35	1,25	-9,22	1530
43	91	1,26	-1,41	-0,15	-9,37	1740
44	92	1,61	-1,53	0,08	-9,29	1715
45	93	1,81	-1,06	0,75	-8,54	1605
46	94	1,52	-1,77	-0,25	-8,79	1800
47	95	1,77	-1,93	-0,16	-8,95	1810
48	96	0,81	-1,84	-1,03	-9,98	1890
49	97	1,75	-2,78	-1,03	-11,01	1875
50	98	1,55	-1,33	0,22	-10,79	1680
51	99	1,67	-1,91	-0,24	-11,03	1830
52	2000	2,04	-1,49	0,55	-10,48	1650
53	01	1,05	-1,32	-0,27	-10,75	1845
54	02	1,09	-2,87	-1,78	-12,53	2075
55	03	1,11	-2,68	-1,57	-14,10	2025
56	04	1,01	-1,59	-0,58	-14,68	1855
57	05	1,83	-1,89	-0,06	-14,74	1795
58	06	0,86	-3,01	-2,15	-16,89	>2100
59	07	1,35	-1,74	-0,39	-17,28	1835
60	08	1,99	-1,88	0,11	-17,17	1770
61	09	1,60	-1,83	-0,22	-17,39	1760
62	2010	0,79	-2,55	-1,76	-19,16	1990
Mean 1949-2010		1,43	-1,74	-0,31		

24 Austre Memurubre - 8.7 km^2 (1966)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1968	1,77	-1,76	0,01	0,01	1960
2	69	0,99	-2,45	-1,46	-1,45	2130
3	1970	0,81	-1,71	-0,90	-2,35	2090
4	71	1,33	-1,51	-0,18	-2,53	1960
5	72	1,02	-1,42	-0,40	-2,93	1985
Mean 1968-72		1,18	-1,77	-0,59		

25 Juvfonne - 0.2 km^2 (2004)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	2010	0,67	-3,91	-3,24	-3,24	<1998
Mean 2010-						

26 Hellstugubreen - 2.9 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	1,18	-0,40	0,78	0,78	
2	63	0,94	-1,92	-0,98	-0,20	2020
3	64	0,71	-0,83	-0,12	-0,32	1900
4	65	1,29	-0,77	0,52	0,20	1690
5	66	0,95	-1,62	-0,67	-0,47	1940
6	67	1,48	-0,93	0,55	0,08	1800
7	68	1,38	-1,49	-0,11	-0,03	1875
8	69	0,95	-2,23	-1,28	-1,31	2130
9	1970	0,70	-1,70	-1,00	-2,31	2020
10	71	1,12	-1,25	-0,13	-2,44	1860
11	72	0,94	-1,43	-0,49	-2,93	1950
12	73	1,20	-1,41	-0,21	-3,14	1880
13	74	1,00	-0,76	0,24	-2,90	1785
14	75	1,35	-1,71	-0,36	-3,26	1950
15	76	1,16	-1,89	-0,73	-3,99	1970
16	77	0,68	-1,40	-0,72	-4,71	2075
17	78	1,05	-1,59	-0,54	-5,25	1890
18	79	1,43	-1,45	-0,02	-5,27	1820
19	1980	0,81	-2,05	-1,24	-6,51	2050
20	81	1,06	-1,39	-0,33	-6,84	1950
21	82	0,85	-1,20	-0,35	-7,19	1920
22	83	1,47	-1,30	0,17	-7,02	1820
23	84	1,22	-1,73	-0,51	-7,53	1965
24	85	1,11	-1,40	-0,29	-7,82	1880
25	86	0,78	-1,27	-0,49	-8,31	1940
26	87	1,15	-0,70	0,45	-7,86	1690
27	88	1,28	-2,32	-1,04	-8,90	2025
28	89	1,62	-0,90	0,72	-8,18	1660
29	1990	1,81	-1,15	0,66	-7,52	1640
30	91	0,98	-1,43	-0,45	-7,97	1950
31	92	1,17	-1,03	0,14	-7,83	1850
32	93	1,25	-0,95	0,30	-7,53	1670
33	94	1,26	-1,19	0,07	-7,46	1850
34	95	1,42	-1,54	-0,12	-7,58	1885
35	96	0,65	-1,39	-0,74	-8,32	1955
36	97	1,12	-2,77	-1,65	-9,97	2200
37	98	1,00	-1,02	-0,02	-9,99	1870
38	99	1,22	-1,64	-0,42	-10,41	1930
39	2000	1,26	-1,16	0,10	-10,31	1840
40	01	0,85	-1,21	-0,36	-10,67	1910
41	02	0,96	-2,37	-1,41	-12,08	2080
42	03	0,71	-2,23	-1,52	-13,60	2200
43	04	0,65	-1,49	-0,84	-14,44	1980
44	05	1,34	-1,63	-0,29	-14,73	1930
45	06	0,73	-2,74	-2,01	-16,74	>2210
46	07	1,03	-1,70	-0,67	-17,41	1975
47	08	1,41	-1,47	-0,06	-17,47	1880
48	09	1,30	-1,53	-0,23	-17,70	1920
49	2010	0,75	-2,09	-1,34	-19,04	2230
Mean 1962-2010		1,10	-1,49	-0,39		

27 Gråsubreen - 2.1 km^2 (2009)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1962	0,86	-0,09	0,77	0,77	1870
2	63	0,40	-1,11	-0,71	0,06	2275
3	64	0,39	-0,71	-0,32	-0,26	2160
4	65	0,77	-0,36	0,41	0,15	1900
5	66	0,72	-1,01	-0,29	-0,14	2150
6	67	1,45	-0,74	0,71	0,57	1870
7	68	1,03	-1,11	-0,08	0,49	2140
8	69	0,74	-2,04	-1,30	-0,81	2275
9	1970	0,57	-1,23	-0,66	-1,47	2200
10	71	0,49	-0,96	-0,47	-1,94	2200
11	72	0,66	-1,30	-0,64	-2,58	2240
12	73	0,72	-1,61	-0,89	-3,47	2275
13	74	0,58	-0,24	0,34	-3,13	1870
14	75	0,91	-1,86	-0,95	-4,08	2275
15	76	0,62	-1,62	-1,00	-5,08	2275
16	77	0,51	-0,90	-0,39	-5,47	2275
17	78	0,67	-0,89	-0,22	-5,69	2140
18	79	0,91	-0,87	0,04	-5,65	2025
19	1980	0,46	-1,35	-0,89	-6,54	2225
20	81	0,62	-0,81	-0,19	-6,73	2180
21	82	0,50	-1,01	-0,51	-7,24	2275
22	83	0,94	-0,99	-0,05	-7,29	2090
23	84	0,98	-1,35	-0,37	-7,66	2275
24	85	0,75	-0,75	0,00	-7,66	2100
25	86	0,42	-1,18	-0,76	-8,42	2275
26	87	0,94	-0,22	0,72	-7,70	1870
27	88	1,08	-1,66	-0,58	-8,28	2195
28	89	1,12	-0,67	0,45	-7,83	1870
29	1990	1,33	-0,60	0,73	-7,10	1870
30	91	0,67	-1,19	-0,52	-7,62	1950
31	92	0,70	-0,80	-0,10	-7,72	Undef.
32	93	0,93	-0,51	0,42	-7,30	<1850
33	94	1,16	-1,16	0,00	-7,30	2075
34	95	1,19	-1,30	-0,11	-7,41	2180
35	96	0,53	-0,98	-0,45	-7,86	2205
36	97	0,70	-2,39	-1,69	-9,55	>2290
37	98	0,78	-0,67	0,11	-9,44	Undef.
38	99	0,91	-1,30	-0,39	-9,83	2210
39	2000	0,87	-0,92	-0,05	-9,88	Undef.
40	01	0,80	-0,78	0,02	-9,86	2070
41	02	0,63	-2,05	-1,42	-11,28	>2290
42	03	0,45	-1,84	-1,39	-12,67	>2290
43	04	0,48	-0,97	-0,49	-13,16	2210
44	05	0,83	-1,33	-0,50	-13,66	2180
45	06	0,51	-2,59	-2,08	-15,74	>2290
46	07	0,61	-1,32	-0,71	-16,45	2265
47	08	0,95	-0,86	0,08	-16,36	Undef.
48	09	0,81	-1,08	-0,28	-16,64	2235
49	2010	0,54	-1,60	-1,06	-17,70	2250
Mean 1962-2010		0,76	-1,12	-0,36		

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

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1970			-1,90	-1,90	
2	71			0,47	-1,43	
3	72			-1,04	-2,47	
4	73			1,44	-1,03	
Mean 1970-73				-0,26		

29 Austre Okstindbre - 14.0 km^2 (1962)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1987	2,30	-1,60	0,70	0,70	1280
2	88	1,50	-3,40	-1,90	-1,20	>1750
3	89	3,70	-2,20	1,50	0,30	1275
4	1990	3,00	-2,70	0,30	0,60	1310
5	91	1,80	-2,30	-0,50	0,10	1315
6	92	2,88	-1,65	1,23	1,33	1260
7	93	2,22	-2,01	0,21	1,54	1290
8	94	1,45	-1,62	-0,17	1,37	1310
9	95	2,25	-1,79	0,46	1,83	1280
10	96	1,62	-1,92	-0,30	1,53	1330
Mean 1987-96		2,27	-2,12	0,15		

30 Høgtuvbreen - 2.6 km^2 (1972)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1971	3,05	-3,78	-0,73	-0,73	950
2	72	3,34	-4,30	-0,96	-1,69	970
3	73	3,90	-2,82	1,08	-0,61	720
4	74	3,46	-3,68	-0,22	-0,83	900
5	75	3,00	-2,27	0,73	-0,10	760
6	76	3,66	-2,75	0,91	0,81	730
7	77	2,20	-2,72	-0,52	0,29	900
Mean 1971-77		3,23	-3,19	0,04		

31 Svartisheibreen - 5.5 km^2 (1985)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1988	2,42	-4,03	-1,61	-1,61	1180
2	89	3,72	-1,36	2,36	0,75	900
3	1990	3,79	-2,97	0,82	1,57	930
4	91	2,61	-2,44	0,17	1,74	950
5	92	3,89	-2,68	1,21	2,95	890
6	93	3,50	-2,59	0,91	3,86	910
7	94	1,83	-1,85	-0,02	3,84	975
Mean 1988-94		3,11	-2,56	0,55		

32 Engabreen - 38.7 km^2 (2008)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	1970	2,05	-3,04	-0,99	-0,99	1280
2	71	3,20	-2,19	1,01	0,02	1070
3	72	3,22	-3,29	-0,07	-0,05	1150
4	73	4,37	-1,65	2,72	2,67	830
5	74	3,39	-2,59	0,80	3,47	1030
6	75	3,18	-1,57	1,61	5,08	960
7	76	3,86	-1,45	2,41	7,49	910
8	77	2,08	-1,20	0,88	8,37	1000
9	78	2,48	-2,99	-0,51	7,86	1250
10	79	3,64	-3,22	0,42	8,28	1130
11	1980	2,68	-3,18	-0,50	7,78	1270
12	81	2,91	-1,93	0,98	8,76	965
13	82	2,27	-1,43	0,84	9,60	1030
14	83	2,34	-1,28	1,06	10,66	1020
15	84	3,83	-2,78	1,05	11,71	1000
16	85	1,50	-2,40	-0,90	10,81	1375
17	86	2,70	-2,45	0,25	11,06	1170
18	87	2,57	-1,63	0,94	12,00	1000
19	88	2,26	-4,05	-1,79	10,21	1400
20	89	4,62	-1,45	3,17	13,38	890
21	1990	3,49	-2,64	0,85	14,23	1035
22	91	2,83	-2,14	0,69	14,92	1090
23	92	4,05	-1,71	2,34	17,26	875
24	93	3,06	-2,02	1,04	18,30	985
25	94	1,95	-1,53	0,42	18,72	1050
26	95	3,50	-1,76	1,74	20,46	940
27	96	2,97	-2,14	0,83	21,29	970
28	97	4,44	-3,22	1,22	22,51	1010
29	98	2,98	-2,77	0,21	22,72	1100
30	99	2,12	-2,15	-0,03	22,69	1215
31	2000	2,76	-1,27	1,49	24,18	970
32	01	1,05	-2,58	-1,53	22,65	>1594
33	02	2,89	-3,48	-0,59	22,06	1200
34	03	2,41	-3,00	-0,59	21,47	1195
35	04	2,92	-2,10	0,82	22,29	1040
36	05	3,31	-2,42	0,89	23,18	1060
37	06	1,76	-3,12	-1,36	21,82	1325
38	07	3,40	-2,30	1,10	22,92	1035
39	08	2,81	-2,50	0,31	23,23	1093
40	09	2,87	-2,90	-0,03	23,20	1170
41	2010	2,04	-2,56	-0,52	22,67	1240
Mean 1970-2010		2,90	-2,34	0,55		

33 Storglombreen - 62.4 km^2 (1968)

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

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

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

35 Glombreen - 2.2 km^2 (1953)

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

36 Kjølbreen - 3.9 km^2 (1953)

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

37 Trollbergdalsbreen - 1.6 km^2 (1985)

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

38 Rundvassbreen - 11.6 km^2 (1998)

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

39 Blåisen - 2.2 km^2 (1960)

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

40 Storsteinsfjellbreen - 5.9 km^2 (1993)

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

41 Cainhavarre - 0.7 km^2 (1960)

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

42 Svartfjelljøkelen - 2.7 km^2 (1966)

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

43 Langfjordjøkelen - 3.2 km^2 (2008)

No. of years	Year	bw	bs	bn	Cum. bn	ELA
		(m w.e.)		(m w.e.)		(m a.s.l.)
1	89	2.40	-2.96	-0.55	-0.55	870
2	1990	2.74	-3.06	-0.32	-0.88	780
3	91	2.31	-2.31	0.00	-0.87	710
4	92	2.68	-2.49	0.19	-0.69	700
5	93	2.55	-2.35	0.20	-0.49	740
6	96	2.25	-2.23	0.02	0.02	700
7	97	2.65	-3.34	-0.69	-0.67	820
8	98	1.80	-3.24	-1.44	-2.11	>1050
9	99	1.33	-2.91	-1.57	-3.68	970
10	2000	2.51	-3.12	-0.61	-4.29	860
11	01	1.36	-3.64	-2.28	-6.57	>1050
12	02	2.19	-3.73	-1.54	-8.12	>1050
13	03	2.44	-3.51	-1.07	-9.18	>1050
14	04	1.69	-3.61	-1.92	-11.10	>1050
15	05	1.88	-3.14	-1.25	-12.35	935
16	06	1.42	-3.83	-2.41	-14.77	>1050
17	07	2.09	-2.90	-0.81	-15.58	870
18	08	1.67	-2.02	-0.35	-15.93	835
19	09	1.88	-3.21	-1.32	-17.25	>1050
20	2010	1.89	-2.65	-0.76	-18.01	1005
Mean 1989-1993		2.54	-2.63	-0.10		
Mean 1996-2010		1.94	-3.14	-1.20		

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