Glaciological investigations in Norway 2011-2015

Bjarne Kjøllmoen (Ed.)

88
2016

RAPPORT

Rapport nr 88-2016
Glaciological investigations in Norway 2011-2015

Utgitt av: Norwegian Water Resources and Energy Directorate

Redaktør: Bjarne Kjøllmoen

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Trykk: NVE
Opplag: 200
Forsidefoto: Oda Jonette Røyset
ISBN 978-82-410-1541-0
ISSN 1501-2832

Sammendrag: Results of glaciological investigations performed at Norwegian glaciers in 2011, 2012, 2013, 2014 and 2015 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.

Emneord: Glaciology, Mass balance, Glacier length change, Glacier velocity, Meteorology, Jøkulhlaup, Laser scanning, Subglacial laboratory

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December 2016

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The Norwegian Water Resources and Energy Directorate (NVE)
2016

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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, Ice and Snow over the years 2011-2015. 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 is 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, November 2016

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Summary

Mass balance

Mass balance investigations were performed on sixteen glaciers in Norway over the years 2011-2013 and on fourteen glaciers in 2014 and 2015.

2011

The winter balance for all the reference glaciers (glaciers with a mass balance record longer than 30 years) was lower than the average of the reference period 1971-2000 and the summer balance was greater than the 1971-2000 average. Hellstugubreen in Jotunheimen had the greatest summer balance (−2.9 m w.e.) since measurements started in 1962. The annual balance was negative for all sixteen measured glaciers. Hellstugubreen had the greatest deficit (−2.0 m w.e.) since 1962.

2012

The winter balance was greater than the 1971-2000 average for five of the reference glaciers. Gråsubreen had the lowest winter balance with 0.7 m w.e., which is 93 % of the average value for 1971-2000. The summer balance was lower than the 1971-2000 average for all reference glaciers except for Storbreen (100 %). The resulting annual balance was strongly positive for eleven of the measured glaciers. Langfjordjøkelen in western Finnmark was negative with −0.8 m w.e.

2013

The winter balance was lower than the 1971-2000 average for all reference glaciers except for Nigardsbreen (101 %). The summer balance was greater than the 1971-2000 average for all reference glaciers. Engabreen at Svartisen had the greatest summer balance (−4.1 m w.e.) since measurements started in 1970. The annual balance was negative for all sixteen measured glaciers.

2014

The winter balance for the reference glaciers was approximately equal to the 1971-2000 average and the summer balance was lower than the average. Rembesdalskåka at Hardangerjøkulen had the greatest summer balance (−3.5 m w.e.) since measurements started in 1963. The annual balance was thus negative for all fourteen measured glaciers.

2015

Genrally, the winter balance for the reference glaciers was greater than the 1971-2000 average and the summer balance was lower than the average. The annual balance was thus positive for all reference glaciers. Langfjordjøkelen however, had the nineteenth successive year with negative mass balance.

Glacier length change

In the period 2011-2015 glacier length changes were measured at 30 glaciers in southern Norway and 10 glaciers in northern Norway. Thirty eight of the glaciers had a decrease in length and two had a small advance over the 5-year period. The greatest retreats were observed at Bødalsbreen (635 m) and Briksdalsbreen (330 m), both outlets from Jostedalsbreen ice cap.

Sammendrag

Massebalanse

I perioden 2011-2013 ble det utført massebalansemålinger på 16 breer i Norge. I 2014 og 2015 ble det målt på fjorten breer.

2011

For referansebreene (breer med måleserie lenger enn 30 år) ble vinterbalansen mindre enn gjennomsnittet for referanseperioden 1971-2000, mens sommerbalansen ble større enn gjennomsnittet. Hellstugubreen i Jotunheimen hadde den største sommerbalansen (−2.9 m v.ekv.) siden målingene startet i 1962. Følgelig ble den årlige balansen negativ for alle de 16 målte breene. Hellstugubreen hadde det største underskuddet (−2.0 m v.ekv.) siden 1962.

2012

Vinterbalansen ble større enn gjennomsnittet for fem av referansebreene. Gråsubreen hadde den minste vinterbalansen med 0.7 m v.ekv., som er 93 % av 1971-2000. Sommerbalansen var mindre enn gjennomsnittet for alle referansebreene med unntak av Storbreen (100 %). Den årlige balansen var signifikant positiv for 11 av de målte breene. Langfjordjøkelen i Finnmark var negativ med −0.8 m v.ekv.

2013

Vinterbalansen var mindre enn gjennomsnittet og sommerbalansen større enn gjennomsnittet for alle referansebreene med unntak av Nigardsbreen der vinterbalansen var 101 %. Engabreen hadde den største sommerbalansen (−4.1 m v.ekv.) siden målingene startet i 1970. Den årlige balansen var negativ for alle de 16 målte breene.

2014

Vinterbalansen var omtrent som gjennomsnittet og sommerbalansen lavere enn gjennomsnittet for referansebreene. Rembesdalskåka hadde den største sommerbalansen (−3.5 m v.ekv.) siden målingene startet i 1963. Den årlige balansen var negativ for alle de 14 målte breene.

2015

Vinterbalansen var genrelt større enn gjennomsnittet og sommerbalansen mindre enn gjennom-snittet for alle referansebreene. Den årlige balansen ble dermed positiv for alle disse breene. Langfjordjøkelen hadde negativ massebalanse for 19. året på rad.

Lengdeendringer

I perioden 2011-2015 ble det målt lengdeendringer på 30 breer i Sør-Norge og 10 breer i Nord-Norge. Trettiåtte av breutløperne hadde tilbakegang og to hadde litt framgang i denne 5 års perioden. Størst tilbakegang ble målt på Bødalsbreen (635 m) og Briksdalsbreen (330 m), begge utløpere fra Jostedalsbreen.

1. Glacier investigations in Norway 2011-2015

1.1 Mass balance

Surface mass balance is the sum of surface accumulation and surface ablation and includes loss due to calving. The surface mass-balance series of the Norwegian Water Resources and Energy Directorate (NVE) contain annual (net), winter, and summer balances. If the winter balance is greater than the summer balance, the annual 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 annual balance is negative and the ice volume decreases.

Method

Methods used to measure mass balance in the field have in principle remained unchanged over the years, although the number of measurements has varied (Andreassen et al., 2005; 2016). With the experience gained from many years of measurements, the measurement network was simplified on individual glaciers at the beginning of the 1990s.

Winter balance

The winter balance is normally measured in April or May by probing to the previous year's summer surface along regular profiles or grids. Stake readings are used to verify the soundings 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 sounding alone, snow coring is also used to confirm the sounding 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 measurements on Langfjordjøkelen in May 2011. Photo: Ragnar Ekker.

Summer and annual balance

Summer and annual balances are obtained from stake measurements, usually performed in September or October. Below the glacier's equilibrium line the annual 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 annual 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 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.

Uncertainty

The uncertainty of the mass balance measurements depends on the uncertainty in the point measurements themselves, the uncertainty in spatial integration of the point measurements to glacier averaged values (representativeness, number of points and uncovered parts) and the uncertainty of the glacier reference area (uncertainties in area-altitude changes and ice-divides) (Zemp et al., 2013). The uncertainty of the point measurements are related to uncertainties in identifying the previous summer surface, in measurements of stakes and towers, in the density measurements and estimates and conversion to snow water equivalents.

As most of the factors are not easily quantified from independent measurements, a best qualified estimate is used to quantify the uncertainties (Andreassen et al., 2016). The determined values of uncertainties are therefore based on subjective estimates.

Mass balance program

Over the years 2011-2013(15) mass balance measurements were performed on 16(14) glaciers in Norway - thirteen in southern Norway and 3 in northern Norway. Included in this number is one small ice mass, Juvfonne, which can be characterised as an ice patch rather than a glacier (chap. 8). In southern Norway, 6 of the glaciers have been measured for 53 consecutive years or more. They constitute a west-east profile extending from the maritime Ålfotbreen glacier with an average winter balance of 3.6 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 67 years of measurements, while Engabreen at Svartisen has the longest series (46 years) in northern Norway. The location of the glaciers investigated is shown in Figure 1-2. A comprehensive review of the glacier mass balance and length measurements in Norway is given in Andreassen et al. (2005).

In the following chapters mass balance studies performed on Norwegian glaciers over the years 2011-2015 are reported.

The mass balance (winter, summer and annual balance) is given both in volume (m^3 water) and specific water equivalent (m w.e.) 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.

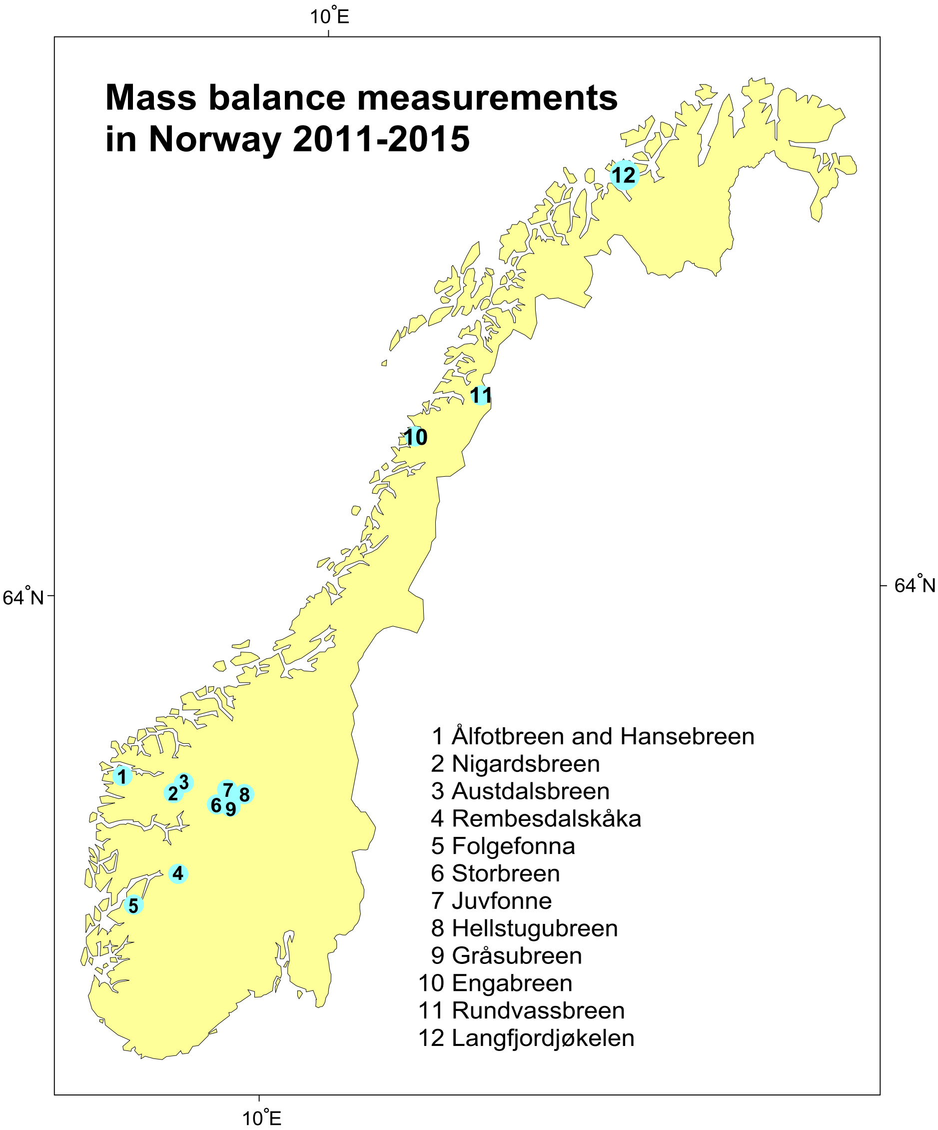


Figure 1-2
Location of the glaciers at which mass balance studies were performed over the years 2011-2015.

Weather conditions and mass balance results

2011

In general the 2010/2011 winter season was cold and dry, and the summer season was warm over the whole country.

The winter balance for all the reference glaciers was lower than the average of the reference period 1971-2000. The summer balance was greater than the 1971-2000 average at all the reference glaciers. Hellstugubreen in Jotunheimen had the greatest summer balance (−2.9 m w.e.) since measurements started in 1962. The annual balance was thus negative for all sixteen measured glaciers. Hellstugubreen had the greatest deficit (−2.0 m w.e.) since 1962.

The results from the mass balance measurements in Norway in 2011 are shown in Table 1-1.

Table 1-1
Summary of the results from mass balance measurements performed in Norway in 2011. The glaciers in southern Norway are listed from west to east.

Glacier	*Period*	*Area* *(km^2)*	*Altitude* *(m a.s.l.)*	*B_w* *(m)*	*% of ref.*	*B_s* *(m)*	*% of ref.*	*B_a* *(m)*	*B_a* *ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-11	4.0	890-1368	3.53	92	−4.38	130	−0.84	0.48	>1368	0
Hansebreen	1986-11	2.8	927-1310	3.43	[1]101	−4.68	[1]119	−1.25	[1]−0.55	>1310	0
Svelgjabreen	2007-11	22.3	829-1632	2.58	-	−3.84	-	−1.26	-	1525	20
Blomstølskardsbreen	2007-11	22.4	1012-1632	2.52	-	−3.49	-	−0.97	-	1600	5
Breidablikkbrea	1963-68 2003-11	3.9 3.2	1219-1660 1232-1648	1.88	[2]79	−4.16	[2]119	−2.28	−0.19 [2]−1.10	>1648	0
Gråfjellsbrea	1964-68 1974-75 2003-11	9.4 8.1	1039-1660 1049-1647	1.89	[2]81	−4.09	[2]124	−2.20	0.20 [2]−0.98	>1647	0
Nigardsbreen	1962-11	47.9	315-1957	1.72	76	−2.86	138	−1.13	0.21	1770	16
Austdalsbreen	1988-11	10.6	1200-1747	1.82	[3]83	[4]−3.26	[3]121	−1.44	[3]−0.51	>1747	0
Rembesdalskåka	1963-11	17.3	1066-1854	2.13	97	−3.40	175	−1.27	0.26	>1854	0
Storbreen	1949-11	5.1	1400-2102	0.99	65	−2.57	159	−1.58	−0.09	2005	3
Juvfonne	2010-11	0.2	1840-1998	1.17	-	−3.05	-	−1.88	-		
Hellstugubreen	1962-11	2.9	1482-2229	0.83	72	−2.87	206	−2.04	−0.24	>2230	0
Gråsubreen	1962-11	2.1	1833-2283	0.65	82	−1.94	181	−1.29	−0.28	2265	2
Engabreen	1970-11	36.8	89-1574	2.84	104	−3.78	155	−0.94	0.27	1268	39
Rundvassbreen	2002-04 2011-	11.6 10.9	788-1537 836-1525	1.74	-	−3.32		−1.58	−0.78 -	1405	3
Langfjordjøkelen	1989-93 1996-11	3.7 3.2	280-1050 302-1050	2.30	[5]110	−3.55	[5]120	−1.26	[5]−0.93	>1050	0

[1]Calculated for the measured period 1986-2010
[2]Calculated for the measured period 2003-2010
[3]Calculated for the measured period 1988-2010
[4]Contribution from calving amounts to 0.35 m for B_s
[5]Calculated for the measured periods 1989-93 and 1996-2010

2012

The winter season 2011/2012 started with some snow-rich months over the whole country. The last part of the winter, however, was dry in northern Norway. Generally, the summer season had average weather conditions over most of the country.

The winter balance was greater than the 1971-2000 average for five of the seven reference glaciers. Gråsubreen had the lowest winter balance with 0.7 m w.e., which is 93 % of the 1971-2000 average. The summer balance was lower than the 1971-2000 average for all reference glaciers except for Storbreen (100 %). The resulting annual balance was strongly positive for eleven of the measured glaciers. Langfjordjøkelen in western Finnmark was negative with −0.8 m w.e.

The results from the mass balance measurements in Norway in 2012 are shown in Table 1-2.

Table 1-2
Summary of the results from mass balance measurements performed in Norway in 2012.

Glacier	*Period*	*Area* *(km^2)*	*Altitude* *(m a.s.l.)*	*B_w* *(m)*	*% of ref.*	*B_s* *(m)*	*% of ref.*	*B_a* *(m)*	*B_a ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-12	4.0	890-1368	3.87	100	−2.51	74	1.36	0.48	1020	96
Hansebreen	1986-12	2.8	927-1310	3.61	[1)]106	−2.79	[1)]70	0.82	[1)]−0.57	1085	76
Svelgjabreen	2007-12	22.3	829-1632	3.38	-	−2.08	-	1.29	-	1190	80
Blomstølskardsbreen	2007-12	22.4	1012-1632	3.50	-	−1.92	-	1.59	-	1255	86
Breidablikkbrea	1963-68 2003-12	3.9 3.2	1219-1660 1232-1648	3.19	[2)]137	−2.06	[2)]58	1.13	−0.19 [2)]−1.23	1290	90
Gråfjellsbrea	1964-68 1974-75 2003-12	9.4 8.1	1039-1660 1049-1647	2.94	[2)]129	−1.73	[2)]51	1.21	0.20 [2)]−1.12	1280	93
Nigardsbreen	1962-12	46.6	330-1952	2.71	119	−1.73	84	0.98	0.21	1330	91
Austdalsbreen	1988-12	10.6	1200-1747	2.68	[3)]123	[4)]−1.91	[3)]70	0.77	[3)]−0.55	1368	84
Rembesdalskåka	1963-12	17.3	1066-1854	2.65	120	−1.74	90	0.91	0.26	1589	86
Storbreen	1949-12	5.1	1400-2102	1.68	110	−1.62	100	0.06	−0.09	1725	62
Juvfonne	2010-12	0.2	1840-1998	1.44	-	−1.38	-	0.07	-		
Hellstugubreen	1962-12	2.9	1482-2229	1.21	105	−1.22	88	−0.01	−0.24	1875	59
Gråsubreen	1962-12	2.1	1833-2283	0.73	93	−0.84	79	−0.11	−0.28	undef.	
Engabreen	1970-12	36.8	89-1574	3.16	116	−2.09	85	1.07	0.27	1041	82
Rundvassbreen	2002-04 2011-12	11.6 10.9	788-1537 836-1525	2.04	-	−1.40		0.64	−0.78 -	1180	65
Langfjordjøkelen	1989-93 1996-12	3.7 3.2	280-1050 302-1050	1.37	[5)]65	−2.13	[5)]71	−0.76	[5)]−0.89	950	27

[1)]Calculated for the measured period 1986-2011
[2)]Calculated for the measured period 2003-2011
[3)]Calculated for the measured period 1988-2011
[4)]Contribution from calving amounts to 0.18 m for B_s
[5)]Calculated for the measured periods 1989-93 and 1996-2011

2013

In general the 2012/2013 winter season was cold and dry, and the summer season was warm and rainy over the whole country.

The winter balance was lower than the 1971-2000 average for all reference glaciers except for Nigardsbreen (101 %). The summer balance was greater than the 1971-2000 average for all reference glaciers. Engabreen at Svartisen had the greatest summer balance (−4.1 m w.e.) since measurements started in 1970. The annual balance was negative for all sixteen measured glaciers.

The results from the mass balance measurements in Norway in 2013 are shown in Table 1-3.

Table 1-3
Summary of the results from mass balance measurements performed in Norway in 2013.

Glacier	*Period*	*Area* *(km²)*	*Altitude* *(m a.s.l.)*	B_w *(m)*	*% of ref.*	B_s *(m)*	*% of ref.*	B_a *(m)*	B_a *ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-13	4.0	890-1368	3.15	82	−4.06	120	−0.90	0.48	>1368	0
Hansebreen	1986-13	2.8	927-1310	2.84	[1]83	−4.53	[1]115	−1.69	[1]−0.52	>1310	0
Svelgjabreen	2007-13	22.3	829-1632	2.58	-	−3.31	-	−0.73	-	1485	29
Blomstølskardsbreen	2007-13	22.4	1012-1632	2.93	-	−3.17	-	−0.23	-	1470	58
Breidablikkbrea	1963-68 2003-13	3.9 3.2	1219-1660 1232-1648					 −1.11	−0.19 [2]−1.00	 >1648	 0
Gråfjellsbrea	1964-68 1974-75 2003-13	9.4 8.1	1039-1660 1049-1647					 −1.15	0.20 [2]−0.88	 >1647	 0
Nigardsbreen	1962-13	46.6	330-1952	2.30	101	−2.96	143	−0.65	0.21	1680	35
Austdalsbreen	1988-13	10.6	1200-1747	1.61	[3]73	[4]−3.26	[3]121	−1.65	[3]−0.50	>1747	0
Rembesdalskåka	1963-13	17.3	1066-1854	1.61	73	−2.84	146	−1.22	0.26	>1854	0
Storbreen	1949-13	5.1	1400-2102	1.31	86	−2.47	153	−1.16	−0.09	1900	14
Juvfonne	2010-13	0.2	1840-1998	0.96	-	−2.51	-	−1.55	-		
Hellstugubreen	1962-13	2.9	1482-2229	1.05	91	−1.83	131	−0.78	−0.24	1980	22
Gråsubreen	1962-13	2.1	1833-2283	0.60	76	−1.41	132	−0.81	−0.28	2235	7
Engabreen	1970-13	36.8	89-1574	2.28	84	−4.14	169	−1.86	0.27	>1575	0
Rundvassbreen	2002-04 2011-13	11.6 10.9	788-1537 836-1525	 1.47	 -	 −3.90	 -	 −2.43	−0.78 -	 >1525	 0
Langfjordjøkelen	1989-93 1996-13	3.7 3.2	280-1050 302-1050	 2.08	 [5]100	 −4.69	 [5]159	 −2.61	 [5]−0.89	 >1050	 0

[1] *Calculated for the measured period 1986-2012*
[2] *Calculated for the measured period 2003-2012*
[3] *Calculated for the measured period 1988-2012*
[4] *Contribution from calving amounts to 0.29 m for B_s*
[5] *Calculated for the measured periods 1989-93 and 1996-2012*

2014

The winter season 2013/2014 started with a snow-rich November in the north and west. The winter continued mild and dry in northern Norway and with average conditions in western Norway. The ending of the winter season was snow-rich both in western and northern Norway. The summer season was warm and dry over most of the country.

The winter balance for the reference glaciers was approximately equal to the 1971-2000 average and the summer balance was lower than average. Rembesdalskåka at Hardanger-jøkulen had the greatest summer balance (−3.5 m w.e.) since measurements started in 1963. The annual balance was thus negative for all fourteen measured glaciers. Langfjordjøkelen had the eighteenth successive year with negative mass balance.

The results from the mass balance measurements in Norway in 2014 are shown in Table 1-4.

Table 1-4
Summary of the results from mass balance measurements performed in Norway in 2014.

Glacier	*Period*	*Area* *(km^2)*	*Altitude* *(m a.s.l.)*	B_w *(m)*	*% of ref.*	B_s *(m)*	*% of ref.*	B_a *(m)*	B_a *ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-14	4.0	890-1368	3.64	94	−5.29	157	−1.65	0.48	>1368	0
Hansebreen	1986-14	2.8	927-1310	3.54	[1]105	−5.65	[1]143	−2.11	[1]−0.56	>1310	0
Svelgjabreen	2007-14	22.3	829-1632	3.30	[2]111	−3.76	[2]127	−0.46	[2]0.01	1460	34
Blomstølskardsbreen	2007-14	22.4	1012-1632	3.46	[2]110	−3.56	[2]134	−0.09	0.49	1470	58
Nigardsbreen	1962-14	46.6	330-1952	2.73	120	−3.07	149	−0.34	0.21	1550	67
Austdalsbreen	1988-14	10.6	1200-1747	2.14	[3]99	[4]−3.44	[3]127	−1.30	[3]−0.54	>1747	0
Rembesdalskåka	1963-14	17.3	1066-1854	2.17	98	−3.46	178	−1.29	0.26	>1854	0
Storbreen	1949-14	5.1	1400-2102	1.57	103	−2.74	169	−1.17	-0.09	1870	19
Juvfonne	2010-14	0.2	1840-1998	1.21	-	−3.51	-	−2.30	-		
Hellstugubreen	1962-14	2.9	1482-2229	1.11	96	−2.33	167	−1.22	−0.24	2025	17
Gråsubreen	1962-14	2.1	1833-2283	0.89	113	−2.06	193	−1.17	−0.28	undef.	
Engabreen	1970-14	36.8	89-1574	2.54	93	−3.51	144	−0.97	0.27	1256	42
Rundvassbreen	2002-04 2011-14	11.6 10.9	788-1537 836-1525	1.80	-	−2.59	-	−0.79	−0.78 -	1335	26
Langfjordjøkelen	1989-93 1996-14	3.7 3.2	280-1050 302-1050	2.36	[5]114	−3.14	[5]103	−0.78	[5]−0.96	>1050	0

[1] Calculated for the measured period 1986-2013
[2] Calculated for the measured period 2007-2013
[3] Calculated for the measured period 1988-2013
[4] Contribution from calving amounts to 0.22 m for B_s
[5] Calculated for the measured periods 1989-93 and 1996-2013

2015

The winter season 2014/2015 started with mild and dry weather. Snow accumulation on the glaciers in western Norway did not start until late November. The winter continued mild and snow-rich in western and northern Norway. Additionally, the winter season was extended with a cool and snowy May in southern Norway. The summer season started relatively cool over the whole country. However, August and September were both warmer than average.

The winter balance for the long-term glaciers was greater than the 1971-2000 average and the summer balance was lower than the average. The annual balance was thus positive for all reference glaciers. However, Langfjordjøkelen had the nineteenth successive year with negative mass balance.

The results from the mass balance measurements in Norway in 2015 are shown in Table 1-5.

Table 1-5
Summary of the results from mass balance measurements performed in Norway in 2015.

Glacier	*Period*	*Area (km²)*	*Altitude (m a.s.l.)*	B_w *(m)*	*% of ref.*	B_s *(m)*	*% of ref.*	B_a *(m)*	B_a *ref.*	*ELA (m a.s.l.)*	*AAR (%)*
Ålfotbreen	1963-15	4.0	890-1368	4.21	109	−2.81	83	1.40	0.48	1020	96
Hansebreen	1986-15	2.8	927-1310	4.08	[1)]120	−3.07	[1)]77	1.01	[1)]−0.62	<927	100
Svelgjabreen	2007-15	22.3	829-1632	3.46	[2)]115	−1.63	[2)]53	1.84	[2)]−0.05	1140	86
Blomstølskardsbreen	2007-15	22.4	1012-1632	3.41	[2)]107	−1.42	[2)]51	1.99	0.41	1250	86
Nigardsbreen	1962-15	46.6	330-1952	3.07	135	−1.35	66	1.71	0.21	1310	92
Austdalsbreen	1988-15	10.6	1200-1747	2.53	[3)]117	[4)]−1.80	[3)]66	0.72	[3)]−0.57	1371	81
Rembesdalskåka	1963-15	17.3	1066-1854	3.00	136	−1.82	93	1.18	0.26	1570	87
Storbreen	1949-15	5.1	1400-2102	1.52	99	−1.03	64	0.49	-0.09	1575	89
Juvfonne	2010-15	0.2	1840-1998	1.46	-	−0.89	-	0.57	-		
Hellstugubreen	1962-15	2.9	1482-2229	1.21	105	−0.72	52	0.49	−0.24	1770	79
Gråsubreen	1962-15	2.1	1833-2283	0.77	98	−0.48	45	0.29	−0.28	undef.	
Engabreen	1970-15	38.7	89-1574	3.22	118	−2.61	107	0.61	0.27	1070	78
Rundvassbreen	2002-04 2011-15	11.6 10.9	788-1537 836-1525	2.12	-	−2.15	-	−0.02	−0.78 -	1230	58
Langfjordjøkelen	1989-93 1996-15	3.7 3.2	280-1050 302-1050	1.88	[5)]90	−2.68	[5)]88	−0.80	[5)]−0.95	1025	6

[1)]Calculated for the measured period 1986-2014
[2)]Calculated for the measured period 2007-2014
[3)]Calculated for the measured period 1988-2014
[4)]Contribution from calving amounts to 0.14 m for B_s
[5)]Calculated for the measured periods 1989-93 and 1996-2014

The results from the mass balance measurements in Norway in 2011, 2012, 2013, 2014 and 2015 are shown in Tables 1-1, 1-2, 1-3, 1-4 and 1-5, respectively. Winter (B_w), summer (B_s) and annual balance (B_a) 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 annual 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 (%).

Figures 1-3, 1-4, 1-5, 1-6 and 1-7 give a graphical presentation of the mass balance results in southern Norway for 2011, 2012, 2013, 2014 and 2015, respectively. The west-east gradient is evident for both winter and summer balances.

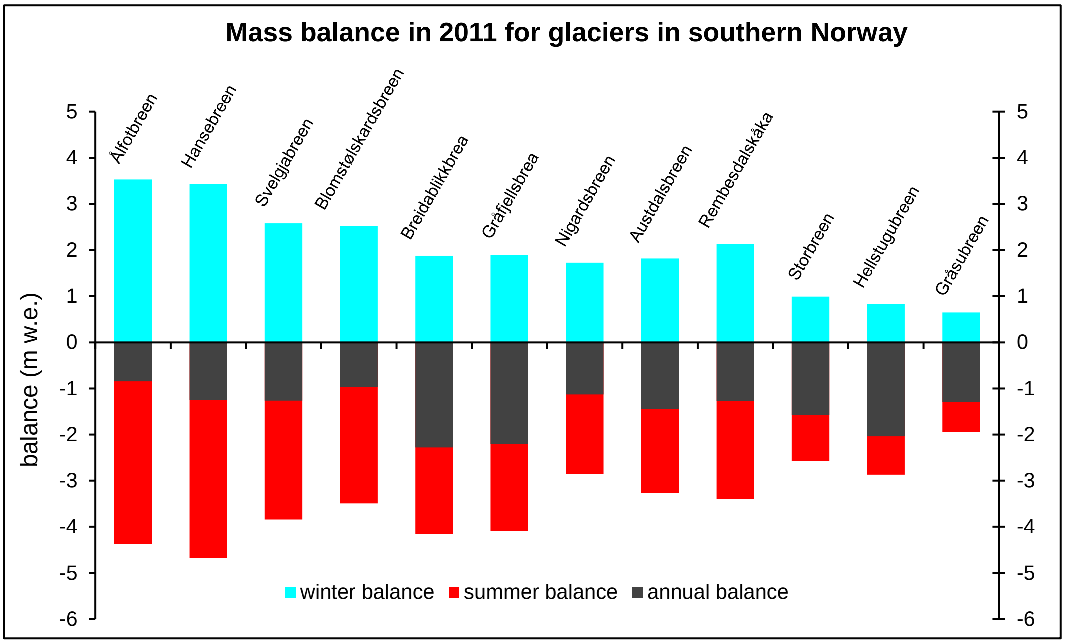


Figure 1-3
Mass balance in 2011 in southern Norway. The glaciers are listed from west to east.

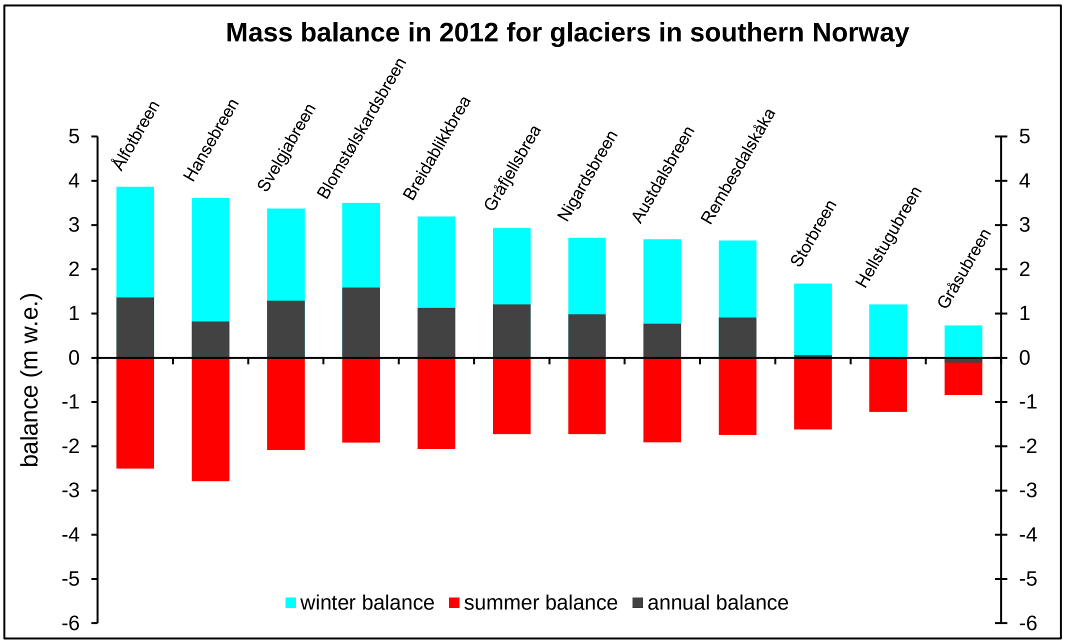


Figure 1-4
Mass balance in 2012 in southern Norway. The glaciers are listed from west to east.

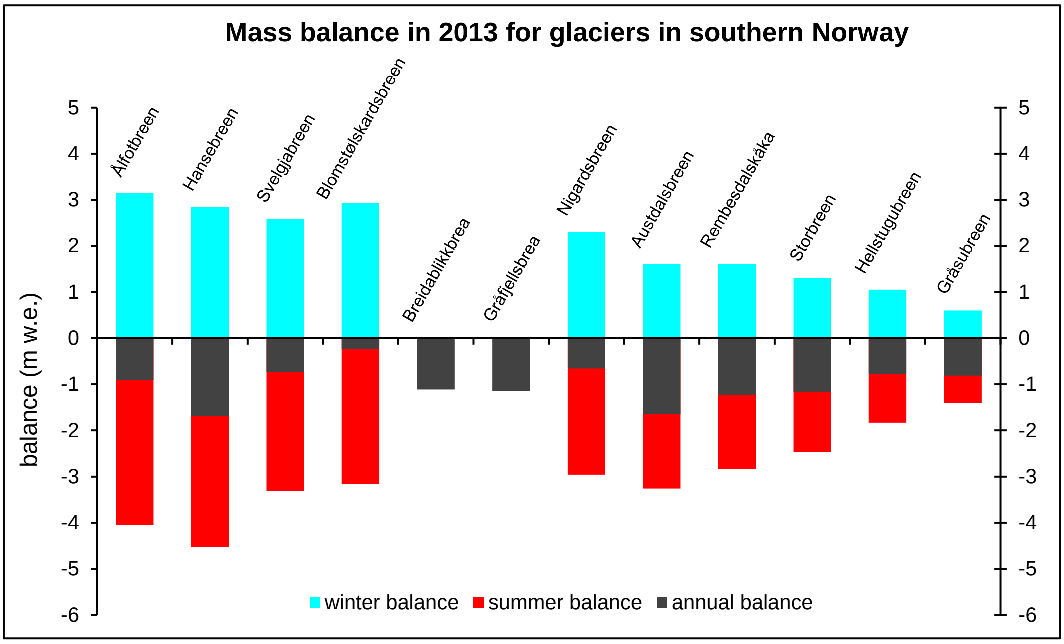


Figure 1-5
Mass balance in 2013 in southern Norway. The glaciers are listed from west to east.

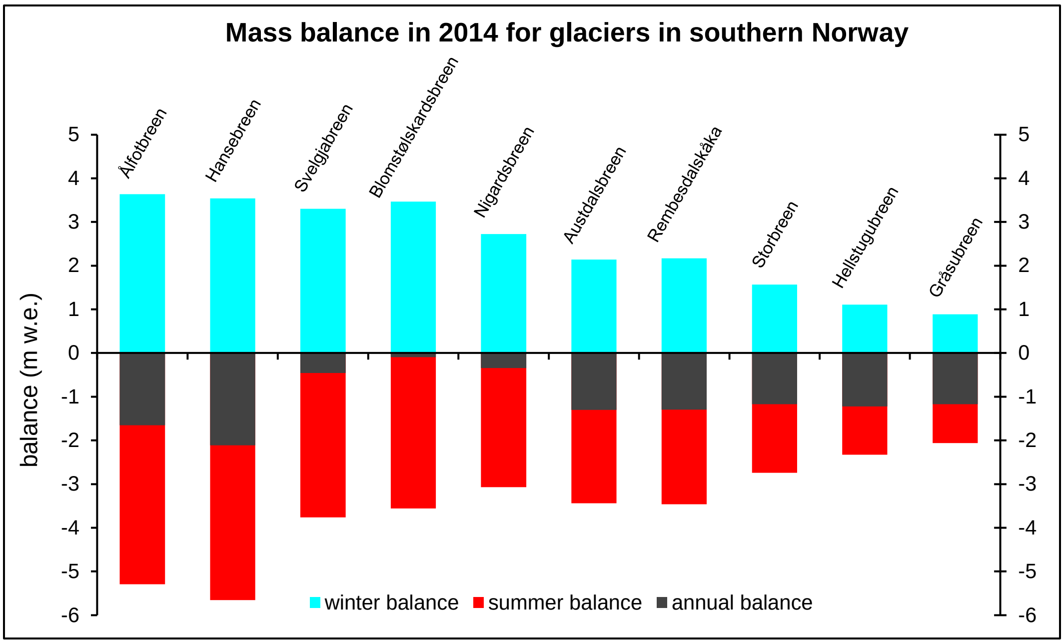


Figure 1-6
Mass balance in 2014 in southern Norway. The glaciers are listed from west to east.

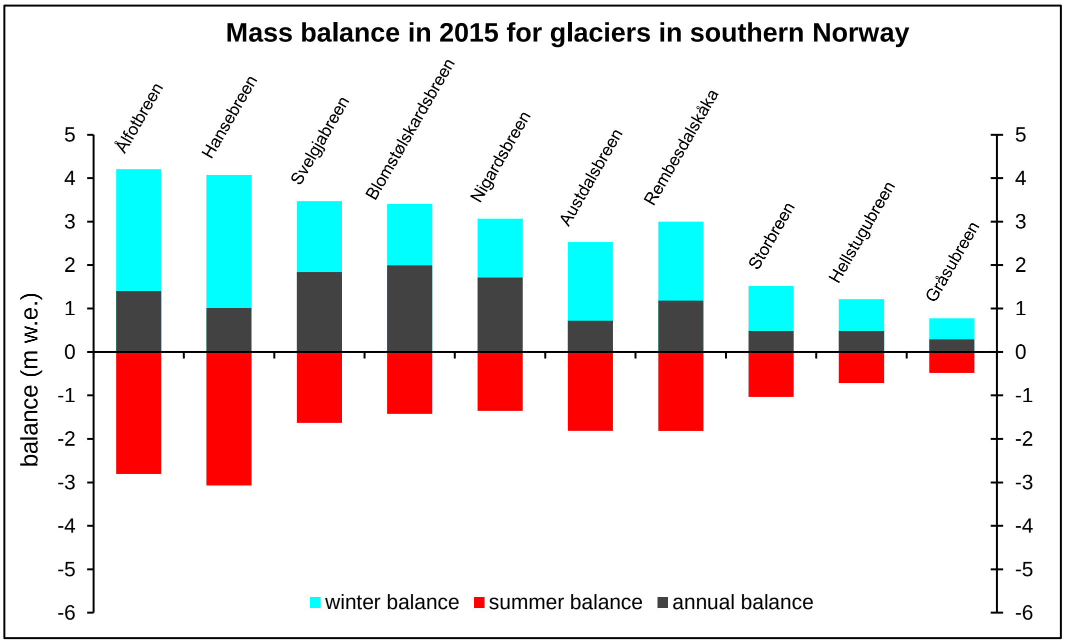


Figure 1-7
Mass balance in 2015 in southern Norway. The glaciers are listed from west to east.

The cumulative annual balance for glaciers in southern Norway with long-term series for the period 1963-2015 is shown in Figure 1-8. The maritime glaciers, Ålfotbreen, Nigardsbreen and Rembesdalskåka, showed a marked increase in volume during the period 1989-95. The surplus was mainly the result of several winters with heavy snowfall.

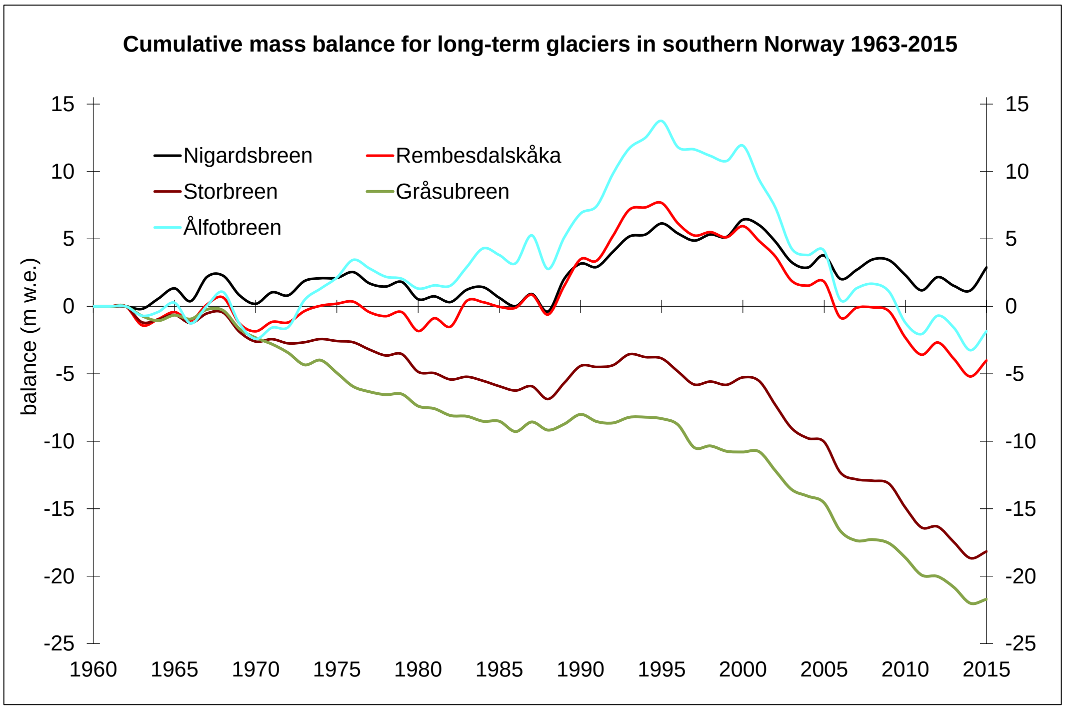


Figure 1-8
Cumulative mass balance for Ålfotbreen, Nigardsbreen, Rembesdalskåka (Hardangerjøkulen), Storbreen and Gråsubreen for the period 1963-2015.

1.2 Homogenisation and revision of mass balance series

Whereas the glaciological method measures the surface mass balance, the geodetic method measures the sum of surface, internal and basal mass balances. In order to make a direct comparison of glaciological and geodetic balances, the methodological differences, such as differences in survey dates (accounts for ablation or accumulation between the survey dates) and surveyed areas (using the same area and ice divides in both methods) must be considered. In addition, the effects of changes in density profiles between the geodetic surveys must be accounted for.

A joint paper from the workshop on "Measurement and Uncertainty Assessment of Glacier Mass Balance" at the Tarfala Research Station in northern Sweden in 2012 describes a standard procedure for reanalysing mass balance series (Zemp et al., 2013), based on best practices. It recommended that mass balance series longer than 20 years should always be reanalysed. In a paper in the Cryosphere, NVE has reanalysed the 10 glaciers with long-term mass balance series in Norway (Andreassen et al., 2016). In addition to the paper, three NVE reports give further details on four of the glaciers analysed; Engabreen (Elvehøy, 2016), Nigardsbreen (Kjøllmoen, 2016) and Ålfotbreen and Hansebreen (Kjøllmoen, 2016b). The reanalysis included (i) homogenisation of both glaciological and geodetic observation series, (ii) uncertainty assessment, (iii) estimates of generic differences including estimates of internal and basal melt, (iv) validation, and for some glaciers, (v) calibration of the mass balance series. In total, 21 periods of data were compared and the results show discrepancies between the glaciological and geodetic methods for some glaciers, which are attributed partly to internal and basal ablation and partly to inhomogeneity in the data processing.

Homogenised glaciological and geodetic results were in overall agreement for Langfjordjøkelen, Austdalsbreen, Storbreen, Hellstugubreen and Gråsubreen for the periods considered, but they differed for Ålfotbreen (one of three periods), Hansebreen (both periods), Engabreen (both periods), Rembesdalskåka (one of two periods), and Nigardsbreen (one of two periods). These seven periods were calibrated by applying an annual correction factor (the annual difference between the homogenised geodetic and glaciological mass balance) to the summer and winter balances according to their relative size.

The reanalysis processes has revised seasonal, annual, and cumulative values as well as ELA and AAR values for many of the years for the 10 glaciers. For most glaciers the discrepancy between the "original" glaciological series as published in the series "Glaciological investigations in Norway" are small, but for others the results differed significantly. The mass balance series are now categorised as 'original' (as published in ''Glasiologiske undersøkelser i Norge''/''Glaciological investigations in Norway''), ''homogenised'' (for selected or all years) or ''calibrated'' (periods are calibrated with geodetic observations) in the NVE databases. The new reanalysed and thus "official" values are available for download from NVE's website: http://glacier.nve.no/viewer/CI/en/.

The reanalysed series shows a more spatially coherent signal over the period of measurements than previously reported: six glaciers have a significant mass loss and four glaciers are nearly in balance. All glaciers have lost mass since the year 2000.

1.3 Other investigations

Glacier length change measurements were performed at 33 glaciers in 2011, 28 glaciers in 2012, 33 glaciers in 2013, 38 glaciers in 2014 and 31 glaciers in 2015. Some of the glaciers have a measurement series going back to about 1900. The length changes are described in chapter 14.

Glacier dynamics (velocity) have been studied at Austdalsbreen since 1987 (chap. 5). The measurements continued in 2011, 2012, 2013, 2014 and 2015.

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

Svartisen Subglacial Laboratory was initiated in 1992 and has since been used by researchers from several different countries (Jackson, 2000). An overview of measurements in the laboratory is given in chapter 11.

Several jökulhlaups have occurred over the years 2011-2015. The jøkulhlaups are described in chapter 14.

Laser scanning (LIDAR) campaigns were carried out in 2011 and 2013 on several glaciers in Norway. The LIDAR surveys are described in chapter 14.

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 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. The Ålfotbreen and Hansebreen basins are shown in Figure 2-1. The mass balance calculations for the years 2011-2015 are based on the DTM from 2010.

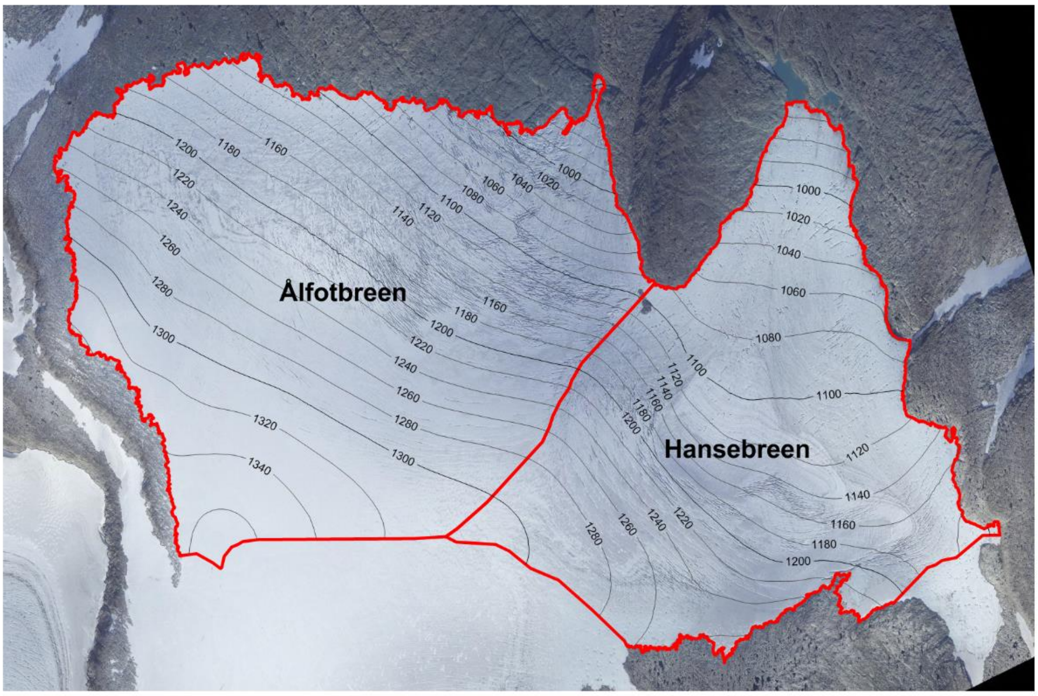


Figure 2-1
Orthophoto showing the two north-facing glaciers Ålfotbreen (left) and Hansebreen (right) at which mass balance studies are performed. Photo: Terratec AS.

2.1 Mass balance 2011

Snow accumulation measurements were performed on 27th and 28th April and the calculation of winter balance was based on measurement of five stakes and 79 snow depth soundings on Ålfotbreen, and four stakes and 53 snow depth probings on Hansebreen (Fig. 2-2). Comparison of the sounded snow depths and the stake readings indicate melting of 40-50 cm of ice in the lowermost areas after the final measurement in September 2010. This additional melting was taken into account when calculating the winter balance for 2011. Overall the sounding conditions were good with coarse snow. The snow depth was between 4.5 and 7.9 m on Ålfotbreen and between 4.2 and 8.2 m on Hansebreen. Snow density was measured in one position (1203 m a.s.l.) applicable for both glaciers. The mean snow density of 5.6 m snow was 558 kg m^{-3}. Ablation was measured on 13th October. The annual balance was measured at stakes in six positions on Ålfotbreen and in five positions on Hansebreen (Fig. 2-2). There was no snow remaining on the two glaciers from the winter season 2010/11. At the time of the ablation measurements between 50 and 90 cm of fresh snow had fallen.

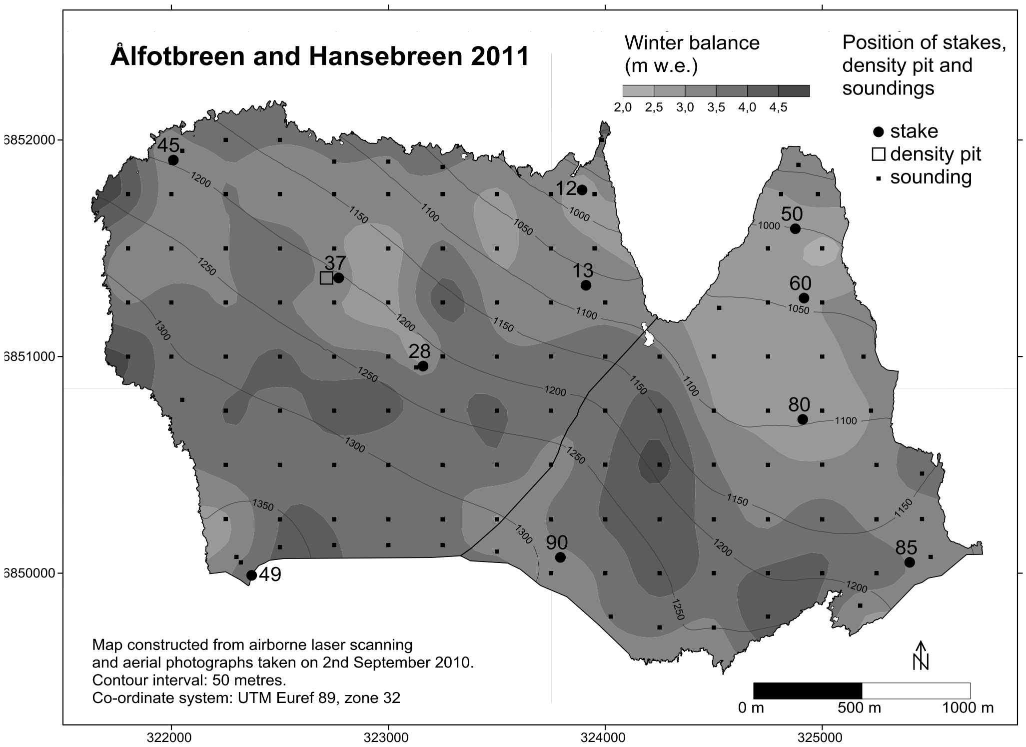


Figure 2-2
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Ålfotbreen (left) and Hansebreen (right) in 2011.

The winter balance was calculated as a mean value for each 50 m height interval and was 3.5 ±0.2 m w.e. at Ålfotbreen and 3.4 ±0.2 m w.e. at Hansebreen. Based on estimated density and stake measurements the summer balance was calculated as −4.4 ±0.3 m w.e. at Ålfotbreen and −4.7 ±0.3 m w.e. at Hansebreen. Hence, the annual balance was negative at −0.8 ±0.4 m w.e. at Ålfotbreen and −1.3 ±0.4 m w.e. at Hansebreen.

The mass balance curves for specific and volume balance are shown in Figure 2-3. According to this figure the Equilibrium Line Altitude (ELA) lies *above* the highest summit on both glaciers. Consequently, the AAR is 0 %.

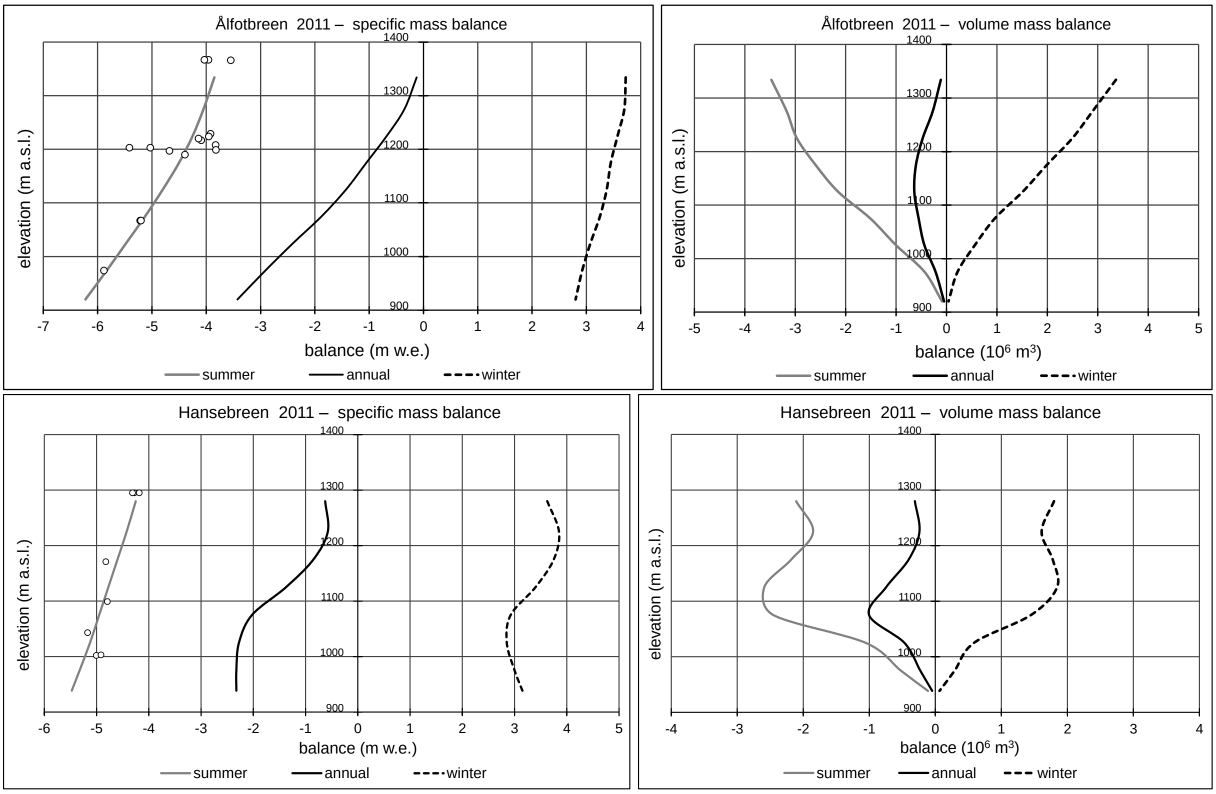


Figure 2-3
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2011.

2.2 Mass balance 2012

Snow accumulation measurements were performed on 16th and 17th April and the calculation of winter balance was based on measurement of two stakes and 77 snow depth soundings on Ålfotbreen, and three stakes and 53 snow depth soundings on Hansebreen (Fig. 2-4). Comparison of stake readings and soundings indicated no significant melting after the final measurements in October 2011. Overall the sounding conditions were good with a well-defined summer surface. The snow depth was between 4.7 and 9.2 m on Ålfotbreen and between 5.0 and 9.9 m on Hansebreen. Snow density was measured in one position (1203 m a.s.l.) applicable for both glaciers. The mean snow density of 6.9 m snow was 521 kg m^{-3}. Ablation was measured on 16th October. The annual balance was measured at eleven stakes in six different positions on Ålfotbreen and at nine stakes in five different positions on Hansebreen (Fig. 2-4). In the upper areas there were 2-3 m snow remaining from the winter season 2011/12. At the time of the ablation measurements between 30 and 90 cm of fresh snow had fallen.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

The winter balance was calculated as 3.9 ±0.2 m w.e. at Ålfotbreen and 3.6 ±0.2 m w.e. at Hansebreen. Based on estimated density and stake measurements the summer balance was calculated as −2.5 ±0.3 m w.e. at Ålfotbreen and −2.8 ±0.3 m w.e. at Hansebreen. There is only one year (−2.6 m w.e. in 1987) with a smaller summer balance on Hansebreen. Thus, the annual balance was +1.4 ±0.4 m w.e. at Ålfotbreen and +0.8 ±0.4 m w.e. at Hansebreen.

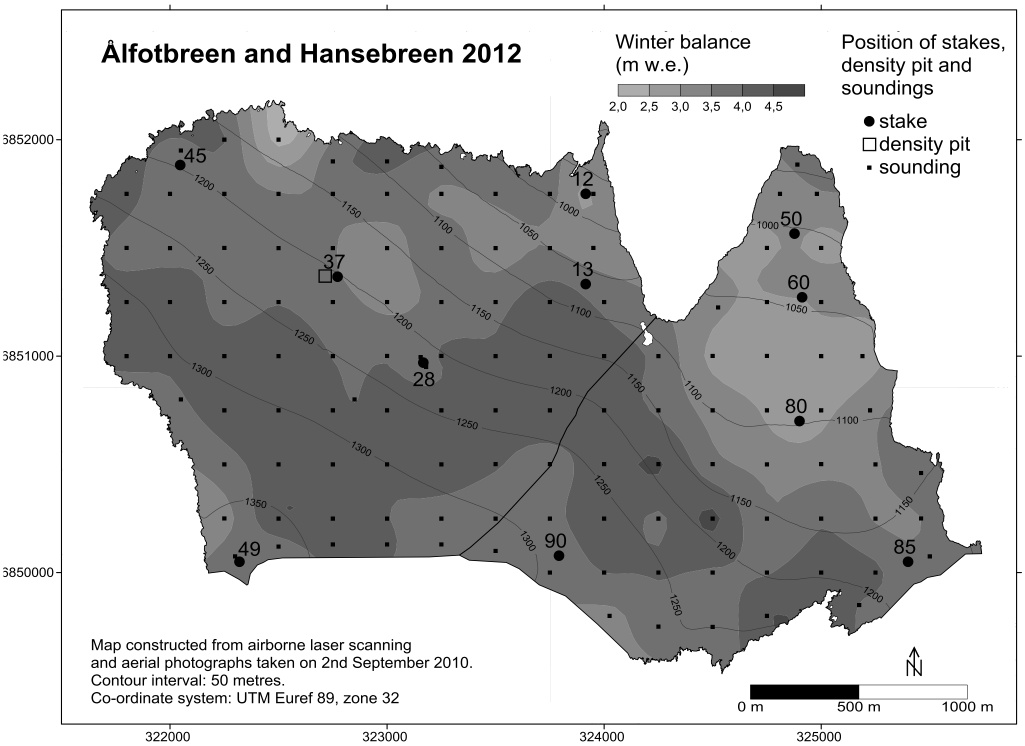


Figure 2-4
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Ålfotbreen (left) and Hansebreen (right) in 2012.

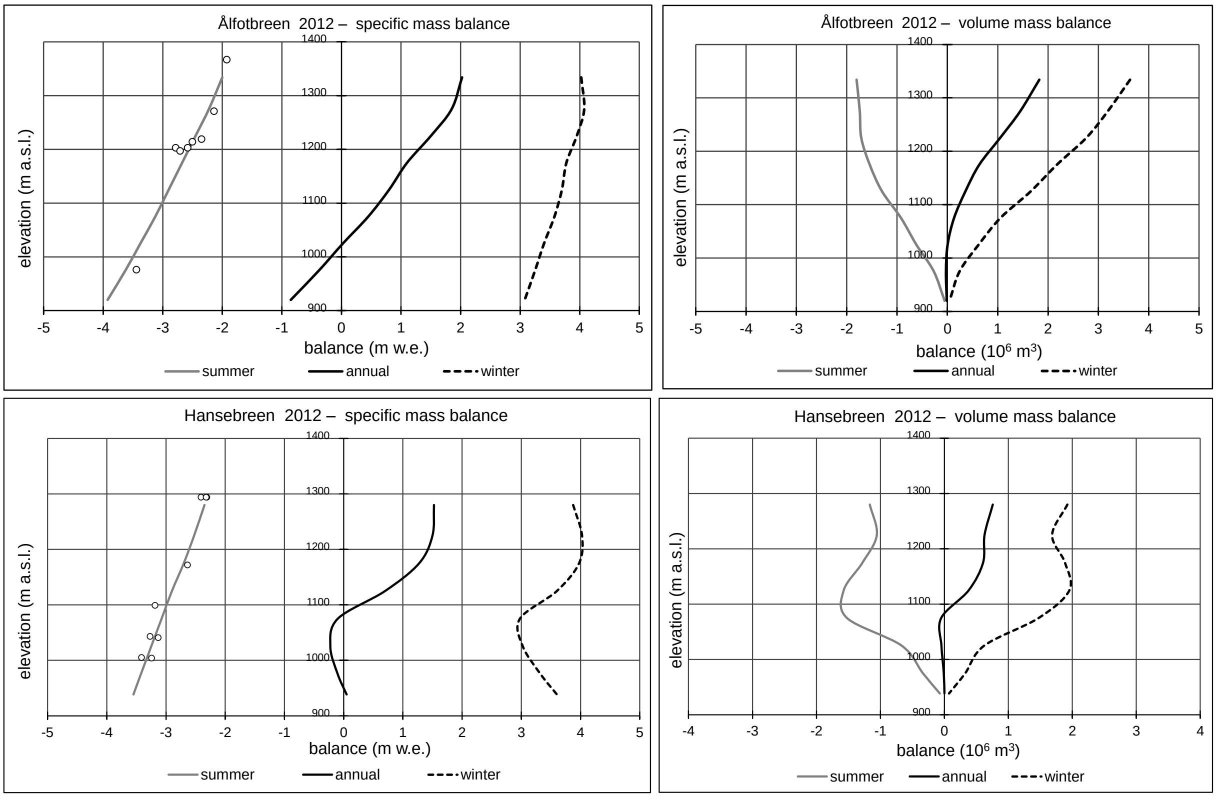


Figure 2-5
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2012.

The mass balance curves for specific and volume balance are shown in Figure 2-5. According to this figure the ELA was 1020 m a.s.l. on Ålfotbreen and 1085 m a.s.l. on Hansebreen. Consequently, the AAR was 96 % and 76 %, respectively.

2.3 Mass balance 2013

Snow accumulation measurements were performed on 23rd and 24th May and the calculation of winter balance was based on measurement of four stakes and 78 snow depth soundings on Ålfotbreen, and five stakes and 53 snow depth soundings on Hansebreen (Fig. 2-6). Comparison of stake readings and soundings indicated no significant melting after the ablation measurements in October 2012. The sounding conditions were good at the lower areas. In the higher areas however, the summer surface was difficult to define due to several harder layers in the snow pack. The snow depth was between 3.8 and 7.9 m on Ålfotbreen and between 3.4 and 8.2 m on Hansebreen. Snow density was measured in one location (1203 m a.s.l.) applicable for both glaciers. The mean snow density of 4.9 m snow was 510 kg m^{-3}. Ablation was measured on 25th September. The annual balance was measured at eight stakes in six different positions on Ålfotbreen and at nine stakes in five positions on Hansebreen. There was no snow remaining on the two glaciers from the winter season 2012/13. At the time of the ablation measurements up to 10 cm of fresh snow had fallen.

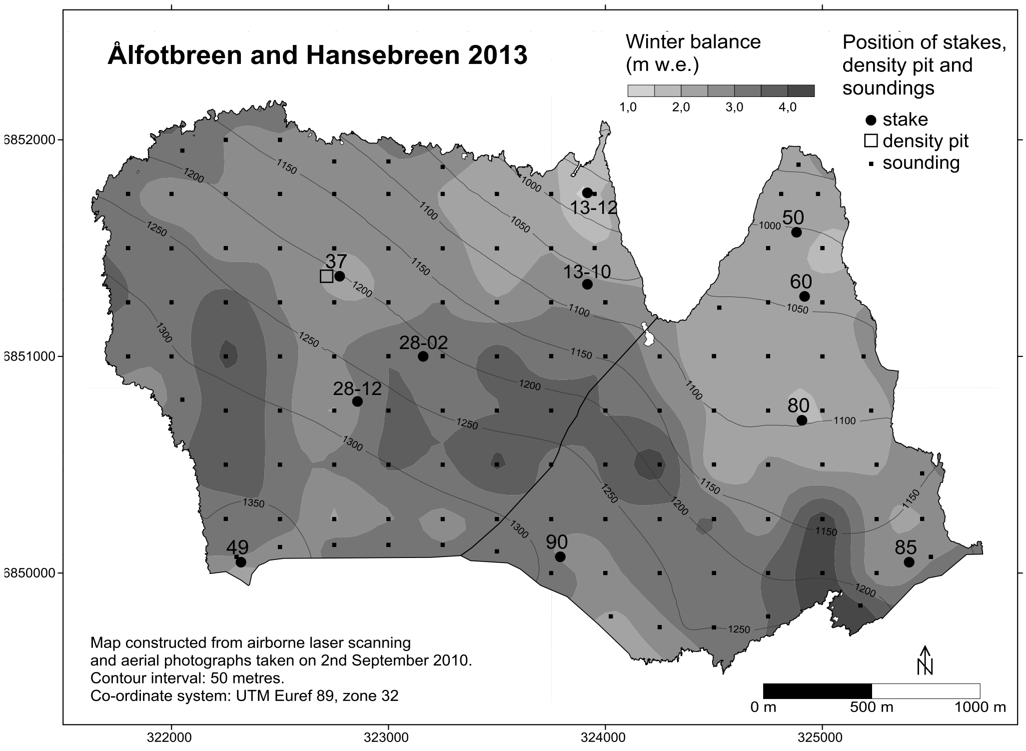


Figure 2-6
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Ålfotbreen (left) and Hansebreen (right) in 2013.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

The winter balance was calculated as 3.2 ±0.2 m w.e. on Ålfotbreen and 2.8 ±0.2 m w.e. on Hansebreen. Based on estimated density and stake measurements the summer balance was calculated as −4.1 ±0.3 m w.e. on Ålfotbreen and −4.5 ±0.3 m w.e. on Hansebreen.

The annual balance was −0.9 ±0.4 m w.e. on Ålfotbreen and −1.7 ±0.4 m w.e. on Hansebreen.

The mass balance curves for specific and volume balance are shown in Figure 2-7. According to this figure the ELA lies above the highest summit on both glaciers. Consequently, the AAR is 0 %.

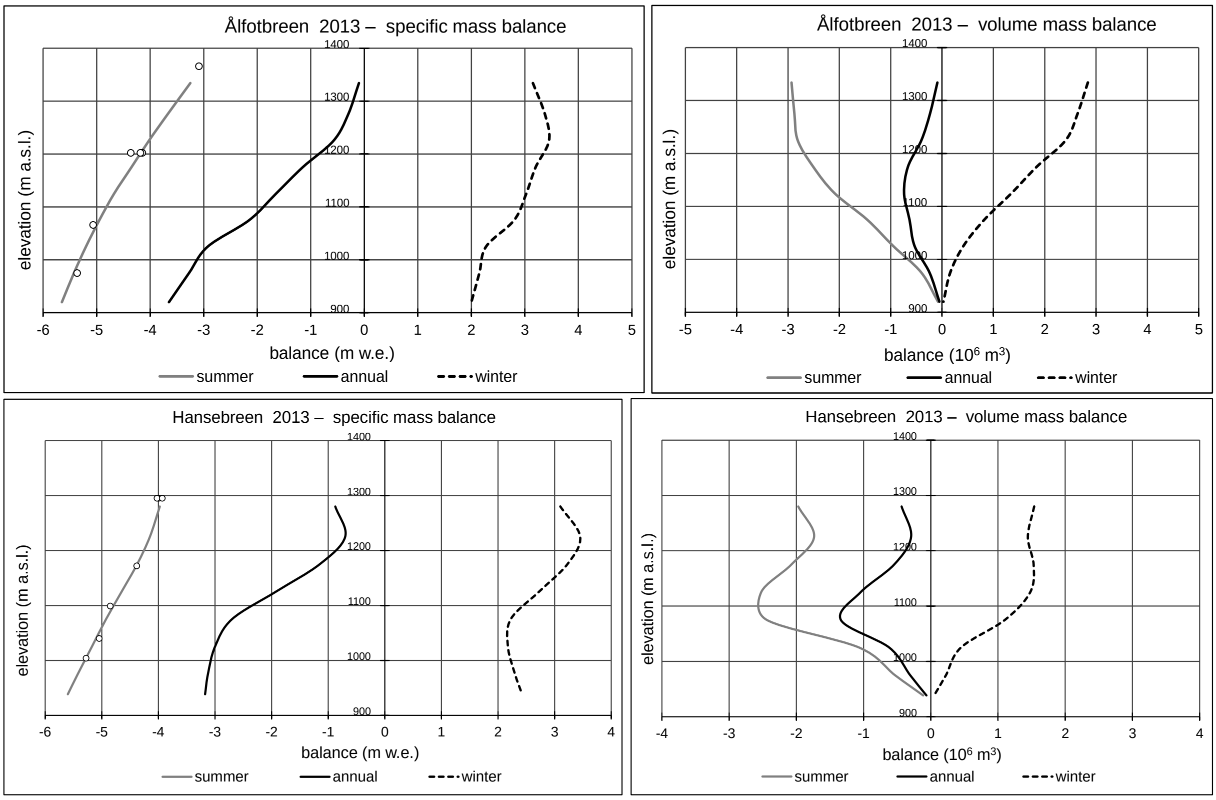


Figure 2-7
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2013.

2.4 Mass balance 2014

Snow accumulation measurements were performed on 23rd and 24th April and the calculation of winter balance was based on measurement of three stakes and 76 snow depth soundings on Ålfotbreen, and four stakes and 53 snow depth soundings on Hansebreen (Fig. 2-8). Comparison of stake readings and snow soundings indicated no significant melting after the ablation measurement in September 2013. Overall the sounding conditions were good and the summer surface was easily defined. At several measurement points a soft layer was found 10-20 cm above the summer surface. The snow depth was between 5.1 and 9.3 m on Ålfotbreen and between 5.3 and 10.0 m on Hansebreen. Snow density was measured in one location (1203 m a.s.l.) applicable for both glaciers. The mean snow density of 6.3 m snow was 504 kg m^{-3}. Ablation was measured on 14th October. The annual balance was measured at stakes in five positions on both glaciers (Fig. 2-8). There was no snow remaining on the two glaciers from the winter season 2013/14. At the time of the ablation measurements up to 10 cm of fresh snow had fallen.

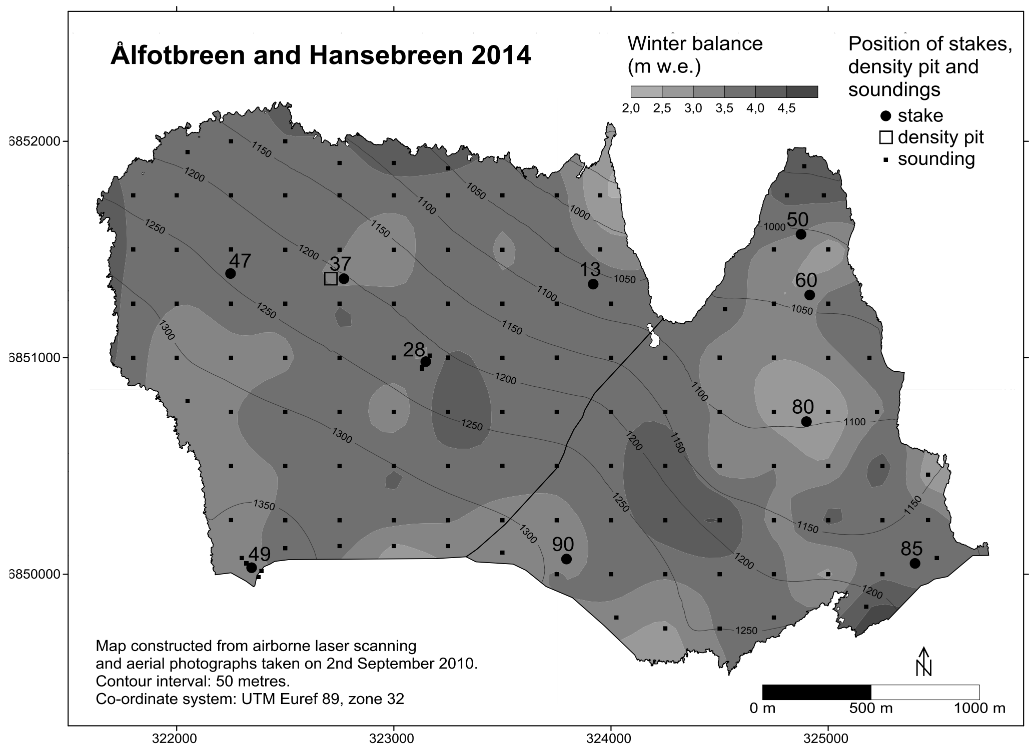


Figure 2-8
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Ålfotbreen (left) and Hansebreen (right) in 2014.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

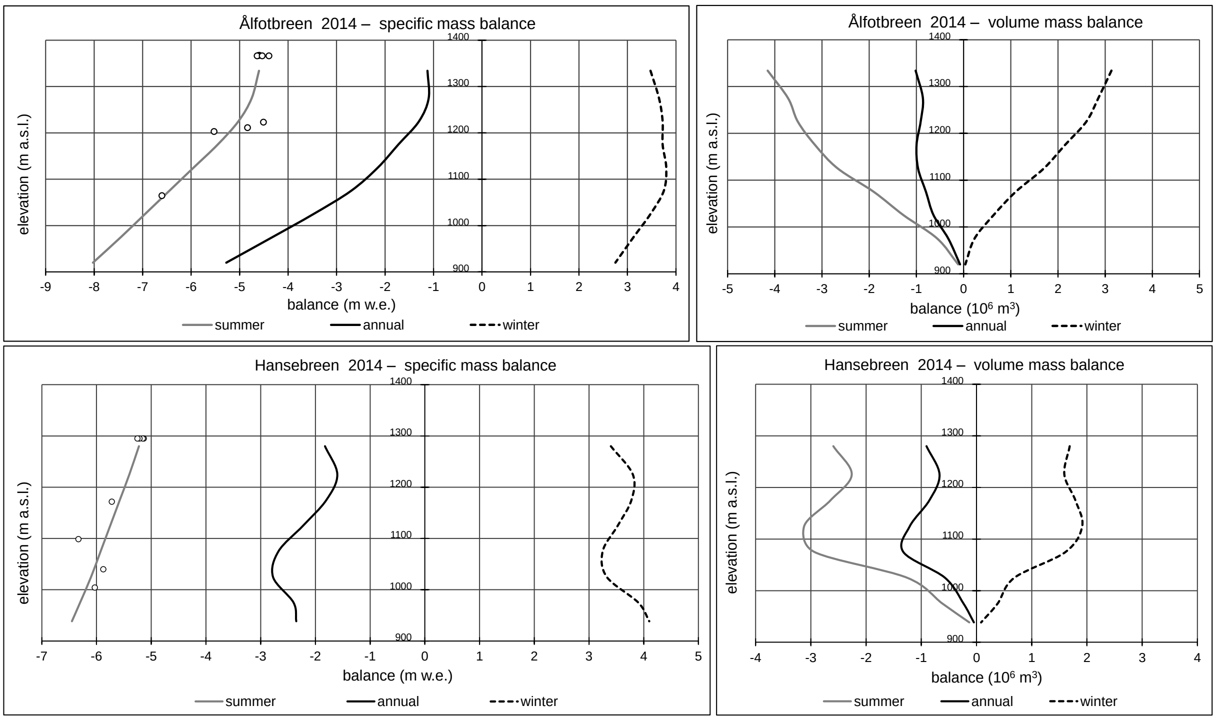


Figure 2-9
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2014.

The winter balance was calculated as 3.6 ±0.2 m w.e. on Ålfotbreen and 3.5 ±0.2 m w.e. on Hansebreen. Based on estimated density and stake measurements the summer balance was calculated as −5.3 ±0.3 m w.e. on Ålfotbreen and −5.7 ±0.3 m w.e. on Hansebreen. Thus the annual balance was negative, at −1.7 ±0.4 m w.e. on Ålfotbreen and −2.1 ±0.4 m w.e. on Hansebreen.

The mass balance curves for specific and volume balance are shown in Figure 2-9. According to this figure the ELA lies above the highest summit on both glaciers. Consequently, the AAR is 0 %.

2.5 Mass balance 2015

Snow accumulation measurements were performed on 20th and 24st April and the calculation of winter balance was based on measurement of four stakes and 77 snow depth soundings on Ålfotbreen, and four stakes and 54 snow depth soundings on Hansebreen (Fig. 2-10). Comparison of stake readings and snow soundings indicated no significant melting after the ablation measurement in October 2014. The snow pack was compact with several ice layers. A soft layer 5-10 cm above the summer surface was found at some measurement points. Overall, detecting the summer surface was easy in the lower parts, but somewhat worse in the upper areas. The snow depth was between 6.2 and 10.3 m on Ålfotbreen and between 6.2 and 10.0 m on Hansebreen. Snow density was measured in one location (1220 m a.s.l.) applicable for both glaciers. The mean snow density of 6.2 m snow was 501 kg m^{-3}.

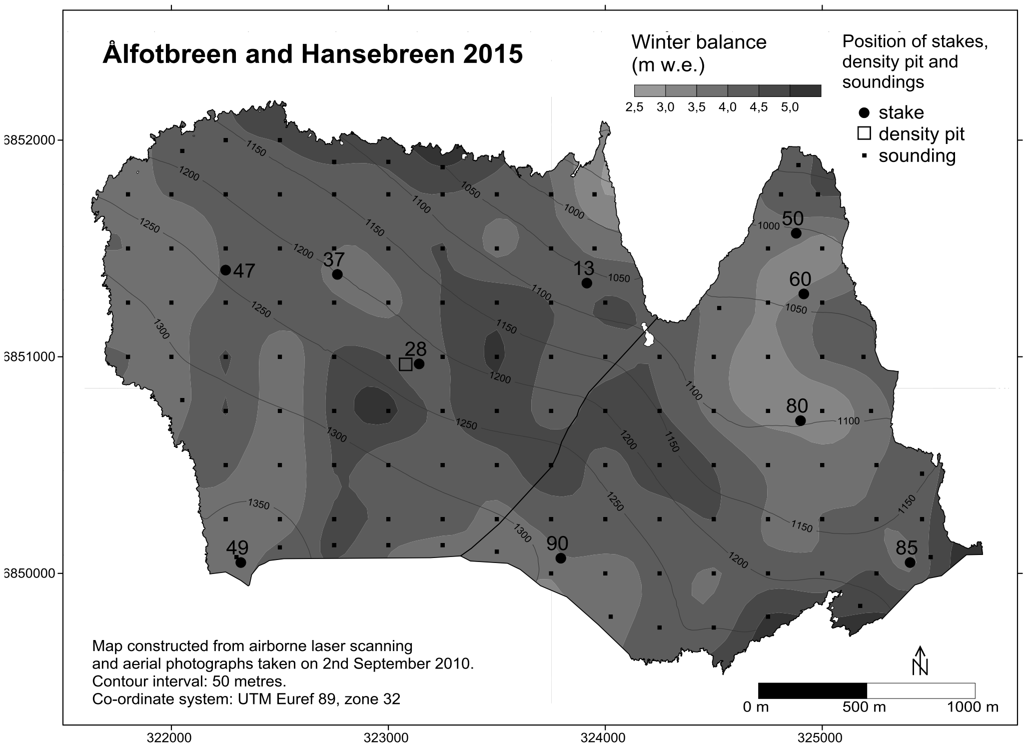


Figure 2-10
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Ålfotbreen (left) and Hansebreen (right) in 2014.

Ablation was measured on 16th October. The annual balance was measured at stakes in five positions on both glaciers (Fig. 2-10). In the upper areas there were almost 3 m snow remaining from the winter season 2014/15. Blue ice was visible only at the lower parts of Hansebreen. At the time of the ablation measurements up to 2 cm of fresh snow had fallen.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

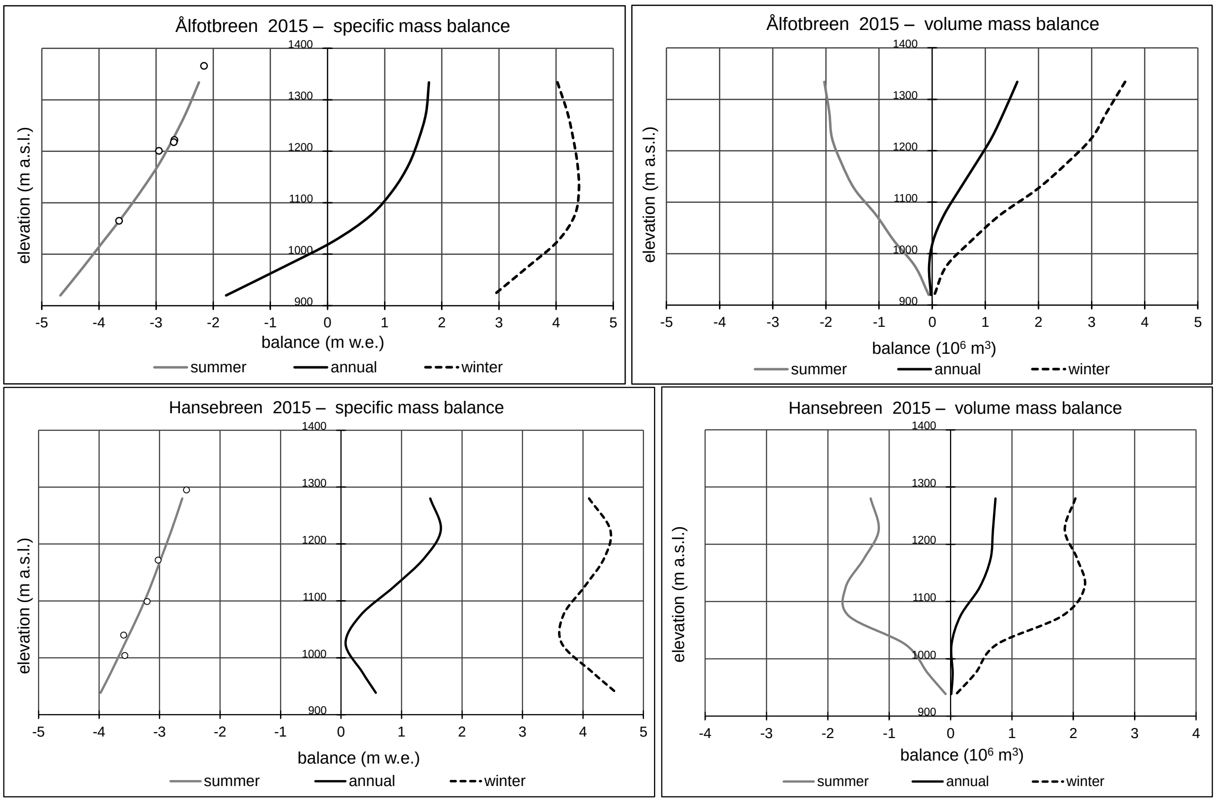


Figure 2-11
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2015.

The winter balance was calculated as 4.2 ±0.2 m w.e. on Ålfotbreen and 4.1 ±0.2 m w.e. on Hansebreen. Based on estimated density and stake measurements the summer balance was calculated as −2.8 ±0.3 m w.e. on Ålfotbreen and −3.1 ±0.3 m w.e. on Hansebreen. Thus the annual balance was positive, at 1.4 ±0.4 m w.e. on Ålfotbreen and 1.0 ±0.4 m w.e. on Hansebreen.

The mass balance curves for specific and volume balance are shown in Figure 2-11. According to this figure the ELA was 1020 m a.s.l. at Ålfotbreen and below the lowest height on Hansebreen. Consequently, the AAR was 96 % and 100 %, respectively.

2.6 Mass balance 1963-2015

A summary of the mass balance measurements and results for the years 2011-2015 is given in Table 2-1.

Table 2-1
Summary values of Ålfotbreen and Hansebreen mass balance measurements and results for the period 2011-2015. Values for Ålfotbreen (Ål) and Hansebreen (Ha) are separated for each year.

	Unit	2011		2012		2013		2014		2015	
		Ål	Ha	Ål	Ha	Ål	Ha	Ål	Ha	Ål	Ha
Date B_w		28 Apr		16 Apr		23 May		24 Apr		20 Apr	
Date B_s		13 Oct		16 Oct		25 Sep		15 Oct		16 Oct	
Density b_w	kg m^{-3}	558		521		510		504		501	
Density firn$_m$	kg m^{-3}	750-800				600-650		650-850			
Density firn$_r$	kg m^{-3}			600						600	
B_w	m w.e.	3.53	3.43	3.87	3.61	3.15	2.84	3.64	3.54	4.21	4.08
B_s	m w.e.	−4.38	−4.68	−2.51	−2.79	−4.06	−4.53	−5.29	−5.65	−2.81	−3.07
B_a	m w.e.	−0.84	−1.25	1.36	0.82	−0.90	−1.69	−1.65	−2.11	1.40	1.01
$\sum B_a$ 2011-	m w.e.	−0.84	−1.25	0.52	−0.43	−0.39	−2.12	−2.04	−4.23	−0.64	−3.22
ELA	m a.s.l.	>1368	>1310	1020	1085	>1368	>1310	>1368	>1310	1020	<927
AAR	%	0	0	96	76	0	0	0	0	96	100

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density firn$_m$ and Density firn$_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

The original mass balance series for Ålfotbreen (1963-2010) and Hansebreen (1986-2010) were reported previously in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). Recently the mass balance series have been homogenised and calibrated (Kjøllmoen, 2016b). The homogenisation and calibration procedures are also described in chapter 1.2. Homogenising by re-calculation of the mass balance series ensures uniform methodology, data processing and interpretation of the calculation process from field data to the final balance values. The homogenisation included the periods 1963-2009 for Ålfotbreen and 1986-2009 for Hansebreen (it was not necessary to re-calculate 2010). Calibrating the mass balance series was based on deviations found between the homogenised series and geodetic surveys. As a result of the detected deviations the calibration included the periods 1998-2010 for Ålfotbreen and 1989-2010 for Hansebreen. The re-analysed mass balance series for Ålfotbreen 1963-2010 and Hansebreen 1986-2010 are presented in Table 2-2.

Following the homogenisation and calibration processes, the presented mass balance series 1963-1997 for Ålfotbreen and 1986-1988 for Hansebreen can be classified as homogenised, while the series 1998-2010 (Ålfotbreen) and 1989-2010 (Hansebreen) can be classified as calibrated. The years 2011-2015 can be classified as original.

Table 2-2
Homogenised and calibrated mass balance series for Ålfotbreen (1963-2010) and Hansebreen (1986-2010).

Homogenised and calibrated mass balance series												
	Ålfotbreen						Hansebreen					
Year	B_w	B_s	B_a	ΣB_a	Hom.	Cal.	B_w	B_s	B_a	ΣB_a	Hom.	Cal.
1963	2,52	-3,21	-0,70	-0,70	H							
1964	2,66	-2,38	0,29	-0,41	H							
1965	3,75	-3,07	0,68	0,27	H							
1966	2,40	-3,93	-1,53	-1,26	H							
1967	4,43	-3,12	1,30	0,04	H							
1968	4,65	-3,64	1,01	1,06	H							
1969	2,58	-4,92	-2,34	-1,28	H							
1970	2,65	-3,78	-1,13	-2,41	H							
1971	4,14	-3,31	0,83	-1,58	H							
1972	3,78	-3,74	0,04	-1,54	H							
1973	4,57	-2,56	2,01	0,47	H							
1974	3,49	-2,63	0,85	1,32	H							
1975	4,32	-3,50	0,82	2,14	H							
1976	4,37	-3,06	1,31	3,45	H							
1977	2,31	-2,94	-0,63	2,82	H							
1978	2,46	-3,08	-0,62	2,20	H							
1979	3,20	-3,36	-0,15	2,05	H							
1980	2,48	-3,21	-0,73	1,32	H							
1981	4,04	-3,81	0,24	1,56	H							
1982	3,30	-3,31	-0,01	1,54	H							
1983	4,61	-3,23	1,38	2,93	H							
1984	4,22	-2,85	1,38	4,30	H							
1985	2,48	-2,98	-0,50	3,81	H							
1986	2,34	-2,95	-0,61	3,19	H		2,16	-2,86	-0,70	-0,70	H	
1987	4,45	-2,38	2,07	5,27	H		3,50	-2,62	0,88	0,18	H	
1988	2,69	-5,18	-2,50	2,77	H		2,48	-5,23	-2,75	-2,57	H	
1989	5,29	-2,95	2,34	5,11	H		4,36	-3,40	0,96	-1,61	H	C
1990	5,96	-4,19	1,76	6,88	H		4,36	-3,87	0,49	-1,12	H	C
1991	3,44	-2,87	0,57	7,44	H		3,21	-2,73	0,48	-0,64	H	C
1992	5,48	-3,08	2,39	9,84	H		4,55	-3,31	1,25	0,61	H	C
1993	4,69	-2,82	1,87	11,71	H		4,50	-3,02	1,48	2,09	H	C
1994	3,72	-2,92	0,80	12,51	H		3,53	-2,59	0,94	3,03	H	C
1995	5,14	-3,91	1,23	13,74	H		4,62	-3,53	1,09	4,12	H	C
1996	1,87	-3,82	-1,94	11,80	H		1,92	-3,16	-1,24	2,88	H	C
1997	4,09	-4,25	-0,16	11,64	H		3,86	-3,50	0,36	3,24	H	C
1998	3,35	-3,83	-0,48	11,15	H	C	3,03	-3,64	-0,60	2,64	H	C
1999	4,32	-4,69	-0,37	10,78	H	C	4,16	-4,31	-0,14	2,49	H	C
2000	4,90	-3,77	1,14	11,92	H	C	4,47	-3,92	0,55	3,04	H	C
2001	1,76	-4,28	-2,52	9,39	H	C	1,63	-4,67	-3,04	0,00	H	C
2002	3,50	-5,57	-2,07	7,32	H	C	3,43	-5,56	-2,14	-2,14	H	C
2003	2,26	-5,29	-3,03	4,29	H	C	2,28	-5,19	-2,90	-5,04	H	C
2004	3,09	-3,58	-0,48	3,81	H	C	2,83	-3,75	-0,93	-5,97	H	C
2005	4,74	-4,42	0,32	4,13	H	C	4,39	-4,77	-0,38	-6,35	H	C
2006	2,51	-6,16	-3,65	0,48	H	C	2,33	-6,71	-4,37	-10,72	H	C
2007	4,23	-3,36	0,86	1,34	H	C	3,91	-3,30	0,61	-10,11	H	C
2008	4,32	-3,99	0,33	1,67	H	C	4,10	-3,93	0,17	-9,95	H	C
2009	3,60	-4,19	-0,58	1,09	H	C	3,35	-4,55	-1,20	-11,15	H	C
2010	2,03	-4,33	-2,30	-1,21		C	2,00	-4,51	-2,50	-13,66		C

The historical mass balance results for Ålfotbreen and Hansebreen are presented in Figure 2-12. The cumulative annual balance for Ålfotbreen over 1963-2015 is −1.8 m w.e., which gives a mean annual balance of −0.03 m w.e. a^{-1}. The cumulative annual balance for Hansebreen over 1986-2015 is −16.9 m w.e., which gives a mean annual balance of −0.56 m w.e. a^{-1}.

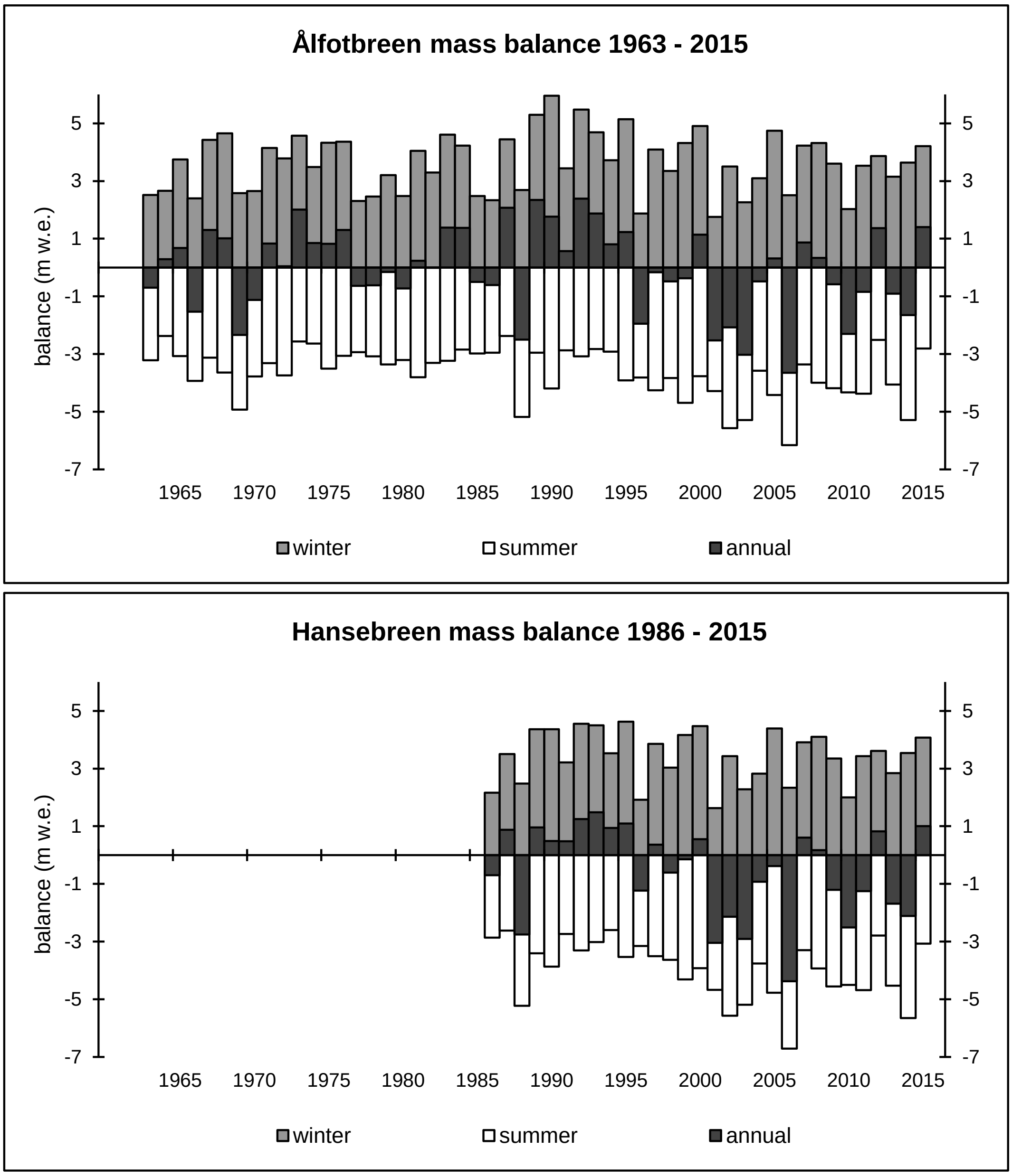


Figure 2-12
Mass balance at Ålfotbreen (upper) 1963-2015 and Hansebreen (lower) 1986-2015.

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 (158 km^2 in 2013) 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 (3.2 km^2) and Gråfjellsbrea (8.1 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 (22.3 km^2) and Blomstølskardsbreen (22.4 km^2).

Mass balance measurements were previously carried out on 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 3-7. Mass balance measurements were also carried out at Svelgjabreen/Blomstølskardsbreen (then called Blomsterskardsbreen) in 1971 (Tvede, 1973), and annual balance only was measured in the period 1972-77.

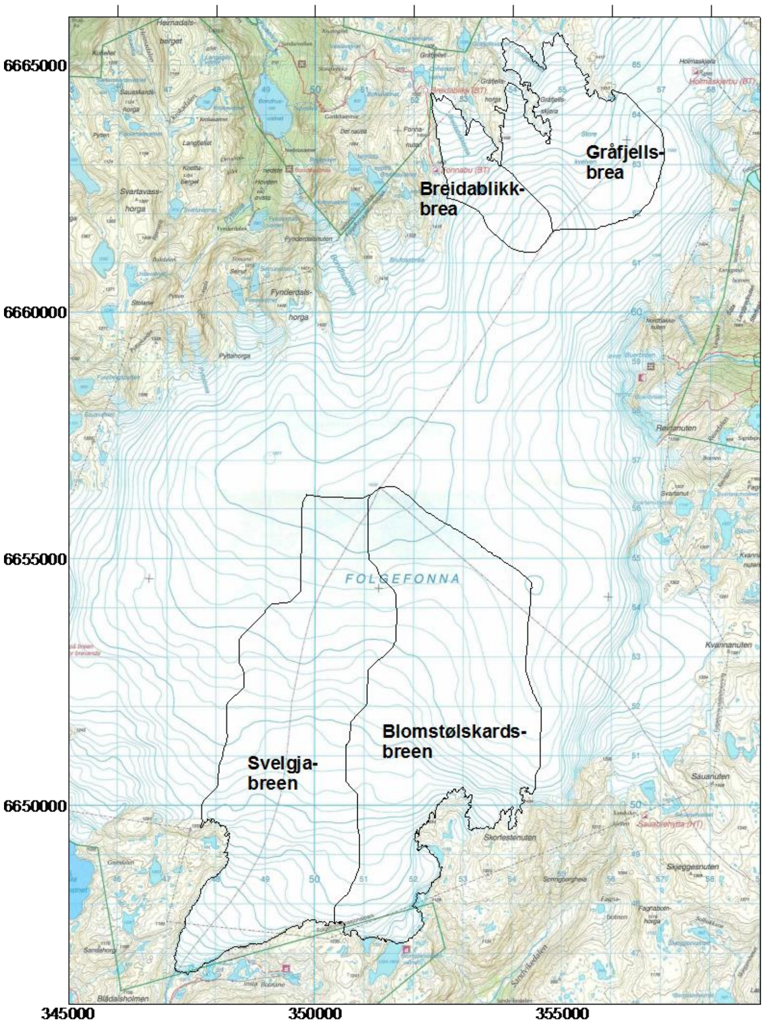


Figure 3-1
Southern Folgefonna with Breidablikkbrea and Gråfjellsbrea in the northwest and Svelgjabreen and Blomstølskardsbreen in the south.

3.1 Mapping

A new mapping of Folgefonna was performed in 2013. The glacier surface was mapped by aerial photographs and airborne laser scanning on 20th September. A Digital Terrain Model (DTM) was processed based on the laser scanning data. The glacier boundary was determined from an orthophoto composed of the air photos. The ice divides between the different glaciers were processed using GIS, and revised height-area distributions for Gråfjellsbrea, Breidablikkbrea, Svelgjabreen and Blomstølskardsbreen were calculated. The mass balance calculations for the years 2011-2015 are based solely on the DTM from 2013.

3.2 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2011

Snow accumulation measurements were performed on 29th April and the calculation of winter balance was based on measurement of two stakes and 34 snow depth probings on Breidablikkbrea, and five stakes and 59 snow depth probings on Gråfjellsbrea (Fig. 3-2). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in September 2010. The sounding conditions were good and the summer surface (S.S.) could be detected easily on both glaciers. The snow depth was between 1.4 and 5.9 metres. Snow density was measured in one position (1478 m a.s.l.) applicable for both glaciers. The mean snow density of 3.4 m snow was 486 kg m^{-3}. Ablation was measured on 1st October. The annual balance was measured at stakes in seven different positions on Breidablikkbrea and six positions on Gråfjellsbrea (Fig. 3-2). All snow from the previous winter had disappeared. At the time of the ablation measurements no fresh snow had fallen.

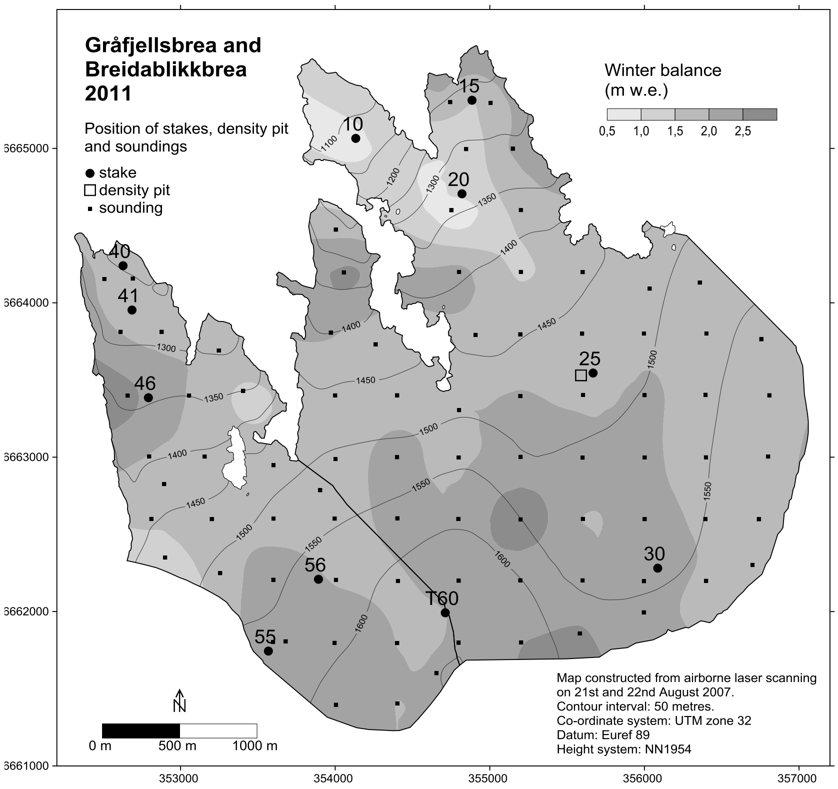


Figure 3-2 Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Breidablikkbrea and Gråfjellsbrea in 2011.

Stake measurements in position T60 are included in the mass balance calculations for both glaciers.

The winter balance was calculated as a mean value for each 50 m height interval and was 1.9 ±0.2 m w.e. at both Breidablikkbrea and Gråfjellsbrea. Based on estimated density and stake measurements the summer balance was calculated as −4.2 ±0.3 m w.e. at Breidablikk-brea and −4.1 ±0.3 m w.e. at Gråfjellsbrea. As the winter balance was low and the summer balance high, the annual balance was negative at −2.3 ±0.4 m w.e. for Breidablikkbrea and −2.2 ±0.4 m w.e. for Gråfjellsbrea.

The mass balance curves for specific and volume balance are shown in Figure 3-3. As shown, the Equilibrium Line Altitude (ELA) lies above the summit (>1648 m a.s.l.) on both glaciers. Consequently, the Accumulation Area Ratios (AAR) are both 0 %.

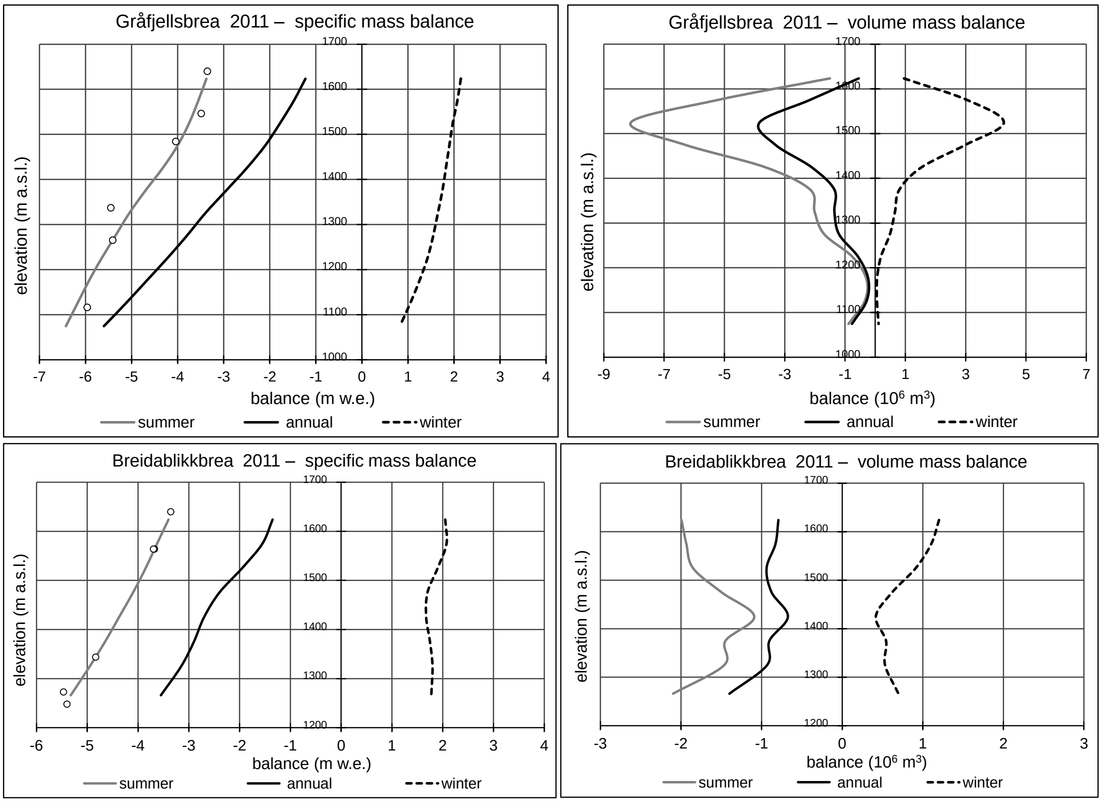


Figure 3-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2011. Specific summer balance for the stakes is shown as dots (○).

3.3 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2012

Snow accumulation measurements were performed on 2nd May and the calculation of winter balance was based on measurement of one stake and 32 snow depth probings on Breidablikkbrea, and three stakes and 56 snow depth probings on Gråfjellsbrea (Fig. 3-4). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in October 2011. The sounding conditions were relatively good, although with some solid ice layers. The snow depth was between 4.1 and 6.9 metres. Snow density was measured in one location (1478 m a.s.l.) applicable for both glaciers. The mean snow density of 4.8 m snow was 529 kg m^{-3}. Ablation was measured on 12th October. The annual balance was measured at stakes in five different positions on Breidablikkbrea and four positions on Gråfjellsbrea (Fig. 3-4). There was approximately 3 m of snow remaining in the uppermost areas. At the time of the ablation measurements up to 55 cm fresh snow had fallen.

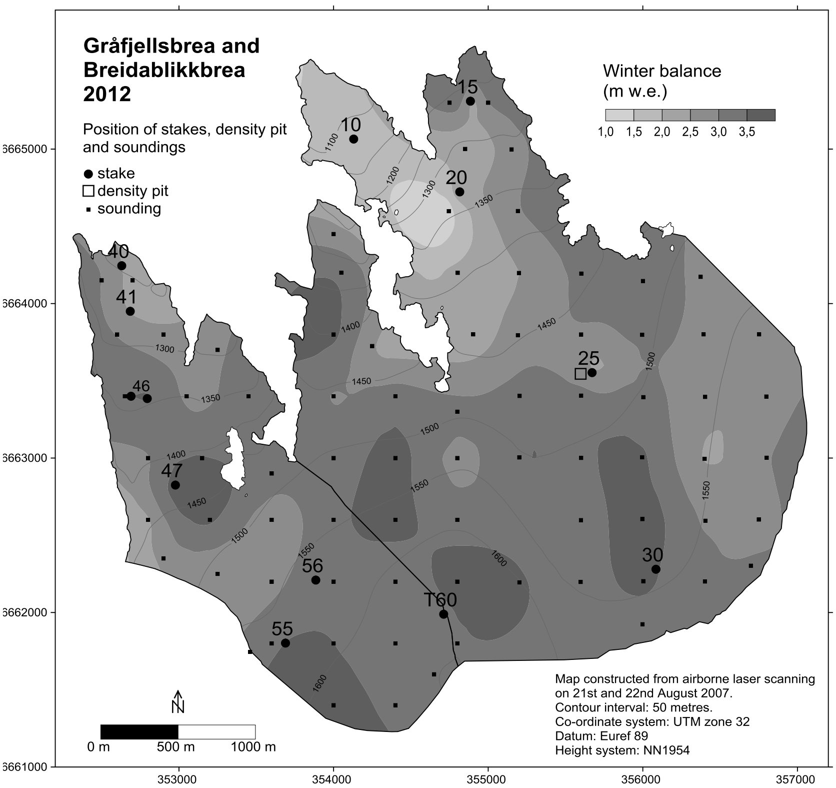


Figure 3-4 Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Breidablikkbrea and Gråfjellsbrea in 2012.

The calculations of winter, summer and annual balances are based on the same method as for 2011. Stake measurements in position T60 are included in the mass balance calculations for both glaciers.

The winter balance was calculated as 3.2 ±0.2 m w.e. at Breidablikkbrea and 2.9 ±0.2 m w.e. at Gråfjellsbrea. The summer balance was calculated for eight stakes at Breidablikkbrea and for six stakes at Gråfjellsbrea (Fig. 3-5). The summer balance for four of the stakes (30, 60, 55 and 56) is partly estimated. Based on estimated density and stake measurements the summer balance was calculated as −2.1 ±0.3 m w.e. at Breidablikkbrea and −1.7 ±0.3 m w.e. at Gråfjellsbrea. The summer balances for both Breidablikkbrea and Gråfjellsbrea in 2012 are the lowest since measurements started in 2003. Accordingly the annual balance was positive at +1.1 ±0.4 m w.e. for both glaciers.

The mass balance curves for specific and volume balance are shown in Figure 3-5. As shown, the ELA lies at 1290 m a.s.l. on Breidablikkbrea and 1280 m a.s.l. on Gråfjellsbrea. Consequently, the AAR are 90 % and 93 %, respectively.

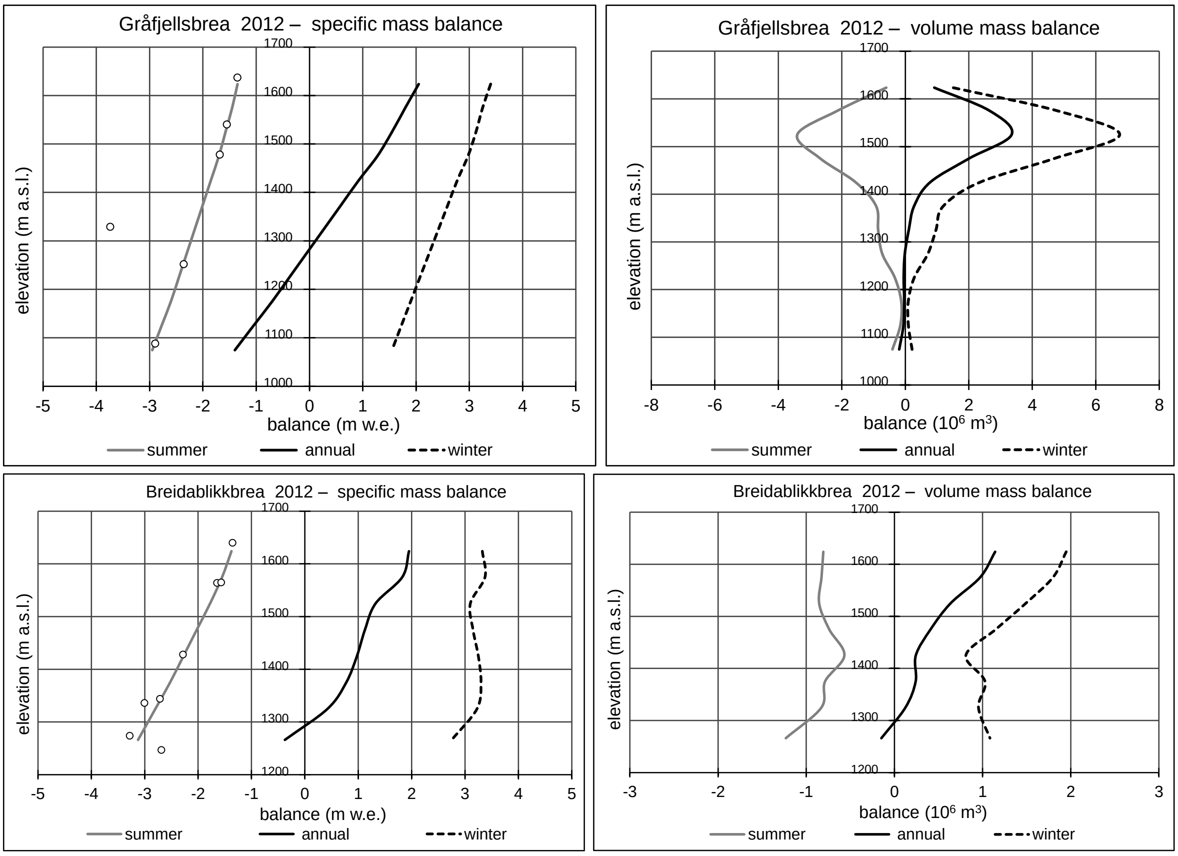


Figure 3-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2012. Specific summer balance for the stakes is shown as dots (○).

3.4 Mass balance at Gråfjellsbrea and Breidablikkbrea in 2013

The mass balance measurements at Breidablikkbrea and Gråfjellsbrea were terminated in 2012. However, the stakes were not removed and the annual balance for 2013 was measured at eight stakes on Breidablikkbrea and five stakes on Gråfjellsbrea on 24th September. All snow from the previous winter had disappeared. At the time of the ablation measurements only a thin layer (<5 cm) of fresh snow had fallen.

Stake measurements in position T60 are included in the mass balance calculations for both glaciers.

The annual balance was calculated as −1.1 ±0.4 m w.e. at Breidablikkbrea and −1.2 ±0.4 m w.e. at Gråfjellsbrea.

The mass balance curves for specific and volume balance are shown in Figure 3-6. As shown, the ELA lies above the highest summit (>1648 m a.s.l.) on both glaciers. Consequently, the AAR are both 0 %.

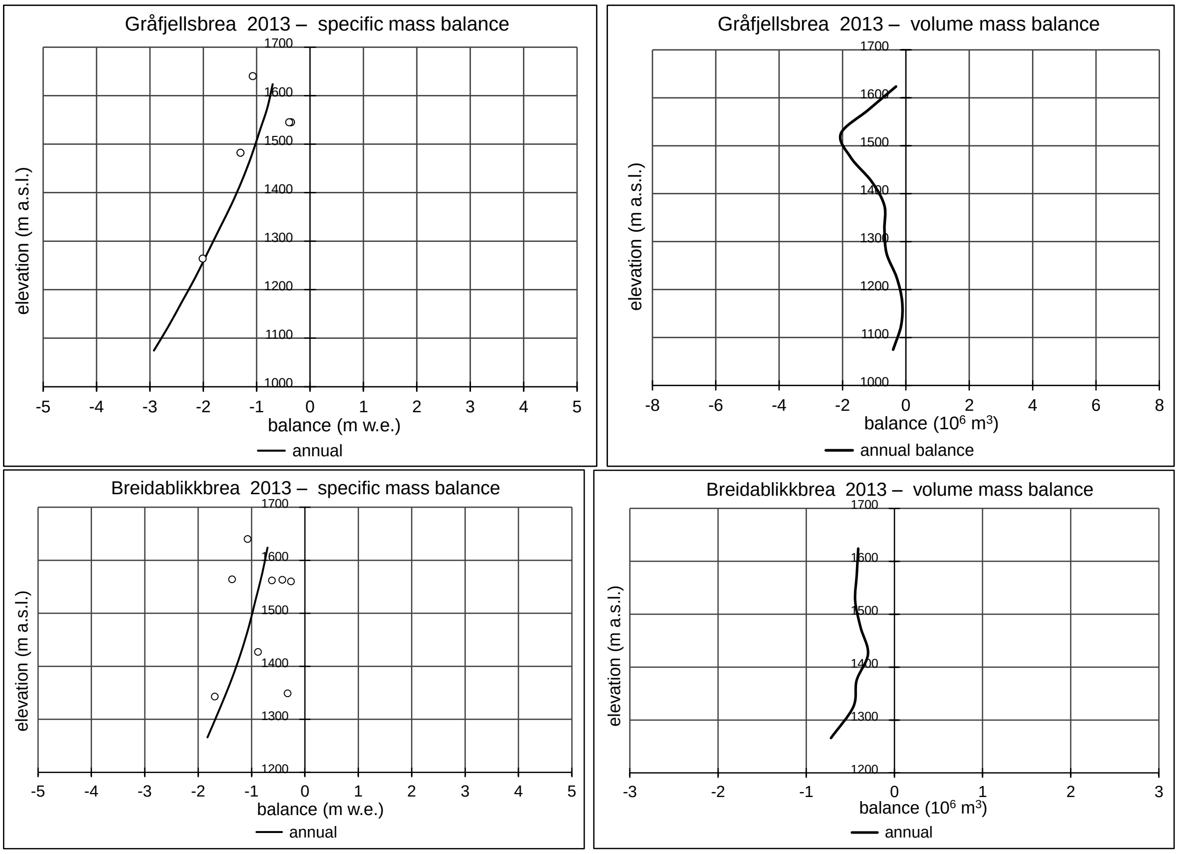


Figure 3-6
Mass balance diagram showing specific annual balance (left) and volume annual balance (right) for Gråfjellsbrea (upper) and Breidablikkbrea (lower) in 2013. Specific annual balance for the stakes is shown as dots (○).

3.5 Mass balance at Gråfjellsbrea and Breidablikkbrea 2003-2013

A summary of the mass balance measurements and results for the years 2011-2013 is given in Table 3-1. The historical mass balance results are presented in Figure 3-7.

The presented mass balance series for Breidablikkbrea and Gråfjellsbrea for 2003-2013 can be classified as original. During the period 2003-2013, the balance year 2012/2013 was the seventh year with significant negative (>0.4 m w.e.) annual balance at both glaciers. The cumulative annual balance for 2003-2013 is −11.1 m w.e. for Breidablikkbrea and −10.0 m w.e. for Gråfjellsbrea.

Table 3-1
Summary values of Gråfjellsbrea and Breidablikkbrea mass balance measurements and results for the period 2011-2013. Values for Gråfjellsbrea (Gr) and Breidablikkbrea (Br) are separated for each year.

	Unit	Gr 2011	Br 2011	Gr 2012	Br 2012	Gr 2013	Br 2013
Date B_w		29 Apr		2 May			
Date B_s		1 Oct		12 Oct		24 Sep	
Density b_w	kg m^{-3}	486		529			
Density $firn_m$	kg m^{-3}	800	800-850			650	
Density $firn_r$	kg m^{-3}			600			
B_w	m w.e.	1.89	1.88	2.94	3.19		
B_s	m w.e.	−4.09	−4.16	−1.73	−2.06		
B_a	m w.e.	−2.20	−2.28	1.21	1.13	−1.15	−1.11
$\sum B_a$ 2011-	m w.e.	−2.20	−2.28	−0.99	−1.15	−2.15	−2.27
ELA	m a.s.l.	>1648		1280	1290	>1648	
AAR	%	0		93	90	0	

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_m$ and Density $firn_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

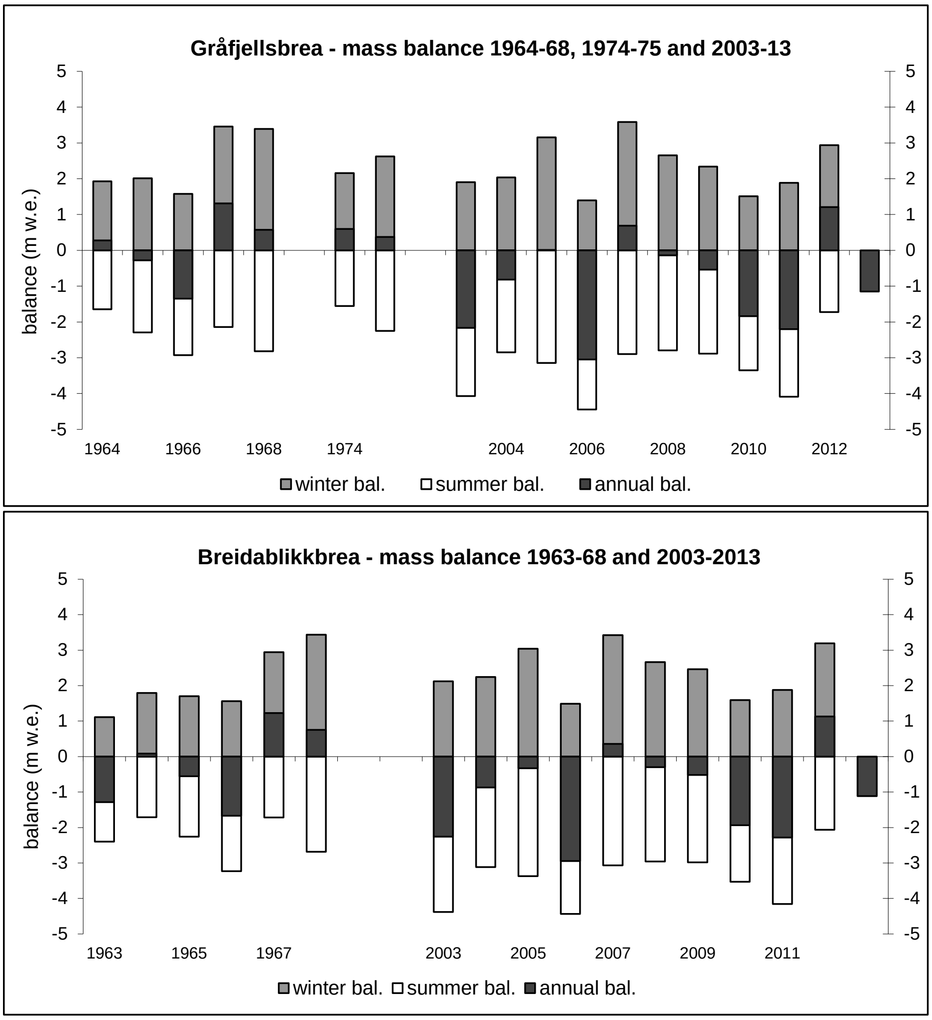


Figure 3-7
Winter, summer and annual balance at Gråfjellsbrea for the periods 1964-68, 1974-75 and 2003-13 (upper), and at Breidablikkbrea for the periods 1963-68 and 2003-2013 (lower).

3.6 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2011

Snow accumulation measurements were performed on 28th April and the calculation of winter balance was based on measurement of five stakes and 53 snow depth probings on Svelgjabreen, and three stakes and 51 snow depth probings on Blomstølskardsbreen (Fig. 3-8). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in September 2010. The summer surface (S.S.) was easy to detect over the whole glacier. The snow depth varied from 2.1 m to 6.5 m at Svelgjabreen, and from 3.4 m to 5.9 m at Blomstølskardsbreen. Snow density was measured in one position (1512 m a.s.l.) applicable for both glaciers. The mean snow density of 5.7 m snow was 512 kg m^{-3}. Ablation was measured on 1st October. The annual balance was measured at stakes in all thirteen positions on the two glaciers (Fig. 3-8). There was almost no snow remaining on the glacier surface from the winter season 2010/2011. At the time of the ablation measurement up to 30 cm of fresh snow had fallen in the uppermost areas.

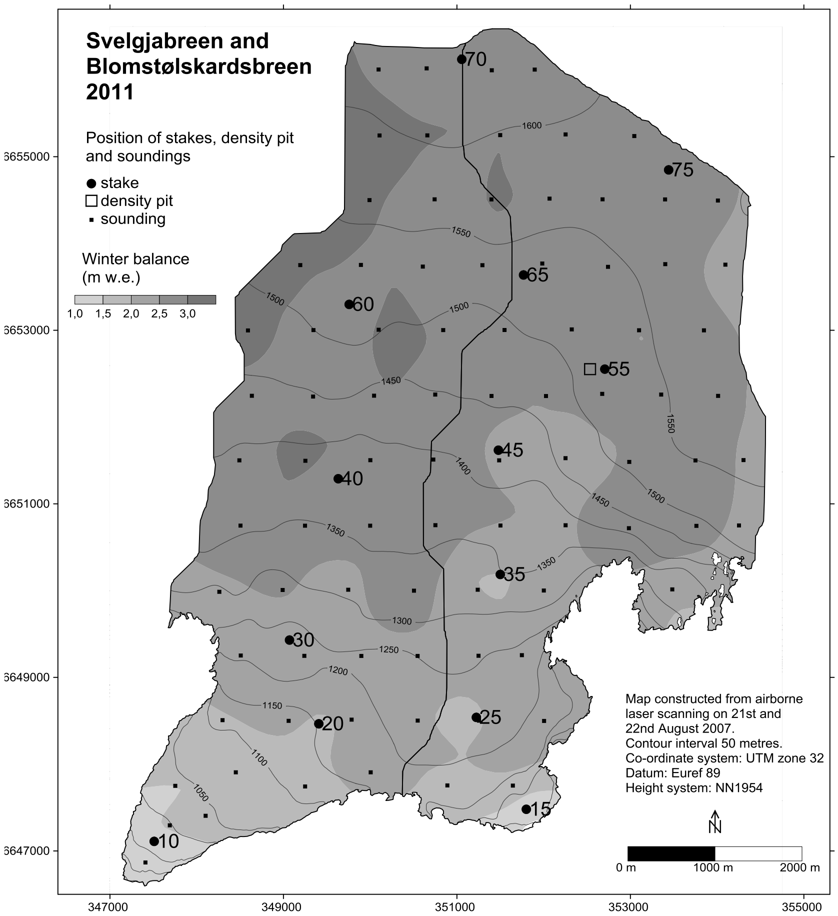


Figure 3-8
Location of stakes, soundings and density pit, and spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2011.

Stake measurements in positions 65 and 70 are included in the mass balance calculations for both Svelgjabreen and Blomstølskardsbreen. All height intervals are well represented with point measurements (b_w) for both glaciers except the very lowest interval (829-900 m a.s.l.) at Svelgjabreen.

The winter balance was calculated as a mean value for each 50 m height interval and was 2.6 ±0.2 m w.e. at Svelgjabreen and 2.5 ±0.2 m w.e. at Blomstølskardsbreen. Based on estimated density and stake measurements the summer balance was calculated as −3.8 ±0.3 m w.e. at Svelgjabreen and −3.5 ±0.3 m w.e. at Blomstølskardsbreen. The annual balance was calculated as −1.3 ±0.4 m w.e. at Svelgjabreen and −1.0 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance curves for specific and volume balance are shown in Figure 3-9. As shown, the ELA lies at 1525 m a.s.l. on Svelgjabreen and at 1600 m a.s.l. on Blomstølskardsbreen. Accordingly the AAR are 20 % and 5 % respectively.

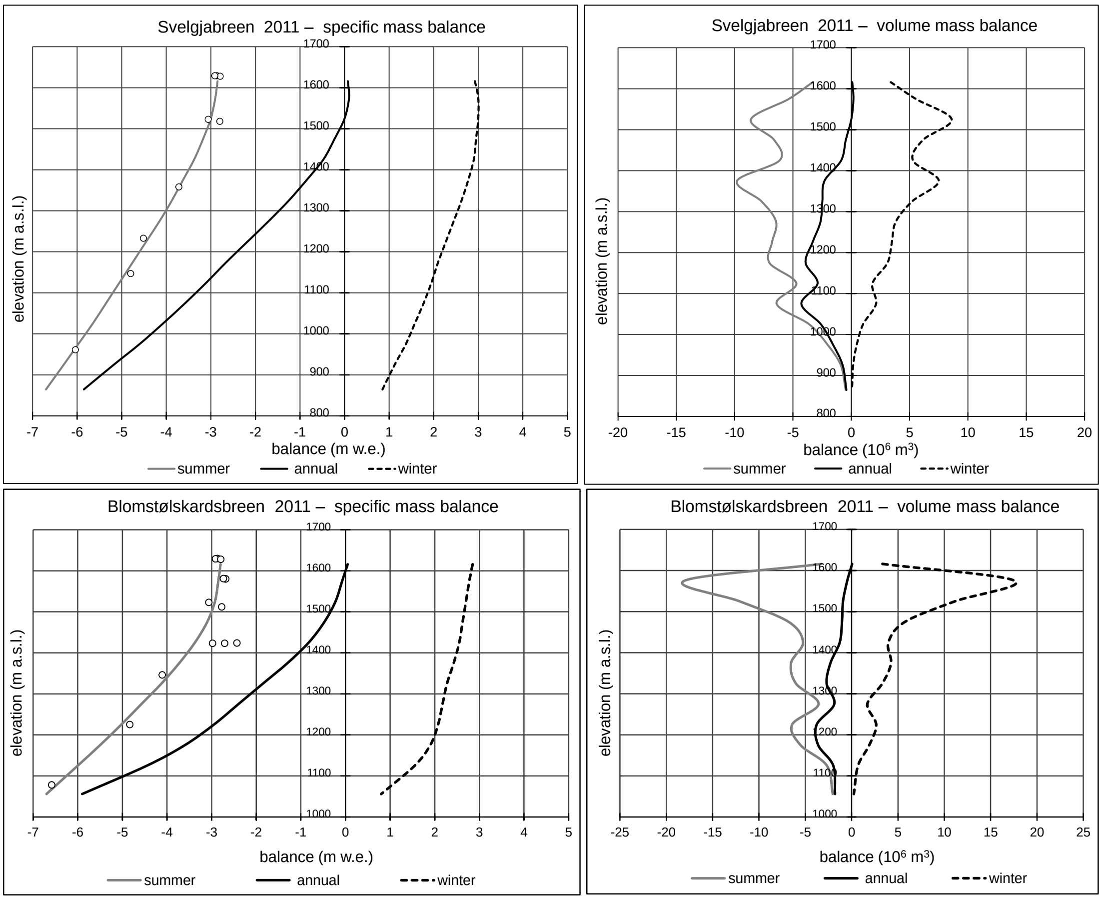


Figure 3-9
Mass balance diagram showing specific balance (left) and volume balance (right) for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2011. Specific summer balance for the stakes is shown as dots (○).

3.7 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2012

Snow accumulation measurements were performed on 3rd May and the calculation of winter balance was based on measurement of three stakes and 55 snow depth probings on Svelgjabreen, and three stakes and 53 snow depth probings on Blomstølskardsbreen (Fig. 3-10). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in October 2011. The S.S. was easy to detect over the whole glacier. The snow depth varied from 3.4 to 9.0 metres. Snow density was measured down to 1.5 m depth in one location (1513 m a.s.l.) applicable for both glaciers. The mean snow density of 1.5 m snow was 407 kg m^{-3}. Ablation was measured on 12th October. The annual balance was measured at stakes in all twelve positions (stake position 65 is removed) on the two glaciers (Fig. 3-10). There was almost 5 m of snow remaining in the uppermost areas. At the time of the ablation measurements between 0.3 and 1.7 m of fresh snow had fallen.

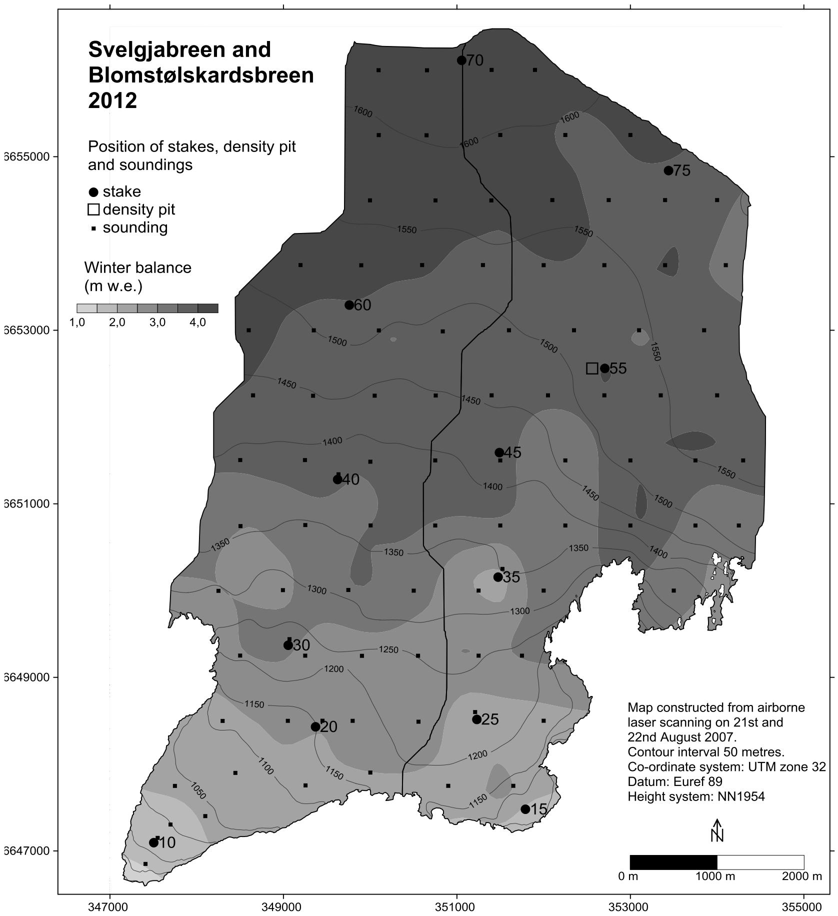


Figure 3-10 Location of stakes, soundings and density pit, and spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2012.

The calculations of winter, summer and annual balances are based on the same method as for 2011. Stake measurements in position 70 are included in the mass balance calculations for both glaciers.

The winter balance was calculated as 3.4 ±0.2 m w.e. at Svelgjabreen and 3.5 ±0.2 m w.e. at Blomstølskardsbreen. Based on estimated density and stake measurements the summer balance was calculated as −2.1 ±0.3 m w.e. at Svelgjabreen and −1.9 ±0.3 m w.e. at Blomstølskardsbreen. Thus, the annual balance was calculated as +1.3 ±0.4 m w.e. at Svelgjabreen and +1.6 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance curves for specific and volume balance are shown in Figure 3-11. According to Figure 3-11, the ELA lies at 1190 m a.s.l. on Svelgjabreen and at 1255 m a.s.l. on Blomstølskardsbreen. Accordingly the AAR are 80 % and 86 %, respectively.

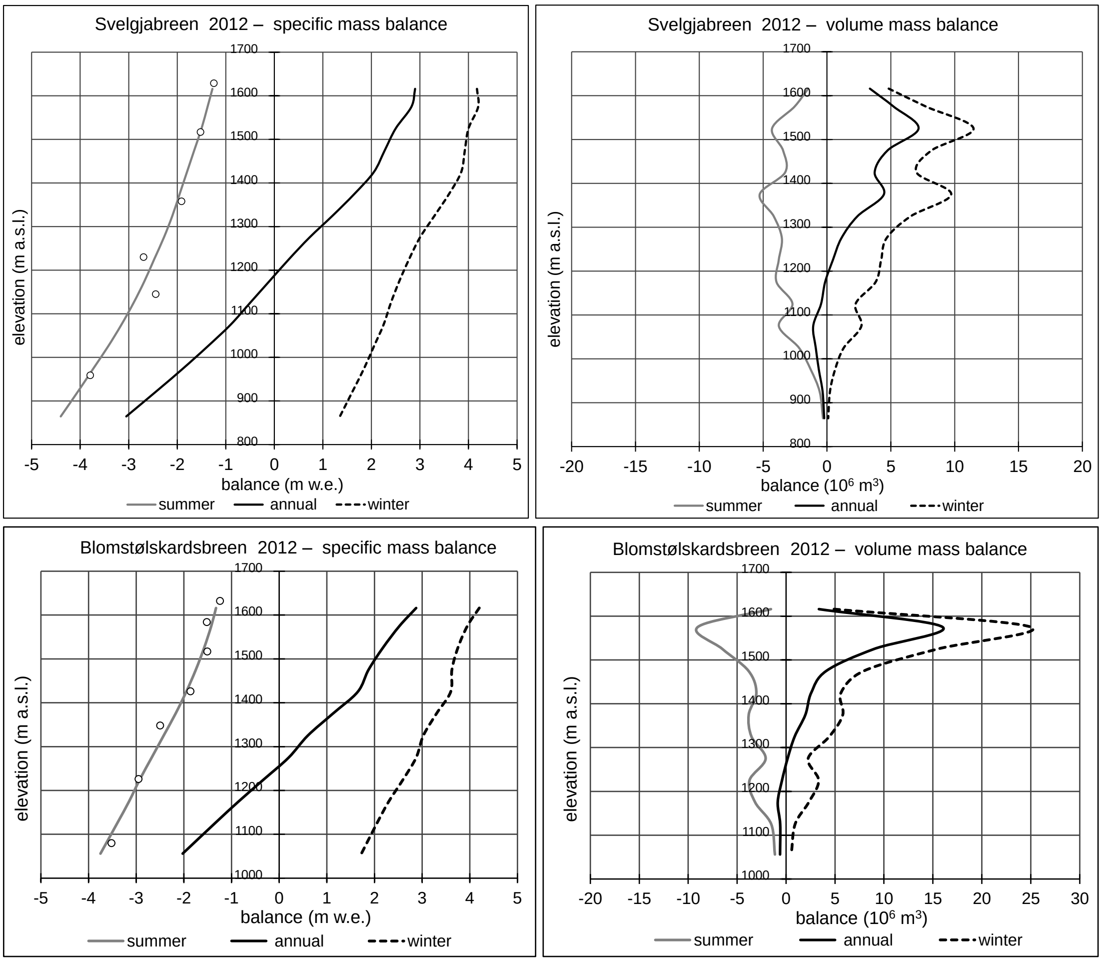


Figure 3-11
Mass balance diagram showing specific balance (left) and volume balance (right) for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2012. Specific summer balance for the stakes is shown as dots (○)

3.8 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2013

Snow accumulation measurements were performed on 29th May and the calculation of winter balance was based on measurement of five stakes and 50 snow depth probings on Svelgjabreen, and five stakes and 47 snow depth probings on Blomstølskardsbreen (Fig. 3-12). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in October 2012. Assessing the snow depths in the accumulation areas above 1400 m elevation was difficult. The S.S. was indistinct with a gradual change from loose snow to more solid snow. The snow depth varied from 1.5 m to 6.0 m at Svelgjabreen, and from 2.1 m to 6.5 m at Blomstølskardsbreen. Measurements of replacement stakes and older stakes that appeared during the melt season revealed discrepancies compared with the snow depth soundings from 29th May. Some of the snow depth soundings were under-estimated and, hence an increase in snow depth between 0.25 and 1.50 m was assigned. Snow density was measured in one location (1513 m a.s.l.) applicable for both glaciers. The mean snow density of 4.4 m snow was 552 kg m^{-3}. Ablation was measured on 24th September. The annual balance was measured at stakes in eleven positions on the two glaciers (Fig. 3-12). There was about 1 m of snow remaining in the uppermost areas from the winter season 2012/2013. At the time of the ablation measurement up to 50 cm of fresh snow had fallen in the uppermost areas.

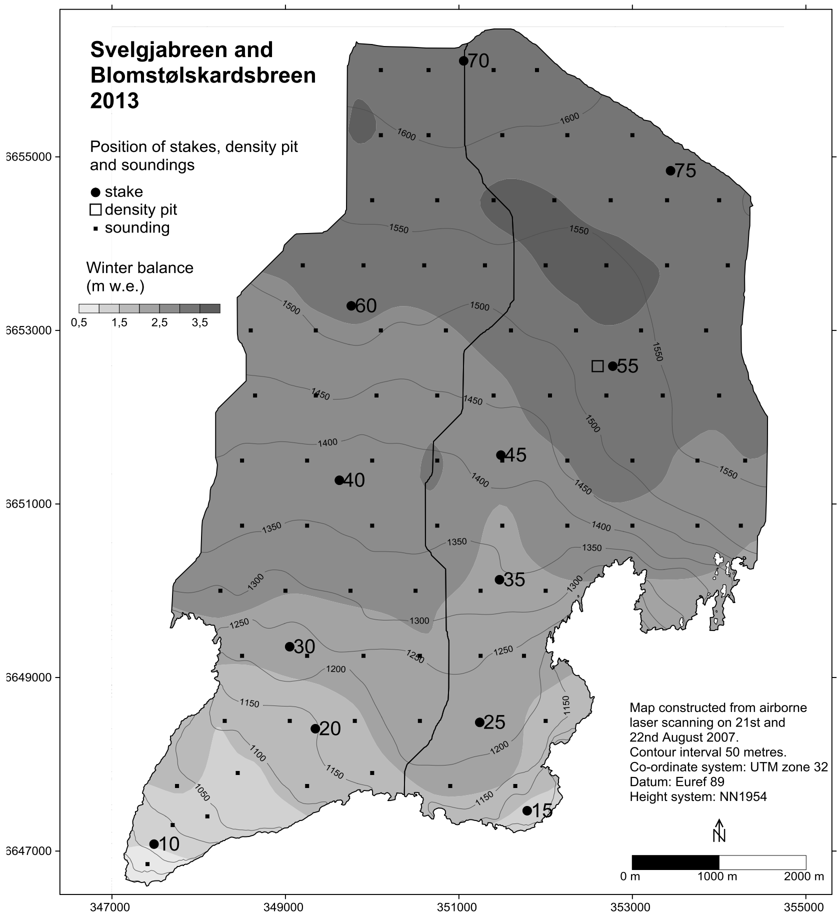


Figure 3-12 Location of stakes, soundings and density pit, and spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2013.

The calculations of winter, summer and annual balances are based on the same method as for 2011. Stake measurements in position 70 are included in the mass balance calculations for both glaciers.

The winter balance was calculated as 2.6 ±0.2 m w.e. at Svelgjabreen and 2.9 ±0.2 m w.e. at Blomstølskardsbreen. Based on estimated density and stake measurements the summer balance was calculated as −3.3 ±0.3 m w.e. at Svelgjabreen and −3.2 ±0.3 m w.e. at Blomstølskardsbreen. The annual balance was thus calculated as −0.7 ±0.4 m w.e. at Svelgjabreen and −0.2 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance curves for specific and volume balance are shown in Figure 3-13. According to Figure 3-13, the ELA lies at 1485 m a.s.l. on Svelgjabreen and at 1470 m a.s.l. on Blomstølskardsbreen. Accordingly the AAR are 29 % and 58 %, respectively.

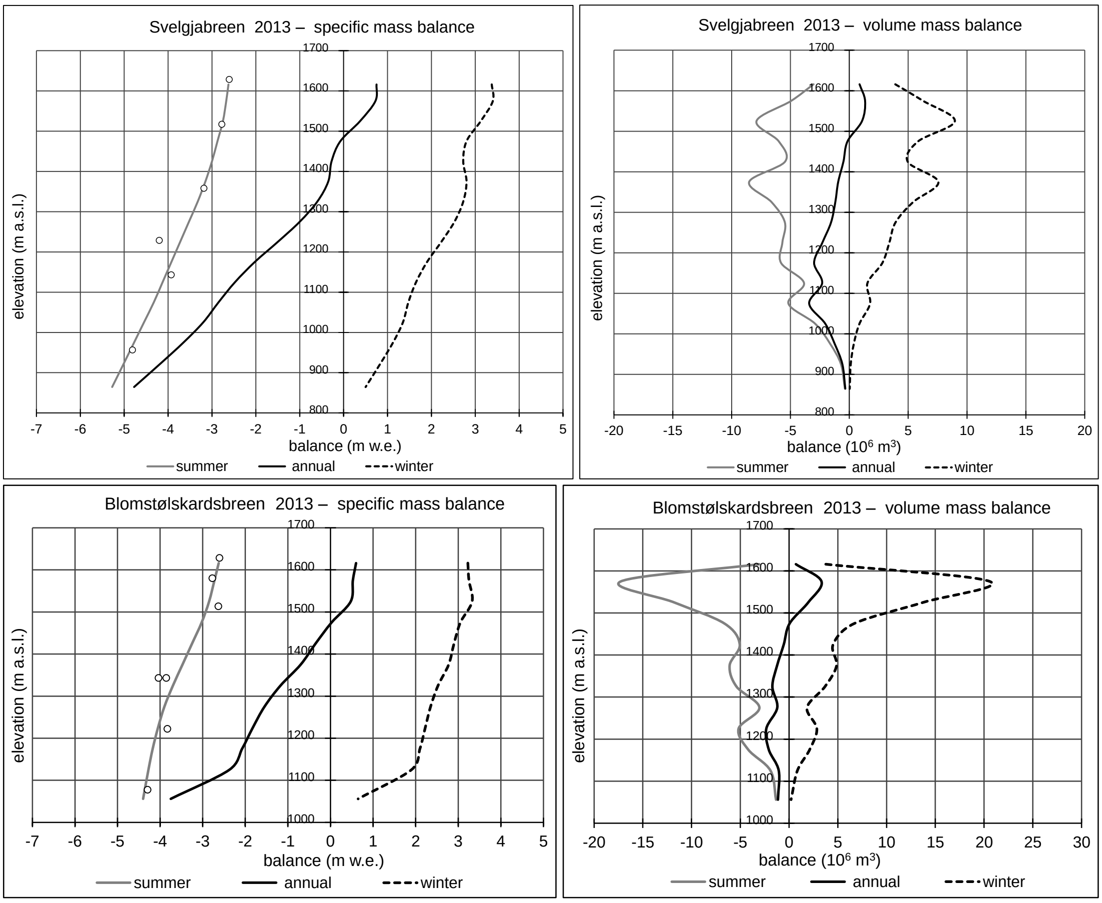


Figure 3-13
Mass balance diagram showing specific balance (left) and volume balance (right) for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2013. Specific summer balance for the stakes is shown as dots (○).

3.9 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2014

Snow accumulation measurements were performed on 24th April and the calculation of winter balance was based on measurement of one stake and 49 snow depth probings on Svelgjabreen, and 47 snow depth probings on Blomstølskardsbreen (Fig. 3-14). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in September 2013. Assessing the snow depths in the accumulation areas above 1400 m elevation was difficult. The summer surface (S.S.) was indistinct with a gradual change from loose snow to more solid snow. The snow depth varied from 4.2 m to 8.9 m at Svelgjabreen, and from 4.4 m to 8.5 m at Blomstølskardsbreen. Snow density was measured in one location (1513 m a.s.l.) applicable for both glaciers. The mean snow density of 6.0 m snow was 490 kg m^{-3}. Ablation was measured on 14th October. The annual balance was measured at stakes in eleven positions on the two glaciers (Fig. 3-14). There was about 2 m of snow remaining in the uppermost areas from the winter season 2013/2014. At the time of the ablation measurement up to 60 cm of fresh snow had fallen in the uppermost areas.

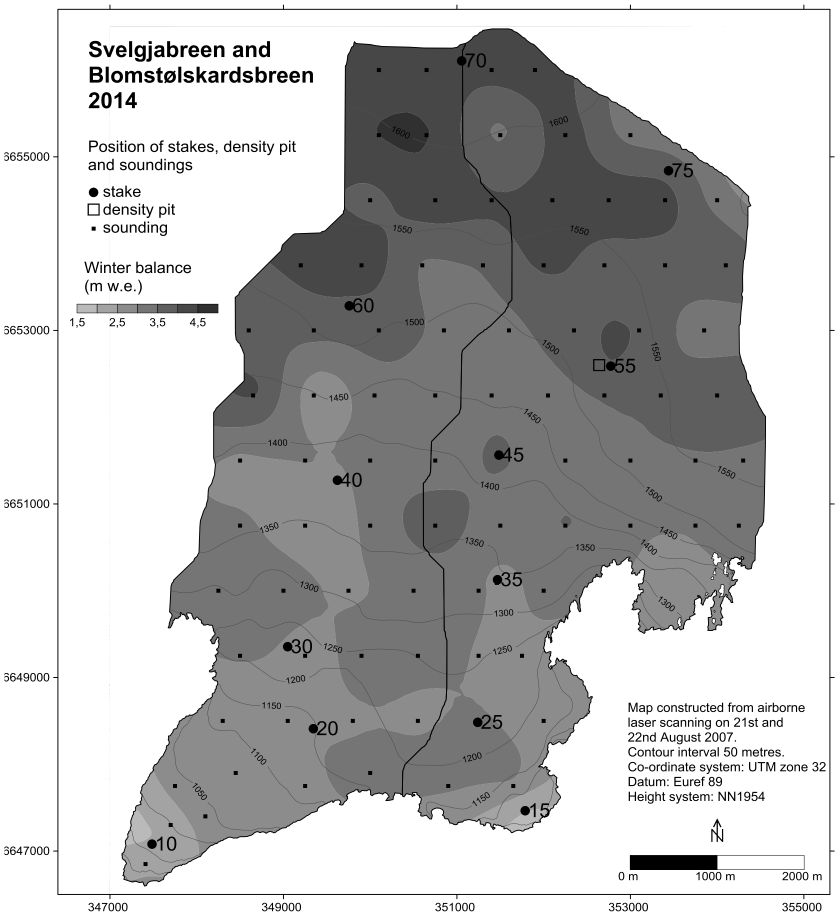


Figure 3-14 Location of stakes, soundings and density pit, and spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2014.

The calculations of winter, summer and annual balances are based on the same method as for 2011. Stake measurements in position 70 are included in the mass balance calculations for both glaciers.

The winter balance was calculated as 3.3 ±0.2 m w.e. at Svelgjabreen and 3.5 ±0.2 m w.e. at Blomstølskardsbreen. Based on estimated density and stake measurements the summer balance was calculated as −3.8 ±0.3 m w.e. at Svelgjabreen and −3.6 ±0.3 m w.e. at Blomstølskardsbreen. Hence, the annual balance was calculated as −0.5 ±0.4 m w.e. at Svelgjabreen and −0.1 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance curves for specific and volume balance are shown in Figure 3-15. According to Figure 3-15, the ELA lies at 1460 m a.s.l. on Svelgjabreen and at 1470 m a.s.l. on Blomstølskardsbreen. Accordingly the AAR are 34 % and 58 %, respectively.

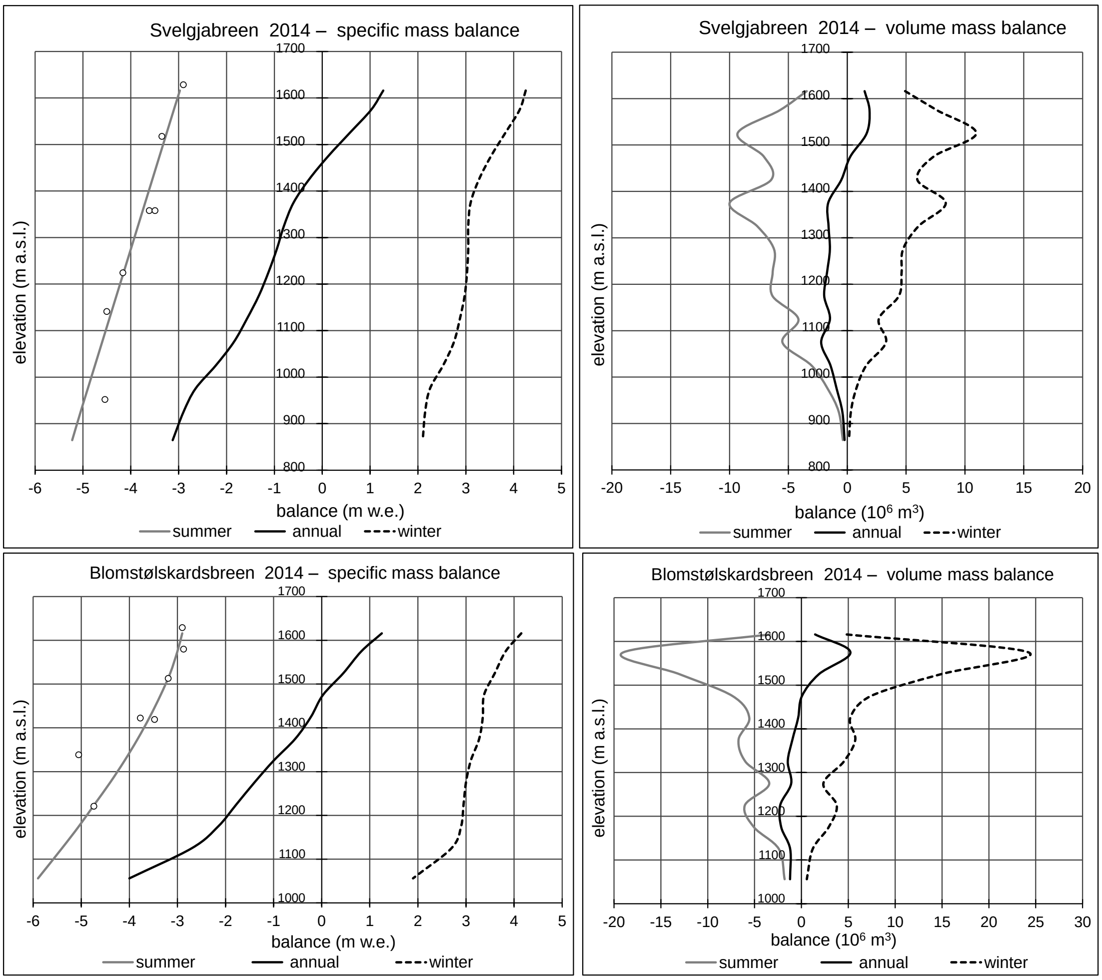


Figure 3-15
Mass balance diagram showing specific balance (left) and volume balance (right) for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2014. Specific summer balance for the stakes is shown as dots (○).

3.10 Mass balance at Svelgjabreen and Blomstølskardsbreen in 2015

Snow accumulation measurements were performed on 22nd April and the calculation of winter balance was based on measurement of one stake and 34 snow depth probings on Svelgjabreen, and one stake and 30 snow depth probings on Blomstølskardsbreen (Fig. 3-16). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in October 2014. The sounding conditions were good and the summer surface could be detected easily on both glaciers. The snow depth varied from 4.8 m to 9.4 m at Svelgjabreen, and from 5.6 m to 9.1 m at Blomstølskardsbreen. Snow density was measured in one location (1513 m a.s.l.) applicable for both glaciers. The mean snow density of 8.2 m snow was 459 kg m^{-3}. Ablation was measured on 14th October. The annual balance was measured at stakes in twelve positions on the two glaciers (Fig. 3-16). There was about 5 m of snow remaining in the uppermost areas from the winter season 2014/2015. At the time of the ablation measurement 0-2 cm of fresh snow had fallen.

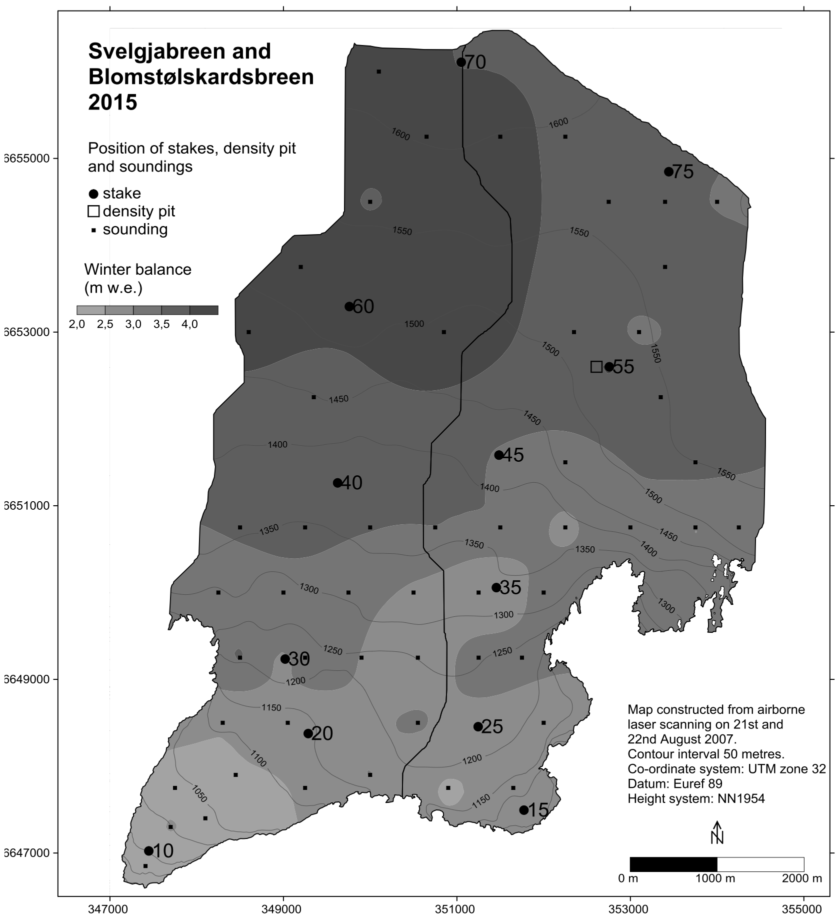


Figure 3-16 Location of stakes, soundings and density pit, and spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2015.

The calculations of winter, summer and annual balances are based on the same method as for 2011. Stake measurements in position 70 are included in the mass balance calculations for both Svelgjabreen and Blomstølskardsbreen.

The winter balance was calculated as 3.5 ±0.2 m w.e. at Svelgjabreen and 3.4 ±0.2 m w.e. at Blomstølskardsbreen. Based on estimated density and stake measurements the summer balance was calculated as −1.6 ±0.3 m w.e. at Svelgjabreen and −1.4 ±0.3 m w.e. at Blomstølskardsbreen. Hence, the annual balance was calculated as +1.8 ±0.4 m w.e. at Svelgjabreen and +2.0 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance curves for specific and volume balance are shown in Figure 3-17. According to Figure 3-17, the ELA lies at 1140 m a.s.l. on Svelgjabreen and at 1250 m a.s.l. on Blomstølskardsbreen. Accordingly the AAR is 86 % for both glaciers.

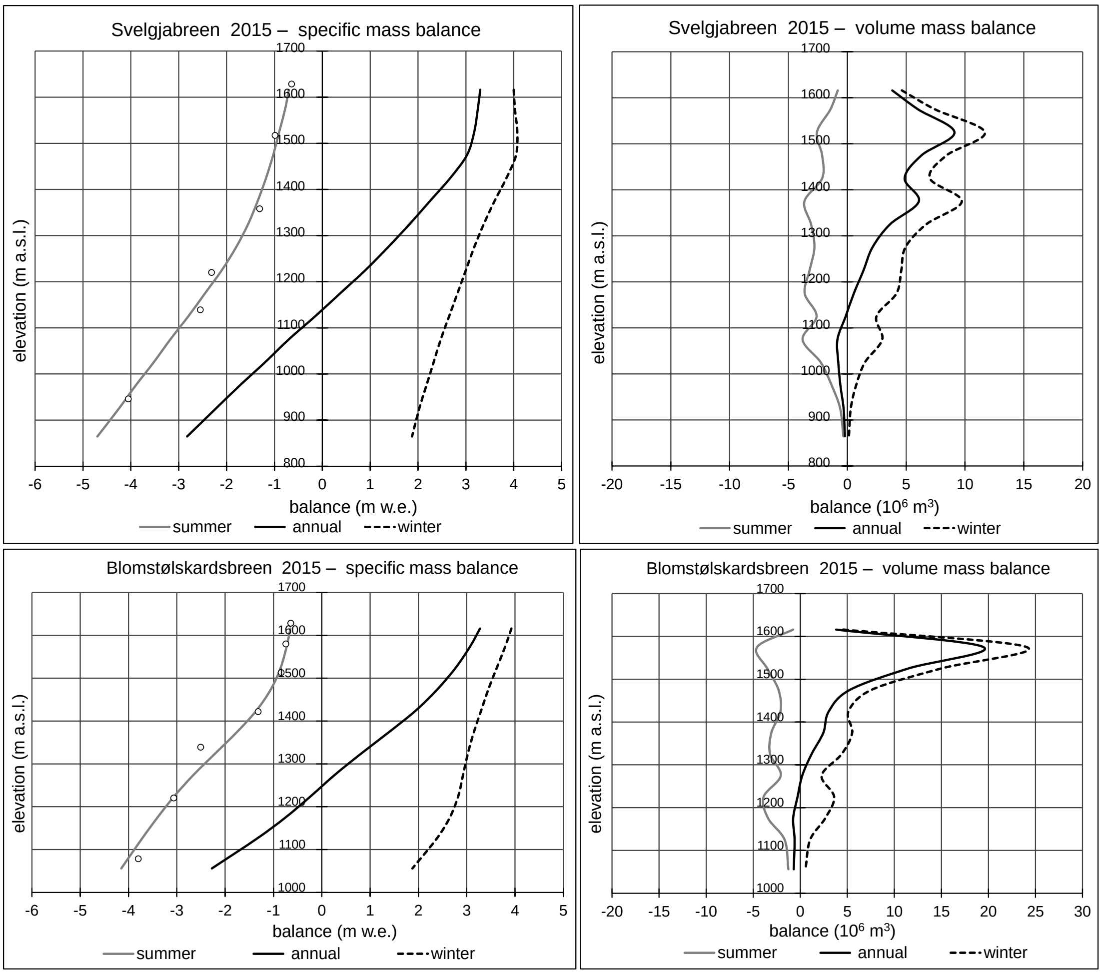


Figure 3-17
Mass balance diagram showing specific balance (left) and volume balance (right) for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2015. Specific summer balance for the stakes is shown as dots (○).

3.11 Mass balance at Svelgjabreen and Blomstølskardsbreen 2007-2015

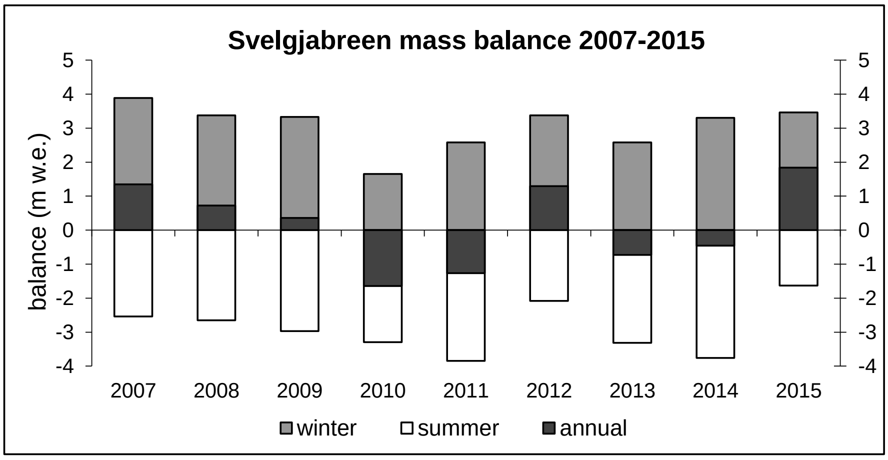
A summary of the mass balance measurements and results for 2011-2015 is given in Table 3-2. The historical mass balance results for 2007-2015 are presented in Figure 3-18.

The presented mass balance series for 2007-2015 for Svelgjabreen and Blomstølskardsbreen can be classified as original. The cumulative annual balance for the period 2007-2015 is +1.5 m w.e. for Svelgjabreen and +2.0 m w.e. for Blomstølskardsbreen.

Table 3-2
Summary values of Svelgjabreen and Blomstølskardsbreen mass balance measurements and results for the period 2011-2015. Values for Svelgjabreen (Sv) and Blomstølskardsbreen (Bl) are separated for each year.

	Unit	2011		2012		2013		2014		2015	
		Sv	Bl	Sv	Bl	Sv	Bl	Sv	Bl	Sv	Bl
Date B_w		28 Apr		3 May		29 May		24 Apr		22 Apr	
Date B_s		1 Oct		12 Oct		24 Sep		14 Oct		14 Oct	
Density b_w	kg m^{-3}	512		407		552		490		459	
Density $firn_m$	kg m^{-3}	700-850				650		700			
Density $firn_r$	kg m^{-3}	600		600		600		600		600	
B_w	m w.e.	2.58	2.52	3.38	3.50	2.58	2.93	3.30	3.46	3.46	3.41
B_s	m w.e.	−3.84	−3.49	−2.08	−1.92	−3.31	−3.17	−3.76	−3.56	−1.63	−1.42
B_a	m w.e.	−1.26	−0.97	1.29	1.59	−0.73	−0.23	−0.46	−0.09	1.84	1.99
$\sum B_a$ 2011-	m w.e.	−1.26	−0.97	0.03	0.62	−0.70	0.38	−1.16	0.29	0.68	2.28
ELA	m a.s.l.	1525	1600	1190	1255	1485	1470	1460	1470	1140	1250
AAR	%	20	5	80	86	29	58	34	58	86	86

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_m$ and Density $firn_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.



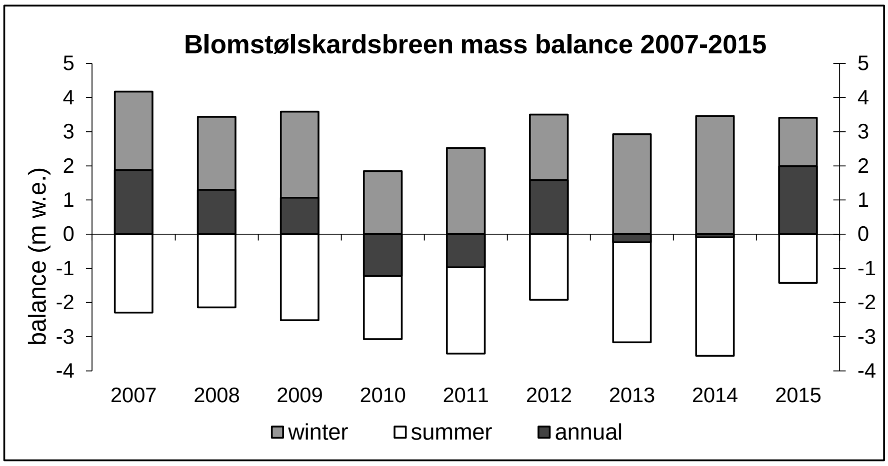


Figure 3-18
Winter, summer and annual balance at Svelgjabreen (upper) and Blomstølskards-breen (lower) for the years 2007-2015.

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 46.6 km^2 (2013) and flows south-east from the centre of the ice cap. Nigardsbreen accounts for approximately 10 % of the total area of Jostedals-breen, and extends from 1952 m a.s.l. down to 330 m a.s.l. (Fig. 4-1).

Glaciological investigations in 2011-2015 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 4-1
The outlet of Nigardsbreen photographed in August 2014. Photo by Hallgeir Elvehøy.

4.1 Mapping

A new survey of Nigardsbreen was performed in 2013. The glacier surface was mapped by aerial photographs and airborne laser scanning on 10th September.

A Digital Terrain Model (DTM) was calculated based on the laser scanning data. The glacier boundary was determined from an orthophoto composed of the aerial photos. The ice divides between the different glaciers were calculated using GIS, and a revised height-area distribution for Nigardsbreen was calculated.

The mass balance calculations for 2011 were based on the previous DTM from 2009, while the calculations in 2012-2015 were based on the DTM from 2013.

4.2 Mass balance 2011

Snow accumulation measurements were performed on 2nd and 3rd May and the calculation of winter balance is based on measurement of six stakes and 132 snow depth soundings Fig. 4-2). Comparison of sounded snow depth and stake readings indicate melting of 25 cm of ice at 600 m altitude after the final measurements in late September 2010. However, the melting observation, is somewhat uncertain and the melted amount is small. Hence, the possible additional melting is not included in the calculation. The sounding conditions were good with a soft snowpack and the summer surface was easy to identify. The snow depth varied between 0.8 and 5.9 metres. Snow density was measured in one position at 1687 m a.s.l. The mean density of 4.4 m snow was 476 kg m^{-3}.

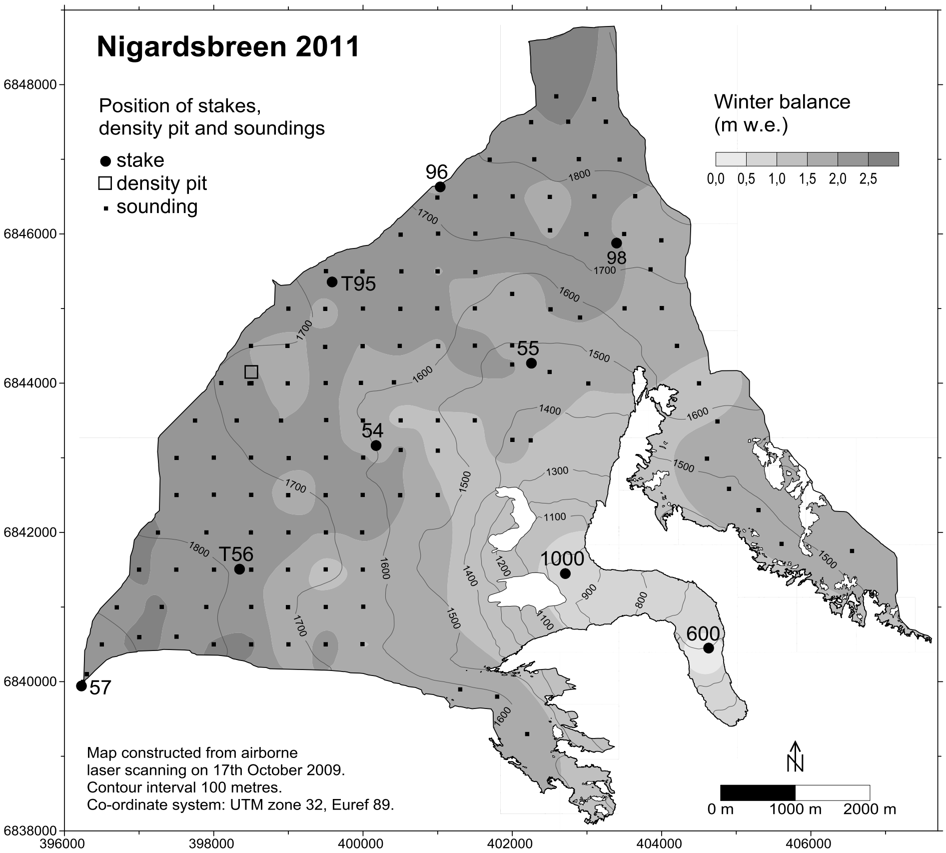


Figure 4-2
Location of towers and stakes, snow pit and soundings, and spatial distribution of winter balance on Nigardsbreen in 2011.

Ablation was measured on 13th October. Measurements were made at stakes and towers in nine locations (Fig. 4-2). In the accumulation areas there were between 0.5 and 1 m of snow remaining from winter 2010/11. At the time of measurement, between 0.3 and 1.2 m of fresh snow had fallen on the glacier plateau.

The elevations above 1350 m a.s.l., which cover about 90 % of the catchment area, were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 974 and 598 m altitude.

The winter balance was calculated as a mean value for each 100 m height interval and was 1.7 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −2.9 ±0.3 m w.e. Hence, the annual balance, was negative, at −1.1 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 4-3. According to Figure 4-3, the Equilibrium Line Altitude (ELA) was 1770 m a.s.l. Consequently, the Accumulation Area Ratio (AAR) was 16 %.

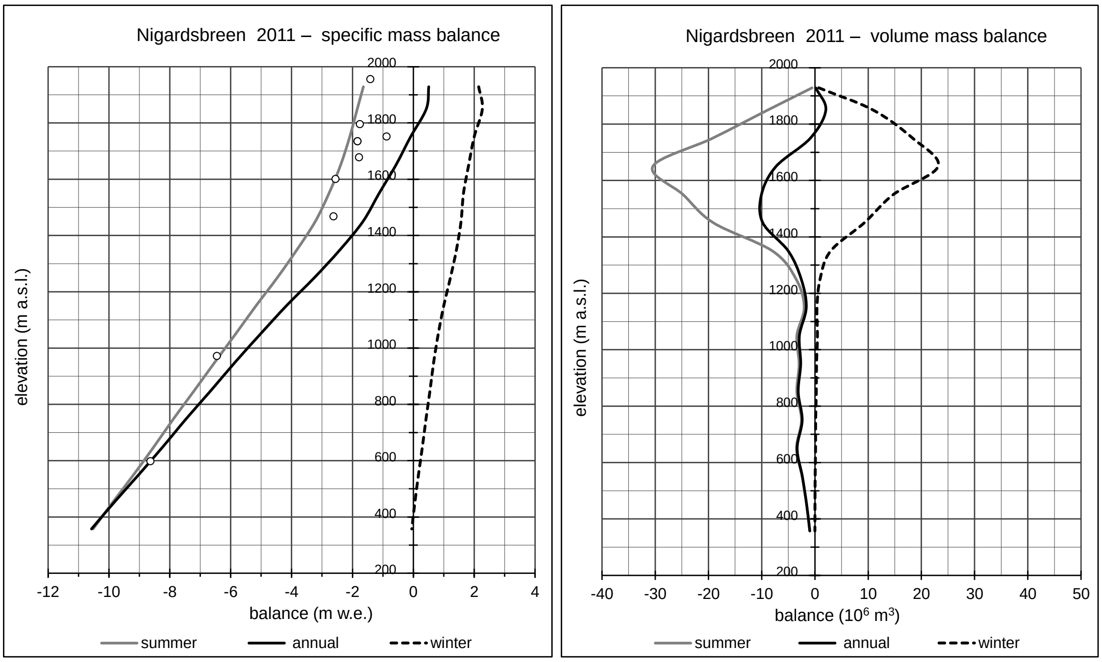


Figure 4-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2011. Specific summer balance at nine stake positions is shown as dots (○).

4.3 Mass balance 2012

Snow accumulation measurements were performed on 21st to 23rd May and the calculation of winter balance was based on measurement of four stakes and 105 snow depth soundings (Fig. 4-4). Comparison of sounded snow depth and stake readings indicated no significant melting after the ablation measurement in October 2011. The sounding conditions were difficult with several solid layers, but no distinct summer surface. However, a soft layer of corn snow was identified lying just above the summer surface. The snow depth varied between 1.2 and 8.3 metres. Snow density was measured in one position at 1687 m a.s.l. The mean snow density of 6.6 m snow was 475 kg m^{-3}. Ablation was measured on 11th October. Measurements were made at stakes and towers in seven locations (Fig. 4-4). In the accumulation areas there were 3-4 m of snow remaining from winter 2011/12. At the time of measurement, between 1 and 1.5 m of fresh snow had fallen on the glacier plateau.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 2.7 ±0.2 m w.e. At the time of the ablation measurements two stakes (57 and 96) had disappeared, presumably buried by fresh snow. Thus, the summer balance for these two stakes was partly estimated. Based on estimated density and stake values in nine different positions the summer balance was calculated as −1.7 ±0.3 m w.e. The annual balance was positive at +1.0 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 4-5. According to Figure 4-5, the ELA was 1330 m a.s.l. Consequently, the AAR was 91 %.

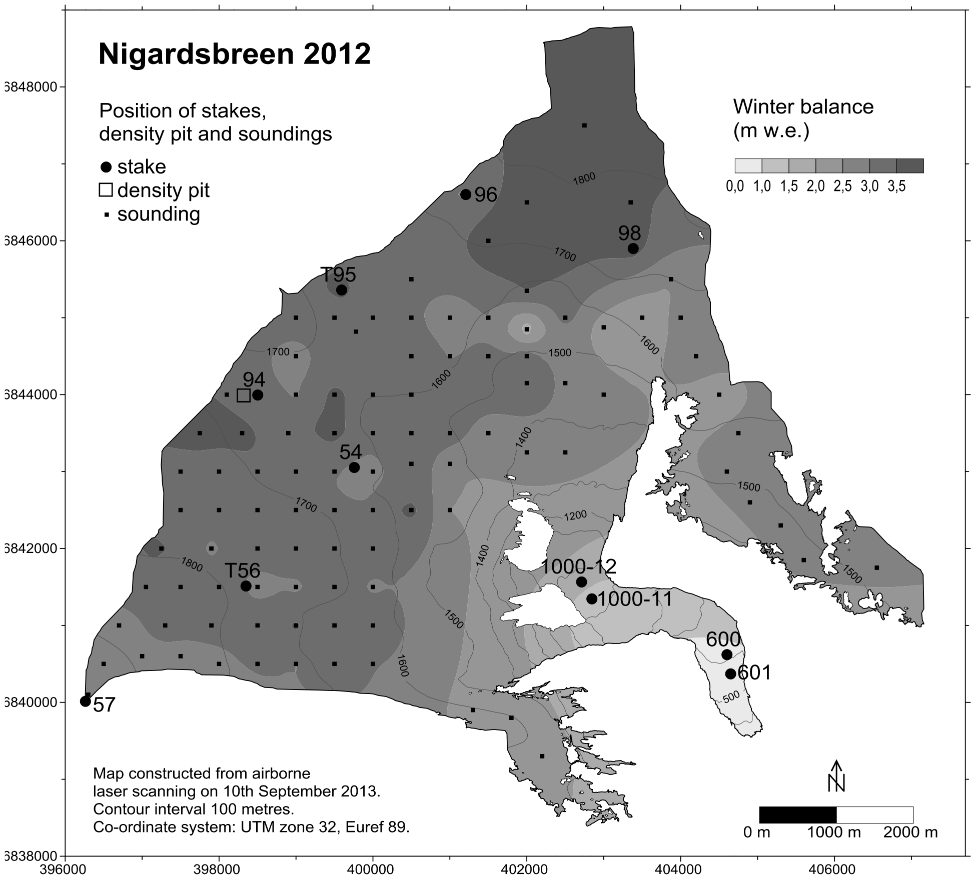


Figure 4-4
Location of towers and stakes, snow pit and soundings, and spatial distribution of winter balance on Nigardsbreen in 2012.

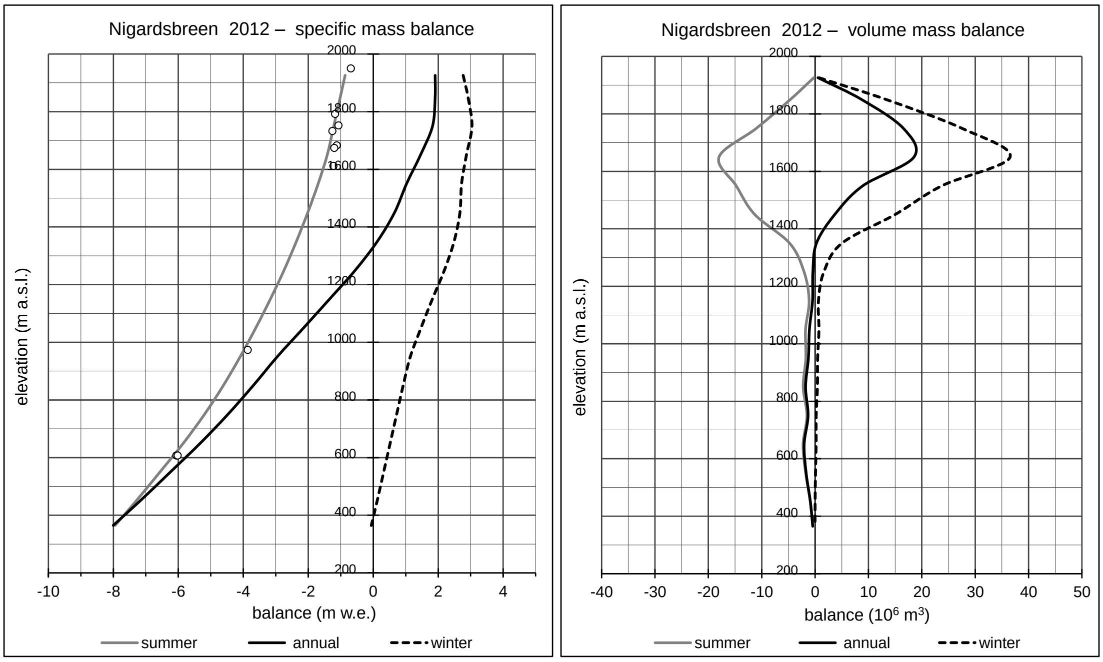


Figure 4-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2012. Specific summer balance at nine stake positions is shown as dots (○).

4.4 Mass balance 2013

Snow accumulation measurements were performed on 23rd and 24th May and the calculation of winter balance was based on measurement of five stakes and 127 snow depth soundings (Fig. 4-6). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in October 2012. Generally the sounding conditions were good, but the summer surface was somewhat indistinct in the uppermost parts of the glacier. The snow depth varied between 0.2 and 5.5 metres. Snow density was measured in one location at 1683 m a.s.l. The mean snow density of 4.9 m snow was 550 kg m^{-3}. Ablation was measured on 25th September. Measurements were made at stakes and towers in ten locations (Fig. 4-6). In the accumulation areas there were 1-2 m of snow remaining from winter 2012/13. At the time of measurement up to 0.5 m of fresh snow had fallen on the glacier plateau.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

The winter balance was calculated as 2.3 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −3.0 ±0.3 m w.e. Hence, the annual balance was negative at −0.7 m ±0.3 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 4-7. Based on Figure 4-7, the ELA was 1680 m a.s.l. Accordingly, the AAR was 35 %.

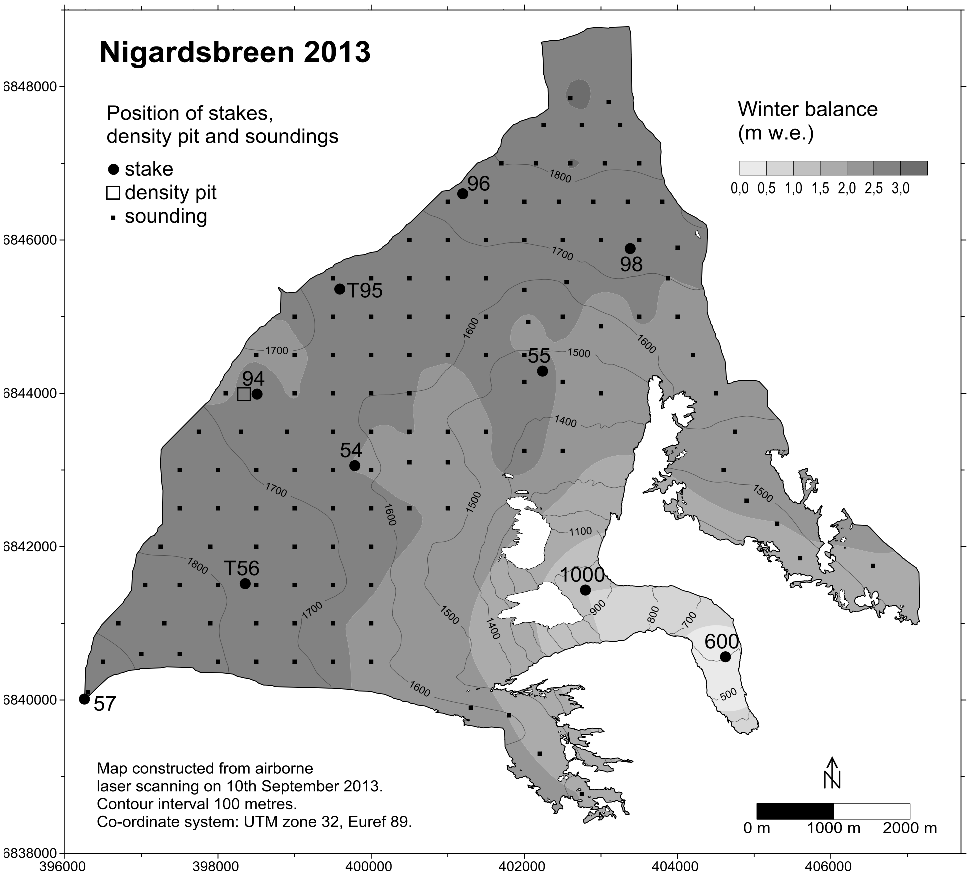
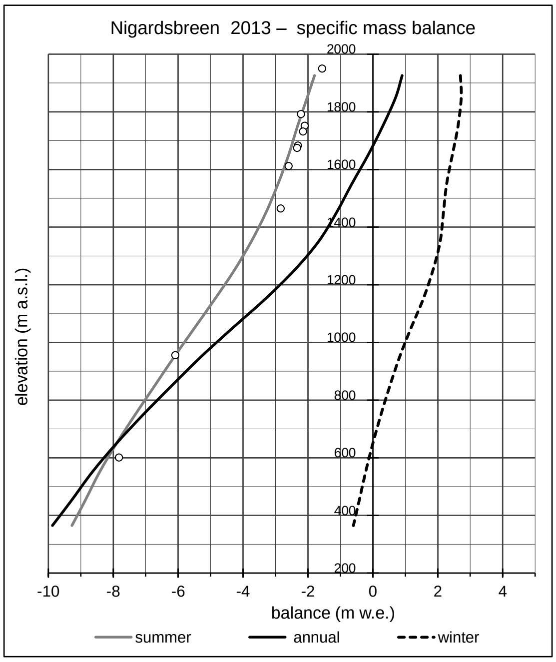


Figure 4-6
Location of towers and stakes, snow pit and soundings, and spatial distribution of winter balance on Nigardsbreen in 2013.



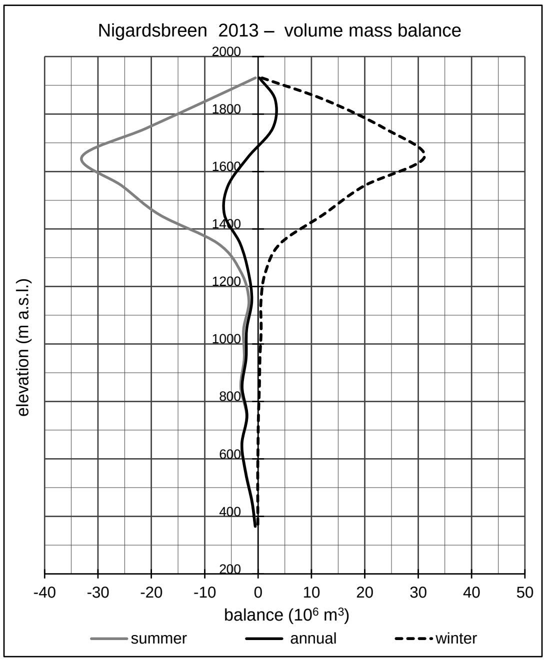


Figure 4-7
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2013. Specific summer balance at ten stake positions is shown as dots (○).

4.5 Mass balance 2014

Snow accumulation measurements were performed on 19th and 20th May and the calculation of winter balance was based on measurement of seven stakes and 132 snow depth soundings (Fig. 4-8). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in September 2013. The summer surface was difficult to detect in some areas, particularly in the uppermost part of the glacier. The snow depth varied between 1.0 and 7.0 metres. Snow density was measured in one location at 1683 m a.s.l. The mean snow density of 5.6 m snow was 509 kg m^{-3}. Ablation was measured on 17th November. Measurements were made at stakes and towers in ten locations (Fig. 4-8). In the accumulation areas there were 1-1.5 m of snow remaining from winter 2013/14. At the time of measurement between 1.3 and 2.4 m of fresh snow had fallen on the glacier plateau.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 2.7 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −3.1 ±0.3 m w.e. Hence, the annual balance was negative at −0.3 m ±0.3 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 4-9. According to Figure 4-9, the ELA was 1550 m a.s.l. Consequently, the AAR was 67 %.

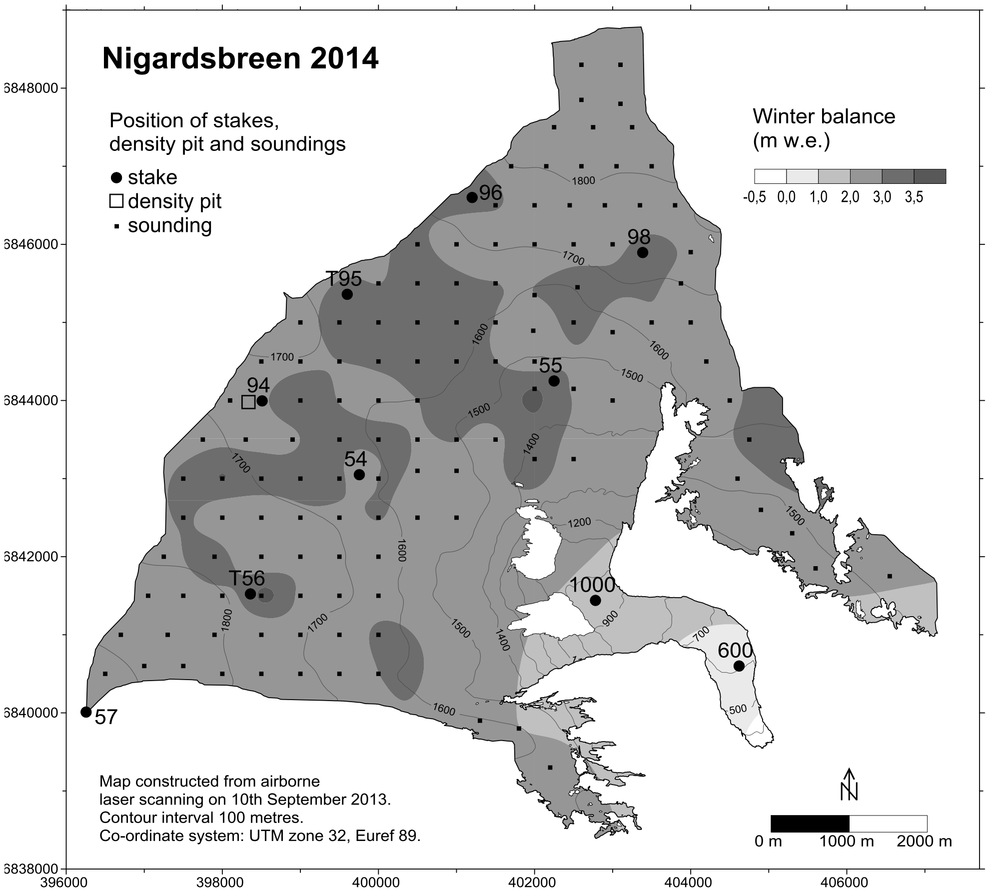


Figure 4-8
Location of towers and stakes, snow pit and soundings, and spatial distribution of winter balance on Nigardsbreen in 2014.

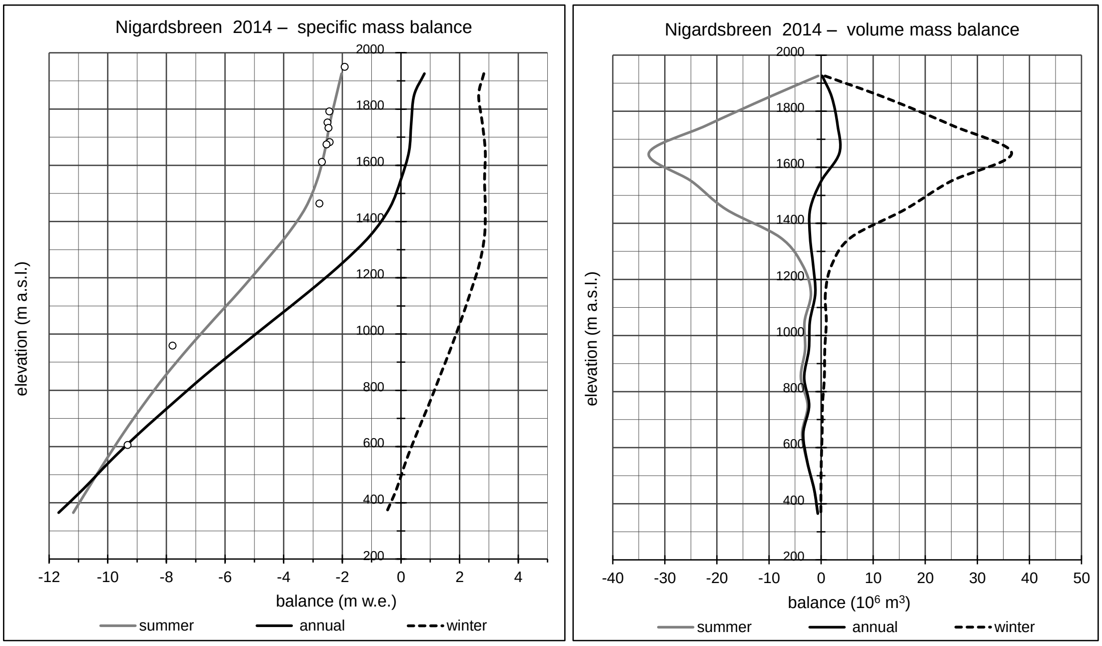


Figure 4-9
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2014. Specific summer balance at nine stake positions is shown as dots (○).

4.6 Mass balance 2015

Snow accumulation measurements were performed on 8th and 9th June and the calculation of winter balance was based on measurement of four stakes and 76 snow depth soundings (Fig. 4-10). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in November 2014. Overall the sounding conditions were good, but the summer surface was somewhat indistinct in the uppermost areas. The snow depth varied between 1.1 and 9.3 metres. Snow density was measured in one location at 1683 m a.s.l. The mean snow density of 6.5 m snow was 454 kg m^{-3}. Ablation was measured on 17th November. Measurements were made at stakes and towers in ten locations (Fig. 4-10). In the accumulation areas there were 3-5 m of snow remaining from winter 2014/15. At the time of measurement between 5 and 9 cm of fresh snow had fallen on the glacier plateau.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 3.1 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −1.4 ±0.3 m w.e. Hence, the annual balance was positive at 1.7 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 4-11. According to Figure 4-11, the ELA was 1310 m a.s.l. Consequently, the AAR was 92 %.

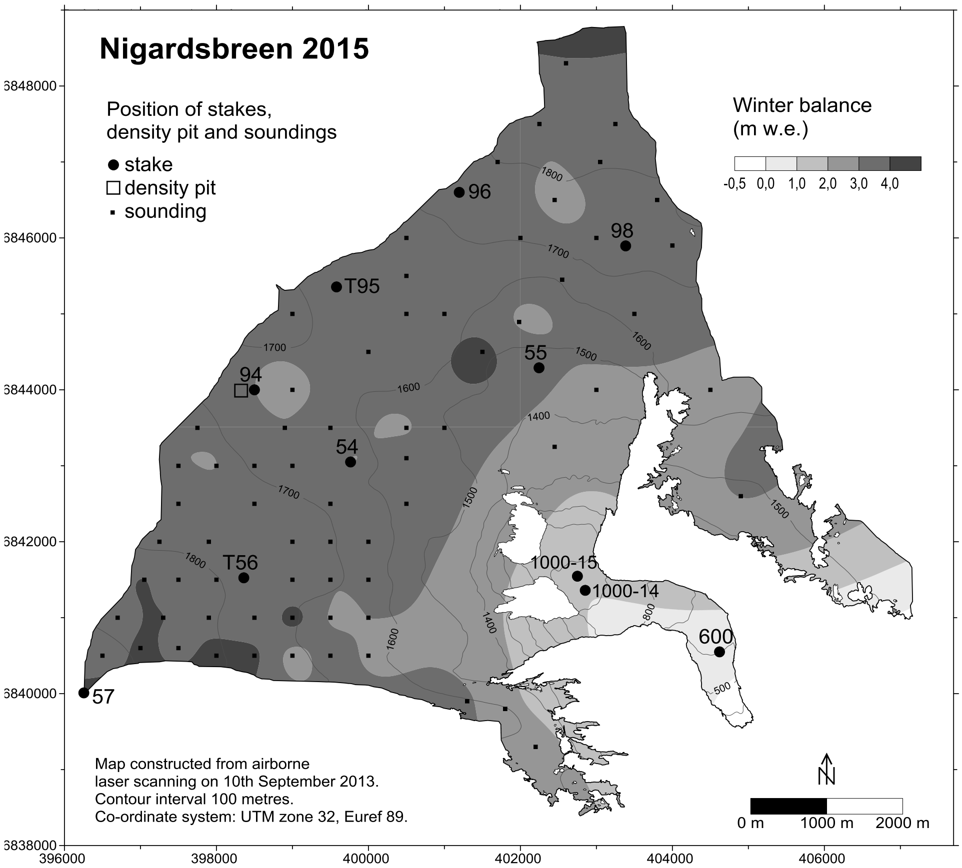


Figure 4-10
Location of towers and stakes, snow pit and soundings, and spatial distribution of winter balance on Nigardsbreen in 2015.

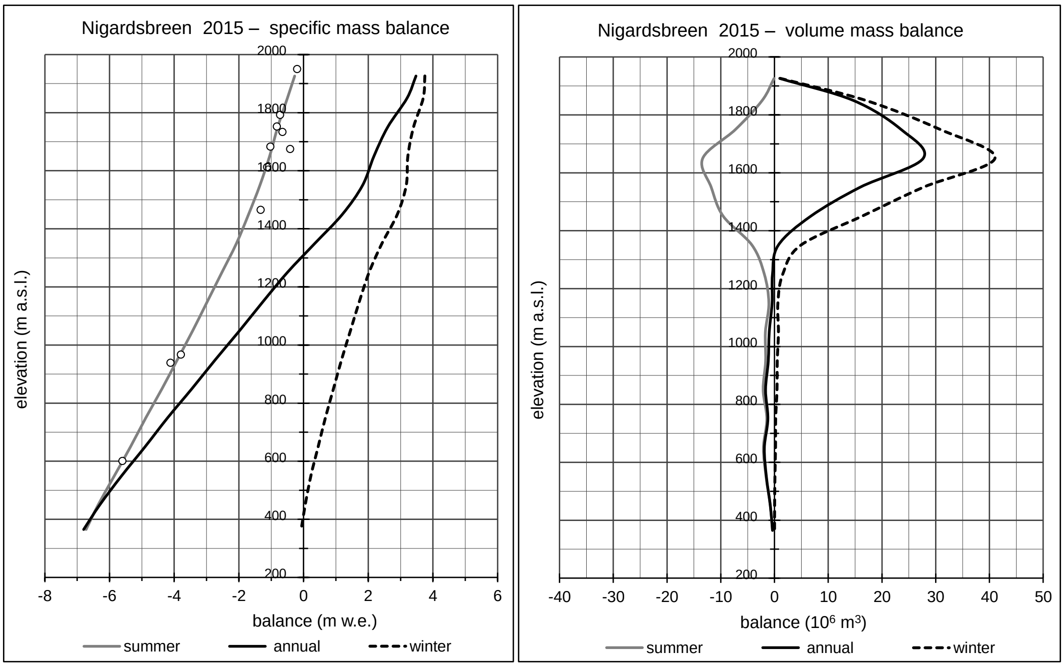


Figure 4-11
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2014. Specific summer balance at nine stake positions is shown as dots (○).

4.7 Mass balance 1962-2015

A summary of the mass balance measurements and results for 2011-2015 is given in Table 4-1.

Table 4-1
Summary values of Nigardsbreen mass balance measurements and results for the years 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		2 May	22 May	23 May	19 May	8 June
Date B_s		13 Oct	11 Oct	25 Sep	17 Nov	14 Oct
Density b_w	kg m^{-3}	476	475	549	509	454
Density $firn_m$	kg m^{-3}	650-750		650		
Density $firn_r$	kg m^{-3}	600	600	600	600	600
B_w	m w.e.	1.72	2.71	2.30	2.73	3.07
B_s	m w.e.	−2.86	−1.73	−2.96	−3.07	−1.35
B_a	m w.e.	−1.13	0.98	−0.65	−0.34	1.71
$\sum B_a$	m w.e.	−1.13	−0.15	−0.80	−1.15	0.56
ELA	m a.s.l.	1770	1330	1680	1550	1310
AAR	%	16	91	35	67	92

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_m$ and Density $firn_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

The mass balance series for Nigardsbreen 1962-2010 was reported in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). Subsequently the mass balance series has been homogenised (1962-2010) and calibrated (1985-2013) (Kjøllmoen, 2016). The homogenisation and calibration procedures are described in chapter 1.2. Homogenising by re-calculation of the mass balance series ensures a uniform methodology, data processing and interpretation of the calculation process from field data to the final balance values. The homogenisation included the period 1962-2010 (2011-2013 were not necessary to homogenise). Calibrating the mass balance series was based on discrepancy found between the homogenised series and geodetic surveys over the years 1964-2013. As a result of the detected discrepancies the calibration included the period 1985-2013.

Following the homogenisation and calibration processes, the re-analysed mass balance series 1962-2013 is presented in Table 4-2.

Table 4-2
Homogenised (H) and calibrated (C) mass balance series for Nigardsbreen 1962-2013.

Homogenised and calibrated mass balance series													
Year	B_w	B_s	B_a	ΣB_a	Hom.	Cal.	Year	B_w	B_s	B_a	ΣB_a	Hom.	Cal.
1962	2,11	0,17	2,27	2,27	H		1988	2,08	-3,37	-1,30	1,89	H	C
1963	1,78	-1,96	-0,19	2,09	H		1989	3,36	-0,93	2,42	4,32	H	C
1964	1,96	-1,19	0,76	2,85	H		1990	3,34	-2,22	1,12	5,44	H	C
1965	1,93	-1,17	0,76	3,61	H		1991	1,79	-2,03	-0,24	5,20	H	C
1966	1,74	-2,69	-0,95	2,66	H		1992	2,66	-1,53	1,13	6,33	H	C
1967	2,98	-1,18	1,80	4,46	H		1993	2,52	-1,40	1,12	7,45	H	C
1968	2,49	-2,41	0,09	4,54	H		1994	2,01	-1,85	0,15	7,60	H	C
1969	1,69	-3,14	-1,45	3,09	H		1995	2,85	-2,03	0,82	8,42	H	C
1970	1,67	-2,30	-0,63	2,46	H		1996	1,25	-1,99	-0,74	7,68	H	C
1971	2,17	-1,31	0,85	3,32	H		1997	2,45	-2,98	-0,53	7,15	H	C
1972	1,79	-2,02	-0,23	3,09	H		1998	2,29	-1,83	0,46	7,61	H	C
1973	2,47	-1,41	1,06	4,15	H		1999	2,21	-2,39	-0,18	7,43	H	C
1974	1,93	-1,72	0,21	4,36	H		2000	3,13	-1,86	1,27	8,70	H	C
1975	2,43	-2,41	0,02	4,38	H		2001	1,69	-2,09	-0,40	8,30	H	C
1976	2,87	-2,44	0,44	4,82	H		2002	2,24	-3,47	-1,23	7,07	H	C
1977	1,49	-2,33	-0,83	3,98	H		2003	1,49	-3,01	-1,52	5,55	H	C
1978	2,00	-2,24	-0,24	3,74	H		2004	1,83	-2,23	-0,40	5,15	H	C
1979	2,43	-2,10	0,34	4,08	H		2005	2,72	-1,83	0,89	6,04	H	C
1980	1,76	-3,03	-1,28	2,80	H		2006	1,63	-3,36	-1,73	4,31	H	C
1981	2,19	-1,98	0,21	3,02	H		2007	2,86	-2,20	0,66	4,97	H	C
1982	1,88	-2,30	-0,42	2,60	H		2008	2,82	-2,04	0,78	5,76	H	C
1983	2,94	-2,03	0,91	3,51	H		2009	2,04	-2,10	-0,06	5,70	H	C
1984	2,49	-2,30	0,19	3,70	H		2010	1,36	-2,46	-1,10	4,59	H	C
1985	1,60	-2,39	-0,79	2,91	H	C	2011	1,72	-2,86	-1,13	3,46		C
1986	1,34	-1,95	-0,62	2,29	H	C	2012	2,71	-1,73	0,98	4,45		C
1987	2,47	-1,57	0,90	3,19	H	C	2013	2,30	-2,96	-0,65	3,79		C

The historical mass balance results for Nigardsbreen 1962-2015 are presented in Figure 4-12. The cumulative annual balance for 1962-2015 is +5.2 m w.e., which gives a mean annual balance of +0.10 m w.e. a^{-1}.

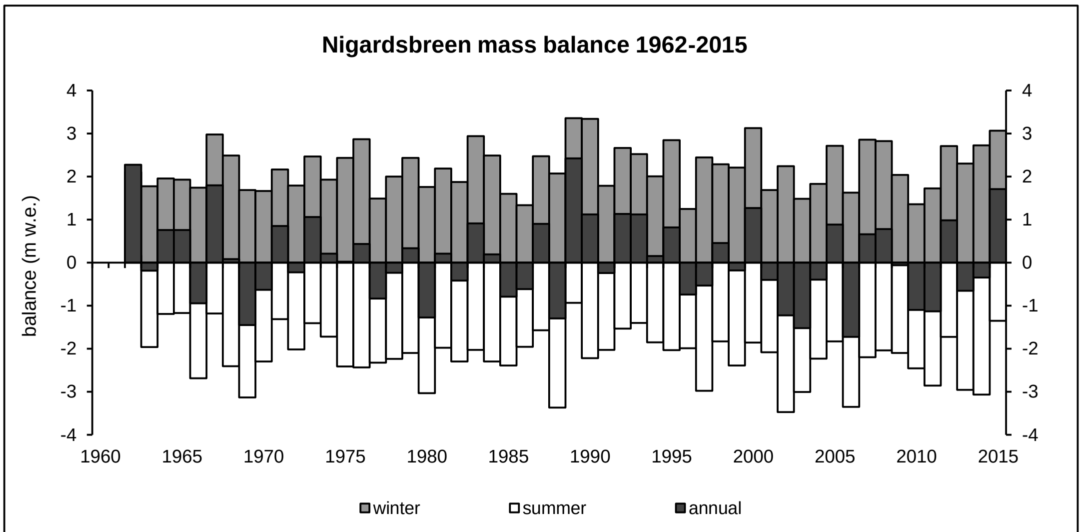


Figure 4-12
Mass balance at Nigardsbreen 1962-2015.

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 (Fig. 5-1). Glaciological investigations started in 1986 in connection with the construction of the hydropower reservoir. The mass balance has been measured since 1988.

The glaciological investigations in 2011-15 included mass balance, front position change and glacier velocity. The calculations were based on a DTM and glacier outlines from 17th October 2009 (Fig. 5-2).

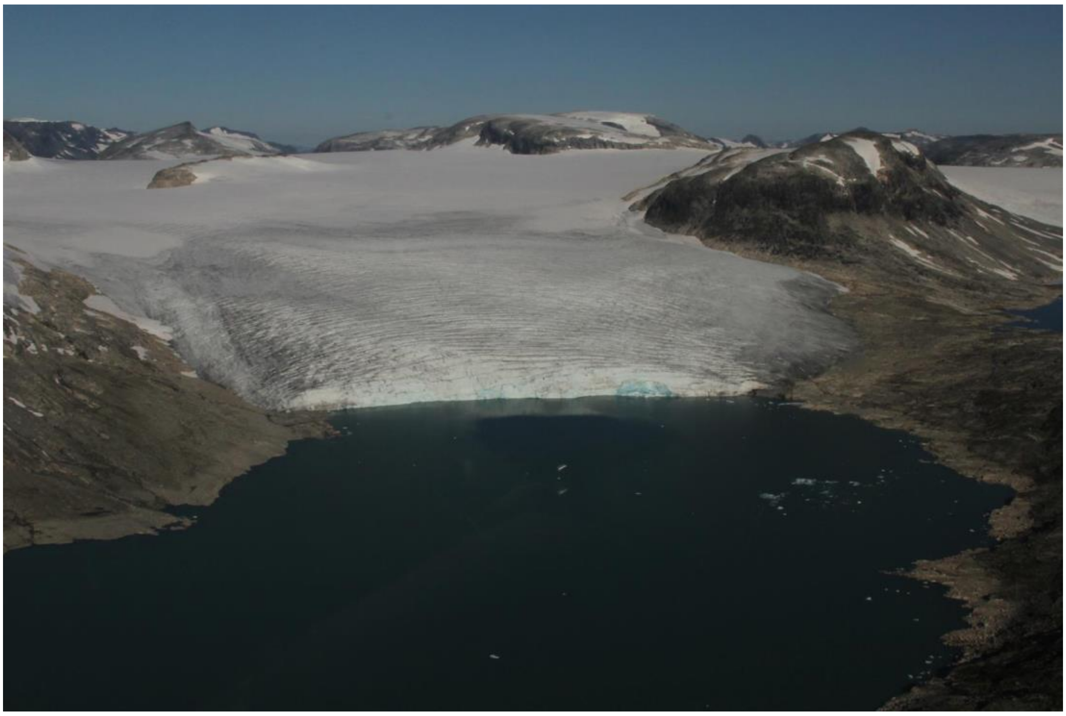


Figure 5-1
Austdalsbreen on 23rd August 2013. The lake level was 1190 m a.s.l. which is 10 m below the highest regulated lake level. Photo: Hallgeir Elvehøy.

5.1 Mass balance 2011

The winter accumulation measurements were carried out on 4th May. Snow depth was measured at six old and one replacement stake, and 39 snow depth soundings were performed in a grid with 500 m spacing between measurements (Fig. 5-3). The sounding conditions were good and the summer surface (SS) was well defined. Generally the snow depth varied between 2 and 4.5 metres. Snow density was measured down to the SS at 3.75 m depth at A60. The mean snow density was 480 kg m^{-3}.

The summer ablation measurements were performed on 13th October. The entire glacier was covered with up to 1 m of new snow. Eight stakes in six locations were found. Based on stake measurements all the snow from the previous winter had melted.

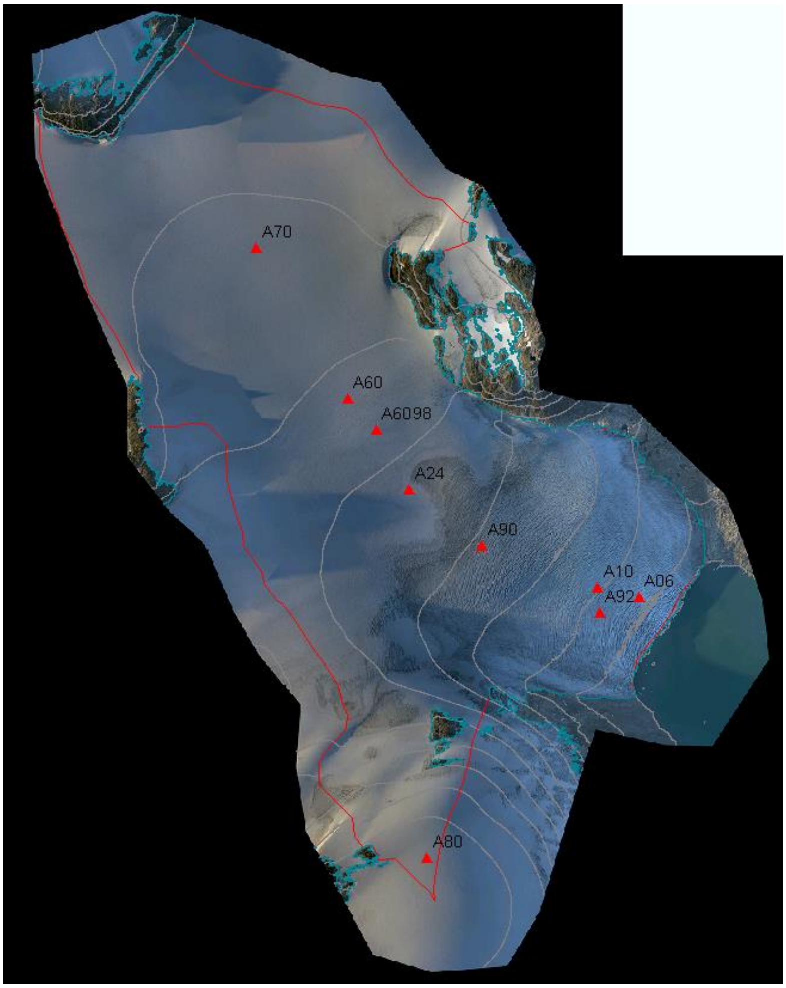


Figure 5-2 Orthophoto of Austdalsbreen from 14th September 2009. Stake locations (red dots) and the drainage divide (red line) are shown.

A comparison of stake readings and snow depth soundings on 4th May indicate no significant melting after the autumn measurements on 9th October 2010.Mean values of SWE and altitude 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 curve a mean value for each 50 m altitude interval was determined. The winter balance was 1.8 ±0.2 m w.e. The winter balance calculated with a gridding method was 2.0 m w.e.

The summer balance was calculated directly at four stake locations, and at another three stake locations with support from snow depth soundings or melting at neighbouring stakes. 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:

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

where ρ_{ice} is 900 kg/m^3, u_{ice} is annual glacier velocity, A_f is change in area between surveyed terminus positions, W is terminus width and H is mean ice thickness at the terminus. The mean ice thickness was calculated from mean surface altitudes along the calving terminus, and mean bottom elevation along the terminus calculated from a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989) (Tab. 5-3). The resulting calving volume was 3.7 ±1.0 mill. m^3. The summer balance, including calving, was calculated as −3.3 ±0.3 m w.e. The calving contributed 11 % of the summer balance.

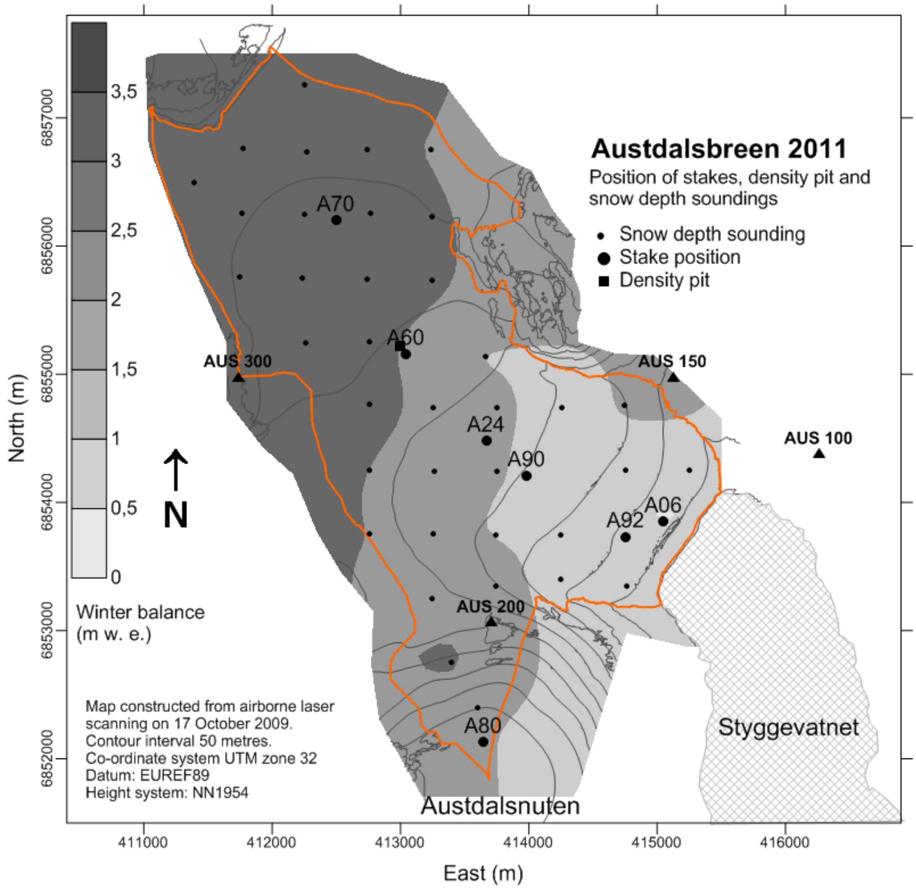


Figure 5-3
Winter balance in 2011 interpolated from 47 SWE values calculated from 39 snow depth soundings and 8 stake measurements of snow depth. The drainage divide (orange polygon) based on the DTM from 2009 is shown.

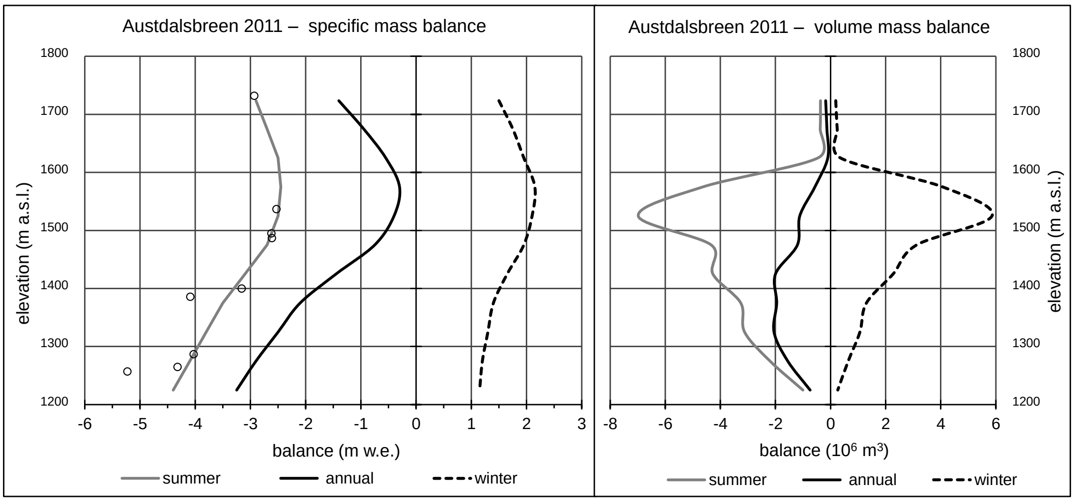


Figure 5-4
Altitudinal distribution of winter, summer and net balances is shown as specific balance (left) and volume balance (right) for Austdalsbreen in 2011. Specific summer balance at seven stake locations is shown (○).

The annual balance in 2011 was calculated as −1.4 ±0.3 m w.e. The equilibrium line altitude (ELA) in 2011 was above the top of the glacier. Consequently, the Accumulation Area Ratio (AAR) was 0 %. The altitudinal distribution of winter, summer and annual balance is shown in Figure 5-4.

5.2 Mass balance 2012

The winter accumulation measurements were performed on 10th May. Snow depth was measured at two old and five new stakes. Comparison of stake length and snow depth sounding at stake A06 indicated no ice melt after the autumn measurements in 2011. Snow depth sounding was performed at 32 positions in a grid with 500 m spacing between measurements and at four stake positions. Generally, the snow depth was between 4 and 6 m. The sounding conditions were good and the SS was well defined. Snow density was measured down to the SS at 5.4 m depth at stake A60. The mean density was 485 kg m^{-3}.

The summer ablation measurements were performed on 11th October. Eleven stakes in nine positions were found. A80 was not found. Based on stake measurements the temporary snow line elevation was around 1350 m a.s.l.

The winter balance was calculated from snow depth and snow density measurements on 10th May. The calculations were performed by the same methods as described for 2011 (section 5-1), and the resulting winter balance was 2.7 ±0.2 m w.e. The winter balance calculated with a gridding method was 2.9 m w.e.

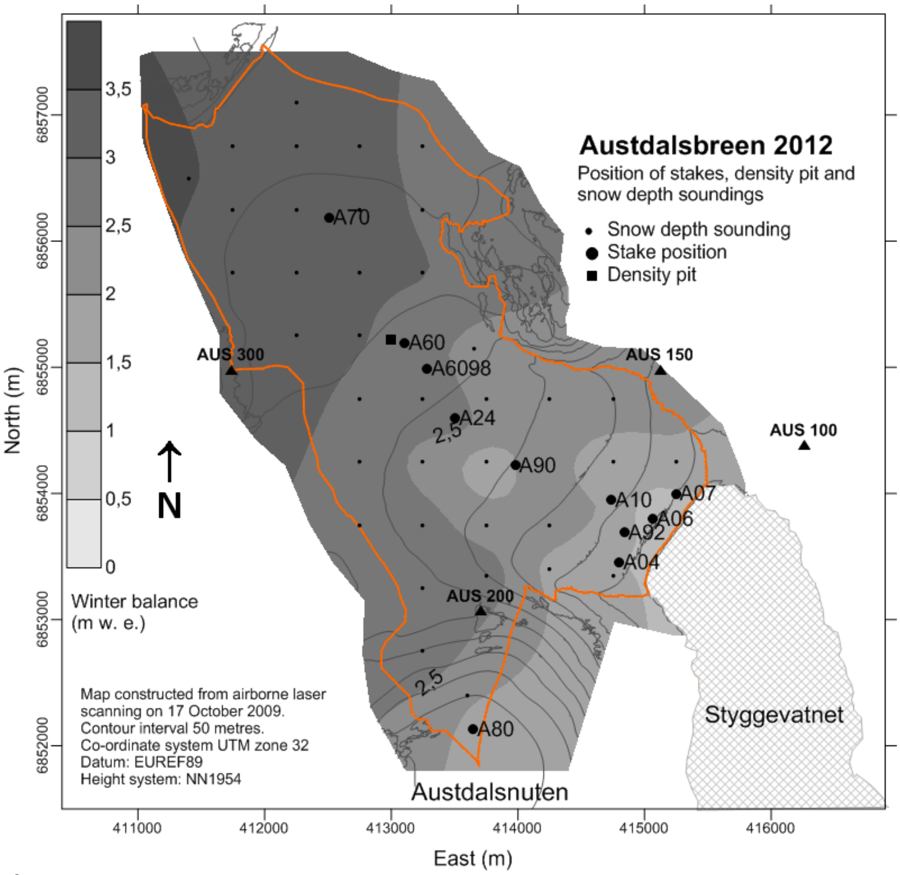


Figure 5-5
Winter balance at Austdalsbreen in 2012 interpolated from 44 SWE values calculated from 32 snow depth soundings and 12 stake measurements of snow depth. The drainage divide (orange polygon) based on the DTM from 2009 is shown.

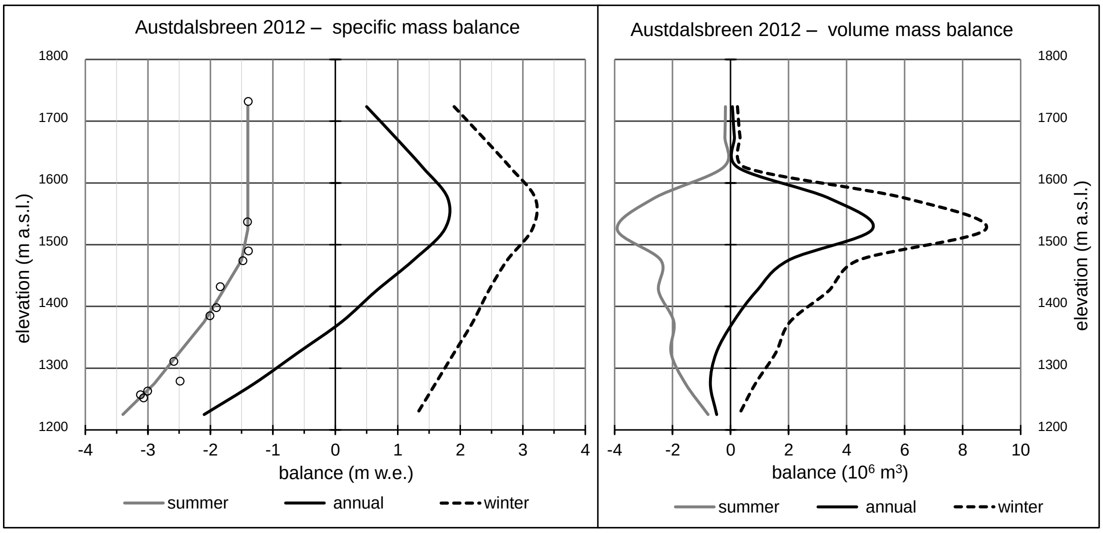


Figure 5-6
Altitudinal distribution of winter, summer and annual balance is shown as specific balance (left) and volume balance (right) for Austdalsbreen in 2012. Specific summer balance at twelve stake positions is shown (○).

The summer balance was calculated directly for stake locations A06 and A70. At A60 the summer balance was calculated from measured SWE in the density pit and stake measurements. At locations A04, A07, A10, A92, A90 and A24 the summer balance was calculated from snow depth soundings and stake measurements. The summer balance curve was drawn from these nine point values (Fig. 5-4). The calving from the glacier terminus was calculated as described for 2011 in chapter 5-1. The resulting calving volume was 1.9 ±1.0 mill. m³. The summer balance, including calving, was calculated as −1.9 ±0.3 m w.e. The calving contributed 9 % of the summer balance.

The annual balance in 2012 was calculated as +0.8 ±0.3 m w.e. The ELA in 2012 was 1370 m a.s.sl., and the AAR was 83 %. The altitudinal distribution of winter, summer and annual balance is shown in Figure 5-6.

5.3 Mass balance 2013

The winter accumulation measurements were carried out on 29th May. Snow depth was measured at five old and two new stakes. Comparison of stake length at A06 and A92 indicated no ice melt after the autumn measurements in 2012. Snow depth was sounded in 39 positions. The sounding conditions were good and the SS was well defined. Generally, the snow depth was between 2 and 4.5 m. Snow density was measured down to the SS at 3.40 m depth at stake A60. The mean snow density was 520 kg m^{-3}.

The summer ablation measurements were performed on 25th September. Twelve stakes in eight locations were found. Up to 0.3 m of new snow covered the glacier above 1350 m a.s.l. Based on stake measurements all the winter snow had melted.

The winter balance was calculated from snow depth and snow density measurements on 29th May. The calculations were performed by the same methods as described for 2011 (section 5-1). The winter balance was 1.6 ±0.2 m w.e. The winter balance calculated with a gridding method was 1.8 m w.e.

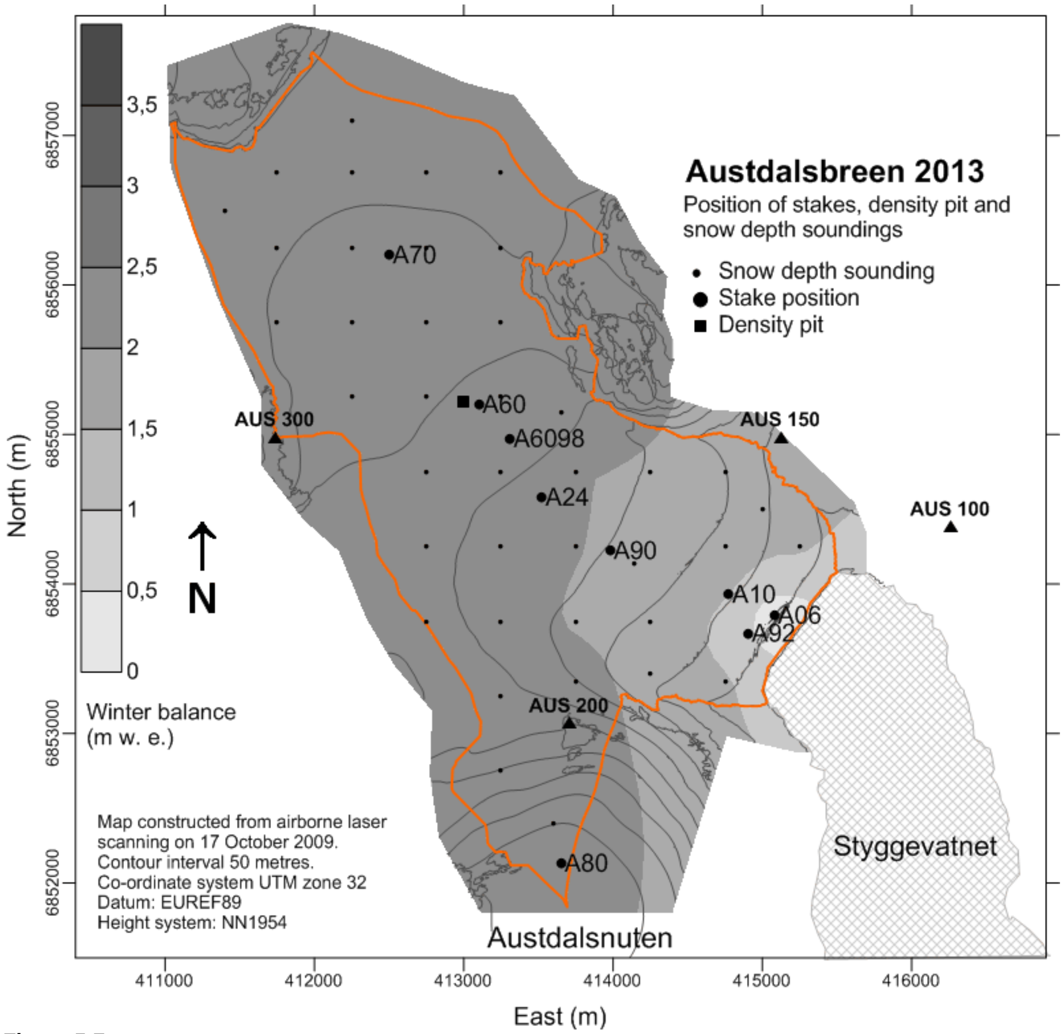


Figure 5-7
Winter balance on Austdalsbreen in 2013 interpolated from 46 SWE values calculated from 39 snow depth soundings and 7 stake measurements of snow depth. The drainage divide (orange polygon) based on the DTM from 2009 is shown.

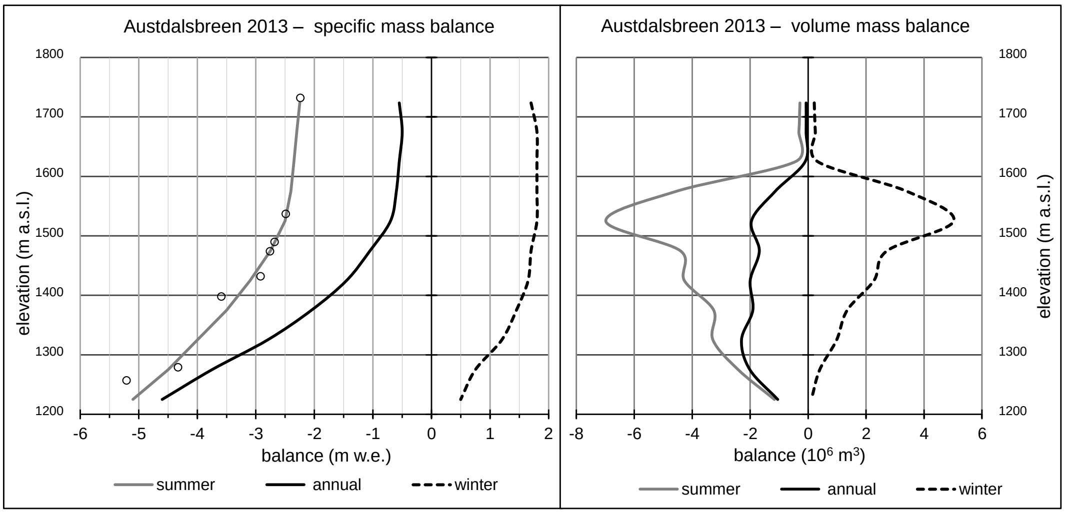


Figure 5-8
Altitudinal distribution of winter, summer and annual balance is shown as specific balance (left) and volume balance (right) for Austdalsbreen in 2013. Specific summer balance at eight stake positions is shown (○).

The summer balance was calculated directly for six stake locations. At A6098 the summer balance was calculated from sounded snow depth and the SWE function, and measurements at A24 and A60. Comparison of stake length at A06 and A90 on 24th April 2014 indicated up to 0.25 m of ice melt below 1450 m a.s.l. before the snow accumulation started in 2013. This melt has been included in the summer balance for 2013. The density of melted firn from 2012 was assessed as 650 kg m^{-3}. The density of older firn from before 2009 at A24 was assessed as 750 kg m^{-3}. The summer balance curve was drawn from these eight point values (Fig. 5-4).

The calving from the glacier terminus was calculated as described in Section 5-1 for 2011. The resulting calving volume was 3.1 ±0.8 mill. m^3. The summer balance, including calving, was calculated as −3.2 ±0.3 m w.e. The calving contributed 9 % of the summer balance.

The annual balance in 2013 was calculated as −1.6 ±0.3 m w.e. The ELA in 2013 was above the top of the glacier. Correspondingly, the AAR was 0 %. The altitudinal distribution of winter, summer and annual balances is shown in Figure 5-8.

5.4 Mass balance 2014

The winter accumulation measurements were carried out on 24th April. Snow depth was measured at five old and one new stake. Comparison of stake length at A06 and A90 indicated up to 0.25 m of ice melt below 1450 m a.s.l. before the snow accumulation started in 2013. Snow depth was sounded in 41 positions and at two old stake locations. The sounding conditions were good and the SS was well defined. Generally the snow depth varied between 3 and 5 m. Snow density was measured down to the SS at 4.6 m depth at stake A60. The mean snow density was 466 kg m^{-3}.

The summer ablation measurements were performed on 2nd October. Twelve stakes at nine stake locations were found. Above 1350 m a.s.l. the glacier was covered with up to 0.3 m of new snow. Based on stake measurements all the winter snow had melted.

The winter balance was calculated from snow depth and snow density measurements on 24th April. The calculations were performed by the same methods as described for 2011 (section 5-1). The winter balance was 2.1 ±0.2 m w.e. The winter balance calculated with a gridding method was 2.3 m w.e.

The summer balance was calculated directly at seven stake positions. At stake A10 the melting between 24th April and 22nd August was assessed as equal to melting at A92. At A80 the summer balance was calculated from snow depth in April and stake measurements in September 2013 and August 2014. The summer balance curve was drawn from these nine specific summer balance values. The calving from the glacier terminus was calculated as described in chapter 5-1 for 2011. The resulting calving volume was 2.4 ±0.8 mill. m^3. The summer balance, including calving, was calculated as −3.5 ±0.3 m w.e. The calving contributed 6 % of the summer balance.

The annual balance in 2014 was calculated as –1.4 ±0.3 m w.e. The ELA in 2014 was above the top of the glacier. Correspondingly, the AAR was 0 %. The altitudinal distribution of winter, summer and annual balances is shown in Figure 5-10.

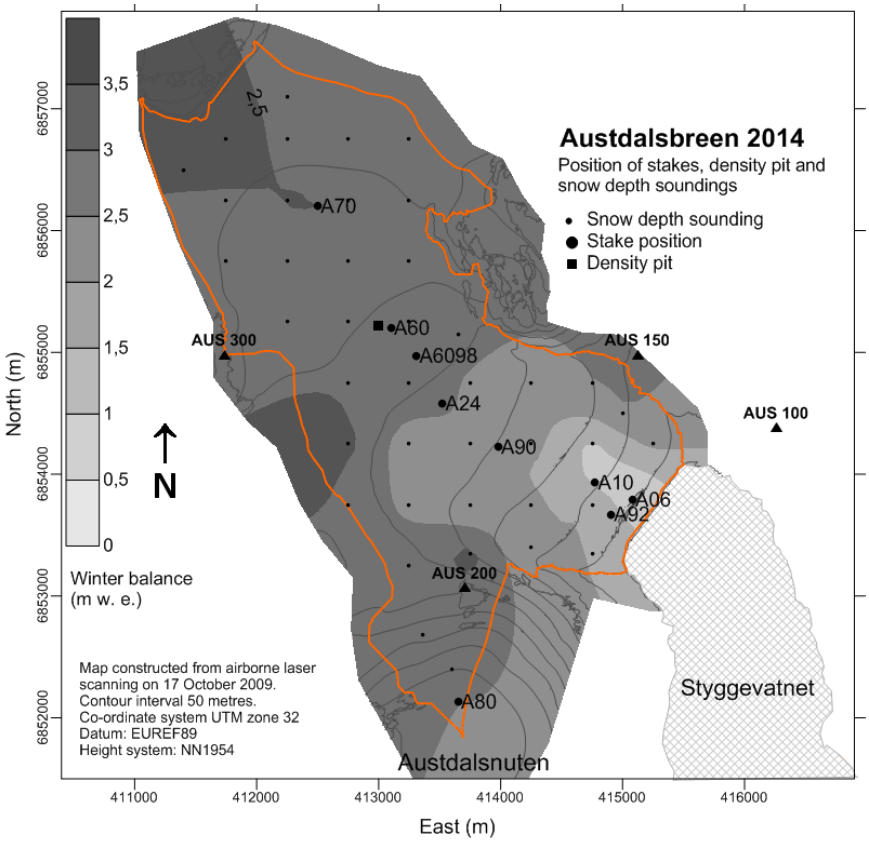


Figure 5-9
Winter balance on Austdalsbreen in 2014 interpolated from 47 SWE values calculated from 41 snow depth soundings and 6 stake measurements of snow depth. The drainage divide (orange polygon) based on the DTM from 2009 is shown.

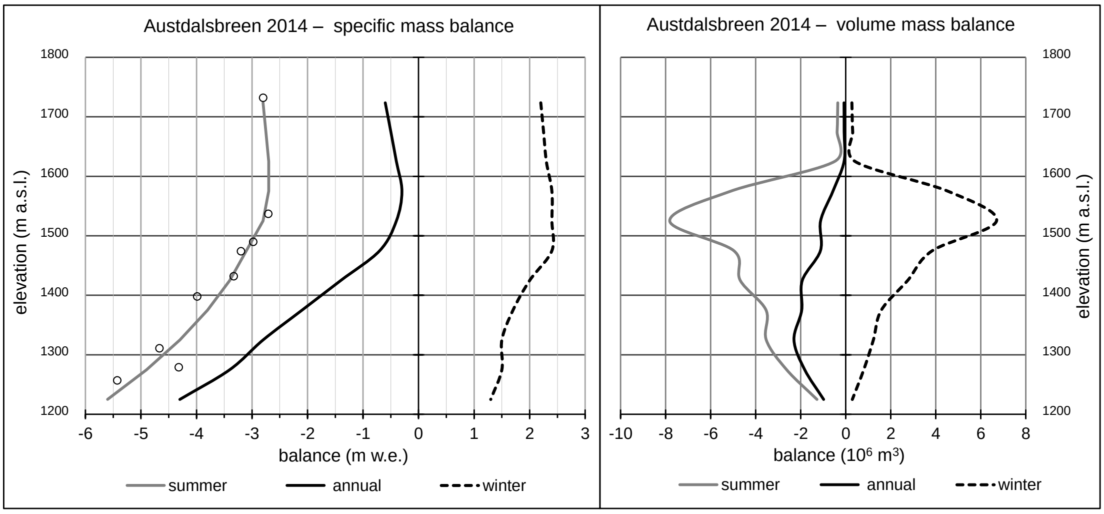


Figure 5-10
Altitudinal distribution of winter, summer and annual balance is shown as specific balance (left) and volume balance (right) for Austdalsbreen in 2014. Specific summer balance at nine stake locations is shown (○).

5.5 Mass balance 2015

The winter accumulation measurements were carried out on 21st May. Snow depth was measured at six old and one new stake. Comparison of stake readings and probings at stake A10 and A92 indicated 0.25 and 0.15 m of ice melt after the autumn measurements on

2nd October 2014. Snow depth soundings were performed in 38 positions. The sounding conditions were good and the SS was well defined. Generally the snow depth varied between 3.5 and 5.5 m. Snow density was measured down to the SS at 4.85 m depth at A60. The mean snow density was 466 kg m^{-3}.

The summer ablation measurements were performed on 14th October. A thin layer of up to 0.05 m of new snow covered the glacier. Ten stakes in nine locations were found. Between 3 and 5 m of snow and ice had melted. The transient snow line (TSL) was at about 1400 m a.s.l. At A70, the density of remaining snow was measured to 1.8 m depth whereas the SS was located at 2.6 m depth. The mean snow density down to 1.8 m was 572 kg m^{-3}. The mean snow density down to the SS at 2.6 m depth was estimated as 587 kg m^{-3}.

The winter balance was calculated from snow depth and snow density measurements on 21st May. The calculations were performed by the same methods as described for 2011 (section 5-1). The winter balance was 2.5 ±0.2 m w.e. The winter balance calculated with a gridding method was 2.8 m w.e.

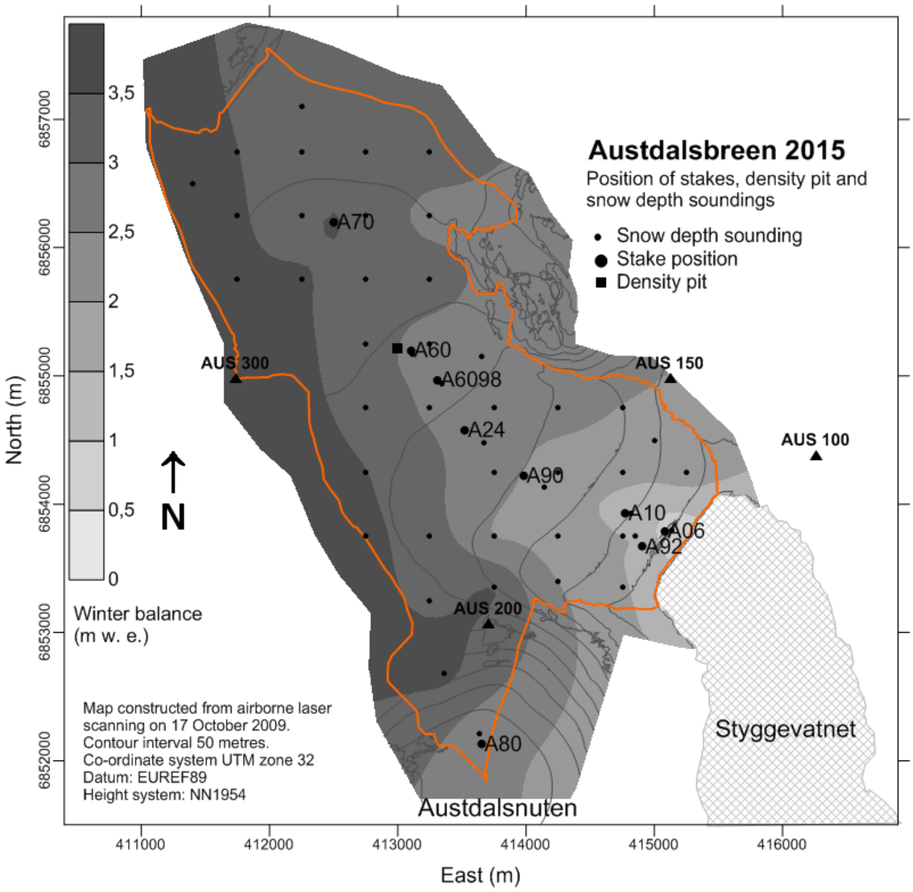


Figure 5-11
Winter balance on Austdalsbreen in 2015 interpolated from 47 SWE values calculated from 38 snow depth soundings and 9 stake measurements of snow depth. The drainage divide (orange polygon) based on the DTM from 2009 is shown.

The summer balance was calculated directly at eight stake positions. In addition, the summer balance at stake A80 was assessed from stake readings and coring. The summer balance curve was drawn from these nine specific summer balance values. The calving from the glacier terminus was calculated as described in section 5-1 for 2011. The resulting calving volume was 1.5 ±0.8 mill. m^3. The summer balance, including calving, was calculated as −1.8 ±0.3 m w.e. The calving contributed 8 % of the summer balance.

The annual balance in 2015 was calculated as +0.7 ±0.3 m w.e. The ELA in 2015 was 1371 m a.s.l. Correspondingly, the AAR was 81 %. The altitudinal distribution of winter, summer and annual balance is shown in Figure 5-12.

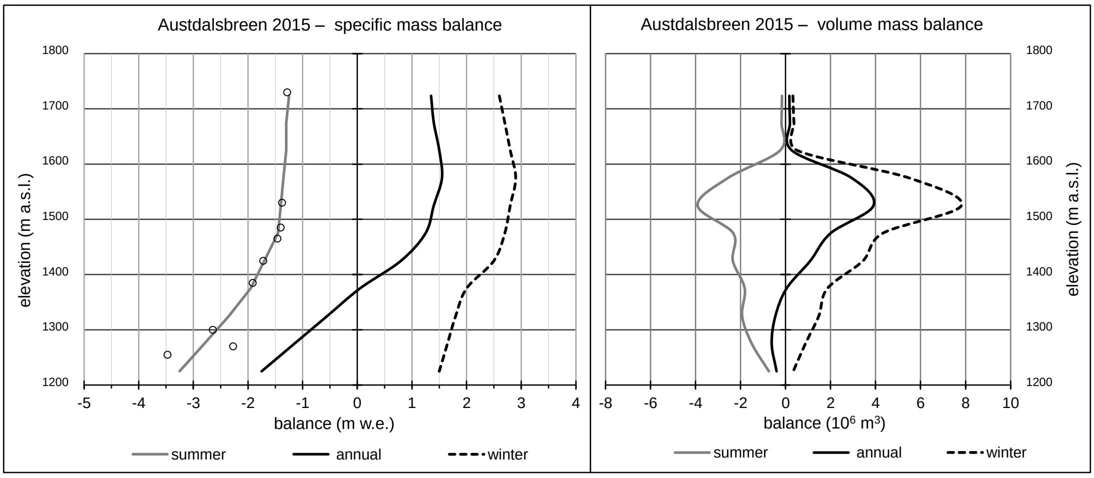


Figure 5-12
Altitudinal distribution of winter, summer and annual balance is shown as specific balance (left) and volume balance (right) for Austdalsbreen in 2015. Specific summer balance at nine stake locations is shown (○).

5.6 Mass balance 1987-2015

A summary of the mass balance measurements and results for 2011-2015 is given in Table 5-1. The historical mass balance results are presented in Figure 5-13.

Table 5-1
Summary values of Austdalsbreen mass balance measurements and results for 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		4 May	10 May	29 May	24 April	1 May
Date B_s		13 Oct	11 Oct	25 Sep	2 Oct	1 Oct
Density b_w	kg m^{-3}	480	485	520	472	450
Density $firn_r$	kg m^{-3}		600			580
Density $firn_m$	kg m^{-3}	700		650/700*	650/700*	
Calving	10^6 m^3 ice	4.1	2.1	3.4	2.7	1.7
B_w	m w.e.	1.82	2.68	1.61	2.14	2.53
B_s	m w.e.	-3.26	-1.91	-3.24	-3.50	-1.80
B_a	m w.e.	-1.44	+0.77	-1.63	-1.35	+0.73
ELA	m a.s.l.	>1747	1368	>1747	>1747	1371
AAR	%	0	84	0	0	81

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_r$ and Density $firn_m$ are the mean snow density of the measured snow pack, the estimated density of remaining snow and the estimated density of melted firn, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.
* density of firn from 2012 and older than 2010.

The original mass balance record for 1987-2010 (23 years) has been reported in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). As the first part of a reanalysis of the mass balance record, the measurements and calculations for 1988-2014 were homogenised to ensure more uniform data processing from field data to the final balance values (Andreassen et al., 2016). The reference area for the annual mass balance calculations has been homogenised. Austdalsbreen was mapped in 1966, 1988 and 2009. When mass balance measurements started in autumn 1987, the map from 1966 was used to calculate the area-elevation distribution. This map was used as a map reference up to and including 2008. The ice divide/drainage divide based on the DTM from 2009 was used to define the reference area for the map from 1988 and DTM from 2009.

The new reference area for 1987-1998 was calculated from the 1988 map and 2009 ice divide, and the reference area for 1998-2015 was calculated from the DEM and ice divide from 2009. The lowest part of Austdalsbreen calved in 1988-89 due to the regulation of Austdalsvatnet and Styggevatnet. Consequently, the lowest altitudinal interval (below 1200 m a.s.l., 0.093 km^2) was excluded in 1990-98. Between 1988 and 2009 the glacier area was reduced by 0.647 km^2. Even though the annual front position change has been mapped, the reference area has not been reduced annually because the glacier-wide annual elevation change has not been mapped. The procedure for calculating the volume of glacier calving was standardised in the homogenisation process (section 5-8).

Comparison of the homogenised surface mass balance record to geodetic mass balance for 1988-2009 showed a difference between the mean annual glaciological surface mass balance and the geodetic mass balance of 0.11 m w.e.a $^{-1}$ which is below the detection level for systematic bias (Andreassen et al., 2016).

The homogenised mass balance series for the period 1987-2015 shows a deficit of −14.70 m w.e., while the original series showed a deficit of −11.30 m w.e. Thus the cumulative deficit over 1987-2014 was increased by 3.40 m w.e. The mean winter balance increased from 2.14 to 2.18 m w.e. a^{-1}, and the mean summer balance changed from −2.59 to −2.71 m w.e. a^{-1}. The homogenised mass balance series for 1987-2015 is presented in Table 5-2.

The mass balance record for 1988-2010 is classified as homogenised as the results were previously published. The results from 2011-2015 have not been published earlier, and the years 2011-2015 are classified as original. The mass balance record for 1988-2015 is presented in Figure 5-13. The cumulative annual balance for the 28 year period is −14.7 m w.e., which gives a mean annual balance of −0.53 m w.e. a^{-1}.

Table 5-2
The homogenised mass balance record for 1988-2015.

	Homogenized mass balance record								Homogenization steps				
Year	B_w	B_s	B_a	ΣB_a	ELA	AAR	DEM	Area	Status	[1]Bw-map	[2]DEM	[3]Divide	[4]Calv
1988	1.95	-3.37	-1.42	-1.42	1575	21 %	1988	11.276	H	x	x	x	x
1989	3.19	-1.87	1.32	-0.10	1271	95 %	1988	11.276	H	x	x	x	x
1990	3.66	-3.24	0.42	0.32	1315	90 %	1988	11.183	H		x	x	x
1991	1.66	-1.81	-0.15	0.17	1420	73 %	1988	11.183	H		x	x	x
1992	2.80	-2.61	0.19	0.36	1375	82 %	1988	11.183	H		x	x	x
1993	2.60	-2.18	0.42	0.78	1321	89 %	1988	11.183	H		x	x	x
1994	1.80	-2.12	-0.32	0.46	1425	73 %	1988	11.183	H		x	x	x
1995	2.71	-2.40	0.31	0.77	1358	83 %	1988	11.183	H		x	x	x
1996	1.20	-2.54	-1.34	-0.57	1566	24 %	1988	11.183	H		x	x	x
1997	2.67	-3.53	-0.86	-1.43	1450	63 %	1988	11.183	H		x	x	x
1998	2.21	-2.32	-0.11	-1.54	1407	75 %	1988	11.183	H		x	x	x
1999	2.10	-2.56	-0.46	-2.00	1461	62 %	2009	10.629	H		x	x	x
2000	3.02	-1.77	1.25	-0.75	1337	90 %	2009	10.629	H		x	x	x
2001	1.23	-2.76	-1.53	-2.28	>1747	0 %	2009	10.629	H		x	x	x
2002	2.11	-3.94	-1.83	-4.11	>1747	0 %	2009	10.629	H		x	x	x
2003	1.61	-3.94	-2.33	-6.44	>1747	0 %	2009	10.629	H		x	x	x
2004	1.61	-2.56	-0.95	-7.39	1500	48 %	2009	10.629	H		x	x	x
2005	2.86	-2.63	0.23	-7.16	1388	82 %	2009	10.629	H		x	x	x
2006	1.33	-3.37	-2.04	-9.20	>1747	0 %	2009	10.629	H		x	x	x
2007	2.48	-2.28	0.20	-9.00	1407	75 %	2009	10.629	H		x	x	x
2008	2.57	-2.63	-0.06	-9.06	1422	73 %	2009	10.629	H		x	x	x
2009	1.92	-2.63	-0.71	-9.77	1458	62&	2009	10.629	H				x
2010	1.02	-3.05	-2.03	-11.80	>1747	0 %	2009	10.629	H				x
2011	1.82	-3.26	-1.44	-13.24	>1747	0 %	2009	10.629	O				
2012	2.68	-1.91	0.77	-12.47	1368	84 %	2009	10.629	O				
2013	1.61	-3.26	-1.65	-14.12	>1747	0 %	2009	10.629	O				
2014	2.14	-3.44	-1.30	-15.42	>1747	0 %	2009	10.629	O				
2015	2.53	-1.81	0.72	-14.70	1371	81 %	2009	10.629	O				

[1]Bw-map: The original winter balance was integrated from a winter balance map, recalculated using the profile method.
[2]DEM: reference DEM for the calculations has been changed.
[3] Divide: The ice divide has been changed
[4]Calv: The calving volume has been re-calculated

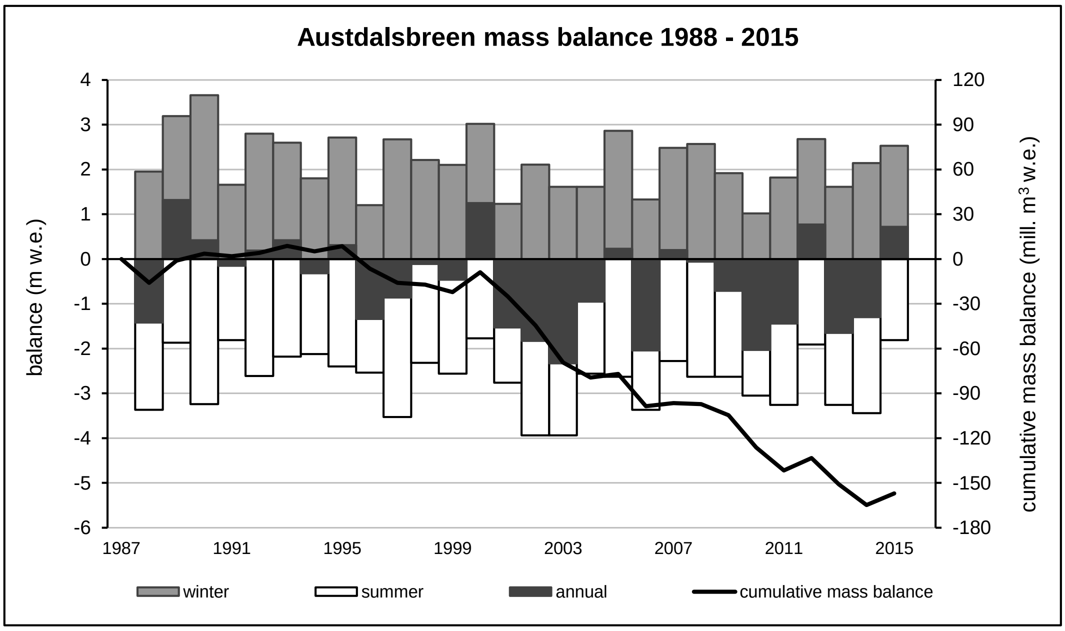


Figure 5-13
Winter, summer and annual balances for Austdalsbreen during the period 1987-2015. Mean winter and summer balance is 2.18 and −2.71 m w.e. a^{-1}, respectively. The average contribution from calving to the summer balance is -0.30 m w.e. a^{-1} (11 %). The cumulative mass balance 1987-2015 is −157 mill. m³ w.e.

5.7 Glacier velocity

Glacier velocities are calculated from repeated surveys of stakes using GNSS. The reference stations used was either AUS150 (Fig. 5-11) or SATREF-station Jostedal (Norwegian Mapping Authority, 20 km south of Austdalsbreen). The surveyed positions are evaluated by comparison of calculated stake movement direction to expected direction from previous measurements. The expected position accuracy is assessed as ±0.2 m when referenced from AUS150, and ±0.5 m when referenced from SATREF Jostedalen.

The glacier velocity averaged across the terminus was assessed in order to calculate the annual calving volumes (sections 5-1 to 5-5). The mean surface velocity at the terminus was calculated as 80 % of the velocity in the middle of the terminus from calculated stake velocities at several stakes along the terminus in 1996-97 and 2012 (Fig. 5-14). We expect glacier sliding to contribute 50 to 90 % of the movement (varying due to lake level and season), and expect most of the movement due to ice deformation to take place in the lower ⅓ of the glacier. Consequently, the annual terminus-averaged glacier velocity is 70 % of the surface velocity at the central part of the glacier. This is assessed from annual velocity at stake A06, average distance from stake A06 to the ice cliff in first and second autumn, and an estimate of velocity increase towards the terminus (10 m a^{-1} per 100 metres, based on earlier measurements). Annual results are listed in Table 5-4. The uncertainty in cross-sectional averaged glacier velocity is assessed as ±10 m a^{-1}.

Glacier velocity 2011

The stake network was surveyed on 9th October 2010, and 4th May, 18th August and 13th October 2011. Annual velocities were calculated for four stake locations for the period 9th October 2010 – 13h October 2011 (369 days, Tab. 5-3). At stake A06 the annual velocity was calculated from winter season velocity based on the ratio between winter and annual velocity in 2010.

Annual terminus-averaged glacier velocity was calculated from annual velocity at stake A0610B (46 m a^{-1}) and average distance from stake to the ice cliff on 9th October 2010 (170 m) and 13th October 2011 (90 m). The resulting glacier velocity averaged across the terminus for 2010/2011 is 40 ±10 m a^{-1}.

Glacier velocity 2012

The stake network was surveyed on 10th May, 16th August and 11th October 2012. Annual velocities were calculated for ten stake locations for 13th October 2011 – 11th October 2012 (364 days) (Tab. 5-3 and Fig. 5-14).

Stake A06 was re-drilled 20 m up-glacier in August, and annual velocity was calculated as a combination of the two. At stake A04, A07, A10, A9012, A2412 and A6012 only the summer velocity was measured. The annual velocity at A04, A07 and A10 was calculated using the ratio between summer and annual velocity at stake A06 (91 %). At stake A90, A24 and A60 the annual velocity was calculated using the ratio between summer and annual velocity at stake A24 in 2010 (112 %).

Annual terminus-averaged glacier velocity was calculated from annual velocity at stake A0611B/A0612 (60 m a^{-1}), and average distance from stake to ice cliff on 13th October 2011 (155 m) and 11th October 2012 (100 m). The resulting glacier velocity averaged across the terminus for 2011/2012 is 50 ±10 m a^{-1}.

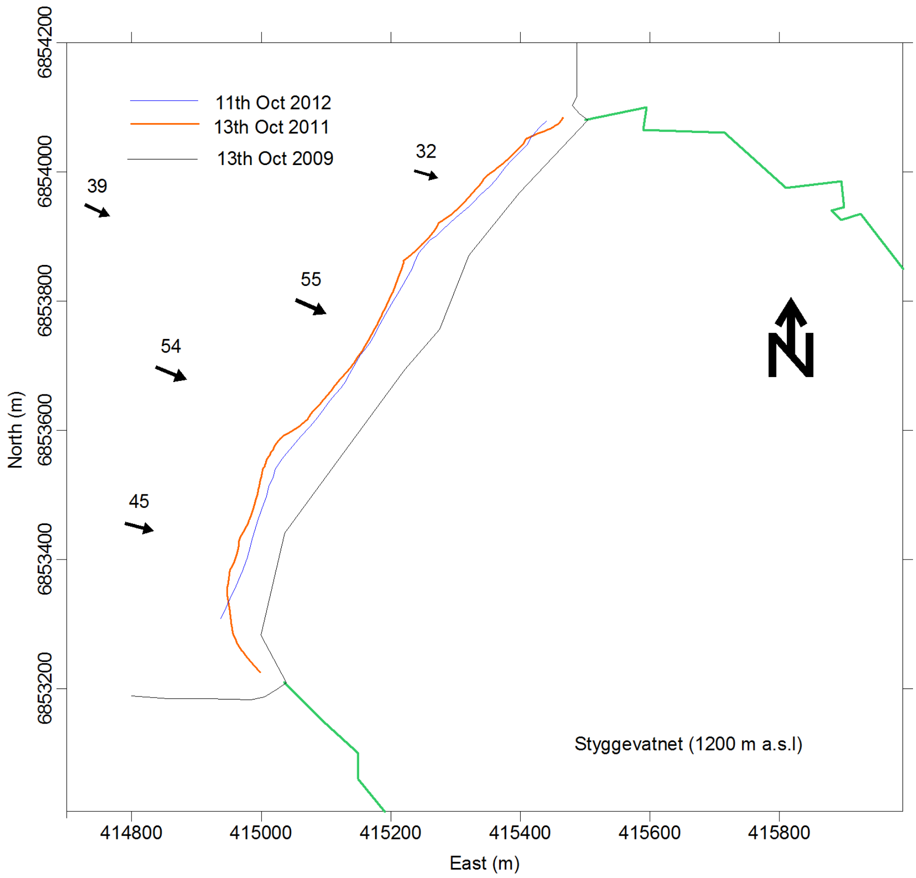


Figure 5-14
Annual stake velocity in 2012 (m/a) based on stake measurements in 2011 and 2012, mapped glacier outline in 2009, and surveyed front positions of Austdalsbreen in 2011 and 2012. The lake shoreline in 2009 is shown in green.

Glacier velocity 2013

The stake network was surveyed on 23rd August and 25th September 2013. Annual velocities were calculated for seven stake locations for 11th October 2012 to 23rd August 2013 (316 days) (Tab. 5-3).

Annual terminus-averaged glacier velocity was calculated from annual velocity at stake A612 (64 m a^{-1}), and average distance from stake to ice cliff on 11th October 2012 (119 m) and 25th September 2013 (23 m). The resulting glacier velocity averaged across the terminus cross-section for 2012/2013 was 50 ±10 m a^{-1}.

Glacier velocity 2014

The stake network was surveyed on 24th April, 22nd (lower part) and 26th August (upper part), and 2nd October. Annual velocities were calculated for eight stake locations for 23rd August 2013 – 22nd/26th August 2014 (364/368 days) (Tab. 5-3).

Annual terminus-averaged glacier velocity was calculated from annual velocity at stake A613 (48 m a^{-1}), and average distance from stake to ice cliff on 25th September 2013 (115 m) and 2nd October 2014 (40 m). The resulting glacier velocity averaged across the terminus cross-section for 2013/2014 was 40 ±10 m a^{-1}.

Glacier velocity 2015

The stake network was surveyed on 21st May, 21st August, and 14th October. Annual velocities were calculated for eight stake locations for 2nd October 2014 – 14th October 2015 (377 days) (Tab. 5-3).

Annual terminus-averaged glacier velocity was calculated from annual velocity at stake A0614/A0615 (41 m a^{-1}). Normally, the glacier velocity has increased towards the calving terminus due to higher subglacial water pressure. In 2014/2015 the lake level was lower than usual, and the velocity did not increase significantly towards the terminus. Consequently, the glacier velocity at the terminus is assumed to be the same as at stake A06. The resulting glacier velocity averaged across the terminus cross-section for 2014/2015 was 30 ±10 m a^{-1}.

Table 5-3
Annual mean velocity (m a^{-1}) at stake locations (Fig. 5-2).

Stake locations	2011	2012	2013	2014	2015
A06	**46	**64	64	46	41
A04		*45			
A07		*31			
A10		*43		43	39
A92	46	60	60	52	47
A90		32	28	29	28
A24		*25	23	24	22
A6098	20	22	20	21	21
A60	20	*18	17	17	17
A70	5.4	7		7	7

* Values calculated for the summer season only.
** Values calculated for the winter season only.

5.8 Front position change

The terminus position is surveyed using GNSS from a helicopter. The GNSS-antenna is placed inside the helicopter while the helicopter flies slowly (2-5 m s^{-1}) along the ice cliff. The ice cliff elevation is assessed at seven to twelve locations as the helicopter touches the ice at the glacier front. Front position change since 1988 is illustrated in Figure 5-15. Annual area change is calculated from annual terminus polygons defined by the surveyed front position, the glacier outline on dry land above 1200 m a.s.l. south and north of the terminus in 2009 and 2015, and a corner point north-west of the central terminus. Annual area change is the difference between the areas of two terminus polygons. The frontal width is defined as the distance between the connection points between the surveyed calving terminus and the glacier outline on dry land (above 1200 m a.s.l.) in 2009 (990 ±20 m) and 2015 (930 ±20 m). Data for calving volume calculations are listed in Table 5-4.

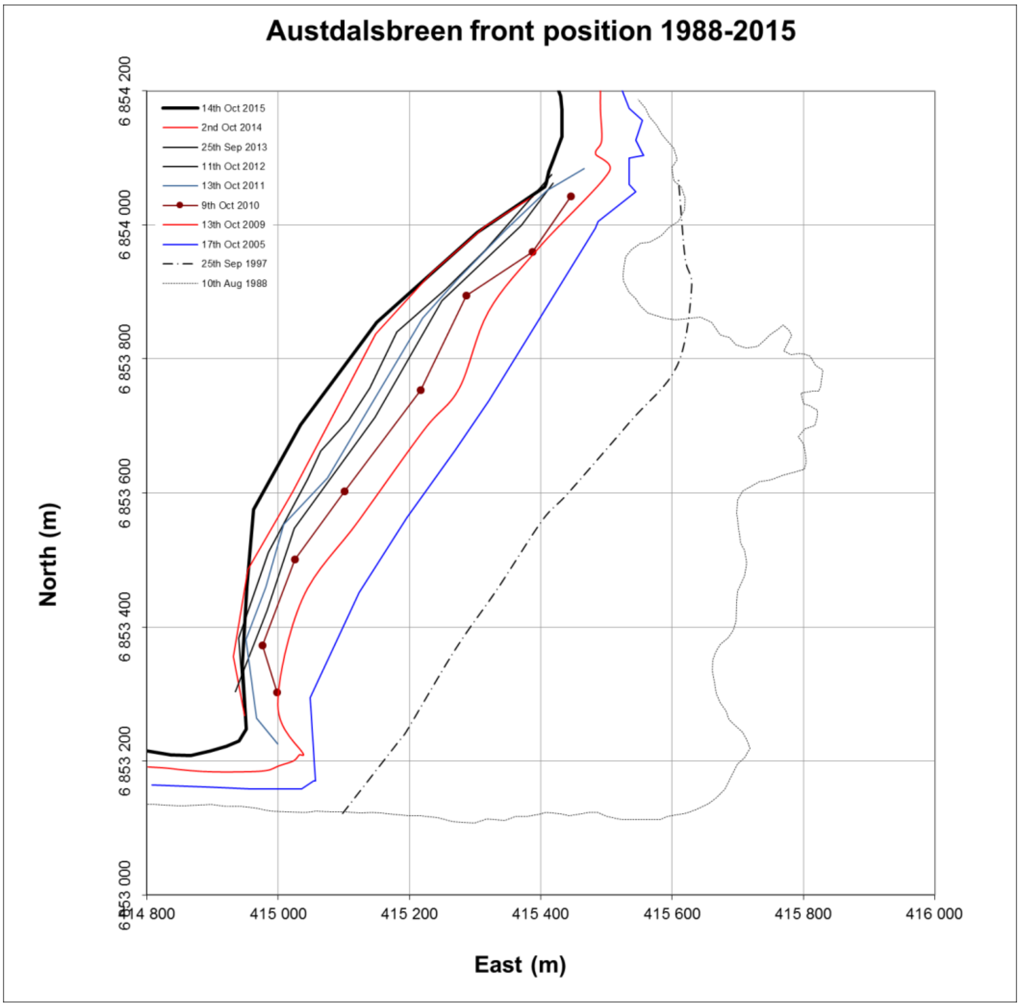


Figure 5-15
Surveyed front position of Austdalsbreen in 1988 (first mapping), 1997, 2005 and in 2009-2015.

Table 5-4
Lake level, front width, area and length change, surveyed elevation along terminus position, and estimated bottom elevation along the surveyed terminus.

Date of survey	Annual mean lake level (m a.s.l.)	Area change (m²)	Frontal width (m)	Length change (m)	Average glacier velocity (m a⁻¹)	Average surface elevation (m a.s.l.)	Average bottom elevation (m a.s.l.)	Mean thickness (m)
9.10.2010			990 ±20			1228	1173	
13.10.2011	1175	−37284	990 ±20	-38	40	1229	1178	53
11.10.2012	1187	+8180	990 ±20	+8	50	1228	1177	51
25.9.2013	1179	−22912	990 ±20	-24	50	*	1177	49
02.10.2014	1179	−17036	930 ±20	-18	40	1223	1178	49
14.10.2015	1171	−7336	930 ±20	-8	30	1226	1178	47

*In 2013 a navigator GPS was used. Consequently, the surface elevation was not measured.

6. Rembesdalskåka (Hallgeir Elvehøy)

Rembesdalskåka (17 km², 60°32'N, 7°22'E, Fig. 6-1) is a south-western outlet glacier from Hardangerjøkulen (73 km^2), and drains towards Simadalen valley and Hardangerfjorden. Simadalen was flooded by jøkulhlaups (glacier lake outburst floods) from the glacier-dammed lake Demmevatnet on several occasions. Artificial lowering of the lake level in 1897 and 1938 prevented jøkulhlaups until 2014 (chap. 14).

Mass balance investigations at Rembesdalskåka were initiated in 1963 by the Norwegian Polar Institute, and have been performed by The Norwegian Water Resources and Energy Directorate (NVE) since 1985. The basin investigated covers the altitudinal range between 1066 and 1854 m a.s.l. (2010). The glaciological investigations in 2011-15 included mass balance, glacier velocity and length change (chap. 14).

The University of Utrecht, Netherlands, operated an automatic weather station (AWS) close to the terminus of Midtdalsbreen, a northern outlet glacier from Hardangerjøkulen adjacent to Rembesdalskåka, between 2000 and 2013. Data from 2011 to 2013 are presented in section 6-8.

In this chapter, the annual mass balance measurements and calculations are presented as well as maps of the monitoring network, the interpolated winter balance distribution, and diagrams showing the altitudinal distribution of specific and volume winter, summer and annual balances.

Figure 6-1
Rembesdalskåka on 23rd September 2013. Photo: Hallgeir Elvehøy.

6.1 Mass balance 2011

The snow accumulation measurements were performed on 1st June. Snow depth was measured at six stakes in five locations and 21 sounding locations in a grid with 500 m spacing between measurements (Fig. 6-2). The summer surface was well defined. Snow density was measured in the top 1.5 m of the snow pack at H7. The mean snow density was 459 kg m^{-3}. The snow depth was 4.4 m from stake readings.

The summer ablation measurements were performed on 8th and 10th November. The glacier was covered with up to 1.2 m of new snow. Five stakes in five locations were found. Based on stake measurements, all the winter snow at Rembesdalskåka had melted during the summer. At H2, H4 and H7, 0.65, 0.8 and 1.25 m of firn had melted, respectively. At H8, 3.1 m of ice had melted. Stake H10 melted out during the summer and was replaced on 16th September. Between 16th September and 8th November, 0.45 m of ice melted at H10.

Comparison of stake measurements and sounded snow depth at H10 and H8 on 1st June 2011 showed no significant melting after 8th October 2010 at the plateau. Based on a visual evaluation of daily snow conditions maps from (www.senorge.no), the date of minimum mass balance was assessed as 12th October. These maps showing modeled snow parameters are based on gridded (1 x 1 km) precipitation and temperature interpolated from meteorological stations.

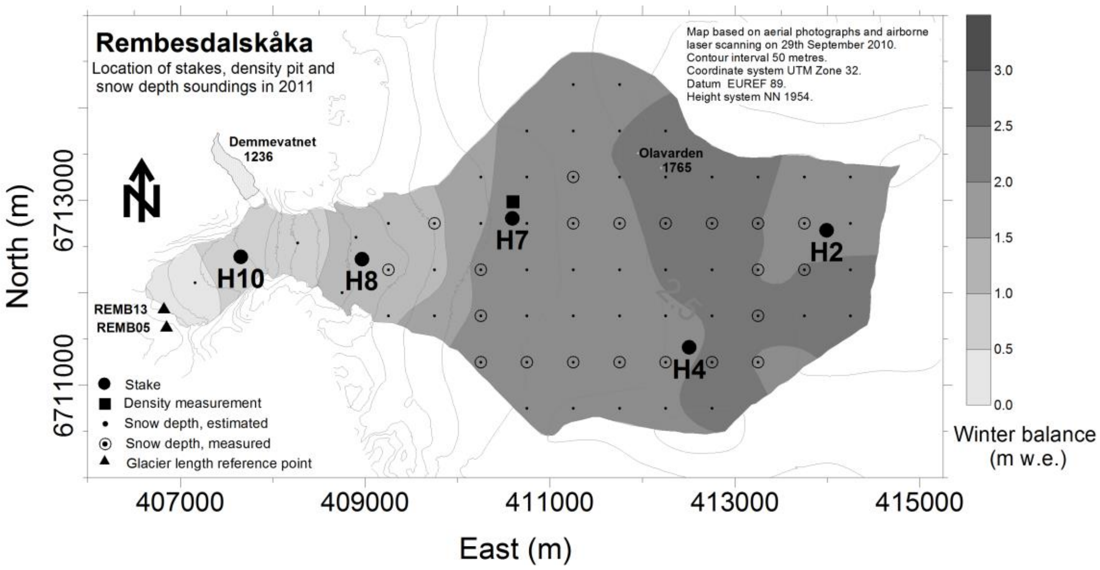


Figure 6-2
Location of stakes, snow depth soundings and snow pit, and the spatial distribution of winter balance at Rembesdalskåka in 2011.

The winter balance for 2011 was calculated from the snow depth and snow density measurements on 1st June. The drainage basin and area to elevation distribution were defined from a DTM based on aerial laser scanning on 29th September 2010. A function correlating snow depth with Snow Water Equivalent (SWE) was calculated based on snow density measurements at stake H7. The density of the snow pack from 1.5 to 4.4 m depth was assessed to be similar to the deepest measured sample (547 kg m^{-3}). Consequently, the mean snow density of the snow pack was 517 kg m^{-3}. This function was used to calculate the point winter balance of the snow depth measurements. Mean values of SWE and altitude 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 curve a mean value for each altitude interval was determined. The resulting winter balance was 2.1 ±0.2 m w.e. The winter balance calculated with a gridding method from calculated point winter balance at 21 sounding locations, five stake locations, and estimated point winter balance at five locations, was 2.3 m w.e. (Fig. 6-2).

Comparison of stake measurements and sounded snow depth at H10 and H8 on 23rd May 2012 showed no significant melting at the plateau after the ablation measurements on

11th November 2011. The minimum date in 2011 was assessed as 3rd October (www.senorge.no). From the record of measurements, the melted firn at H2 and H4 originated from 2008 and 2009. The density of this firn was assessed as 720 kg m^{-3}. The melted firn at H7 originated from 2007 and before 2000, and the density of this firn was assessed as 750 kg m^{-3}. Stake H10 melted out in July and was replaced on 16th September. The snow and ice melting at H10 between 1st June and 16th September was modelled using a positive degree-day model with daily precipitation and temperature at the meteorological station Fet in Eidfjord (no 49800, 735 m a.s.l., 15 km south of H10) calibrated to stake measurements at H10 from 2007 to 2010. The model results indicate that the snow pack at H10 (1.65 m) had melted by about 1st July, and that 4.4 m of ice melted until 16th September.

The summer balance was calculated directly at four stake locations, and modelled at H10. The summer balance was calculated as −3.4 ±0.2 m w.e. The annual balance in 2011 was calculated as −1.3 ±0.3 m w.e. The Equilibrium Line Altitude (ELA) in 2011 was above the top of the glacier. Consequently, the Accumulation Area Ratio (AAR) was 0 %. The altitudinal distribution of winter, summer and annual balance is presented in Figure 6-3.

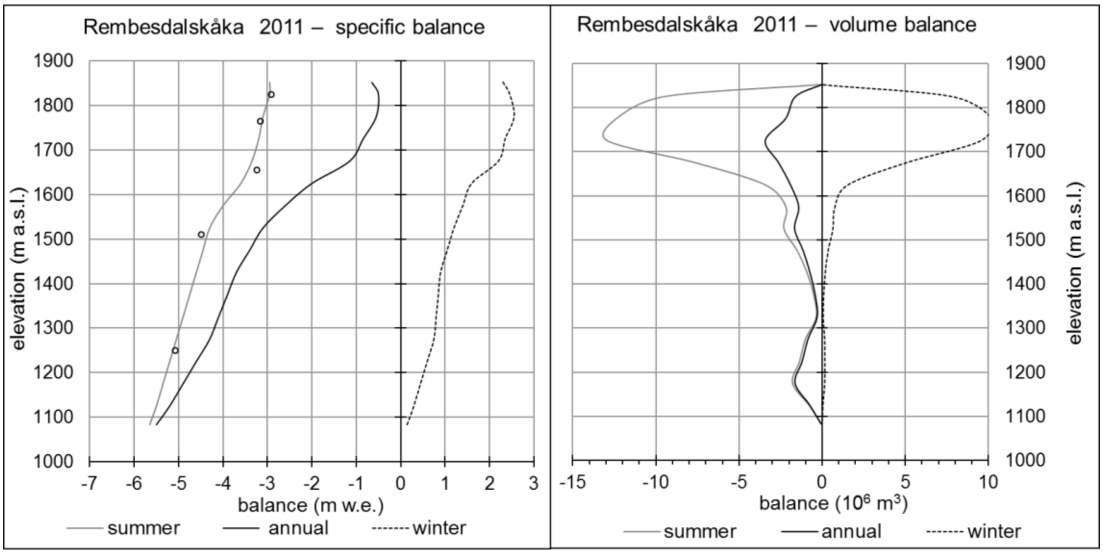


Figure 6-3
Mass balance diagram for Rembesdalskåka in 2011, showing specific balance on the left and volume balance on the right. Specific summer balance at five stake locations is shown.

6.2 Mass balance 2012

The snow accumulation measurements were performed on 23rd May. Snow depth was measured at three old and two replacement stakes, and at 53 sounding locations (Fig 6-4). The summer surface was well defined at most locations. Snow density was measured down to the summer surface (SS) at 6.05 m depth at H7. The average snow density was 485 kg m^{-3}.

The summer ablation measurements were carried out on 5th and 11th October. The glacier was covered with up to 0.75 m of new snow. At H4 and H2, about 3 m of winter snow remained. Comparison of the re-emerged stake H710 and the replacement stake H712 showed that snow depth had been assessed correctly, and 1.8 m of winter snow remained. At H10 and H8, 3.25 m and 1.85 m of ice melted, respectively. Based on stake measurements the temporary snow line elevation was around 1600 m a.s.l.

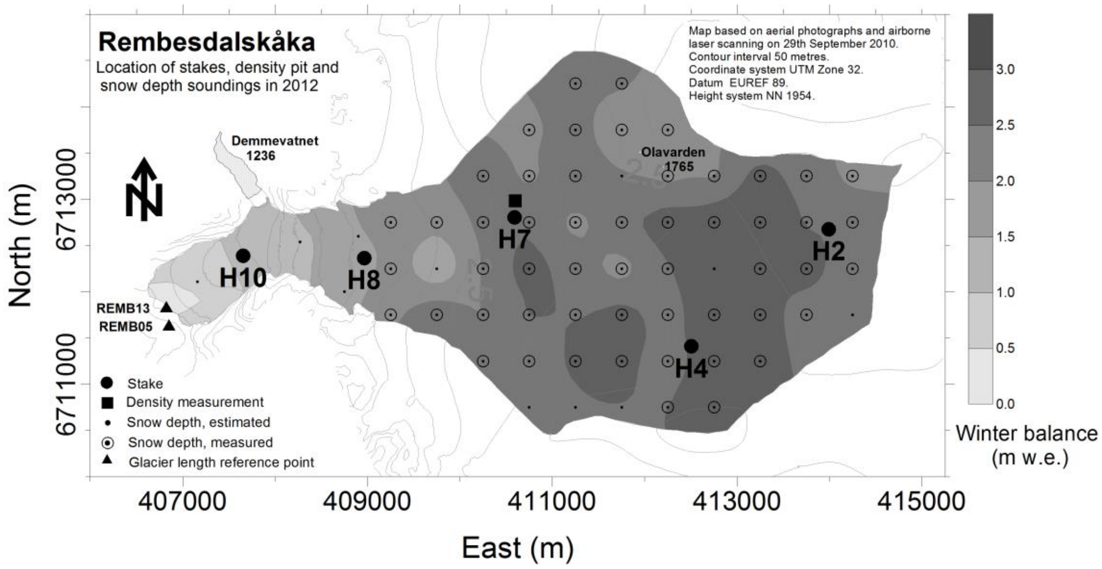


Figure 6-4
Location of stakes, snow depth soundings and snow pit, and the spatial distribution of winter balance at Rembesdalskåka in 2012.

The calculations of the winter balances were performed using the same methods as described for 2011 (section 6-1). The resulting winter balance was 2.7 ±0.2 m w.e. When calculated with a gridding method from point winter balance in 53 sounding locations, five stake positions, and seven estimated point winter balances, the resulting winter balance was 2.8 m w.e.

Snow depth sounding and stake measurements at stake H10 on 8th May 2013 showed there was no melting after the autumn measurements on 5th October 2012. The minimum date was assessed as 17th September from www.senorge.no. The point summer balance was calculated directly at five stake locations. The density of the remaining snow at stake H2, H4 and H7 was set as 600 kg m^{-3}, and the density of ice was set as 900 kg m^{-3}. The resulting summer balance was −1.7 ±0.2 m w.e., and the annual balance was calculated as +0.9 ±0.3 m w.e. The ELA in 2012 was 1590 m a.s.l., and the AAR was 85 %. The altitudinal distribution of winter, summer and annual balance is presented in Figure 6-5.

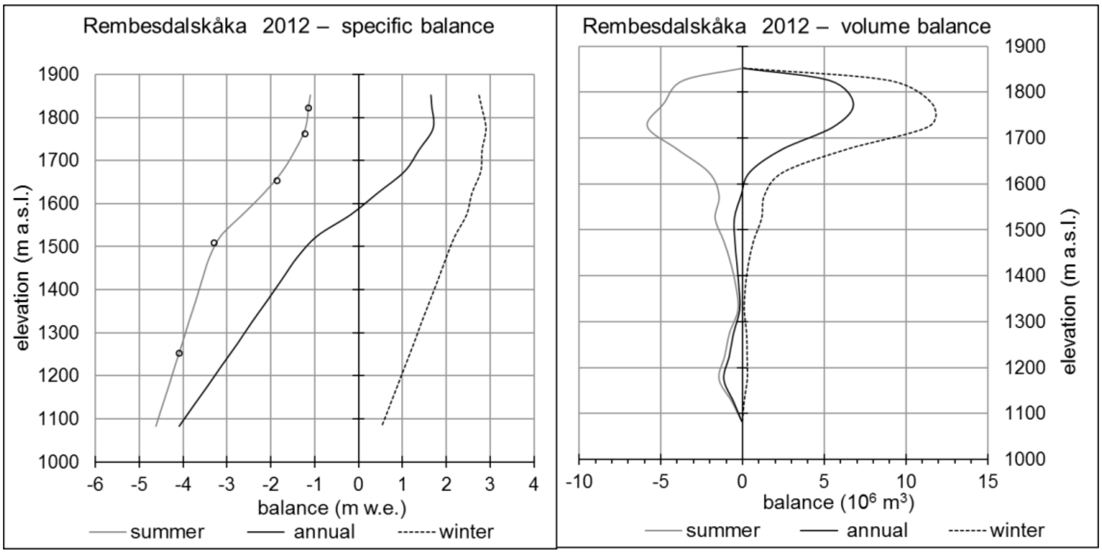


Figure 6-5
Mass balance diagram for Rembesdalskåka in 2012, showing specific balance on the left and volume balance on the right. Specific summer balance at five stake locations is shown.

6.3 Mass balance 2013

The snow accumulation measurements were performed on 8th May. Snow depth was measured at four old and one replacement stake, and at 51 sounding locations (Fig. 6-6). Stake H2 was lost during winter but re-appeared during summer. Comparison with the spring replacement stake confirmed the snow depth at H2. The summer surface was well-defined at most locations. Snow density was measured down to the SS at 4.1 m depth at H7. The average snow density was 439 kg m^{-3}.

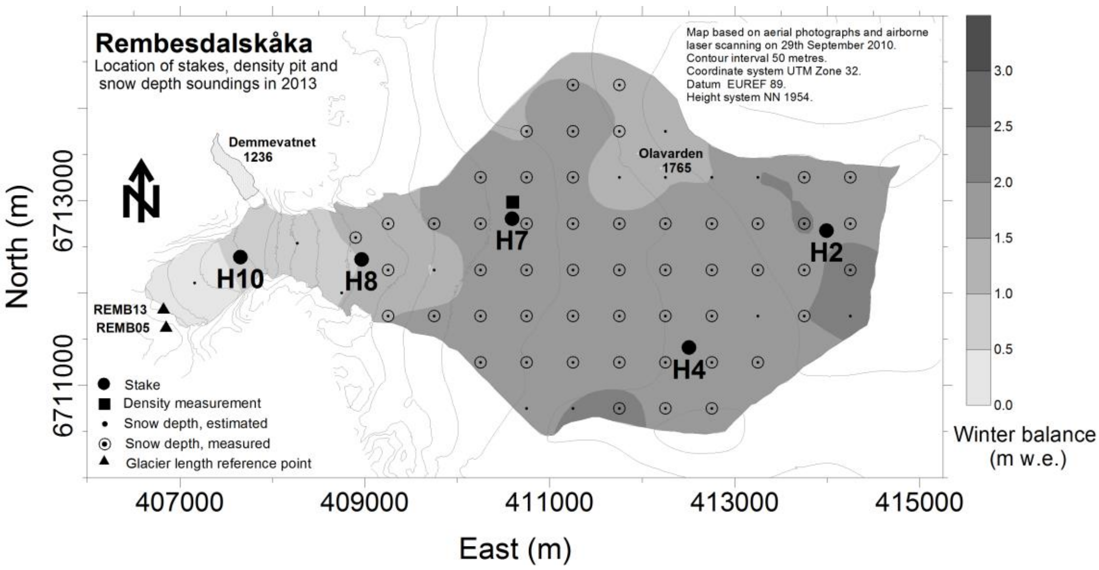


Figure 6-6
Location of stakes, snow depth soundings and snow pit, and the spatial distribution of winter balance at Rembesdalskåka in 2012.

The summer ablation measurements were carried out on 26th September. The glacier was covered with up to 0.45 m of new snow. The stakes were checked again on 21st November, revealing that between 0.15 and 0.35 m ice and firn had melted after 26th September. All the winter snow had melted at the stake locations. At H2, H4 and H7, 0.60, 0.85 and 1.65 m of firn from 2012 melted, respectively. At stake H8, 3.7 m of ice melted. Stake H10 melted out in July and was replaced on 26th September.

The calculations of the winter balances were performed using the same methods as described for 2011 (section 6-1). The resulting winter balance was 1.6 ±0.2 m w.e. The winter balance was 1.6 ±0.2 m w.e. When calculated with a gridding method from point winter balance in 51 sounding locations, five stake positions, and eleven estimated point winter balances, the resulting winter balance was 1.8 m w.e.

The annual minimum date was assessed as 23rd October from www.senorge.no. Snow depth sounding and stake measurements at stake H10 on 20th May 2014 verified that there was no melting after the measurements on 21st November 2013. The point summer balance was calculated directly at four stake locations above 1500 m a.s.l. The density of the melted firn from 2012 at stake H7, H4 and H2 was set as 650 kg m^{-3}, and the density of ice was set as 900 kg m^{-3}. The snow and ice melting at H10 between 12th June and 26th September was modelled. A positive degree day model using daily precipitation and temperature at the meteorological station Fet in Eidfjord (no 49800, 735 m a.s.l., 15 km south of H10) was calibrated to stake measurements at H10 from 2011 to 2013. The model results indicate that 5.65 m of ice melted between 12th June and 26th September. The total summer balance was calculated as −3.0 ±0.2 m w.e., and the resulting annual balance was −1.4 ±0.3 m w.e. The ELA was above the top of the glacier, and consequently, the AAR was 0 %. The altitudinal distribution of winter, summer and annual balance is presented in Figure 6-7.

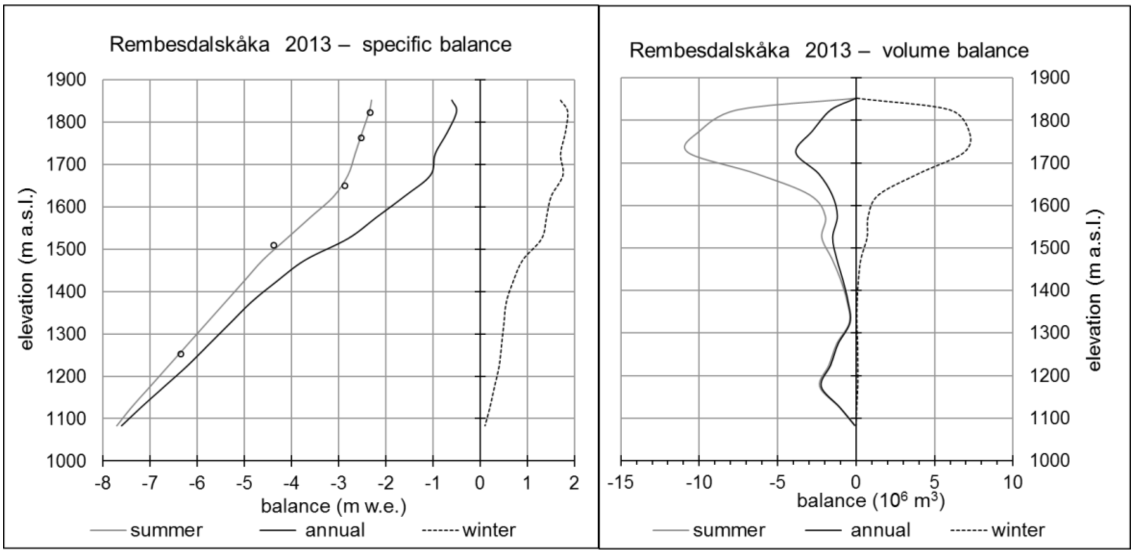


Figure 6-7
Mass balance diagram for Rembesdalskåka in 2013, showing specific balance on the left and volume balance on the right. Specific summer balance at five stake locations is shown (○).

6.4 Mass balance 2014

The snow accumulation measurements were performed on 20th May. Snow depth was measured at four old and one replacement stake, and at 59 sounding locations (Fig. 6-8). Below 1500 m a.s.l. snow depth was measured at stake H10 (1252 m a.s.l.) and at two locations 1185 and 1408 m a.s.l. The summer surface was difficult to define in the upper areas. Snow density was measured to the SS at 3.95 m depth at H7, and mean density was 531 kg m^{-3}.

The summer ablation measurements were carried out on 15th September and 5th November. On 15th September, some winter snow still remained at H4 and H2. Between 15th September and 5th November, 0.8 and 0.45 m of ice melted at H10 and H8, respectively.

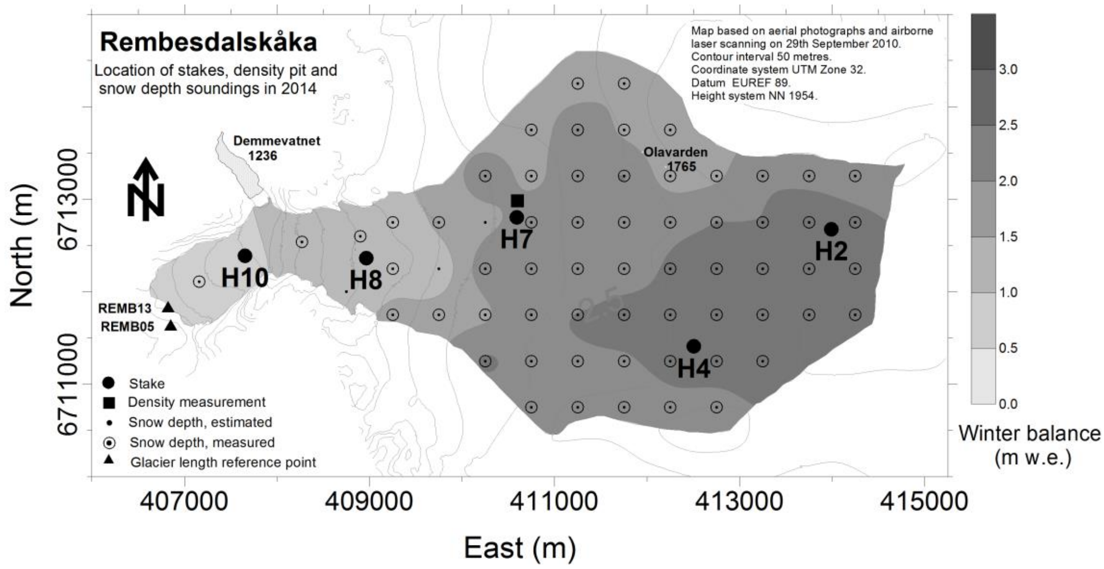


Figure 6-8
Location of stakes, snow depth soundings and snow pit, and the spatial distribution of winter balance at Rembesdalskåka in 2014.

The calculations of the winter balances were performed using the same methods as described for 2011 (section 6-1). The resulting winter balance was 2.2 ±0.2 m w.e. When calculated with a gridding method from point winter balance in 62 sounding locations, five stake locations, and one estimated point, the resulting winter balance was 2.2 m w.e.

The annual minimum date at Hardangerjøkulen was assesed as 6th October (www.senorge.no). Melting at stakes H7, H4 and H2 between 15th September and 6th October was assessed from temperature records at Finsevatn and Fet i Eidfjord as 0.2 m firn (H7), 0.15 m snow (H4) and 0.1 m snow (H2). Consequently, 0.15 and 0.40 m of snow remained at stakes H4 and H2, respectively. The summer balance was calculated at five stake locations. The density of remaining snow at H2 and H4 was set as 600 kg m^{-3}. The density of the melted firn from 2012 at stake H7 was set as 700 kg m^{-3}, and the density of ice was set as 900 kg m^{-3}.

The point summer balance was calculated directly at four stake locations above 1500 m a.s.l. The density of the remaining snow at stake H4 and H2 was set as 600 kg m^{-3}, density of melted firn from 2012 at H7 was set as 650 kg m^{-3}, and the density of ice was set as 900 kg m^{-3}. Even though some snow remained at H2 and H4, the calculated summer balance was larger than the mean winter balance from soundings between 1750 and 1850 m a.s.l., resulting in a negative annual balance. The total summer balance was calculated as −3.5 ±0.2 m w.e. The annual balance in 2014 was calculated as −1.3 ±0.3 m w.e. The ELA in 2014 was above the top of the glacier. Consequently, the AAR was 0 %. The altitudinal distribution of winter, summer and annual balances are presented in Figure 6-9.

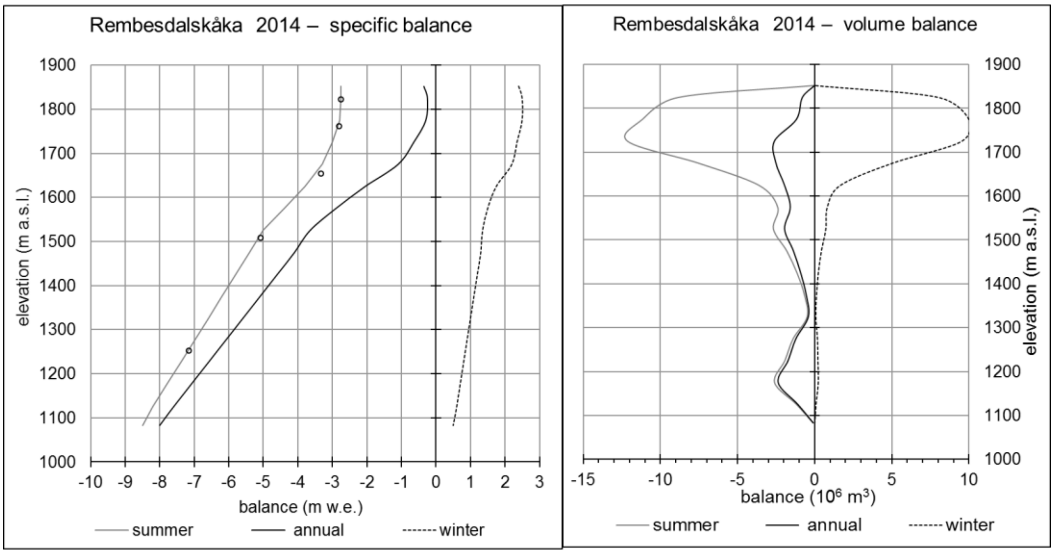


Figure 6-9
Mass balance diagram for Rembesdalskåaka in 2014, showing specific balance on the left and volume balance on the right. Specific summer balance at five stake locations is shown (○).

6.5 Mass balance 2015

The snow accumulation measurements were performed as late as 16th June. Due to a cool spring and late start to the summer, the melting had been limited. Snow depth was measured at two old and two new stakes, and at 52 snow depth positions (Fig. 6-10). At H2, a combination of a replacement stake and coring in October confirmed the snow depth. At H7, snow depth was confirmed by coring to firn at 6.5 m depth. Below 1500 m a.s.l. snow depth was sounded at stake H10 (1252 m a.s.l.) and two locations 1200 and 1400 m a.s.l. The summer surface was well defined at most locations. Snow density was measured down to 5.1 m depth at H7, and mean density was 490 kg m^{-3}. The SS was located at 6.5 m depth.

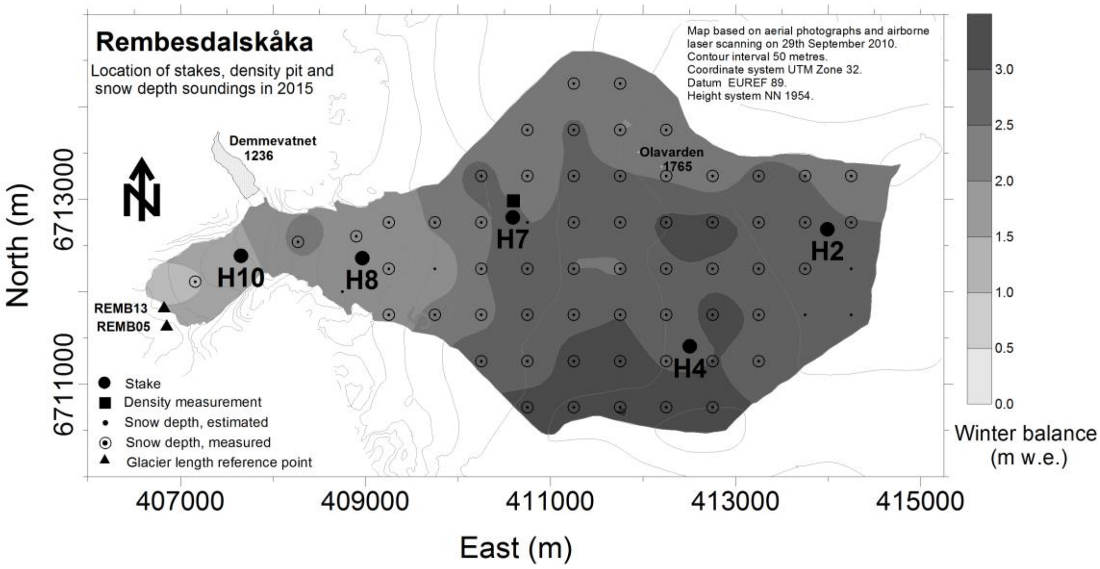


Figure 6-10
Location of stakes, snow depth soundings and snow pit, and the spatial distribution of winter balance at Rembesdalskåka in 2015.

The summer ablation measurements were carried out on 14th October. At stakes H10 and H8, 2.8 and 0.9 m of ice had melted, respectively. At stakes H7, H4 and H2, the remaining snow depth was 2.5, 3.25 and 3.6 m, respectively. The density of the remaining snow at H2 was measured as 574 kg m^{-3}.

The calculations of the winter balance were performed using the same methods as described for 2011 (section 6-1), and the resulting winter balance was 3.0 ±0.2 m w.e. The winter balance calculated with a gridding method was 3.2 m w.e. based on point winter balance in 62 sounding locations, five stake positions, and one estimated point winter balance.

The annual minimum date at Hardangerjøkulen was assesed as 6th October (www.senorge.no). Snow depth sounding and stake measurements at stake H10 on 6th January 2016 showed that there was about 0.2 m of ice melt at the glacier tongue after the autumn measurements on 14th October 2015. No indication of additional melting was found at H8. The summer balance was calculated at five stake locations. The density of remaining snow at H7, H4 and H2 was set as 575 kg m^{-3}, and the density of the melted ice was assessed as 900 kg m^{-3}. The total summer balance was calculated as −1.8 ±0.2 m w.e., and the annual balance was calculated as 1.2 ±0.3 m w.e. The ELA was 1570 m a.s.l., and the corresponding AAR was 87 %. The altitudinal distribution of winter, summer and annual balances are presented in Figure 6-11.

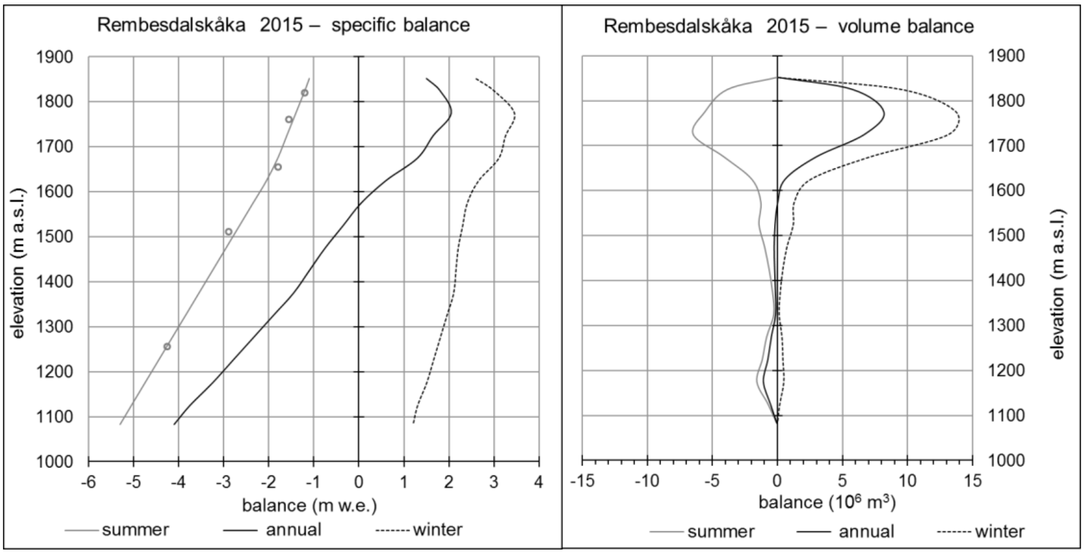


Figure 6-11
Specific (left) and volume (right) winter, summer and annual balance at Rembesdalskåka in 2015. Specific summer balance at five stakes is shown (○).

6.6 Mass balance 1963-2015

A summary of the mass balance measurements and results for 2011-2015 is given in Table 6-1.

Table 6-1
Summary of mass balance results at Rembesdalskåka for 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		1 Jun	23 May	8 May	20 May	16 June
Date B_s		10 Nov	11 Oct	26 Sep	5 Nov	14 Oct
Density b_w	kg m^{-3}	460	485	439	531	490
Density $firn_m$	kg m^{-3}	720-750		650	700	
Density $firn_r$	kg m^{-3}		600		600	575
B_w	m w.e.	2.13	2.65	1.61	2.17	3.00
B_s	m w.e.	-3.40	-1.74	-2.84	-3.46	-1.82
B_a	m w.e.	-1.27	+0.91	-1.22	-1.29	+1.18
ELA	m a.s.l.	>1854	1589	>1854	>1854	1570
AAR	%	0	86	0	0	87

Date B_w and Date B_s are the dates of snow accumulation and summer ablation measurements, respectively.
Density b_w, Density $firn_m$ and Density $firn_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

The original mass balance record for 1963-2010 (48 years) has been reported in the series “Glaciological investigations in Norway” (e.g. Kjøllmoen et al., 2011). This record has been revised (Andreassen et al, 2016.). The annual glaciological surface mass balance record from 1962-2014 and geodetic volume balances 1962-1995 and 1995-2010 were homogenised. Detailed documentation of measurements and calculations performed by the Norwegian Polar Institute between 1963 and 1984 have not been available. Consequently, the homogenisation was limited to applying new drainage divides from 2010 and new area-altitude distribution curves for all the years. The period for the different maps were split between the years (at 1973/74 and 2002/03).

Comparison of the homogenised surface mass balance record with geodetic mass balance for 1962-1995 and 1995-2010 showed a difference between the mean annual glaciological surface mass balance, and the geodetic mass balance reduced for estimated internal melting of 0.02 and 0.45 m w.e.a $^{-1}$, respectively. The difference is larger than the detection level for systematic bias for the second period, and consequently the surface mass balance record was calibrated (Andreassen et al., 2016).

The calibration reduced the mean winter balance for 1962-2010 from 2.10 to 2.03 m w.e. a^{-1}. The mean summer balance decreased from −2.03 to −2.07 m w.e. a^{-1}. Consequently, the mean surface mass balance changed from +0.07 to −0.04 m w.e. a^{-1}. The mass balance record for 1962-2015 is presented in Figure 6-12 and Table 6-2, and original, homogenised and revised cumulative surface mass balance is presented in Figure 6-13. The cumulative mass balance since 1962 amounts to −68 mill. m^3 w.e. (Fig. 6-13). However, since 1995 the glacier has had a mass deficit of 203 mill. m^3 w.e., corresponding to −0.59 m w.e. a^{-1}.

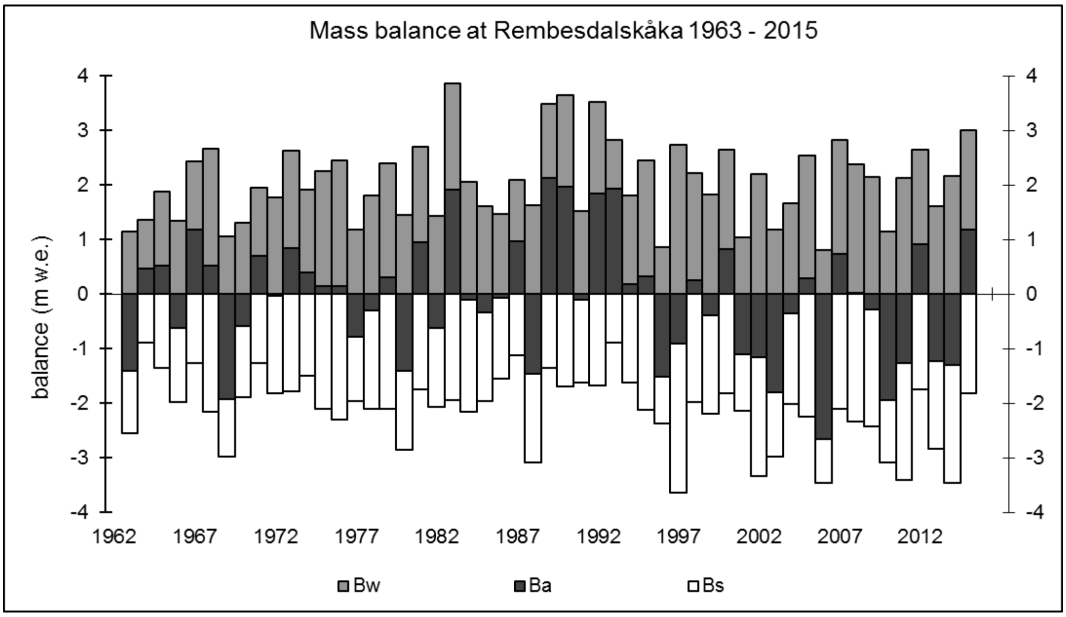


Figure 6-12
Winter, summer and annual balance at Rembesdalskåka for the period 1963-2015. The results from 1963-1995 are homogenised, and 1996-2010 are calibrated values. Mean balance values are B_w = 2.05 m w.e. a^{-1}, B_s = –2.13 m w.e. a^{-1} and B_a = –0.08 m w.e. a^{-1}.

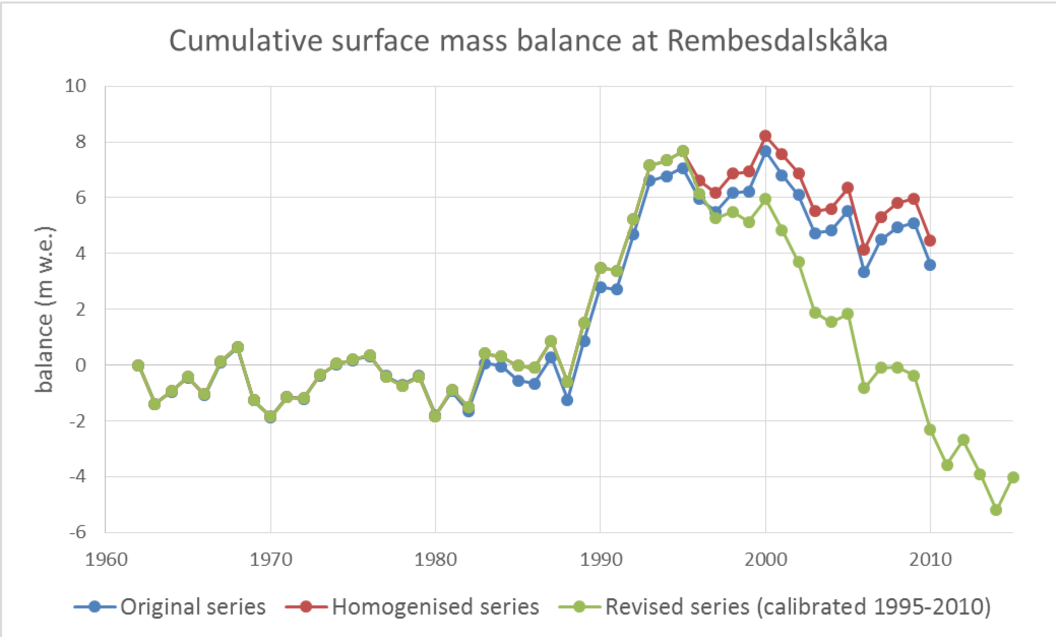


Figure 6-13
Cumulative mass balance at Rembesdalskåka for the period 1963-2015 (53 years).

Table 6-2
The revised surface mass balance series for 1963-2010. Status is either original (O), homogenised (H) or calibrated (C).

Year	B_w	B_s	B_a	ΣB_a	ELA	AAR	DTM	Area	Status
1962				0					
1963	1.15	-2.55	-1.40	-1.40	>1860	0%	1961	17.620	O
1964	1.36	-0.90	0.46	-0.94	1655	80%	1961	17.620	H
1965	1.88	-1.36	0.52	-0.42	1644	81%	1961	17.620	H
1966	1.35	-1.97	-0.62	-1.04	1780	36%	1961	17.620	H
1967	2.44	-1.26	1.18	0.14	1569	88%	1961	17.620	H
1968	2.67	-2.16	0.51	0.65	1668	79%	1961	17.620	H
1969	1.06	-2.98	-1.92	-1.26	>1860	0%	1961	17.620	H
1970	1.30	-1.89	-0.58	-1.85	1775	38%	1961	17.620	H
1971	1.95	-1.26	0.70	-1.15	1604	85%	1961	17.620	H
1972	1.78	-1.81	-0.04	-1.19	1663	80%	1961	17.620	H
1973	2.62	-1.79	0.84	-0.35	1587	85%	1961	17.620	H
1974	1.90	-1.50	0.40	0.05	1658	80%	1961	17.620	H
1975	2.25	-2.10	0.15	0.20	1625	82%	1961	17.620	H
1976	2.45	-2.29	0.15	0.35	1672	79%	1961	17.620	H
1977	1.18	-1.96	-0.78	-0.43	>1860	0%	1961	17.620	H
1978	1.80	-2.10	-0.30	-0.73			1961	17.620	O
1979	2.40	-2.10	0.30	-0.43			1995	17.634	O
1980	1.45	-2.85	-1.40	-1.83	>1862	0%	1995	17.634	O
1981	2.7	-1.75	0.95	-0.88	1611	85%	1995	17.634	H
1982	1.44	-2.06	-0.62	-1.50	>1862	0%	1995	17.634	H
1983	3.85	-1.94	1.91	0.41	1450	92%	1995	17.634	H
1984	2.05	-2.15	-0.10	0.31	1675		1995	17.634	O
1985	1.61	-1.95	-0.34	-0.03	1741	59%	1995	17.634	H
1986	1.47	-1.55	-0.08	-0.11	1692	74%	1995	17.634	H
1987	2.09	-1.13	0.96	0.85	1557	88%	1995	17.634	H
1988	1.62	-3.09	-1.47	-0.62	>1862	0%	1995	17.634	H
1989	3.49	-1.36	2.13	1.51	1439	92%	1995	17.634	H
1990	3.65	-1.69	1.96	3.47	1475	91%	1995	17.634	H
1991	1.52	-1.62	-0.10	3.37	1688	75%	1995	17.634	H
1992	3.52	-1.68	1.84	5.21	1525	89%	1995	17.634	H
1993	2.82	-0.89	1.93	7.14	1475	91%	1995	17.634	H
1994	1.80	-1.62	0.18	7.32	1633	82%	1995	17.634	H
1995	2.45	-2.12	0.33	7.65	1600	85%	1995	17.634	H
1996	0.86	-2.37	-1.51	6.14	>1862	0%	1995	17.634	C
1997	2.74	-3.64	-0.9	5.24	>1862	0%	1995	17.634	C
1998	2.22	-1.97	0.25	5.49	1661	81%	1995	17.634	C
1999	1.82	-2.2	-0.38	5.11	1768	53%	1995	17.634	C
2000	2.64	-1.82	0.82	5.93	1550	88%	1995	17.634	C
2001	1.03	-2.13	-1.1	4.83	>1862	0%	1995	17.634	C
2002	2.19	-3.34	-1.15	3.68	>1862	0%	1995	17.634	C
2003	1.18	-2.98	-1.8	1.88	>1854	0%	2010	17.263	C
2004	1.66	-2.02	-0.36	1.52	1733	58%	2010	17.263	C
2005	2.54	-2.25	0.29	1.81	1661	81%	2010	17.263	C
2006	0.8	-3.46	-2.66	-0.85	>1854	0%	2010	17.263	C
2007	2.83	-2.1	0.73	-0.12	1636	82%	2010	17.263	C
2008	2.37	-2.34	0.03	-0.09	1663	81%	2010	17.263	C
2009	2.14	-2.43	-0.29	-0.38	1725	59%	2010	17.263	C
2010	1.14	-3.09	-1.95	-2.33	>1854	0%	2010	17.263	C

6.7 Ice velocity and surface elevation change

Stake positions have been surveyed once or twice per year since 2008 using differential GNSS. A Topcon GR3 has been used to collect raw data. SATREF data from Maurset at 740 m a.s.l., 14 km southwest of Rembesdalskåka were used when the data was post-processed. Average stake velocities are calculated for the periods between surveys. Stake positions, length of period between surveys and time of year have varied. Consequently, any changes in glacier velocity during the period has not been deduced.

Rembesdalskåka dams the lake Demmevatnet. Diversion tunnels constructed in 1938 and in the 1980s reduced the lake volume from about 10 mill m³ to about 2 mill m³, and prevented jøkulhlaups until 25th August 2014 when the lake emptied for the first time in 76 years. A comparison of surface elevations from surveyed point elevations on 6th September 1996 (Elvehøy et al., 1997) to the DTM from 2010 shows a reduction in glacier thickness of up to 30 m between 1996 and 2010 (Fig. 6-15). Between 2010 and

2015 the glacier thickness adjacent to Demmevatnet decreased by an additional 5 to 7 m. On the glacier plateau, the thinning was considerably less (Tab. 6-3).

Table 6-3
Representative stake velocities at Rembesdalskåka between 2010 and 2015, and elevation change between 29th September 2010 (DTM) and 14th October 2015 (GNSS). The results are illustrated in Figure 6-14.

Stake	Date 1	Date 2	Hor. velocity (m/y)	Direction (360°)	Elevation 14.10.2015 (m a.s.l.)	Elev. change 2010-15 (m)
H10	20.05.2014	27.08.2014	57	239	1240.0	-6.6
H8	26.09.2013	27.08.2014	70	272	1504.9	-1.4
H7	08.10.2010	26.09.2013	22	275	1653.1	-2.2
H4	08.10.2010	14.10.2015	10	280	1757.6	-1.3
H2	05.10.2012	26.09.2013	3	257	1820.7	-1.9

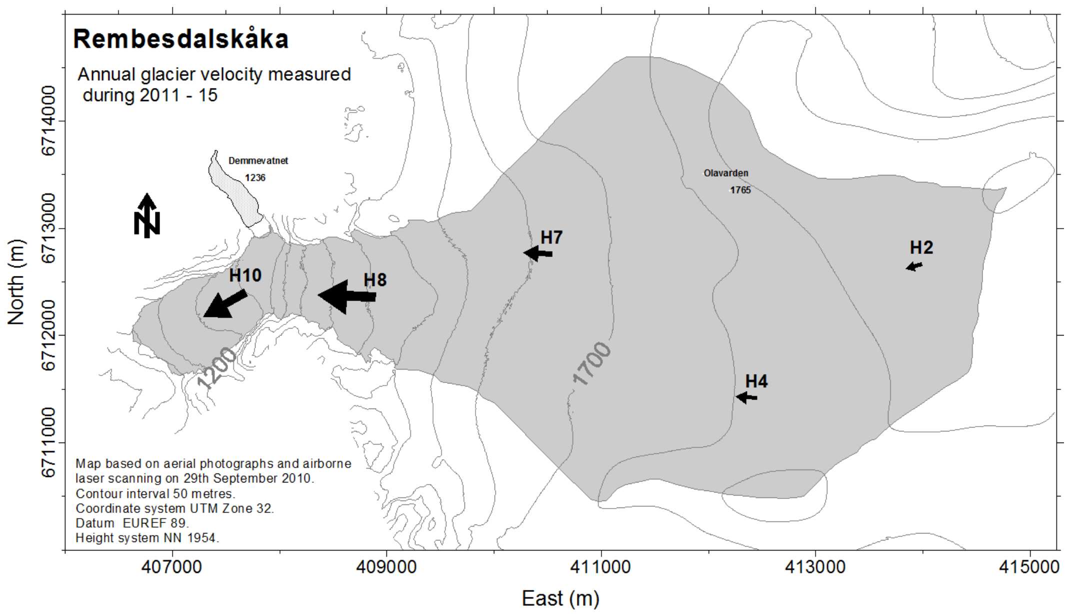


Figure 6-14
Glacier velocity at Rembesdalskåka between 2010 and 2015. See Table 6-3 for details.

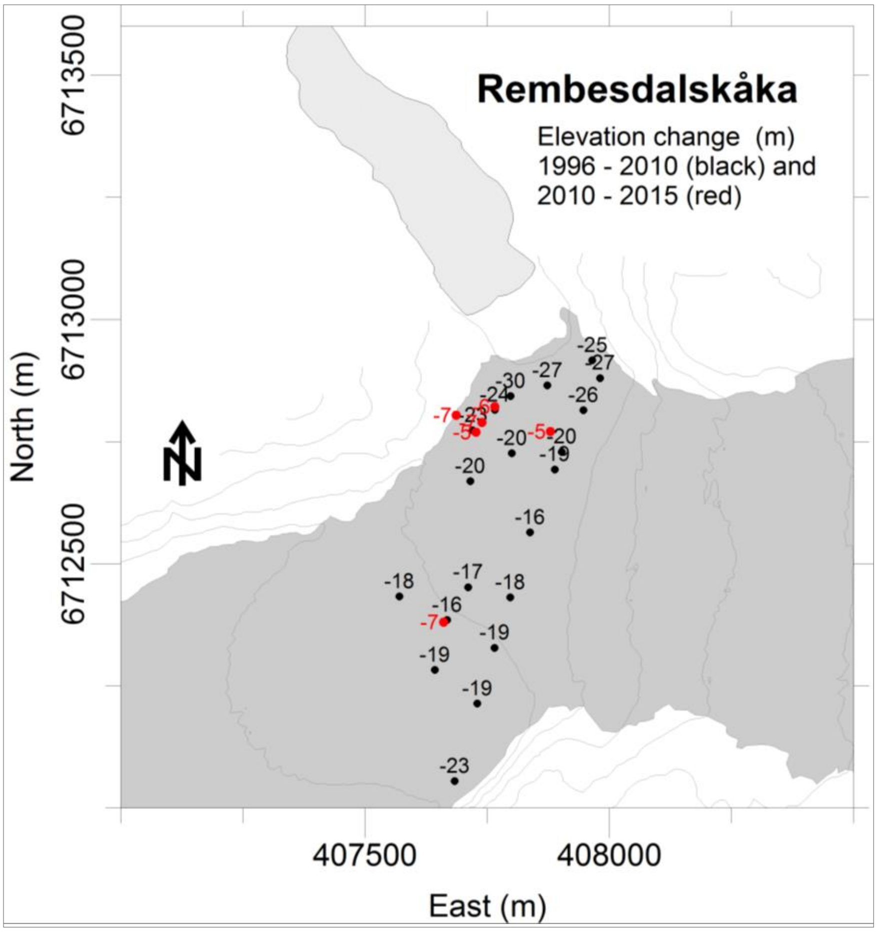


Figure 6-15
Elevation change at surveyed points in 1996 (black) and 2015 (red) adjacent to Lake Demmevatnet when compared with the DTM from 29th September 2010.

6.8 Meteorological measurements on Midtdalsbreen 2011-2013 (Rianne H. Giesen)

An automatic weather station (AWS) was operational in the ablation area on Midtdalsbreen, a northern outlet glacier of Hardangerjøkulen, between October 2000 and March 2013. The station (Fig. 6-16) was owned and maintained by the Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht University (contact: c.h.tijm-reijmer@uu.nl). The station recorded incoming and outgoing shortwave and longwave radiation, 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. Here, we present a selection of data collected between 24th August 2010 and 21st March 2013. Due to cable damage, data for most variables are missing between January and August 2012. The AWS series were fully terminated in March 2013, in total spanning more than twelve years.

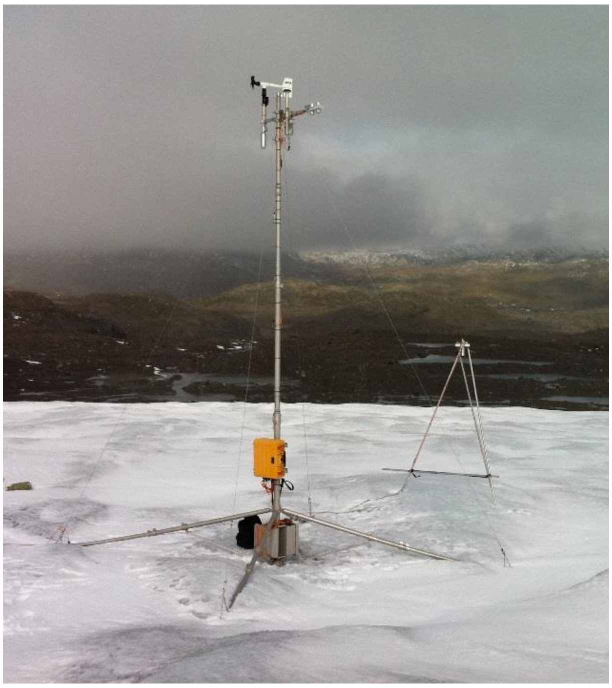


Figure 6-16
The AWS site on Midtdalsbreen on 19th September 2010. Photo: Wim Boot.

Air temperature

In contrast to most other variables, the air temperature record is almost complete, with 18 days missing in February and March 2012 and 1 day missing in August 2012 (Fig. 6-17). Two of the three winters in the record were approximately 2 °C colder than the mean of the previous ten years. The summer of 2011 was almost 1 °C warmer than the ten-year average, while the summer of 2012 was 1 °C colder.

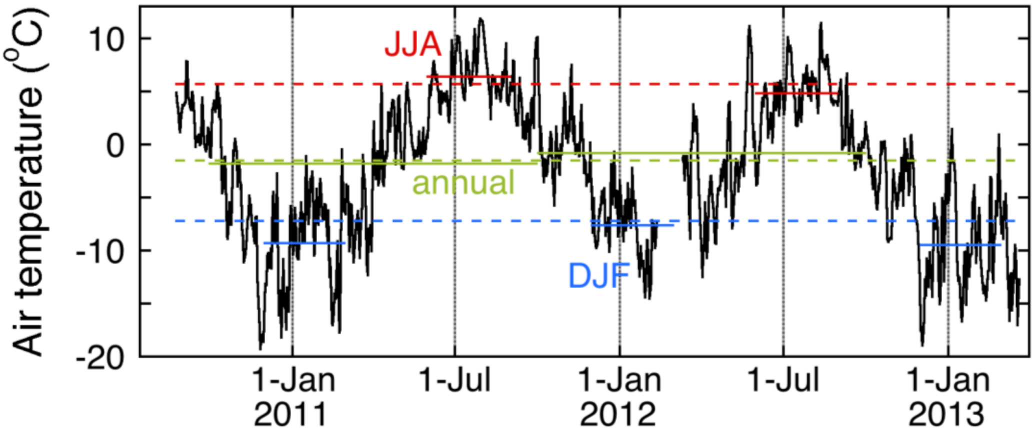


Figure 6-17
Daily air temperature for the period 25th August 2010 to 21st March 2013 (black line). The horizontal lines show the mean annual (October-September), winter (December-February) and summer (June-August) values for the period shown (solid) and the previous ten years (dashed).

Late summer melt and build-up of the snowpack

Surface height changes for the two summer seasons were unfortunately not recorded. Instead we present here late summer to early winter records for the three consecutive years (Fig. 6-18). For the 2010-11 season, surface height was recorded only until late September. From surface albedo and air temperature it can be deduced that the snow present in late September melted in early October, after which the winter snowpack started to build up. In the next winter, air temperatures up to 10 °C were measured in the first half of November, delaying the build-up of the winter snowpack until late November. Compared with the previous two years, the build-up of the snowpack started early in the third year; no significant melt events occurred after the first half of September. Despite the two months difference in the onset, the snow depth in January was almost equal in 2012 and 2013.

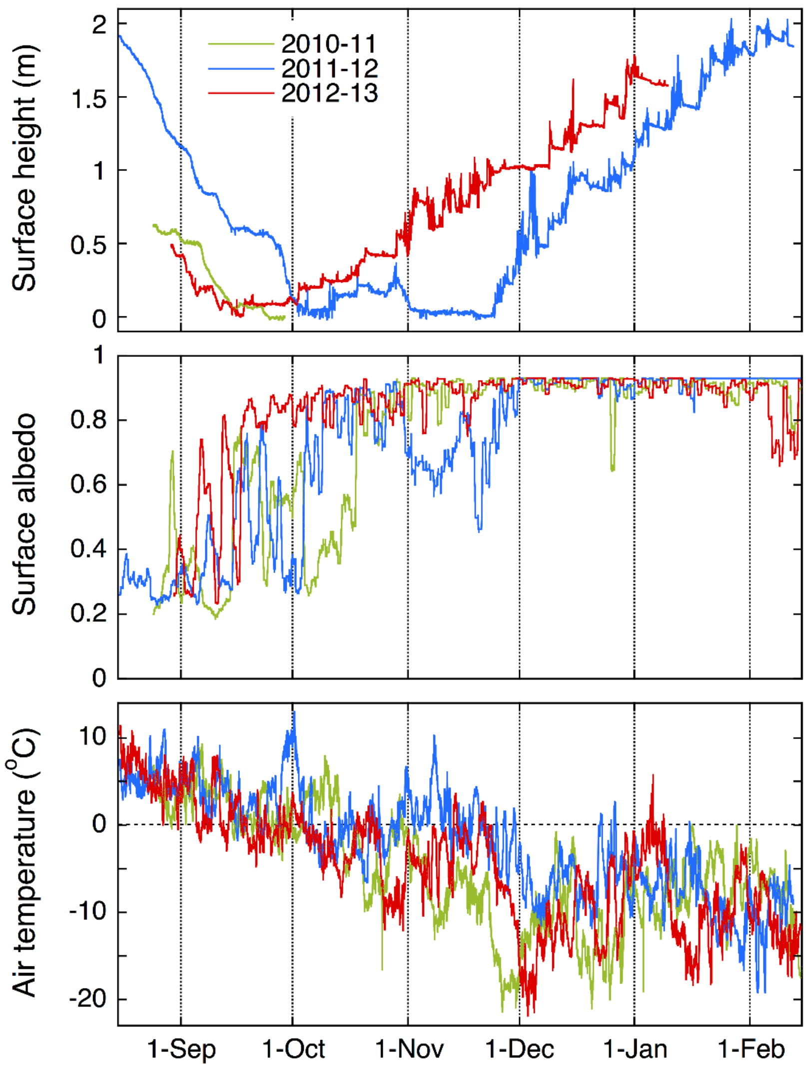


Figure 6-18
Half-hourly values of surface height, surface albedo and air temperature over the period 15th August to 15th February for three years. For surface albedo a moving average with a 24-hour period was applied to the ratio of reflected and incoming solar radiation.

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 and front position (change in length) since 1902 (chap. 14).

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). The mass balance for the years 2011-2015 is calculated based on the DTM and glacier outline from 2009. In 2015, Storbreen was surveyed with an unmanned vehicle to obtain new orthophotos and measure surface elevation of the glacier (Kraaijenbrink et al., 2016). An automatic weather station (AWS) has been operated on the glacier since 2001 (section 7-7).

Figure 7-1
Storbreen on 8th August 2012. Photo: Liss M. Andreassen.

7.1 Mass balance 2011

Snow accumulation was measured on 3rd and 4th May 2011 at stakes in 9 different positions and 223 snow depth soundings (Fig. 7-2). The stake readings showed no significant additional surface melting after the ablation measurements in the previous mass balance year (28th September 2010). 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 0.70 and 3.5 m, the mean being 2.2 m. Snow density was measured in two positions, at stake 4 at 1715 m a.s.l. (2.0 m snow) and at the AWS at 1563 m a.s.l. (1.65 m snow). Ablation measurements were performed on 13th September at stakes in all positions.

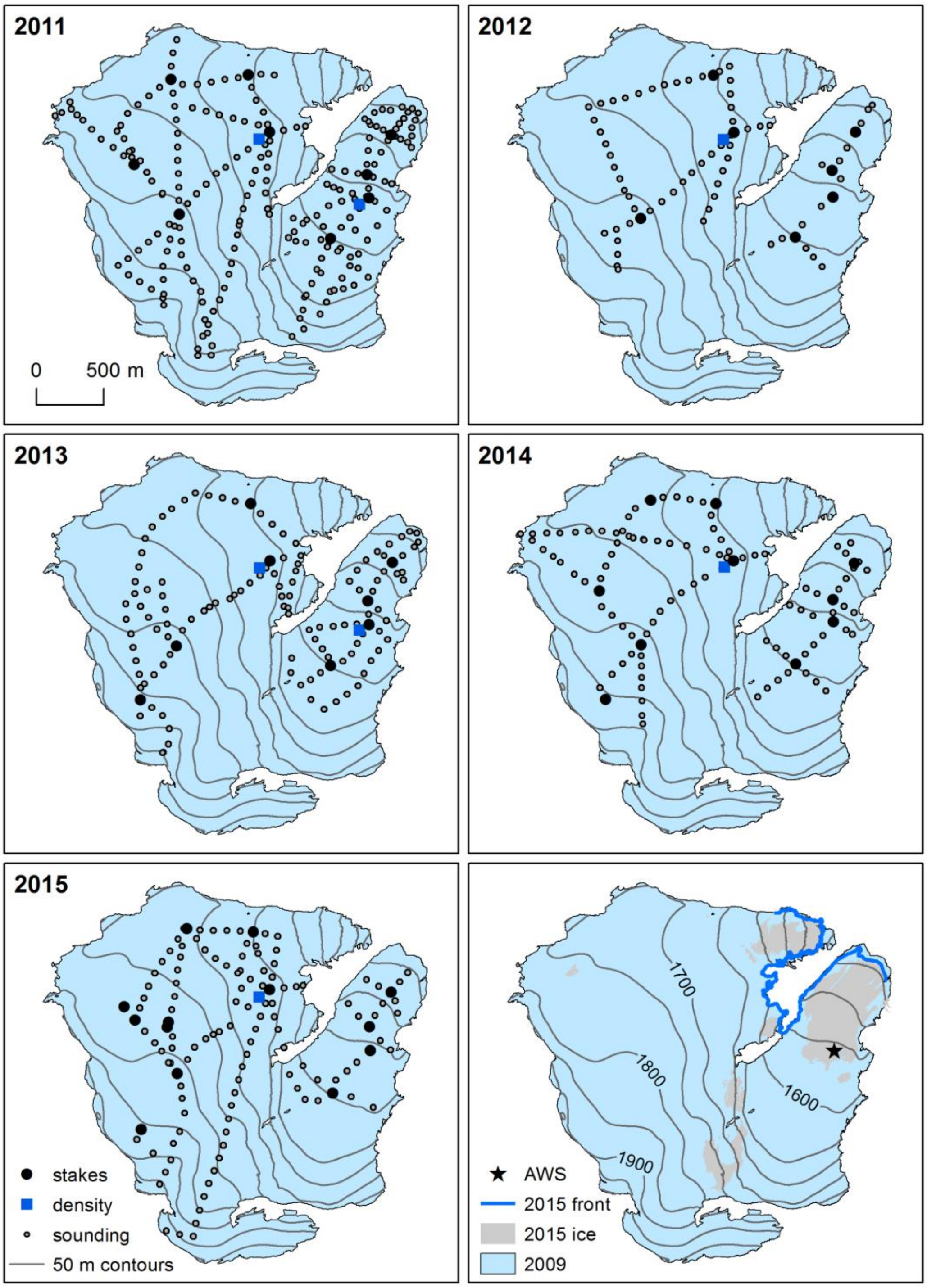


Figure 7-2
Location of stakes, soundings and density pits at Storbreen in the mass balance years 2011-2015. The 50 m contours and the glacier outline is from aerial photos and laser scanning acquired in September and October 2009. The figure at bottom right shows the position of the terminus and exposure of bare ice based on aerial photos taken 9-10. September 2015 from an unmanned vehicle. The position of the automatic weather station (AWS) is also shown.

Winter balance was calculated from soundings and the snow density measurements. The mean measured snow density was 507 kg m^{-3} at the AWS and 383 kg m^{-3} at stake 4. A polynomial density function was fitted to each density measurement, and the function 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 balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.0 ± 0.2 m w.e. Summer balance was calculated directly from stakes at seven locations (1, 2, 3, 4, 6, 7 and 8). There was no remaining winter snow at any of the stakes. The density of the melted ice was assumed to be 900 kg m^{-3}. The density of melted firn was assumed to be 750-800 kg m^{-3}. Stake readings on 3rd May 2012 showed significant extra melting on stakes lower than 1800 m a.s.l. after the minimum measurements in 2011. This melt was accounted for by adding it to the summer and annual balance of 2011. The summer balance was calculated to be −2.6 ±0.3 m w.e.; without accounting for this melt the summer balance would be −2.3 m w.e. for 2011.

The annual balance of Storbreen was negative in 2011, at −1.6 ±0.3 m w.e. The ELA calculated from the annual balance diagram (Fig. 7-3) was ~2005 m a.s.l. resulting in an accumulation area ratio (AAR) of 3 %. Note that no stakes are located above 1900 m a.s.l. Thus, above this height the mass balance values and the derived ELA and AAR values are only estimates.

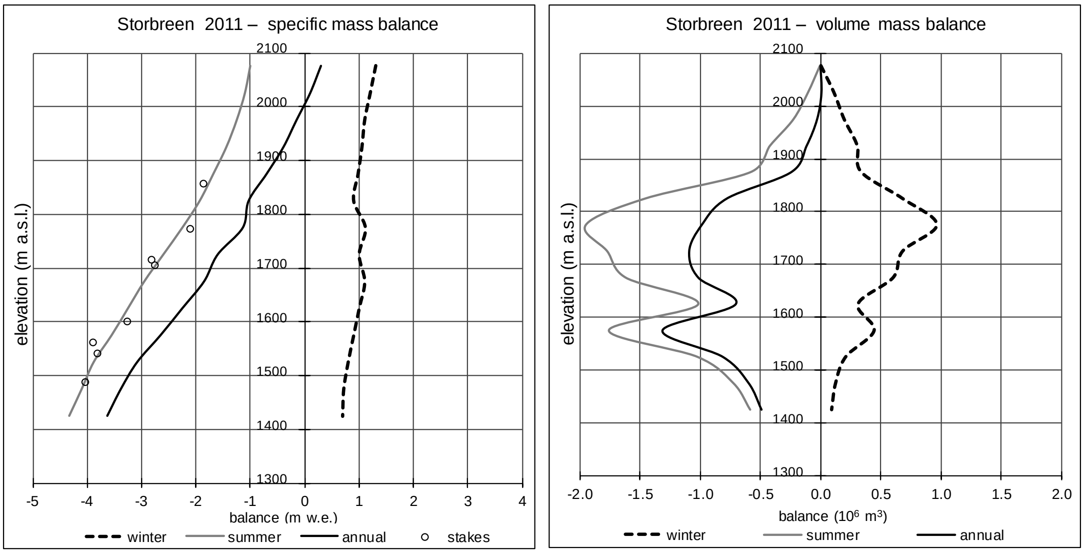


Figure 7-3
Mass balance versus altitude for Storbreen 2011, showing specific balance on the left and volume balance on the right. Summer balance at 8 stakes is shown (○).

7.2 Mass balance 2012

Accumulation measurements were performed on 3rd May 2012 and the calculation of winter balance is based on measurements of stakes in 8 different positions and 75 snow depth soundings. The stake readings showed significant surface melting after the ablation measurements (11th September 2011) in the previous mass balance year; this melt was accounted for in the mass balance year 2011. The summer surface was relatively easy to identify over the whole glacier. The snow depth varied between 2.1 and 5.1 m, the mean being 3.5 m. Snow density was measured at stake 4 at 1715 m a.s.l. The total snow depth was 3.4 m. Ablation measurements were performed on 16th October on stakes in all positions. A layer of fresh snow covered most of the glacier, and snow depth varied between 0.37 and 0.76 m at the stakes.

Winter accumulation was calculated from soundings and the snow density measurement. The mean measured snow density was 442 kg m^{-3} at stake 4. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. The winter accumulation was calculated to be 1.7 ±0.2 m w.e.

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}, and the density of remaining snow was assumed to be 600 kg m^{-3}. The summer balance was calculated to be −1.6 ±0.3 m w.e.

The annual balance of Storbreen was in balance in 2012, +0.1 ±0.3 m w.e. The ELA calculated from the annual balance diagram (Fig. 7-4) was 1725 m a.s.l. resulting in an accumulation area ratio (AAR) of 62 %.

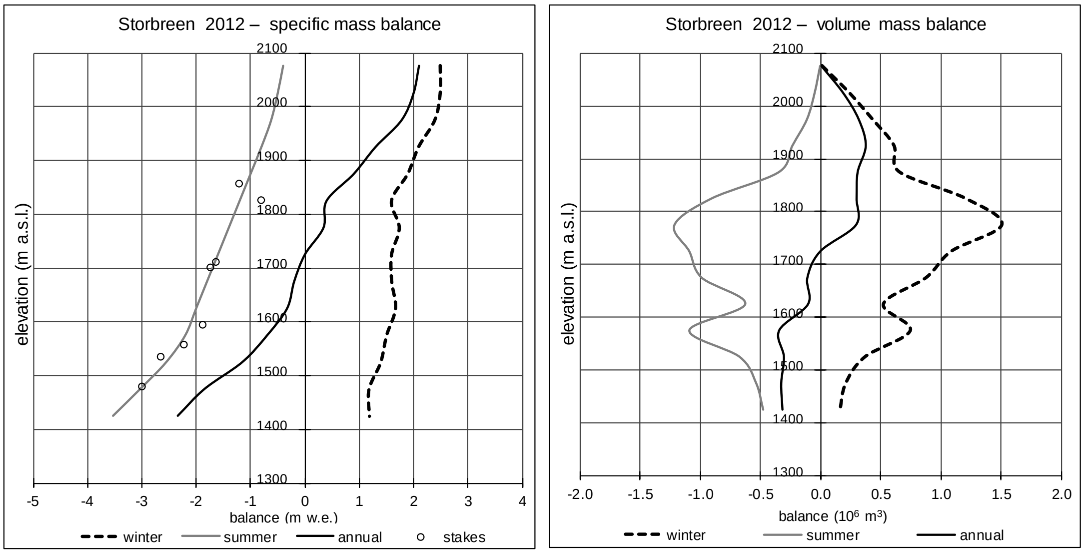


Figure 7-4
Mass balance diagram for Storbreen 2012, showing specific balance on the left and volume balance on the right. Summer balance at 8 stakes is shown (○).

7.3 Mass balance 2013

Accumulation measurements were performed on 7th May 2013 and the calculation of winter balance is based on measurements of stakes in 8 positions and soundings of snow depth at 128 points between 1444 and 1902 m a.s.l. The summer surface was easy to identify, except for some parts at higher elevation. The snow depth varied between 2.1 and 4.8 m, the mean being 3.2 m. Snow density was measured at the AWS at 1560 m a.s.l. and at stake 4 at 1715 m a.s.l. The total snow depth was 2.9 and 2.7 m respectively. Ablation measurements were performed on 12th September on stakes in all positions.

Winter accumulation was calculated from soundings and the snow density measurement at the AWS, where the measured snow density was 397 kg m^{-3}. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 1.3 ±0.2 m w.e. Summer balance was calculated directly from stakes in nine locations. The density of the melted ice was assumed to be 900 kg m^{-3}. The density of melted firn was assumed to be 700-850 kg m^{-3}, and the density of the remaining snow was 600 kg m^{-3}. The summer balance was calculated to be −2.5 ±0.3 m w.e.

The annual balance of Storbreen was negative in 2013, −1.2 ± 0.3 m w.e. The ELA calculated from the mass balance diagram (Fig. 7-5) was calculated to be ~1900 m a.s.l. resulting in an accumulation area ratio (AAR) of 14 %.

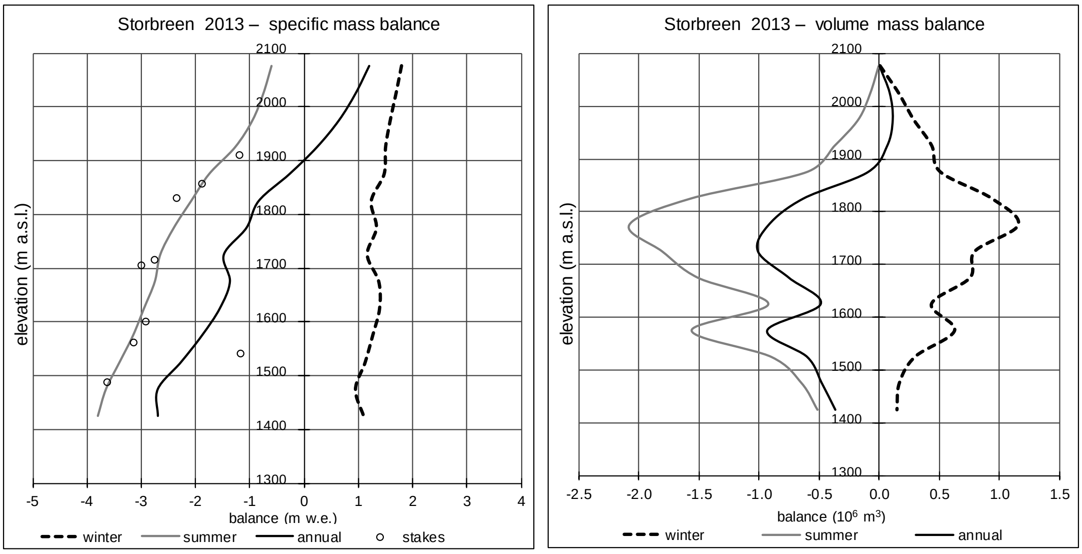


Figure 7-5
Mass balance diagram for Storbreen 2013, showing specific balance on the left and volume balance on the right. Summer balance at 8 stakes is shown (○).

7.4 Mass balance 2014

Accumulation measurements were performed on 14-15th May on the upper part and 20th May on the lower part. The calculation of winter balance is based on measurements of stakes in 7 different positions and soundings of snow depth at 112 points between 1464 and 1938 m a.s.l. The summer surface was difficult to identify in the uppermost parts of the glacier. The snow depth varied between 1.6 and 5.2 m, the mean being 3.3 m. The stake readings showed additional surface melting at the stakes below 1600 m a.s.l. after the ablation measurements in the previous mass balance year (12th September 2013). Snow density was measured at stake 4 at 1715 m a.s.l. The total snow depth was 2.7 m. Ablation measurements were performed on 18th September 2014 on stakes in all positions.

Winter accumulation was calculated from soundings and the snow density measurement at stake 4, where the measured snow density was 467 kg m^{-3}. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 1.63 ±0.2 m w.e. Subtracting for additional melting below 1650 m a.s.l., the resulting winter balance was 1.57 ±0.2 m w.e. Summer balance was calculated directly from stakes in six locations. The density of the melted ice, firn and remaining snow was assumed to be 900 kg m^{-3}, 800-850 kg m^{-3} and 600 kg m^{-3}, respectively. The summer balance was calculated to be −2.7 ±0.3 m w.e. The annual balance of Storbreen was negative in 2014, −1.2 ±0.3 m w.e. The ELA calculated from the mass balance diagram (Fig. 7-6) was ~1870 m a.s.l. resulting in an accumulation area ratio (AAR) of 19 %.

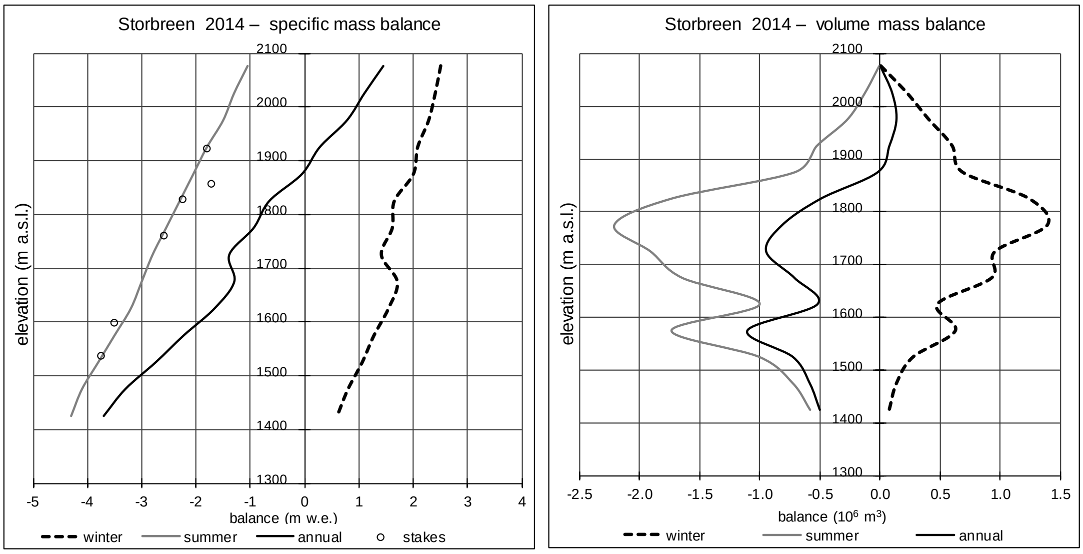


Figure 7-6
Mass balance diagram for Storbreen 2014, showing specific balance on the left and volume balance on the right. Summer balance at 6 stakes is shown (○).

7.5 Mass balance 2015

Accumulation measurements were performed on 14-15th May. The calculation of winter balance is based on measurements of stakes in 7 different positions and 130 snow depth soundings. The stake readings indicated 10-25 cm additional surface melting at the stakes below 1850 m a.s.l. after the ablation measurements in the previous mass balance year (18th September 2014). Soundings of snow depth were carried out at 130 points between 1455 and 2019 m a.s.l. The snow depth varied between 2.1 and 5.9 m, the mean being 3.7 m. Snow density was measured at stake 4 at 1715 m a.s.l. The total snow depth was 3.3 m. Ablation measurements were performed on 9-10th September 2015 on stakes in all positions. Density of the remaining snow was measured at stake 4 and two nearby locations, at depths of 0.45 m (1713 m a.s.l.), 0.59 m (1717 m a.s.l.) and 1.31 m (1739 m a.s.l.). The resulting densities were 453, 516 and 543 kg m^{-3}, respectively, showing increasing density with increasing snow depth. Some of the snow may also be summer snow, as the summer was cold with several snowfalls. The snow line was unusually low at the time of the measurements, at about 1570 m a.s.l. The thickness of the remaining snow was measured at 31 points, showing depths of 0.45 to 1.83 m, with a mean of 1.31 m.

The winter accumulation (B_{acc}) was calculated as the mean of the soundings within each 50-metre height interval and was 1.6 ±0.2 m w.e. Subtracting for additional melting below 1850 m a.s.l., the winter balance was 1.5 ±0.2 m w.e. Summer balance was calculated directly from stakes in 11 locations. The density of the melted ice was assumed to be 900 kg m^{-3}. The density of remaining snow was assumed to be 480-600 kg m^{-3} depending on snow depth. The summer balance was calculated to be −1.0 ±0.3 m w.e. The mass balance of Storbreen was positive in 2015, 0.4 ±0.3 m w.e. for the balance year from 18th September 2014 to 10th September 2015. The ELA derived from the curve was about 1575 ±5 m a.s.l., similar to that which was observed in the field, resulting in an AAR of 89 %.

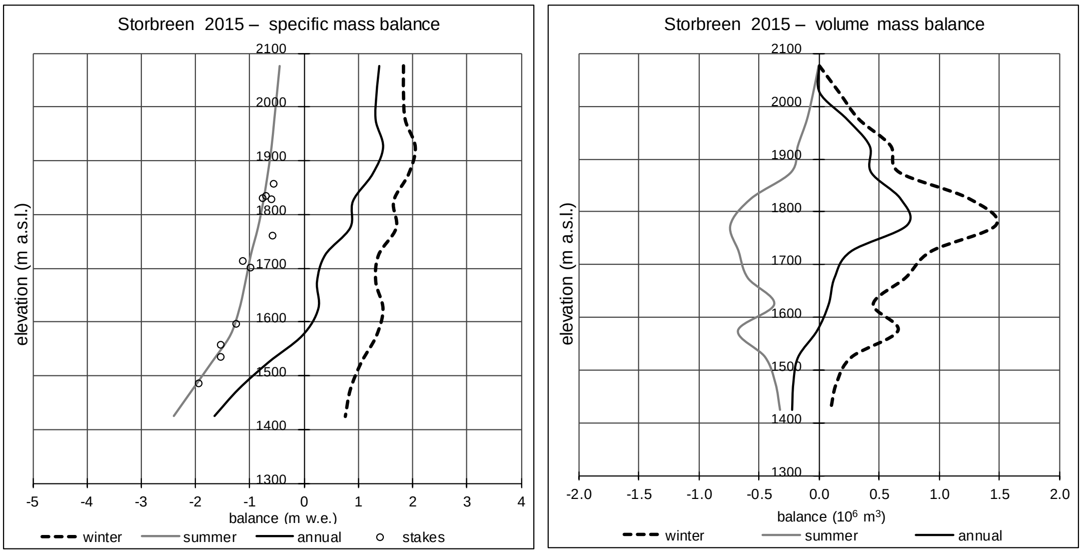


Figure 7-7
Mass balance diagram for Storbreen 2015, showing specific balance on the left and volume balance on the right. Summer balance at the stakes is shown (○).

7.6 Mass balance 1949-2015

The annual mass-balance calculations of Storbreen are based on a series of maps. Each time a new survey was performed and a revised map became available, the mass balance was calculated henceforth using the new map. In a recent reanalysis study of 10 Norwegian glaciers, the glaciological mass balance record of Storbreen was also studied (Andreasssen et al., 2016). The glacier-wide averages were recalculated by taking into account both area–altitude distributions by using the older map for the first half of the period and then the newer map for the second half. For Storbreen, only the years from 1991 were homogenised due to the lack of data (and metadata) prior to this date.

Table 7-1
Summary values of Storbreen mass balance measurements and results for the years 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		3-4 May	3 May	7 May	14-15,20 May	14 May
Date B_s		13 Sep	16 Oct	12 Sep	18 Sep	10 Sep
Density b_w	kg m^{-3}	383/507	442	397	472	427
Density firn$_m$	kg m^{-3}	750-800	–	700-850	800-850	–
Density snow$_r$	kg m^{-3}	–	600	600	600	480-600
B_w	m w.e.	0.99	1.68	1.31	1.57	1.52
B_s	m w.e.	−2.57	−1.62	−2.47	−2.74	−1.03
B_a	m w.e.	−1.58	0.06	−1.16	−1.17	0.49
$\sum B_a$	m w.e.	−1.58	−1.52	−2.68	−3.85	−3.36
ELA	m a.s.l.	2005	1725	1900	1870	1575
AAR	%	3	62	14	19	89

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density firn$_m$ and Density snow$_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

The cumulative balance over 2011-2015 is −3.4 m w.e, the mean of the five-year period is −0.67 m w.e. Over the entire period of measurements 1949-2015 the cumulative balance is −23 m w.e.; the mean annual balance over the 67 years of measurements is thus −0.34 m w.e. (Fig. 7-8).

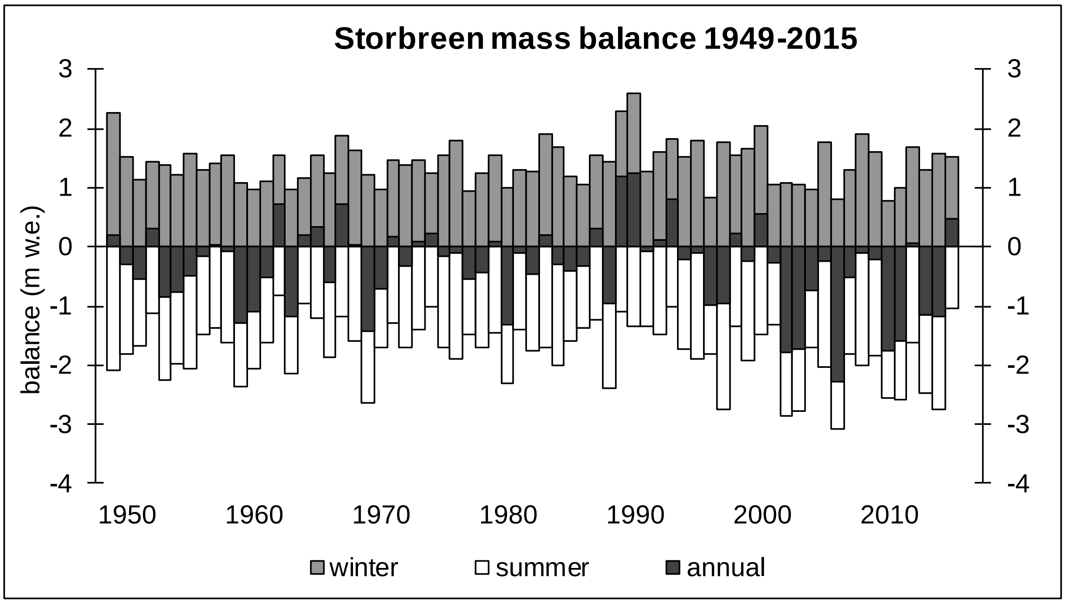


Figure 7-8
Winter, summer and annual balance at Storbreen for the period 1949-2015.

7.7 Meteorological measurements

(Liss M. Andreassen and Rianne H. Giesen)

An automatic weather station (AWS) has operated in the ablation zone of Storbreen, at about 1570 m a.s.l. (Figs. 7-2 and 7-9), since September 2001. The station is part of the Institute of Marine and Atmospheric Research (IMAU) network of AWS on glaciers (contact: c.h.tijm-reijmer@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 (solar) and longwave radiation, humidity, pressure and height above the surface.

The data have been used to study the local microclimate and surface energy balance (Andreassen et al., 2008; Andreassen and Oerlemans, 2009) and have been compared with data from other stations in Norway (Giesen et al., 2009 and Giesen et al., 2014).

Measurements over the five mass balance years reported here reveal that mean summer temperatures for the summer period 1st June to 31st August were highest in 2014 with 5.9 °C, and lowest in 2012 with 3.8 °C (Tab. 7-2). The highest daily temperature was recorded in 2015 with 13.8 °C on 2nd July (Fig. 7-10). The average summer wind speed was 3 m s^{-1} (Tab. 7-2), with small inter-annual fluctuations. Winds are notably less in summer than in winter (Fig. 7-10). The highest wind speed was recorded on 25th December 2011 with a daily mean of 11.2 m s^{-1} and a maximum half-hourly value of 20.8 m s^{-1}.

Daily mean incoming solar radiation has a marked seasonal cycle (Fig. 7-10). The large inter-daily fluctuations are caused by cloudiness. The albedo record derived from incoming and reflected solar radiation shows only short periods of bare ice at the AWS location. In summer 2015 the albedo was higher than usual due to repeated snowfalls and late onset of melt (Fig. 7-10).

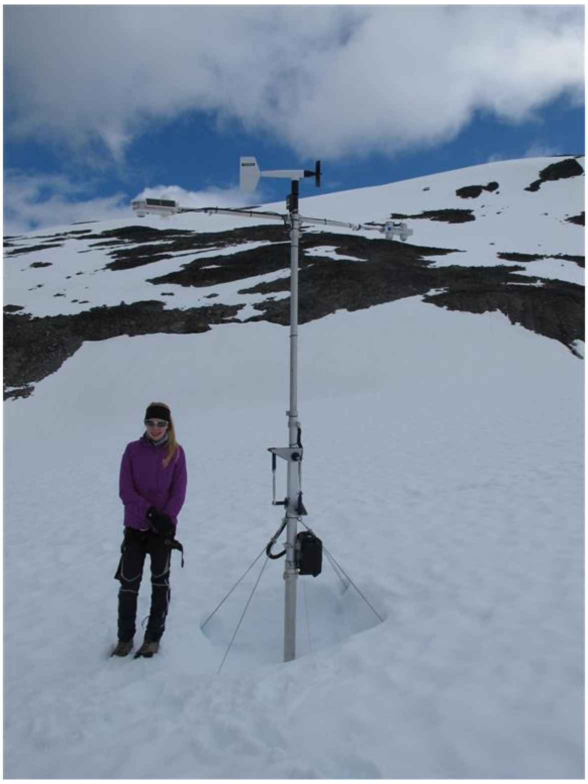


Figure 7-9
The AWS at Storbreen on 31st July 2015. Usually the snow has vanished by this time of year from the AWS site, but in 2015 there was 1.25 m snow remaining. Photo: Liss M. Andreassen.

Table 7-2
Mean air temperatures and wind speeds for the summers 2011-2015 (defined here as 1st June -31st August).

	2011	2012	2013	2014	2015
Air temperature (°C)	5.5	3.8	4.9	5.9	4.4
Wind speed (m/s)	2.8	2.8	3.3	3.0	3.1

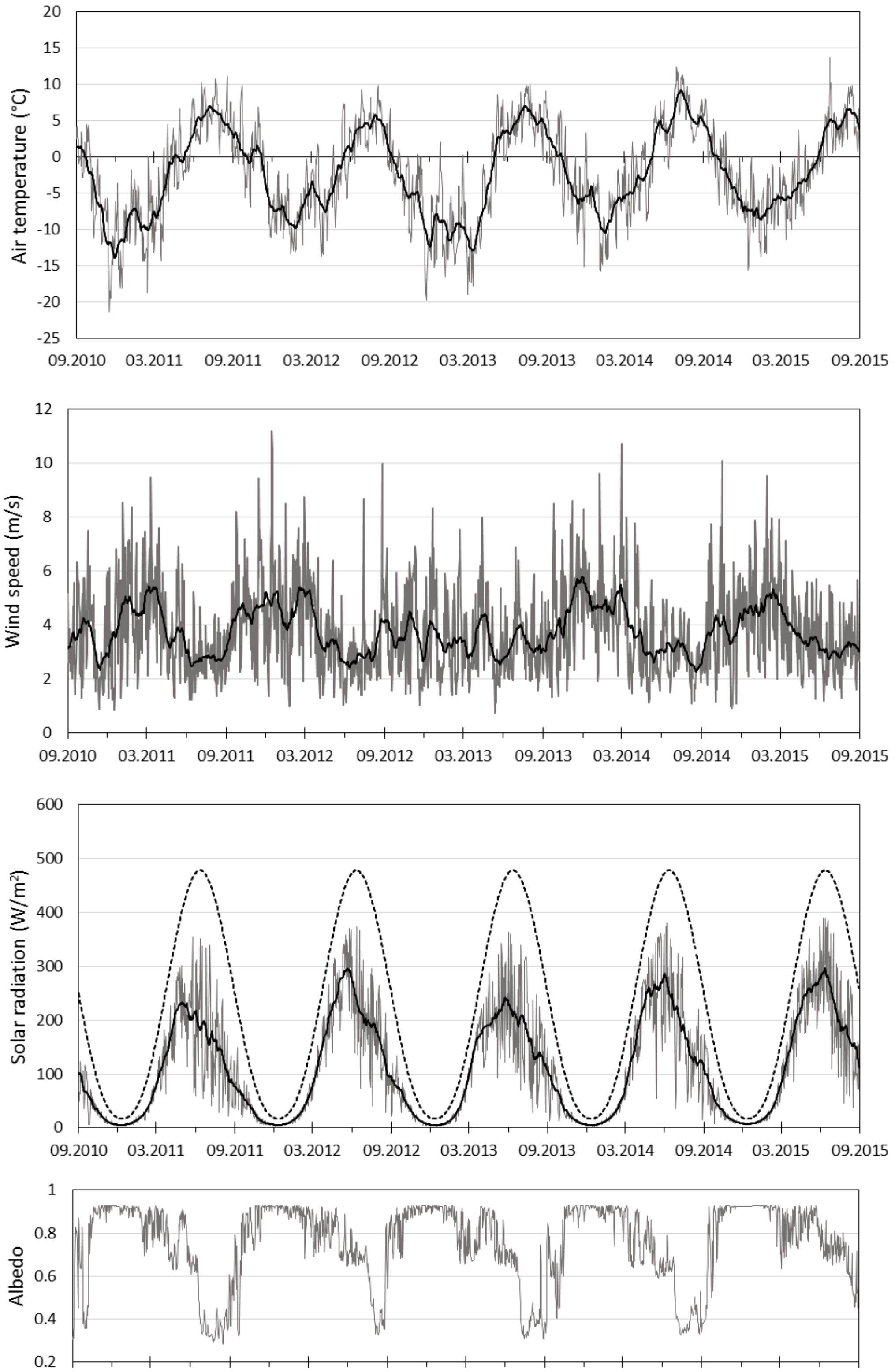


Figure 7-10
Daily mean values (grey lines) and moving averages over 31 days (black lines) of air temperature, wind speed and incoming solar radiation for 10th September 2010 to 9th September 2015. The dashed line in the solar panel is incoming solar radiation at the top of the atmosphere.

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 and since then the area of Juvfonne and positions of stakes have also been monitored annually by differential Global Navigation Satellite System (GNSS) measurements. The measurements on Juvfonne were started as a contribution to 'Mimisbrunnr\Klimapark 2469' – a nature park and forum for research and dissemination activities in the alpine region around Galdhøpiggen, the highest mountain peak in Norway (2469 m a.s.l.).

Figure 8-1
Juvfonne on 2nd August 2011. Photo: Liss M. Andreassen.

8.1 Survey

To obtain a detailed map of Juvfonne, the ice patch and surrounding terrain were scanned with an airborne laser on 17th September 2011. The area was scanned with 5 points/m^2, with accuracy better than 0.1 m (COWI, 2011). Aerial photos were taken on the same day. The data have been used to produce a high quality 1-metre digital terrain model and orthophotos of the ice patch. The aerial extent was digitised from the orthophotos. According to this survey Juvfonne had an area of 0.127 km^2 and ranged in altitude from 1841 to 1986 m a.s.l. The extent of Juvfonne has also been surveyed on foot with differential GNSS mounted on a backpack. Surveys have been done annually in August or September from 2010 to 2015, but the survey in 2012 was done only along the lowermost part due to snow conditions. In 2015 the whole ice patch was snow covered, so the survey shows the snow extent, not ice extent for that year. The measurements of area show that the ice patch shrink and grow along the whole margin (Fig. 8-2). The calculated area varies from 0.149 km^2 (25th Aug 2010) to a maximum of 0.185 (11th Sep 2015), and to a minimum of 0.101 km^2 on 9th Sep 2014. Observations in the field show that the ice is very thin along the margins.

8.2 Mass balance 2011-2015

The observation programme of Juvfonne in the five mass balance years between 2010 and 2015 has consisted of accumulation measurements in spring and point mass balance on 1-3 stakes in spring, summer and autumn. Between 26 and 47 snow depths were measured each year and snow density was measured in a pit down to the previous summer surface at stake 2 (Fig. 8-3). Point mass balance was measured at 1-3 stakes, but the measurements are continuous at stake 2 only. Glacier-wide mass balance was not calculated, but stake 2 is considered representative for the central part of the ice patch. The GNSS surveys reveal no significant movement of the stake from 2010 to 2015, only a surface lowering, indicating a stagnant ice mass without ice movement.

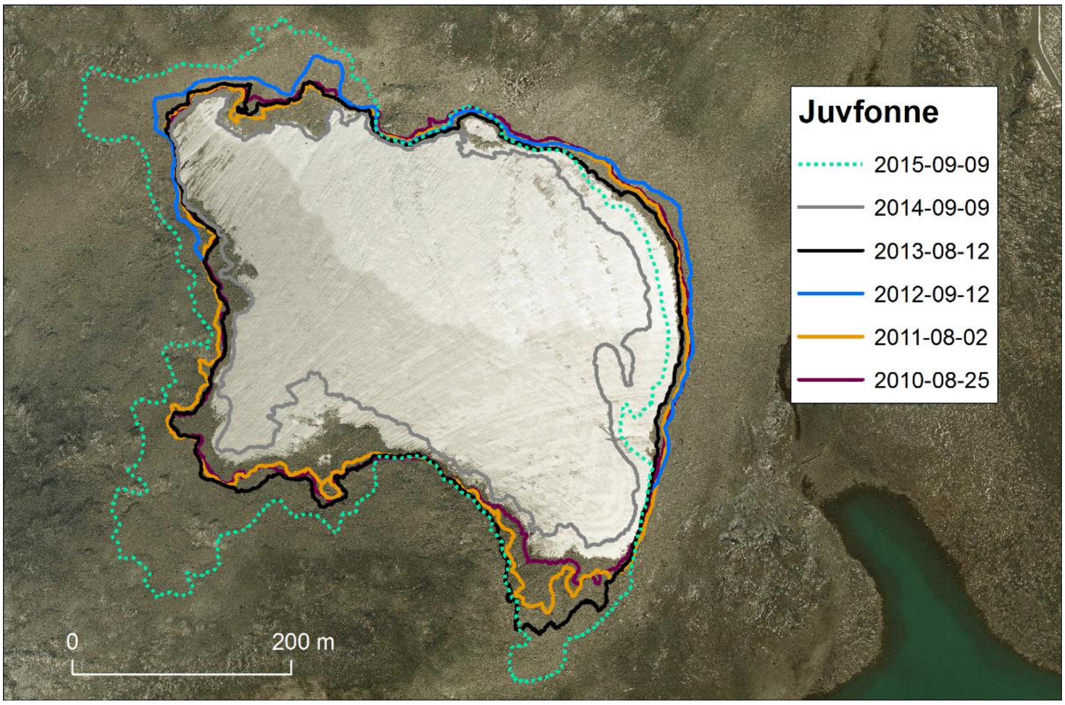


Figure 8-2
Annual GNSS measurements of ice patch extent for 2010-2015 projected on an orthophoto of Juvfonne taken on 17th September 2011. The 2012 and 2015 outlines are snow extents, not ice extent.

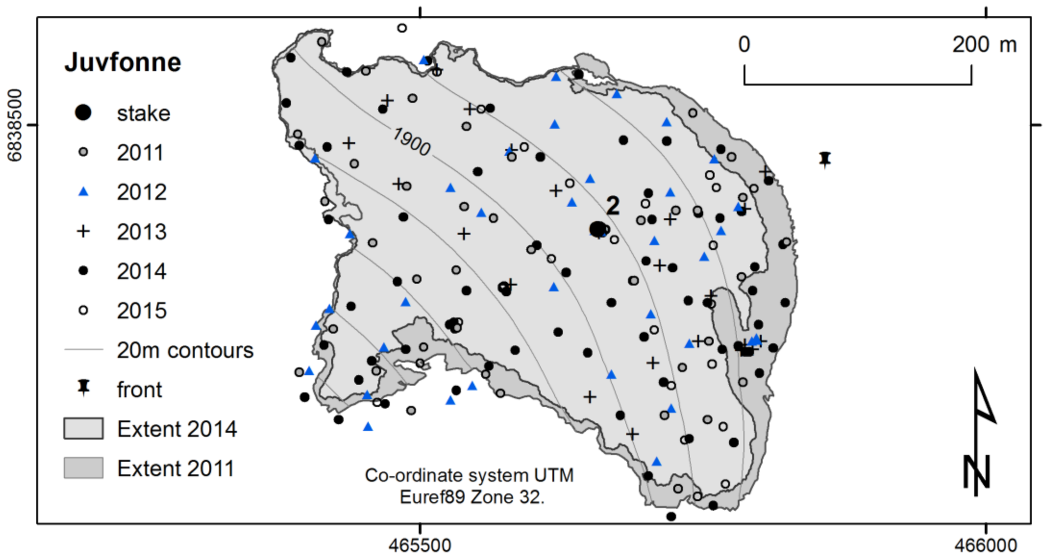


Figure 8-3
Location of snow depth soundings (sd) in 2011-2015 and the position of stake 2 where the snow density was measured each year. The annual extent in 2014 (GNSS-measurements on 9th September) and 2011 (orthophoto from 17th September) are shown. Front marks the point for front position and length change measurements (see chap. 14).

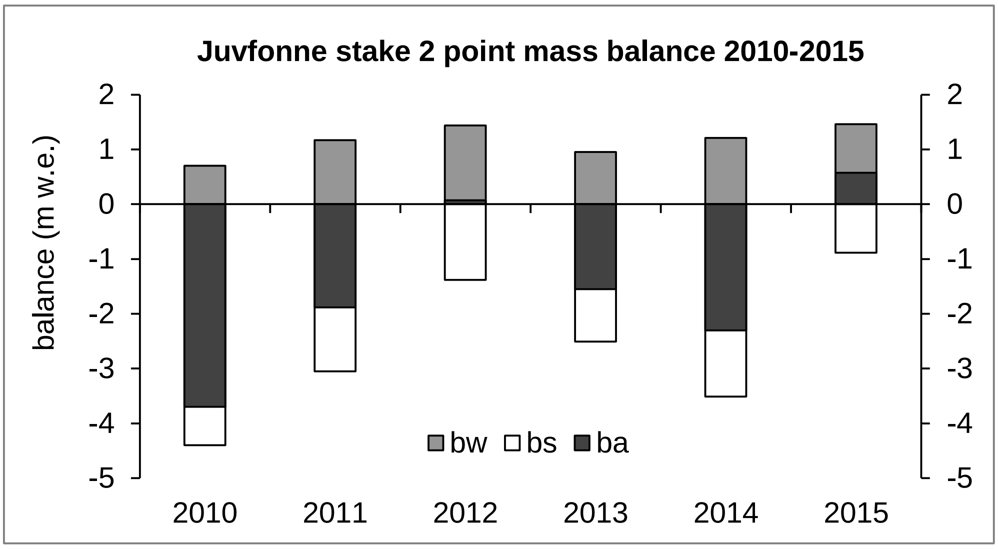


Figure 8-4
Point mass balance at stake 2 at Juvfonne 2010-2015, given as winter balance (bw), summer balance (bs) and annual balance (ba).

The point mass balance data over the five years show deficits in 2011, 2013 and 2014, little change in 2012 and a mass surplus in 2015 when there were 0.96 m snow remaining at stake 2 at the time of the minimum measurements in autumn. The density of the remaining snow was measured as 598 kg m^{-3}. The whole ice patch was snow covered; no ice was exposed in 2015. The cumulative mass balance for stake 2 over the five years is −5.1 m w.e., or −8.8 m w.e. when including also the first year in the record, 2010.

The snow density in spring is below 500 kg m^{-3} except for 2012 when the density was measured in June and was 515 kg m^{-3}. Snow thickness was lowest in 2011 with a mean of 2.2 m; highest in 2015 with a mean of 3.6 m (Tab. 8-1).

Table 8-1
Summary of the mass balance measurements at Juvfonne for 2011-2015: point mass balance and density measurements at stake 2 and snow depth measurements of the ice patch. Statistics of the probings (n-number, min-minimum, max-maximum and mean) are for measurements inside the ice patch extent of the same year.

	Unit	2011	2012	2013	2014	2015
Date b_w		6-May	11-Jun	25-May	12-May	13-May
Date b_s		10-Oct	12-Sep	11-Sep	9-Sep	11-Sep
Density b_w	kg m^{-3}	440	515	490	463	451
b_w	m w.e.	1.17	1.44	0.96	1.21	1.46
b_s	m w.e.	−3.05	−1.38	−2.51	−3.51	−0.89
b_a	m w.e.	−1.88	0.07	−1.55	−2.30	0.57
n bw	-	41	41	26	47	32
bw min	m	0.60	1.20	1.70	1.77	1.90
bw max	m	2.90	4.63	3.70	3.61	4.80
bw mean	m	2.17	3.15	2.27	2.70	3.57

Date b_w and Date b_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, b_w, b_s and b_a are the mean snow density, the winter balance, the summer balance and the annual balance at stake 2.
n bw, bw min, bw max and bw mean are the number of probings, the minimum, the maximum and the mean snow depth for all snow depth measurements inside the ice patch extent.

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 shares a 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 (Fig 9-2).

Annual mass balance measurements began in 1962. The mass balance years 2010/2011 - 2014/2015 were the 50th - 54th year of continuous measurements at Hellstugubreen. The calculations for the five years presented here are based on the latest survey of the glacier from 2009. The mass balance results are summarised in Table 9-1.

Figure 9-1
Hellstugubreen on 4th August 2011. Previously the glacier was connected with the small glacier to the right and they became detached in the 1960s. Photo: Liss M. Andreassen.

9.1 Mass balance 2011

Accumulation measurements were performed on 5th May. Stake readings in seven positions indicated no significant additional melting after the ablation measurements on 28th September 2010. Snow depths were measured in 103 positions between 1532 and 2162 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 0.15 and 3.62 m, with a mean of 1.87 m. Snow density was measured in a density pit at 1953 m a.s.l. The total snow depth was 2.33 m and the resulting density was 454 kg m^{-3}. Ablation measurements were carried out on 28th September. Many stakes had melted out due to the record high melting in 2011, and only three stakes were used for summer and annual balances.

The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 0.8 ±0.2 m w.e. The summer balance was −2.9 ±0.2 m w.e. The low winter balance and the highly negative summer balance of Hellstugubreen resulted in an annual balance of Hellstugubreen of −2.0 ±0.3 m w.e. This is the second most negative annual balance on record for Hellstugubreen. The equilibrium line altitude (ELA) was calculated to be at, or above, the highest point of the glacier, ~2230 m a.s.l., resulting in an accumulation area ratio (AAR) of 0 %.

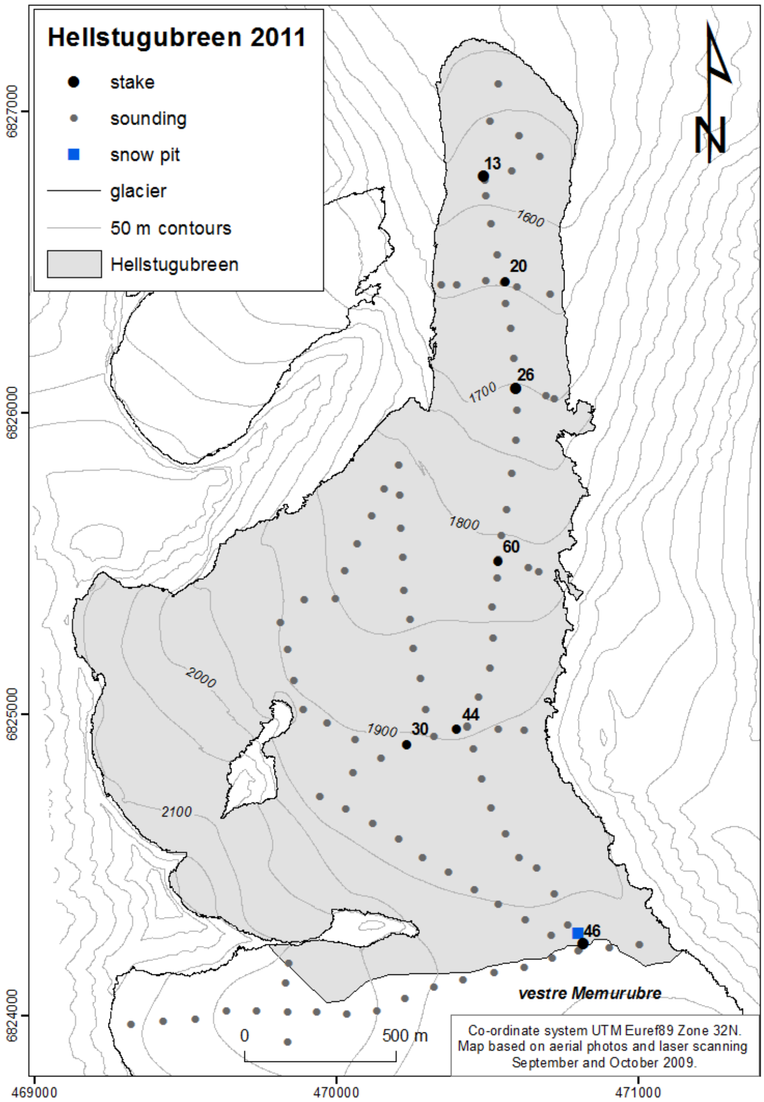


Figure 9-2
Map of Hellstugubreen showing the location of stakes, snow depth soundings and snow pit in 2011.

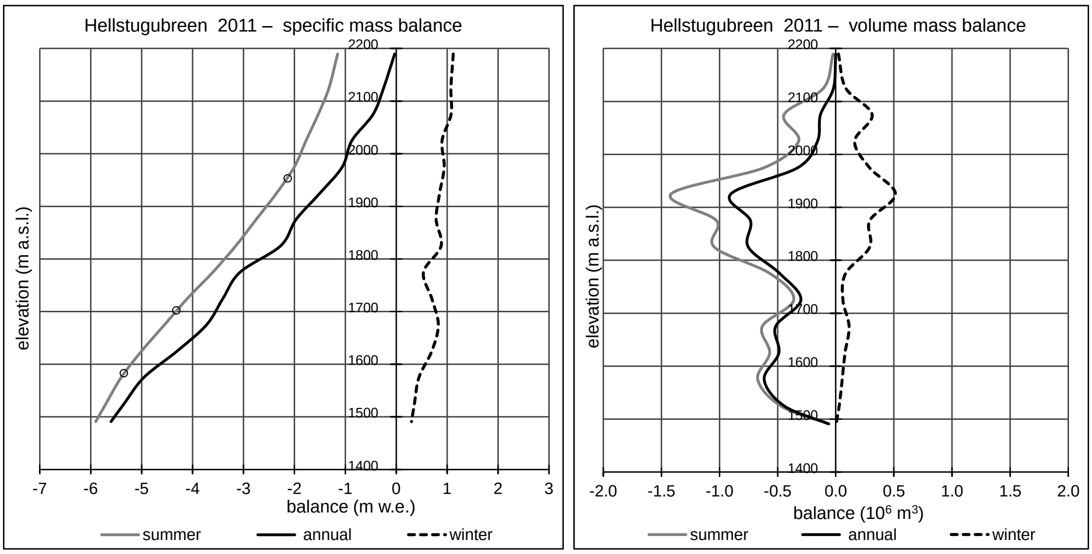


Figure 9-3
Mass balance diagram for Hellstugubreen in 2011, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

9.2 Mass balance 2012

Accumulation measurements were performed on 2nd May. Stake measurements were done in 6 different positions and indicated that at stakes below 1900 m a.s.l. there had been additional melting below 1850 m a.s.l. after the ablation measurements on 14th September 2011. This was subtracted from the winter accumulation. Snow depths were measured in 72 positions between 1555 and 2115 m a.s.l., covering most of the altitudinal range of the glacier. The snow depth varied between 1.31 and 4.23 m, with a mean of 2.56 m. Snow density was measured in a snow pit at 1954 m a.s.l. where the total snow depth was 3.05 m. Ablation measurements were carried out on 20th September at all visible stakes. At that time a layer of 20-40 cm of fresh snow covered the surface.

Figure 9-4
Hellstugubreen on 9th August 2012. Note the lower, temporary snowline in august 2012 compared with August 2011 (Fig. 9-1). The glacier front retreated 13 m from September 2011 to September 2012. Photo: Liss M. Andreassen.

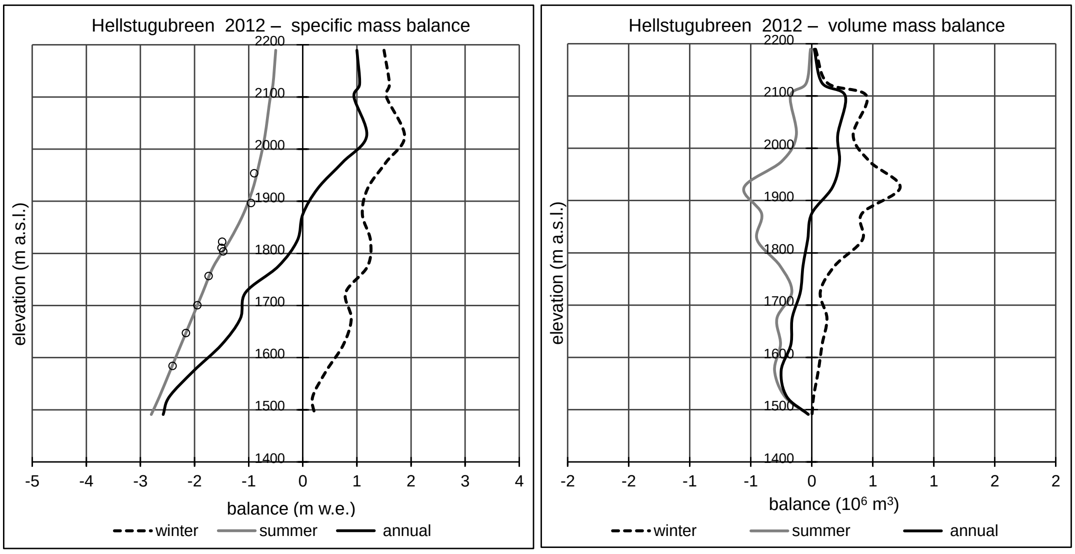


Figure 9-5
Mass balance diagram for Hellstugubreen in 2012, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 1.25 m w.e. Subtracting for the additional autumn melting gave a winter balance of 1.2 m w.e. Summer balance was calculated from stakes in 9 locations and was −1.2 ±0.3 m w.e. The winter and summer balances for Hellstugubreen were almost balanced in 2012, resulting in an annual balance of −0.01 m ±0.3 m w.e. The equilibrium line altitude (ELA) was calculated to be about 1875 m a.s.l., resulting in an accumulation area ratio (AAR) of 59 %.

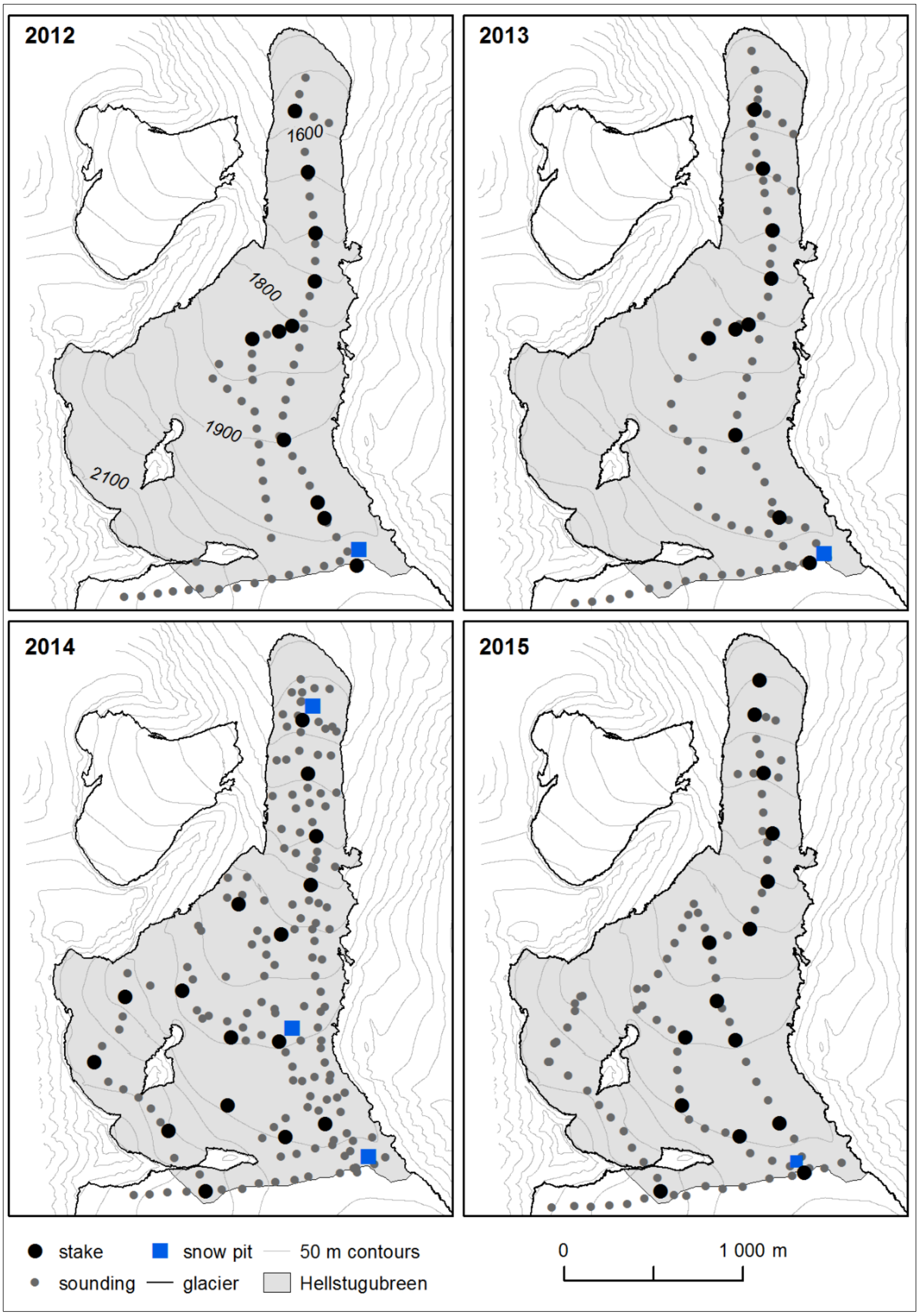


Figure 9-6
Map of Hellstugubreen showing the location of stakes, sounding profiles and snow pits in 2012-2015.

9.3 Mass balance 2013

Accumulation measurements were performed on 24th May. Stake readings in nine positions indicated no significant additional melting after the ablation measurements on 20th September 2012. Snow depth soundings were made in 75 positions between 1525 and 2117 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 0.97 and 3.92 m, with a mean of 2.24 m. Snow density was measured in a snow pit at 1954 m a.s.l. The total snow depth was 2.7 m and the resulting density was 448 kg m^{-3}. Ablation measurements were carried out on 10th September at all visible stakes.

The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.0 ±0.2 m w.e. Summer balance was calculated from stakes in 6 locations resulting and was −1.8 ±0.3 m w.e. The annual balance was thus −0.8 m ±0.3 w.e. The equilibrium line altitude (ELA) was calculated to be about 1980 m a.s.l., resulting in an accumulation area ratio (AAR) of 20 %.

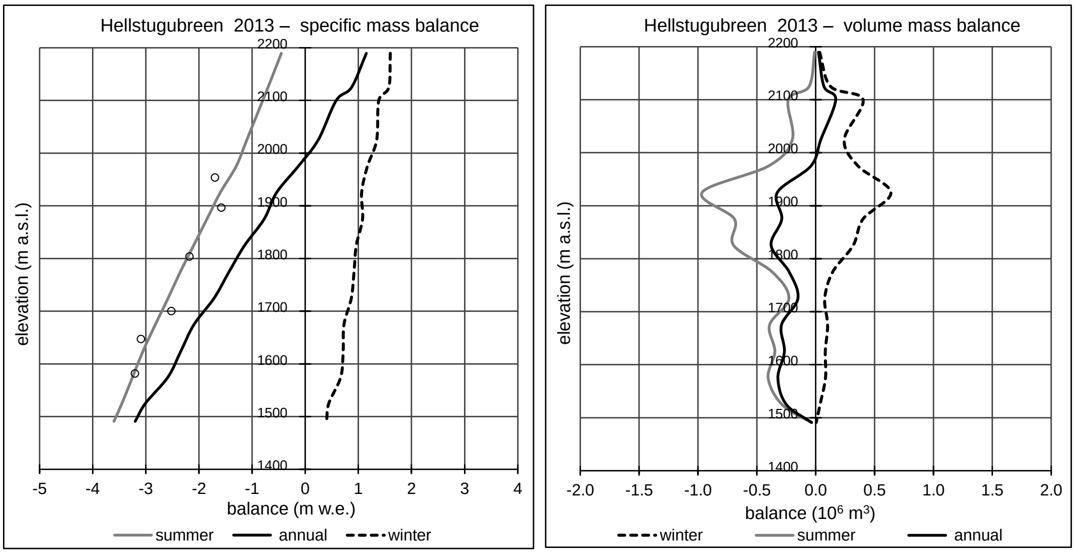


Figure 9-7
Mass balance diagram for Hellstugubreen in 2013, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

9.4 Mass balance 2014

In 2014 an extended mass balance network was tested out with many additional stakes and also a few in the two steep cirques (Fig. 9-6). Accumulation measurements were carried out on 1st-2nd April with snow depth soundings in 175 positions between 1551 and 2109 m a.s.l. The snow depth varied between 1.44 and 4.75 m, with a mean of 2.77 m. Snow density was measured in snow pits on three locations: at stake 13 (1586 m a.s.l.), stake 44 (1896 m a.s.l.) and stake 46 (1954 m a.s.l.). The total snow depths were 1.87 m, 2.75 m and 3.00 m, and the resulting densities were 409, 407 and 427 kg m^{-3} respectively. Stake readings indicated some additional melting after the ablation measurements on 10th September 2013. Additional accumulation measurements were taken on 15th May (about 70 soundings, two shallow density pits, stake readings), but to be consistent it was decided to use the comprehensive measurements from April for the calculations and the results from May were thus not used.

Ablation measurements were carried out on 16-17th September at all visible stakes. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 1.2 ±0.2 m w.e. Subtracting the additional melt gave a winter balance of 1.1 ±0.2 m w.e. The summer balance was calculated from stakes in 10 locations and was −2.3 ±0.3 m w.e. An average winter balance combined with very negative summer balance of Hellstugubreen resulted in an annual balance of −1.2 ±0.3 m w.e. The equilibrium line altitude (ELA) was about 2075 m a.s.l. resulting in an accumulation area ratio (AAR) of 8 %. Analysis of Landsat imagery of 15th September 2014 (Røyset, 2015) and field observations (see front page photo) showed that there was snow remaining in the upper cirques.

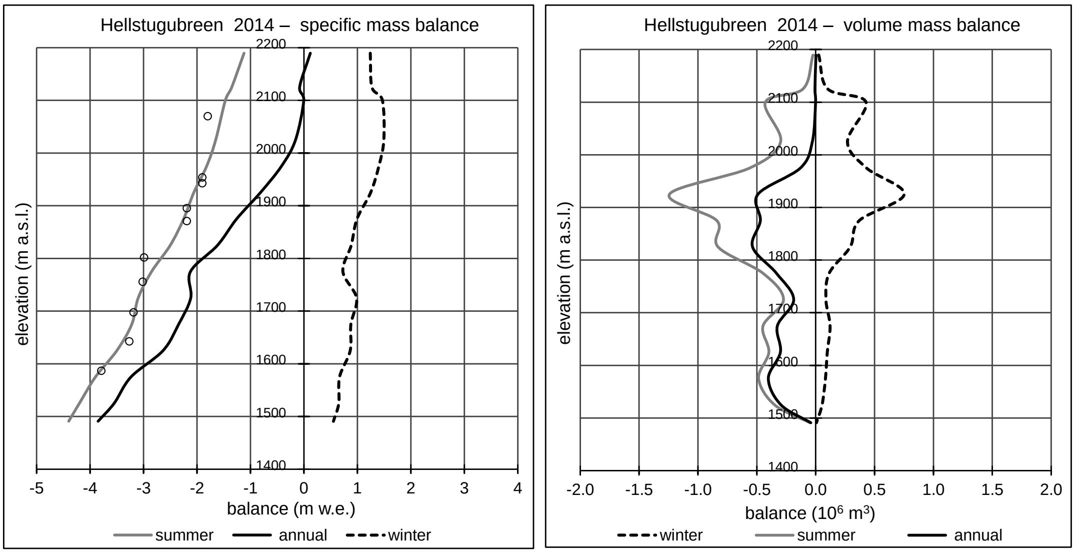


Figure 9-8
Mass balance diagram for Hellstugubreen in 2014, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

9.5 Mass balance 2015

Accumulation measurements were performed on 29th April. Stake readings in 6 positions indicated some additional melting below 1600 m a.s.l. after the ablation measurements on 16th September 2014. Snow depths were measured in 98 positions between 1553 and 2153 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 1.62 and 4.78 m, with a mean of 2.98 m. Snow density was measured by in a snow pit at 1954 m a.s.l. The total snow depth was 3.45 m and the density was 440 kg m^{-3}. Ablation measurements were carried out on 23rd September.

The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.2 ±0.2 m w.e. The summer balance was calculated from 7 stakes and was −0.7 ±0.2 m w.e. The low winter balance and the highly negative summer balance resulted in an annual balance of Hellstugubreen of +0.5 ±0.3 m w.e. The ELA was observed in field and calculated from the mass balance diagram, to be at 1770 m a.s.l., resulting in an AAR of 79 % (Fig. 9-10).

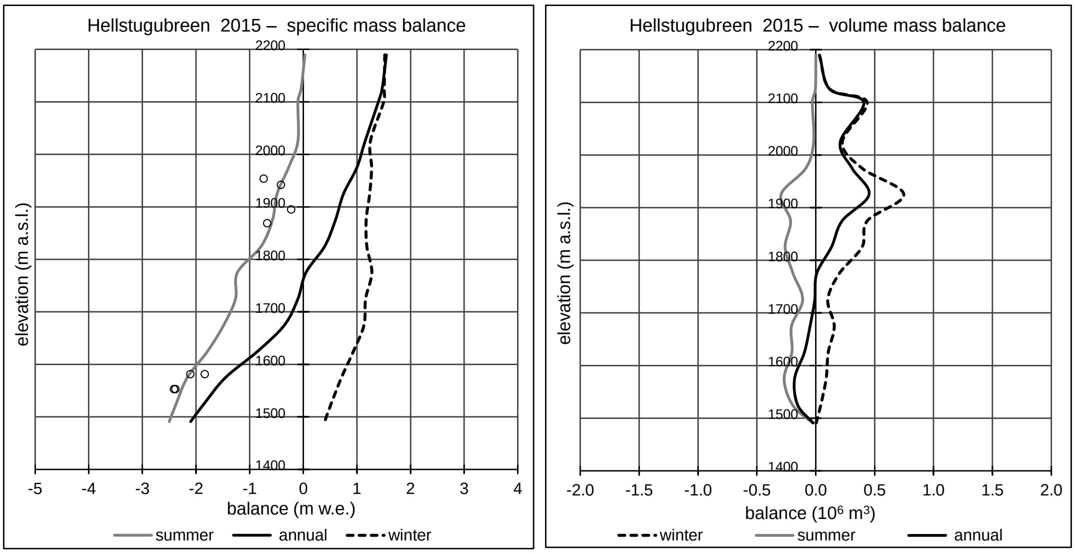


Figure 9-9
Mass balance diagram for Hellstugubreen in 2015, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

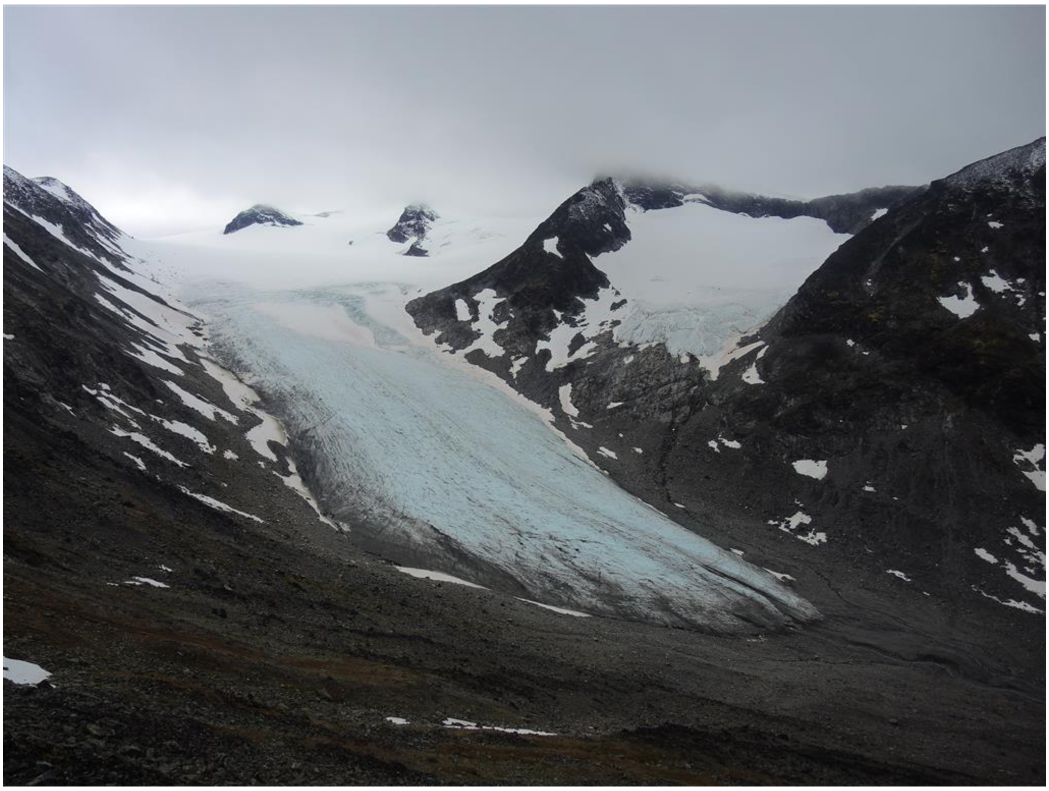


Figure 9-10
Hellstugubreen on 23rd September, 2015. Most of the glacier had snow remaining at the end of the ablation season and the annual mass balance was positive. Photo: Oda J. Røyset.

9.6 Mass balance 1962-2015

The annual mass-balance calculations of Gråsubreen are based on maps from 1962, 1968, 1980, 1997 and 2009. In a recent reanalysis study of 10 Norwegian glaciers, the glaciological mass balance record of Hellstugubreen was homogenised for the period 1964-2009 (Andreasssen et al., 2016). This resulted in minor changes in some of the annual values of B_w, B_s and B_a (see appendix C for current values).

The cumulative annual balance of Hellstugubreen since 1962 amounts to −22.6 m w.e., giving a mean annual deficit of 0.42 m w.e. per year. Over the reported period here, 2011-2015, the cumulative annual balance is −3.6 m w.e.

Table 9-1
Summary values of Hellstugubreen mass balance measurements and results for 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		5 May	2 May	24 May	1-2 April	29 April
Date B_s		14 Sep	20 Sep	10 Sep	16 Sep	23 Sep
Density b_w	kg m^{-3}	454	425	448	407/427/409	440
Density $firn_m$	kg m^{-3}	830	–	–	850	–
Density $snow_r$	kg m^{-3}	–	600	600	600	600
B_w	m w.e.	0.83	1.21	1.05	1.11	1.21
B_s	m w.e.	−2.87	−1.22	−1.83	−2.33	−0.72
B_a	m w.e.	−2.04	−0.01	−0.78	−1.22	0.49
$\sum B_a$	m w.e.	−2.04	−2.05	−2.83	−4.05	−3.56
ELA	m a.s.l.	22230	1875	1980	2075	1770
AAR	%	0	59	22	8	79

Date B_w is the date of snow accumulation measurements. Date B_s is the date of ablation measurements.
Density b_w is the mean snow density of the measured snow pack. Density $firn_m$ is the estimated density of melted firn. Density $snow_r$ is the estimated density of remaining snow.
B_w, B_s, B_a and $\sum B_a$ are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA is the equilibrium-line altitude and AAR is the accumulation-area ratio.

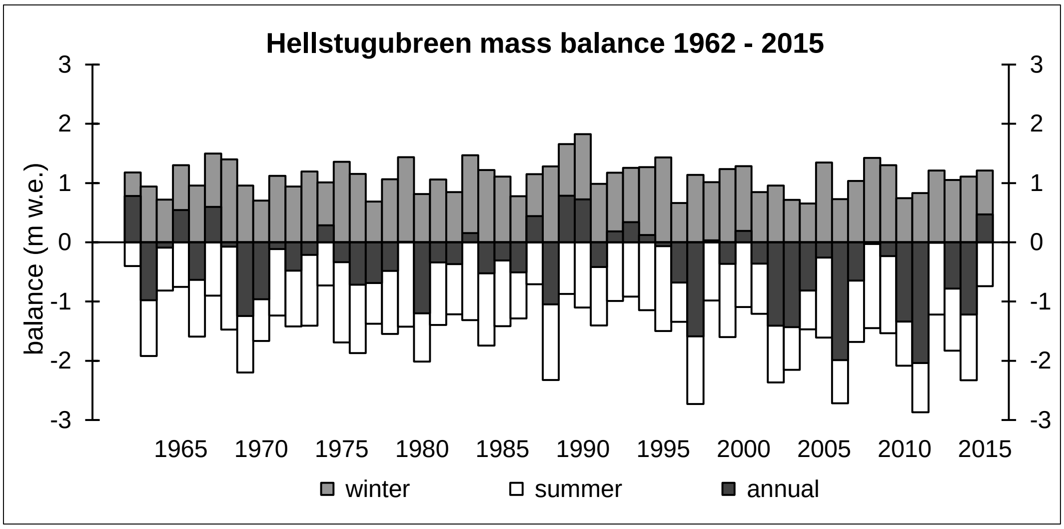


Figure 9-11
Winter, summer and annual balance at Hellstugubreen for 1962-2015.

10. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39' N, 8°37' E) is a small, polythermal glacier in the eastern part of the Jotunheimen mountain area in southern Norway (Fig. 10-1). Gråsubreen has an area of 2.12 km^2 and ranges in elevation from 1833 to 2283 m a.s.l. Mass balance investigations have been carried out annually since 1962.

The distribution of accumulation and ablation at Gråsubreen is strongly dependent on the glacier geometry. In the central part of the glacier snowdrift causes a relatively thin snow pack, whereas snow accumulates in sheltered areas at the lower elevations. Thus, at Gråsubreen the equilibrium line altitude (ELA) and accumulation area ratio (AAR) are often difficult to define from the mass balance curve or in the field, and the estimated values of ELA and AAR have little physical significance. Gråsubreen is the easternmost glacier, has the smallest mass turnover and the densest stake network of the monitored glaciers in Norway.

Figure 10-1
The lowermost western part of Gråsubreen viewed towards the east on 8th September 2011. Photo: Liss M. Andreassen.

10.1 Mass balance 2011

Accumulation measurements were performed on 15-16th May 2011. The calculation of winter balance is based on stake measurements in 14 different positions and snow depth soundings in 90 positions between 1861 and 2261 m a.s.l (Fig. 10-2). The snow depth varied between 0.80 and 3.20 m, with a mean snow depth of 1.86 m. The snow density was measured in a density pit near stake 8 (elevation 2142 m a.s.l.) where the total snow depth was 1.6 m and the mean density was 335 kg m^{-3}. Ablation measurements were carried out on 8th September, when all visible stakes were measured and a thin layer of 1-20 cm of fresh snow covered most of the glacier (Fig. 10-1). The calculation of summer and annual balance was based on stakes in ten different positions.

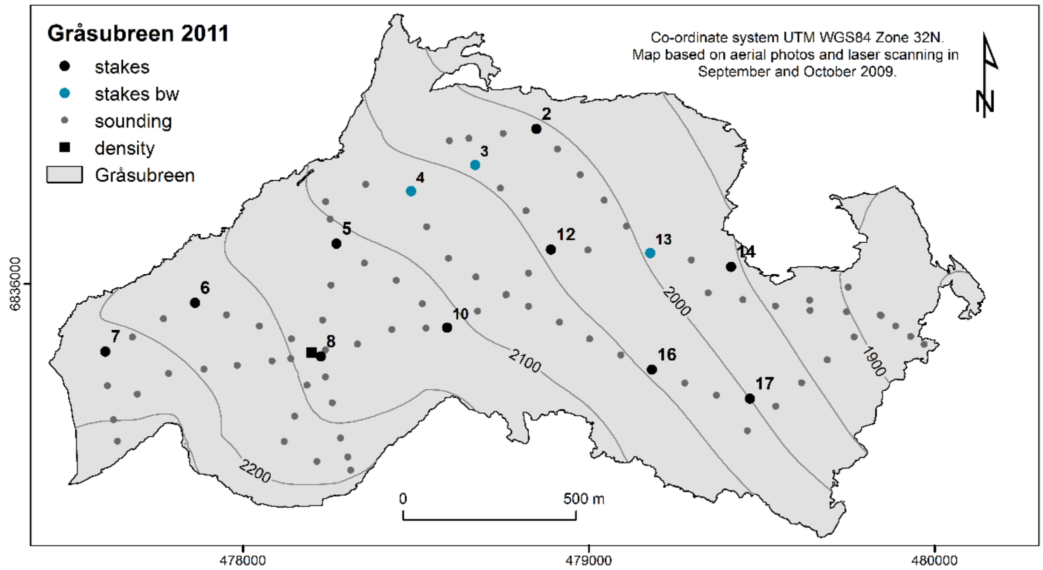


Figure 10-2
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2011.

The stake recordings showed no significant melting after the previous year's ablation measurements or the 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 0.65 ±0.15 m w.e. Kriging interpolation of the measurements gave a similar result. Summer and annual balance were calculated from direct measurements of stakes in nine locations. Stake readings in June 2012 showed additional melt of 2-29 cm on the glacier after the minimum measurements in 2011. This melt was accounted for by adding it to the summer and annual balance of 2011. The resulting summer balance was −1.9 ±0.3 m w.e. The annual balance of Gråsubreen was negative in 2011, −1.3 ±0.3 m w.e. The equilibrium line altitude (ELA) was estimated to be 2265 m a.s.l. and the resulting accumulation area ratio (AAR) was 2 %.

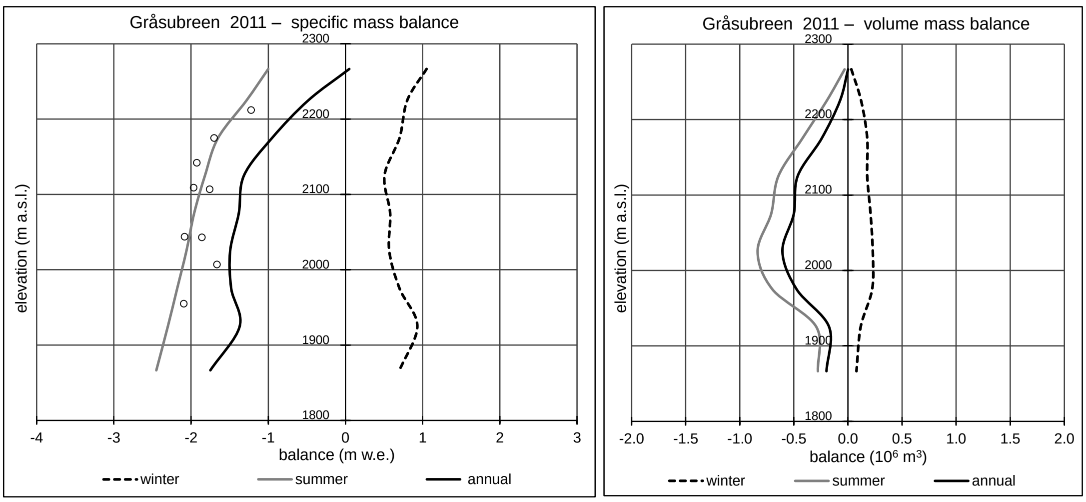


Figure 10-3
Mass balance diagram for Gråsubreen in 2011, showing specific balance on the left and volume balance on the right. Summer balance at stakes (○) is also shown.

10.2 Mass balance 2012

Accumulation measurements were performed late in 2012, on 18-19th June. The calculation of winter balance is based on stake measurements in 10 different positions and snow depth soundings in 92 positions between 1874 and 2268 m a.s.l. (Fig. 10-4). The snow depth varied between 0.16 and 3.45 m, with a mean snow depth of 1.53 m. The snow density was measured in a density pit near stake 5 (elevation 2110 m a.s.l.) where the total snow depth was 1.57 m and the mean density was 452 kg m^{-3}.

Ablation measurements were carried out on 13th September, when all visible stakes were measured (Fig. 10-4). The calculation of summer balance was based on stakes in nine different positions. All snow from the previous winter had melted at the stake locations, but there was some snow remaining at lower elevations and in the cirque above stake 8. Superimposed ice covered much of the ice surface in 2012 (Fig. 10-5). Parts of the glacier had a patchy layer of 1-5 cm fresh snow. The location of stakes, snow pit and soundings in 2012 are shown in Figure 10-4.

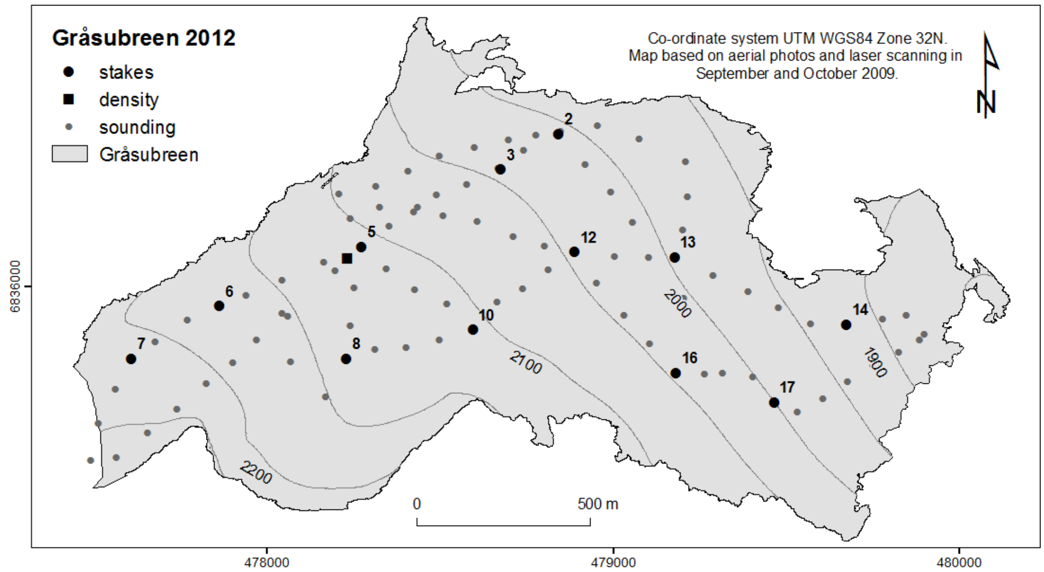
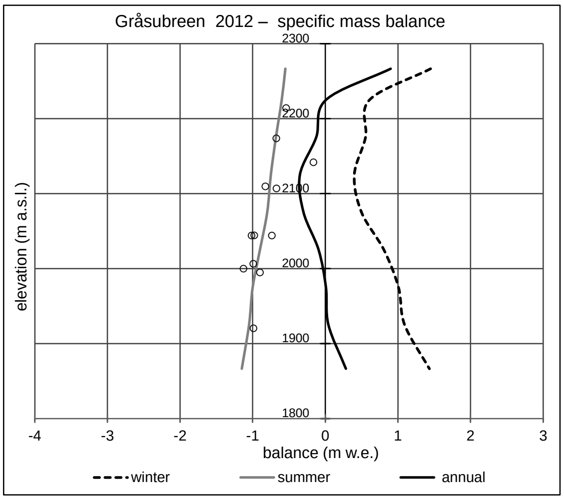


Figure 10-4
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2012.

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter accumulation of 0.73 ± 0.15 m w.e. Kriging interpolation of the measurements gave a slightly higher result (0.80 m w.e.). Summer and annual balance were calculated from direct measurements of stakes in nine locations. The resulting summer balance was −0.8 ±0.3 m w.e. The annual balance of Gråsubreen was slightly negative in 2012 at −0.1 ±0.3 m w.e. The equilibrium line altitude (ELA) and accumulation area ratio (AAR) were undefined in 2012.

Figure 10-5
Gråsubreen on 13th September 2012, view from stake 12 towards the south-east (stake 16 and 17). Most of the central part of the glacier is covered by superimposed ice. Almost all the snow from the previous winter had disappeared except for along the edges and in some sheltered areas. Note the two people walking on the glacier. Photo: Liss M. Andreassen.



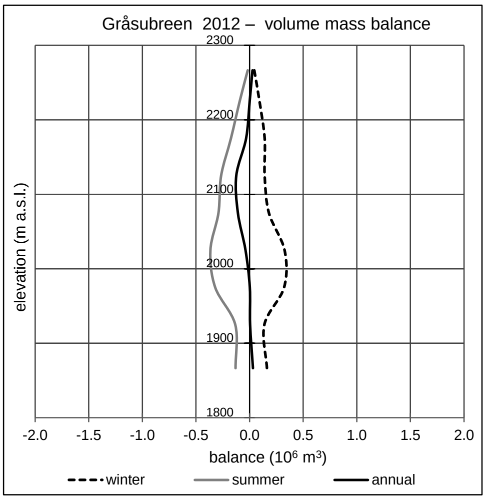


Figure 10-6
Mass balance diagram for Gråsubreen in 2012, showing specific balance on the left and volume balance on the right. Winter and summer balance at the stakes are also shown together with the individual snow depth soundings.

10.3 Mass balance 2013

Accumulation measurements were performed on 26th April 2013. The calculation of winter balance is based on stake measurements in 10 different positions and snow depth soundings in 84 positions between 1868 and 2270 m a.s.l (Fig. 10-7). The snow depth varied between 0.14 and 3.15 m, with a mean snow depth of 1.52 m. The snow density was measured in a density pit near stake 8 (elevation 2143 m a.s.l.) where the total snow depth was 1.3 m and the mean density was 354 kg m^{-3}. Ablation measurements were carried out on 13th September, when all visible stakes were measured. The calculation of summer and annual balance was based on stakes in nine different positions.

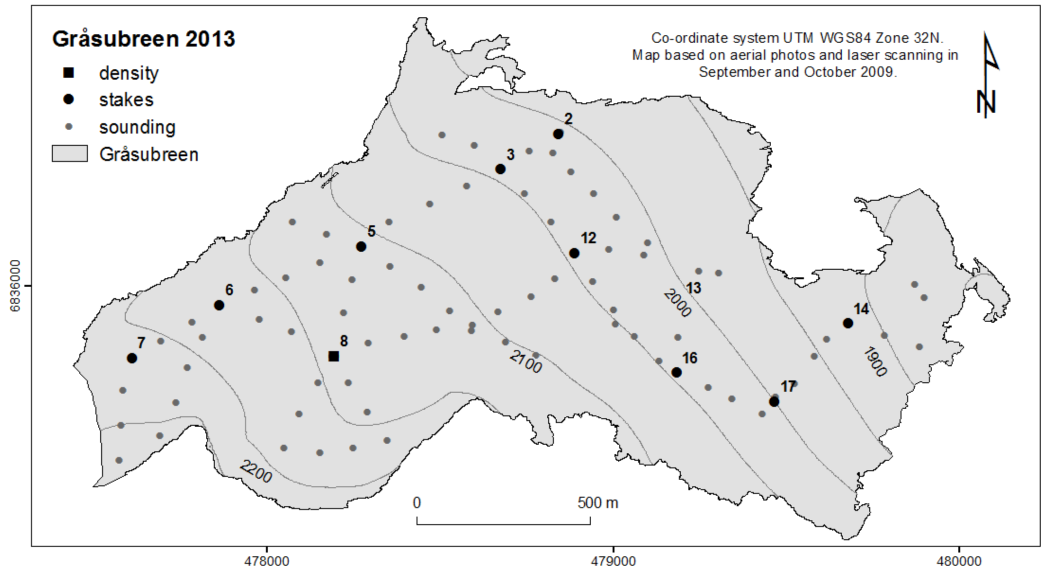


Figure 10-7
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2013.

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 ± 0.15 m w.e. Summer and annual balance were calculated from direct measurements of stakes in nine locations. The resulting summer balance was −1.4 ±0.3 m w.e. The annual balance of Gråsubreen was negative in 2013 at −0.8 ±0.3 m w.e. The equilibrium line altitude (ELA) was estimated to be 2235 m a.s.l. from the balance curve and the accumulation area ratio (AAR) was 7 %.

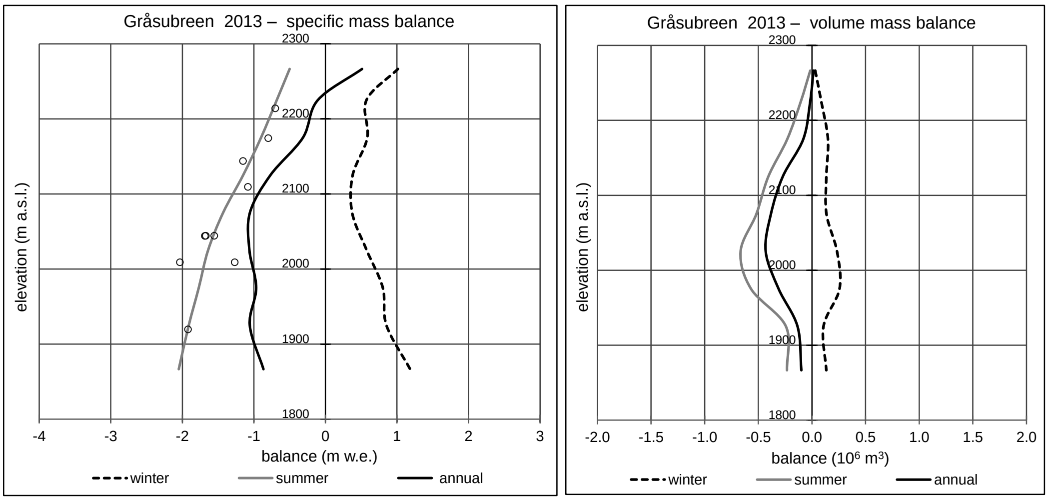


Figure 10-8
Mass balance diagram for Gråsubreen in 2013, showing specific balance on the left and volume balance on the right. Winter and summer balance at the stakes are also shown together with the individual snow depth soundings.

10.4 Mass balance 2014

Accumulation measurements were performed on 13th May 2014. The calculation of winter balance is based on stake measurements in 10 different positions and snow depth soundings in 143 positions between 1857 and 2265 m a.s.l. (Fig. 10-9). The snow depth varied between 0.05 and 3.19 m, with a mean snow depth of 1.93 m. The snow density was measured in density pits near stake 8 and stake 6, where the total snow depths were 0.74

and 2.2 m respectively and the mean density was 339 and 415 kg m^{-3}, respectively. Ablation measurements were carried out on 13th September at all visible stakes.

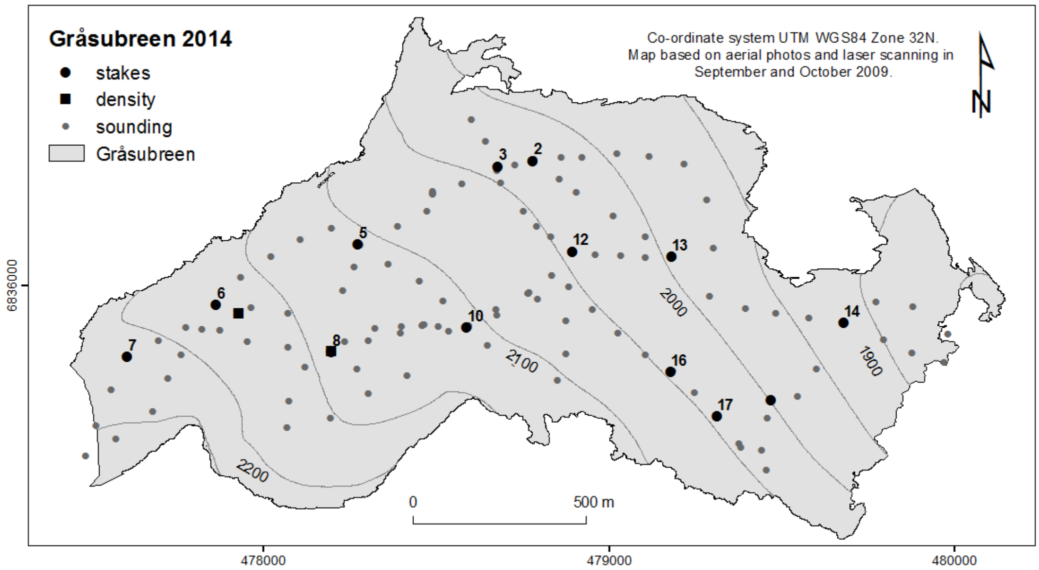


Figure 10-9
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2014.

The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter accumulation of 0.89 ± 0.15 m w.e.; a similar result was retrieved with kriging. Summer and annual balance were calculated from direct measurements of stakes in nine locations. The resulting summer balance was −2.1 ±0.3 m w.e. The annual balance of Gråsubreen was negative in 2014 at −1.2 ±0.3 m w.e. Most of Gråsubreen experienced mass loss in 2014. From the mass balance curve, the ELA was above the glacier in 2014 and the AAR was thus 0 %.

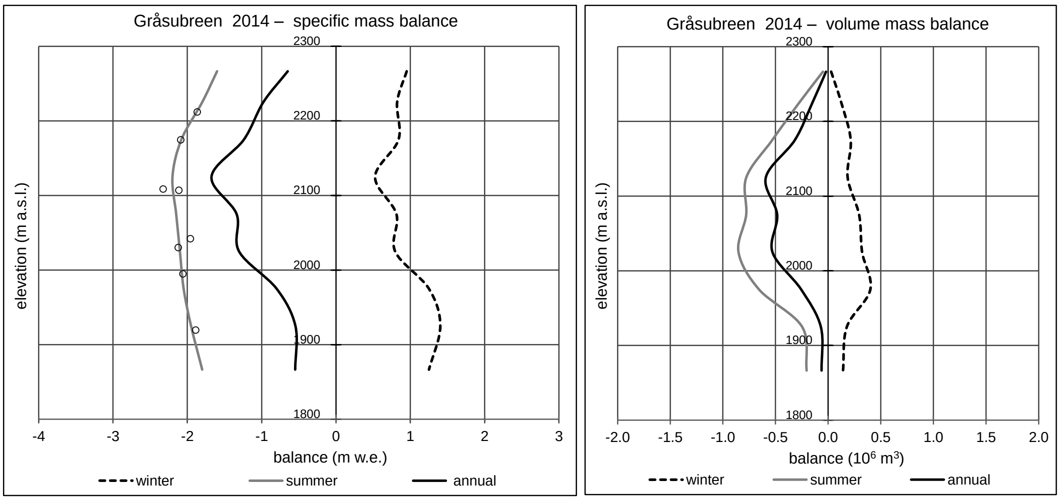


Figure 10-10
Mass balance diagram for Gråsubreen in 2014, showing specific balance on the left and volume balance on the right. Winter and summer balance at the stakes are also shown together with the individual snow depth soundings.

10.5 Mass balance 2015

Accumulation measurements were performed on 28th April 2015. Snow depth soundings were made in 118 positions between 1860 and 2270 m a.s.l. (Fig. 10-11). The snow depth varied between 0.0 and 3.6 m, with a mean snow depth of 1.8 m. The snow density was measured in a density pit near stake 8 (elevation 2142 m a.s.l.) where the total snow depth was 2.0 m and the mean density was 385 kg m^{-3}. Ablation measurements were carried out on 22nd September. There was snow remaining from the winter at several stakes. However, multiple summer snowfalls made it difficult to distinguish summer snow, fresh snow and remaining snow from the winter. The density of the remaining snow was measured at stake 7 (2053 m a.s.l.) at a depth of 0.49 m, where the uppermost 13 cm was fresh snow. The density of the remaining snow was 448 kg m^{-3}. The calculation of summer and annual balance was based on stakes in 10 and 14 different positions respectively.

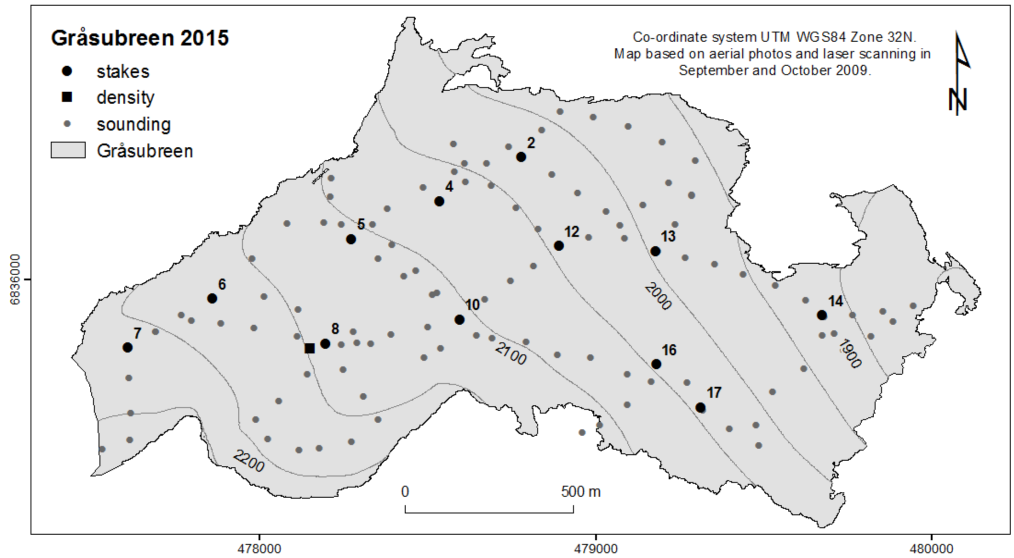


Figure 10-11
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2015.

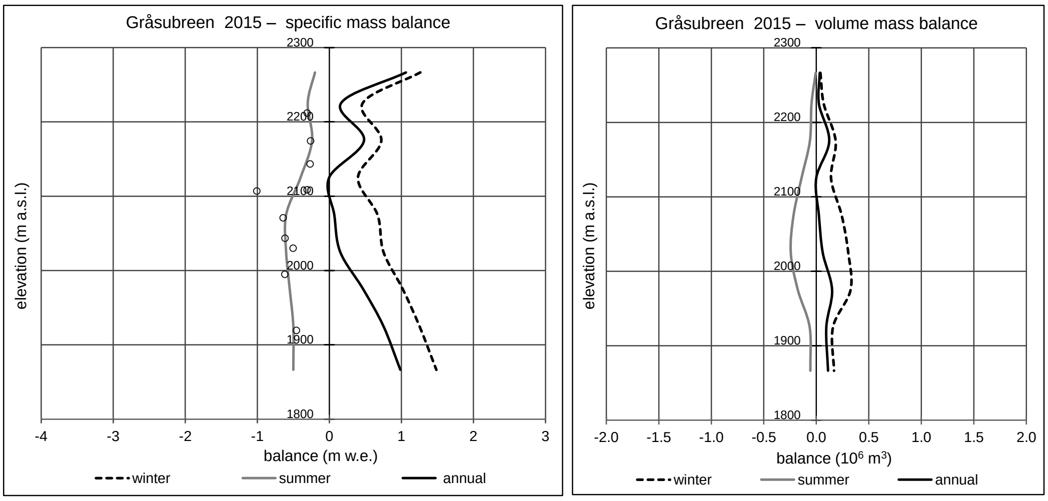


Figure 10-12
Mass balance diagram for Gråsubreen in 2015, showing specific balance on the left and volume balance on the right. Winter and summer balance at the stakes are also shown together with the individual snow depth soundings.

10.6 Mass balance 1962-2015

The annual mass-balance calculations of Gråsubreen are based on several maps. Each time a new survey was performed and a revised map became available, the mass balance was calculated henceforth using the new map. In a recent reanalysis study of 10 Norwegian glaciers, the glaciological mass balance record of Gråsubreen was homogenised for the periods 1984-1997 and 1997-2009 (Andreasssen et al., 2016). The glacier-wide averages were recalculated by taking into account both area–altitude distributions by using the older map for the first half of the period and then the newer map for the second half. This resulted in minor changes of some of the annual values of B_w, B_s and B_a (see appendix C for current values and which years were homogenised).

The results for 2011-2015 show that Gråsubreen had a cumulative deficit of 3.29 m w.e. over this period. The cumulative annual balance of Gråsubreen amounts to –20.9 m w.e. since measurements began in 1962. The average annual balance is thus –0.39 m w.e. a^{-1}. Except for small surpluses in 2001, 2008 and 2015, the glacier has had a negative mass balance every year since 1999.

Table 13-1
Summary values of Gråsubreen mass balance measurements and results for the years 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		15-16 May	18 June	26 April	13 May	28 April
Date B_s		9 Sep	13 Sep	13 Sep	10 Sep	22 Sep
Density b_w	kg m^{-3}	335	452	354	415	385
Density $firn_m$	kg m^{-3}	830	-	750	700	-
Density $snow_r$	kg m^{-3}	-	600	-	-	450-600
B_w	m w.e.	0.65	0.73	0.60	0.89	0.77
B_s	m w.e.	−1.94	-0.84	−1.41	-2.06	-0.48
B_a	m w.e.	−1.29	-0.11	−0.81	-1.17	0.29
$\sum B_a$	m w.e.	−1.29	−1.40	−2.41	-3.58	-3.29
ELA	m a.s.l.	2265	Undef.	2235	>2290	Undef.
AAR	%	2	Undef.	7	0/Undef.	Undef.

Date B_w is the date of snow accumulation measurements. Date B_s is the date of ablation measurements. Density b_w is the mean snow density of the measured snow pack. Density $firn_m$ is the estimated density of melted firn. Density $snow_r$ is the estimated density of remaining snow. B_w, B_s, B_a and $\sum B_a$ are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively. ELA is the equilibrium-line altitude. AAR is the accumulation-area ratio.

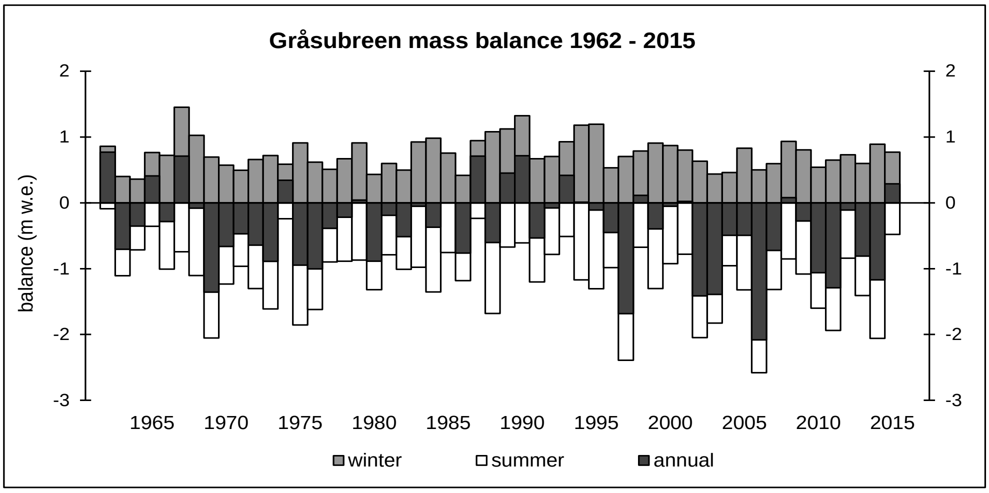


Figure 10-13
Winter, summer and annual balance at Gråsubreen for the period 1962-2015.

11. Engabreen (Hallgeir Elvehøy and Miriam Jackson)

Engabreen (66°40'N, 13°45'E) is a 37 km^2 north-western outlet from the western Svartisen ice cap. It covers an altitude range from 1575 m a.s.l. (at Snøtind) down to 89 m a.s.l. (2008), as shown in Figure 11-1. Mass balance measurements have been performed annually since 1970, and length change observations started in 1903 (chap. 14).The pressure sensor records from the Svartisen Subglacial Laboratory under Engabreen date back to 1992 and are presented in section 11-8. Results from other research performed at the subglacial laboratory in 2011-15 will be published elsewhere.

Figure 11-1
Engabreen on 14th October 2014. The entrance to Svartisen Subglacial Laboratory is located east of the glacier tongue at 520 m a.s.l. (white circle). Photo: Ragnar Ekker.

11.1 Mass balance 2011

The snow accumulation measurements were performed on 11th May. None of the stakes on the glacier plateau were found after the winter. Snow depth was measured at four replacement stakes (E34, E20, E5 and E101) and 43 sounding locations (Fig. 11-2). The summer surface (SS) was easy to define, and the snow depth was between 5 and 7 metres. The mean snow density down to the SS at 6.65 m depth at stake E5 was 491 kg m^{-3}. At E17 on the glacier tongue, 0.6 m of ice had melted since 28th September 2010.

The summer ablation measurements were carried out on 4th November. There was a few cm of new snow at E34, and up to 1.7 m at E105. Stakes were found in six locations on the plateau. From stake measurements the Transient Snow Line altitude (TSL) was about 1250 m a.s.l. Up to 1.4 m of snow remained at the stakes above the TSL. All the snow and 3.8 m of ice melted during the summer at stake E34 all. Stake measurements showed that 11.5 m of ice melted between 10th May and 4th November on the glacier tongue.

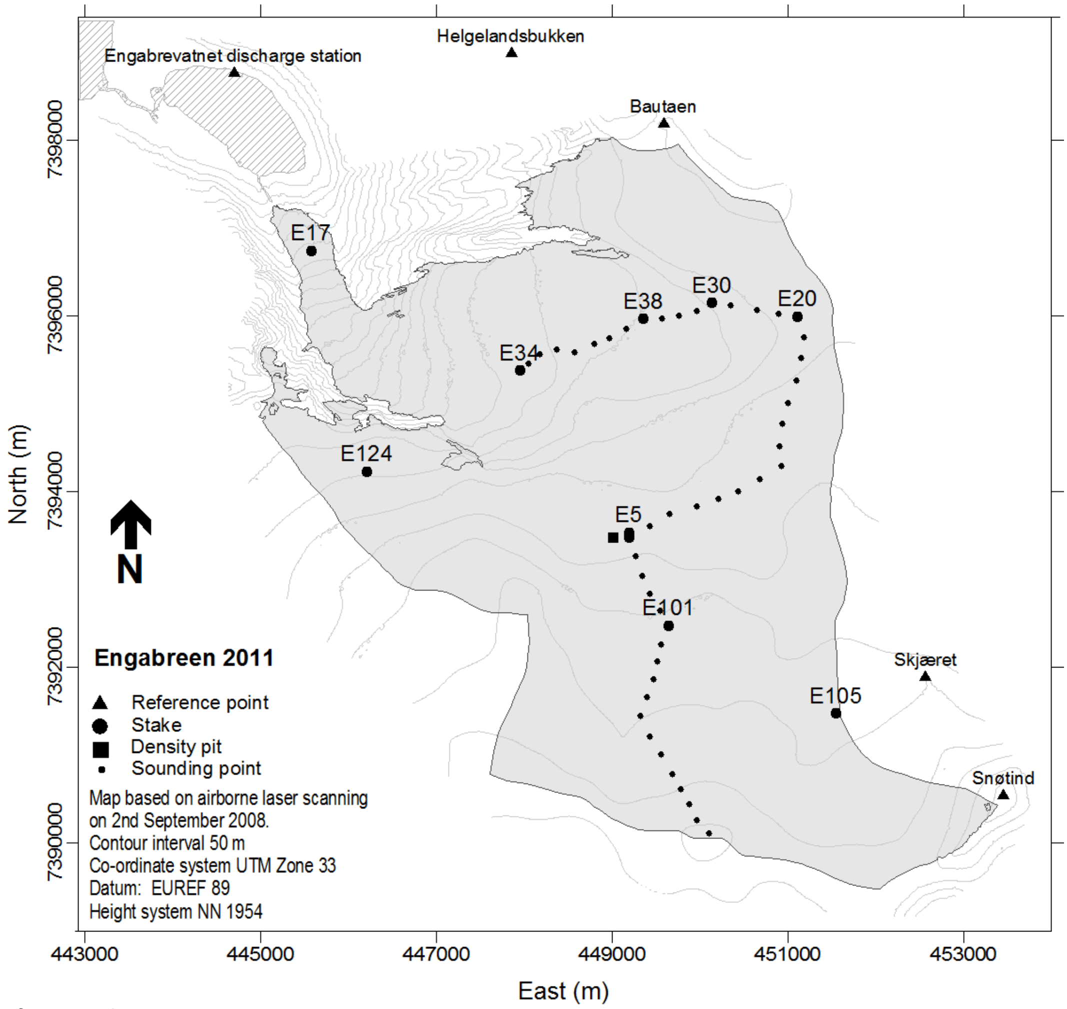


Figure 11-2
Location of stakes, density pit and sounding profiles on Engabreen in 2011.

As none of the stakes on the glacier plateau were maintained during the winter, possible melting after the ablation measurements on 28th September 2010 could not be assessed from measurements. The date of the 2010 mass balance minimum for Engabreen was assessed from daily gridded data of snow amounts at www.senorge.no (Saloranta, 2014). A visual inspection of the daily changes in snow amount during the autumn suggested that the snow accumulation started at most of the glacier plateau on 10th October, 12 days after the ablation measurements. The melting on the glacier plateau after the measurements on 28th September 2010 was assessed as 0.2 to 0.4 m w.e., corresponding to 0.3 m of snow at E105 and 0.45 m of ice at E34 The assessment was based on air temperature recorded at Skjæret (Fig. 11-2 for location) and precipitation at Reipå (7 m a.s.l., 32 km north of Skjæret). At stake E17 on the glacier tongue, the winter melt occurred mainly between 28th September and 10th October as assessed from air temperature at Engabrevatnet (10 m a.s.l., 2 km north of E17). The late autumn melt in 2010 has been included in the revised mass balance for 2010 (Elvehøy, 2016).

The winter balance for 2011 was calculated from the snow depth and snow density measurements. The drainage basin and area elevation distribution was defined from a DTM based on aerial laser scanning on 2nd September 2008. A function correlating snow depth with Snow Water Equivalent (SWE) was calculated based on snow density measurements at stake E5. This function was then used to calculate the point winter balance of the snow depth measurements. Mean values of altitude and SWE in 100 m elevation bins were calculated and plotted. An altitudinal winter balance curve was drawn from a visual evaluation of the mean values. Below 950 m a.s.l. the winter balance curve was interpolated from the calculated winter balance at stake E34 and E17. The winter balance in each 100 m altitude interval was determined from this curve. The total winter balance was calculated as 2.8 ±0.2 m w.e.

Comparison of stake length and sounded snow depth at E34 on 1st June 2012 showed no melting after 4th November 2011 on the glacier plateau. The minimum date at the plateau was assessed as 9th October from www.senorge.no. The point summer balance was calculated from snow depth and stake measurements at stake locations E105, E101, E5, E38, E34 and E17. At stake locations E124, E20 and E30 part of the summer melting was assessed from comparison with neighboring stake locations. The total summer balance was calculated from the summer balance curve drawn from these nine point values between 300 and 1340 masl. (Fig. 11-3) as −3.8 ±0.2 m w.e. The resulting annual balance was −1.0 ±0.3 m w.e. The Equilibrium Line Altitude (ELA) was determined as 1270 m a.s.l. from the annual balance curve in Figure 11-3. This corresponds to an Accumulation Area Ratio (AAR) of 41 %.

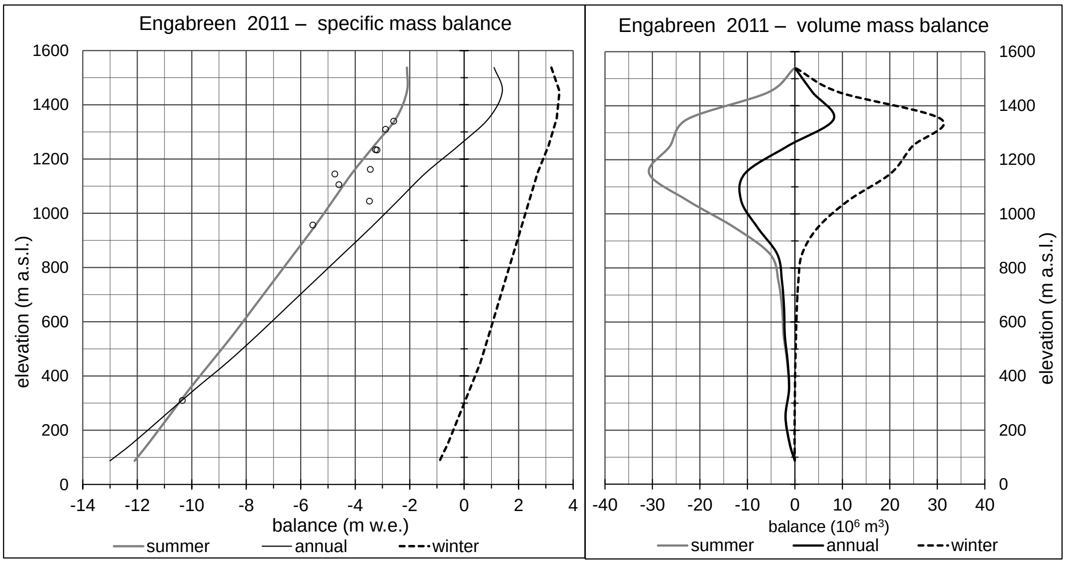


Figure 11-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2011. Summer balance at nine stake locations (○) is shown.

11.2 Mass balance 2012

The snow accumulation measurements were performed on 1st June. Snow depth was measured at E34 and E105T, at one replacement stake (E5), and at 17 snow depth sounding locations on an 11 km long profile. The SS was well defined. The snow depth was between 4 and 8 m. The average snow density down to 6.9 m depth at stake E5 was 498 kg m^{-3}. The SS was located at a depth of 7.15 m. 0.7 m of ice had melted between 4th November 2011 and 1st June 2012 at E17 on the glacier tongue.

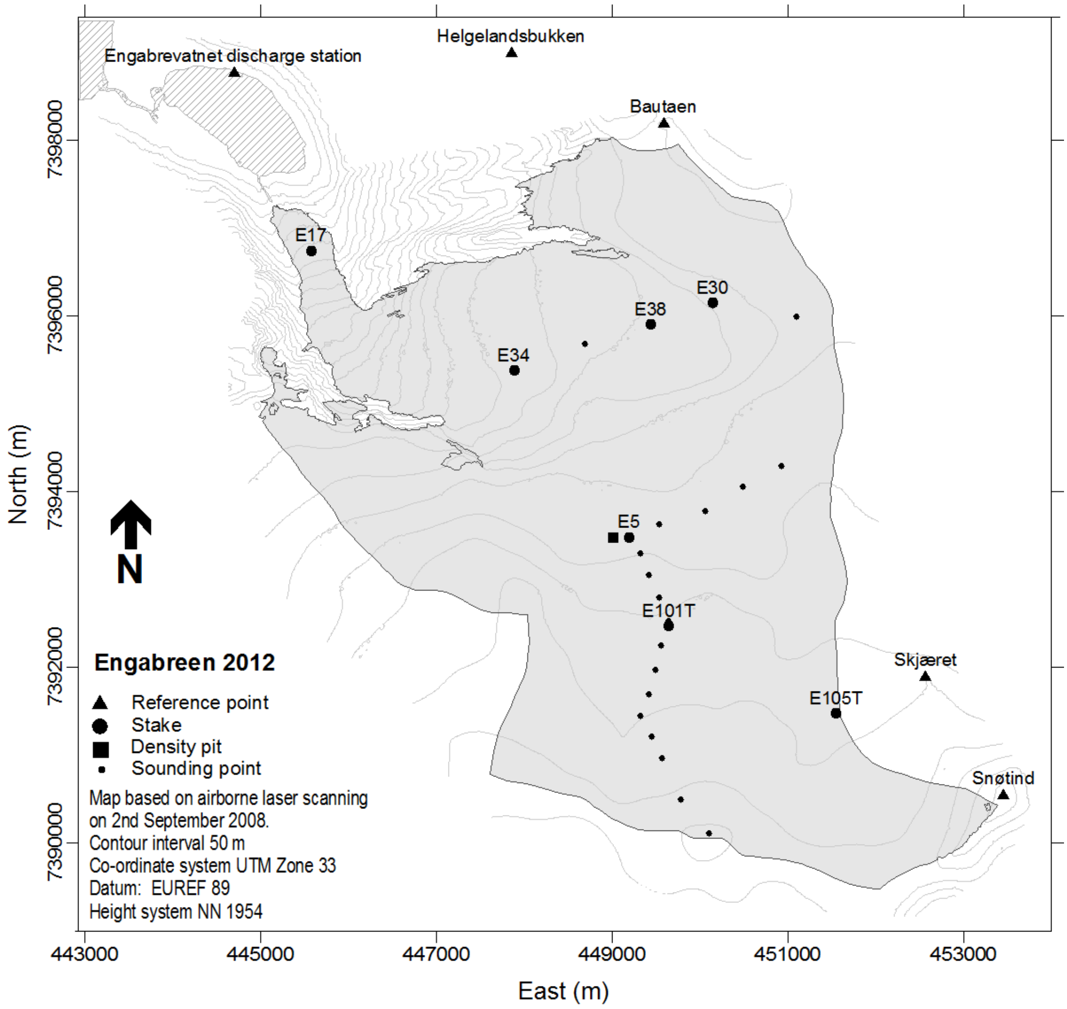


Figure 11-4
Location of stakes, density pit and sounding points on Engabreen in 2012.

The summer ablation measurements were performed on 25th September. There was from a few cm of new snow at E34 up to 1 m of new snow on the upper part of the glacier plateau. Nine stakes were found in seven locations. From stake measurements, the TSL was about 1000 m a.s.l. Up to 4.65 m of winter snow remained. All the winter snow and 1.25 m of ice had melted at E34. 6.3 m of ice melted between 1st June and 25th September at E17.

The calculation of winter balance was performed by the same methods as described for 2011 (section 11-1). The winter balance was calculated as 3.2 ±0.2 m w.e.

Comparison of stake measurements and sounded snow depth at E34 on 23rd May 2013 showed no significant melting after 25th September 2012 on the plateau. The minimum date on the glacier plateau was assessed as 8th October from www.senorge.no.

The point summer balance was calculated at seven stake locations between 300 and 1340 m a.s.l. At stakes E38, E30 and E101, part of the summer melting was assessed from neighboring stakes and probed snow depth. 0.3 m of ice melt was recorded between 25th September 2012 and 9th May 2013 at stake E17. This melt was attributed to the winter balance of 2013. The total summer balance was calculated from the summer balance curve drawn from the seven points as −2.1 ±0.2 m w.e. The resulting annual balance was +1.0

±0.3 m w.e. The ELA was determined as 1050 m a.s.l. from the annual balance curve in Figure 11-5. This corresponds to an AAR of 82 %.

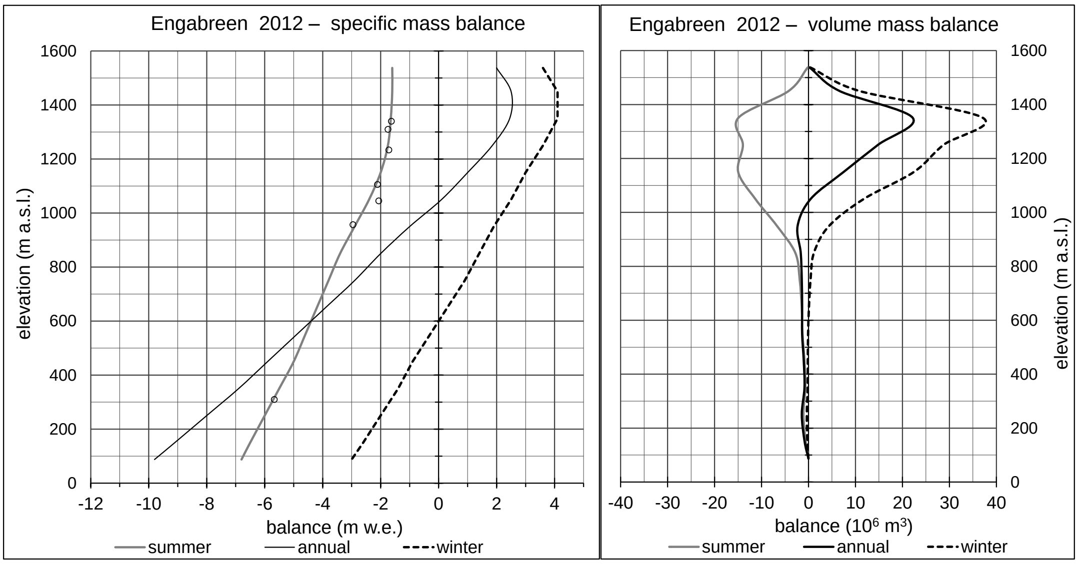


Figure 11-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2012. The summer balance at seven stakes (○) is shown.

11.3 Mass balance 2013

The snow accumulation measurements were performed on 22nd -23rd May. Snow depth was measured at five stakes and 107 snow depth soundings in a grid with 500 m spacing between the measurements (fig. 11-6). The SS was easy to define, and the snow depth was between 3.5 and 5 m. Snow density was measured down to the SS at 4.3 m depth at stake E5, and the mean snow density was 524 kg m^{-3}. 1.25 m of ice melt was measured between 25th September 2012 and 22nd May 2013 on the glacier tongue at stake E17.

The summer ablation measurements were performed on 21st October. There was up to 0.7 m of new snow on the glacier plateau. Six stakes were found in four locations. Stakes E17, E38, E30 and E121 had melted out. At stake E105 all the snow from the previous winter and 0.7 m of firn from 2012 had melted. A comparison between E105 and E121 indicated that at E121 all the winter snow had melted, but no firn had melted. Consequently, the TSL was about 1340 m a.s.l. At stake E34 all the winter snow and 5.25 m of ice had melted. Stake measurements showed that 8.9 m of ice melted between 23rd May and 13th September on the glacier tongue.

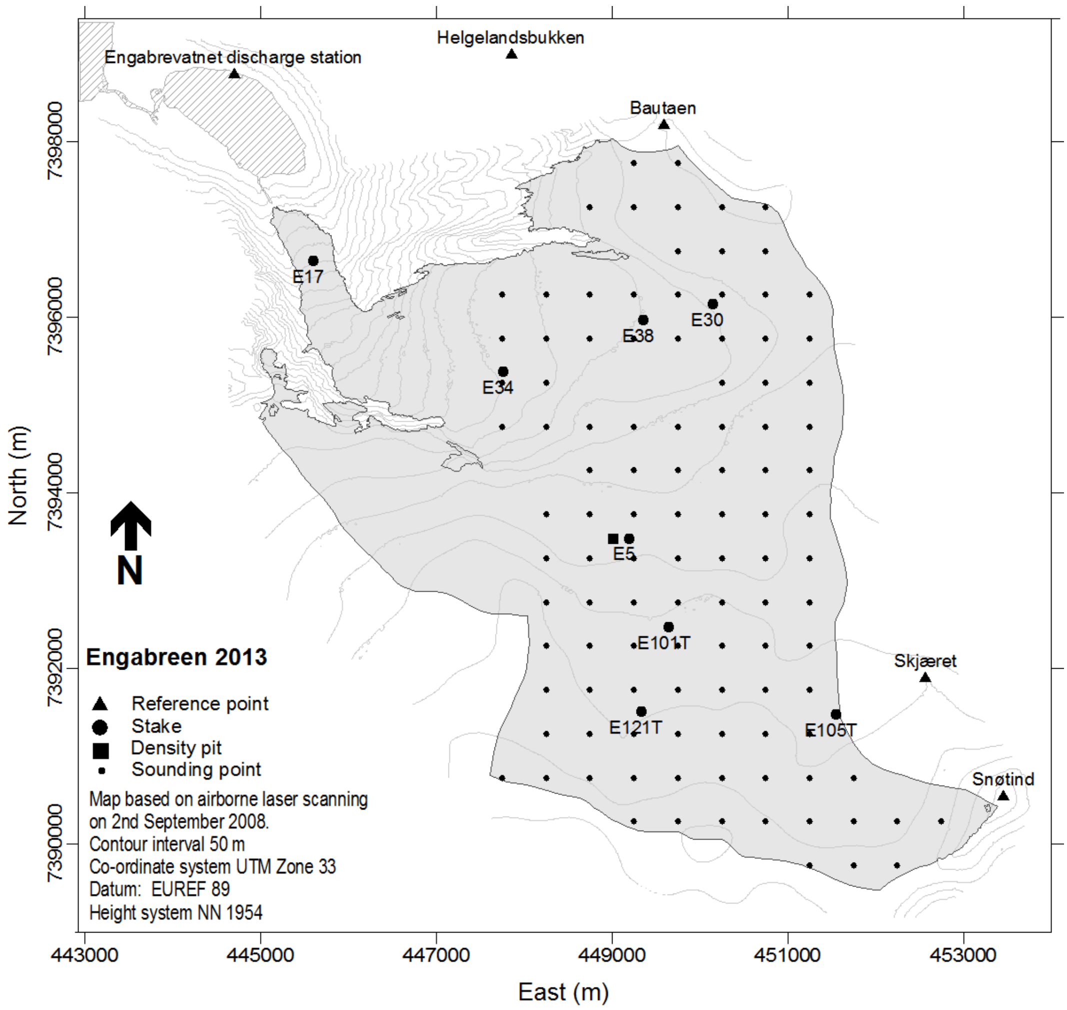


Figure 11-6
Location of stakes, density pit and sounding points on Engabreen in 2013.

The calculations of the winter balance was performed using the same methods as described for 2011 (section 11-1). The winter balance was 2.3 ±0.2 m w.e.

A comparison of stake measurements and sounded snow depth at E34 on 13th and 14th May 2014 showed no significant melting after 21st October 2013 on the plateau. The minimum date in 2013 was assessed as 23rd September (www.senorge.no). The summer balance was calculated directly at four stake locations. At three locations on the plateau, the melting between 14th August and 21st October was assesed from measurements at other stakes. On the glacier tongue, the melting between 13th September and 21st October was estimated from air temperature at the discharge station 159.3 Engabrevatn (10 m a.s.l.) as 0.8 m of ice. The summer balance curve was drawn from these eight point values between 300 and 1340 m a.s.l. The summer balance was calculated as −4.1 ±0.2 m w.e., and the resulting annual balance was −1.8 ±0.3 m w.e. The ELA was above the top of the glacier, and thus the AAR was 0 %. The mass balance results are shown in Figure 11-7.

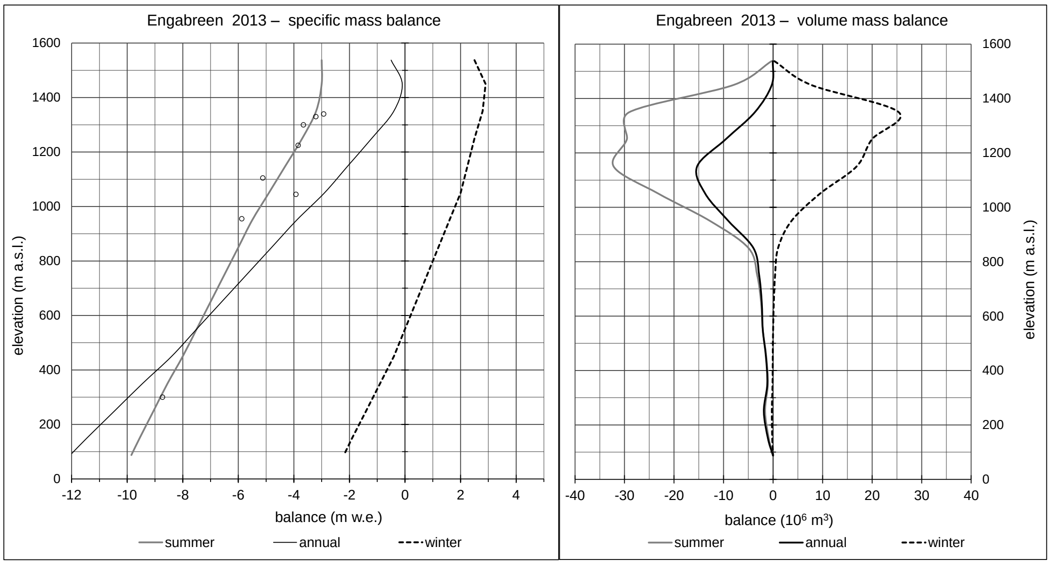


Figure 11-7
Mass balance diagram showing specific balance (left) and volume balance (right) forEngabreen in 2013. The summer balance at eight stakes (○) is shown.

11.4 Mass balance 2014

The snow accumulation measurements were performed on 13th -14th May. None of the stakes on the plateau was found after the winter. Snow depth was measured at three new stakes and 26 soundings The summer surface was difficult to define, and consequently eight soundings were discarded. Snow depth was between 4 and 7.5 m on the plateau. The mean snow density down to the SS at 6.0 m depth at stake E5 was 463 kg m^{-3}. 0.25 m of ice melted at E17 between 21st October 2013 and 13th May 2014.

The summer ablation measurements were performed on 14th October. There was up to 0.45 m of new snow on the glacier plateau. Eight stakes were found in seven locations. From stake measurements the TSL was about 1230 m a.s.l. At E5 results from two stakes indicate that about all the winter snow had melted (±30 cm). Up to 1.7 m of snow remained at the stakes above 1230 m a.s.l. Stake E17 on the glacier tongue melted out after 17th July, and was replaced on 29th July. Between 13th May and 17th July, and between 29th July and 14th October, 4.95 m and 4.65 m of ice melted, respectively.

The winter balance was calculated using the same methods as described for 2011 (section 11-1) as 2.5 ±0.2 m w.e.

A comparison of stake readings and probing at E34 on 19th June 2015 indicated no significant melting after the ablation measurements on 14th October 2014. The minimum date at the plateau was assessed as 27th October from www.senorge.no. The point summer balance was calculated directly at six stake locations between 960 and 1340 m a.s.l. The ice melting at E17 between 17th and 29th July was assessed as 1.4 m using average melt rates from 23rd June – 17th July (0.12 m d^{-1}) and 29th July – 14th August (0.11 m d^{-1}). The total summer balance was calculated from the summer balance curve drawn from seven point values (Fig. 11-9) as −3.5 ±0.2 m w.e. The resulting annual balance was −1.0 ±0.3 m w.e. The ELA was determined as 1255 m a.s.l. from the annual balance curve in Figure 11-9. This corresponds to an AAR of 41 %.

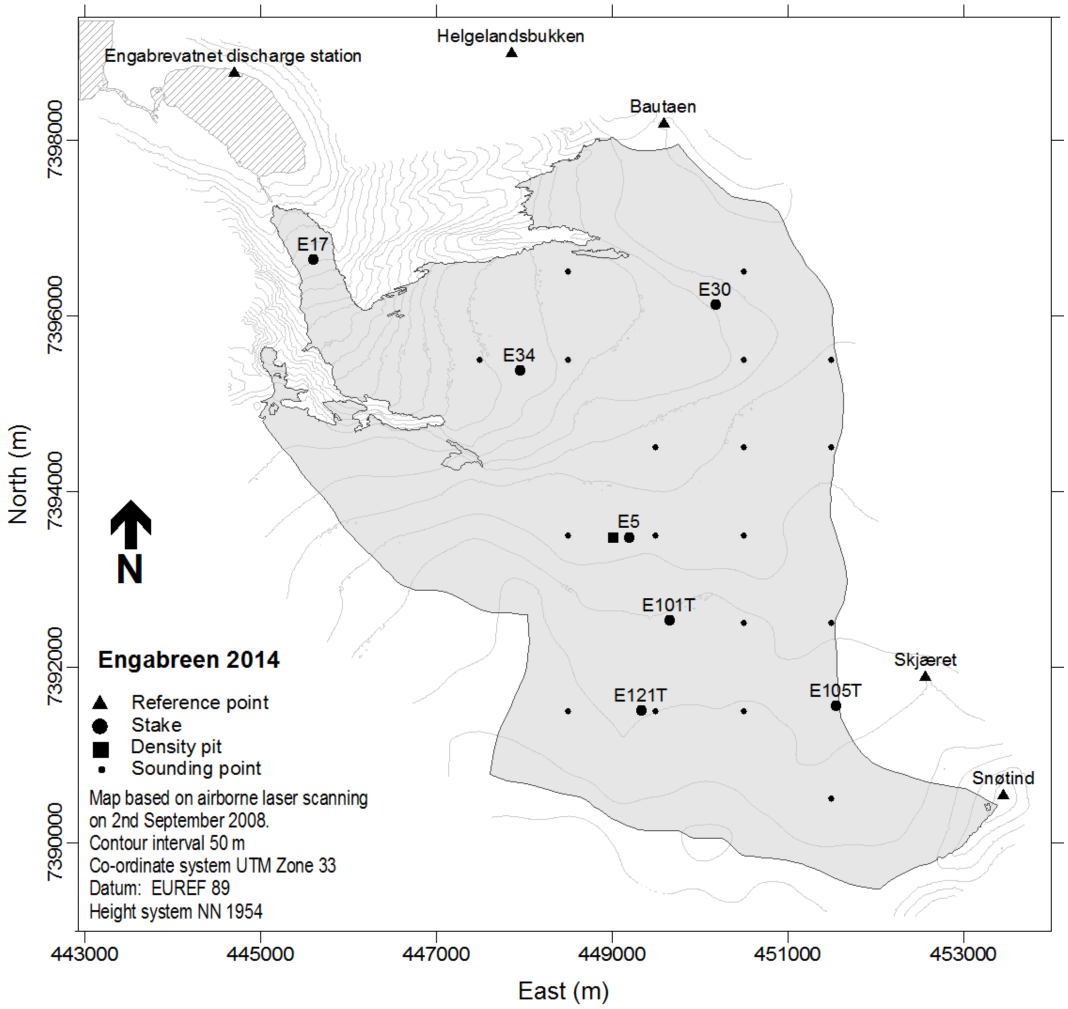


Figure 11-8
Location of stakes, density pit and sounding points on Engabreen in 2014.

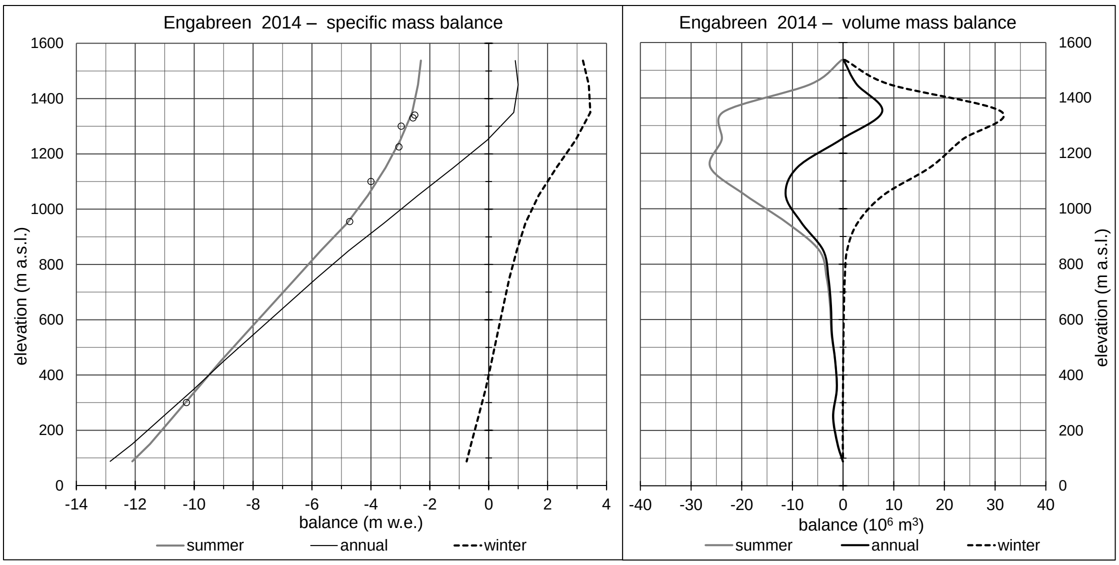


Figure 11-9
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2014. The summer balance at seven stakes (○) is shown.

11.5 Mass balance 2015

The snow accumulation measurements were carried out on 19th June. Snow depth was measured at three original and one replacement stake, and 12 snow depth soundings were performed along the profile from E121 to E34. In addition, snow depth was estimated at four stakes that re-appeared. The SS was difficult to define. Generally, the snow depth varied between 4 and 9 m. Snow density was measured down to the SS at 7.0 m depth at E5. The mean snow density was 499 kg m^{-3}. At the glacier tongue, 0.55 m of ice melted between 14th October 2014 and 19th June 2015.

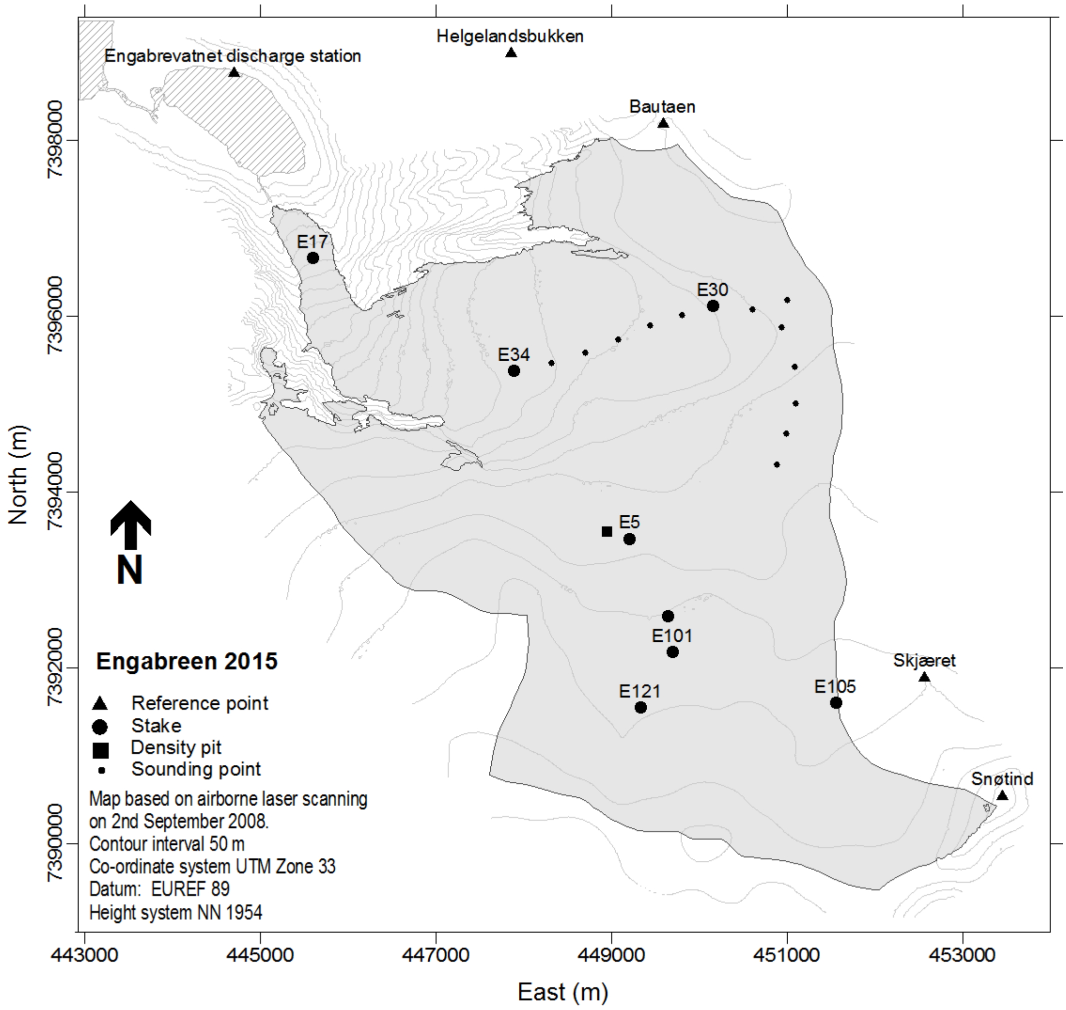


Figure 11-10
Location of stakes, density pit and sounding points on Engabreen in 2015.

The ablation measurements were carried out on 27th October. There was up to 1.5 m of new snow on the glacier plateau. Eight stakes were found in six locations. From stake measurements the TSL was about 1100 m a.s.l. Up to 3.8 m of snow remained at the stakes above 1100 m a.s.l.. The mean density of 3.05 m of snow at E105 was measured as 575 kg m^{-3}. 7.7 m of ice melted between 19th June and 27th October at stake E17.

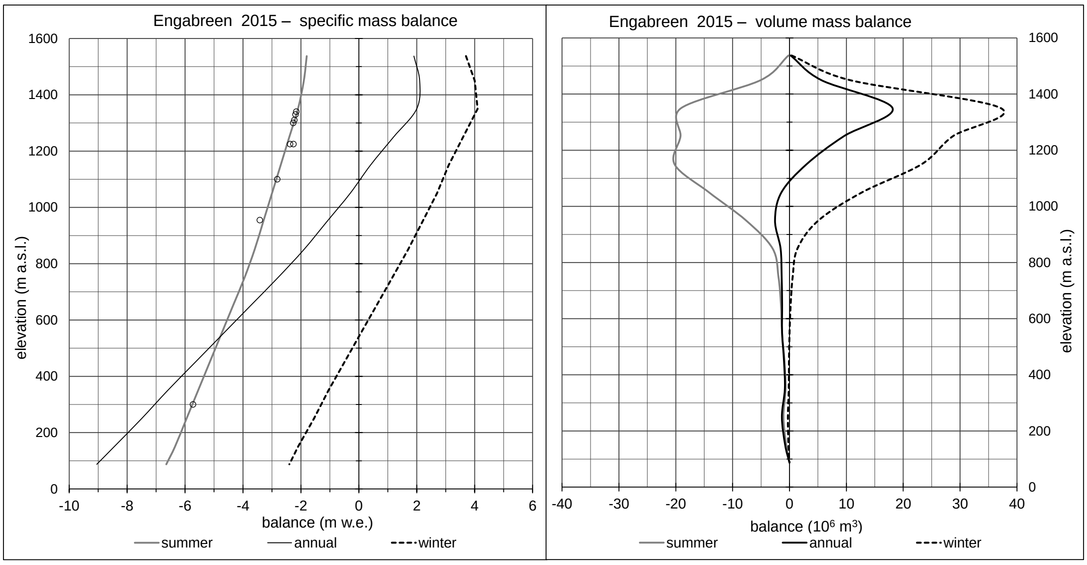


Figure 11-11
Mass balance diagram showing specific (left) and volume (right) winter, summer and annual balance for Engabreen in 2015. The summer balance at nine stakes (○) is shown.

The winter balance was calculated by the same methods as described for 2011 (section 11-1) as 3.2 ±0.2 m w.e. Even though the spring measurements were performed unusually late, the snow maximum seems to have occurred correspondingly late on the glacier plateau.

A comparison of stake readings and probings at E34 on 26th May 2016 indicate no significant melting after the ablation measuremenst on 27th October 2015. The minimum date at the plateau was assessed as 3rd October from www.senorge.no . The point summer balance was calculated dierectly at seven stake locations between 300 and 1340 m a.s.l. The total summer balance was calculated from the summer balance curve drawn from these seven point values (Fig. 11-11) as −2.6 ±0.2 m w.e. The resulting annual balance was +0.6 ±0.3 m w.e. The ELA was assessed as 1070 m a.s.l. from the annual balance curve in Figure 11-11. This corresponds to an AAR of 78 %.

11.6 Mass balance 1970-2015

The mass balance record for 1970-2010 (41 years) has been reported in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). This record has been revised (Elvehøy, 2016 and Andreassen et al., 2016) following procedures described by Zemp et al. (2013). The glaciological surface mass balance record from 1969-2008 and geodetic volume balances 1969-2001 and 2001-08 were homogenised, and relevant uncertainties were assessed. The comparison of homogenised glaciological and geodetic mass balances showed statistical significant differences for both geodetic periods. Consequently, the glaciological surface mass balance records for 1969-2008 were calibrated. The previously reported glaciological mass balance results for 2009 and 2010 have been adjusted according to the homogenisation of results for 2001-2008, but not calibrated. The cumulative mass balance over 1970-2015 is −0.3 m w.e., corresponding to a mean annual balance of −0.01 m w.e. a^{-1}. However, since 1997 the cumulative mass change (loss) is −7.6 m.w.e.

A summary of the mass balance measurements and results for 2011-2015 is given in Table 11-1. The results presented here have been calculated according to the homogenisation of results for 2001-2008. The mass balance series for 1969-2015 is presented in Table 11-2 and Figure 11-12. The summer balance for 2013 is the largest (156 % of the mean) in the record. The annual balance in 2013 is the most negative result in the record.

Table 11-1
Summary values of Engabreen mass balance measurements and results for 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		10 May	1 June	22 May	14 May	19 June
Date B_s		4 Nov	25 Sep	21 Oct	14 Oct	27 Oct
Density b_w	kg m^{-3}	491	498	524	463	499
Density $firn_r$	kg m^{-3}	600	600	600	600	575
Density $firn_m$	kg m^{-3}	650		650	*700/860	
B_w	m w.e.	2.84	3.16	2.28	2.54	3.22
B_s	m w.e.	−3.78	−2.09	−4.14	−3.51	−2.61
B_a	m w.e.	−0.94	1.07	−1.86	−0.97	0.61
$\sum B_a$	m w.e.	−0.94	0.13	−1.73	−2.70	−2.09
ELA	m a.s.l.	1268	1041	>1575	1256	1070
AAR	%	39	82	0	42	78

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_r$ and Density $firn_m$ are the mean snow density of the measured snow pack, the estimated density of remaining snow and the estimated density of melted firn, respectively.
B_w, B_s and B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.
*Density of firn from 2012 and older than 2010.

Table 11-2
The mass balance series for Engabreen 1970-2015. The single years are either original (O), homogenised (H) or calibrated (C).

Year	B_w	B_s	B_a	$\sum B_a$	Hom/Cal/Orig	Year	B_w	B_s	B_a	$\sum B_a$	Hom/Cal/Orig
1970	1,77	-3,04	-1,27	-1,27	C	1993	2,84	-2,14	0,70	5,35	C
1971	2,95	-2,21	0,74	-0,53	C	1994	1,60	-1,64	-0,04	5,31	C
1972	2,94	-3,52	-0,58	-1,11	C	1995	3,17	-1,95	1,22	6,53	C
1973	3,84	-1,91	1,93	0,82	C	1996	2,78	-2,48	0,30	6,83	C
1974	3,12	-2,66	0,46	1,28	C	1997	4,15	-3,64	0,51	7,34	C
1975	2,67	-1,68	0,99	2,27	C	1998	2,66	-3,03	-0,37	6,97	C
1976	3,4	-1,6	1,80	4,07	C	1999	1,88	-2,49	-0,61	6,36	C
1977	1,91	-1,58	0,33	4,40	C	2000	2,49	-1,88	0,61	6,97	C
1978	1,92	-3,18	-1,26	3,14	C	2001	1,39	-2,97	-1,58	5,39	C
1979	3,12	-3,31	-0,19	2,95	C	2002	2,66	-3,69	-1,03	4,36	C
1980	2,41	-3,34	-0,93	2,02	C	2003	2,19	-3,28	-1,09	3,27	C
1981	2,54	-2,51	0,03	2,05	C	2004	2,65	-2,46	0,19	3,46	C
1982	2,03	-1,62	0,41	2,46	C	2005	3,03	-2,55	0,48	3,94	C
1983	1,98	-1,53	0,45	2,91	C	2006	1,57	-3,41	-1,84	2,10	C
1984	3,55	-2,75	0,80	3,71	C	2007	3,14	-2,47	0,67	2,77	C
1985	1,24	-2,86	-1,62	2,09	C	2008	2,58	-2,71	-0,13	2,64	C
1986	2,5	-2,72	-0,22	1,87	C	2009	2,88	-2,95	-0,07	2,57	H
1987	2,33	-1,88	0,45	2,32	C	2010	2,00	-2,75	-0,75	1,82	H
1988	2,05	-3,79	-1,74	0,58	C	2011	2,84	-3,78	-0,94	0,88	O
1989	4,11	-1,97	2,14	2,72	C	2012	3,16	-2,09	1,07	1,95	O
1990	3,20	-2,91	0,29	3,01	C	2013	2,28	-4,14	-1,86	0,09	O
1991	2,42	-2,12	0,30	3,31	C	2014	2,54	-3,51	-0,97	-0,88	O
1992	3,78	-2,44	1,34	4,65	C	2015	3,22	-2,61	0,61	-0,27	O

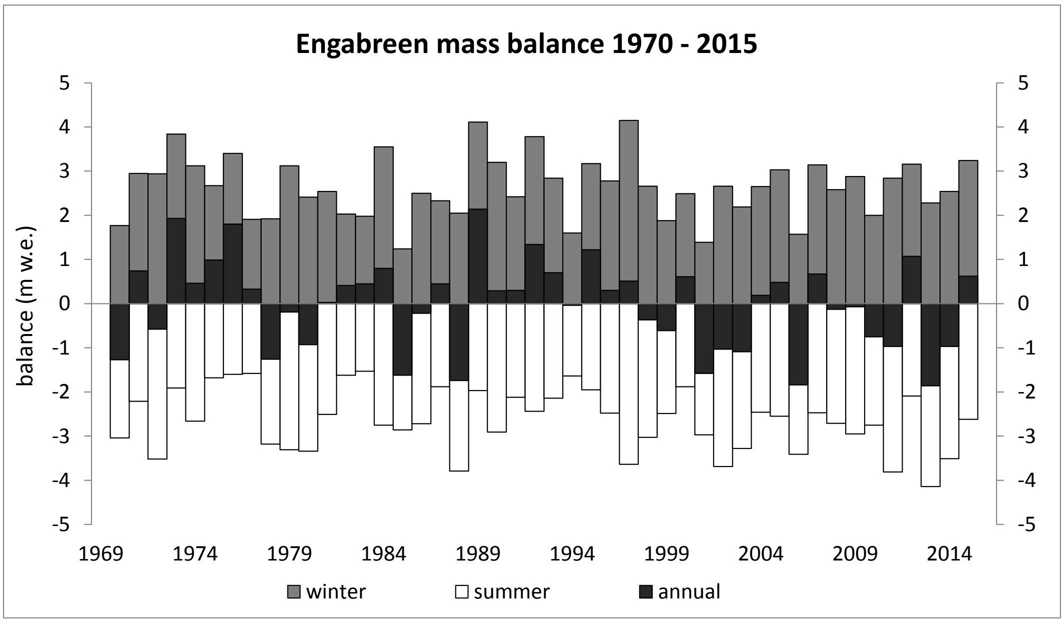


Figure 11-12
Mass balance for Engabreen in the period 1970-2015. The average winter and summer balances are B_w = +2.64 m w.e. and B_s = −2.65 m w.e.

11.7 Meteorological observations

A meteorological station recording air temperature and global radiation at 3 m level is located on the nunatak Skjæret (1364 m a.s.l., Fig. 11-10) close to the drainage divide between Engabreen and Storglombreen. The station has been operating since 1995 with some gaps. In the period 2011-15 there was a major data gap between 26th May 2012 and 21st March 2013.

The summer mean temperature (1st June – 30th September) at Skjæret in 2013, 2014 and 2015 was 3.7, 5.7 and 3.0 °C, respectively. The mean summer temperature over 16 years between 1995 and 2015 is 3.0 °C. The summer 2014 was the warmest summer on record. In 2013 and 2014 the melting season started early, while in 2015 it started unusually late (Fig. 11-13). Even though summer 2014 was warmer than summer 2013, the summer balance in 2013 was larger than in 2014. This is probably due to a smaller than average winter snow pack in 2013 and larger than average snow pack in 2014.

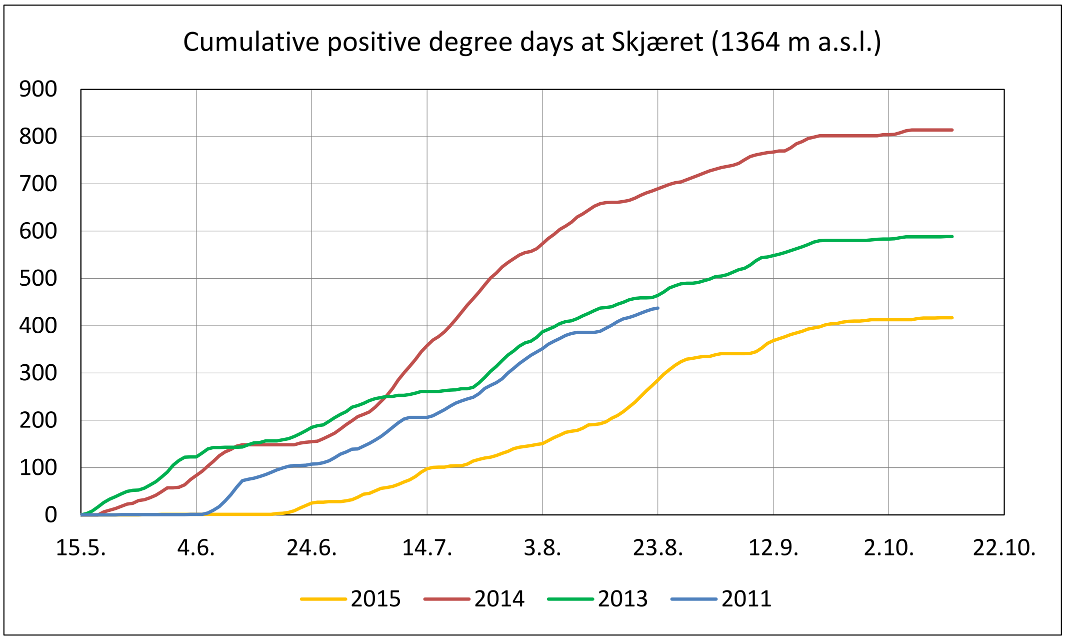


Figure 11-13
The daily mean temperature for days with positive mean temperature is accumulated from 15th May until 13th October. Days with negative mean temperature are ignored.

11.8 Glacier velocity

The mass balance stake network has been surveyed repeatedly since May 2000 using precision GNSS. Reference data for the calculations have been collected at either Bautaen (NVE), Holandsfjord (5 km north-west of Bautaen) or Ørnes (19 km north of Bautaen). Stake velocities have been calculated from the stake positions. Results from 2011-15 are shown in Figure 11-14. As individual stakes are maintained for periods of varying length, and measurements are performed at different time of year, the average values reflect different time intervals within the period 2011-15.

Stake velocities measured in 2000-03, 2007-09 and 2013-15 are compared in Table 11-3. Due to slightly varying stake locations, time of year and length of periods between surveys, the stake velocities from different periods are not directly comparable. However, larger differences probably reflect changes in glacier dynamics. The results show that a considerable slow-down has taken place on the glacier tongue (E17) and at the top of the icefall (E34). This is related to the retreat of the glacier terminus that started around year 2000, and thinning of the glacier tongue since 2001 (Elvehøy, 2016 and Haug et al., 2009). During the glacier advance between 1991 and 1998 the glacier velocities were considerably higher and accelerating, as illustrated by measurements from 1992-95 at stake E17 showing an increase from 180 to 300 m y^{-1} in annual velocity (Elvehøy et al., 1997). The measurements at the glacier plateau show only minor changes since 2000. The velocity increase at E101 between 2007-09 and 2013-15 is probably related to the stake approaching steeper terrain.

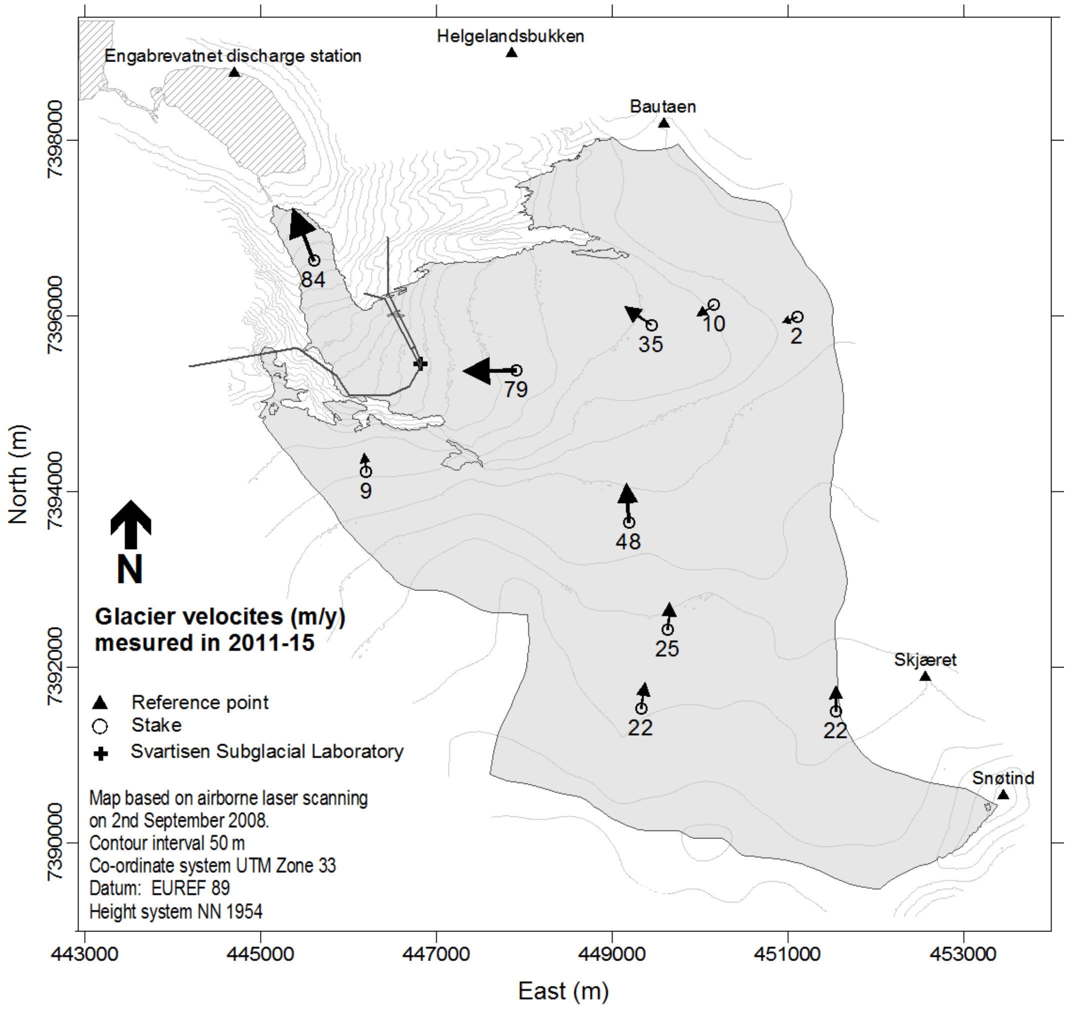


Figure 11-14
Glacier velocities calculated from repeated surveying of mass balance stakes for more than one year during the period 2011 to 2015.

Table 11-3
Average stake velocity (m y^{-1}) for 1 to 3 years at Engabreen. See figure 11-10 for stake locations.

Stake location	Elevation (m a.s.l.)	2000-03 (m y^{-1})	2007-09 (m y^{-1})	2013-15 (m y^{-1})
E17	300	165	127	85
E34	960	101	88	79
E5	1230	48	49	48
E101	1305	23	24	29
E105	1330	22	23	21

11.9 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. 11-5). The research shaft allows direct access to the bed of the glacier and is used for measuring subglacial parameters, extracting samples and performing experiments. Further general information about the laboratory is available in an NVE report entitled 'Svartisen Subglacial Laboratory' (Jackson, 2000).

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. 11-16). The load cells are Geonor Earth Pressure Cells (P-100 and P-105). Readings are made from the load cells at 15-minute intervals (more frequently when experiments are being performed in the laboratory). Two new loads cells were installed in November 1997. Of these eight load cells, six were still recording in 2011, although two of them (1e and 97-1) recorded somewhat inter-mittently. The data from the load cells are briefly summarised here but are available for more comprehensive analysis. The interannual variability of the load cells is examined in detail in Lefeuvre et al. (2015).

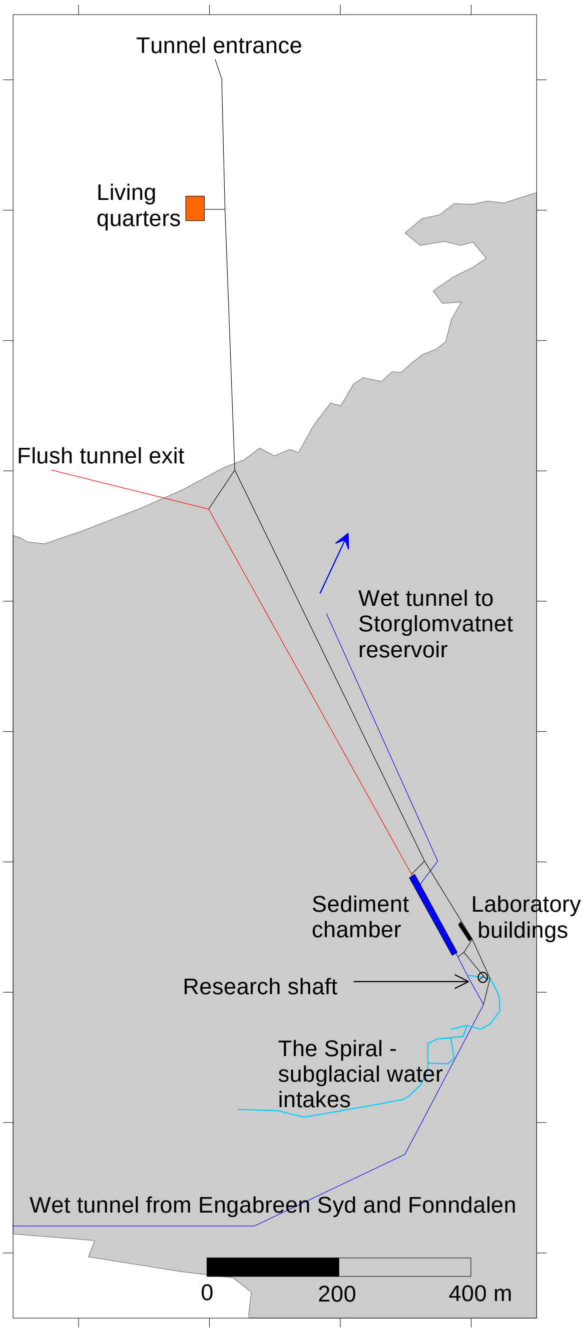


Figure 11-15
Map of tunnel system under Engabreen, showing research shaft and other facilities.

Continuous load cell data are available for most of the period 2011-2015 (Fig. 11-17). There was a problem with the datalogger for the load cells in 2010 and this problem continued into 2011. The datalogger was reset and re-installed in May 2011, so the data in 2011 are from 4th May 2011 and are continuous to 14th December 2011. There were further problems with the datalogger, so there is a three-month gap in the data record. Data are available again from 19th March 2012 and, except for a few days in April 2012, are then continuous until the end of 2015.

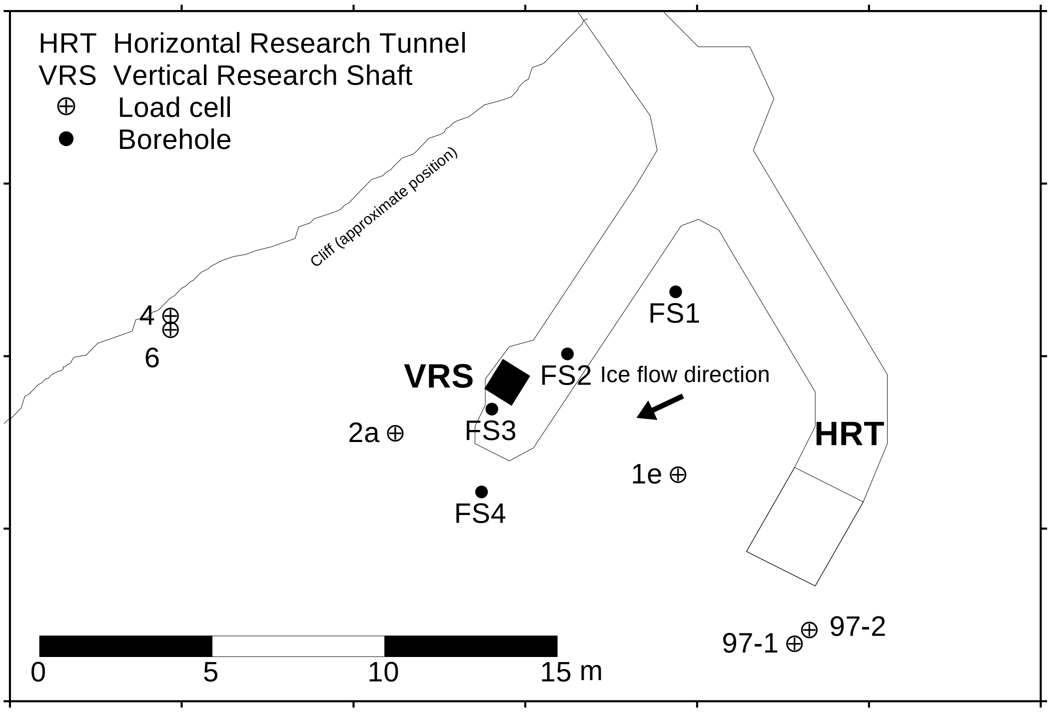


Figure 11-16
Tunnel system showing locations of horizontal research tunnel (HRT) and vertical research shaft (VRS), load cells 1e, 2a, 4, 6, 97-1 (12-1) and 97-2 (12-2) and boreholes, marked FS.

The six load cells shown in Figure 11-16 were operational as described above, except for load cell 1e, which is missing data for parts of 2013, 2014 and 2015, and load cell 97-1, which is missing data for part of 2011. Load cells 97-1 and 97-2 were replaced by load cells 12-1 and 12-2 in the same locations on 24th March 2012.

Figure 11-17 shows the seasonality of the pressure recorded at the glacier base. During the winter there is little melt at the glacier base and the pressure is approximately stable. When the weather warms up, this is registered in the load cell record as the glacier base reacts to the increased meltwater generally and to the change in loading at the glacier bed due to the existence of nearby channels. The large variations in pressure continue into the autumn and are often closely correlated with significant precipitation events. As the weather cools and melt decreases, the pressure becomes stable once more, and gradually rises over the course of the winter. The pressure is shown for load cells 4 and 6 only so that the seasonality of the signal is more distinct.

The load cells are within 20 m of each other (Fig. 11-16), but are in slightly different settings at the glacier base. Load cells 4 and 6 are in an overhang, in a "quiet" environment so respond to only significant changes at the glacier bed. Load cells 97-1 and 97-2 (12-1 and 12-2 from 2012) are in a more exposed, "noisy" environment and respond to relatively small changes in the subglacial hydrology and show bigger variations in the pressure recorded. Figure 11-18 shows the pressure recorded at five load cells in 2011. Load cell 97-1 gave erroneous values during this period, so these data are omitted. The beginning of the period is unstable due to experimental work being performed and an ice tunnel melted out. The load cell values were generally very low and increased when the cavity closed and ice settled on the sensors again. This was immediately followed by the spring-speed up, which started on about 9th May.

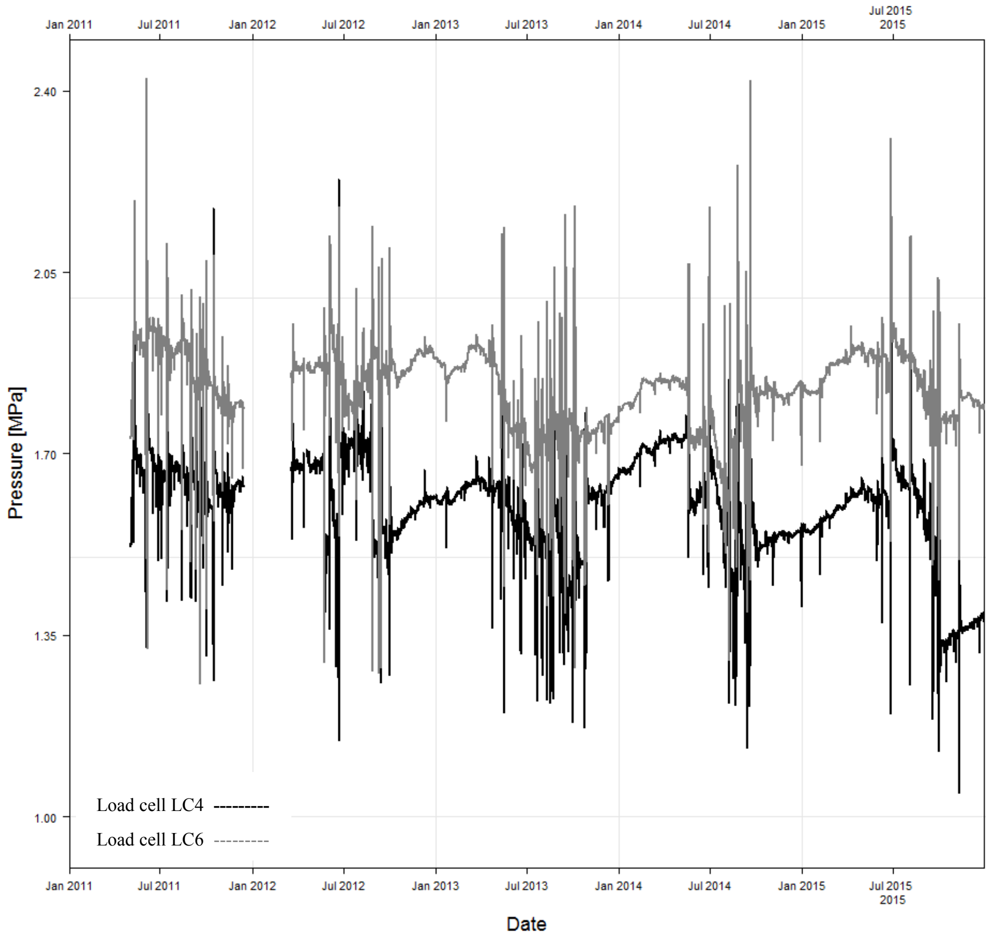


Figure 11-17
Pressure at load cells 4 and 6 for 2011-2015.

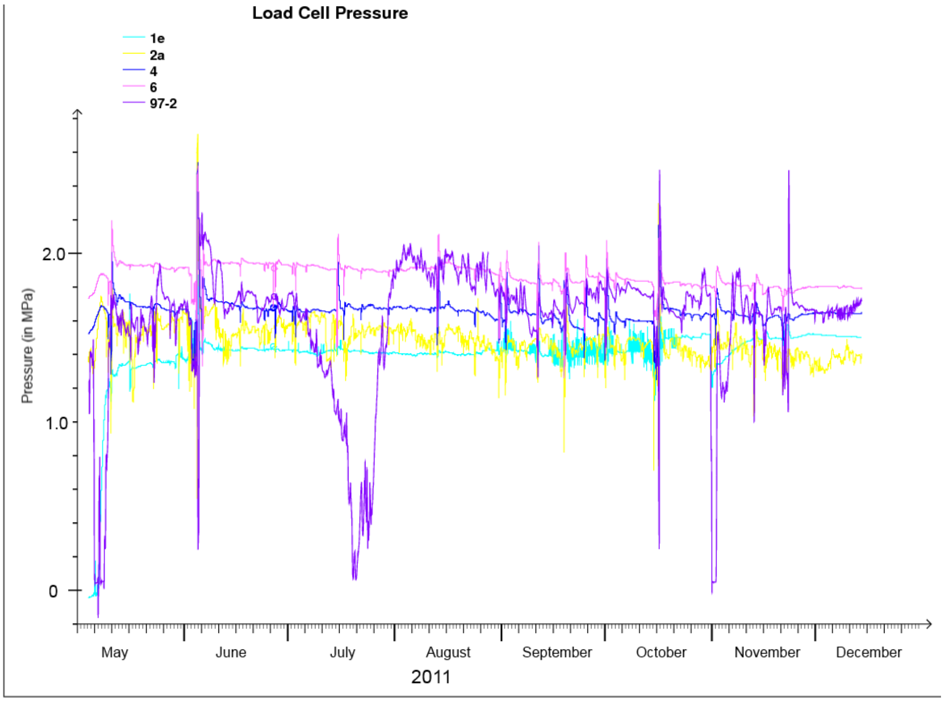


Figure 11-18
Pressure at all load cells for 4th May to 14th December 2011.

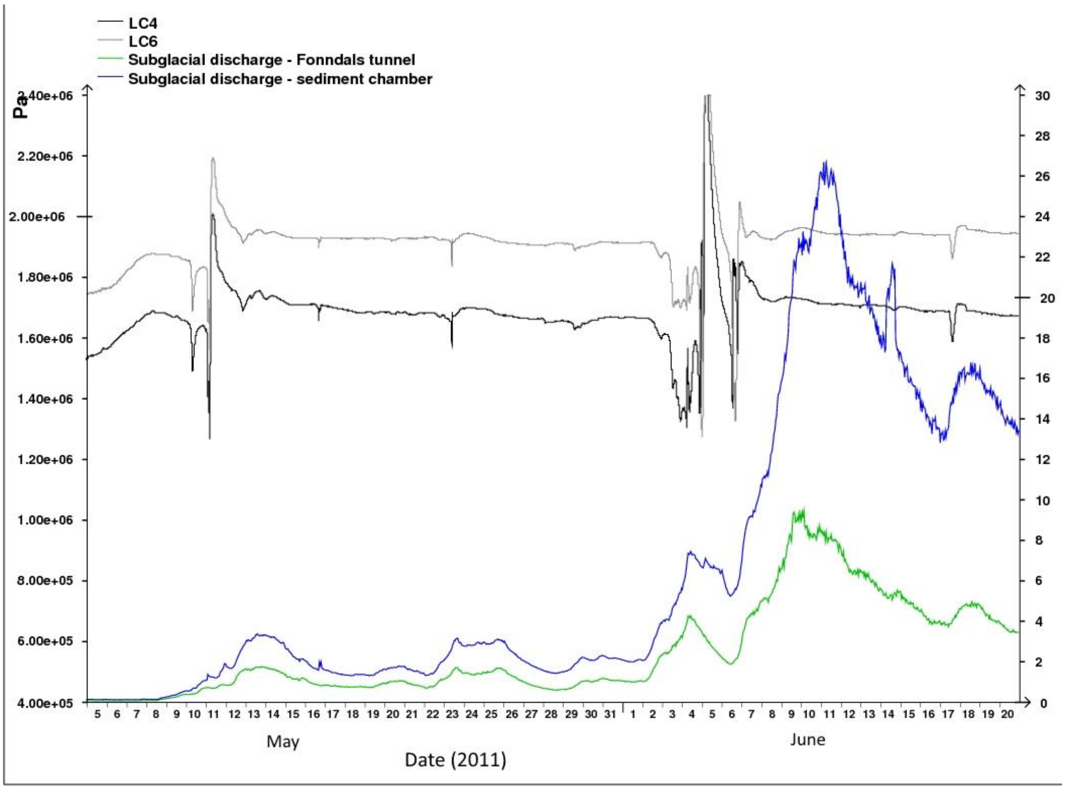


Figure 11-19
Example of load cell response to increase in meltwater in the spring, 5th May to 20th June 2011.

Figure 11-19 shows a typical load cell response to the increase in meltwater at the base of the glacier in spring, and in 2011 started about 9th May. Meltwater from the glacier and surrounding area is captured by intakes and then flows along tunnels underneath the glacier and is routed to the Storglomvatn hydropower reservoir. Hydrological stations record the water level in these tunnels, which is then converted into discharge. The discharge at two stations is shown in Figure 11-19 – at Fonndals tunnel, which is primarily snowmelt and precipitation, and at sediment chamber, which is downstream of the junction of Fonndals tunnel and a tunnel from intakes that capture subglacial melt only. The initial increase in discharge under the glacier is small, but is enough to redistribute load at the glacier base, causing a sudden drop and then an increase in the pressure measured at the load cells. The even stronger event at the load cells from about 2nd to 6th June is caused by an even greater increase in melt and discharge under the glacier.

Pressure data for individual years from 2012 to 2015 are shown in Figure 11-20. The pressure recorded in 2012 follows the usual pattern with considerable changes in pressure between the spring and autumn, and generally quiescent during the winter. The first significant event in 2012 starts on 24th May, related to an increase in meltwater under the glacier and recorded in the subglacial discharge starting on the same day. After two more notable pressure events with a characteristic drop, increase then back to background pressure in June, the pressure record is relatively stable for most of the summer. In a five-week period between 28th August and 1st October, there are four major events, mainly corresponding with increases in subglacial discharge. After this, the subglacial pressure is stable, and gradually rises over the rest of the year.

The data for 2013 show the same general pattern as other years, with no major changes in pressure during the winter. However, there are many events throughout the whole summer and continuing until late October. The data for summer 2013 appear much noisier than most other years. This may be due to more rain in summer 2013 – the meteorological station at Reipå, about 27 km from Engabreen, recorded 417 mm rain between 1st June and 31st August 2013. Corresponding values are 248, 246, 255 and 321 mm for 2011, 2012, 2014 and 2015 respectively.

There were fewer events in 2014 than in 2013 but they are greater in magnitude. Although 2014 was warmer than 2013 (see Figure 11-13), the summer balance in 2014 was less, and the discharge measured under the glacier was lower with fewer distinct events.

The pattern for 2015 is similar to 2014, with only a few events in the summer. The most distinctive features of the pressure record in 2015 are the late start to the melt season, with no significant pressure event occurring until the end of May, and the late event occurring in early November.

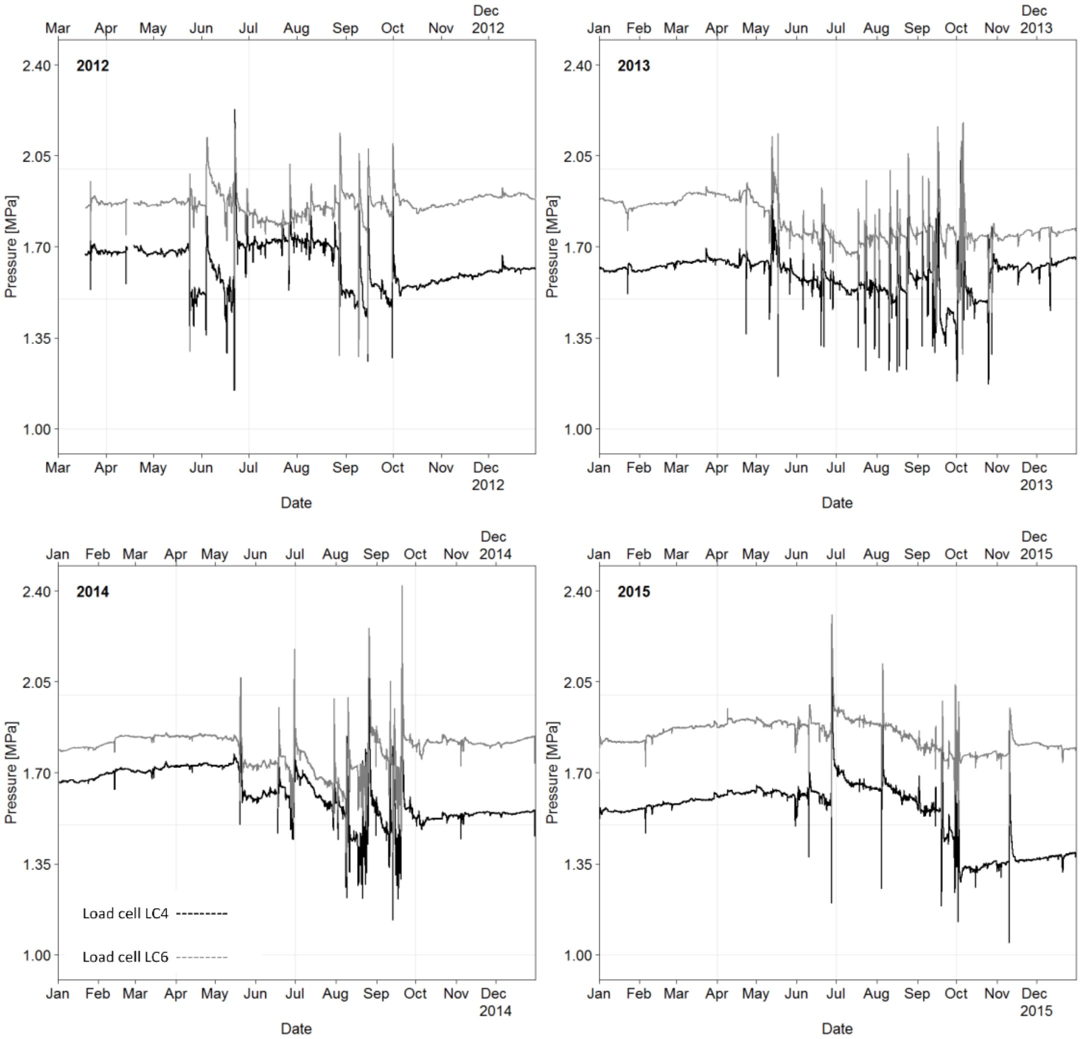


Figure 11-20
Pressure records for LC4 and LC6 for 2012, 2013, 2014 and 2015.

12. Rundvassbreen (Bjarne Kjøllmoen)

Rundvassbreen (Fig. 1-2) is a northern outlet glacier of the ice cap Blåmannsisen (67°20'N, 16°05'E). At 80 km^2 (2010), it is the fifth largest ice cap in Norway. Rundvassbreen has an area of 10.9 km^2 (2010) and extends from 1525 m elevation down to 836 m a.s.l. Rundvassbreen is adjacent to lake Vatn 1051, from which a jøkulhlaup drained beneath the glacier in September 2001. Since then several jøkulhlaups have occurred. A comprehensive observation programme related to the jøkulhlaup was started in autumn 2001 and mass balance measurements were included in spring 2002 and continued until 2004. An extensive observation programme was resumed in 2011.

12.1 Mapping

A new mapping of Blåmannsisen was performed in 2011. The glacier surface was mapped by aerial photographs and airborne laser scanning on 18th September. A Digital Terrain Model (DTM) 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 GIS, and a revised height-area distribution for Rundvassbreen is calculated. The mass balance calculations for the years 2011-2015 are based solely on the DTM from 2011.

12.2 Mass balance 2011

Snow accumulation measurements were performed on 10th May and the calculation of winter balance was based on 109 snow depth soundings (Fig. 12-1). The summer surface (S.S.) was easy to define below 1320 m a.s.l. In the upper areas (1320-1525 m a.s.l.) the S.S. was rather difficult to determine. The snow depth varied between 0.8 and 6.8 metres. Snow density was measured in one position at 1323 m a.s.l. The mean snow density of 4.1 m snow was 448 kg m^{-3}. Ablation was measured on 26th October. The annual balance was measured at stakes in eight locations (Fig. 12-1. Almost all snow from winter 2010/2011 had melted and there was only 15 cm of snow remaining in the uppermost areas. At the time of measurement, up to 1 m of fresh snow had fallen in the uppermost areas.

The elevations above 1060 m a.s.l., which cover 99 % of the glacier catchment area, are well represented with point measurements. Below 1060 m elevation the curve pattern is based on one point measurement at 947 m a.s.l.

The winter balance was calculated as a mean value for each 50 m height interval and was 1.7 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −3.3 ±0.3 m w.e. As the winter balance was low and the summer balance was high, the annual balance was negative at −1.6 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 12-2. As shown here, the Equilibrium Line Altitude (ELA) was 1405 m a.s.l. Accordingly, the Accumulation Area Ratio (AAR) was 3 %.

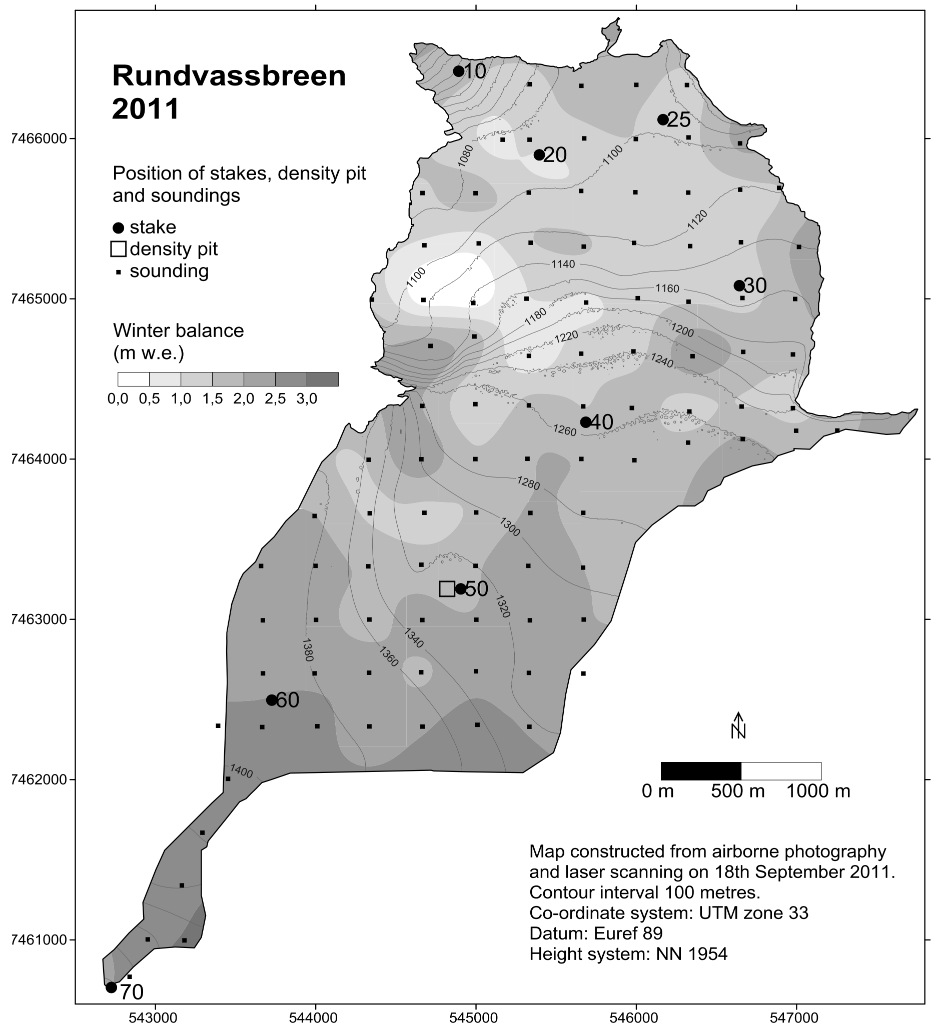
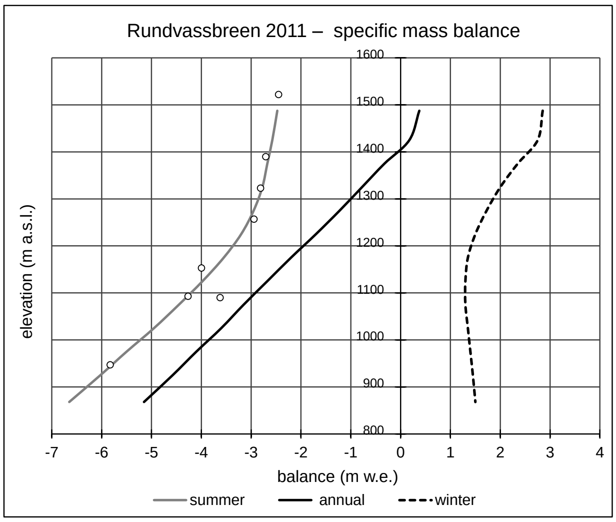


Figure 12-1
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2011.



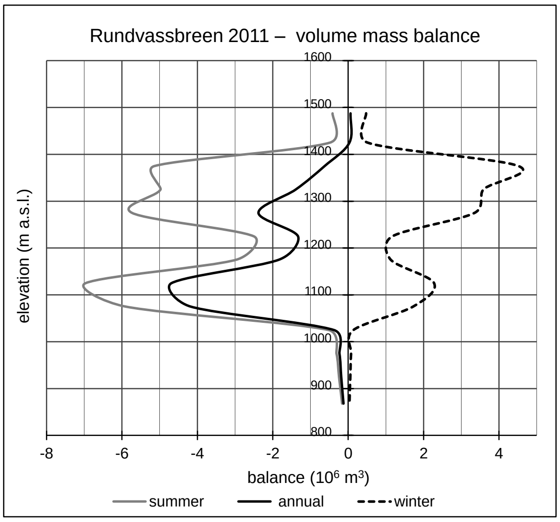


Figure 12-2
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2011. Specific summer balance at eight stake positions is shown as dots (○).

12.3 Mass balance 2012

Snow accumulation measurements were performed on 10th May and the calculation of winter balance was based on measurements of five stakes and 55 snow depth probings (Fig. 12-3). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in October 2011. In areas below 1330 m elevation the S.S. was easy to define. In the upper areas (1330-1525 m a.s.l.) the S.S. was rather difficult to determine. The snow depth varied between 1.3 and 7.3 metres. Snow density was measured in one location at 1323 m a.s.l. The mean snow density of 4.5 m snow was 490 kg m^{-3}. Ablation was measured on 25th September. The annual balance was measured at stakes in seven locations (Fig. 12-3). There was up to 3.5 m of snow remaining in the areas above 1250 m elevation. At the time of measurement, up to 40 cm of fresh snow had fallen on the glacier.

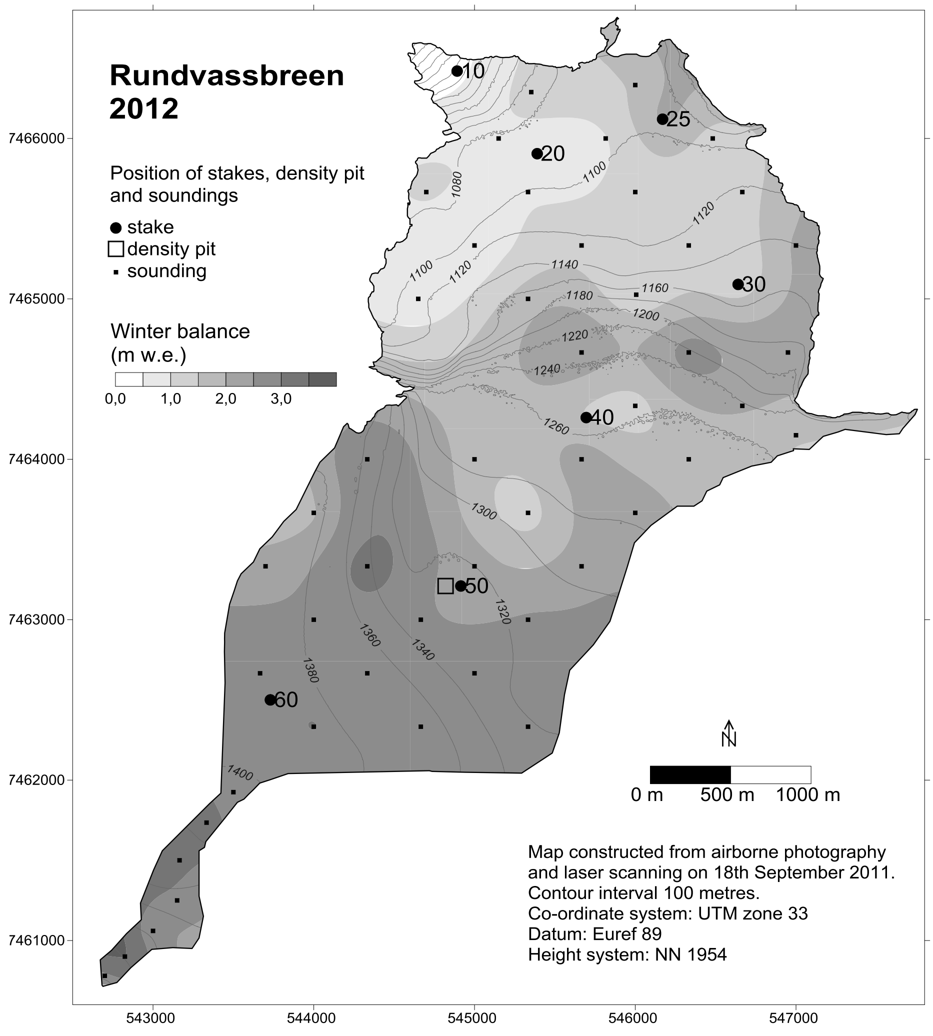


Figure 12-3
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2012.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 2.0 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −1.4 ±0.3 m w.e. Hence, the annual balance was calculated as +0.6 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 12-4. According to Figure 12-4, the ELA was 1180 m a.s.l. Consequently the AAR was 65 %.

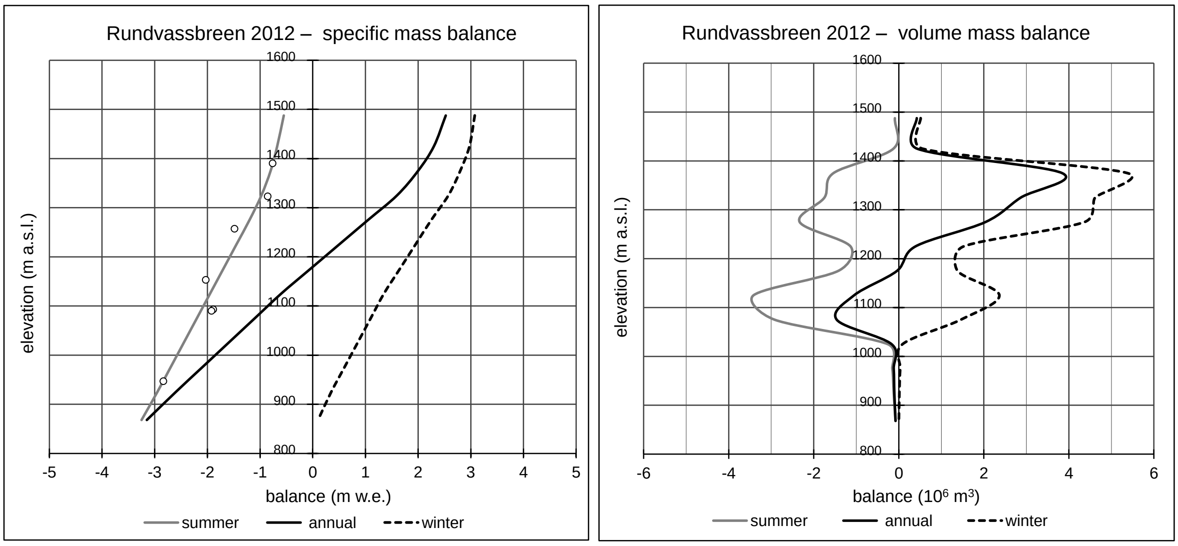


Figure 12-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2012. Specific summer balance at seven stake positions is shown as dots (○).

12.4 Mass balance 2013

Snow accumulation measurements were performed on 14th May and the calculation of winter balance was based on measurements of six stakes and 101 snow depth probings (Fig. 12-5). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in September 2012. The S.S. was easy to define over the whole glacier surface. The snow depth varied between 0.6 and 5.5 metres. Snow density was measured in one location at 1324 m a.s.l. The mean snow density of 3.5 m snow was 434 kg m^{-3}. Ablation was measured on 27th September. The annual balance was measured at six locations (Fig. 12-5). All snow from winter 2012/2013 had melted. At the time of measurement up to 20 cm of fresh snow had fallen in the uppermost areas.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 1.5 ±0.2 m w.e. The summer balance was calculated for eight stakes. For two of the stakes (40 and 70) the balance values were partly estimated. Based on estimated density and stake measurements the summer balance was calculated as −3.9 ±0.3 m w.e. Hence, the annual balance was calculated as −2.4 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 12-6. Based on this figure, the ELA was above the summit. Accordingly, the AAR was 0 %.

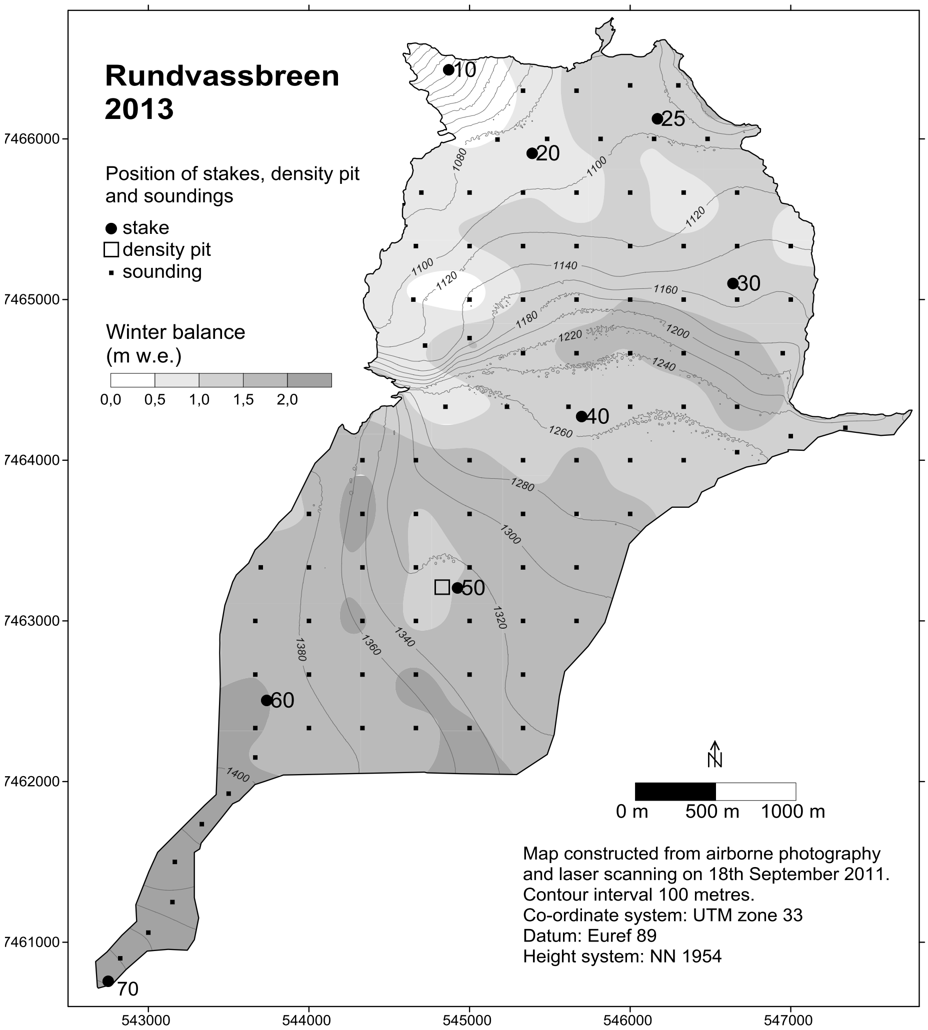


Figure 12-5
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2013.

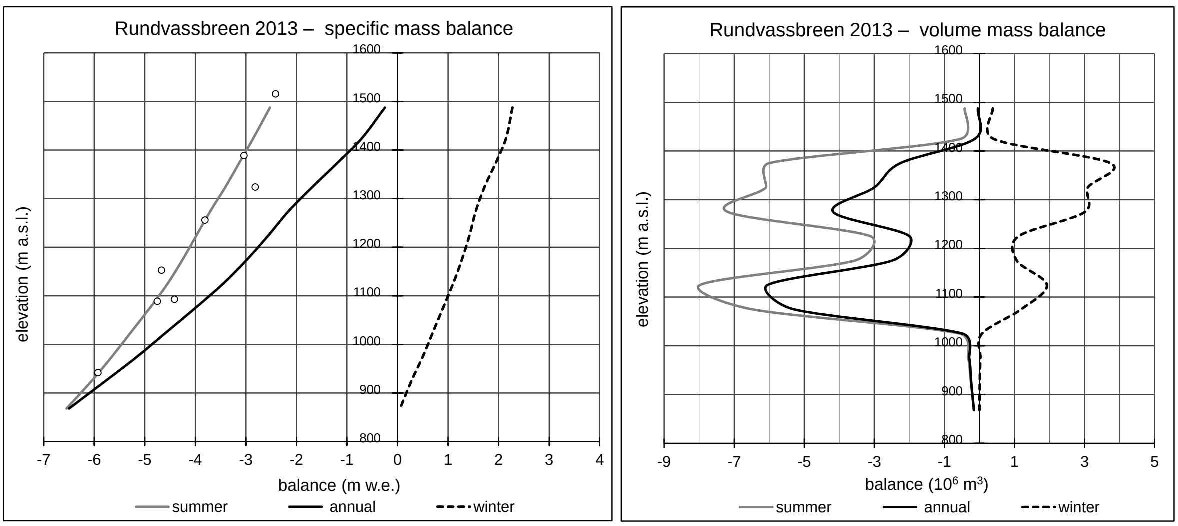


Figure 12-6
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2013. Specific summer balance at eight stake positions is shown as dots (○).

12.5 Mass balance 2014

Snow accumulation measurements were performed on 15th May and the calculation of winter balance was based on measurements of four stakes and 100 snow depth soundings (Fig. 12-7). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in September 2013. The S.S. was easy to detect below 1400 m a.s.l. Above 1400 m elevation the S.S. was rather difficult to determine. The snow depth varied between 0.3 and 6.8 metres. Snow density was measured in one location at 1323 m a.s.l. The mean snow density of 4.2 m snow was 432 kg m^{-3}. Ablation was measured on 23rd September. The annual balance was measured at stakes in seven locations (Fig. 12-7). There was approximately 1 m of snow remaining in the uppermost areas. At the time of measurement, less than 5 cm of fresh snow had fallen on the glacier surface.

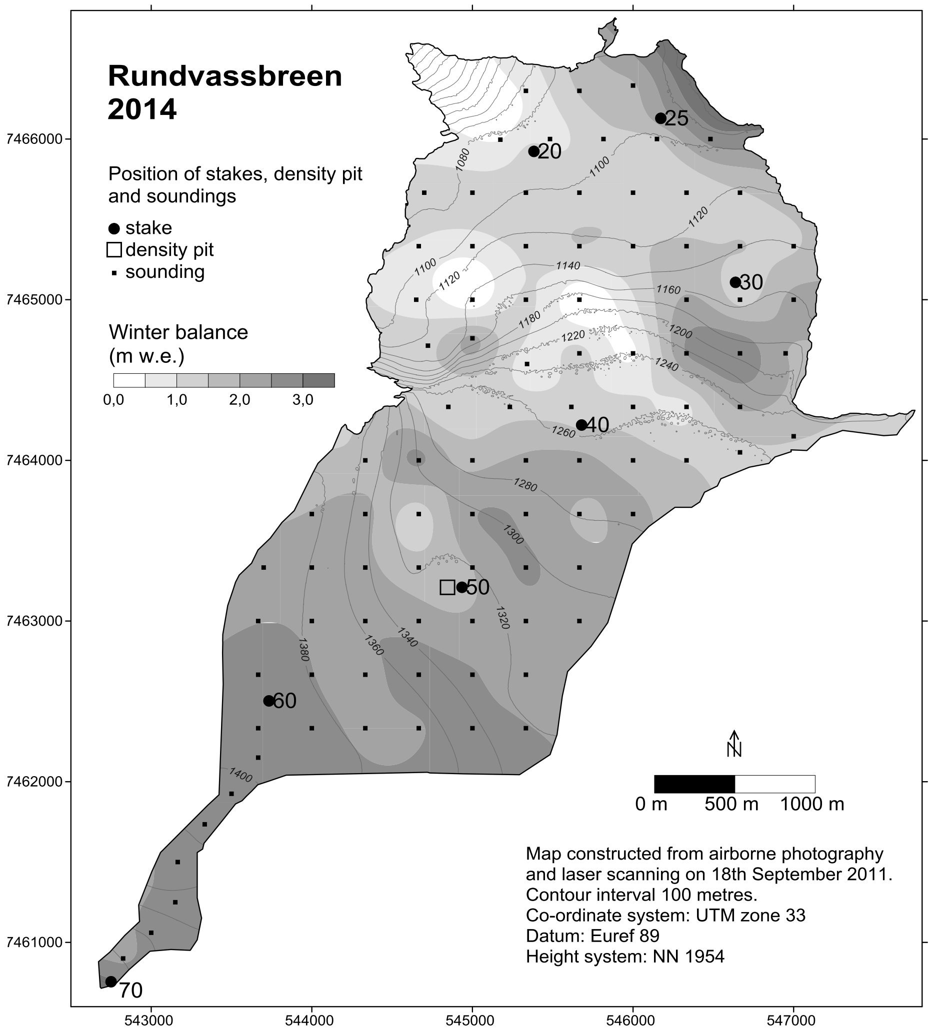


Figure 12-7
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2014.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 1.8 ±0.2 m w.e. The summer balance was calculated at seven stakes. For stake 30 the balance values were partly estimated. Based on estimated density and stake measurements the summer balance was calculated as −2.6 ±0.3 m w.e. Accordingly, the annual balance was calculated as −0.8 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 12-8. Based on this figure, the ELA was 1335 m a.s.l. Accordingly, the AAR was 26 %.

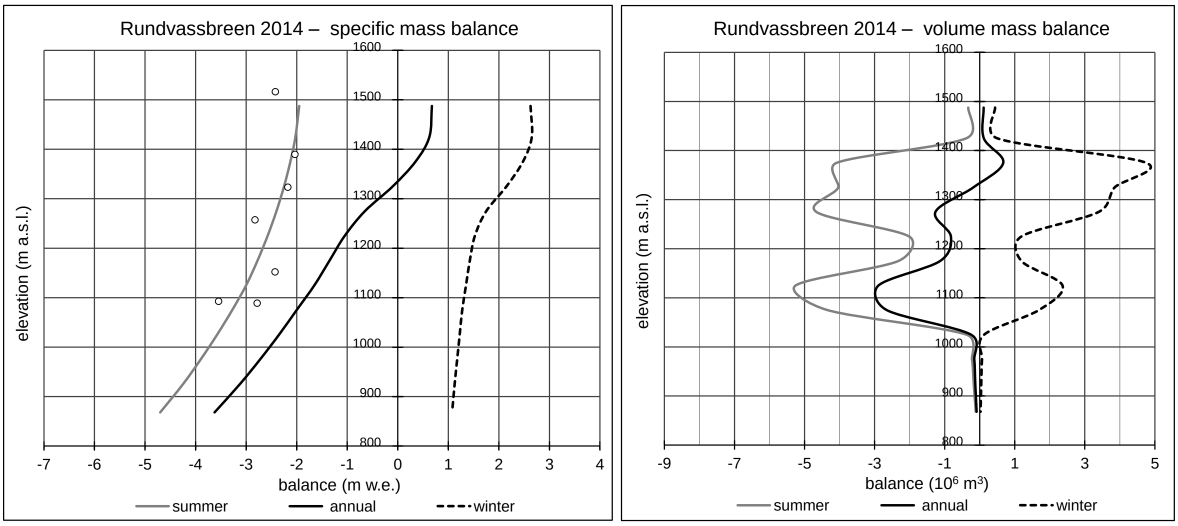


Figure 12-8
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2014. Specific summer balance at eight stake positions is shown as dots (○).

12.6 Mass balance 2015

Snow accumulation measurements were performed on 19th May and the calculation of winter balance was based on measurements of five stakes and 95 snow depth soundings (Fig. 12-9). Comparison of stake readings and soundings indicated no significant melting after the ablation measurement in September 2014. The S.S. was easy to detect below 1400 m a.s.l. Above 1400 m elevation the S.S. was rather difficult to determine. The snow depth varied between 1.2 and 7.6 metres. Snow density was measured in one location at 1323 m a.s.l. The mean snow density of 5.1 m snow was 470 kg m^{-3}. Ablation was measured on 7th October. The annual balance was measured at stakes in six locations (Fig. 12-9). There was approximately 1 m of snow remaining in the uppermost areas. At the time of measurement less than 5 cm of fresh snow had fallen on the glacier surface.

The calculations of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 2.1 ±0.2 m w.e. Based on estimated density and measurements at six stakes the summer balance was calculated as −2.1 ±0.3 m w.e. Accordingly, the annual balance was calculated as 0.0 m ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 12-10. Based on this figure the ELA was 1230 m a.s.l. Accordingly, the AAR was 58 %.

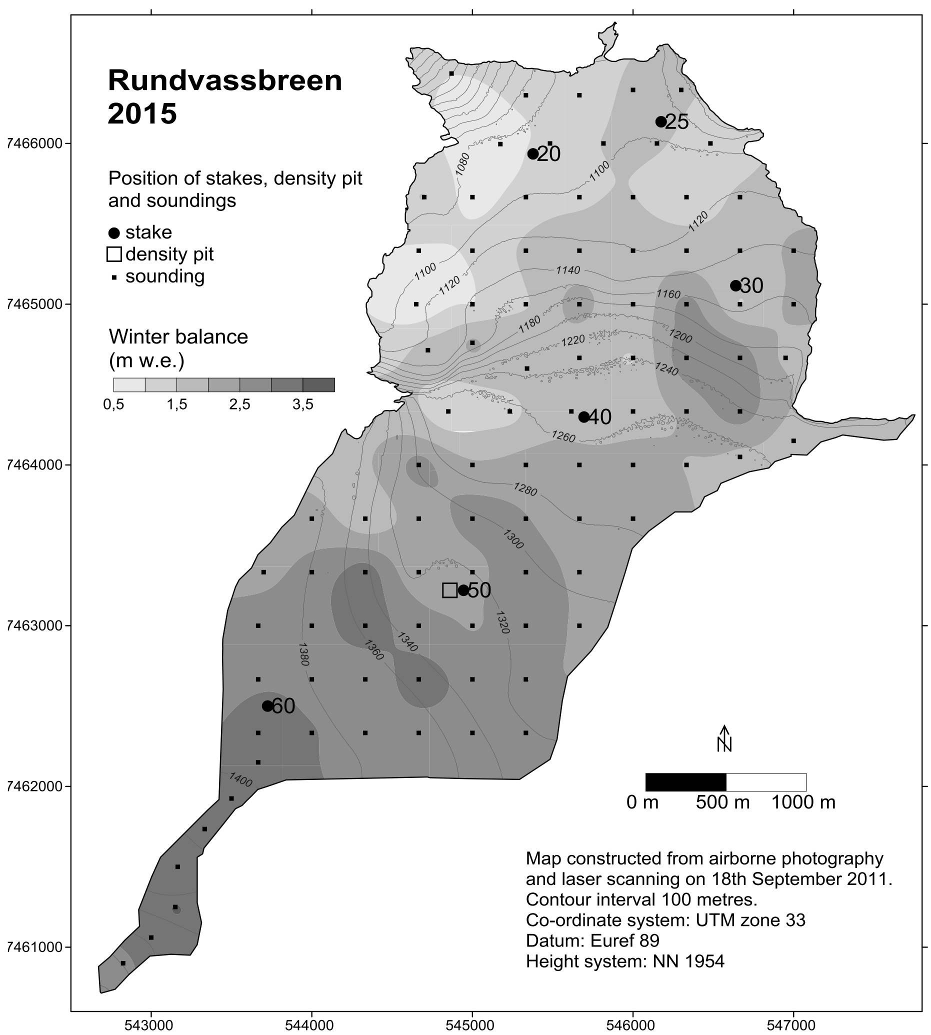


Figure 12-9
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2015.

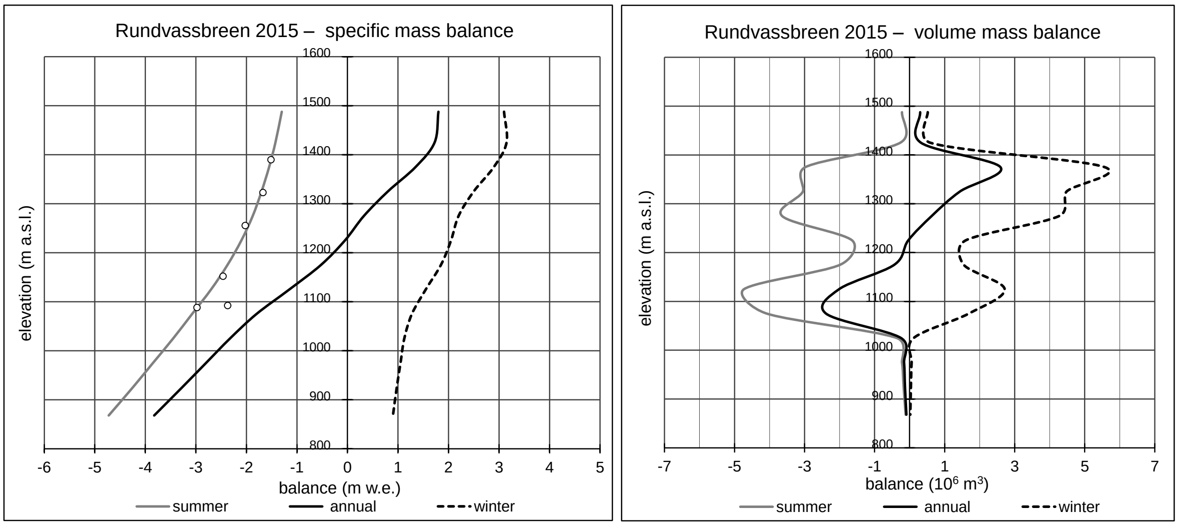


Figure 12-10
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2015. Specific summer balance at eight stake positions is shown as dots (○).

12.7 Mass balance 2002-2015

A summary of the mass balance measurements and results over the years 2011-2015 are given in Table 12-1. The historical mass balance results are presented in Figure 12-11.

Table 12-1
Summary values of Rundvassbreen mass balance measurements and results for the years 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		10 May	7 June	14 May	15 May	19 May
Date B_s		26 Oct	25 Sep	27 Sep	23 Sep	7 Oct
Density b_w	kg m^{-3}	448	490	434	432	470
Density $firn_m$	kg m^{-3}	650		600-650	700	
Density $firn_r$	kg m^{-3}	600	600	600	600	600
B_w	m w.e.	1.74	2.04	1.47	1.80	2.12
B_s	m w.e.	−3.32	−1.40	−3.90	−2.59	−2.15
B_a	m w.e.	−1.58	0.64	−2.43	−0.79	−0.02
$\sum B_a$ 2011-	m w.e.	−1.58	−0.94	−3.37	−4.16	−4.18
ELA	m a.s.l.	1405	1180	>1525	1335	1230
AAR	%	3	65	0	26	58

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density $firn_m$ and Density $firn_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011, respectively.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

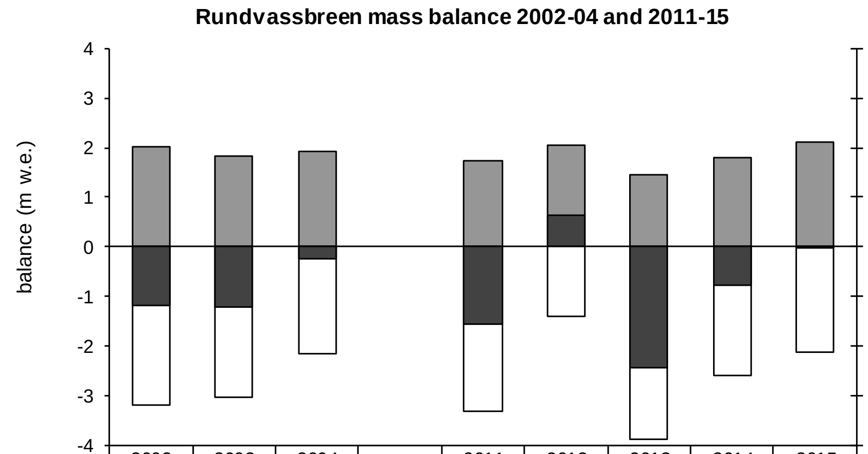
The original mass balance series for 2002-2004 was earlier reported in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). Lately the mass balance for these years has been homogenised. The homogenisation process included a reprocessing of the 2011 DEM, an updating of the glacier area and height distribution using the ice divide from the 2011 DEM and application of a trend line model in the snow density conversion. The original and homogenised mass balance series for 2002-2004 are presented in Table 12-2.

Table 12-2
The original and homogenised mass balance for 2002-2004.

	Original mass balance series								Homogenised mass balance series								Homogen. in relatioon to		
Year	B_w	B_s	B_a	$\sum B_a$	ELA	AAR	DEM	Area	B_w	B_s	B_a	$\sum B_a$	ELA	AAR	DEM	Area	1)DEM	2)Dvd	3)Dens
2002	2.14	-3.19	-1.05	-1.05	1320	32	1998	11.58	2.01	-3.20	-1.19	-1.19	1335	26	1998	11.71	x	x	x
2003	1.88	-2.95	-1.07	-1.07	1360	19	1998	11.58	1.84	-3.05	-1.21	-1.21	1370	15	1998	11.71	x	x	x
2004	1.95	-2.16	-0.21	-0.21	1260	51	1998	11.58	1.92	-2.15	-0.23	-0.23	1290	41	1998	11.71	x	x	x

1)DEM means whether the DEM is re-processed.
2)Dvd means whether the ice divide from 2011 is used.
3)Dens means whether the conversion from snow depth to water equivalent is based on a trend line model.

The presented mass balance series 2011-2015 can be classified as original as the results are not published earlier. The cumulative annual balance for the period 2011-2015 is −4.2 m w.e.



	2002	2003	2004		2011	2012	2013	2014	2015
Winter balance	2.01	1.84	1.92		1.74	2.04	1.47	1.80	2.12
Summer balance	-3.20	-3.05	-2.15		-3.32	-1.40	-3.90	-2.59	-2.15
Annual balance	-1.19	-1.21	-0.23		-1.58	0.64	-2.43	-0.79	-0.02

Figure 12-11
Winter, summer and annual balance at Rundvassbreen for 2002-2004 and 2011-2015. The mass balance series for 2002-2004 is homogenised, and the series 2011-2015 is considered original.

13. 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. 13-1), ranging in elevation from 302 to 1050 m a.s.l.

The glaciological investigations in 2011-15 include mass balance and change in glacier length (chap. 14). Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995. The mass balance for the years 2011-2015 is calculated based on the DTM from 2008.

Figure 13-1
The east-facing outlet of Langfjordjøkelen photographed on 7th August 2013. Photo: Hallgeir Elvehøy.

13.1 Mass balance 2011

Snow accumulation was measured on 11th May and the calculation of winter balance is based on measurements of one stake and 65 snow depth soundings (Fig. 13-2). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in September 2010. Generally, identification of the summer surface (S.S.) was easy. The snow depth varied between 3 and 6 metres. Snow density was measured in one position at 884 m a.s.l. The mean density of 3.2 m snow was 460 kg m^{-3}. Ablation was measured on 20th September. The summer and annual balance was measured at eight stakes in six locations (Fig. 13-2). At the time of the ablation measurements only a thin layer (5 cm) of fresh snow had fallen in the uppermost part of the glacier.

The winter balance was calculated as a mean value for each 50 m height interval and was 2.3 ±0.2 m w.e. At the time of the accumulation measurements all stakes were covered with snow and only one substitute stake (30) was drilled. Thus, the summer balances for the other stakes are calculated using snow depths from the soundings. Based on estimated density and stake measurements the summer balance was calculated as −3.6 ±0.3 m w.e. Thus the annual balance was negative, at −1.3 ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 13-3. According to Figure 13-3, the Equilibrium Line Altitude (ELA) lies above the glacier. Consequently, the Accumulation Area Ratio (AAR) is 0 %.

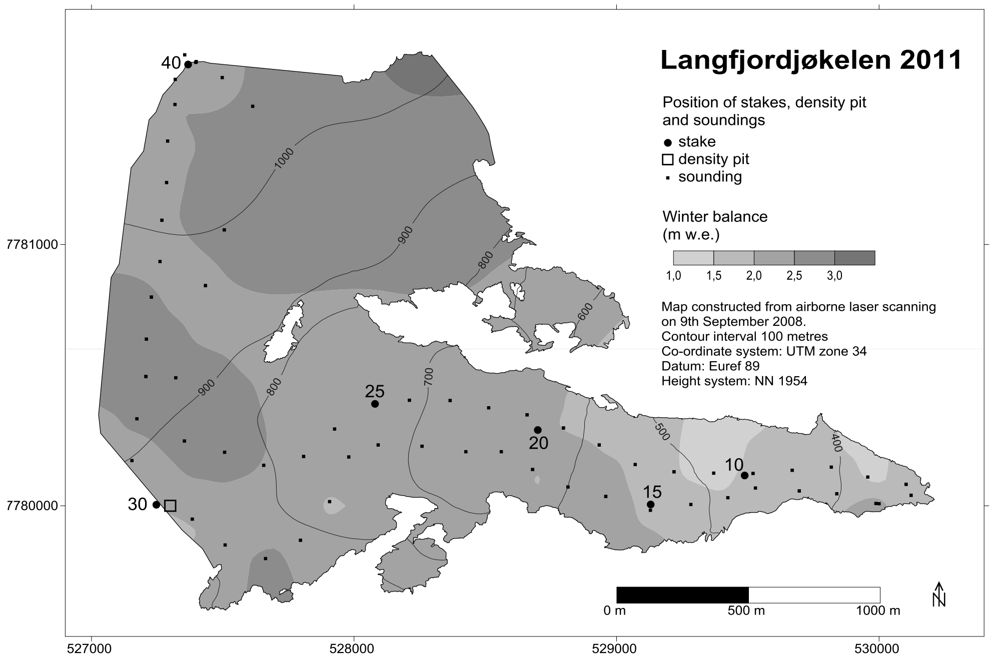


Figure 13-2
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Langfjordjøkelen in 2011.

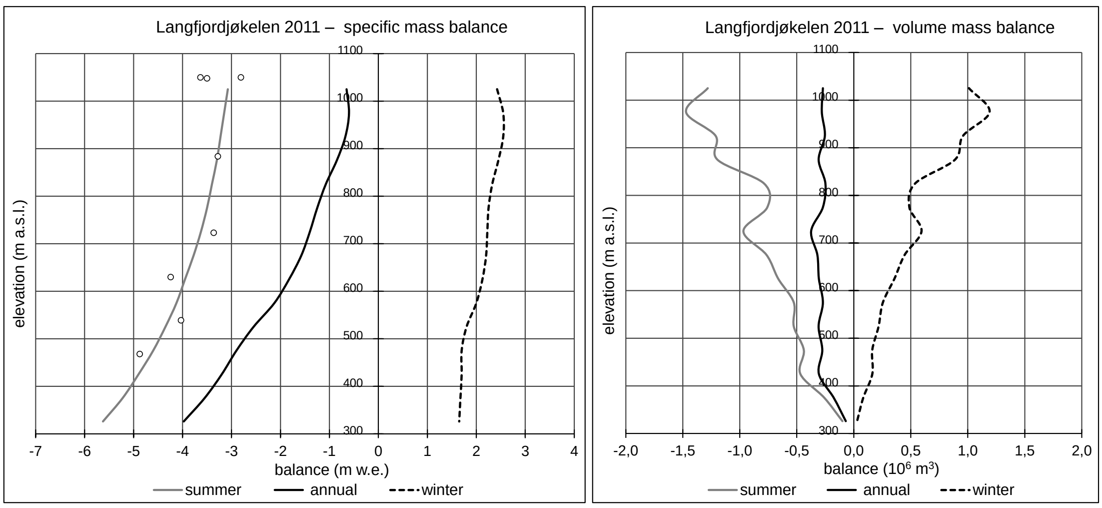


Figure 13-3
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2011. The summer balance for eight stakes is shown (○).

13.2 Mass balance 2012

Snow accumulation was measured on 19th April and the calculation of winter balance was based on measurements of seven stakes and 74 snow depth soundings (Fig. 13-4). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in September 2011. Generally, identification of the S.S. was easy. The snow depth varied between 2 and 4.5 metres. Snow density was measured in one position (722 m a.s.l.). The mean snow density of 2.5 m snow was 348 kg m^{-3}. Ablation was measured on 25th September. The annual balance was measured at nine stakes in six different locations (Fig. 13-4). At the time of measurements up to 20 cm of fresh snow had fallen in the uppermost part of the glacier.

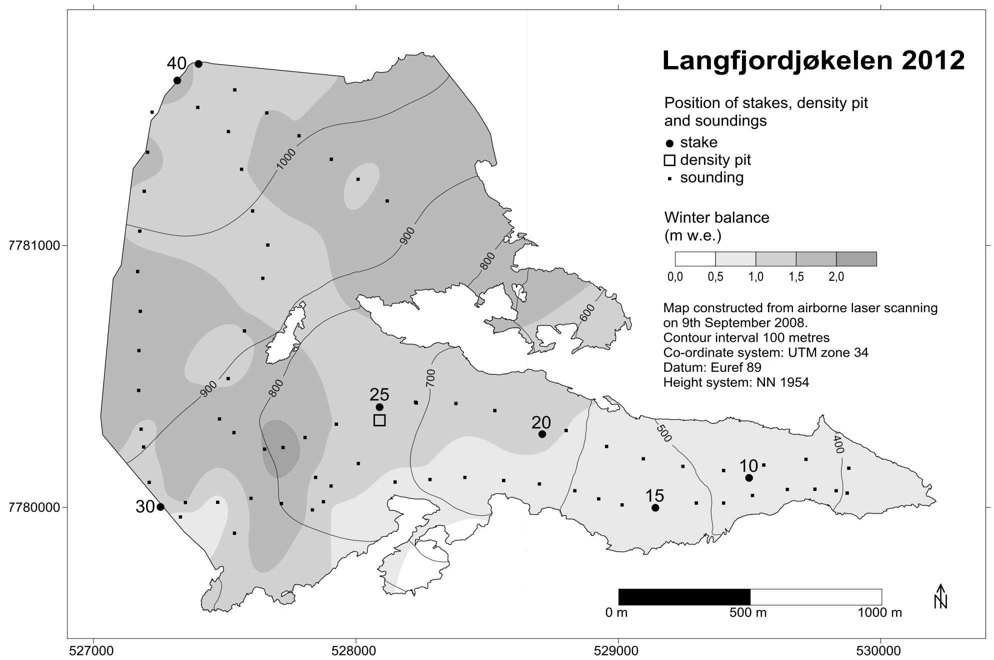


Figure 13-4
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Langfjordjøkelen in 2012.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

The winter balance was calculated as 1.4 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −2.1 ±0.3 m w.e. Hence, the annual balance was −0.8 ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 13-5. According to Figure 13-5, the ELA lies at 950 m a.s.l. Consequently, the AAR is 28 %.

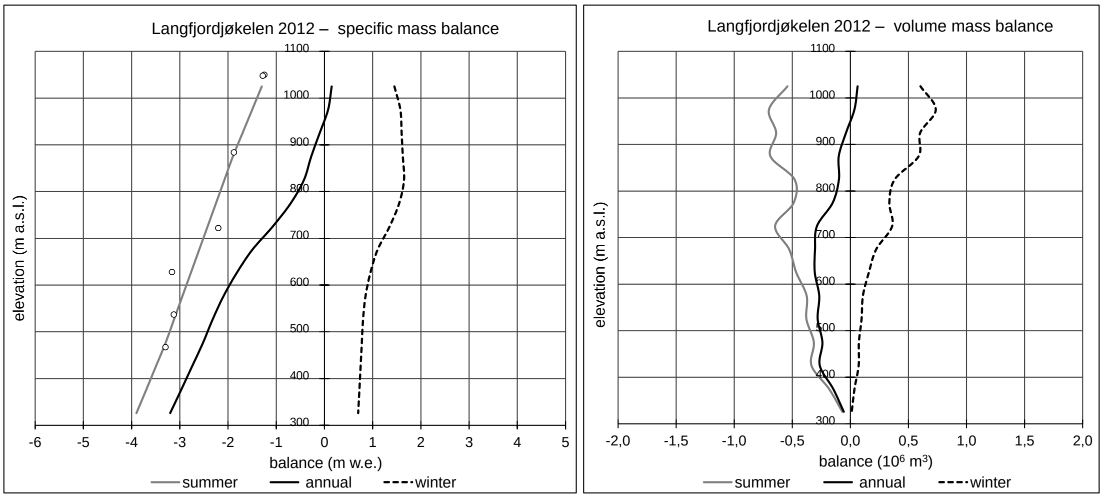


Figure 13-5
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2012. Summer balance for six stakes is shown (○).

13.3 Mass balance 2013

Snow accumulation was measured on 14th May and the calculation of winter balance was based on measurement of one stake and 45 snow depth soundings (Fig. 13-6). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in September 2012. The snow depth varied between 3 and 5.5 metres. Snow density was measured in one location at 722 m a.s.l. The mean density of 4.2 m snow was 448 kg m^{-3}. Ablation was measured on 7th November. The annual balance was measured at seven stakes in six different locations (Fig. 13-6). At the time of measurements between 70 and 155 cm of fresh snow had fallen on the glacier.

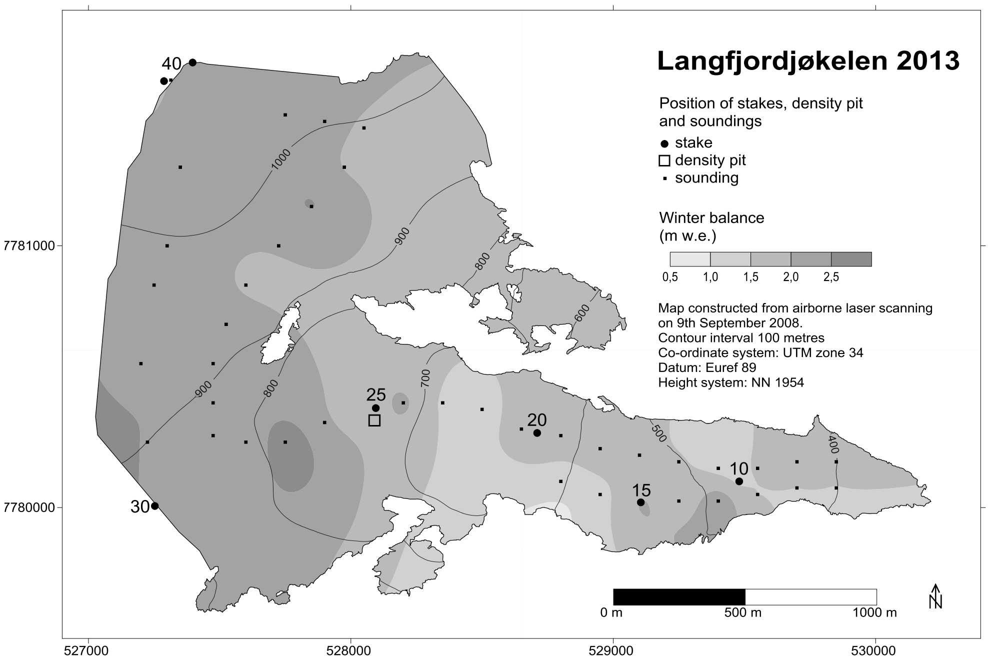


Figure 13-6
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Langfjordjøkelen in 2013.

The calculation of winter, summer and annual balances is based on the same method as for 2011.

The winter balance was calculated as 2.1 ±0.2 m w.e.. Based on estimated density and stake measurements the summer balance was calculated as −4.7 ±0.3 m w.e. This is the biggest summer balance measured at Langfjordjøkelen since measurements started in 1989. The annual balance was −2.6 ±0.4 m w.e. This is the biggest mass loss since 1989.

The mass balance curves for specific and volume balance are shown in Figure 13-7. Based on Figure 13-7, the ELA lies above the glacier. Accordingly, the AAR is 0 %.

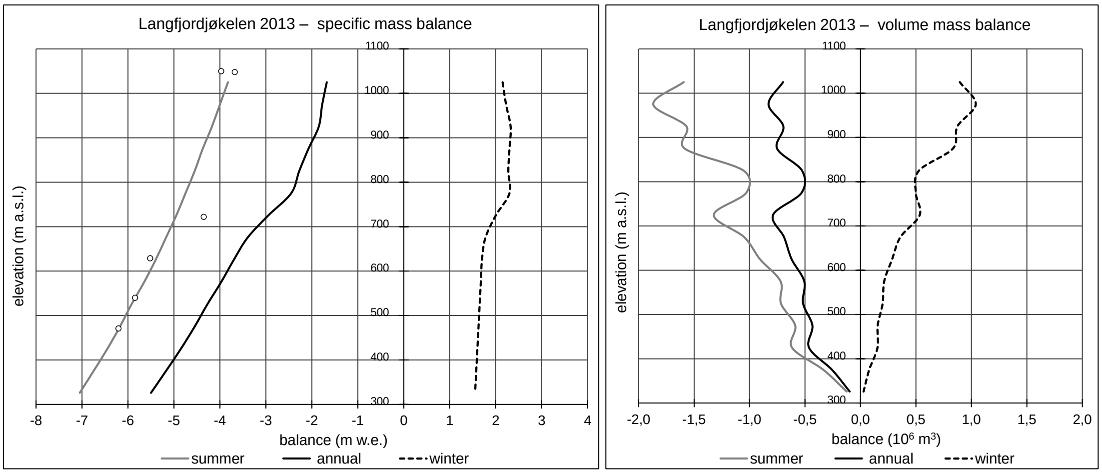


Figure 13-7
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2013. Summer balance for six stakes is shown (○).

13.4 Mass balance 2014

Snow accumulation was measured on 9th May and the calculation of winter balance was based on measurements of five stakes and 60 snow depth soundings (Fig. 13-8). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in November 2013. The snow depth varied between 3.5 and 6.5 metres. Snow density was measured in one location at 721 m a.s.l. The mean density of 4.3 m snow was 460 kg m^{-3}. Ablation was measured on 24th September. The annual balance was measured at seven stakes in six different locations (Fig. 13-8). At the time of measurements between 10 and 30 cm of fresh snow had fallen on the glacier.

The calculation of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 2.4 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −3.1 ±0.3 m w.e. Hence, the annual balance was −0.8 ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 13-9. Based on Figure 13-9, the ELA lies above the glacier. Accordingly, the AAR is 0 %.

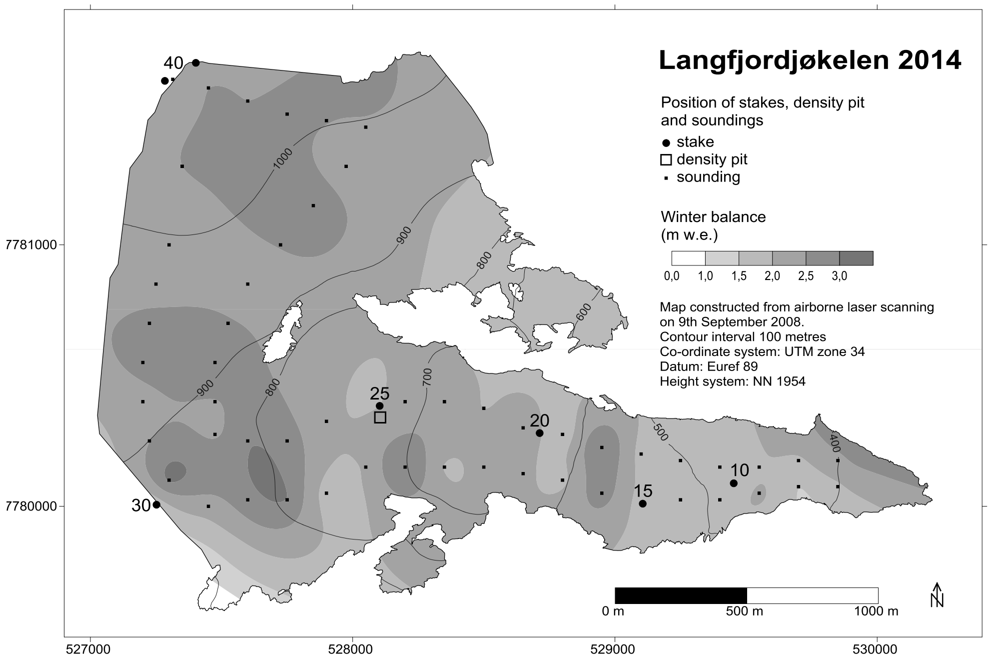


Figure 13-8
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Langfjordjøkelen in 2014.

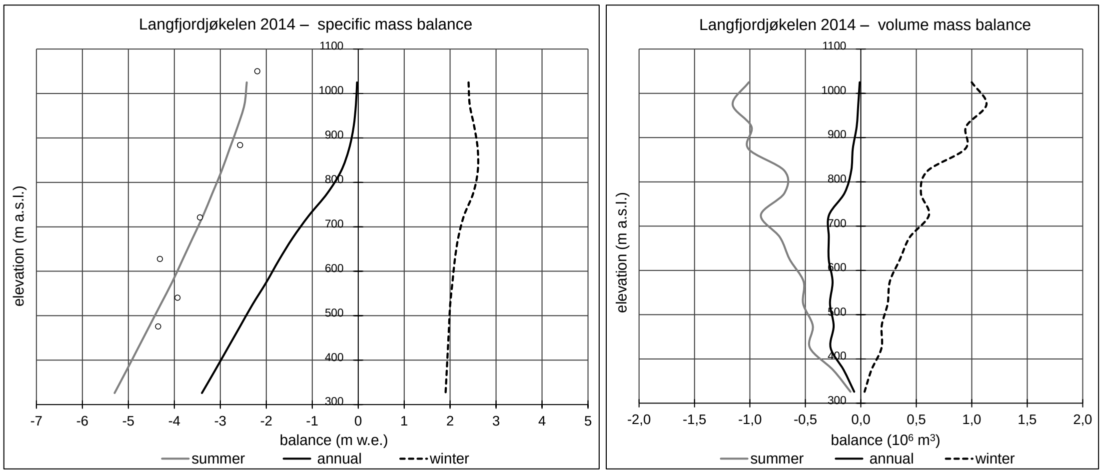


Figure 13-9
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2014. Summer balance for six stakes is shown (○).

13.5 Mass balance 2015

Snow accumulation was measured on 8th May and the calculation of winter balance was based on measurements of five stakes and 55 snow depth soundings (Fig. 13-10). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in September 2014. Generally the snow depth varied between 2 and 5 metres. Snow density was measured in one location at 720 m a.s.l. The mean density of 3.3 m snow was 485 kg m^{-3}. Ablation was measured on 23rd September. The annual balance was measured at seven stakes in six different locations (Fig. 13-10). No fresh snow had fallen on the glacier at the time of measurement.

The calculation of winter, summer and annual balances are based on the same method as for 2011.

The winter balance was calculated as 1.8 ±0.2 m w.e. Based on estimated density and stake measurements the summer balance was calculated as −2.7 ±0.3 m w.e. Hence, the annual balance was −0.8 ±0.4 m w.e.

The mass balance curves for specific and volume balance are shown in Figure 13-11. Based on Figure 13-11, the ELA lies at 1025 m a.s.l.. Accordingly, the AAR is 6 %.

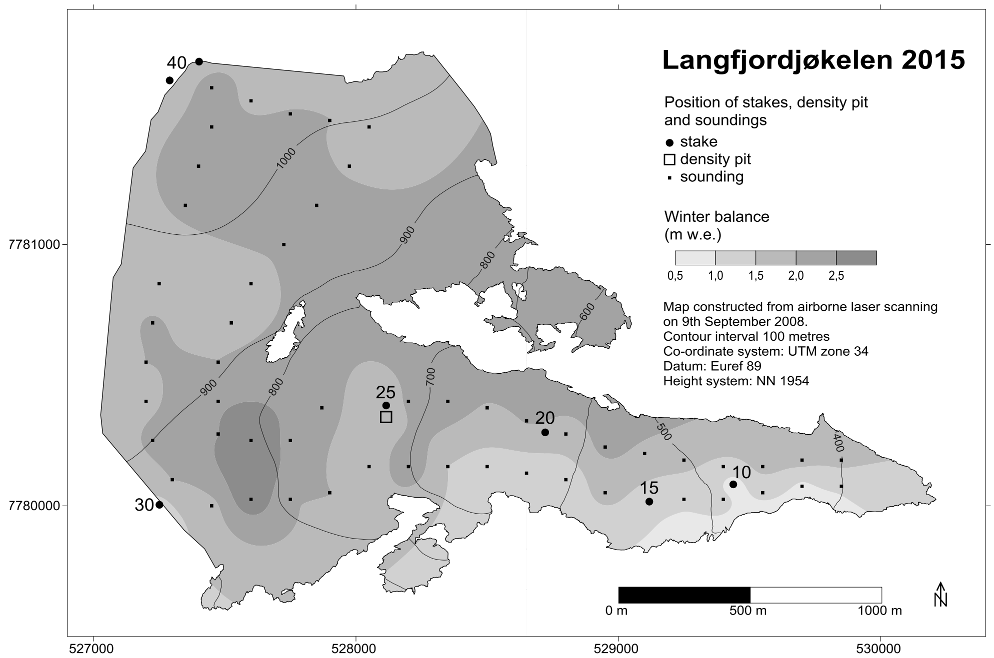


Figure 13-10
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Langfjordjøkelen in 2015.

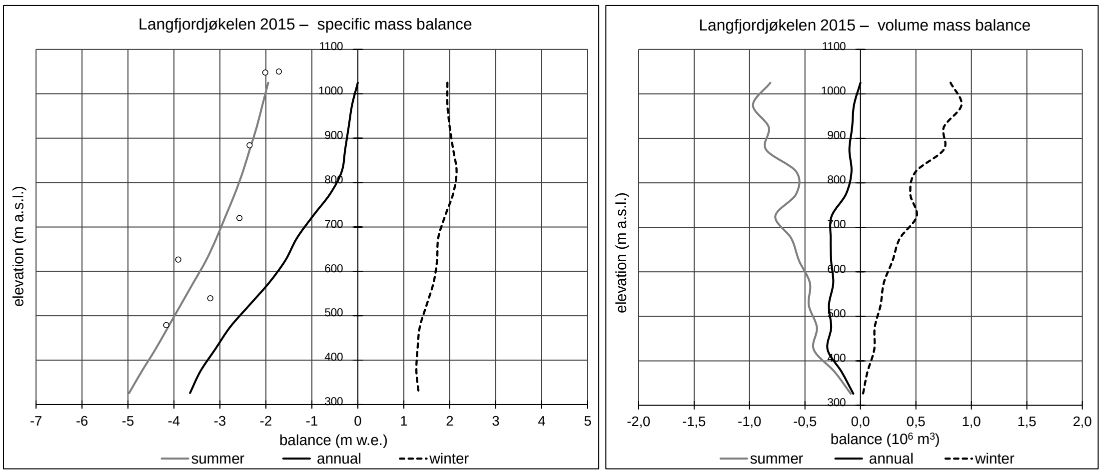


Figure 13-11
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2015. Summer balance for seven stakes is shown (○).

13.6 Mass balance 1989-2015

A summary of the mass balance measurements and results for 2011-2015 is given in Table 13-1.

Table 13-1
Summary values of Langfjordjøkelen mass balance measurements and results for the years 2011-2015.

	Unit	2011	2012	2013	2014	2015
Date B_w		11 May	19 Apr	14 May	9 May	8 May
Date B_s		20 Sep	25 Sep	7 Nov	24 Sep	23 Sep
Density b_w	kg m^{-3}	460	348	448	463	485
Density firn$_m$	kg m^{-3}	650-850		650-800	850	850
Density firn$_r$	kg m^{-3}		600		600	600
B_w	m w.e.	2.30	1.37	2.08	2.36	1.88
B_s	m w.e.	−3.55	−2.13	−4.69	−3.14	−2.68
B_a	m w.e.	−1.26	−0.76	−2.61	−0.78	−0.80
$\sum B_a$ 2011-	m w.e.	−1.26	−2.02	−4.63	−5.41	−6.21
ELA	m a.s.l.	>1050	950	>1050	>1050	1025
AAR	%	0	27	0	0	6

Date B_w and Date B_s are the dates of snow accumulation and ablation measurements, respectively.
Density b_w, Density firn$_m$ and Density firn$_r$ are the mean snow density of the measured snow pack, the estimated density of melted firn and the estimated density of remaining snow, respectively.
B_w, B_s, B_a and $\sum B_a$ 2011- are annual winter balance, annual summer balance, annual balance and cumulative annual balance from 2011.
ELA and AAR are the spatially averaged altitude of the equilibrium line and the ratio of the area of the accumulation zone to the area of the glacier.

The original mass balance series for 1989-2010 was reported earlier in the series "Glaciological investigations in Norway" (e.g. Kjøllmoen et al., 2011). The mass balance series for 1989-2009 has recently been homogenised. Homogenising by recalculation of the mass balance series from 1989 to 2009 (2010 was not necessary to recalculate) ensures uniform methodology, data processing and interpretation of the calculation process from field data to the final balance values. The homogenisation process includes extended use of the 2008 DEM, an update of the glacier area and height distribution using the ice divide from the 2008 DEM, and application of a trend line model in the snow density conversion. The homogenised mass balance series over the period 1989-2009 shows a deficit of −17.2 m w.e., while the original series shows a deficit of −18.2 m w.e. Thus the cumulative deficit over 1989-2009 was reduced by 1.0 m w.e. The mean winter balance increase was 0.009 m w.e. a^{-1}, and the mean summer balance decrease was 0.039 m w.e. a^{-1}. The original and homogenised mass balance series over 1989-2009 are presented in Table 13-2.

According to the homogenisation process, the presented mass balance series 1989-2009 can be classified as homogenised as the results was previously published. As 2010 is not recalculated and 2011-2015 is not published earlier, the years 2010-2015 can be classified as original.

Table 13-2
The original and homogenised mass balance for 1989-2009.

	Original mass balance series								Homogenised mass balance series								Homogenised in relation to		
Year	B_w	B_s	B_a	ΣB_a	ELA	AAR	DEM	Area	B_w	B_s	B_a	ΣB_a	ELA	AAR	DEM	Area	[1)]DEM	[2)]Dvd	[3)]Dens
1989	2.46	-3.03	-0.57	-0.57	865	47	1966	4.80	2.38	-2.98	-0.60	-0.60	890	39	1994	3.62		x	x
1990	2.64	-3.04	-0.40	-0.97	780	53	1966	4.80	2.60	-2.98	-0.38	-0.98	835	49	1994	3.62		x	x
1991	2.31	-2.23	0.09	-0.89	680	67	1966	4.80	2.25	-2.29	-0.04	-1.02	730	64	1994	3.62		x	x
1992	2.76	-2.49	0.27	-0.61	690	69	1966	4.80	2.58	-2.37	0.22	-0.80	705	68	1994	3.62		x	x
1993	2.47	-2.39	0.08	-0.54	700	64	1966	4.80	2.49	-2.34	0.15	-0.65	745	62	1994	3.62		x	x
1994	1.91	-2.63	-0.73	-1.26	849	46	1994	3.65	1.91	-2.63	-0.73	-1.38	849	47	1994	3.62			
1995	2.33	-2.09	0.25	-1.02	698	69	1994	3.65	2.33	-2.09	0.25	-1.13	698	69	1994	3.62			
1996	2.25	-2.23	0.02	-1.00	700	69	1994	3.65	2.23	-2.24	-0.01	-1.14	735	64	1994	3.62		x	x
1997	2.65	-3.34	-0.69	-1.69	820	50	1994	3.65	2.77	-3.43	-0.66	-1.81	805	53	1994	3.62		x	x
1998	1.80	-3.24	-1.44	-3.13	>1050	0	1994	3.65	1.81	-3.27	-1.47	-3.28	>1053	0	1994	3.62		x	x
1999	1.33	-2.91	-1.57	-4.70	970	22	1994	3.65	1.33	-3.02	-1.68	-4.96	1025	8	1994	3.62		x	x
2000	2.51	-3.12	-0.61	-5.31	860	44	1994	3.65	2.53	-3.05	-0.52	-5.48	850	47	1994	3.62		x	x
2001	1.36	-3.64	-2.28	-7.59	>1050	0	1994	3.65	1.46	-3.64	-2.18	-7.67	>1053	0	1994	3.62		x	x
2002	2.19	-3.73	-1.54	-9.13	>1050	0	1994	3.65	2.36	-3.67	-1.31	-8.98	>1050	0	2008	3.21	x	x	x
2003	2.44	-3.51	-1.07	-10.20	>1050	0	1994	3.65	2.45	-3.39	-0.95	-9.92	>1050	0	2008	3.21	x	x	x
2004	1.69	-3.61	-1.92	-12.11	>1050	0	1994	3.65	1.81	-3.50	-1.69	-11.61	>1050	0	2008	3.21	x	x	x
2005	1.88	-3.14	-1.25	-13.37	935	31	1994	3.65	1.95	-2.97	-1.02	-12.63	945	29	2008	3.21	x	x	x
2006	1.42	-3.83	-2.41	-15.78	>1050	0	1994	3.65	1.39	-3.59	-2.20	-14.83	>1050	0	2008	3.21	x	x	x
2007	2.09	-2.90	-0.81	-16.60	870	45	1994	3.65	2.15	-2.79	-0.64	-15.47	880	44	2008	3.21	x	x	x
2008	1.67	-2.02	-0.35	-16.94	835	53	2008	3.21	1.58	-2.01	-0.43	-15.90	875	45	2008	3.21			x
2009	1.88	-3.21	-1.32	-18.27	>1050	0	2008	3.21	1.93	-3.25	-1.31	-17.21	>1050	0	2008	3.21			x

[1)]DEM indicates whether the map base of the recalculated mass balance series is changed.
[2)]Dvd indicates whether the ice divide from 2008 is used for the recalculation.
[3)]Dens indicates whether the conversion from snow depth to water equivalent is based on a trend line model.

The historical mass balance results for 1989-2015 are presented in Figure 13-12. The balance year 2014/2015 was the nineteenth successive year with significant negative annual balance at Langfjordjøkelen. The cumulative annual balance for the 27 year period (estimated values for 1994 and 1995 included) is −24.2 m w.e., which gives a mean annual balance of −0.90 m w.e. a^{-1}.

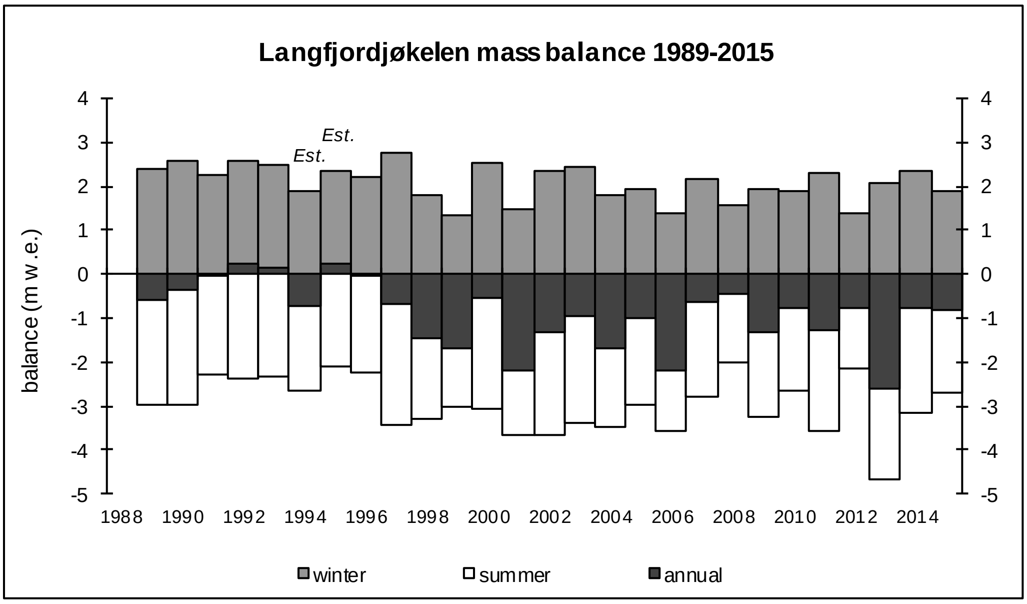


Figure 13-12
Mass balance at Langfjordjøkelen for the period 1989-2015. The mass balance series 1989-2009 is homogenised, while 2010-2015 is original. The total accumulated mass loss for 1989-2015 is 24 m w.e. (includes estimated values for 1994 and 1995).

14. Glacier monitoring

(Hallgeir Elvehøy, Miriam Jackson and Liss M. Andreassen)

14.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started in 1899. Between 1899 and 2015, glacier length change has been measured over several years at 68 glaciers. The total number of observations up to and including 2015 is 2529. The median and mean number of observations at one glacier is 26 and 37, indicating many glaciers with few observations. The median and mean number of observations in one year is 21 and 22 glaciers per year, respectively. At Briksdalsbreen, the length change has been measured every year since 1900, resulting in 115 observations. Stigaholtbreen, Fåbergstølsbreen and Nigardsbreen have more than 100 observations, too. Twenty-one glaciers have more than 50 observations, and an additional 11 glaciers have more than 30 observations.

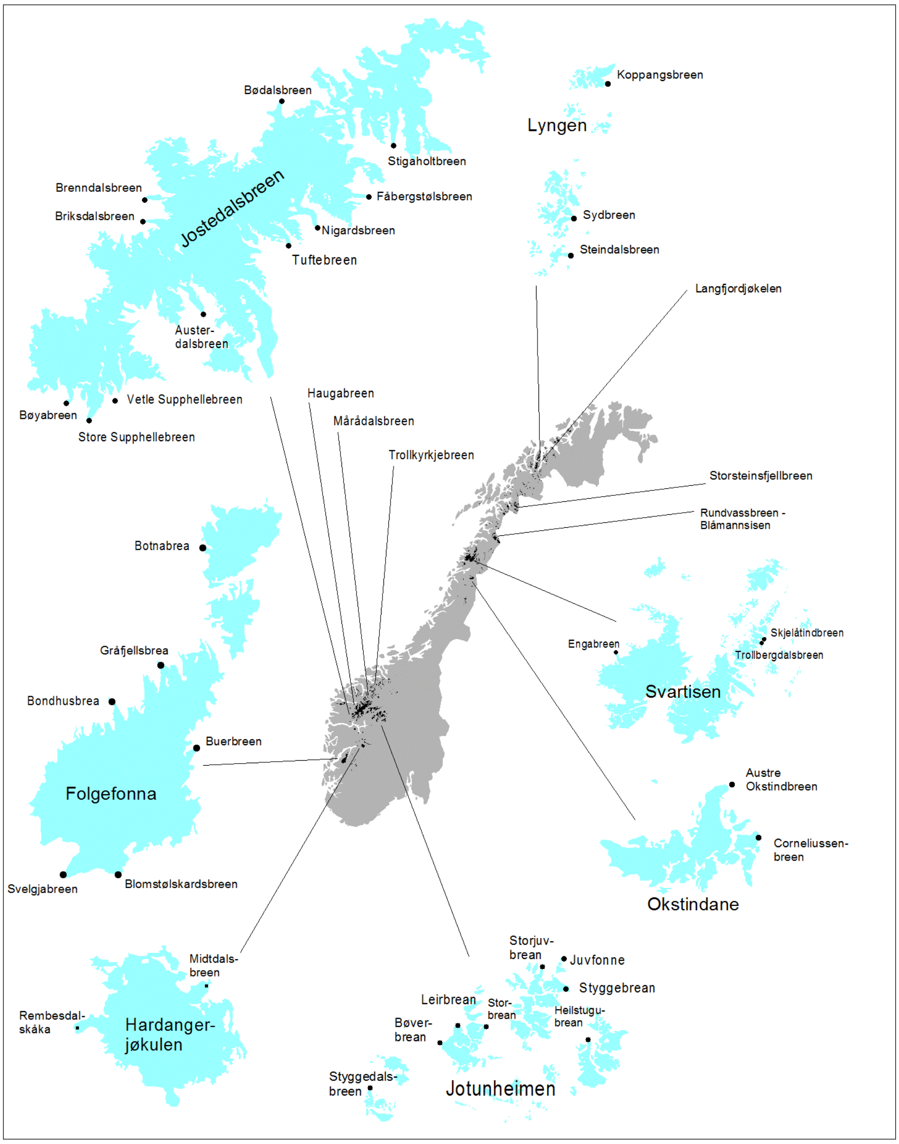


Figure 14-1
Location map showing glaciers where length change observations were performed in 2011-15. Note that the different glacier areas are not to the same scale.

Monitoring programme 2011-15

In 2011-15, glacier length change was measured at about 40 glaciers, - 30 glaciers in southern Norway and 10 glaciers in northern Norway (Fig. 14-1). Changes in the monitoring programme are listed below.

In Nordland, measurements were initiated at two small valley glaciers in Beiarn, - at Trollbergdalsbreen in 2010 and at Skjelåtindbreen in 2014, and at Rundvassbreen, an outlet glacier from Blåmannsisen, in 2011. Mass balance measurements was performed at Trollbergdalsbreen from 1970 to 1975, and from 1990 to 1994, and at Rundvassbreen during the periods 2002 - 2004 and from 2011 to present.

In Jotunheimen, measurements were resumed at Styggebrean in 2011 by The Norwegian Mountain Museum (Norsk Fjellmuseum). In Breheimen, measurements were initiated at Mårådalsbreen at Strynsfjellet in 2013. In Fjærland, measurements were aborted at the two re-generated glaciers Bøyabreen and Store Supphellebreen in 2014 and 2015, respectively. The Norwegian Glacier Museum (Norsk Bremuseum) resumed measurements at Vetle Supphellebreen in 2011 and at Haugabreen in 2013. At Briksdalsbreen in Stryn, the 115-year continuous record was aborted in 2015. After several periods of glacier advance in the 1950s, 1970s and 1990s, the glacier terminus retreated rapidly after 2000. The lower tongue separated from the main glacier in 2011. Since 2012 the terminus of the steep and narrow glacier tongue has been situated at the top of a rock cliff. Glacier length is not affected by mass balance variations, and consequently the measurements were aborted (Fig. 14-2). The measurements at Bødalsbreen were aborted in 2015, too, because the terminus had retreated above a rock cliff resulting in dangerous and difficult surveying conditions.

Figure 14-2
Briksdalsbreen in Stryn. Photo: Hallgeir Elvehøy (1997), Bjarne Kjøllmoen (2006). Erling Briksdal (2011) and Atle Nesje (2015).

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 2010-15

Forty glaciers were measured in this period, 10 glaciers in northern Norway and 30 glaciers in southern Norway. The area of the measured glaciers is 420 km², and that constitutes about 16 % of the glacier area in Norway (Andreassen et al., 2012). Results for the five-year period 2010-15, period of measurements and number of observations (calculated length changes) are listed in Table 14-1. Data are available at www.nve.no\glacier .

The length change from 2010 to 2015 was calculated at 28 glaciers. The change varied from +3 m (Blomstølskardsbreen) to −633 m (Bødalsbreen). The median change was −57.5 metres (−11.5 m y^{-1}), while the mean change was −104 m metres (−21 m y^{-1}).

Table 14-1
Glacier length change for 2011 – 2015 (5 years). See Figure 14-1 for locations.

	Glacier	Glacier-ID	2011-15	Observer	Period(s)	Number obs.
Finnmark and Nord-Troms	Langfjordjøkelen	54	-85	NVE	1998-	17
	Koppangsbreen	205	-	NVE	1998-	13
	Sydbreen	257	-49	NVE	2007-	8
	Steindalsbreen	288	-44	NVE	1998-	13
Nordland	Storsteinsfjellbreen	675	-134	NVE	2006-	8
	Rundvassbreen	941	-	SISO	2011-	3
	Engabreen	1094	-104	S	1903-	83
	Trollbergdalsbreen	1280	-	NVE	2010-	4
	Austre Okstindbreen	1438	-133	NVE	1909-44, 2006-	25
	Corneliussenbreen	1439	-58	NVE	2006-	7
Sunnmøre and Breheimen	Trollkyrkjebreen	1804	-39	NVE	1944-74, 2008-	19
	Mårådalsbreen	2430	-	NVE	2013-	3
Jostedalsbreen	Bødalsbreen	2273	-633	NVE	1900-53, 96-2015	64
	Fåbergstølsbreen	2289	-104	NVE	1899-	110
	Nigardsbreen	2297	-179	NVE	1899-	105
	Haugabreen	2298	-	NBM	1933-41, 2013-	10
	Brenndalsbreen	2301	-209	NVE	1900-62, 96-	79
	Tuftebreen	2308	-89	NVE	2007-	8
	Briksdalsbreen	2316	-330	NVE	1900-2015	115
	Austerdalsbreen	2327	-217	NVE	1905-20, 33-	95
	Bøyabreen	2349	-	NBM	1899-1953, 2003-14	67
	Store Supphellebreen	2352	-47	NBM	1899-1958, 77-83, 92-2015	83
	Vetle Supphellebreen	2355	-	NBM	1899-44, 2011-	40
	Stigaholtbreen	2480	-68	NVE	1903-	109
Jotunheimen	Juvfonne	2597	-38	NVE	2010-	4
	Styggebrean	2608	-	NFM	1905-76, 2011-	13
	Storjuvbrean	2614	-34	NVE	1901-12, 33-63, 97-	55
	Storbrean	2636	-	NVE	1902-	78
	Leirbrean	2638	-90	NVE	1909-	56
	Bøverbrean	2643	-	NVE	1903-12, 36-63, 97-	42
	Styggedalsbreen	2680	-43	NVE	1901-	94
	Hellstugubrean	2768	-60	NVE	1901-	76
Hardanger	Midtdalsbreen	2964	-21	AN	1982-	33
	Rembesdalskåka	2968	-24	S	1918-41, 68-83, 95-	40
	Botnabrea	3117	-	GK	1996-	13
	Gråfjellsbrea	3127	-	S	2002-	11
	Buerbreen	3131	-37	NVE	1900-80, 95-	68
	Bondhusbrea	3133	-46	S	1901-86, 96-	84
	Svelgjabreen	3137	+1	SKL	2007-	7
	Blomstølskardsbreen	3141	+3	SKL	1994-	16

Observers other than NVE:

SISO Siso Energi AS
S Statkraft
NBM Norsk Bremuseum & Ulltveit-Moe senter for klimaviten
NFM Norsk fjellmuseum, Lom
AN Prof. Atle Nesje, University of Bergen
GK Geir Knudsen, Tyssedal
SKL Sunnhordland Kraftlag

14.2 Jøkulhlaups

There have been several jøkulhlaups or Glacier Lake Outburst Floods (GLOFs) in Norway in the period 2011 to 2015. A summary of these events is given here, but a detailed overview of all known jøkulhlaups in Norway up to 2014 is published in an NVE report (Jackson and Ragulina, 2014). This report also includes known icefalls and mountaineering accidents related to glaciers. The report is available as a pdf file from http://publikasjoner.nve.no/rapport/2014/rapport2014_83.pd and as a hard copy on request.

Blåmannsisen (Rundvassbreen)

Rundvassbreen (chap. 12) is a northern outlet glacier of the Blåmannsisen icecap east of Fauske in Nordland county. The first known jøkulhlaup from this glacier was in September 2001, when about 40 million cubic metres of water from a glacier-dammed lake (Messingmalmvatnet) suddenly emptied 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 volume in 2001 was calculated from records of water level at Sisovatnet and the water-level volume table for the reservoir (Engeset et al., 2005). Several corrections had to be applied due to water used for energy production, disturbances in water level due to hydroelectric generator operation and normal inflow to the reservoir.

The trend over the next ten years was for the events to occur at a lower initial water level in the glacier dammed lake, consequently with less water being released and the event in September 2011 followed this pattern (see Table 14-2). It occurred when the water level was about 1029 m a.s.l., estimated from the height according to laser scanning of the glacier performed on 19th September and estimated filling rate (Kjøllmoen, 2012). The next jøkulhlaup occurred three years later, the longest interval between events since 2005. The lake was full again prior to the event – the altitude of the strandline was measured 18 days later and was 1050 m a.s.l., but this measurement is approximate as the exact height of the strandline was difficult to identify. Approximately 35 million cubic metres of water emptied under the glacier and to Sisovatnet in this event, making it the biggest since 2005. As with all the previous events, there was enough capacity in the hydropower reservoir downstream to accommodate the extra volume.

Table 14-2
Dates and approximate volumes of jøkulhlaups from Blåmannsisen. The volume in 2001 was estimated from the change in volume of water in the reservoir Sisovatnet. The water level after each event differed, and also accounts for different volumes calculated at the same pre-event water level.

Year	Date	Water volume	Water level before event
2001	5th – 7th September	40 mill. m^3	~ full (1053 m a.s.l.)
2005	27th – 29th August	35 mill. m^3	~ full (1053 m a.s.l.)
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
2011	22nd September	12 mill. m^3	less than half-full (1029 m a.s.l.)
2014	11th August	35 mill. m^3	~ full (estimated 1050 m a.s.l.)

Rembesdalskåka

On 25th August 2014 a jøkulhlaup occurred from Demmevatn, a lake dammed by the glacier Rembesdalskåka (see chap. 6) a western outlet from Hardangerjøkulen icecap in Hordaland fylke. There have been many previous events at Rembesdalskåka but this is the first since 1938. (Jackson and Ragulina, 2014). The earliest observation of flood from Rembesdalskåka is from 1736. There were several events in the 19th century including a great flood in 1861 in which two bridges were destroyed, and catastrophic flooding occurred in 1893 that caused considerable damage in Simadal (Liestøl, 1956). After this, a drainage tunnel was constructed and was completed in 1899. The water level in Demmevatn was then 20 m below its previous level. A new event occurred in 1937, causing even more damage than the previous one. The total water volume was smaller in 1937, 11.5 million m^3 compared with 35 million m^3 in 1893, but the water drained in only 3½ hours compared with 24 hours previously, so the average discharge was much higher (Liestøl, 1956). A new tunnel was constructed, but before it was completed, there was another event in 1938.

After this, it was 76 years before the next event occurred. This occurred on 25th August 2014 and was first detected when people staying at a nearby cabin, Demmevasshytta, heard a rumbling sound. The next day they saw that Demmevatnet had drained. Subsequent calculations by Statkraft showed that the inflow to Rembesdalsvatnet, part of their hydropower reservoir system, increased by about 2 million m^3 in only three hours.

Harbardsbreen

There were two jøkulhlaups from Harbardsbreen in the period 2011 – 2015. 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. Mass balance measurements were performed on the central glacier unit of Harbardsbreen (area 11.3 km^2 in 2006) that drains eastward between 1996 and 2001. At this time, there were almost annual jøkulhlaups from the glacier-dammed lake on the western margin of Harbardsbreen, in 1996, 1997, 1998, 2000 and 2001 (Jackson and Ragulina, 2014). The next event didn't occur until 10 years later in 2011 and had a total volume of 5.5 million m^3.

There was a small event of approximate magnitude 0.6 million m^3 in the early summer of 2012, possibly in early July based on recorded water volume in Fivlemyrane. However, this event was not observed directly, but is based on observations made in August that included stranded ice blocks at the site of the glacier-dammed lake west of the glacier that emptied in 2010. The stranded ice blocks were used to estimate the lake level prior to drainage, and hence the volume of water.

The glacier-dammed lake was observed to be full again in summer 2015 (Fig. 14-3). NVE performed GNSS measurements of the lake level and the glacier surface on 6th August. The level of the lake was only a few metres lower than the adjacent glacier surface, and suggested that a jøkulhlaup could occur at any time. Radial cracks emanating from the lake were also observed, as well as discolouration on the glacier surface adjacent to the lake, which suggested that some water was being stored under the glacier.

Figure 14-3
Harbardsbreen on 6th August 2015, exactly two weeks before the jøkulhlaup. LHS: View of the glacier-dammed lake, looking NE; the glacier is to the right. RHS: View of the glacier-dammed lake looking SE across the glacier. Note the radial cracks in the glacier surface. Photos: Miriam Jackson.

The hydropower company was advised to lower the water level in the hydropower reservoir Fivlemyrane in order to have capacity to take the extra water from the jøkulhlaup when it occurred. The jøkulhlaup occurred one week later, on 20th August 2015 and two weeks after the GPS measurements. The total volume of water was about 5 million m^3. Although the total volume of water was greater than the capacity of the reservoir (3.5 million m^3), the water was released through the reservoir and out of the spillways in a controlled manner over the next three days.

Koppangsbreen

Koppangsbreen is a valley glacier situated on the eastern side of Lyngen peninsula in Troms. Koppangsbreen drains to Koppangsvatnet lake and further towards Koppangen village. Several jøkulhlaups occurred from a glacier-dammed lake near the tongue of Koppangsbreen in the period 2011-2015 (Fig. 14-4). These are summarised in Table 14-3. There had previously been an event in September 2010, which cut off a house downstream in Koppangen. The next event occurred in 2011. It was a small volume of water and was of such little consequence that the date is unknown. Two further events occurred in 2012, one in the summer and the second in late September or early October. Again, there is little information about the two events and they were both minor.

Nine jøkulhlaups occurred from Koppangsbreen in 2013. The first event started in the evening of 4th June. Almost 2 million cubic metres of water drained from the glacier-dammed lake. The volume is calculated by measuring changes in the level of the glacier-dammed lake using GPS, but the measurements are approximate as the lake was still snow-covered at the time. The water drained over eleven hours giving an average discharge of about 48 $m^3\ s^{-1}$. Several houses downstream in Koppangen were evacuated as the river took a new course. Several more events occurred the rest of the summer, with a total of nine events in 2013 (see Table 14-3), but all smaller than the initial event. Some of the events may have been triggered by heavy precipitation but there is no simple correspondence between occurrence and local weather. Over the course of the summer, flood defences were constructed in Koppangen, including digging channels and building a flood barrier. Later events were contained by the flood defences.

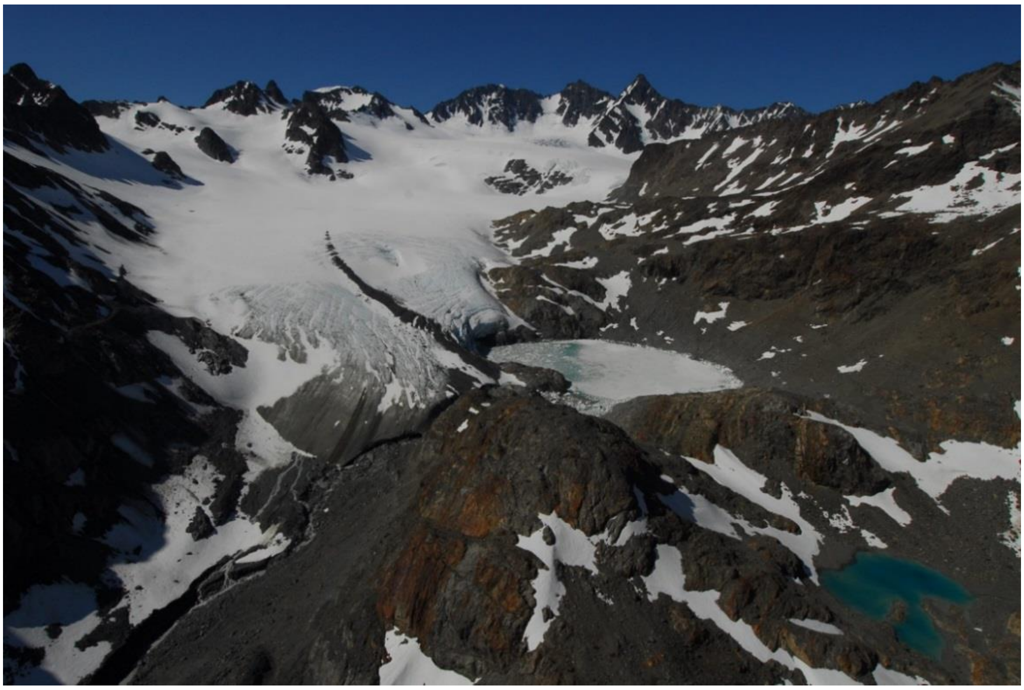


Figure 14-4
Koppangsbreen on 27th June 2013, showing the glacier-dammed lake in the centre. Photo: Knut Hoseth.

A jøkulhlaup occurred on 17th June 2014. It started in the late evening and lasted about 20 hours. An instrument recorded the water level in the glacier-dammed lake and showed a water drop of 20 m and thus the corresponding volume of water in the jøkulhlaup was about 1.8 million m^3.

Table 14-3
Summary of jøkulhlaups from Koppangsbreen.

Year	Date	Time	Duration
2010	6 September	unknown	-
2011	unknown	unknown	-
2012	summer	unknown	-
2012	autumn	unknown	-
2013	4-5 June	15:00 – 02:00	11 hours
2013	9 June	09:00 – 11:00	2 hours
2013	19 June	13:00 – 15:00	~2 hours
2013	23 June	17:30 – 19:30	~2 hours
2013	26 June	08:00 – 09:30	~1.5 hours
2013	30 June	15:00 – 16:20	~1 hour 20 mins.
2013	3 July	19:20 – 20:25	~1 hour 5 mins.
2013	12 August		20 hours
2013	3-4 September	21:00 – 05:00	8 hours
2014	17 June	late evening	20 hours

Svartisheibreen

Svartisheibreen is a small valley glacier south-west of the western Svartisen ice cap that calves into a recently formed proglacial lake, Heiavatnet. Svartisheibreen stretches from Steintinden (1533 m a.s.l.) and Svartisheia (1471 m a.s.l.) down to lake Heiavatnet (774 m a.s.l.). Run-off from the glacier drains both through lake Heiavatnet over the mountain ridge down to Slukta (a deep ravine) as well as under the ice down to Slukta, and further to the river Glomåga and lake Langvatnet in Rana.

Three previous events are believed to have occurred at Svartisheibreen, although rather than being directly observed, two of the events were registered due to the water level being lower than normal. The mass balance was measured at Svartisheibreen between 1988 and 1994 (Elvehøy et al., 1997), and for several years after this the lake level was observed annually. The most recent previous event was in summer 1999. Photographs taken from an aeroplane on 23rd September 2014 (Fig. 14-5) show that the lake had recently drained. Photographs taken in July 2013 show that the lake was then full. Measurements of river discharge in the area, including downstream from Svartisheibreen at Berget hydrological station, suggest 6th to 7th September as a possible date for the event.

Figure 14-5
Lake Heievatnet observed on 23rd September 2014 showing stranded icebergs. Photo: Bjarne Kjøllmoen.

Tystigbreen

Two of the outlet glaciers from Tystigbreen in Stryn (Sogn and Fjordane county) drain to the river Videdøla in the valley Videdalen and further to the river Hjelledøla. Increased discharge was observed in the river Videdøla on 16th August 2014 by personnel at Videseter Hotel. It is probable that a glacier-dammed lake on the western side of Kvitlenova and to the north of the ridge (Fig. 14-6), drained under the glacier to the northwest and thence into the river Videdøla.

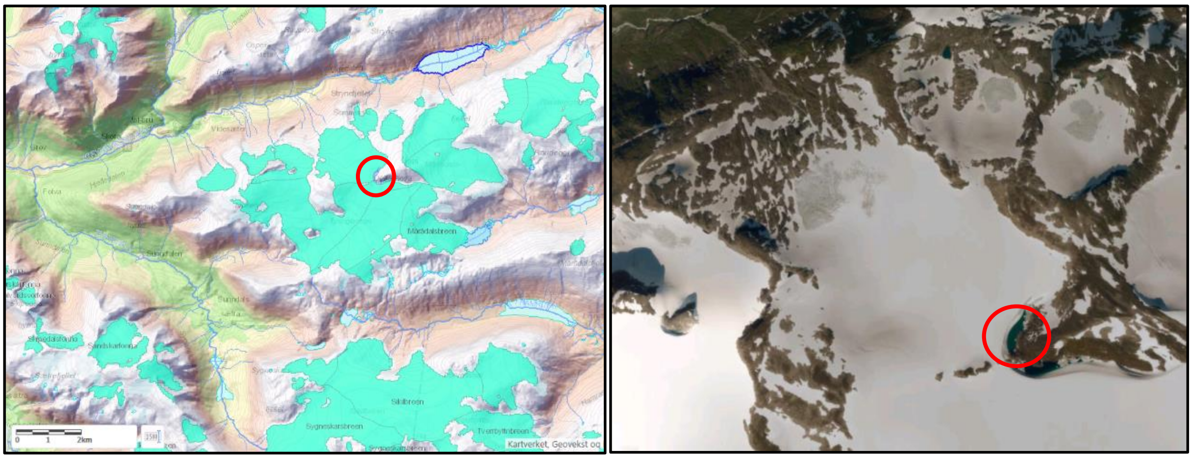


Figure 14-6
Map and aerial photo from 19th August 2015 (www.norgibilder.no) showing probable source of increased flow in river Videdøla. The glacier-dammed lake is marked with a red circle.

14.3 Surveys

Background

Accurate maps of glaciers are essential for mass balance calculations. Previously, glacier maps were usually constructed from aerial photos. However, poor optical contrast of snow-covered parts of the glacier surfaces can cause large uncertainties in derived elevations. Lidar, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure distances. Lidar is very accurate on snow covered surfaces with low roughness. The first lidar campaigns of Norwegian glaciers were conducted in 2001-2003 when Engabreen was mapped several times (Geist et al., 2005). From 2007 to 2013 lidar surveys were conducted on a selection of glaciers in Norway (Fig. 14-7). Simultaneous air photos have been taken in addition to the lidar measurements since 2009. The goals of the surveys were to produce high quality digital terrain models (DTMs) and orthophotos, document the present state of the glaciers and assess mass changes since previous mappings of the glaciers. The DTMs and orthophotos also provide an accurate baseline for future repeated mapping and glacier change detection.

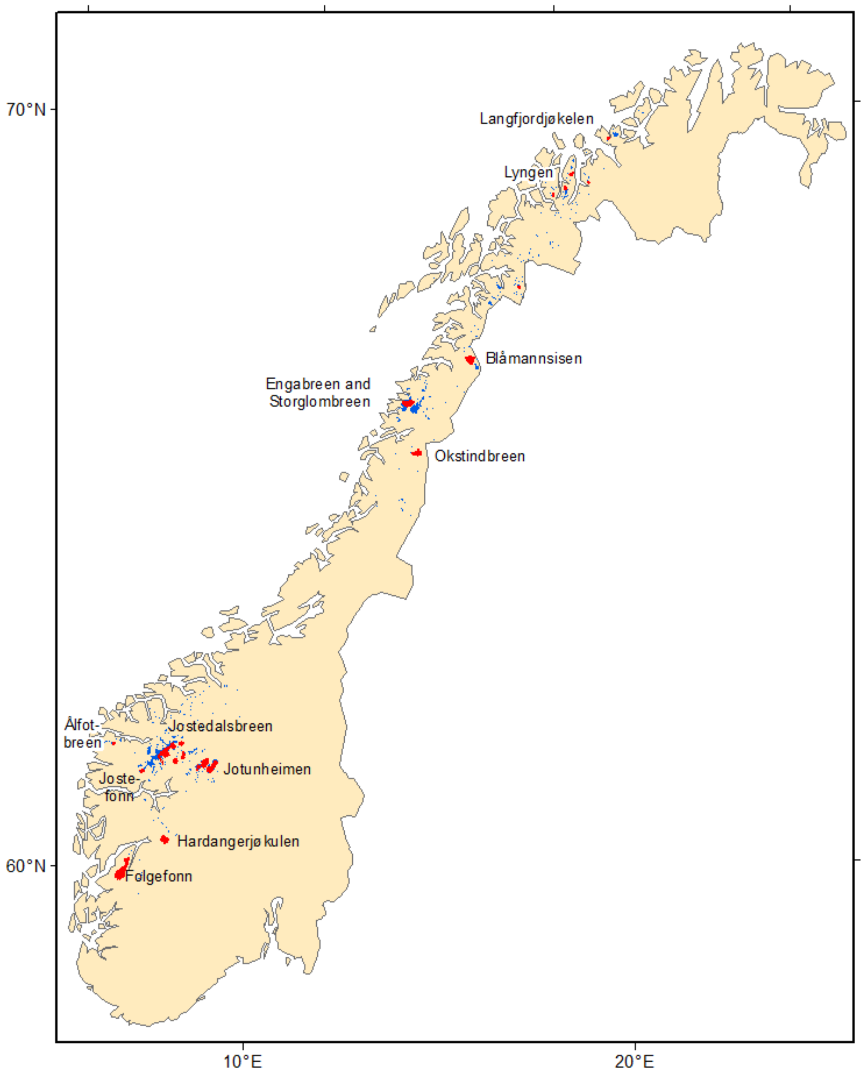


Figure 14-7
Overview of Lidar surveys of glaciers in Norway in 2007-2013. Scanned glaciers are shaded in red, other glaciers are shaded in blue.

Surveys in 2011 and 2013

Lidar surveys were carried out in 2011 and 2013 on several glaciers in Norway (Tab. 14-4 and Fig. 14-7). In 2011 surveys were carried out on Blåmannsisen, Okstindbreen, Jostefonn (Fig. 14-8), Spørteggbreen, Sekkebreen and the Galdhøpiggen massif in Jotunheimen. In 2013 surveys were carried out on Nigardsbreen, Tunsbergdalsbreen (both part of Jostedalsbreen), Folgefonna and part of Engabreen. Altogether about 550 km² were mapped.

Table 14-4
Lidar surveys in 2011 and 2013 and glacier area covered by survey.

Year	Glacier	Area (km²)
2011	Jostefonn, Spørteggbreen, Sekkebreen	63
2011	Galdhøpiggmassif	40
2011	Blåmannsisen	85
2011	Okstindbreen	50
2013	Folgefonn	219
2013	Nigardsbreen, Tunsbergdalsbreen	90
2013	Engabreen (part)	6
	Total	553

Together with previous campaigns in 2007-2010, one third of the total glacier area is now covered by detailed laser scanning, and campaigns include all glaciers with ongoing mass-balance measurement programmes. Folgefonna, Engabreen and Nigardsbreen are covered by repeated measurements. The campaigns have been funded by NVE with support from Statkraft and through the project "Mapping the Surface and surface changes of glaciers and ice caps in Norway, Iceland and Greenland with LiDAR", funded by Nordisk Ministerråd and EU project "Omega – Development of an Operational Monitoring System for European Glacial Areas". The data have been used to compare glaciological and geodetic mass balances of Langfjordjøkelen (Andreassen et al., 2012) and to reanalyse 10 long-term glacier mass balance series (Andreassen et al., 2016). The data have also been used in several master and Ph.D. theses (e.g. Engh, 2013; Linuza, 2014; Tachon, 2015; Smisted, 2015 and Messerli, 2015).

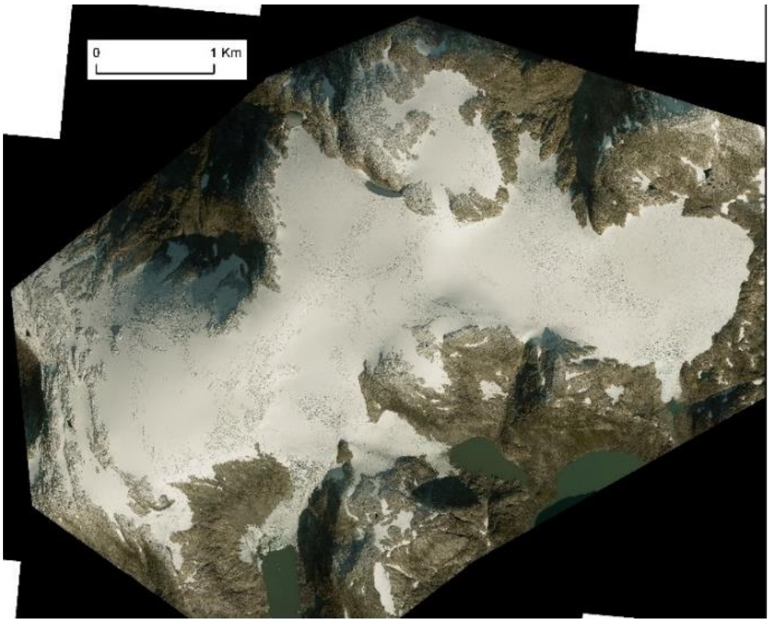


Figure 14-8
Jostefonn in southern Norway was one of the ice caps surveyed by lidar and orthophotos in 2011.

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Appendix A

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Appendix B

Mass balance measurements in Norway – an overview

Mass balance measurements were carried out at 45 Norwegian glaciers during the period 1949-2015. 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-	53
2 Hansebreen	2,8	927-1310	2010	1986-	30
Folgefonna					
3 Blomsterskardsbreen	45.7	850-1640	1959	1970-77	8
3a Svelgjabreen*	22.3	829-1632	2013	2007-	9
3b Blomstølskardsbreen*	22.4	1012-1632	2013	2007-	9
4 Bondhusbrea	10.7	477-1636	1979	1977-81	5
5 Breidablikkbrea	3.2	1232-1648	2013	1963-68, 2003-13	17
6 Gråfjellsbrea	8.1	1049-1647	2013	64-68, 74-75, 2003-13	18
7 Blåbreen	2.3	1060-1602	1959	1963-68	6
8 Ruklebreen	1.8	1603-1235	1959	1964-68	5
9 Midtre Folgefonna	8.6	1100-1570	1959	1970-71	2
Jostedalsbreen					
10 Jostefonn	3.8	960-1622	1993	1996-2000	5
11 Vesledalsbreen	4.1	1126-1745	1966	1967-72	6
12 Tunsbergdalsbreen	52.2	536-1942	1964	1966-72	7
13 Nigardsbreen	46.6	330-1952	2013	1962-	54
14 Store Supphellebreen	12.0	80-300/ 720-1740	1966	1964-67, 73-75, 79-82	11
15 Austdalsbreen	10.6	1197-1747	2009	1988-	28
16 Spørteggbreen	27.9	1260-1770	1988	1988-91	4
17 Harbardsbreen	13.2	1242-1978	1996	1997-2001	5
Hardangerjøkulen					
18 Rembesdalskåka	17.3	1066-1854	2010	1963-	53
19 Midtdalsbreen	6.7	1380-1862	1995	2000-2001	2
20 Omnsbreen	1.5	1460-1570	1969	1966-70	5
Jotunheimen					
21 Tverråbreen	5.9	1415-2200		1962-63	2
22 Blåbreen	3.6	1550-2150	1961	1962-63	2
23 Storbreen	5.1	1400-2102	2009	1949-	67
24 Vestre Memurubre	9.2	1565-2270	1966	1968-72	5
25 Austre Memurubre	8.7	1627-2277	1966	1968-72	5
26 Juvfonne	0.2	1840-1998	2004	2010-	6
27 Hellstugubreen	2.9	1482-2229	2009	1962-	54
28 Gråsubreen	2.1	1833-2284	2009	1962-	54
Okstindbreene					
29 Charles Rabot Bre	1.1	1090-1760	1965	1970-73	4
30 Austre Okstindbre	14.0	730-1750	1962	1987-96	10
Svartisen					
31 Høgtuvbreen	2.6	588-1162	1972	1971-77	7
32 Svartisheibreen	5.7	765-1424	1995	1988-94	7
33 Engabreen	38.7	89-1574	2008	1970-	46
34 Storglombreen	59.2 62.4	520-1580 520-1580	1968	1985-88 2000-05	10
35 Tretten-null-tobreen	4.3	580-1260	1968	1985-86	2
36 Glombreen	2.2	870-1110	1953	1954-56	3
37 Kjølbreen	3.9	850-1250	1953	1954-56	3
38 Trollbergdalsbreen	2.0 1.8	907-1366 907-1369	1968 1998	1970-75 1990-94	11
Blåmannsisen					
39 Rundvassbreen	11.7 10.9	788-1533 836-1525	1998 2011	2002-04, 2011-	8
Skjomen					
40 Blåisen	2.2	860-1204	1959	1963-68	6
41 Storsteinsfjellbreen	6.2 5.9	926-1846 969-1852	1960 1993	1964-68 1991-95	10
42 Cainhavarre	0.7	1214-1538	1960	1965-68	4
Vest-Finnmark					
43 Svartfjelljøkelen	2.7	500-1080	1966	1978-79	2
44 Langfjordjøkelen	3.6 3.2	277-1053 302-1050	1994 2008	1989-93, 1996-	25

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 694 years of measurements at Norwegian glaciers. The following tables show winter (B_w), summer (B_s) and annual balance (B_a) together with cumulative annual balance (Cum. B_a) and equilibrium line altitude (ELA) for each year at every glacier. The column to the right shows whether the reported mass balance series are original (O), homogenised (H) or calibrated (C). 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 km² (2010)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1963	2,52	-3,21	-0,70	-0,70	1270	H
2	64	2,66	-2,38	0,29	-0,41	1165	H
3	65	3,75	-3,07	0,68	0,27	1105	H
4	66	2,40	-3,93	-1,53	-1,26	>1380	H
5	67	4,43	-3,12	1,30	0,04	1020	H
6	68	4,65	-3,64	1,01	1,06	1090	H
7	69	2,58	-4,92	-2,34	-1,29	>1380	H
8	1970	2,65	-3,78	-1,13	-2,41	>1380	H
9	71	4,14	-3,31	0,83	-1,58	1130	H
10	72	3,78	-3,74	0,04	-1,54	1205	H
11	73	4,57	-2,56	2,01	0,47	<869	H
12	74	3,49	-2,63	0,85	1,32	1080	H
13	75	4,32	-3,50	0,82	2,14	undef.	H
14	76	4,37	-3,06	1,31	3,45	<869	H
15	77	2,31	-2,94	-0,63	2,82	undef.	H
16	78	2,46	-3,08	-0,62	2,20	1340	H
17	79	3,20	-3,36	-0,15	2,05	1250	H
18	1980	2,48	-3,21	-0,73	1,32	1295	H
19	81	4,04	-3,81	0,24	1,56	1195	H
20	82	3,30	-3,31	-0,01	1,54	undef.	H
21	83	4,61	-3,23	1,38	2,92	1005	H
22	84	4,22	-2,85	1,38	4,30	undef.	H
23	85	2,48	-2,98	-0,50	3,80	1295	H
24	86	2,34	-2,95	-0,61	3,19	undef.	H
25	87	4,45	-2,38	2,07	5,27	995	H
26	88	2,69	-5,18	-2,50	2,77	>1376	H
27	89	5,29	-2,95	2,34	5,11	1035	H
28	1990	5,96	-4,19	1,76	6,88	995	H
29	91	3,44	-2,87	0,57	7,44	1085	H
30	92	5,48	-3,08	2,39	9,84	1020	H
31	93	4,69	-2,82	1,87	11,71	<903	H
32	94	3,72	-2,92	0,80	12,51	975	H
33	95	5,14	-3,91	1,23	13,74	1105	H
34	96	1,87	-3,82	-1,94	11,80	>1383	H
35	97	4,09	-4,25	-0,16	11,64	1220	H
36	98	3,35	-3,83	-0,48	11,15	1255	C
37	99	4,32	-4,69	-0,37	10,78	1265	C
38	2000	4,90	-3,77	1,14	11,92	1105	C
39	01	1,76	-4,28	-2,52	9,39	>1383	C
40	02	3,50	-5,57	-2,07	7,32	>1383	C
41	03	2,26	-5,29	-3,03	4,29	>1383	C
42	04	3,09	-3,58	-0,48	3,81	1265	C
43	05	4,74	-4,42	0,32	4,13	1185	C
44	06	2,51	-6,16	-3,65	0,48	>1368	C
45	07	4,23	-3,36	0,86	1,34	1055	C
46	08	4,32	-3,99	0,33	1,67	1160	C
47	09	3,60	-4,19	-0,58	1,09	1315	C
48	2010	2,03	-4,33	-2,30	-1,21	>1368	C
49	11	3,53	-4,38	-0,84	-2,05	>1368	O
50	12	3,87	-2,51	1,36	-0,69	1020	O
51	13	3,15	-4,06	-0,90	-1,60	>1368	O
52	14	3,64	-5,29	-1,65	-3,25	>1368	O
53	15	4,21	-2,81	1,40	-1,85	1020	O
Mean 1963-2015		3,61	-3,65	-0,03			

2 Hansebreen - 2.8 km² (2010)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1986	2,16	-2,86	-0,70	-0,70	undef.	H
2	87	3,50	-2,62	0,88	0,18	1110	H
3	88	2,48	-5,23	-2,75	-2,57	>1318	H
4	89	4,36	-3,40	0,96	-1,61	1095	C
5	1990	4,36	-3,87	0,49	-1,12	1130	C
6	91	3,21	-2,73	0,48	-0,64	1105	C
7	92	4,55	-3,31	1,25	0,61	1095	C
8	93	4,50	-3,02	1,48	2,09	<929	C
9	94	3,53	-2,59	0,94	3,03	1085	C
10	95	4,62	-3,53	1,09	4,12	undef.	C
11	96	1,92	-3,16	-1,24	2,88	>1325	C
12	97	3,86	-3,50	0,36	3,24	1130	C
13	98	3,03	-3,64	-0,60	2,64	1195	C
14	99	4,16	-4,31	-0,14	2,49	1165	C
15	2000	4,47	-3,92	0,55	3,04	1105	C
16	01	1,63	-4,67	-3,04	0,00	>1325	C
17	02	3,43	-5,56	-2,14	-2,14	>1325	C
18	03	2,28	-5,19	-2,90	-5,04	>1325	C
19	04	2,83	-3,75	-0,93	-5,97	>1310	C
20	05	4,39	-4,77	-0,38	-6,35	1170	C
21	06	2,33	-6,71	-4,37	-10,72	>1310	C
22	07	3,91	-3,30	0,61	-10,11	1060	C
23	08	4,10	-3,93	0,17	-9,95	1120	C
24	09	3,35	-4,55	-1,20	-11,15	>1310	C
25	2010	2,00	-4,51	-2,50	-13,66	>1310	C
26	11	3,43	-4,68	-1,25	-14,91	>1310	O
27	12	3,61	-2,79	0,82	-14,09	1085	O
28	13	2,84	-4,53	-1,69	-15,77	>1310	O
29	14	3,54	-5,65	-2,11	-17,89	>1310	O
30	15	4,08	-3,07	1,01	-16,88	<927	O
Mean 1986-2015		3,42	-3,98	-0,56			

3 Blomsterskardsbreen - 45.7 km² (1959)

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

3a Svelgjabreen - 22.3 km² (2013)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	2007	3,89	-2,54	1,35	1,35	1205	O
2	08	3,38	-2,65	0,72	2,07	1235	O
3	09	3,33	-2,97	0,36	2,43	1310	O
4	2010	1,65	-3,29	-1,64	0,78	>1636	O
5	11	2,58	-3,84	-1,26	-0,48	1525	O
6	12	3,38	-2,08	1,29	0,81	1190	O
7	13	2,58	-3,31	-0,73	0,09	1485	O
8	14	3,30	-3,76	-0,46	-0,37	1460	O
9	15	3,46	-1,63	1,84	1,46	1140	O
Mean 2007-15		3,06	-2,90	0,16			

3b Blomstølskardsbreen - 22.4 km^2 (2013)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	2007	4,17	-2,30	1,88	1,88	1230	O
2	08	3,44	-2,14	1,30	3,18	1265	O
3	09	3,59	-2,52	1,07	4,24	1290	O
4	2010	1,85	-3,07	-1,23	3,02	>1636	O
5	11	2,52	-3,49	-0,97	2,05	1600	O
6	12	3,50	-1,92	1,59	3,64	1255	O
7	13	2,93	-3,17	-0,23	3,40	1470	O
8	14	3,46	-3,56	-0,09	3,31	1470	O
9	15	3,41	-1,42	1,99	5,30	1250	O
Mean 2007-15		3,21	-2,62	0,59			

4 Bondhusbrea - 10.7 km^2 (1979)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	77	1,88	-3,00	-1,11	-1,11	1615	H
2	78	2,377	-2,90	-0,52	-1,63	1545	H
3	79	2,70	-2,49	0,21	-1,43	1470	H
4	1980	2,36	-2,82	-0,46	-1,88	1540	H
5	81	3,37	-1,99	1,38	-0,51	1445	H
Mean 1977-81		2,54	-2,64	-0,10			

5 Breidablikkbrea - 3.2 km^2 (2013)

No. of years	Year	B_w	B_s	B_s	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1963	1,11	-2,40	-1,29	-1,29	1635	H
2	64	1,79	-1,71	0,08	-1,20	1485	H
3	65	1,70	-2,26	-0,55	-1,76	1520	H
4	66	1,57	-3,23	-1,67	-3,42	>1660	H
5	67	2,94	-1,72	1,23	-2,20	1355	H
6	68	3,44	-2,69	0,75	-1,44	1370	H
7	2003	2,12	-4,38	-2,26	-2,26	>1651	H
8	04	2,25	-3,12	-0,87	-3,13	1595	H
9	05	3,04	-3,37	-0,33	-3,45	1510	H
10	06	1,49	-4,44	-2,95	-6,40	>1651	H
11	07	3,42	-3,07	0,36	-6,05	1410	H
12	08	2,66	-2,96	-0,30	-6,34	1515	O
13	09	2,47	-2,98	-0,52	-6,86	1565	O
14	2010	1,60	-3,53	-1,94	-8,80	>1651	O
15	11	1,88	-4,16	-2,28	-11,08	>1648	O
16	12	3,19	-2,06	1,13	-9,95	1290	O
17	13			-1,11	-11,06	>1648	O
Mean 1963-68		2,09	-2,33	-0,24			
Mean 2003-12(13)		2,41	-3,41	-1,01			

6 Gråfjellsbrea - 8.1 km^2 (2013)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1964	1,93	-1,62	0,31	0,31	1395	H
2	65	1,95	-2,31	-0,37	-0,06	1505	H
3	66	1,54	-2,88	-1,33	-1,39	>1656	H
4	67	3,00	-1,70	1,30	-0,10	1350	H
5	68	3,46	-2,84	0,62	0,53	1395	H
6	1974	2,17	-1,55	0,62	0,62	1370	H
7	75	2,57	-2,28	0,28	0,90	1425	H
8	2003	1,91	-4,09	-2,18	-2,18	>1651	H
9	04	2,05	-2,82	-0,76	-2,95	1565	H
10	05	3,15	-3,13	0,02	-2,93	1460	H
11	06	1,40	-4,55	-3,15	-6,07	>1651	H
12	07	3,60	-2,85	0,75	-5,32	1395	H
13	08	2,66	-2,80	-0,14	-5,46	1490	O
14	09	2,34	-2,88	-0,54	-6,00	1540	O
15	2010	1,51	-3,35	-1,84	-7,84	>1651	O
16	11	1,89	-4,09	-2,20	-10,05	>1647	O
17	12	2,94	-1,73	1,21	-8,84	1280	O
18	13			-1,15	-9,99	>1647	O
Mean 1964-68		2,38	-2,27	0,11			
Mean 1974-75		2,37	-1,92	0,45			
Mean 2003-12(13)		2,34	-3,23	-0,91			

7 Blåbreen - 2.3 km^2 (1959)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1963	1,15	-3,44	-2,30	-2,30	>1602	H
2	64	1,929	-1,76	0,17	-2,13	1375	H
3	65	1,87	-2,69	-0,82	-2,95	1500	H
4	66	1,58	-3,52	-1,94	-4,89	>1602	H
5	67	3,09	-2,30	0,79	-4,10	1300	H
6	68	2,54	-3,16	-0,61	-4,72	1475	H
Mean 1963-68		2,03	-2,81	-0,79			

8 Ruklebreen - 1.8 km^2 (1959)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1964	2,23	-1,55	0,68	0,68	1375	H
2	65	1,90	-2,08	-0,18	0,50	1485	H
3	66	1,81	-3,13	-1,33	-0,83	>1602	H
4	67	3,24	-2,04	1,19	0,36	1360	H
5	68	3,25	-2,56	0,69	1,06	1400	H
Mean 1964-68		2,49	-2,27	0,21			

9 Midtre Folgefonna - 8.7 km^2 (1959)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1970	2,07	-2,69	-0,62	-0,62	>1580	O
2	71	2,33	-1,96	0,37	-0,25	1260	O
Mean 1970-71		2,20	-2,33	-0,13			

10 Jostefonn - 3.8 km^2 (1993)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1996	1,19	-2,81	-1,63	-1,63	>1620	O
2	97	3,45	-3,87	-0,42	-2,05	1500	O
3	98	2,84	-2,54	0,30	-1,75	1250	O
4	99	2,92	-2,54	0,38	-1,37	1200	O
5	2000	3,49	-2,47	1,03	-0,34	1050	O
Mean 1996-2000		2,78	-2,85	-0,07			

11 Vesledalsbreen - 4.1 km^2 (1966)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1967	2,22	-1,69	0,52	0,52	1375	H
2	68	3,10	-2,51	0,59	1,12	1325	H
3	69	1,30	-3,48	-2,18	-1,07	>1745	H
4	1970	1,49	-2,71	-1,21	-2,28	>1745	H
5	71	2,22	-1,81	0,40	-1,88	1340	H
6	72	1,97	-2,37	-0,40	-2,28	1460	H
Mean 1967-72		2,05	-2,43	-0,38			

12 Tunsbergdalsbreen - 52.2 km^2 (1964)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1966	1,65	-2,57	-0,93	-0,93	1645	H
2	67	3,43	-1,41	2,02	1,09	1160	H
3	68	2,81	-2,61	0,20	1,29	1355	H
4	69	1,52	-3,19	-1,66	-0,37	1715	H
5	1970	1,58	-2,22	-0,64	-1,01	1560	H
6	71	2,42	-1,76	0,66	-0,36	1305	H
7	72	2,10	-2,46	-0,36	-0,71	1435	H
Mean 1966-72		2,22	-2,32	-0,10			

13 Nigardsbreen - 46.6 km^2 (2013)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1962	2,11	0,17	2,27	2,27	1295	H
2	63	1,78	-1,96	-0,19	2,09	1550	H
3	64	1,96	-1,19	0,76	2,85	1460	H
4	65	1,93	-1,17	0,76	3,61	1410	H
5	66	1,74	-2,69	-0,95	2,66	1695	H
6	67	2,98	-1,18	1,80	4,46	1330	H
7	68	2,49	-2,41	0,09	4,54	1555	H
8	69	1,69	-3,14	-1,45	3,09	1890	H
9	1970	1,67	-2,30	-0,63	2,46	1655	H
10	71	2,17	-1,31	0,85	3,32	1425	H
11	72	1,79	-2,02	-0,23	3,09	1595	H
12	73	2,47	-1,41	1,06	4,15	1405	H
13	74	1,93	-1,72	0,21	4,36	1540	H
14	75	2,43	-2,41	0,02	4,38	1520	H
15	76	2,87	-2,44	0,44	4,82	1530	H
16	77	1,49	-2,33	-0,83	3,98	1670	H
17	78	2,00	-2,24	-0,24	3,74	1610	H
18	79	2,43	-2,10	0,34	4,08	1560	H
19	1980	1,76	-3,03	-1,28	2,80	1735	H
20	81	2,19	-1,98	0,21	3,02	1150	H
21	82	1,88	-2,30	-0,42	2,60	1615	H
22	83	2,94	-2,03	0,91	3,51	1455	H
23	84	2,49	-2,30	0,19	3,70	1530	H
24	85	1,60	-2,39	-0,79	2,91	1690	C
25	86	1,34	-1,95	-0,62	2,29	1645	C
26	87	2,47	-1,57	0,90	3,19	1460	C
27	88	2,08	-3,37	-1,30	1,89	1720	C
28	89	3,36	-0,93	2,42	4,32	1280	C
29	1990	3,34	-2,22	1,12	5,44	1450	C
30	91	1,79	-2,03	-0,24	5,20	1585	C
31	92	2,66	-1,53	1,13	6,33	1410	C
32	93	2,52	-1,40	1,12	7,45	1410	C
33	94	2,01	-1,85	0,15	7,60	1500	C
34	95	2,85	-2,03	0,82	8,42	1360	C
35	96	1,25	-1,99	-0,74	7,68	1690	C
36	97	2,45	-2,98	-0,53	7,15	1690	C
37	98	2,29	-1,83	0,46	7,61	1470	C
38	99	2,21	-2,39	-0,18	7,43	1570	C
39	2000	3,13	-1,86	1,27	8,70	1325	C
40	01	1,69	-2,09	-0,40	8,30	1600	C
41	02	2,24	-3,47	-1,23	7,07	1800	C
42	03	1,49	-3,01	-1,52	5,55	>1957	C
43	04	1,83	-2,23	-0,40	5,15	1610	C
44	05	2,72	-1,83	0,89	6,04	1430	C
45	06	1,63	-3,36	-1,73	4,31	>1957	C
46	07	2,86	-2,20	0,66	4,97	1365	C
47	08	2,82	-2,04	0,78	5,76	1370	C
48	09	2,04	-2,10	-0,06	5,70	1525	C
49	2010	1,36	-2,46	-1,10	4,59	>1957	C
50	11	1,72	-2,86	-1,13	3,46	1770	C
51	12	2,71	-1,73	0,98	4,45	1330	C
52	13	2,30	-2,96	-0,65	3,79	1680	C
53	14	2,73	-3,07	-0,34	3,45	1550	O
54	15	3,07	-1,35	1,71	5,16	1310	O
Mean 1962-2015		2,22	-2,12	0,10			

14 Store Supphellebreen - 12.0 km^2 (1966)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1964	2,20	-1,50	0,70	0,70	1190	O
2	65	2,32	-1,76	0,56	1,26	1250	O
3	66	1,63	-2,40	-0,77	0,49	1590	O
4	67	2,72	-1,50	1,22	1,71	1190	O
5	73			1,50	1,50		O
6	74			0,80	2,30		O
7	75			1,00	3,30		O
8	79			1,10	1,10		O
9	1980			-1,40	-0,30		O
10	81			0,20	-0,10		O
11	82			-1,70	-1,80		O
Mean 1964-67		2,22	-1,79	0,43			
Mean 1973-75				1,10			
Mean 1979-82				-0,45			

15 Austdalsbreen - 10.6 km^2 (2009)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1988	1,95	-3,37	-1,42	-1,42	1575	H
2	89	3,19	-1,87	1,32	-0,10	1271	H
3	1990	3,66	-3,24	0,42	0,32	1315	H
4	91	1,66	-1,81	-0,15	0,17	1420	H
5	92	2,80	-2,61	0,19	0,36	1375	H
6	93	2,60	-2,18	0,42	0,78	1321	H
7	94	1,80	-2,12	-0,32	0,46	1425	H
8	95	2,71	-2,40	0,31	0,77	1358	H
9	96	1,20	-2,54	-1,34	-0,57	1566	H
10	97	2,67	-3,53	-0,86	-1,43	1450	H
11	98	2,21	-2,32	-0,11	-1,54	1407	H
12	99	2,10	-2,56	-0,46	-2,00	1461	H
13	2000	3,02	-1,77	1,25	-0,75	1337	H
14	01	1,23	-2,76	-1,53	-2,28	>1747	H
15	02	2,11	-3,94	-1,83	-4,11	>1747	H
16	03	1,61	-3,94	-2,33	-6,44	>1747	H
17	04	1,61	-2,56	-0,95	-7,39	1500	H
18	05	2,86	-2,63	0,23	-7,16	1388	H
19	06	1,33	-3,37	-2,04	-9,20	>1747	H
20	07	2,48	-2,28	0,20	-9,00	1407	H
21	08	2,57	-2,63	-0,06	-9,06	1422	H
22	09	1,92	-2,63	-0,71	-9,77	1458	H
23	2010	1,02	-3,05	-2,03	-11,80	>1747	H
24	11	1,82	-3,26	-1,44	-13,24	>1747	H
25	12	2,68	-1,91	0,77	-12,47	1368	H
26	13	1,61	-3,26	-1,65	-14,12	>1747	H
27	14	2,14	-3,44	-1,30	-15,42	>1747	H
28	15	2,53	-1,80	0,73	-14,69	1371	O
Mean 1988-2015		2,18	-2,71	-0,52			

16 Spørteggbreen - 27.9 km^2 (1988)

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

17 Harbardsbreen - 13.2 km^2 (1996)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1997	2,18	-2,74	-0,55	-0,55	Undef.	H
2	98	1,65	-1,65	0,00	-0,56	1535	H
3	99	1,78	-2,15	-0,37	-0,93	>1978	H
4	2000	2,29	-1,71	0,58	-0,35	1405	H
5	01	1,00	-2,24	-1,24	-1,59	>1978	H
Mean 1997-2001		1,78	-2,10	-0,32			

18 Rembesdalskåka - 17.3 km^2 (2010)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1963	1,15	-2,55	-1,40	-1,40	>1860	O
2	64	1,36	-0,90	0,46	-0,94	1655	H
3	65	1,88	-1,36	0,52	-0,42	1644	H
4	66	1,35	-1,97	-0,62	-1,04	1780	H
5	67	2,44	-1,26	1,18	0,14	1569	H
6	68	2,67	-2,16	0,51	0,65	1668	H
7	69	1,06	-2,98	-1,92	-1,26	>1860	H
8	1970	1,30	-1,89	-0,58	-1,85	1775	H
9	71	1,95	-1,26	0,70	-1,15	1604	H
10	72	1,78	-1,81	-0,04	-1,19	1663	H
11	73	2,62	-1,79	0,84	-0,35	1587	H
12	74	1,90	-1,50	0,40	0,05	1658	H
13	75	2,25	-2,10	0,15	0,20	1625	H
14	76	2,45	-2,29	0,15	0,35	1672	H
15	77	1,18	-1,96	-0,78	-0,43	>1860	H
16	78	1,80	-2,10	-0,30	-0,73		O
17	79	2,40	-2,10	0,30	-0,43		O
18	1980	1,45	-2,85	-1,40	-1,83	>1862	O
19	81	2,70	-1,75	0,95	-0,88	1611	H
20	82	1,44	-2,06	-0,62	-1,50	>1862	H
21	83	3,85	-1,94	1,91	0,41	1450	H
22	84	2,05	-2,15	-0,10	0,31	1675	O
23	85	1,61	-1,95	-0,34	-0,03	1741	H
24	86	1,47	-1,55	-0,07	-0,10	1692	H
25	87	2,09	-1,13	0,96	0,86	1557	H
26	88	1,62	-3,09	-1,46	-0,60	>1862	H
27	89	3,49	-1,36	2,13	1,53	1439	H
28	1990	3,65	-1,69	1,96	3,49	1475	H
29	91	1,52	-1,62	-0,10	3,39	1688	H
30	92	3,52	-1,68	1,84	5,23	1525	H
31	93	2,82	-0,89	1,93	7,16	1475	H
32	94	1,80	-1,62	0,18	7,34	1633	H
33	95	2,45	-2,12	0,33	7,67	1600	H
34	96	0,86	-2,37	-1,51	6,16	>1862	C
35	97	2,74	-3,64	-0,90	5,26	>1862	C
36	98	2,22	-1,97	0,25	5,51	1661	C
37	99	1,82	-2,20	-0,38	5,13	1768	C
38	2000	2,64	-1,82	0,82	5,95	1550	C
39	01	1,03	-2,13	-1,10	4,85	>1862	C
40	02	2,19	-3,34	-1,15	3,70	>1862	C
41	03	1,18	-2,98	-1,80	1,90	>1854	C
42	04	1,66	-2,02	-0,36	1,54	1733	C
43	05	2,54	-2,25	0,29	1,83	1661	C
44	06	0,80	-3,46	-2,66	-0,83	>1854	C
45	07	2,83	-2,10	0,73	-0,10	1636	C
46	08	2,37	-2,34	0,03	-0,07	1663	C
47	09	2,14	-2,43	-0,29	-0,36	1725	C
48	2010	1,14	-3,09	-1,95	-2,31	>1854	C
49	11	2,13	-3,40	-1,27	-3,59	>1854	H
50	12	2,65	-1,74	0,91	-2,68	1589	H
51	13	1,61	-2,84	-1,22	-3,90	>1854	H
52	14	2,17	-3,46	-1,29	-5,20	>1854	H
53	15	3,00	-1,82	1,18	-4,01	1570	H
Mean 1963-2015		2,05	-2,13	-0,08			

19 Midtdalsbreen - 6.7 km^2 (1995)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	2000	2,89	-1,57	1,32	1,32	1500	O
2	01	1,26	-1,90	-0,64	0,68	1785	O
Mean 2000-2001		2,08	-1,74	0,34			

20 Omnsbreen - 1.5 km^2 (1969)

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

21 Tverråbreen - 5.9 km^2

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1962	2,03	-1,28	0,75	0,75		O
2	63	1,24	-2,46	-1,22	-0,47		O
Mean 1962-63		1,64	-1,87	-0,24			

22 Blåbreen - 3.6 km^2 (1961)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1962	1.15	-0.35	0.80	0.80	<1550	O
2	63	0.85	-1.71	-0.86	-0.06	1970	O
Mean 1962-63		1.00	-1.03	-0.03			

23 Storbreen - 5.1 km^2 (2009)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	49	2.28	-2.08	0.20	0.20	1650	O
2	1950	1.52	-1.81	-0.29	-0.09	1750	O
3	51	1.13	-1.67	-0.54	-0.63	1770	O
4	52	1.44	-1.13	0.31	-0.32	1630	O
5	53	1.40	-2.25	-0.85	-1.17	1850	O
6	54	1.21	-1.98	-0.77	-1.94	1830	O
7	55	1.57	-2.06	-0.49	-2.43	1800	O
8	56	1.31	-1.48	-0.17	-2.60	1705	O
9	57	1.42	-1.37	0.05	-2.55	1680	O
10	58	1.54	-1.62	-0.08	-2.63	1700	O
11	59	1.07	-2.35	-1.28	-3.91	1930	O
12	1960	0.98	-2.07	-1.09	-5.00	1910	O
13	61	1.10	-1.62	-0.52	-5.52	1820	O
14	62	1.54	-0.82	0.72	-4.80	1510	O
15	63	0.96	-2.14	-1.18	-5.98	1900	O
16	64	1.16	-0.95	0.21	-5.77	1655	O
17	65	1.54	-1.20	0.34	-5.43	1650	O
18	66	1.25	-1.86	-0.61	-6.04	1815	O
19	67	1.89	-1.17	0.72	-5.32	1570	O
20	68	1.64	-1.59	0.05	-5.27	1700	O
21	69	1.22	-2.64	-1.42	-6.69	2020	O
22	1970	0.97	-1.69	-0.72	-7.41	1840	O
23	71	1.46	-1.28	0.18	-7.23	1690	O
24	72	1.39	-1.70	-0.31	-7.54	1770	O
25	73	1.48	-1.40	0.08	-7.46	1705	O
26	74	1.26	-1.02	0.24	-7.22	1630	O
27	75	1.55	-1.70	-0.15	-7.37	1760	O
28	76	1.81	-1.90	-0.09	-7.46	1740	O
29	77	0.94	-1.48	-0.54	-8.00	1840	O
30	78	1.26	-1.70	-0.44	-8.44	1815	O
31	79	1.55	-1.45	0.10	-8.34	1700	O
32	1980	0.99	-2.30	-1.31	-9.65	1975	O
33	81	1.30	-1.40	-0.10	-9.75	1730	O
34	82	1.28	-1.75	-0.47	-10.22	1785	O
35	83	1.90	-1.70	0.20	-10.02	1625	O
36	84	1.70	-2.00	-0.30	-10.32	1765	O
37	85	1.20	-1.60	-0.40	-10.72	1790	O
38	86	1.05	-1.37	-0.32	-11.04	1770	O
39	87	1.55	-1.23	0.32	-10.72	1570	O
40	88	1.45	-2.40	-0.95	-11.67	1970	O
41	89	2.30	-1.10	1.20	-10.47	1550	O
42	1990	2.60	-1.35	1.25	-9.22	1530	O
43	91	1.28	-1.35	-0.07	-9.29	1740	H
44	92	1.62	-1.49	0.13	-9.16	1715	H
45	93	1.82	-1.01	0.81	-8.35	1605	H
46	94	1.53	-1.74	-0.21	-8.56	1800	H
47	95	1.79	-1.89	-0.10	-8.66	1810	H
48	96	0.83	-1.80	-0.97	-9.63	1890	H
49	97	1.77	-2.74	-0.96	-10.59	1875	H
50	98	1.55	-1.33	0.22	-10.37	1680	O
51	99	1.67	-1.91	-0.24	-10.61	1830	O
52	2000	2.04	-1.49	0.55	-10.06	1650	O
53	01	1.05	-1.32	-0.27	-10.33	1845	O
54	02	1.09	-2.87	-1.78	-12.11	2075	O
55	03	1.07	-2.79	-1.72	-13.83	2025	H
56	04	0.97	-1.71	-0.74	-14.58	1855	H
57	05	1.77	-2.04	-0.27	-14.84	1795	H
58	06	0.81	-3.08	-2.27	-17.12	>2090	H
59	07	1.30	-1.81	-0.51	-17.63	1835	H
60	08	1.90	-2.01	-0.10	-17.73	1770	H
61	09	1.60	-1.83	-0.22	-17.95	1760	O
62	2010	0.79	-2.55	-1.76	-19.71	1990	O
63	11	0.99	-2.57	-1.58	-21.29	2005	O
64	12	1.68	-1.62	0.06	-21.23	1725	O
65	13	1.31	-2.47	-1.16	-22.39	1900	O
66	14	1.57	-2.74	-1.17	-23.56	1870	O
67	15	1.52	-1.03	0.49	-23.07	1575	O
Mean 1949-2015		1.43	-1.77	-0.34			

24 Vestre Memurubre - 9.2 km^2 (1966)

No. of years	Year	bw	bs	bn	Cum. bn	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1968	1,67	-1,48	0,19	0,19	1830	H
2	69	0,95	-2,14	-1,19	-0,99	2125	H
3	1970	0,80	-1,59	-0,80	-1,79	1980	H
4	71	1,23	-1,23	0,00	-1,79	1845	H
5	72	1,14	-1,54	-0,41	-2,19	1915	H
Mean 1968-72		1,16	-1,60	-0,44			

25 Austre Memurubre - 8.7 km^2 (1966)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1968	1,56	-1,66	-0,10	-0,10	1950	H
2	69	0,85	-2,35	-1,50	-1,60	2170	H
3	1970	0,77	-1,68	-0,91	-2,51	2085	H
4	71	1,16	-1,48	-0,32	-2,83	2000	H
5	72	0,99	-1,56	-0,58	-3,41	2055	H
Mean 1968-72		1,06	-1,75	-0,68			

26 Juvfonne - 0.2 km^2 (2004)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	2010	0,67	-3,91	-3,24	-3,24	<1998	O
2	11	1,17	-3,05	-1,88	-5,12		O
3	12	1,44	-1,38	0,06	-5,06		O
4	13	0,96	-2,51	-1,55	-6,61		O
5	14	1,21	-3,51	-2,30	-8,91		O
6	15	1,46	-0,89	0,57	-8,34		O
Mean 2010-15							

27 Hellstugubreen - 2.9 km^2 (2009)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1962	1,18	-0,40	0,78	0,78		O
2	63	0,94	-1,92	-0,98	-0,20	2020	O
3	64	0,72	-0,81	-0,09	-0,29	1900	H
4	65	1,30	-0,75	0,55	0,26	1690	H
5	66	0,96	-1,59	-0,63	-0,38	1940	H
6	67	1,50	-0,90	0,60	0,22	1800	H
7	68	1,40	-1,47	-0,08	0,14	1875	H
8	69	0,96	-2,20	-1,24	-1,10	2130	H
9	1970	0,70	-1,67	-0,96	-2,06	2020	H
10	71	1,12	-1,24	-0,11	-2,17	1860	H
11	72	0,94	-1,42	-0,48	-2,65	1950	H
12	73	1,20	-1,41	-0,21	-2,87	1880	H
13	74	1,01	-0,73	0,29	-2,58	1785	H
14	75	1,36	-1,69	-0,33	-2,92	1950	H
15	76	1,15	-1,87	-0,72	-3,63	1970	H
16	77	0,69	-1,37	-0,69	-4,32	2075	H
17	78	1,06	-1,55	-0,48	-4,80	1890	H
18	79	1,44	-1,43	0,01	-4,79	1820	H
19	1980	0,82	-2,01	-1,20	-5,99	2050	H
20	81	1,06	-1,40	-0,34	-6,33	1950	H
21	82	0,85	-1,22	-0,37	-6,69	1920	H
22	83	1,47	-1,31	0,16	-6,54	1820	H
23	84	1,22	-1,74	-0,52	-7,06	1965	H
24	85	1,11	-1,42	-0,31	-7,37	1880	H
25	86	0,78	-1,28	-0,51	-7,88	1940	H
26	87	1,15	-0,71	0,44	-7,43	1690	H
27	88	1,28	-2,33	-1,05	-8,48	2025	H
28	89	1,66	-0,87	0,79	-7,69	1660	H
29	1990	1,83	-1,10	0,72	-6,97	1640	H
30	91	0,99	-1,40	-0,42	-7,39	1950	H
31	92	1,18	-0,99	0,18	-7,20	1850	H
32	93	1,26	-0,92	0,34	-6,86	udef.	H
33	94	1,27	-1,15	0,12	-6,74	1850	H
34	95	1,43	-1,50	-0,07	-6,80	1885	H
35	96	0,66	-1,34	-0,68	-7,48	1955	H
36	97	1,14	-2,73	-1,60	-9,08	2200	H
37	98	1,01	-0,98	0,03	-9,04	1870	H
38	99	1,24	-1,60	-0,36	-9,41	1930	H
39	2000	1,29	-1,09	0,19	-9,22	1840	H
40	01	0,85	-1,21	-0,36	-9,58	1910	H
41	02	0,96	-2,37	-1,41	-10,99	2080	H
42	03	0,72	-2,15	-1,43	-12,42	2200	H
43	04	0,65	-1,47	-0,81	-13,24	1980	H
44	05	1,35	-1,61	-0,26	-13,49	1930	H
45	06	0,73	-2,72	-1,99	-15,48	>2210	H
46	07	1,03	-1,68	-0,65	-16,13	1975	H
47	08	1,42	-1,45	-0,03	-16,16	1880	H
48	09	1,30	-1,53	-0,23	-16,39	1920	O
49	2010	0,75	-2,09	-1,34	-17,73	>2230	O
50	11	0,83	-2,87	-2,04	-19,77	>2230	O
51	12	1,21	-1,22	-0,01	-19,78	1875	O
52	13	1,05	-1,83	-0,78	-20,56	1980	O
53	14	1,11	-2,33	-1,22	-21,78	2025	O
54	15	1,21	-0,72	0,49	-21,29	1770	O
Mean 1962-2015		1,10	-1,50	-0,39			

28 Gråsubreen - 2.1 km^2 (2009)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1962	0.86	-0.09	0.77	0.77	1870	O
2	63	0.40	-1.11	-0.71	0.06	2350	O
3	64	0.36	-0.71	-0.35	-0.29	2160	O
4	65	0.77	-0.36	0.41	0.12	1890	O
5	66	0.72	-1.01	-0.29	-0.17	2150	O
6	67	1.45	-0.74	0.71	0.54	1870	O
7	68	1.03	-1.11	-0.08	0.46	2140	O
8	69	0.70	-2.05	-1.36	-0.90	2275	O
9	1970	0.57	-1.24	-0.66	-1.56	2200	O
10	71	0.49	-0.97	-0.47	-2.03	2200	O
11	72	0.66	-1.30	-0.64	-2.67	2240	O
12	73	0.72	-1.61	-0.89	-3.56	2275	O
13	74	0.59	-0.24	0.34	-3.22	1870	O
14	75	0.91	-1.86	-0.95	-4.17	2275	O
15	76	0.62	-1.62	-1.00	-5.17	2275	O
16	77	0.51	-0.90	-0.39	-5.56	2275	O
17	78	0.67	-0.89	-0.22	-5.78	2140	O
18	79	0.91	-0.87	0.04	-5.73	undef.	O
19	1980	0.43	-1.32	-0.89	-6.62	2225	O
20	81	0.60	-0.79	-0.19	-6.81	2180	O
21	82	0.50	-1.01	-0.51	-7.32	2275	O
22	83	0.93	-0.98	-0.05	-7.38	undef.	O
23	84	0.98	-1.35	-0.37	-7.75	2275	H
24	85	0.76	-0.76	0.00	-7.75	2100	H
25	86	0.42	-1.18	-0.76	-8.51	2275	H
26	87	0.95	-0.24	0.71	-7.80	1870	H
27	88	1.08	-1.68	-0.60	-8.40	2195	H
28	89	1.12	-0.67	0.45	-7.95	1870	H
29	1990	1.32	-0.61	0.72	-7.24	1870	H
30	91	0.67	-1.20	-0.53	-7.77	2195	H
31	92	0.71	-0.78	-0.08	-7.85	undef.	H
32	93	0.93	-0.51	0.42	-7.43	1850	H
33	94	1.18	-1.17	0.01	-7.42	2075	H
34	95	1.19	-1.31	-0.11	-7.53	2170	H
35	96	0.53	-0.98	-0.45	-7.98	2205	H
36	97	0.71	-2.39	-1.69	-9.67	2290	H
37	98	0.79	-0.67	0.12	-9.55	undef.	H
38	99	0.91	-1.30	-0.40	-9.95	2205	H
39	2000	0.87	-0.923	-0.05	-10.00	undef.	O
40	01	0.80	-0.78	0.02	-9.98	2070	O
41	02	0.63	-2.048	-1.41	-11.39	2290	O
42	03	0.44	-1.828	-1.39	-12.79	2290	H
43	04	0.46	-0.956	-0.49	-13.28	2210	H
44	05	0.83	-1.323	-0.49	-13.77	2180	H
45	06	0.50	-2.58	-2.08	-15.85	2290	H
46	07	0.60	-1.32	-0.72	-16.58	2265	H
47	08	0.93	-0.85	0.08	-16.50	undef.	H
48	09	0.80	-1.08	-0.28	-16.77	2235	O
49	2010	0.54	-1.60	-1.06	-17.83	2250	O
50	11	0.65	-1.94	-1.29	-19.12	2265	O
51	12	0.73	-0.84	-0.11	-19.23	undef.	O
52	13	0.60	-1.41	-0.81	-20.04	2235	O
53	14	0.89	-2.06	-1.17	-21.21	undef.	O
54	15	0.77	-0.48	0.29	-20.92	undef.	O
Mean 1962-2015		0.75	-1.14	-0.39			

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

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1970			-1.90	-1.90		O
2	71			0.47	-1.43		O
3	72			-1.04	-2.47		O
4	73			1.44	-1.03		O
Mean 1970-73				-0.26			

30 Austre Okstindbre - 14.0 km^2 (1962)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1987	2.26	-1.55	0.71	0.71	1280	O
2	88	1.46	-3.39	-1.93	-1.21	<1750	O
3	89	3.73	-2.17	1.56	0.35	1275	O
4	1990	3.00	-2.70	0.30	0.65	1310	O
5	91	1.80	-2.30	-0.50	0.15	1315	O
6	92	2.88	-1.65	1.23	1.38	1260	O
7	93	2.22	-2.01	0.21	1.59	1290	O
8	94	1.45	-1.62	-0.17	1.42	1310	O
9	95	2.25	-1.79	0.46	1.88	1280	O
10	96	1.62	-1.92	-0.30	1.58	1330	O
Mean 1987-96		2.27	-2.11	0.16			

31 Høgtuvbreen - 2.6 km^2 (1972)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1971	2,99	-3,77	-0,77	-0,77	980	H
2	72	3,29	-4,37	-1,08	-1,85	1020	H
3	73	3,96	-2,86	1,10	-0,75	735	H
4	74	3,42	-3,73	-0,31	-1,06	930	H
5	75	2,95	-2,18	0,77	-0,29	780	H
6	76	3,65	-2,82	0,83	0,55	740	H
7	77	2,20	-2,72	-0,52	0,03	900	H
Mean 1971-77		3,21	-3,21	0,00			

32 Svartisheibreen - 5.7 km^2 (1995)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1988	2,36	-3,95	-1,59	-1,59	1155	H
2	89	3,78	-1,92	1,86	0,28	905	H
3	1990	3,79	-2,98	0,82	1,09	940	H
4	91	2,56	-2,69	-0,13	0,96	960	H
5	92	3,66	-2,63	1,03	1,99	900	H
6	93	3,35	-2,48	0,87	2,87	865	H
7	94	1,76	-2,09	-0,32	2,54	1045	H
Mean 1988-94		3,04	-2,68	0,36			

33 Engabreen - 36.8 km^2 (2008)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1970	1,77	-3,04	-1,27	-1,27	1418	C
2	71	2,95	-2,21	0,74	-0,53	1116	C
3	72	2,94	-3,52	-0,58	-1,11	1254	C
4	73	3,84	-1,91	1,93	0,82	945	C
5	74	3,12	-2,66	0,46	1,28	1044	C
6	75	2,67	-1,68	0,99	2,27	1036	C
7	76	3,40	-1,60	1,80	4,07	998	C
8	77	1,91	-1,58	0,33	4,40	1090	C
9	78	1,92	-3,18	-1,26	3,14	1315	C
10	79	3,12	-3,31	-0,19	2,95	1143	C
11	1980	2,41	-3,34	-0,93	2,02	1302	C
12	81	2,54	-2,51	0,03	2,05	1145	C
13	82	2,03	-1,62	0,41	2,46	1068	C
14	83	1,98	-1,53	0,45	2,91	1124	C
15	84	3,55	-2,75	0,80	3,71	1012	C
16	85	1,24	-2,86	-1,62	2,09	>1577	C
17	86	2,50	-2,72	-0,22	1,87	1199	C
18	87	2,33	-1,88	0,45	2,32	1061	C
19	88	2,05	-3,79	-1,74	0,58	>1577	C
20	89	4,11	-1,97	2,14	2,72	970	C
21	1990	3,20	-2,91	0,29	3,01	1088	C
22	91	2,42	-2,12	0,30	3,31	1092	C
23	92	3,78	-2,44	1,34	4,65	1021	C
24	93	2,84	-2,14	0,70	5,35	1053	C
25	94	1,60	-1,64	-0,04	5,31	1144	C
26	95	3,17	-1,95	1,22	6,53	1021	C
27	96	2,78	-2,48	0,30	6,83	1070	C
28	97	4,15	-3,64	0,51	7,34	1090	C
29	98	2,66	-3,03	-0,37	6,97	1184	C
30	99	1,88	-2,49	-0,61	6,36	1280	C
31	2000	2,49	-1,88	0,61	6,97	1063	C
32	01	1,39	-2,97	-1,58	5,39	>1577	C
33	02	2,66	-3,69	-1,03	4,36	1249	C
34	03	2,19	-3,28	-1,09	3,27	1310	C
35	04	2,65	-2,46	0,19	3,46	1127	C
36	05	3,03	-2,55	0,48	3,94	1099	C
37	06	1,57	-3,41	-1,84	2,10	1419	C
38	07	3,14	-2,47	0,67	2,77	1072	C
39	08	2,58	-2,71	-0,13	2,64	1149	C
40	09	2,88	-2,95	-0,07	2,57	1164	H
41	2010	2,00	-2,75	-0,75	1,82	1275	H
42	11	2,84	-3,78	-0,94	0,88	1268	H
43	12	3,16	-2,09	1,07	1,95	1041	H
44	13	2,28	-4,14	-1,86	0,09	>1575	H
45	14	2,54	-3,51	-0,97	-0,88	1256	H
46	15	3,22	-2,61	0,61	-0,27	1070	O
Mean 1970-2015		2,64	-2,65	-0,01			

34 Storglombreen - 62.4 km^2 (1968)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1985	1,40	-2,59	-1,19	-1,19	1300	O
2	86	2,45	-2,87	-0,42	-1,61	1100	O
3	87	2,32	-1,87	0,45	-1,16	1020	O
4	88	2,06	-3,88	-1,82	-2,98	1350	O
5	2000	2,66	-1,55	1,11	1,11	1000	O
6	01	1,15	-2,91	-1,76	-0,65	>1580	O
7	02	2,33	-3,58	-1,25	-1,90	>1580	O
8	03	2,18	-3,28	-1,10	-3,00	>1580	O
9	04	2,26	-2,14	0,12	-2,88	1075	O
10	05	2,74	-2,41	0,33	-2,55	1060	O
Mean 1985-88		2,06	-2,80	-0,75			
Mean 2000-05		2,22	-2,65	-0,43			

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

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1985	1,47	-3,20	-1,73	-1,73	>1260	O
2	86	2,40	-2,84	-0,44	-2,17	1100	O
Mean 1985-86		1,94	-3,02	-1,09			

36 Glombreen - 2.2 km^2 (1953)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1954	2,30	-3,50	-1,20	-1,20		O
2	55	2,60	-2,70	-0,10	-1,30		O
3	56	1,50	-2,10	-0,60	-1,90		O
Mean 1954-56		2,13	-2,77	-0,63			

37 Kjølbreen - 3.9 km^2 (1953)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1954	1,90	-2,60	-0,70	-0,70		O
2	55	2,10	-2,80	-0,70	-1,40		O
3	56	1,10	-1,10	0,00	-1,40		O
Mean 1954-56		1,70	-2,17	-0,47			

38 Trollbergdalsbreen - 1.8 km^2 (1998)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1970	1,77	-3,97	-2,21	-2,21	>1366	H
2	71	2,12	-2,35	-0,24	-2,44	1115	H
3	72	2,44	-3,67	-1,24	-3,68	1335	H
4	73	3,26	-2,42	0,84	-2,84	<907	H
5	74	2,71	-2,87	-0,17	-3,01	1090	H
6	75			0,01	-2,99	1065	H
7	1990	2,98	-3,17	-0,18	-0,18	1080	H
8	91	2,27	-2,41	-0,14	-0,32	1070	H
9	92	2,65	-1,96	0,69	0,37	<907	H
10	93	2,40	-2,25	0,15	0,52	1050	H
11	94	1,52	-2,42	-0,90	-0,38	1185	H
Mean 1970-74(75)		2,46	-3,06	-0,50			
Mean 1990-94		2,36	-2,44	-0,08			

39 Rundvassbreen - 10.9 km^2 (2011)

No. of years	Year	B_w	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	2002	2,01	-3,20	-1,19	-1,19	1335	H
2	03	1,84	-3,05	-1,21	-2,40	1370	H
3	04	1,92	-2,15	-0,23	-2,63	1290	H
4	2011	1,74	-3,32	-1,58	-1,58	1405	O
5	12	2,04	-1,40	0,64	-0,94	1180	O
6	13	1,47	-3,90	-2,43	-3,37	>1525	O
7	14	1,80	-2,59	-0,79	-4,16	1335	O
8	15	2,12	-2,15	-0,02	-4,18	1230	O
Mean 2002-04		1,92	-2,80	-0,88			
Mean 2011-15		1,83	-2,67	-0,84			

40 Blåisen - 2.2 km^2 (1960)

No. of years	Year	B_w (m w.e.)	B_s	B_a (m w.e.)	Cum. B_a	ELA (m a.s.l.)	Series (O/H/C)
1	1963	2,42	-2,36	0,06	0,06	1045	H
2	64	2,16	-1,73	0,43	0,49	1005	H
3	65	2,00	-1,42	0,58	1,07	965	H
4	66	1,07	-2,33	-1,27	-0,20	>1204	H
5	67	1,37	-2,33	-0,96	-1,16	1175	H
6	68	1,62	-1,36	0,26	-0,90	1005	H
Mean 1963-68		1,77	-1,92	-0,15			

41 Storsteinsfjellbreen - 5.9 km^2 (1993)

No. of years	Year	B_w (m w.e.)	B_s	B_a (m w.e.)	Cum. B_a	ELA (m a.s.l.)	Series (O/H/C)
1	1964	1,82	-1,20	0,62	0,62	1205	H
2	65	1,58	-1,30	0,28	0,90	1300	H
3	66	1,02	-1,88	-0,86	0,03	1515	H
4	67	1,33	-1,71	-0,38	-0,35	1435	H
5	68	1,44	-0,99	0,45	0,10	1255	H
6	1991	1,57	-1,65	-0,08	-0,08	1390	H
7	92	2,26	-1,13	1,12	1,05	1230	H
8	93	2,15	-1,34	0,80	1,85	1245	H
9	94	1,13	-1,30	-0,18	1,67	1385	H
10	95	1,76	-1,28	0,48	2,16	1295	H
Mean 1964-68		1,44	-1,42	0,02			
Mean 1991-95		1,77	-1,34	0,43			

42 Cainhavarre - 0.7 km^2 (1960)

No. of years	Year	B_w (m w.e.)	B_s	B_a (m w.e.)	Cum. B_a	ELA (m a.s.l.)	Series (O/H/C)
1	1965	1,36	-1,18	0,18	0,18	1350	H
2	66	1,11	-2,11	-0,99	-0,82	>1538	H
3	67	1,55	-1,75	-0,20	-1,02	1460	H
4	68	1,32	-1,03	0,29	-0,73	1270	H
Mean 1965-68		1,34	-1,52	-0,18			

43 Svartfjelljøkelen - 2.7 km^2 (1966)

No. of years	Year	B_w (m w.e.)	B_s	B_a (m w.e.)	Cum. B_a	ELA (m a.s.l.)	Series (O/H/C)
1	1978	2,30	-2,40	-0,10	-0,10		O
2	79	2,10					O
Mean 1978-79		2,20					

44 Langfjordjøkelen - 3.2 km^2 (2008)

No. of years	Year	B_w (m w.e.)	B_s	B_a (m w.e.)	Cum. B_a	ELA (m a.s.l.)	Series (O/H/C)
1	89	2,38	-2,98	-0,60	-0,60	890	H
2	1990	2,60	-2,98	-0,38	-0,98	835	H
3	91	2,25	-2,29	-0,04	-1,02	730	H
4	92	2,58	-2,37	0,22	-0,80	705	H
5	93	2,49	-2,34	0,15	-0,65	745	H
6	96	2,23	-2,24	-0,01	-0,01	735	H
7	97	2,77	-3,43	-0,66	-0,68	805	H
8	98	1,81	-3,27	-1,47	-2,14	>1053	H
9	99	1,33	-3,02	-1,68	-3,83	1025	H
10	2000	2,53	-3,05	-0,52	-4,35	850	H
11	01	1,46	-3,64	-2,18	-6,53	>1053	H
12	02	2,36	-3,67	-1,31	-7,85	>1050	H
13	03	2,45	-3,39	-0,95	-8,79	>1050	H
14	04	1,81	-3,50	-1,69	-10,48	>1050	H
15	05	1,95	-2,97	-1,02	-11,50	945	H
16	06	1,39	-3,59	-2,20	-13,70	>1050	H
17	07	2,15	-2,79	-0,64	-14,34	880	H
18	08	1,58	-2,01	-0,43	-14,77	875	H
19	09	1,93	-3,25	-1,31	-16,08	>1050	H
20	2010	1,89	-2,65	-0,76	-16,84	1005	O
21	11	2,30	-3,55	-1,26	-18,09	>1050	O
22	12	1,37	-2,13	-0,76	-18,85	950	O
23	13	2,08	-4,69	-2,61	-21,47	>1050	O
24	14	2,36	-3,14	-0,78	-22,25	>1050	O
25	15	1,88	-2,68	-0,80	-23,05	1025	O
Mean 1989-1993		2,46	-2,59	-0,13			
Mean 1996-2015		1,98	-3,13	-1,15			

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