Glaciological investigations in Norway 2016

Bjarne Kjøllmoen (Ed.)

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REPORT

Glaciological investigations in Norway 2016

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Summary: Results of glaciological investigations performed at Norwegian glaciers in 2016 are presented in this report. The main part concerns mass balance investigaions. Results from investigations of glacier length changes are discussed in a separate chapter.

Keywords: Glaciology, Mass Balance, Glacier length change, Glacier Dynamics, Meteorology, Jøkulhlaup, Ice thickness, Subglacial Laboratory.

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Glaciological investigations in Norway 2016

The Norwegian Water Resources and Energy Directorate (NVE)
2017

Contents

Preface **3**
Summary **4**
Sammendrag **5**
1. Glacier investigations in Norway 2016 **6**
2. Ålfotbreen **17**
3. Folgefonna **22**
4. Nigardsbreen **27**
5. Austdalsbreen **31**
6. Rembesdalskåka **36**
7. Storbreen **41**
8. Juvfonne **45**
9. Hellstugubreen **48**
10. Gråsubreen **52**
11. Engabreen **56**
12. Rundvassbreen **68**
13. Langfjordjøkelen **72**
14. Glacier monitoring **76**
15. References **92**

Appendix A (Publications published in 2016) i
Appendix B (Mass balance measurements in Norway - an overview) ii
Appendix C (Mass balance measurements in Norway - annual results) iii

Preface

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

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

The report is published in English with a summary in Norwegian. The purpose of this report is to provide a joint presentation of the investigations and calculations made mainly by NVE's Section for Glaciers, Ice and Snow during 2016. 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, October 2017

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Summary

Mass balance

Mass balance investigations were performed on fourteen glaciers in Norway in 2016.

The winter balance for four of the reference glaciers (mass balance series back to at least 1971) was greater than the 1971-2000 average, and three were lower than average. Nigardsbreen had the greatest relative winter balance with 124 % of the reference period and Storbreen had the lowest with 72 %.

The summer balance was greater than the average for all seven reference glaciers. Ålfotbreen had the greatest relative summer balance with 142 % of the reference period and Gråsubreen had the lowest with 110 %.

Consequently, the annual balance was negative for six of the reference glaciers. Only Nigardsbreen had positive mass balance.

Glacier length change

Glacier length changes were measured at 25 glaciers in southern Norway and 11 glaciers in northern Norway. Thirty of the glaciers had a decrease in length, four were unchanged and two outlets had a small advance. The greatest retreats were observed at Gråfjellsbrea (117 m), an outlet from southern Folgefonna ice cap, Langfjordjøkelen (96 m) in western Finnmark and Nigardsbreen (70 m), an outlet from Jostedalsbreen ice cap.

Sammendrag

Massebalanse

I 2016 ble det utført massebalansemålinger på 14 breer i Norge – tre i Nord-Norge og elleve i Sør-Norge.

Av referansebreene (de breene som har massebalanseserie tilbake til 1971 eller lengre) ble vinterbalansen større enn gjennomsnittet for referanseperioden 1971-2000 for fire breer og mindre enn gjennomsnittet for tre breer. Nigardsbreen hadde relativt størst vinterbalanse med 124 % av referanseperioden og Storbreen hadde relativt minst med 72 %.

Sommerbalansen ble større enn gjennomsnittet for alle sju referansebreene. Ålfotbreen hadde relativt størst sommerbalanse med 142 % av referanseperioden og Gråsubreen hadde relativt minst med 110 %.

Det ble negativ årlig balanse på seks av de sju referansebreene. Bare Nigardsbreen hadde positiv massebalanse.

Lengdeendringer

Lengdeendringer ble målt på 25 breer i Sør-Norge og 11 breer i Nord-Norge. Tretti av breutløperne hadde tilbakegang, fire var uendret og to hadde litt framgang. Størst tilbakegang ble målt på Gråfjellsbrea (117 m), Langfjordjøkelen (96 m) og Nigardsbreen (70 m).

1. Glacier investigations in Norway 2016

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.

Acronyms and terminology

Many acronyms and terminologies are used in this report. Mass balance terms are in accordance with Cogley et al. (2011) and Østrem and Brugman (1991).

AAR
Accumulation-area ratio. The ratio (expressed as a percentage) of the area of the accumulation zone to the area of the entire glacier.

Ablation
All processes that reduce the mass of the glacier, mainly caused by melting. Other processes of ablation can be calving, sublimation, windborne snow and avalanching.

Accumulation
All processes that add to the mass of the glacier, mainly caused by snowfall. Other processes of accumulation can be deposition of hoar, freezing rain, windborne snow and avalanching.

Airborne laser scanning (Lidar)
Airborne laser scanning or *Lidar* (Light Detection And Ranging) is an optical remote sensing technique used for measuring position and altitude of the earth surface. For the purpose of mapping glaciers airborne laser scanning is most useful.

Ames Stereo Pipeline
A suite of free and open source automated geodesy and stereogrammetry tools designed for processing stereo imagery captured from satellites, for example.

Annual balance (b_a/B_a)
The sum of *accumulation* and *ablation* over the *mass-balance year* calculated for a single point ($b_w + b_s = b_a$) and for a *glacier* ($B_w + B_s = B_a$).

AO
The Arctic Oscillation is a climate index of the state of the atmosphere circulation over the Arctic.

ArcGIS
A Geographical Information System for working with maps and geographic information.

Area-altitude distribution
The glacier is classified in height intervals (50 or 100 m) and the areas within all intervals give the *Area-altitude distribution*.

CNES
National Centre for Space Studies in France.

Density
In this report *density* means the ratio of the mass of snow, *firn* or ice to the volume that it occupies. The *snow density* is measured annually during snow measurements in April/May. *Firn density* is measured occasionally during ablation measurements in September/October. *Ice density* is not measured but estimated as 900 kg m^{-3}.

DTM
Digital terrain model. A digital model of a terrain surface created from terrain elevation data.

EGM96
Earth Gravitational Model 1996. A geopotential model of the earth.

ELA
Equilibrium-line altitude. The spatially averaged altitude (m a.s.l.) where *accumulation* and *ablation* are equal.

Ellipsoidal elevation
The elevation above the ellipsoid, which is a mathematical model that approximates the shape of the earth.

Firn
Snow which is older than one year and has gone through an ablation period.

GCP
Ground Control Points. Marked targets on the ground with known coordinates in a spatial co-ordinate system. *GCP's* are used to georeference the DTM and to improve the relative and absolute accuracy.

GNSS/dGNSS
Global Navigation Satellite System/differential. A generic term for all satellite-based navigation systems, e.g. the American GPS, the Russian GLONASS, the Chinese BeiDou and the European Galileo. Differential GNSS (*dGNSS*) makes use of data from at least one reference station which is located in a precise, known location. The purpose of the dGNSS technique is to enhance the accuracy of the measurements.

GPR
Ground Penetrating Radar. A radar instrument that uses high-frequency radio-waves to measure the thickness of a glacier.

Homogenisation of mass balance series
A procedure to correct for errors, non-conformity and biases that are not a result of real changes in the mass balance, but are due to variations in methodology or changes in observation pattern or method of calculation.

IDW
Inverse Distance Weighting. An interpolation method with a known set of points.

Jøkulhlaup
A *jøkulhlaup* or Glacier Lake Outburst Flood (GLOF) is a sudden release of water from a glacier. The water source can be a glacier-dammed lake, a pro-glacial moraine-dammed lake or water stored within, under or on the glacier.

LEGOS
Laboratoire d'Etudes en Géophysique et Océanographie Spatiales. A multi-disciplinary French research organisation, concerned with environmental research centred on physical oceanography, marine geochemistry and biogeochemistry, spatial hydrology and the dynamics of polar ice sheets.

LIA
The *Little Ice Age* was a period of cooling that occurred approximately AD1400-1900.

Mass balance (also called Glaciological mass balance or Surface mass balance)
The ratio between the *accumulation* and the *ablation* for a glacier. In this report the term *mass balance* is equal to «Glaciological mass balance» or «Surface mass balance», which means that internal melting is not taken into account.

NAO
The North Atlantic Oscillation is the anomaly in sea level pressure difference between the Icelandic low pressure system and the Azores high pressure system in the Atlantic Ocean. When positive (that is, Azores pressure greater than Iceland pressure, winds from the west are strong, and snow accumulation in Scandinavia is high).

Orthometric elevation
The elevation above the geoid, which is an irregular surface shape that is adjusted to the ellipsoid by a proper geoid model. *Orthometric elevation* is for practical purposes "elevation above sea level" (m a.s.l.).

Orthophoto
An aerial photograph which is geometrically adjusted such that the scale is uniform. The orthophoto has the same characteristics and lack of distortion as a map.

Pléiades satellite
Two very-high-resolution optical Earth-imaging satellites (**Pléiades-HR 1A** and **Pléiades-HR 1B)** providing coverage of Earth's surface with a repeat cycle of 26 days.

Probing/sounding
Measuring method for snow depth measurements using thin metal rods.

Snow coring
Use of a coring auger to obtain cylindrical samples of snow and *firn*. The purpose is to measure the *density* of the snow or to identify the *summer surface*.

Stake
Aluminum poles inserted in the glacier for measuring snow accumulation (depth) and melting.

Stratigraphic method
A method for calculating the glacier *mass balance*. In principal the method describes the annual balance between two successive *summer surfaces*.

Summer balance (b_s/B_s)
The sum of *accumulation* and *ablation* over the summer season. Internal melting is not included. The summer balance can be calculated for a single point (b_s) and for a glacier (B_s).

Summer surface (S.S.)
The surface on which the first snow, that does not melt immediately, of the new balance year falls.

TIN
Triangulated Irregular Network. A digital data structure used for interpolating a *DTM*.

TLA
Transient Snow Line Altitude. The snow line at any instant, particularly during the *ablation* season.

Tower
Galvanised steel towers inserted in the glacier for measuring snow depth and melting. A tower can survive greater snow *accumulation* than a *stake*.

Water equivalent/Snow water Equivalent (SWE)
The amount of snow, *firn* and ice (m) converted to the amount of water expressed as «metres water equivalent» (m w.e.).

Winter balance (b_w/B_w)
The sum of *accumulation* and *ablation* over the winter season. The winter balance can be calculated for a single point (b_w) and for a glacier (B_w).

www.senorge.no
An open web portal showing daily updated maps of snow, weather and water conditions, and climate for Norway.

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.

Summer and annual balance

Summer and annual balances are obtained from measurements of stakes and towers (Fig. 1-1), 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, 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.

Figure 1-1
Tower used for summer and annual balance on Nigardsbreen in October 2016. Photo: Ånund Kvambekk.

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 programme

In 2016 mass balance measurements were performed on fourteen glaciers in Norway - eleven in southern Norway and three in northern Norway (Fig. 1-2). 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, six of the glaciers (Ålfotbreen, Nigardsbreen, Rembesdalskåka, Storbreen, Hellstugubreen and Gråsubreen) have been measured for 54 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 68 years of measurements, while Engabreen at Svartisen has the longest series (47 years) in northern Norway. The six long-term glaciers in southern Norway together with Engabreen in northern Norway, constitute the so-called reference glaciers. For the seven reference glaciers a reference period (1971-2000) is defined and the balance values for 2016 are compared with the average of the reference period. A comprehensive review of the glacier mass balance and length measurements in Norway is given in Andreassen et al. (2005).

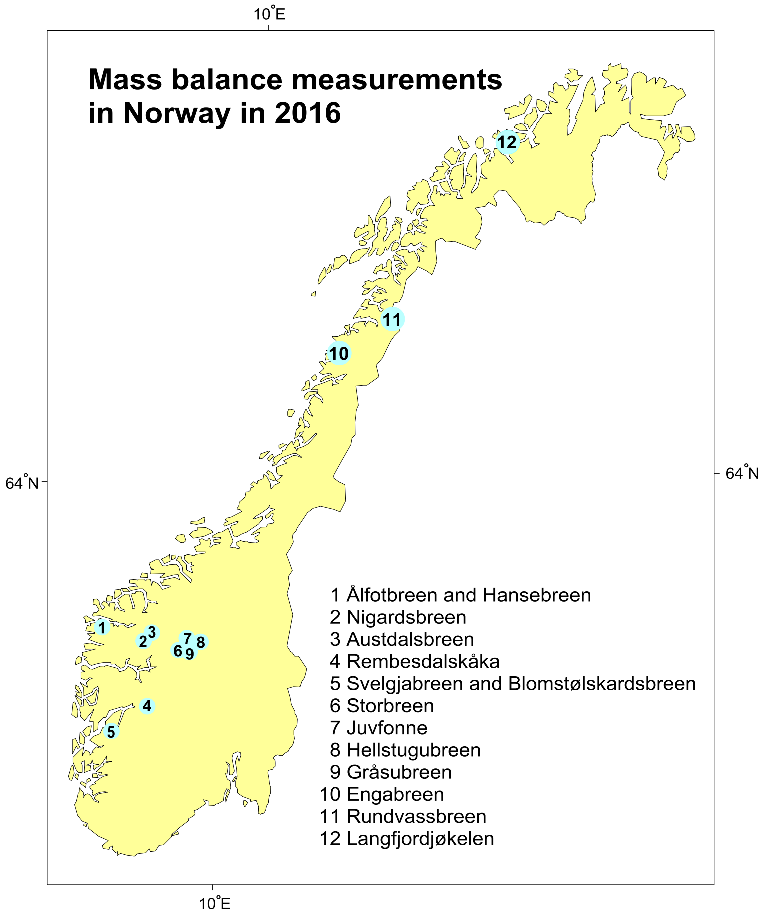


Figure 1-2
Location of the glaciers at which mass balance studies were performed in 2016.

Mass balance studies performed on Norwegian glaciers in 2016 are reported in the following chapters.

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.

Weather conditions and mass balance results

Winter weather

The winter season 2015/2016 started with mild and dry weather in southern Norway and mild and wet weather in northern Norway. In general the last two months in 2015, November and December, were snow-rich over the whole country. The winter season continued with variable weather conditions in 2016. January was cold all over the country. February was snow-rich in southern Norway and snow-poor in northern Norway. March and April were mild and snow-poor.

Snow accumulation and winter balance

The winter balance for four of the reference glaciers (Ålfotbreen, Nigardsbreen, Rembesdalskåka and Hellstugubreen) was greater than the average of the reference period 1971-2000, and three were lower than average. Nigardsbreen had the greatest relative winter balance with 124 % of the reference period and Storbreen had the lowest with 72 %.

Summer weather

Generally the summer season was warm and wet in southern Norway. In northern Norway the summer season was rather dry with average temperatures. The summer season finished with a warm September over the whole country.

Ablation and summer balance

The summer balance was greater than the average for all seven reference glaciers. Ålfotbreen had the greatest relative summer balance with 142 % of the reference period and Gråsubreen had the lowest with 110 %.

Annual balance

The annual balance was negative for six of the seven reference glaciers. Only Nigardsbreen had positive mass balance with +0.5 m w.e. Storbreen had the greatest deficit with −0.8 m w.e.

The results from the mass balance measurements in Norway in 2016 are shown in Table 1-1. Winter (B_w), summer (B_s) and annual balance (B_a) are given in metres water equivalent (m w.e.) averaged over the entire glacier area. 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 annual balance in the same way. ELA is the equilibrium line altitude (m a.s.l.) and AAR is the accumulation area ratio (%).

Circulation patterns AO and NAO

Norway’s climate is strongly influenced by large-scale circulation patterns and westerly winds are dominant. Much of the variation in weather from year to year, in particular the winter precipitation, may be attributed to variations in circulation and wind patterns in the North Atlantic Ocean. Indices such as the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) are used to describe the variation in the pressure gradients in the northern latitudes, and the resulting effects on temperature and storm tracks. When the NAO or AO is positive, the coast of Norway experiences warm and wet winters resulting in high winter precipitation on the glaciers. When the NAO or AO is negative, the winters are colder and drier with less precipitation on the glaciers (Hanssen-Bauer and Førland, 1998; Nesje et al., 2000). Although NAO is more commonly used, Rasmussen (2007) found better correlations for winter balance with AO than NAO for nine of the 10 longest mass balance glaciers in Norway. In winter 2015/2016 (October-April) NAO and AO were slightly positive overall (0.32 and 0.13 calculated from monthly means, source: http://www.cpc.ncep.noaa.gov/), resulting in above normal winter precipitation for most glaciers. The large-scale circulation indices NAO and AO are in units of standard deviations from the mean, in which both statistics are calculated from multi-year records of the two indices.

Table 1-1
Summary of results from mass balance measurements performed in Norway in 2016. The glaciers in southern Norway are listed from west to east. The figures in the *% of ref.* column show the current results as a percentage of the average for the period 1971-2000.

Glacier	*Period*	*Area* *(km^2)*	*Altitude* *(m a.s.l.)*	*B_w* *(m)*	*% of ref.*	*B_s* *(m)*	*% of ref.*	*B_a* *(m)*	*B_a ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-16	4.0	890-1368	4.15	108	−4.79	142	−0.64	0.48	>1368	0
Hansebreen	1986-16	2.8	927-1310	3.81	[1)]112	−5.12	[1)]129	−1.30	[1)]−0.56	>1310	0
Svelgjabreen	2007-16	22.3	829-1632	3.33	[2)]109	−3.33	[2)]115	−0.01	[2)]−0.16	1325	60
Blomstølskardsbreen	2007-16	22.4	1012-1632	3.43	[2)]107	−2.73	[2)]104	0.70	0.59	1320	81
Nigardsbreen	1962-16	46.6	330-1952	2.81	124	−2.33	113	0.49	0.21	1380	89
Austdalsbreen	1988-16	10.6	1200-1747	2.01	[3)]92	[4)]−3.07	[3)]113	−1.06	[3)]−0.52	>1747	0
Rembesdalskåka	1963-16	17.3	1066-1854	2.24	102	−2.63	135	−0.39	0.26	1695	73
Storbreen	1949-16	5.1	1400-2102	1.11	72	−1.91	118	−0.80	-0.09	1835	29
Juvfonne[5)]	2010-16	0.2	1840-1998	0.78	-	−1.98	-	−1.20	-		
Hellstugubreen	1962-16	2.9	1482-2229	1.21	105	−1.55	111	−0.34	−0.24	1940	34
Gråsubreen	1962-16	2.1	1833-2283	0.76	96	−1.18	110	−0.42	−0.28	undef.	
Engabreen	1970-16	36.2	111-1544	2.65	98	−2.88	118	−0.23	0.27	1195	55
Rundvassbreen	2002-04 2011-16	11.6 10.9	788-1537 836-1525	1.52	[6)]81	−2.01	[6)]74	−0.49	−0.78 [6)]−0.85	1265	50
Langfjordjøkelen	1989-93 1996-16	3.7 3.2	280-1050 302-1050	1.66	[7)]80	−3.33	[7)]110	−1.66	[7)]−0.95	>1050	0

[1)]Calculated for the measured period 1986-2015
[2)]Calculated for the measured period 2007-2015
[3)]Calculated for the measured period 1988-2015
[4)]Contribution from calving amounts to 0.12 m for B_a
[5)]Calculated for a point only, b_w, b_s and b_a
[6)]Calculated for the measured periods 2002-04 and 2011-2015
[7)]Calculated for the measured periods 1989-93 and 1996-2015

Figure 1-3 gives a graphical presentation of the mass balance results in southern Norway for 2016. The west-east gradient is evident for both winter and summer balances. The results for 2016 show negative mass balance for twelve of the fourteen measured glaciers in Norway.

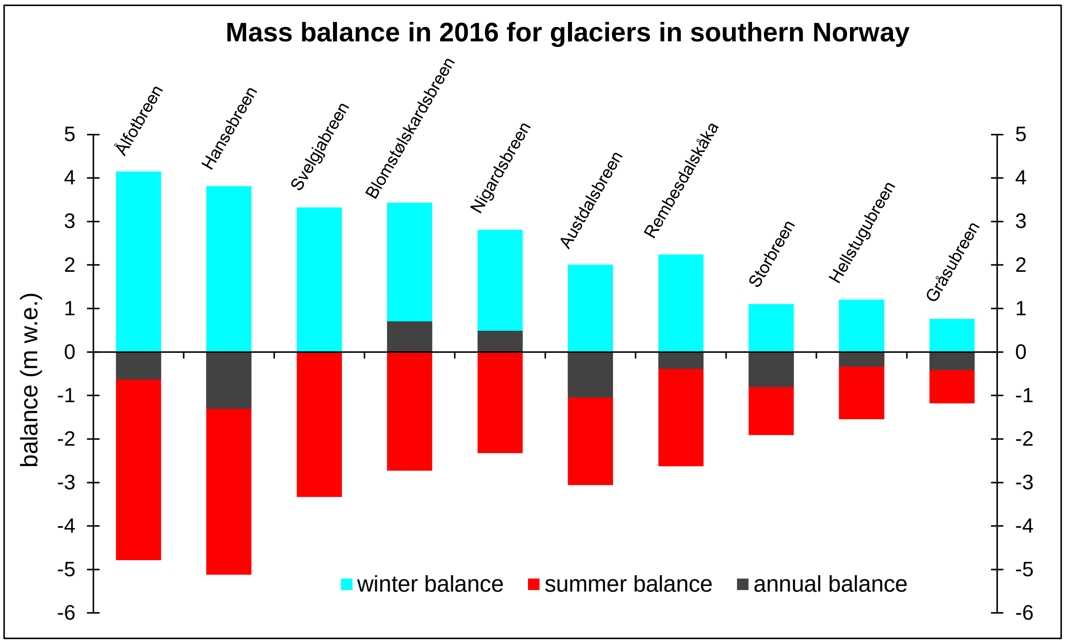


Figure 1-3
Mass balance in 2016 in southern Norway. The glaciers are listed from west to east.

The cumulative annual balance for the five reference glaciers in southern Norway for the period 1963-2016 is shown in Figure 1-4. 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.

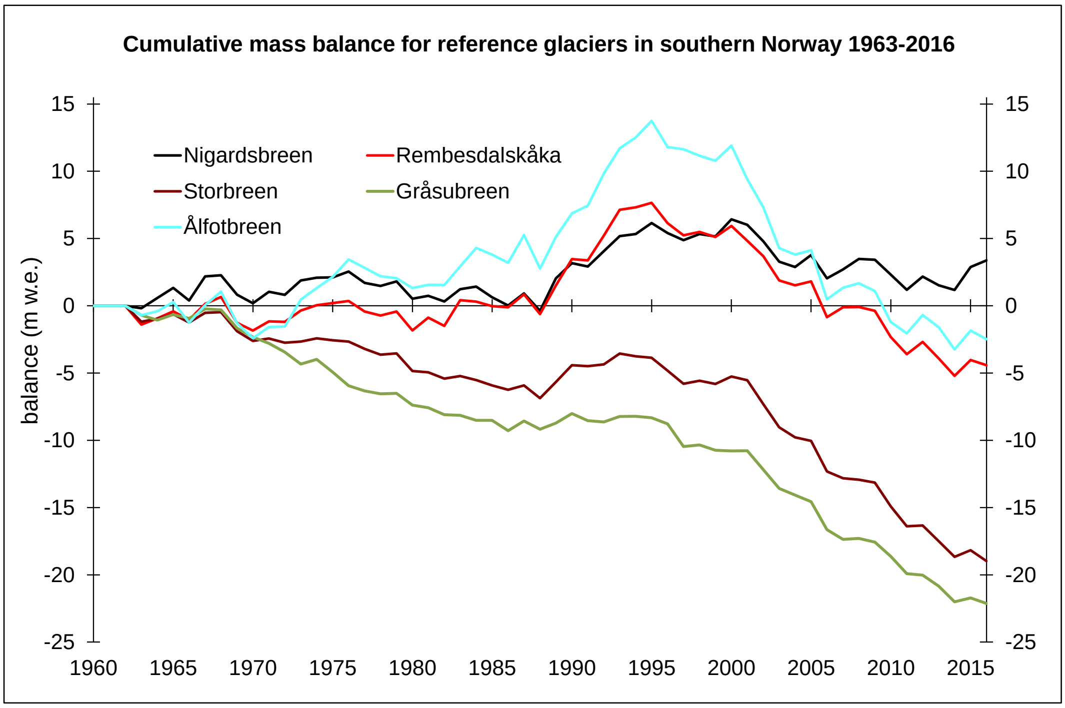


Figure 1-4
Cumulative mass balance for the reference glaciers Ålfotbreen, Nigardsbreen, Rembesdalskåka, Storbreen and Gråsubreen for the period 1963-2016.

1.2 Homogenisation of mass balance series

In order to study glacier change variations and effects on water discharge in rivers, the Norwegian Water Resources and Energy Directorate (NVE) started mass balance measurements at several glaciers in the early 1960s. The very first mass balance measurements in Norway however, were initiated in 1949 at Storbreen in Jotunheimen by Professor Olav Liestøl at the Norwegian Polar Institute (Liestøl, 1967).

For 1963 and 1964 the mass balance measurements from mainland Norway were reported as "NVE Meddelelse" (Østrem and Liestøl, 1964 and Pytte and Østrem, 1965), and from 1965 in NVEs report series "Glasiologiske undersøkelser i Norge" (Pytte and Liestøl, 1966). Since 2000 the report has been published in English in the report series "Glaciological investigations in Norway" (Kjøllmoen et al., 2000). All editions are available as digital downloads at https://www.nve.no/glacier. The reports can also be ordered from NVEs library at biblioteket@nve.no.

Over time, changes in personnel, measuring programme and calculation methods make mass balance series inhomogeneous (Braithwaite, 2002). The glacier can also change in shape and size, hence, it is important to have a map base which is representative for the current measuring period. Homogenising mass balance series can be defined as a procedure to adjust for errors and biases not caused by real changes in the mass balance, but is a result of changes of measuring methodology, observation pattern or calculation routines (Cogley et al., 2011). Homogenising a mass balance series includes several steps and will vary from glacier to glacier depending on data and time availability.

From the measurements started at Storbreen in 1949 to 2016 mass balance has been measured at 45 glacier units in Norway. Ten of these mass balance series are longer than 20 years and measurements are still running at all ten. However, most of the 45 glaciers were measured for a short period (typically 4-10 years) and sometimes even shorter (typically 1-2 years) when related to student papers.

The ten longest mass balance series (Ålfotbreen, Hansebreen, Nigardsbreen, Austdalsbreen, Rembesdalskåka, Storbreen, Hellstugubreen, Gråsubreen, Engabreen and Langfjordjøkelen) have already been homogenised (Andreassen et al., 2016). Five of these time series (Ålfotbreen, Hansebreen, Nigardsbreen, Rembesdalskåka and Engabreen) have also been calibrated (Kjøllmoen, 2016a, Kjøllmoen, 2016b and Elvehøy, 2016).

Of the remaining 35 mass balance series, the homogenisation of 18 series is described in Kjøllmoen (2016). The 18 homogenised series are geographically distributed in seven different areas (Fig. 1-5). The series have a duration from 2 to 8 years, and some of the glaciers were measured over two periods. The area extent of the glaciers are varying, from the small glacier Cainhavarre in northern Norway covering 0.7 km^2 (1960) to the largest glacier outlet from Jostedalsbreen, Tunsbergdalsbreen, covering 52.2 km^2 (1964).

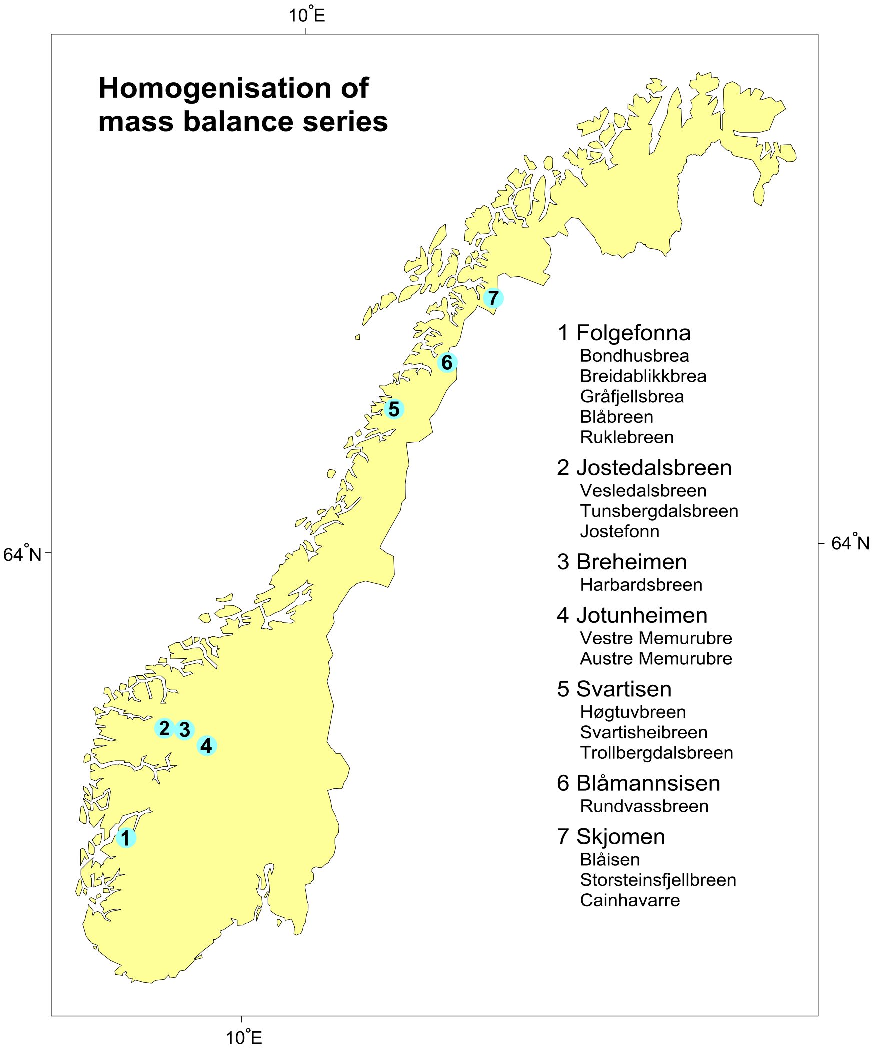


Figure 1-5
Homogenisation of 18 mass balance series, geographically distributed in seven areas.

1.3 Other investigations

Glacier length change measurements were performed at 36 glaciers in Norway in 2016. 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 2016.

Meteorological observations have been performed at 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 pressure measurements in the laboratory is given in chapter 11.

Several jøkulhlaup have occurred in 2016 and these 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, one of 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 (Fig. 2-1), and has been measured since 1986. None of the outlet glaciers from the icecap are given names on the official maps. Re-analysed mass balance series for Ålfotbreen 1963-2010 and Hansebreen 1986-2010 are presented in Kjøllmoen (2016b).

Figure 2-1
Hansebreen photographed in August 2015. Photo: Bjarne Kjøllmoen.

2.1 Mass balance 2016

Fieldwork

Snow accumulation measurements were performed on 10th and 11th May and the calculation of winter balance was based on measurement of four stakes and 76 snow depth soundings on Ålfotbreen, and five stakes and 54 snow depth soundings on Hansebreen (Fig. 2-2). Comparison of stake readings and snow soundings indicated no significant melting after the ablation measurements in October 2015. The snow pack was compact with some ice layers. Detecting the summer surface was easy in the lower parts, but more difficult in the upper areas. The snow depth varied from 4.9 m to 9.0 m at Ålfotbreen, and from 4.6 m to 10.0 m at Hansebreen. Snow density was measured in one location (1221 m a.s.l.) applicable for both glaciers. The mean snow density of 6.0 m snow was 533 kg m^{-3}.

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

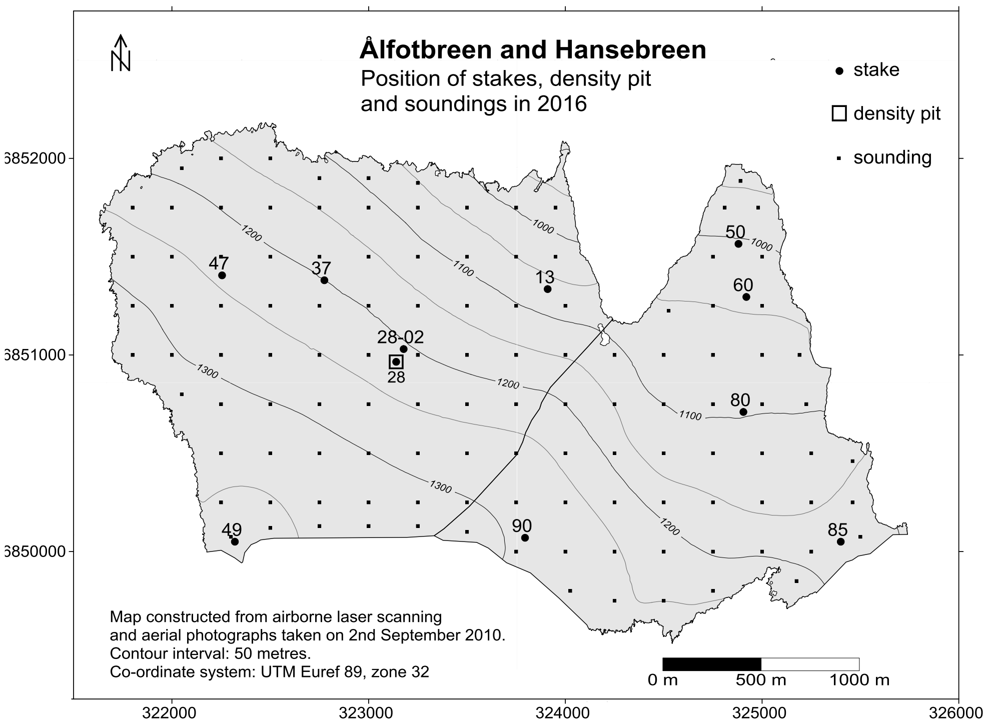


Figure 2-2
Location of stakes, soundings and snow pit at Ålfotbreen (left) and Hansebreen (right) in 2016.

Ablation was measured on 5th October. The annual balance was measured at stakes in five positions on both glaciers (Fig. 2-2). There was no snow remaining on the two glaciers from the winter season 2015/16. At the time of the ablation measurements between 5 and 40 cm of fresh snow had fallen.

Results

The calculations are based on the DTM from 2010.

All height intervals are well-represented with point measurements (b_w) for both glaciers except the very lowest interval (890-950 m a.s.l.) at Ålfotbreen.

The winter balance was calculated as a mean value for each 50 m height interval and was 4.2 ±0.2 m w.e. at Ålfotbreen, which is 108 % of the mean winter balance for the reference period 1971-2000. The winter balance on Hansebreen was calculated as 3.8 ±0.2 m w.e., which is 112 % of the mean winter balance for the measurement period 1986-2015. Spatial distribution of the winter balance at Ålfotbreen and Hansebreen is shown in Figure 2-3.

Based on estimated density and stake measurements the summer balance was also calculated as a mean value for each 50 m height interval and was −4.8 ±0.3 m w.e. on Ålfotbreen, which is 142 % of the reference period. The summer balance on Hansebreen was −5.1 ±0.3 m w.e., which is 129 % of the mean winter balance for 1986-2015.

Hence, the annual balance was negative at both glaciers. Ålfotbreen had a deficit of −0.6 ±0.4 m w.e. The mean annual balance for the reference period 1971-2000 is +0.48 m w.e. Over the last ten years (2007-2016), however, the mean annual balance was −0.30 m w.e. Six of these years show a negative annual balance. The annual balance at Hansebreen was −1.3 ±0.4 m w.e. The mean value for the measurement period 1986-2015 is −0.56 m w.e. Over the last ten years the mean annual balance was −0.75 m w.e.

The mass balance results are shown in Table 2-1 and the corresponding curves for specific and volume balance are shown in Figure 2-4.

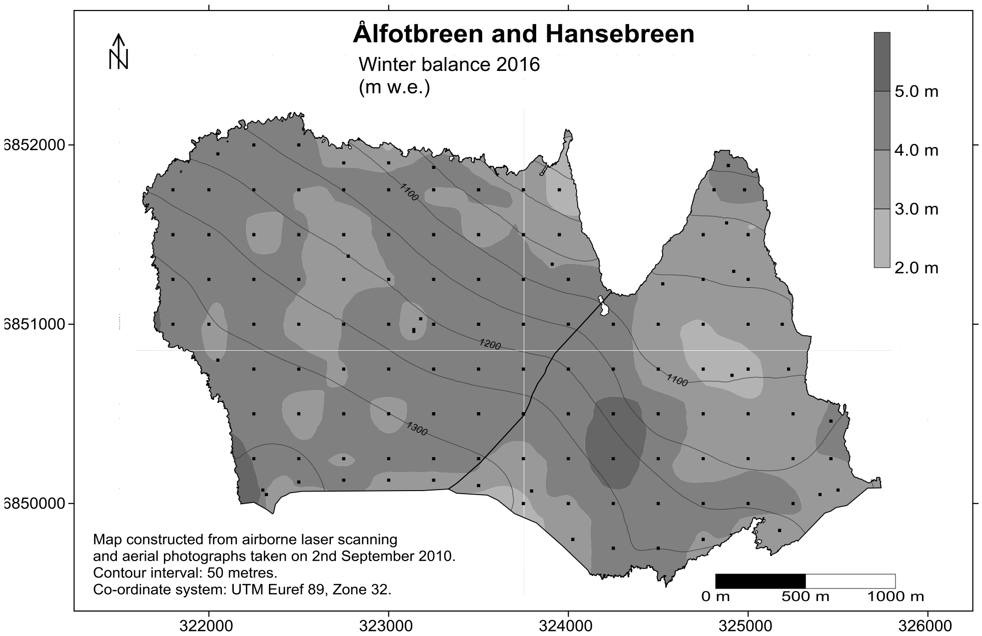


Figure 2-3
Spatial distribution of winter balance at Ålfotbreen and Hansebreen in 2016.

According to Figure 2-4 the ELA lies above the highest point on both glaciers. Consequently, the AAR is 0 %.

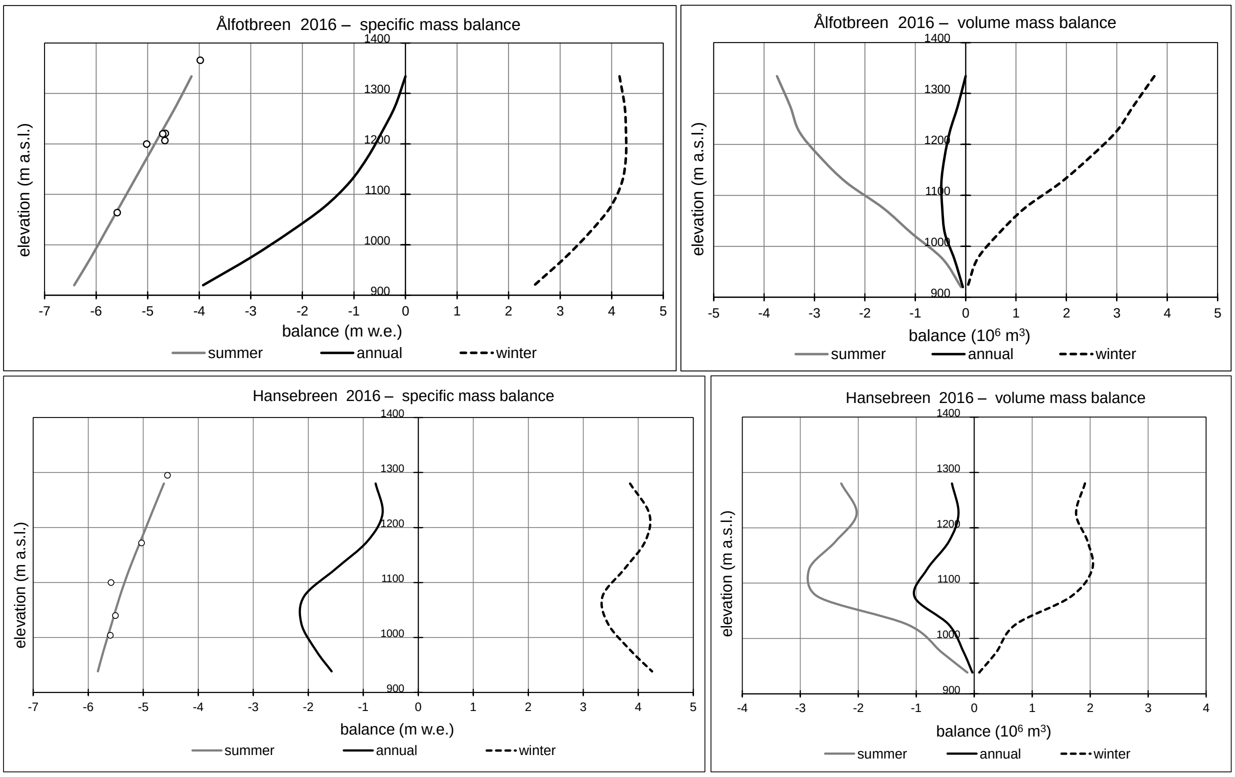


Figure 2-4
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2016 showing altitudinal distribution of specific (left) and volumetric (right) winter, summer and annual balance. Specific summer balance at each stake is shown (○).

Table 2-1
Winter, summer and annual balances for Ålfotbreen (upper) and Hansebreen (lower) in 2016.

Mass balance Ålfotbreen 2015/16 – stratigraphic system

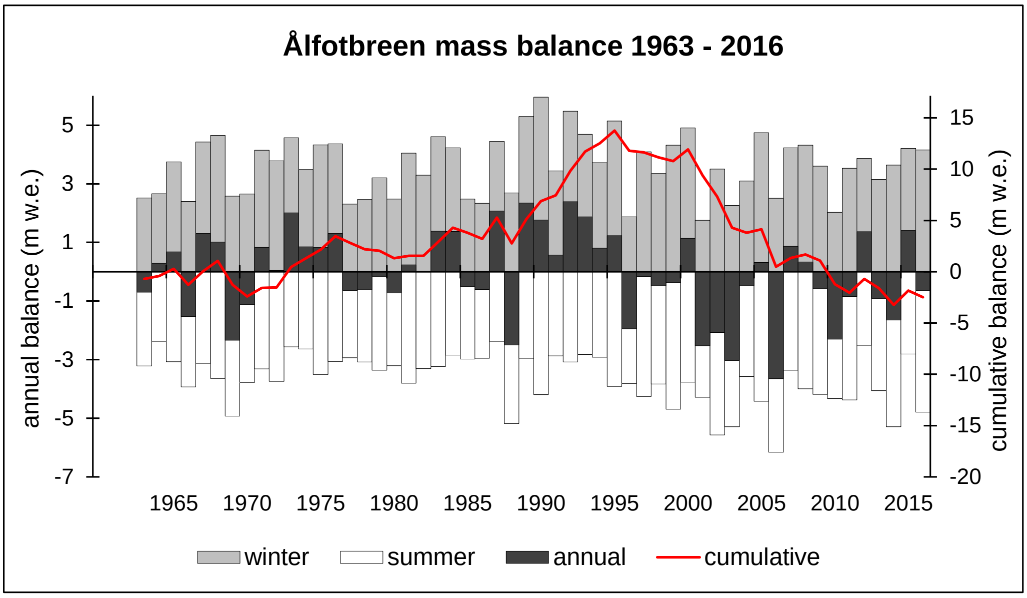
Altitude (m a.s.l.)	Area (km^2)	Winter mass balance Measured 10th May 2016 Specific (m w.e.)	Winter Volume (10^6 m^3)	Summer mass balance Measured 5th Oct 2016 Specific (m w.e.)	Summer Volume (10^6 m^3)	Annual mass balance Summer surface 2015 - 2016 Specific (m w.e.)	Annual Volume (10^6 m^3)
1300 - 1368	0.90	4.15	3.74	-4.15	-3.74	0.00	0.0
1250 - 1300	0.78	4.25	3.33	-4.45	-3.48	-0.20	-0.2
1200 - 1250	0.70	4.28	2.99	-4.73	-3.30	-0.45	-0.3
1150 - 1200	0.58	4.28	2.47	-5.00	-2.89	-0.73	-0.4
1100 - 1150	0.45	4.20	1.88	-5.28	-2.36	-1.08	-0.5
1050 - 1100	0.29	3.98	1.17	-5.55	-1.64	-1.58	-0.5
1000 - 1050	0.18	3.58	0.65	-5.83	-1.06	-2.25	-0.4
950 - 1000	0.07	3.10	0.23	-6.10	-0.45	-3.00	-0.2
890 - 950	0.01	2.50	0.04	-6.43	-0.09	-3.93	-0.1
890 - 1368	**3.97**	**4.15**	**16.5**	**-4.79**	**-19.0**	**-0.64**	**-2.5**

Mass balance Hansebreen 2015/16 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter mass balance Measured 10th May 2016 Specific (m w.e.)	Winter Volume (10^6 m^3)	Summer mass balance Measured 5th Oct 2016 Specific (m w.e.)	Summer Volume (10^6 m^3)	Annual mass balance Summer surface 2015 - 2016 Specific (m w.e.)	Annual Volume (10^6 m^3)
1250 - 1310	0.50	3.85	1.91	-4.63	-2.29	-0.78	-0.38
1200 - 1250	0.42	4.20	1.76	-4.85	-2.03	-0.65	-0.27
1150 - 1200	0.47	4.13	1.96	-5.05	-2.40	-0.93	-0.44
1100 - 1150	0.54	3.75	2.04	-5.25	-2.85	-1.50	-0.81
1050 - 1100	0.50	3.35	1.66	-5.43	-2.69	-2.08	-1.03
1000 - 1050	0.21	3.45	0.71	-5.58	-1.15	-2.13	-0.44
950 - 1000	0.10	3.88	0.38	-5.73	-0.56	-1.85	-0.18
927 - 950	0.02	4.25	0.09	-5.83	-0.12	-1.58	-0.03
927 - 1310	**2.75**	**3.81**	**10.5**	**-5.12**	**-14.1**	**-1.30**	**-3.6**

2.2 Mass balance 1963(86)-2016

The historical mass balance results for Ålfotbreen and Hansebreen are presented in Figure 2-5. The cumulative annual balance for Ålfotbreen over 1963-2016 is −2.5 m w.e., which gives a mean annual balance of −0.05 m w.e. a^{-1}. The cumulative annual balance for Hansebreen over 1986-2016 is −18.2 m w.e., which gives a mean annual balance of −0.59 m w.e. a^{-1}.



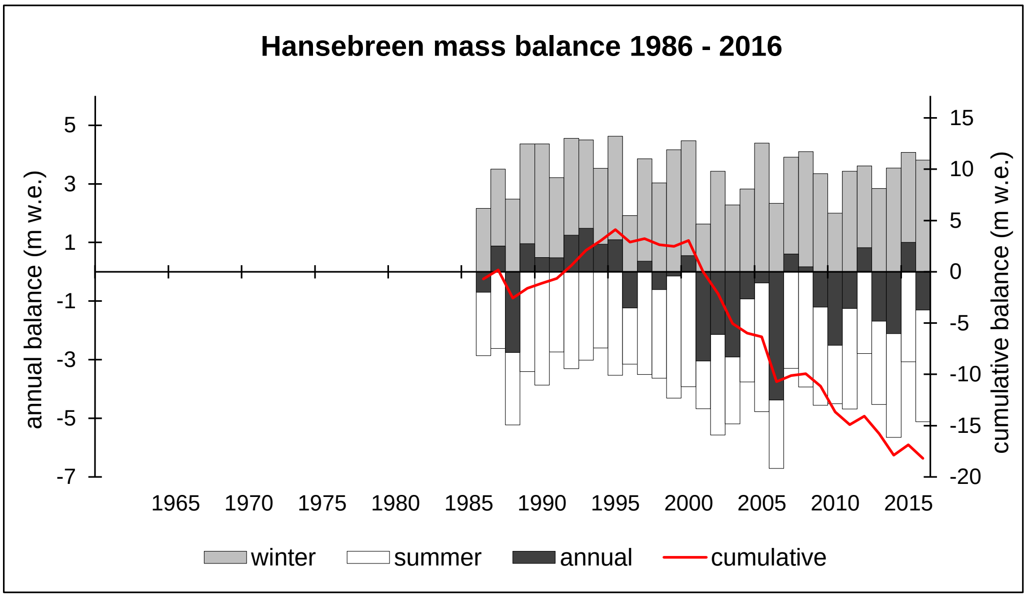


Figure 2-5
Mass balance at Ålfotbreen (upper) 1963-2016 and Hansebreen (lower) 1986-2016. Cumulative mass balance is given on the right axis.

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 (60°1′N, 6°20′E) is the third largest (158 km^2 in 2013) ice cap in Norway. In 2007 mass balance measurements began on two adjacent south-facing outlet glaciers of Southern Folgefonna – Svelgjabreen (22.3 km^2) (Fig. 3-1) and Blomstølskardsbreen (22.4 km^2).

Mass balance measurements were previously carried out at Svelgjabreen/Blomstølskardsbreen (then called Blomsterskardsbreen) in 1971 (Tvede, 1973), and annual balance only was measured in 1970 and over the period 1972-77 (Tvede and Liestøl, 1977).

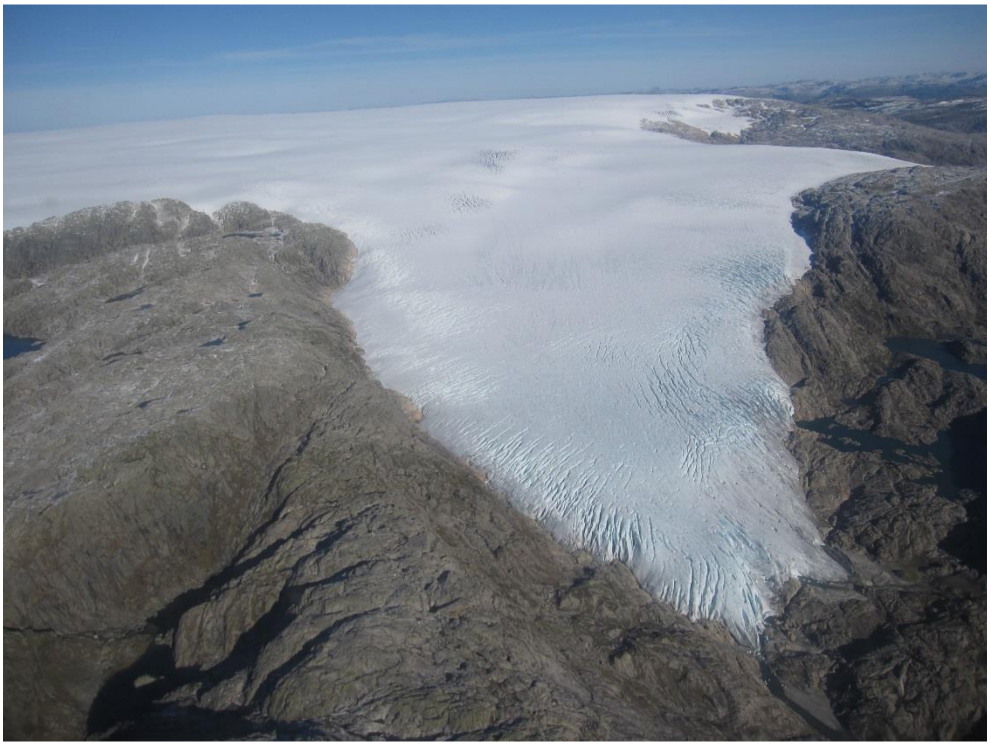


Figure 3-1
Svelgjabreen and Blomstølskardsbreen photographed in October 2016. Photo: Bjarne Kjøllmoen.

3.1 Mass balance 2016

Fieldwork

Snow accumulation measurements were performed on 28th April and the calculation of winter balance was based on measurement of three stakes and 33 snow depth probings on Svelgjabreen, and four stakes and 24 snow depth probings on Blomstølskardsbreen (Fig. 3-2). Comparison of stake readings and probings indicated no significant melting after the ablation measurement in October 2015. The sounding conditions were difficult with several ice layers. The snow depth varied from 3.3 m to 9.9 m at Svelgjabreen, and from 4.1 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 6.0 m snow was 446 kg m^{-3}. Ablation was measured on 6th October. The annual balance was measured directly at stakes in four positions on Svelgjabreen and six positions on Blomstølskardsbreen (Fig. 3-2). In addition, annual balance was partly measured and partly estimated at two more stakes on Svelgjabreen. There was about 2 m of snow remaining in the uppermost areas from the winter season 2015/2016. At the time of the ablation measurement up to 35 cm of fresh snow had fallen.

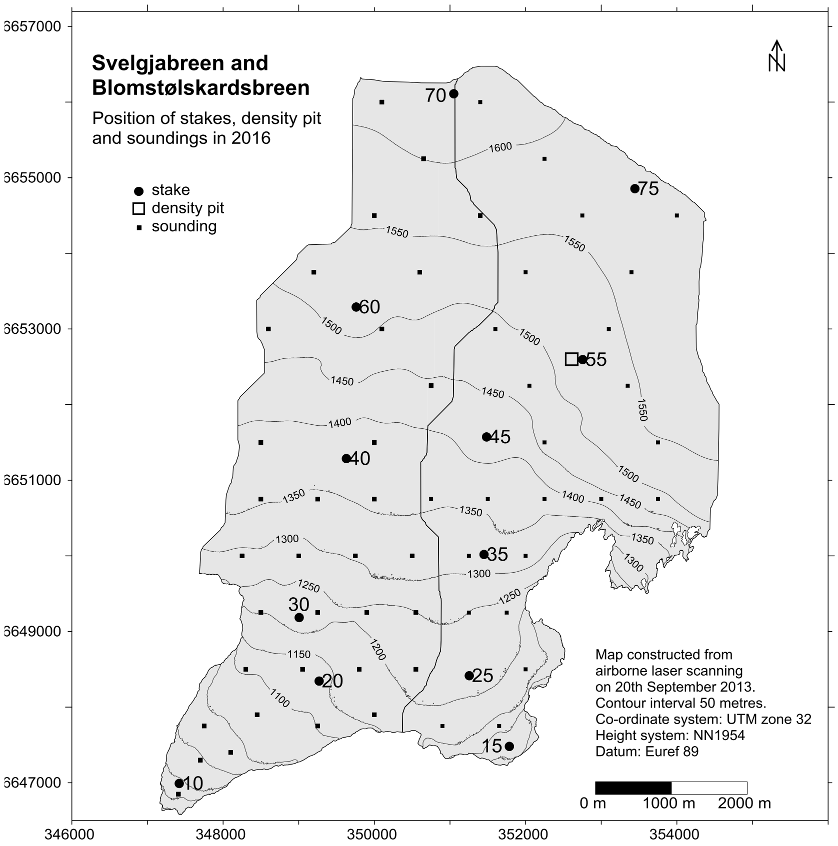


Figure 3-2
Location of stakes, soundings and density pit at Svelgjabreen and Blomstølskards-breen in 2016.

Results

The calculations are based on the DTM from 2013.

Stake measurements in position 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 3.3 ±0.2 m w.e. at Svelgjabreen, which is 109 % of the mean winter balance for the measurement period 2007-15. The winter balance on Blomstølskardsbreen was calculated as 3.4 ±0.2 m w.e., which is 107 % of the mean for 2007-15. Spatial distribution of the winter balance is shown in Figure 3-3.

Based on estimated density and stake measurements the summer balance was calculated as −3.3 ±0.3 m w.e. at Svelgjabreen, which is 115 % of 2007-15. The summer balance on Blomstølskardsbreen was calculated as −2.7 ±0.3 m w.e., which is 104 % of 2007-15.

Hence, the annual balance was calculated as −0.1 ±0.4 m w.e. at Svelgjabreen and +0.7 ±0.4 m w.e. at Blomstølskardsbreen.

The mass balance results are shown in Table 3-1 and the corresponding curves for specific and volume balance are shown in Figure 3-4 and 3-5.

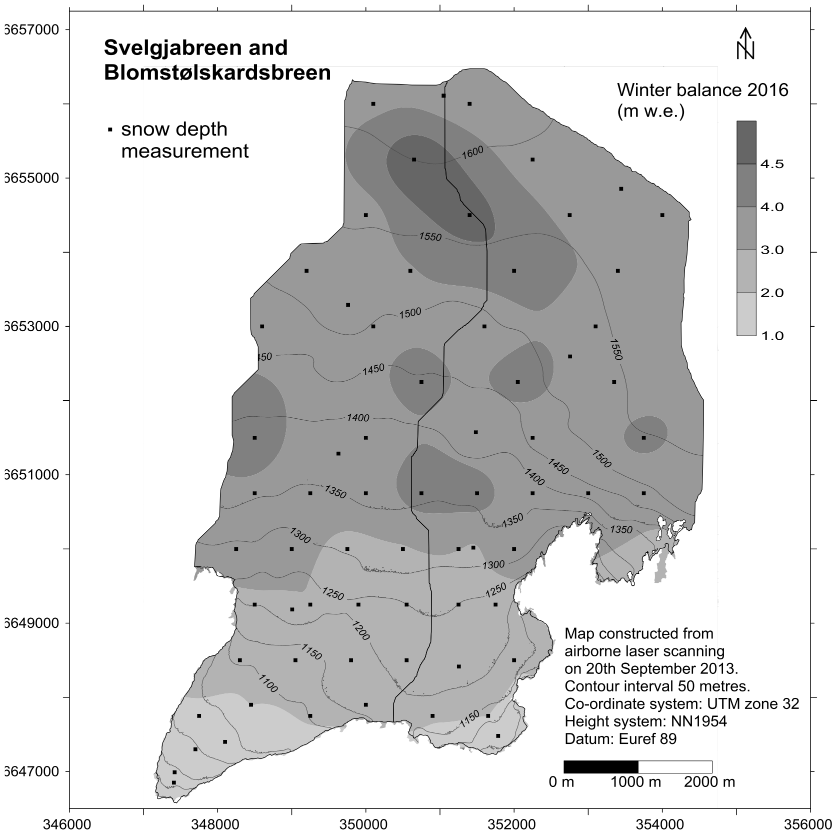


Figure 3-3
Spatial distribution of winter balance at Svelgjabreen and Blomstølskards-breen in 2016.

According to Figure 3-4 and 3-5, the ELA lies at 1325 m a.s.l. on Svelgjabreen and at 1320 m a.s.l. on Blomstølskardsbreen. Accordingly the AARs are 60 % and 81 %, respectively.

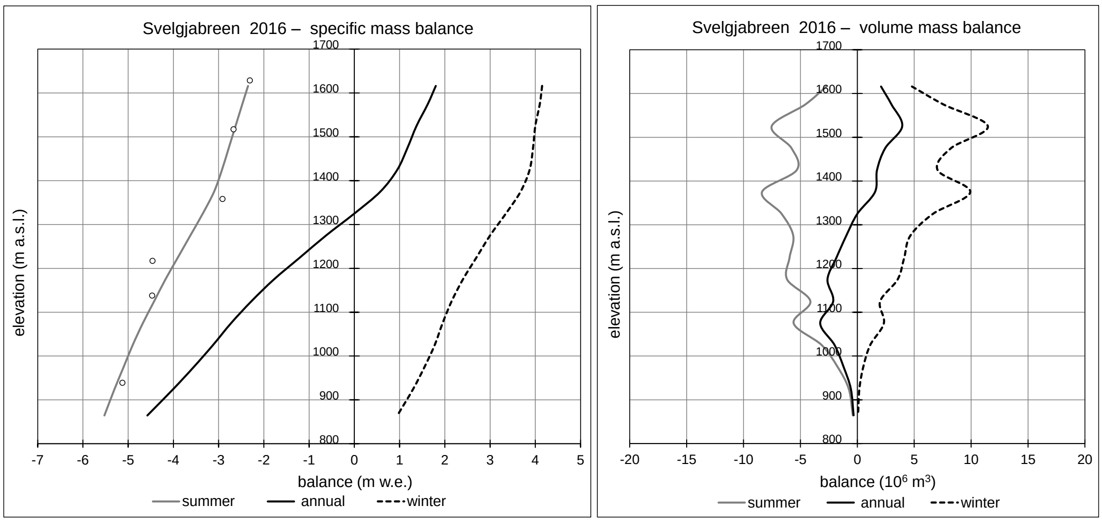


Figure 3-4
Mass balance diagram for Svelgjabreen in 2016.

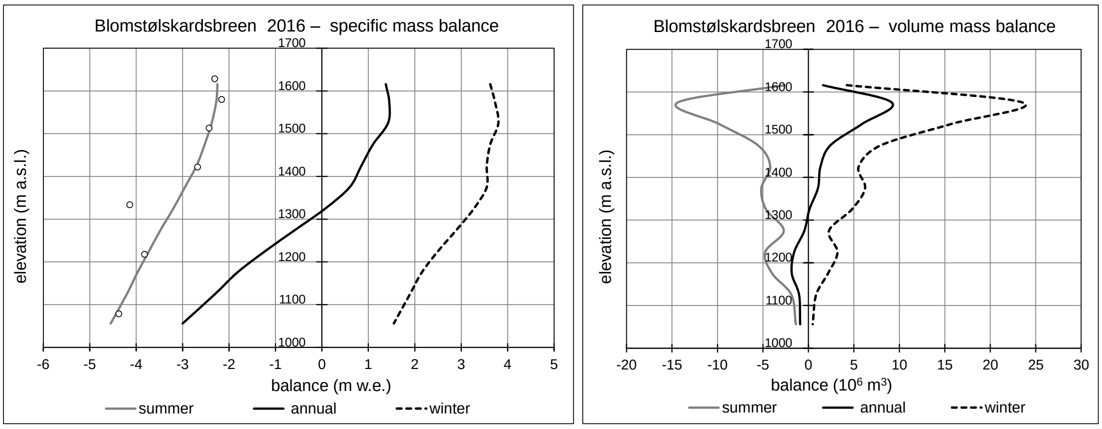


Figure 3-5
Mass balance diagram for Blomstølskardsbreen in 2016.

Table 3-1
Winter, summer and annual balances for Svelgjabreen (upper) and Blomstølskardsbreen (lower) in 2016.

Mass balance Svelgjabreen 2015/16 – stratigraphic system

		Winter mass balance		Summer mass balance		Annual mass balance	
		Measured 28th Apr 2016		Measured 6th Oct 2016		Summer surface 2015 - 2016	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1632	1.16	4.15	4.8	-2.35	-2.7	1.80	2.1
1550 - 1600	1.85	4.10	7.6	-2.48	-4.6	1.63	3.0
1500 - 1550	2.87	4.00	11.5	-2.63	-7.5	1.38	3.9
1450 - 1500	2.08	3.95	8.2	-2.78	-5.8	1.18	2.4
1400 - 1450	1.82	3.88	7.1	-2.93	-5.3	0.95	1.7
1350 - 1400	2.70	3.68	9.9	-3.10	-8.4	0.58	1.6
1300 - 1350	1.99	3.35	6.7	-3.35	-6.7	0.00	0.0
1250 - 1300	1.55	3.00	4.7	-3.63	-5.6	-0.63	-1.0
1200 - 1250	1.53	2.70	4.1	-3.90	-6.0	-1.20	-1.8
1150 - 1200	1.48	2.40	3.5	-4.18	-6.2	-1.78	-2.6
1100 - 1150	0.93	2.15	2.0	-4.43	-4.1	-2.28	-2.1
1050 - 1100	1.20	1.95	2.3	-4.68	-5.6	-2.73	-3.3
1000 - 1050	0.64	1.78	1.1	-4.90	-3.1	-3.13	-2.0
950 - 1000	0.34	1.55	0.5	-5.10	-1.7	-3.55	-1.2
900 - 950	0.14	1.30	0.2	-5.30	-0.8	-4.00	-0.6
829 - 900	0.07	0.95	0.1	-5.53	-0.4	-4.58	-0.3
829 - 1632	**22.35**	**3.33**	**74.3**	**-3.33**	**-74.5**	**-0.01**	**-0.1**

Mass balance Blomstølskardsbreen 2015/16 – stratigraphic system

		Winter mass balance		Summer mass balance		Annual mass balance	
		Measured 28th Apr 2016		Measured 6th Oct 2016		Summer surfaces 2015 - 2016	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1600 - 1632	1.17	3.63	4.2	-2.25	-2.6	1.38	1.6
1550 - 1600	6.34	3.73	23.6	-2.28	-14.4	1.45	9.2
1500 - 1550	4.13	3.80	15.7	-2.38	-9.8	1.43	5.9
1450 - 1500	2.19	3.63	7.9	-2.53	-5.5	1.10	2.4
1400 - 1450	1.56	3.55	5.5	-2.70	-4.2	0.85	1.3
1350 - 1400	1.75	3.55	6.2	-2.95	-5.2	0.60	1.1
1300 - 1350	1.46	3.28	4.8	-3.20	-4.7	0.07	0.1
1250 - 1300	0.78	2.90	2.3	-3.48	-2.7	-0.58	-0.4
1200 - 1250	1.28	2.50	3.2	-3.73	-4.8	-1.23	-1.6
1150 - 1200	1.00	2.15	2.2	-3.98	-4.0	-1.83	-1.8
1100 - 1150	0.44	1.90	0.8	-4.20	-1.9	-2.30	-1.0
1012 - 1100	0.30	1.55	0.5	-4.55	-1.4	-3.00	-0.9
1012 - 1632	**22.40**	**3.43**	**76.9**	**-2.73**	**-61.1**	**0.70**	**15.8**

3.2 Mass balance 2007-2016

The historical mass balance results for Svelgjabreen and Blomstølskardsbreen are presented in Figure 3-6. The cumulative annual balance for Svelgjabreen for 2007-16 is +1.5 m w.e., which gives a mean annual balance of +0.15 m w.e. a^{-1}. The cumulative annual balance for Blomstølskardsbreen for 2007-16 is +6.0 m w.e., which gives a mean annual balance of +0.60 m w.e. a^{-1}.

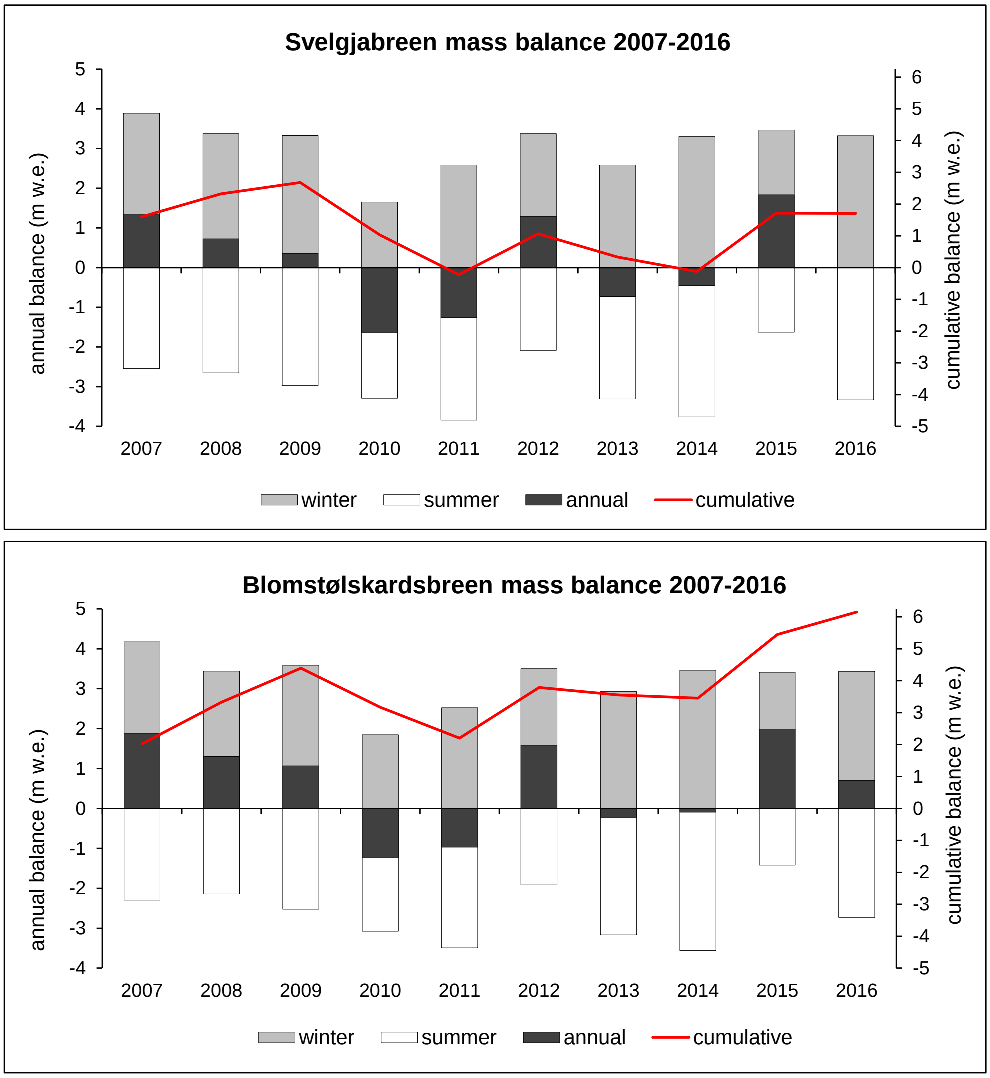


Figure 3-6
Winter, summer and annual balance at Svelgjabreen (upper) and Blomstølskardsbreen (lower) for 2007-2016. Cumulative mass balance is given on the right axis.

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 Jostedalsbreen, and extends from 1952 m a.s.l. down to 330 m a.s.l. (Fig. 4-1).

Glaciological investigations in 2016 include mass balance and glacier length change. Nigardsbreen has been the subject of mass balance investigations since 1962. A re-analysed mass balance series for Nigardsbreen 1962-2013 is presented in Kjøllmoen, 2016.

Figure 4-1
The outlet of Nigardsbreen photographed in August 2016. Photo: Hallgeir Elvehøy.

4.1 Mass balance 2016

Fieldwork

Snow accumulation measurements were performed on 10th and 11th May and the calculation of winter balance is based on measurement of six stakes and 119 snow depth soundings (Fig. 4-2). Comparison of sounded snow depth and stake readings indicated no melting after the ablation measurements in October 2015. Generally the sounding conditions were good and the summer surface was easy to identify, except in the uppermost areas. The snow depth varied between 3.9 and 8.2 m on the plateau. On the tongue, snow depth was 3.4 m in position 1000 (946 m a.s.l.) and 1.5 m in position 600 (590 m a.s.l.). Snow density was measured in position 94 (1683 m a.s.l.), and the mean density of 5.3 m snow was 474 kg m^{-3}.

Ablation was measured on 5th October. Measurements were made at stakes and towers in nine locations (Fig. 4-2). In the accumulation areas there was between 1 and 2 m of snow remaining from winter 2015/16. At the time of measurement, there was between 0.7 and 0.9 m of fresh snow was measured at stakes on the glacier plateau.

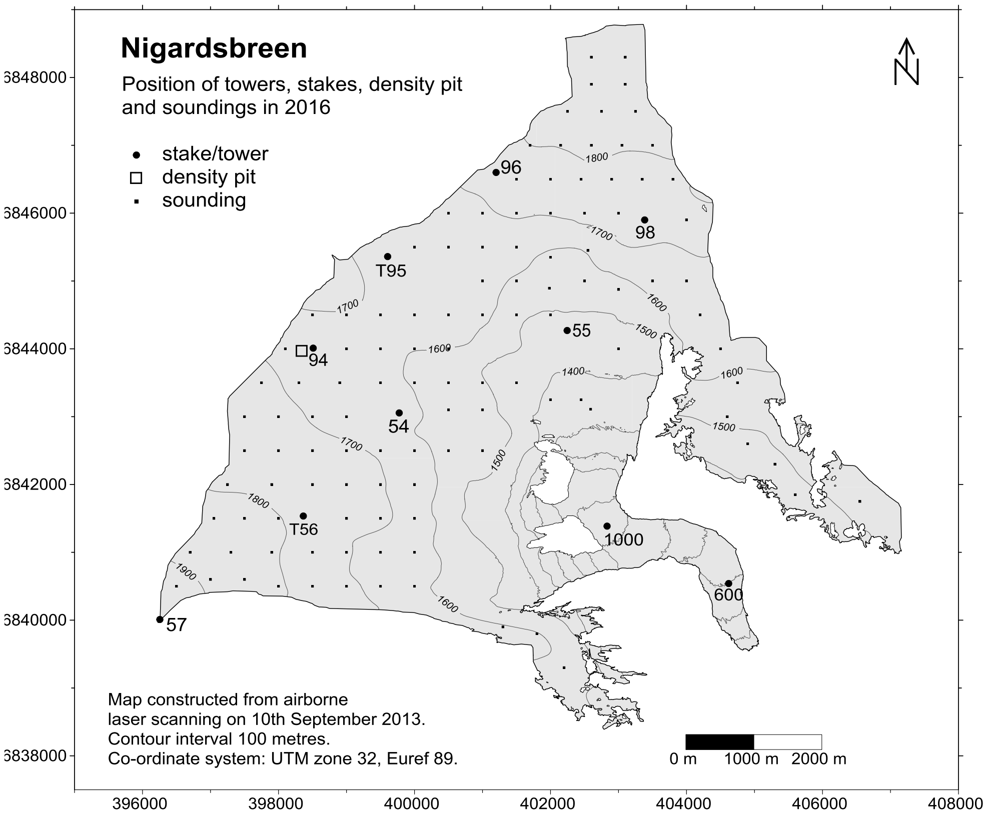


Figure 4-2
Location of towers, stakes, snow pit and soundings on Nigardsbreen in 2016.

Results

The calculations are based on the DTM from 2013.

The elevations above 1325 m a.s.l., which cover about 91 % of the catchment area, were well represented with point measurements. Below this altitude the curve pattern was based on point measurements at 946 and 599 m altitude.

The winter balance was calculated as a mean value for each 100 m height interval and was 2.8 ±0.2 m w.e., which is 124 % of the mean winter balance for the reference period 1971-2000. Spatial distribution of the winter balance is shown in Figure 4-3.

Based on estimated density and stake measurements the summer balance was also calculated as a mean value for each 100 m height interval and was −2.3 ±0.3 m w.e., which is 113 % of the reference period.

Hence, the annual balance was positive, at 0.5 m ±0.4 m w.e. The mean annual balance for the reference period 1971-2000 is +0.21 m w.e. Over the past ten years (2007-2016), the mean annual balance was +0.13 m w.e.

The mass balance results are shown in Table 4-1 and the corresponding curves for specific and volume balance are shown in Figure 4-4.

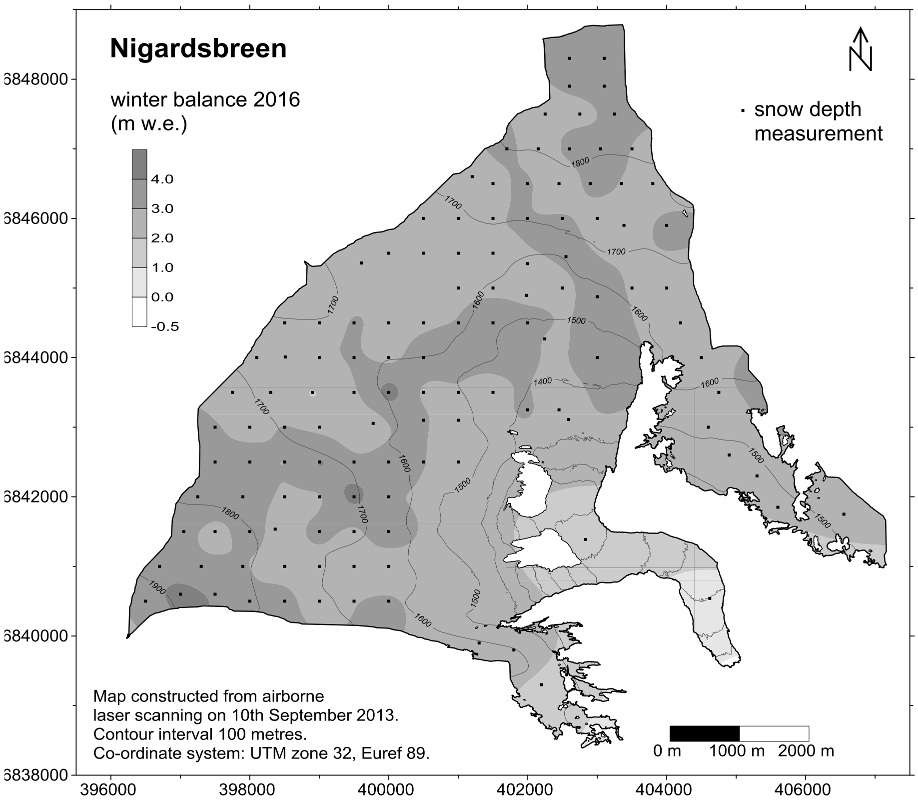


Figure 4-3
Spatial distribution of winter balance at Nigardsbreen in 2016.

According to Figure 4-4, the Equilibrium Line Altitude (ELA) was 1380 m a.s.l. Consequently, the Accumulation Area Ratio (AAR) was 89 %.

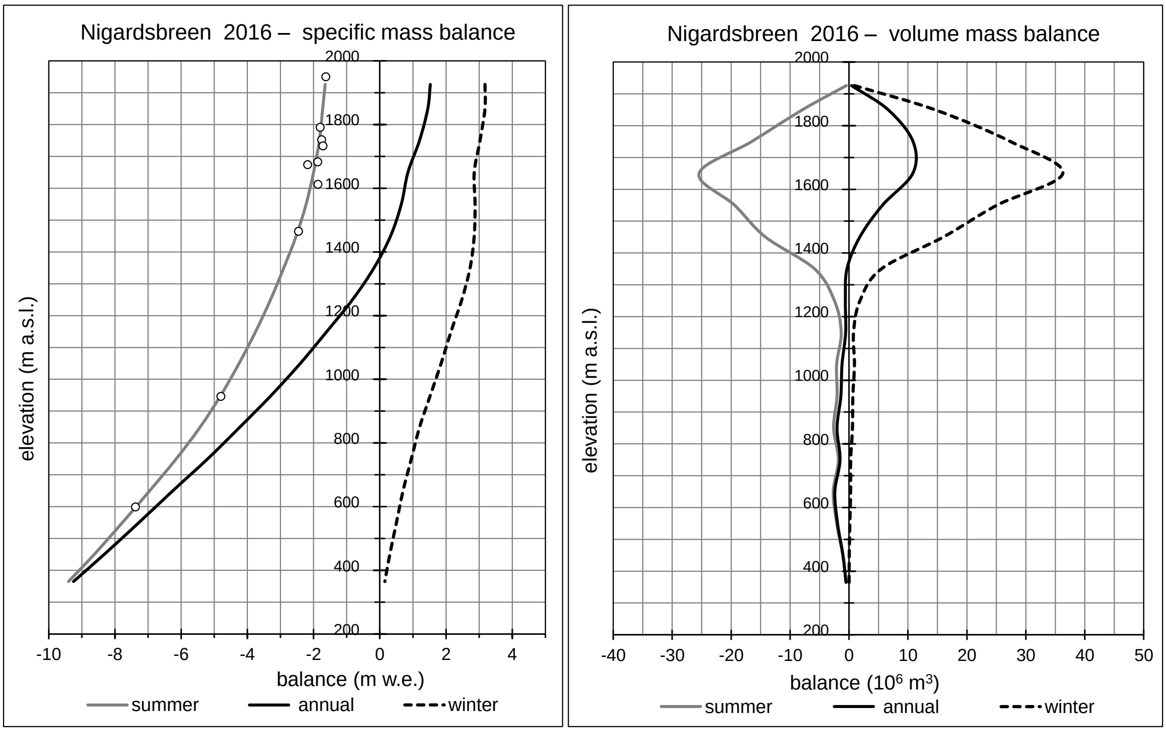


Figure 4-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Nigardsbreen in 2016. Specific summer balance at ten stake positions is shown as dots (○).

Table 4-1
Winter, summer and annual balances for Nigardsbreen in 2016.

Mass balance Nigardsbreen 2015/16 – stratigraphic system

		Winter mass balance Measured 10th May 2016		Summer mass balance Measured 5th Oct 2016		Annual mass balance Summer surface 2015 - 2016	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1900 - 1952	0.28	3.18	0.9	-1.65	-0.5	1.53	0.4
1800 - 1900	4.58	3.18	14.5	-1.73	-7.9	1.45	6.6
1700 - 1800	9.05	3.03	27.4	-1.83	-16.5	1.20	10.9
1600 - 1700	12.72	2.85	36.3	-2.00	-25.4	0.85	10.8
1500 - 1600	8.72	2.88	25.1	-2.23	-19.4	0.65	5.7
1400 - 1500	5.61	2.85	16.0	-2.53	-14.2	0.33	1.8
1300 - 1400	2.01	2.73	5.5	-2.90	-5.8	-0.18	-0.4
1200 - 1300	0.75	2.48	1.9	-3.30	-2.5	-0.83	-0.6
1100 - 1200	0.35	2.15	0.8	-3.75	-1.3	-1.60	-0.6
1000 - 1100	0.50	1.85	0.9	-4.25	-2.1	-2.40	-1.2
900 - 1000	0.42	1.53	0.6	-4.80	-2.0	-3.28	-1.4
800 - 900	0.48	1.20	0.6	-5.43	-2.6	-4.23	-2.0
700 - 800	0.29	0.95	0.3	-6.15	-1.8	-5.20	-1.5
600 - 700	0.39	0.70	0.3	-6.95	-2.7	-6.25	-2.4
500 - 600	0.27	0.50	0.1	-7.78	-2.1	-7.28	-2.0
400 - 500	0.12	0.30	0.0	-8.63	-1.1	-8.33	-1.0
330 - 400	0.05	0.15	0.0	-9.40	-0.5	-9.25	-0.5
330 - 1952	**46.61**	**2.81**	**131.1**	**-2.33**	**-108.4**	**0.49**	**22.7**

4.2 Mass balance 1962-2016

The historical mass balance results for Nigardsbreen are presented in Figure 4-5. The cumulative annual balance over 1962-2016 is +5.6 m w.e., which gives a mean annual balance of 0.10 m w.e. a^{-1}.

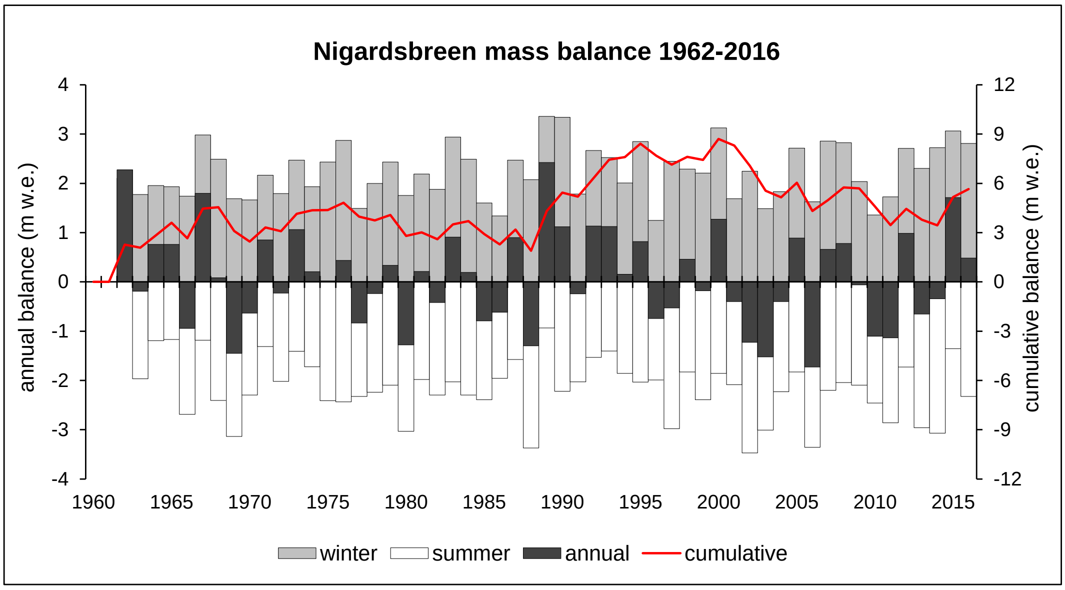


Figure 4-5
Winter, summer and annual balance at Nigardsbreen for 1962-2016. Cumulative mass balance is given on the right axis.

5. Austdalsbreen (Hallgeir Elvehøy)

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

The glaciological investigations in 2016 included mass balance, front position change and glacier velocity. The mass balance has been measured at Austdalsbreen since 1988.

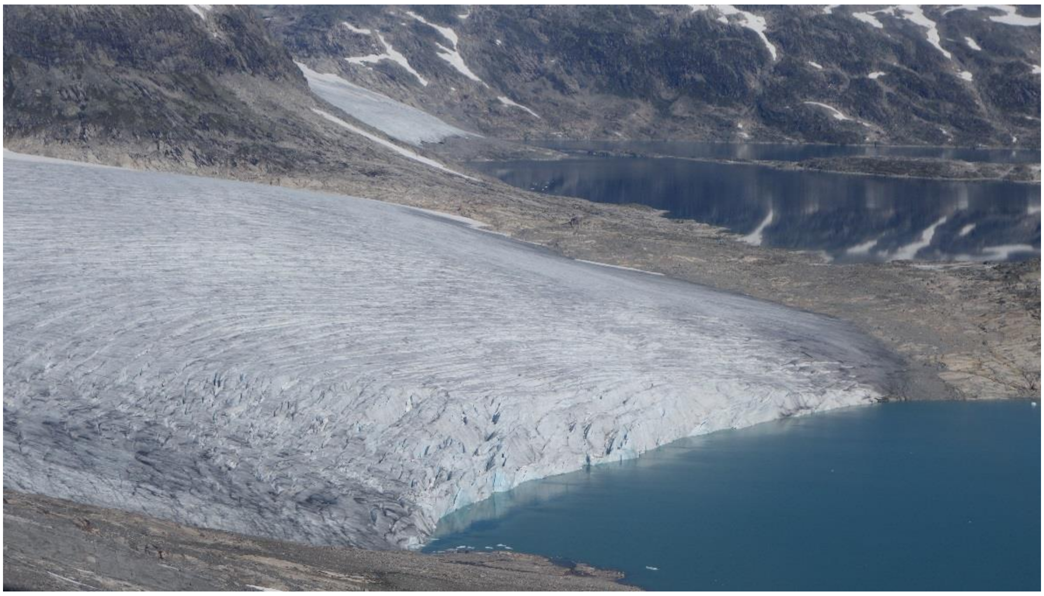


Figure 5-1
Austdalsbreen on 16th August 2016 as seen from the south-west (Fig. 5-2). The lake level was 1196 m a.s.l. which is 4 m below the highest regulated lake level. Kupevatnet and Sygneskardsbreen are seen in the background. Photo: Hallgeir Elvehøy.

5.1 Mass balance 2016

Fieldwork

Stakes were maintained throughout the winter in five of eight stake locations. Snow accumulation measurements were performed on 12th May and the calculation of winter balance was based on measurement of five stakes and 40 snow depth soundings (Fig. 5-2). Detecting the summer surface was relatively easy. The snow depth varied from 2.55 to 5.35 m. Snow density was measured in one location (1490 m a.s.l.). The mean snow density of 4.35 m snow was 493 kg m^{-3}. Comparison of stake readings and snow depth soundings on 12th May 2016 indicated no ice melt after the ablation measurement on 14th October 2015.

By 16th August the winter snow below 1400 m a.s.l. had melted. Visible stake heights were 3 to 4 m longer than measured on 12th May.

Summer and annual balance measurements were carried out on 5th October. There was up to 0.6 m of new snow on the glacier. Eleven stakes in eight locations were found. The stakes were 1.5 to 2 m longer than in August. All the winter snow had melted at all stake locations. Comparison of stake readings and snow depth soundings on 27th January 2017 indicated

5 cm and 15 cm of ice melt at stake A90 and A92, respectively, after the measurement on 5th October 2016.

Results

The calculations are based on a DTM from 17th October 2009.

The winter balance was calculated from snow depth and snow density measurements on 12th May. A function correlating snow depth with water equivalent was calculated based on snow density measurements at stake A60 (1490 m a.s.l.). The winter balance was 21 ±2 mill. m^3 water or 2.0 ±0.2 m w.e., which is 92 % of the 1988-2015 average (2.18 m w.e.).

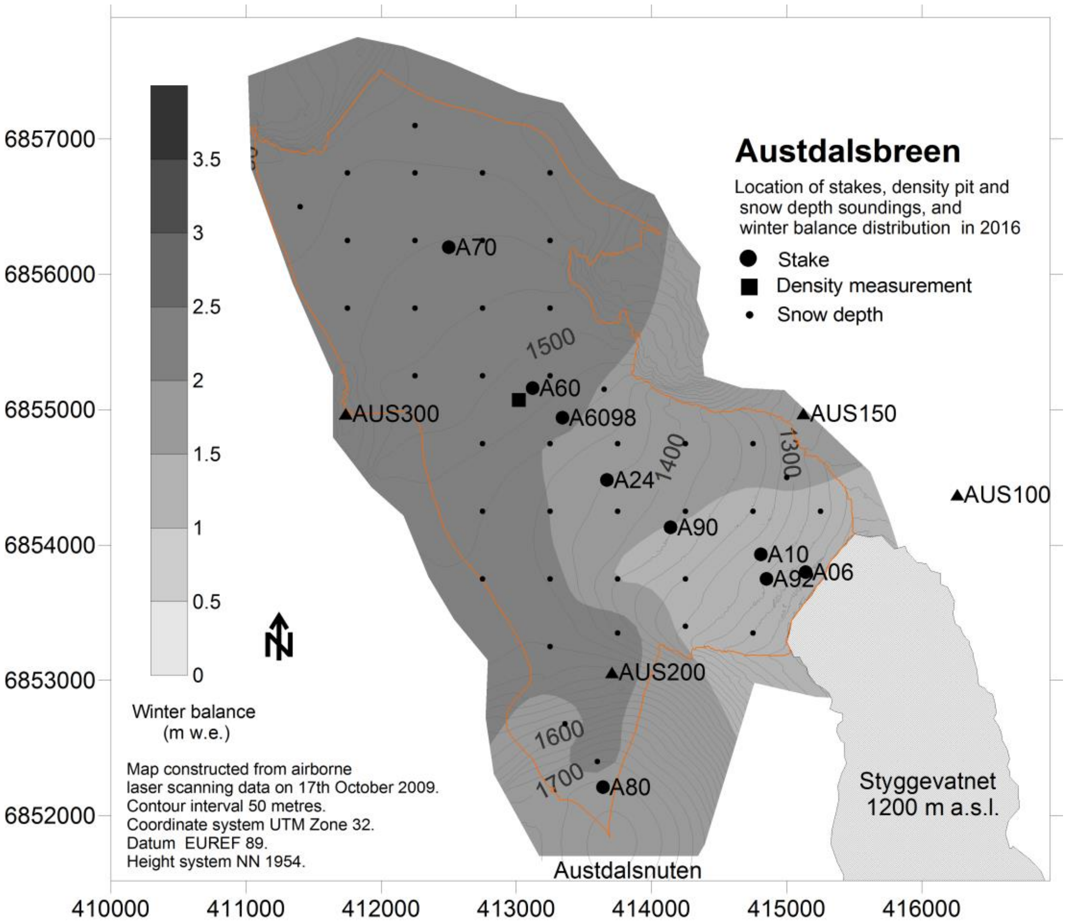


Figure 5-2
Location of stakes, density pit and snow depth soundings, and winter balance at Austdalsbreen in 2016 from 45 water equivalent values calculated from the snow depth measurements.

The summer balance was calculated directly for eight stake locations between 1250 and 1720 m a.s.l. Stake A10 was missing in October, but the ice melt from August to October was interpolated from stakes A06 and A92. The summer balance curve was drawn from these nine point values (Fig. 5-3).

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

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

where ρ_{ice} is 900 kg m^{-3}, u_{ice} is annual glacier velocity (34 ±10 m a^{-1}, chap. 5.3), u_f is front position change averaged across the terminus (+1 ±5 m a^{-1}, chap. 5.2), W is terminus width (930 ±20 m) and H is mean ice thickness at the terminus (47 ±5 m). The mean ice thickness was calculated from mean surface elevations along the calving terminus surveyed on 14th October 2015 (1226 m a.s.l.) and 5th October 2016 (1224 m a.s.l.), and mean bottom elevation along the terminus in October 2014 (1178 m a.s.l.) calculated from a bottom topography map compiled from radar ice thickness measurements (1986), hot water drilling (1987) and lake depth surveying (1988 and 1989). The resulting calving volume was 1.3 ±0.8 mill. m^3 water equivalent.

The summer balance, including calving, was calculated as −33 ±3 mill. m^3 of water, which corresponds to −3.1 ±0.3 m w.e. The result is 113 % of the 1988-2015 average (−2.71 m w.e.). The calving volume was 3 % of the summer balance.

The annual balance at Austdalsbreen was calculated as −11 ±3 mill. m^3 water, corresponding to −1.1 ±0.3 m w.e.. The average annual balance for the measurement period 1988-2015 is −0.52 m w.e. The ELA in 2016 was above the top of the glacier. Correspondingly, the AAR is 0 %. The altitudinal distribution of winter, summer and annual balances is shown in Figure 5-3 and Table 5-1.

Table 5-1
Altitudinal distribution of winter, summer and annual balances at Austdalsbreen in 2016.

Mass balance Austdalsbreen 2015/16 – stratigraphic method

Altitude	Area	Winter mass balance Measured 12th May 2016		Summer mass balance Measured 05th Oct 2016		Annual mass balance Summer surface 2015 - 2016	
(m a.s.l.)	(km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1700 - 1747	0.13	2.00	0.25	-2.50	-0.32	-0.50	-0.06
1650 - 1700	0.14	2.13	0.30	-2.55	-0.35	-0.42	-0.06
1600 - 1650	0.18	2.20	0.40	-2.55	-0.46	-0.35	-0.06
1550 - 1600	1.89	2.26	4.28	-2.60	-4.92	-0.34	-0.64
1500 - 1550	2.79	2.28	6.37	-2.60	-7.26	-0.32	-0.89
1450 - 1500	1.60	2.13	3.42	-2.70	-4.33	-0.57	-0.91
1400 - 1450	1.38	1.97	2.71	-3.00	-4.13	-1.03	-1.42
1350 - 1400	0.93	1.63	1.52	-3.40	-3.17	-1.77	-1.65
1300 - 1350	0.82	1.41	1.16	-3.80	-3.12	-2.39	-1.96
1250 - 1300	0.54	1.29	0.69	-4.30	-2.30	-3.01	-1.61
1200 - 1250	0.23	1.20	0.27	-4.80	-1.09	-3.60	-0.82
Calving					-1.07		-1.07
1200 - 1747	**10.63**	**2.01**	**21.4**	**-3.06**	**-32.5**	**-1.05**	**-11.2**

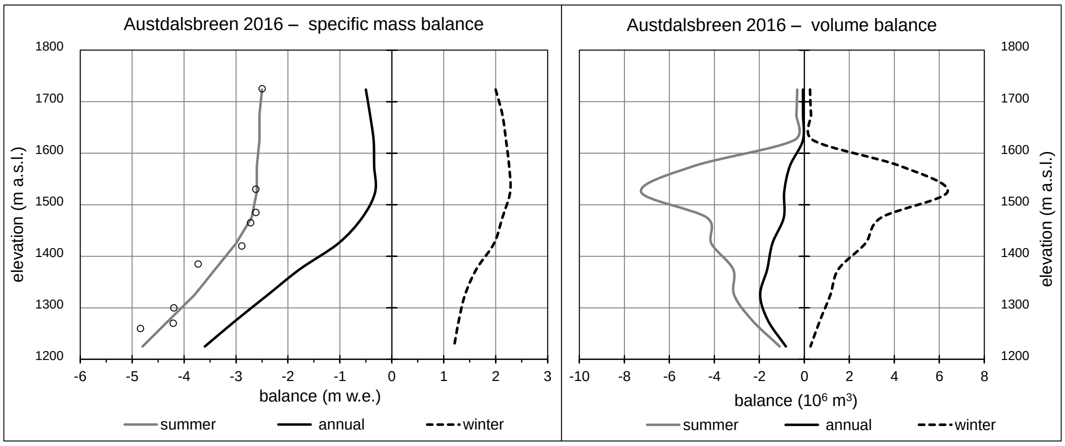


Figure 5-3
Altitudinal distribution of winter, summer and annual balance is shown as specific balance (left) and volume balance (right) at Austdalsbreen in 2016. Specific summer balance at nine stake locations is shown (○).

5.2 Mass balance 1988-2016

Results from 1988-2016 are shown in Figure 5-4.

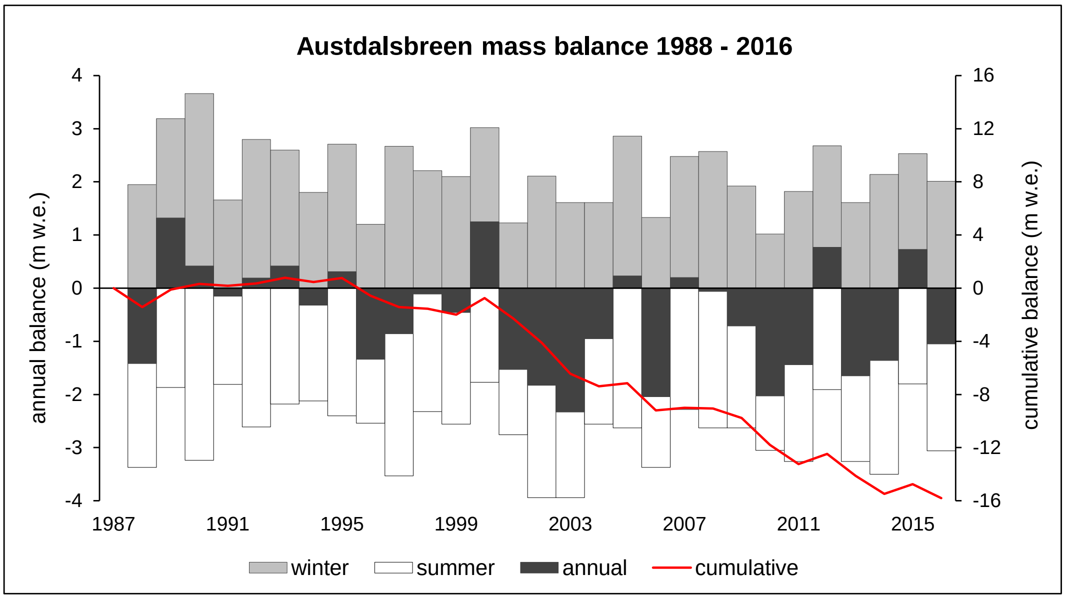


Figure 5-4
Winter, summer, annual and cumulative balances at Austdalsbreen during the period 1988-2016. Mean winter and summer balance is 2.18 and −2.72 m w.e., respectively. The cumulative mass balance is −15.8 m w.e.

5.3 Front position change

Eight points along the calving terminus were surveyed on 5th October 2016. The mean front position change was 1 ±5 m (Fig. 5-5) between 14th October 2010 and 5th October 2016. The width of the calving terminus was 930 ±20 metres. Since 1988 the glacier terminus has retreated about 650 metres, whilst the glacier area has decreased by approximately 0.612 km^2.

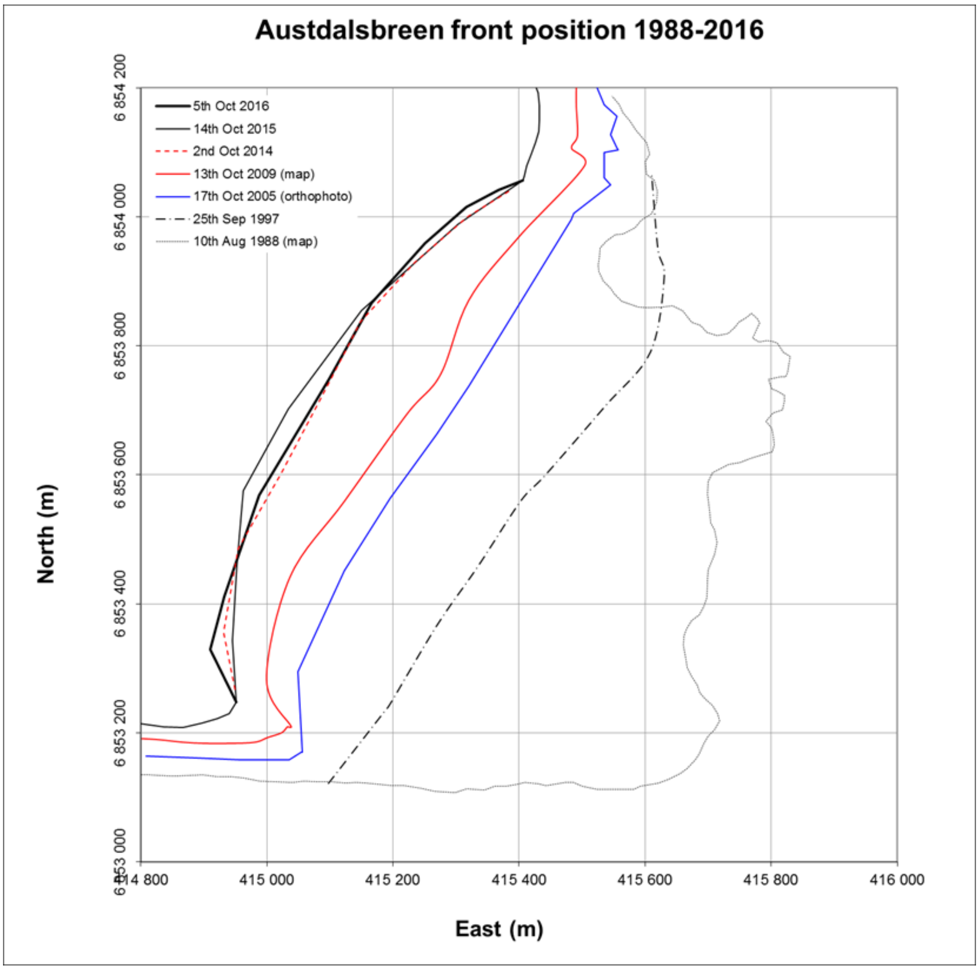


Figure 5-5
Surveyed front position of Austdalsbreen in 1988 when the lake was regulated, in 1997, in 2005, 2009 and 2014-16. The mean front position change between 14th October 2015 and 5th October 2016 was +1 m.

5.4 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 21st August and 14th October 2015, and 12th May, 16th August and 5th October 2016. Annual velocities were calculated for nine stake locations for the period 14th October 2010 – 5th October 2016 (356 days). The annual velocities at stake locations close to the terminus were 40 m a^{-1} at A6 (46 m a^{-1} in 2014 and 2015), 50 m a^{-1} at A92 (52 and 47 m a^{-1} in 2014 and 2015), and 41 m a^{-1} at A10 (43 and 39 m a^{-1} in 2014 and 2015).

The glacier velocity averaged across the front width and thickness must be estimated in order to calculate the calving volume (chap. 5.1). Due to lower velocities at stake A6 than at A92, the expected velocity increase towards the calving front is neglected, and A6 is assumed to be representative for the centre line surface velocity. The glacier velocity averaged over the cross-section is estimated to be 70 % of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed. The resulting glacier velocity averaged across the terminus for 2015/2016 is 28 ±10 m a^{-1}.

6. Rembesdalskåka (Hallgeir Elvehøy)

Rembesdalskåka (17 km^2, 60°32′N, 7°22′E) is a southwestern outlet glacier from Hardangerjøkulen, the sixth largest (73 km^2) glacier in Norway. The glacier is situated on the main water divide between Hardangerfjorden and Hallingdalen valley, and drains towards Simadalen valley and Hardangerfjorden. In the past Simadalen has been flooded by jøkulhlaups (outburst floods) from the glacier-dammed lake Demmevatnet (see section 14-2), the most recent occurring in 1937 and 1938, and then in 2014 and twice in 2016 (Fig. 6-1).

In 1963, the Norwegian Polar Institute began mass balance measurements on Rembesdalskåka. The Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations since 1985. The investigated basin covers the altitudinal range between 1066 and 1854 m a.s.l.

Figure 6-1
Lake Demmevatnet on 15th September 2016 after the GLOF on 6th September. The glacier margin in the lake retreated about 130 m between 1995 and 2010. There is a moraine ridge probably from the mid-18th century (Little Ice Age) about 225 m from the present glacier margin. Photo: Hallgeir Elvehøy.

6.1 Mass balance 2016

Fieldwork

The stake network was checked on 6th January and 8th March. Snow depth sounding and stake measurement at stake H10 on 6th January showed 0.2 m of ice melt after the autumn measurements on 14th October 2015. This melt was included in the mass balance for 2015.

The snow accumulation measurements were carried out on 10th May. Three stakes on the glacier plateau showed up to 5 m of snow. Snow depth was measured at 61 sounding locations in a 500 by 500 metre grid on the glacier plateau above 1500 m a.s.l. (Fig. 6-2).

The snow depth was between 4 and 6 m above 1650 m a.s.l., and between 3 and 5 m between 1500 and 1650 m a.s.l. The summer surface (S.S.) was easy to define. On the lower part of the glacier, snow depth was measured at 1200 and 1400 m a.s.l. The mean snow density down to 4.65 m depth at stake H7 was 481 kg m^{-3}. The snow depth to the S.S. was 5.0 m.

Stake H10 melted out some time in July and was re-drilled on 15th September. At that time, most of the snow below 1700 m a.s.l. had melted, and about 1 m of snow remained above 1700 m a.s.l.

Summer and annual balances were measured on 25th October. Only the three lower stakes were measured due to low cloud cover. There was 35 cm of new snow at stake H7, but no new snow at the lower stakes. At stake H7 all the winter snow had melted. All the snow and 2.9 m of ice melted during the summer at stake H8. At the glacier tongue, 0.8 m of ice melted after 15th September. From stake measurements, the TSL was about 1650 m a.s.l. About 0.7 m of snow remained above the TSL.

Snow depth sounding and stake measurements at stake H10 on 5th January 2017 showed no ice melt after the autumn measurements on 25th October 2016.

Results

The calculation of mass balance is based on a DTM from 2010. The winter balance was calculated from the snow depth and snow density measurements on 10th May. A snow depth-water equivalent profile was calculated based on snow density measurements at location H7 (1655 m a.s.l.). The snow depth measurements were transformed to water equivalent values using this profile. From the calculated water equivalent values, averages for 50 m elevation bands were calculated and plotted against altitude. An altitudinal winter balance curve was drawn from these averages (Fig. 6-3). Below 1500 m a.s.l. the winter balance curve was extrapolated from the measurements at stakes H8 (1510 m a.s.l.) and H10 (1250 m a.s.l.) and soundings at 1200 and 1400 m a.s.l. A value for each 50 m elevation was then determined from this curve. The resulting winter balance was 2.2 ±0.2 m w.e. or 39 ±3 mill. m^3 water. This is 102 % of the 1971-2000 average of 2.20 m w.e. a^{-1}, and 97 % of the 2011-15 average of 2.31 m w.e. a^{-1}.

Based on the snow depth measurements the spatial distribution of the winter balance was interpolated using the kriging method. One point in the upper icefall was estimated. The distributed winter balance is shown in Figure 6-2, and the mean winter balance was 2.4 m w.e.

The date of the 2016 mass balance minimum for Rembesdalskåka was assessed by visual inspection of the daily changes in gridded data of the snow amount from www.senorge.no (Saloranta, 2014). The snow accumulation probably started at the higher part of the glacier plateau on 1st October and at the lower part of the glacier plateau on 27th October.

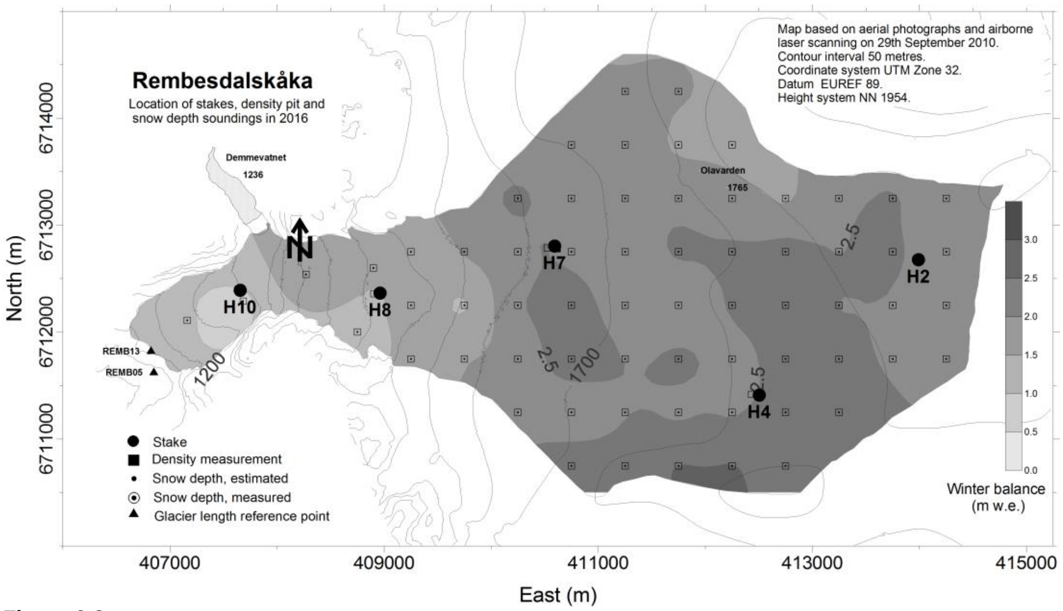


Figure 6-2
Winter balance at Rembesdalskåka interpolated from 68 measurements (•) of snow depth and one estimated point.

The summer balance was calculated directly at stake H8 and H7. The snow and ice melt at H10 between 10th May and 15th September (128 days) was assessed from linear correlation between mean temperature at three meteorological stations around Hardangerjøkulen and melting at H10, and from melting between H8 and H10 using data from 2011-15. According to these assessments, 1.95 m of winter snow at H10 had melted by 12th June, about 3.45 m of ice melted between 12th June and 18th August, and an additional 1.75 m of ice melted between 18th August and 15th September. Stakes H4 and H2 were not measured on 18th October. As 0.4 m of snow melted at H7 between 15th September and 1st October, the corresponding snowmelt at H2 and H4 was estimated as 0.3 m of snow. The density of the remaining snow at stake H2 and H4 was set as 600 kg m^{-3}, and the density of ice was set as 900 kg m^{-3}.

The summer balance curve in Figure 6-3 was drawn from five point values. The summer balance was calculated as −2.6 ±0.2 m w.e., corresponding to −45 ±3 mill. m^3 of water. This is 135 % of the 1971-2000 normal average, which is −1.95 m w.e. a^{-1}, but 99 % of the 2011-15 average of −2.65 m w.e. a^{-1}.

The annual balance at Rembesdalskåka was calculated as −0.4 ±0.3 m w.e. or −7 ±5 mill. m^3 water. The 1971-2000 normal value is +0.25 m w.e. a^{-1}, and the 2011-2015 average is −0.24 m w.e. a^{-1}. The altitudinal distribution of winter, summer and annual balances is shown in Figure 6-3 and Table 6-1. The ELA was 1695 m a.s.l. and the corresponding AAR was 73 %.

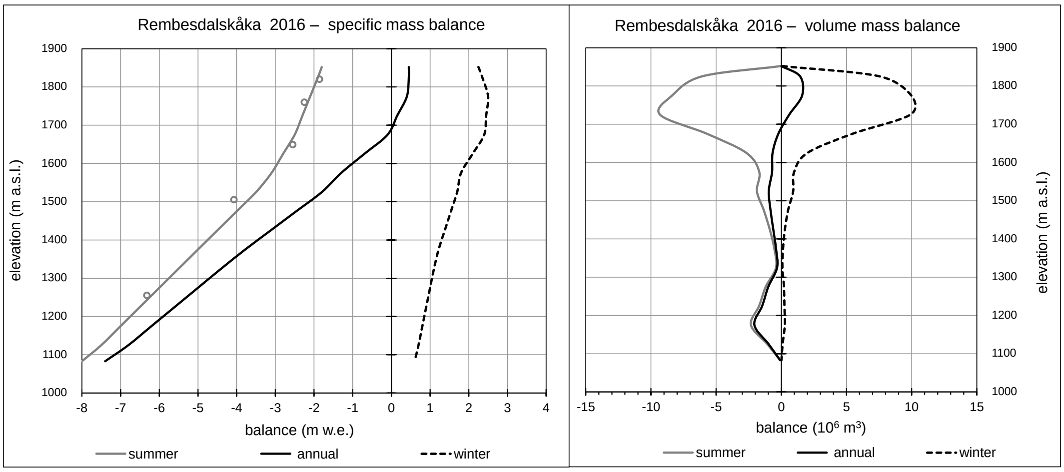


Figure 6-3
Altitudinal distribution of winter, summer and annual mass balance is shown as specific balance (left) and volume balance (right). Specific summer balance at five stakes is shown (○).

Table 6-1
Altitudinal distribution of winter, summer and annual mass balance at Rembesdalskåka in 2016.

Mass balance Rembesdalskåka 2015/16 – stratigrafic method

Altitude	Area	Winter mass balance Measured 10th May 2016		Summer mass balance Measured 25th Oct 2016		Annual mass balance Summer surface 2015 - 2016	
(m a.s.l.)	(km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1850 - 1854	0.03	2.25	0.1	-1.80	-0.1	0.45	0.0
1800 - 1850	3.21	2.35	7.5	-1.90	-6.1	0.45	1.4
1750 - 1800	3.99	2.50	10.0	-2.10	-8.4	0.40	1.6
1700 - 1750	4.05	2.45	9.9	-2.30	-9.3	0.15	0.6
1650 - 1700	2.28	2.40	5.5	-2.50	-5.7	-0.10	-0.2
1600 - 1650	0.96	2.10	2.0	-2.80	-2.7	-0.70	-0.7
1550 - 1600	0.55	1.80	1.0	-3.10	-1.7	-1.30	-0.7
1500 - 1550	0.53	1.70	0.9	-3.50	-1.9	-1.80	-1.0
1450 - 1500	0.34	1.54	0.5	-4.00	-1.3	-2.46	-0.8
1400 - 1450	0.20	1.38	0.3	-4.50	-0.9	-3.12	-0.6
1350 - 1400	0.11	1.22	0.1	-5.00	-0.5	-3.78	-0.4
1300 - 1350	0.07	1.10	0.1	-5.50	-0.4	-4.40	-0.3
1250 - 1300	0.20	1.00	0.2	-6.00	-1.2	-5.00	-1.0
1200 - 1250	0.26	0.90	0.2	-6.50	-1.7	-5.60	-1.5
1150 - 1200	0.33	0.80	0.3	-7.00	-2.3	-6.20	-2.1
1100 - 1150	0.14	0.70	0.1	-7.50	-1.1	-6.80	-1.0
1066 - 1100	0.01	0.60	0.0	-8.00	-0.1	-7.40	-0.1
1066 - 1854	**17.26**	**2.24**	**38.7**	**-2.63**	**-45.4**	**-0.39**	**-6.7**

6.2 Mass balance 1963-2016

Results from 1963-2016 are shown in Figure 6-4. The cumulative net balance is −75 mill. m^3 w.e. However, since 1995 the glacier has had a mass deficit of −210 mill. m^3 w.e.

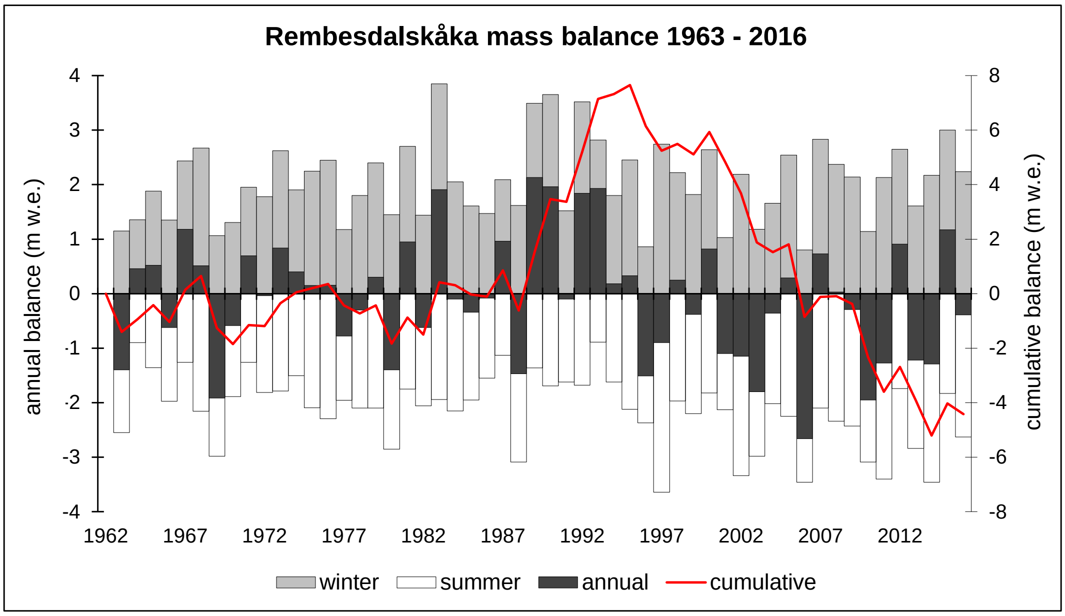


Figure 6-4
Winter, summer, annual and cumulative balances at Rembesdalskåka during the period 1963-2016. Mean values (1963-2016) are B_w=2.06 m w.e a^{-1} and B_s=−2.14 m w.e a^{-1}.

Figure 6-5
Crevasse at the top of the ice fall, close to stake H8, looking south on 15th September 2016. Photo: Hallgeir Elvehøy.

7. Storbreen (Liss M. Andreassen)

Storbreen (61°34′N, 8°8′E) (now written with –an ending on official maps: Storbrean) 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. 14.1).

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 2016 was calculated based on the DTM and glacier outline from 2009.

Figure 7-1
Storbreen on 12th September 2016. Photo: Liss M. Andreassen.

7.1 Mass balance 2016

Field work

Snow accumulation was measured in two campaigns, the lower part on 12th May and the upper part on 19th May. Stakes in nine positions were visible. A total of 136 snow depth soundings were made (Fig. 7-2). The stake readings showed some additional surface melting after the ablation measurements in the previous mass balance year (9th September 2015). The snow depth varied between 1.34 and 4.58 m, the mean being 2.87 m. Snow density was measured in two positions, on 12th May at the AWS at 1563 m a.s.l. (3.22 m snow) and on 19th May at stake 4 at 1715 m a.s.l. (2.62 m snow). The measured snow densities were 453 kg m^{-3} and 456 kg m^{-3}, respectively. Ablation measurements were performed on 12th September at stakes in all positions. There was remaining snow and firn at stakes 6, 8 and 9.

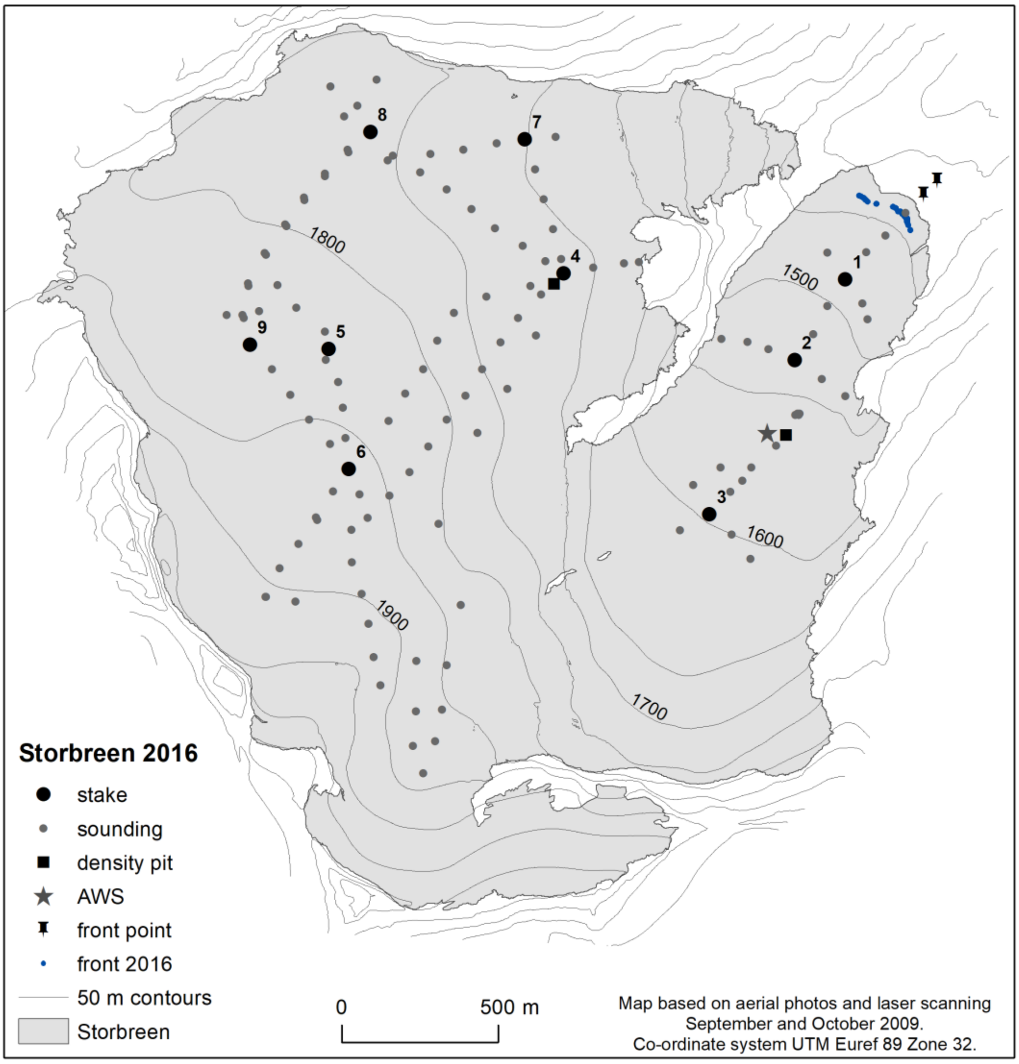


Figure 7-2
Location of stakes, soundings and density pits at Storbreen in 2016. The 50 m contours and the glacier outline is from aerial photos and laser scanning acquired in September and October 2009. The position of the automatic weather station (AWS), reference points used for length change measurements (see chap. 14.1) and part of the glacier outline mapped with a handheld GPS (front 2016) is also shown.

Results

Winter balance was calculated from soundings and the snow density measurements. 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 the pit at stake 4 was used for soundings above 1650 m a.s.l. The winter accumulation was calculated as the mean of the soundings within each 50-metre height interval and was 1.35 ± 0.2 m w.e. Subtracting melting that occurred after the measurements on 9th September 2015 resulted in a winter balance of 1.11 m w.e. ± 0.2 m w.e., which is 72 % of the mean winter balance for the reference period 1971-2000. Summer (and annual) balance was calculated directly from stakes at eight (12) locations. The summer balance was interpolated to 50 m height intervals based on the stake readings and was –1.91 ±0.2 m w.e., which is 118 % of the mean summer balance for the reference period 1971-2000. The annual balance of Storbreen was −0.79 ±0.3 m w.e. in 2016. The ELA calculated from the annual balance diagram (Fig. 7-3) was ~1835 m a.s.l. resulting in an accumulation area ratio (AAR) of 29 %.

The mass balance results are shown in Table 7-1 and the corresponding curves for specific and volume balance are shown in Figure 7-3.

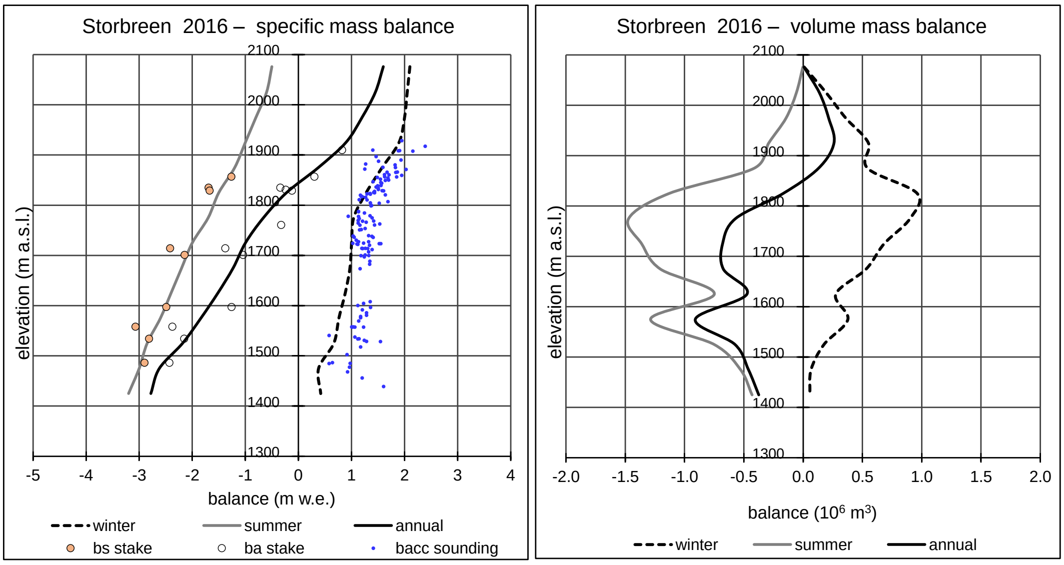


Figure 7-3
Mass balance versus altitude for Storbreen 2016, showing specific balance on the left and volume balance on the right. Winter accumulation soundings and summer and annual balance at 8 stakes is also shown. Winter balance is adjusted for additional melt (not shown) after ablation measurement on 9th September 2015.

Table 7-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Storbreen in 2016.

Mass balance Storbreen 2015/16 – stratigraphic system

Altitude	Area	Winter mass balance		Summer mass balance		Annual mass balance	
		Measured 15th May 2016		Measured 12th Sep 2016		Summer surfaces 2015 - 2016	
(m a.s.l.)	(km²)	Specific (m w.e.)	Volume (10⁶ m³)	Specific (m w.e.)	Volume (10⁶ m³)	Specific (m w.e.)	Volume (10⁶ m³)
2050 - 2102	0.00	2.10	0.01	-0.50	0.00	1.60	0.01
2000 - 2050	0.09	2.05	0.19	-0.60	-0.06	1.45	0.14
1950 - 2000	0.18	2.00	0.36	-0.80	-0.14	1.20	0.21
1900 - 1950	0.29	1.90	0.55	-1.00	-0.29	0.90	0.26
1850 - 1900	0.34	1.58	0.54	-1.20	-0.41	0.38	0.13
1800 - 1850	0.75	1.28	0.96	-1.50	-1.13	-0.22	-0.17
1750 - 1800	0.87	1.04	0.90	-1.70	-1.47	-0.66	-0.57
1700 - 1750	0.68	1.00	0.68	-2.00	-1.36	-1.00	-0.68
1650 - 1700	0.55	0.97	0.53	-2.20	-1.20	-1.23	-0.67
1600 - 1650	0.31	0.88	0.28	-2.40	-0.75	-1.52	-0.47
1550 - 1600	0.49	0.76	0.38	-2.60	-1.29	-1.84	-0.91
1500 - 1550	0.26	0.67	0.18	-2.85	-0.75	-2.18	-0.57
1450 - 1500	0.18	0.38	0.07	-3.00	-0.53	-2.62	-0.46
1400 - 1450	0.13	0.42	0.06	-3.20	-0.43	-2.78	-0.37
1400 - 2102	**5.14**	**1.11**	**5.68**	**-1.91**	**-9.82**	**-0.80**	**-4.13**

7.2 Mass balance 1949-2016

The cumulative balance over 1949-2016 is −23.8 m w.e, and the mean annual balance for this period of 68 years is −0.35 m w.e. (Fig. 7-4). For the period 2001-2016 the mean annual balance is −0.86 m w.e. The five years with the most negative annual mass balance all occurred in this period (ranged with the most negative first: 2006, 2002, 2010, 2003 and 2011). Length change measurements show that Storbreen retreated 114 m from 2001 to 2016, whereof 12 m from 2014 to 2016 (Fig. 7-5).

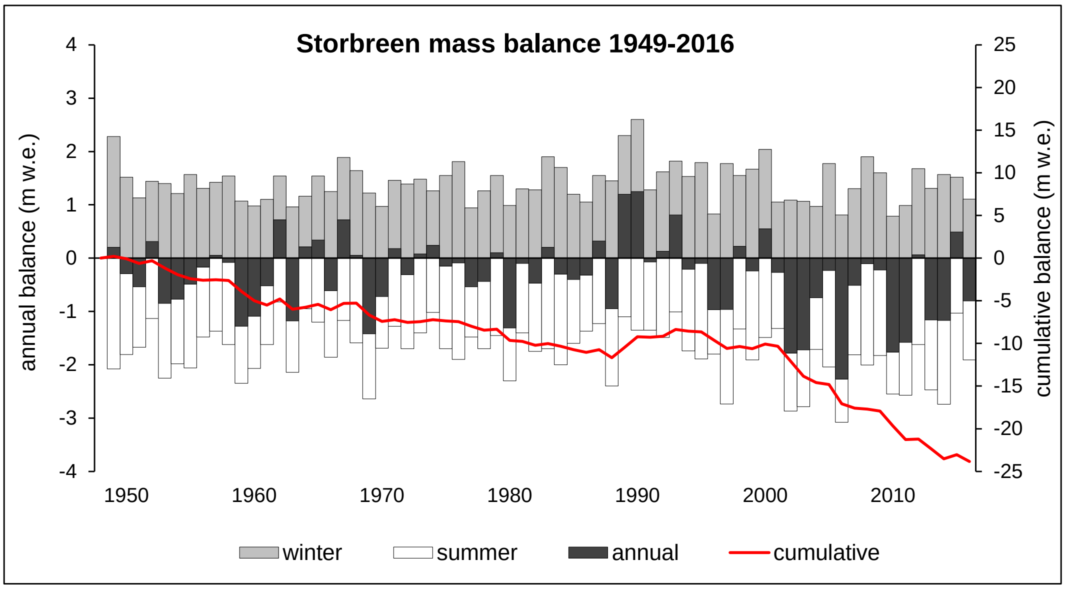


Figure 7-4
Winter, summer, annual and cumulative mass balance at Storbreen for the period 1949-2016.

Figure 7-5
The lower parts of Storbreen on 16th August 2016, view looking northwest. The front position is measured on the southern tongue (Fig. 7-2). Measurements showed a retreat of 12 m from 2014 to 2016 (see chap. 14.1). The terminus was snow covered in 2015. The steep northern tongue has frequent ice avalanches (see red circle). Photo: Liss M. Andreassen.

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. 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.). Dating of ice in a tunnel excavated in Juvfonne shows that the age of the ice in Juvfonne is ca. 7600 years BP at the base (Ødegård et al., 2017). This is the oldest dated ice in mainland Norway.

The observation programme of Juvfonne in 2016 consisted of accumulation measurements in spring, seasonal and annual balances measured at one stake, and survey of the ice patch extent and front position. A survey of the ice patch was also done with an unmanned aerial vehicle (UAV) in September 2016. Mass balance calculations are based on a digital terrain model and digital outline derived from airborne laser scanning and orthophoto taken on 17th September 2011. According to this survey Juvfonne has an area of 0.127 km^2 and ranged in altitude from 1841 to 1986 m a.s.l. The extent of Juvfonne has been annually surveyed on foot with a Global Navigation Satellite System (GNSS) instrument mounted on a backpack since 2010. The annual extent measurements (2010–2015) show fluctuations in area, varying from 0.101 km^2 (9th September 2014) to a maximum of 0.186 km^2 on 11th September 2015 (Tab. 1 in Ødegaard et al., 2017). The extent measurements show that the ice patch shrinks and grows along the whole of the margin.

Figure 8-1
Juvfonne on 13th September 2016. Photo: Liss M. Andreassen.

8.1 Survey 2016

The ice patch extent was measured on 13th September. The upper parts of the ice patch were snow-covered at the time of the survey (Fig. 8-1, 8-2). The total area, including this seasonal and perennial snow was 0.160 ± 0.002 km^2. Juvfonne was also photographed with an UAV on 13th September. The results were used to produce an orthophoto (Fig. 8-2) and digital terrain model of the surface.

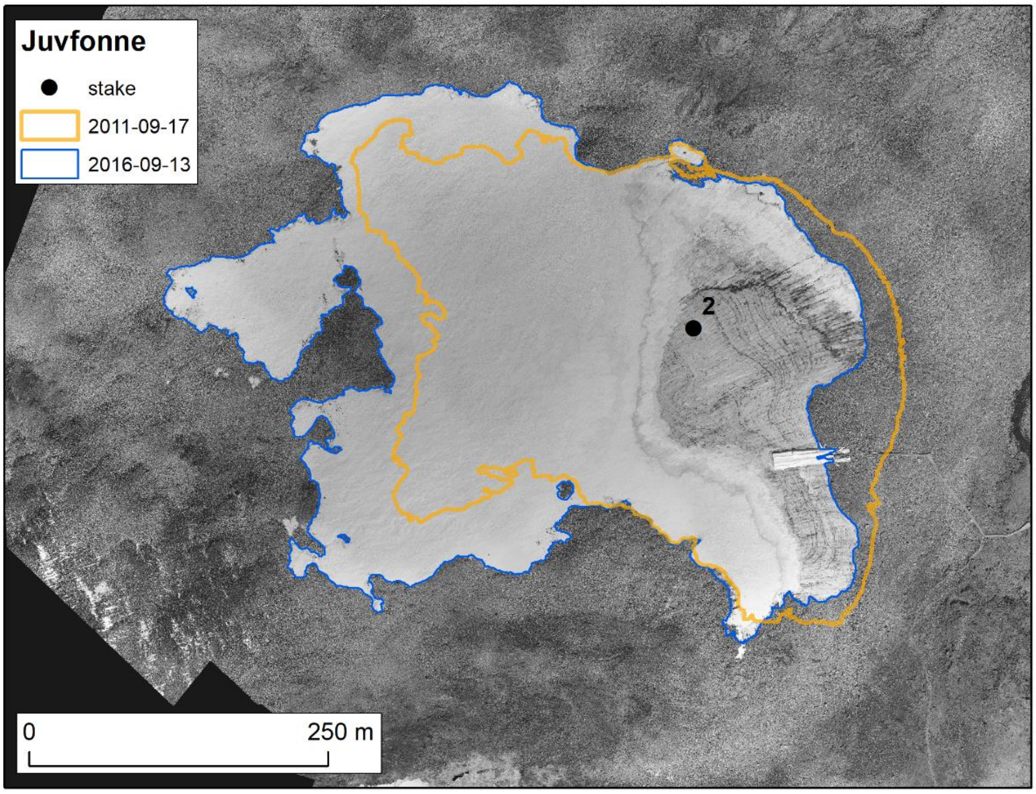


Figure 8-2
Orthophoto of Juvfonne on 13th September 2016 derived from an UAV survey. The position of stake 2 and the ice patch extent measured in 2011 and 2016 are marked. Note the ice tunnel (with white roof) southeast of stake 2 at the ice patch margin.

8.2 Mass balance 2016

Field work

The accumulation measurements on Juvfonne were carried out on 11th May. A total of 29 snow depth soundings were made (Fig. 8-3). Snow depths varied between 1.75 and 2.67 m with a mean of 2.18 m. The snow density was measured in a pit down to the previous summer surface near stake 2, where the total snow depth down to the 2015 summer surface was 2.25 m and the density was 457 kg m^{-3}. Stake readings revealed additional melt after the ablation measurement the previous year. This melting was subtracted from the winter accumulation measured at stake 2.

Ablation measurements were carried out on 13th September at stake 2. The surface was bare ice, thus the snow from winter 2015/2016 as well as the remaining snow from the previous winter had ablated at this location (Fig. 8-2). This is in contrast to 2015 when the whole ice patch had snow remaining at the time of the ablation measurements.

Results

Seasonal surface mass balances have been measured since 2010 at stake 2. In 2016 the summer balance (–1.98 m w.e.) exceeded the winter balance (0.78 m w.e.), giving a net deficit of –1.2 ± 0.1 m w.e. at this location. The cumulative mass balance for stake 2 over the seven years of measurements is –9.99 m w.e., or –1.43 m w.e. a^{-1} (Fig. 8-4). Glacier-wide mass balance was not calculated; this was calculated for only the first year of measurements 2009/2010 when more stakes were measured.

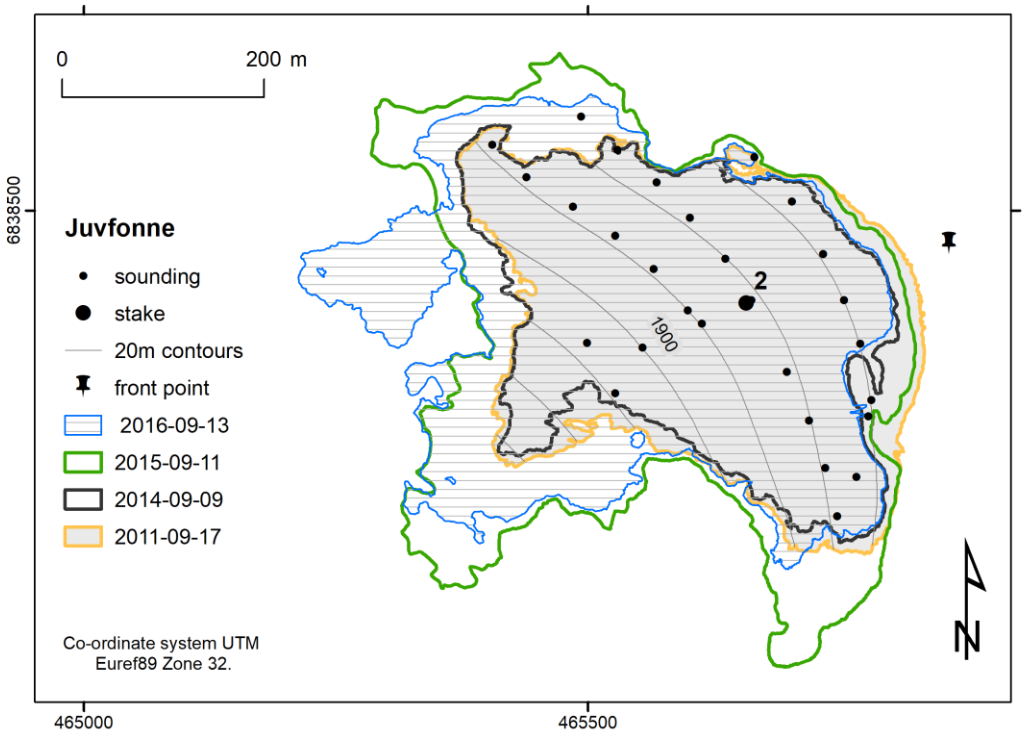


Figure 8-3
Location of snow depth soundings in 2016 and the position of stake 2 where the snow density is measured each year. The ice patch extents in 2016 (GNSS-measurements), 2015 (GNSS-measurements), 2014 (GNSS-measurements) and 2011 (orthophoto) are shown. Front point marks the reference point for front position and length change measurements (see chap. 14.1).

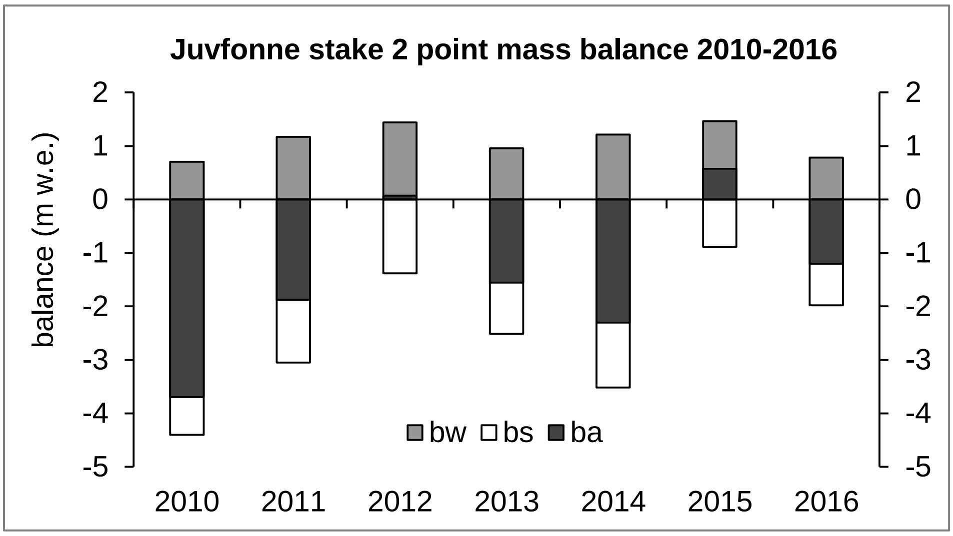


Figure 8-4
Point mass balance at stake 2 at Juvfonne 2010-2016, given as winter balance (b_w), summer balance (b_s) and annual balance (b_a).

9. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61°34′N, 8° 26′E) (now written with –an ending on official maps: Hellstugubrean) is a north-facing valley glacier situated in central Jotun-heimen (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 calculations presented here are based on the latest survey of the glacier from 2009.

Figure 9-1 Hellstugubreen on 4th August 2016. The photo is taken from a helicopter looking south. Photo: Liss M. Andreassen.

9.1 Mass balance 2016

Field work

Accumulation measurements were performed on 13th May. Stake readings indicated no significant additional melting after the ablation measurements on 23rd-24th September 2015. Snow depths were measured in 64 positions between 1552 and 2147 m a.s.l. covering most of the altitudinal range of the glacier. The snow depth varied between 1.93 and 3.80 m, with a mean of 2.65 m. Snow density was measured in a density pit at 1954 m a.s.l. The total snow depth was 2.33 m and the resulting density was 448 kg m^{-3}. Ablation measurements were carried out on 12th September (Fig. 9-3).

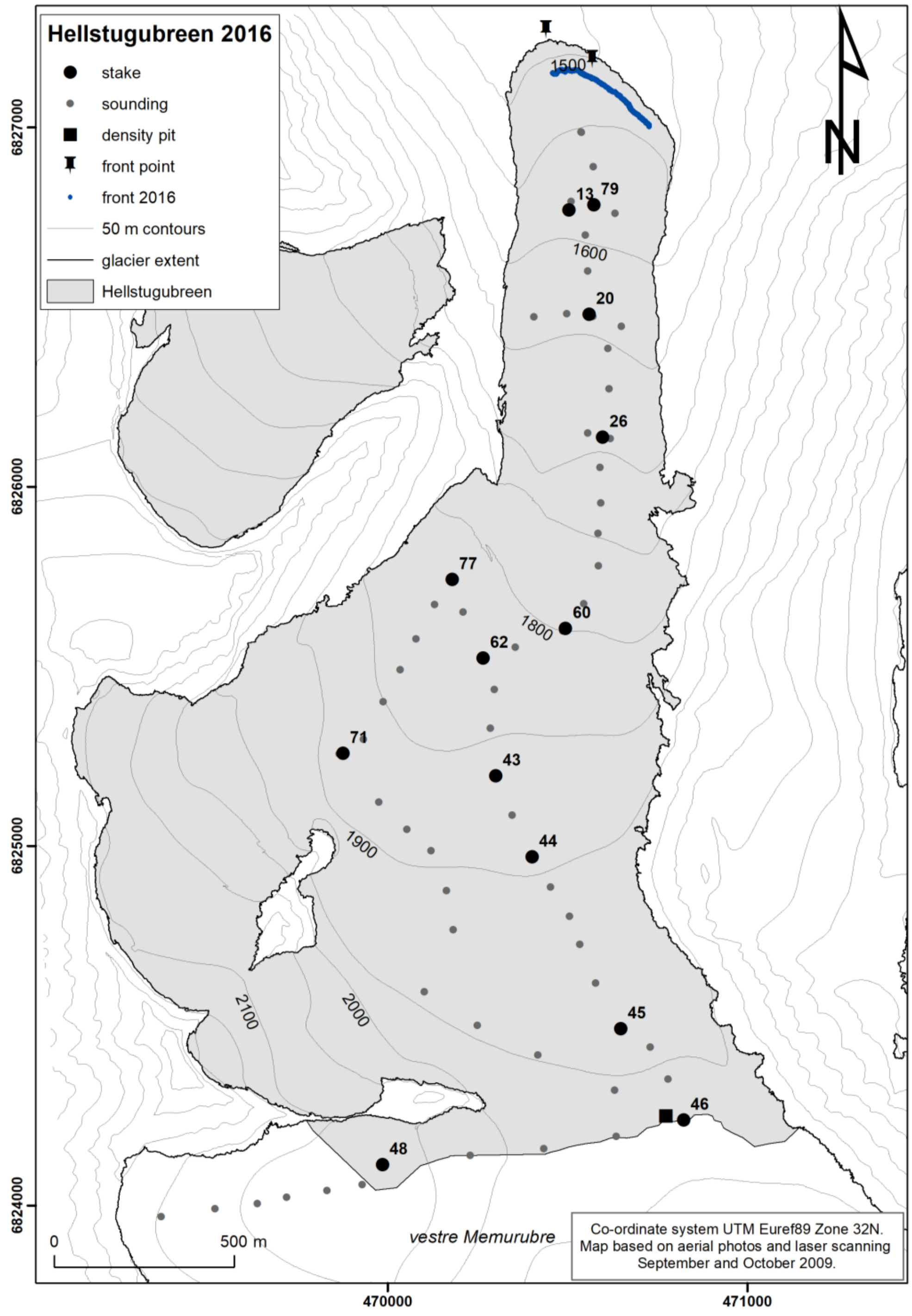


Figure 9-2
Map of Hellstugubreen showing the location of stakes, snow depth soundings and snow pit in 2016. Since 2009 the glacier terminus has retreated. Part of the terminus (front 2016) mapped by foot with GNSS-survey in shown on the map together as well as front reference points used for front position and length change measurements (chap. 14.1).

Figure 9-3
Ablation measurement at stake 26 on 12th September 2016. Photo: Liss M. Andreassen.

Results

The calculations are based on the DTM from 2009. The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 1.21 ±0.2 m w.e., which is 105 % of the mean winter balance for the reference period 1971-2000. The summer balance was interpolated to 50 m height intervals based on the stake readings and was –1.55 ±0.2 m w.e., which is 111 % of the mean summer balance for the reference period 1971-2000. The annual balance of Hellstugubreen was −0.34 ±0.3 m w.e. The equilibrium line altitude (ELA) was estimated as 1940 m a.s.l. resulting in an accumulation area ratio (AAR) of 34 %. The mass balance results are shown in Table 9-1 and the corresponding curves for specific and volume balance are shown in Figure 9-4.

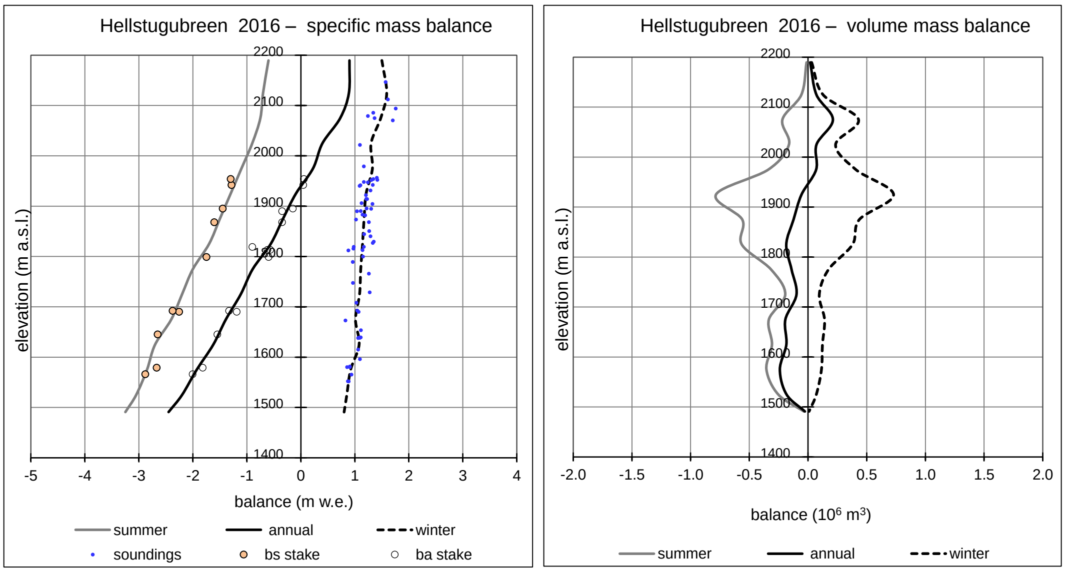


Figure 9-4
Mass balance diagram for Hellstugubreen in 2016, showing specific balance on the left and volume balance on the right. Summer and annul balance at stakes and winter balance soundings is also shown.

Mass balance Hellstugubreen 2015/16 – stratigraphic system							
		Winter massbalance Measured 13th May 2016		Summer massbalance Measured 12th Sep 2016		Annual mass balance Summer surfaces 2015 - 2016	
Altitude (m a.s.l.)	Area (km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
2150 - 2229	0.02	1.50	0.03	-0.60	-0.01	0.90	0.02
2100 - 2150	0.08	1.59	0.13	-0.70	-0.06	0.89	0.07
2050 - 2100	0.29	1.48	0.43	-0.75	-0.22	0.73	0.21
2000 - 2050	0.18	1.30	0.23	-0.90	-0.16	0.40	0.07
1950 - 2000	0.31	1.33	0.41	-1.10	-0.34	0.23	0.07
1900 - 1950	0.60	1.21	0.73	-1.30	-0.78	-0.09	-0.06
1850 - 1900	0.37	1.17	0.44	-1.50	-0.56	-0.33	-0.12
1800 - 1850	0.33	1.14	0.38	-1.70	-0.56	-0.56	-0.19
1750 - 1800	0.16	1.11	0.17	-2.00	-0.31	-0.89	-0.14
1700 - 1750	0.09	1.09	0.10	-2.20	-0.19	-1.11	-0.10
1650 - 1700	0.14	1.01	0.14	-2.40	-0.33	-1.39	-0.19
1600 - 1650	0.11	1.08	0.12	-2.70	-0.31	-1.62	-0.18
1550 - 1600	0.12	0.92	0.11	-2.85	-0.35	-1.93	-0.24
1500 - 1550	0.08	0.85	0.07	-3.05	-0.25	-2.20	-0.18
1482 - 1500	0.01	0.80	0.01	-3.25	-0.04	-2.45	-0.03
1482 - 2229	**2.90**	**1.21**	**3.50**	**-1.55**	**-4.49**	**-0.34**	**-0.99**

Table 9-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Hellstugubreen in 2016.

9.2 Mass balance 1962-2016

The cumulative annual balance of Hellstugubreen since 1962 amounts to −21.6 m w.e. (Fig. 9-5), giving a mean annual deficit of 0.39 m w.e. per year. Since 2001, the cumulative mass balance is –12.4 m w.e.

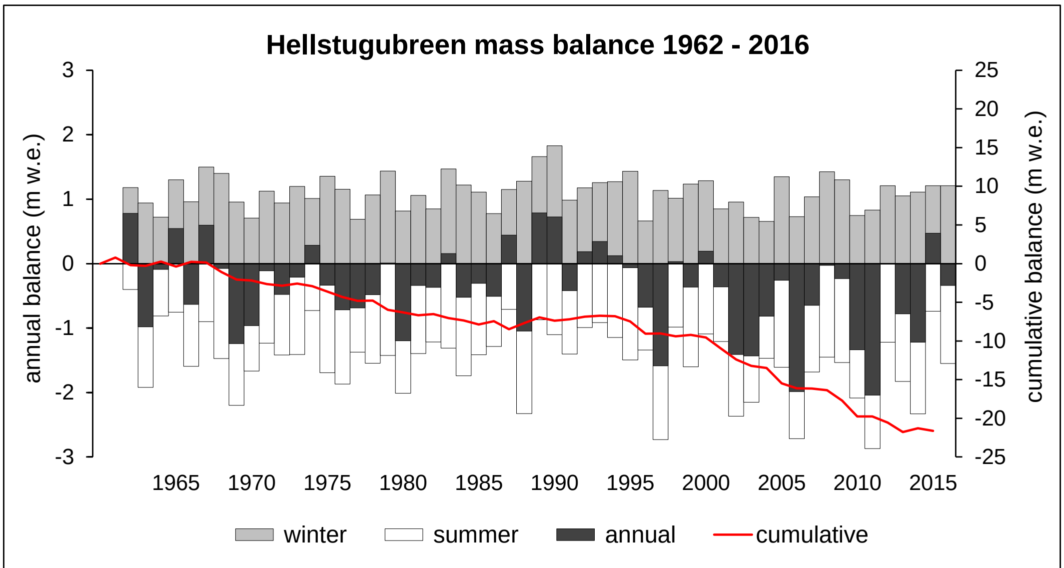


Figure 9-5
Winter, summer and annual balance at Hellstugubreen for 1962-2016, and cumulative mass balance for the whole period.

10. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39′N, 8°37′E) (now written with an -an ending on official maps: Gråsubrean) 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. Gråsubreen is the easternmost glacier, has the smallest mass turnover and the densest stake network of the monitored glaciers in Norway.

Ice temperature and ice thickness measurements carried out in 2012 show that Gråsubreen consists of relatively thin, cold ice which is underlain by a zone of temperate ice in the central, thicker part of the glacier where ice more than 130 m thick is measured (Sørdahl, 2013; Andreassen et al., 2015). 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 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.

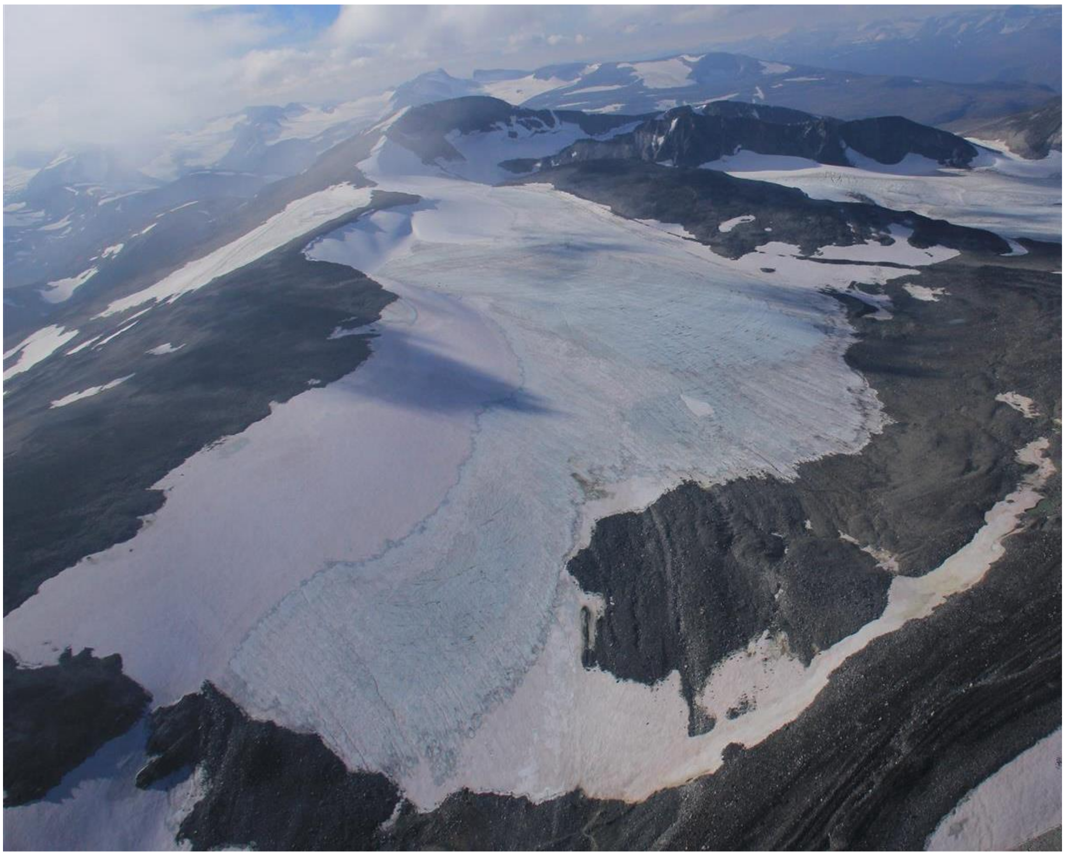


Figure 10-1
Gråsubreen photographed from the air, 20th September 2016. View looking west.
Photo: Hallgeir Elvehøy.

10.1 Mass balance 2016

Fieldwork

Accumulation measurements were performed on 5-6th June 2016. The calculation of winter balance is based on stake measurements in 11 different positions and snow depth soundings in 87 positions between 1880 and 2264 m a.s.l (Fig. 10-2). The snow depth varied between 0.16 and 2.54 m. It was difficult to identify the previous summer surface in the central and upper parts (near stakes 4, 6, 7, 8 and 10). In this area, 30 of the soundings were corrected by subtracting remaining snow from last year from the snow depths (by using kriging interpolation of the remaining snow measured at stakes on 21st-22nd September 2015). The mean snow depth of all the soundings was 1.44 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 496 kg m^{-3}. Ablation measurements were carried out on 14th September, when all visible stakes were measured. The calculation of summer and annual balance was based on stakes in 11 and 14 different positions respectively. The extent of Gråsubreen was measured with handheld GPS along the northern rim (Fig. 10-2).

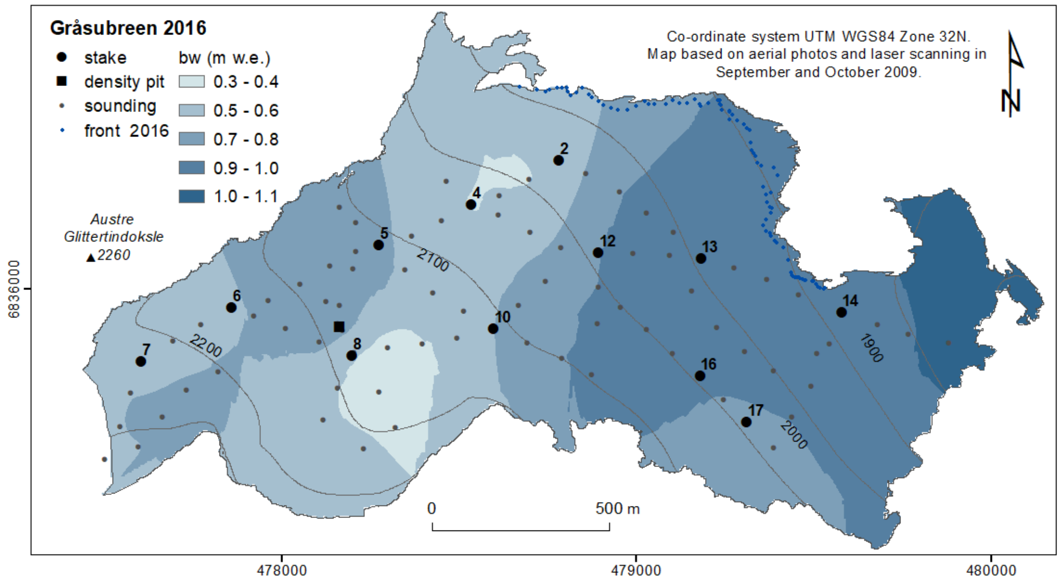


Figure 10-2
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2016. Part of the terminus (front 2016) were mapped by foot using a handheld GPS (front 2016).

Results

The winter balance was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter accumulation of 0.76 ±0.15 m w.e., which is 96 % of the mean winter balance for the reference period 1971-2000. Kriging interpolation of the measurements gave a similar result (0.73 ±0.15 m w.e.). Summer and annual balance were calculated from direct measurements of stakes in nine locations. The resulting summer balance was −1.18 ±0.25 m w.e., which is 110 % of the mean summer balance for the reference period 1971-2000.

The annual balance of Gråsubreen was negative in 2016, −0.42 ±0.3 m w.e. The ELA and AAR were not defined from the mass balance curve or in the field. The transient snowline was partly tracked in the field, but due to remaining snow from the previous year, it was difficult to use this for ELA and AAR estimation.

The mass balance results are shown in Table 10-1 and the corresponding curves for specific and volume balance are shown in Figure 10-3.

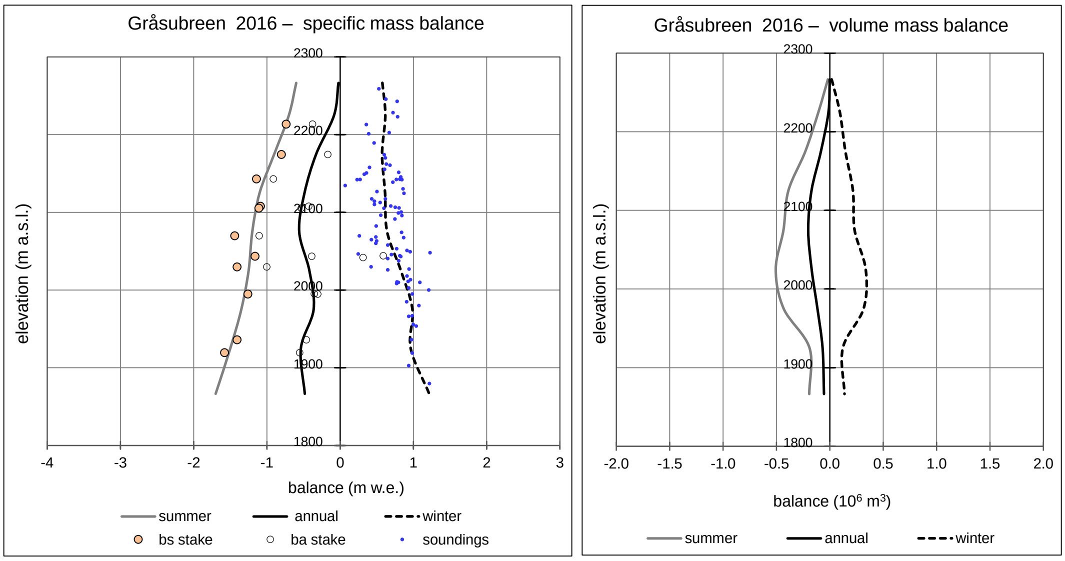


Figure 10-3
Mass balance diagram for Gråsubreen in 2016, showing specific balance on the left and volume balance on the right. Winter and summer balance at the stakes are also shown together with the individual snow depth soundings.

Table 10-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Gråsubreen in 2016.

Mass balance Gråsubreen 2015/16 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter mass balance Measured 6th June 2016 Specific (m w.e.)	Winter mass balance Volume (10^6 m^3)	Summer mass balance Measured 14th Sep 2016 Specific (m w.e.)	Summer mass balance Volume (10^6 m^3)	Annual mass balance Summer surfaces 2015 - 2016 Specific (m w.e.)	Annual mass balance Volume (10^6 m^3)
2250 - 2283	0.03	0.58	0.02	-0.60	-0.02	-0.02	0.00
2200 - 2250	0.15	0.62	0.09	-0.70	-0.11	-0.08	-0.01
2150 - 2200	0.26	0.57	0.15	-0.90	-0.23	-0.33	-0.08
2100 - 2150	0.35	0.61	0.22	-1.10	-0.39	-0.49	-0.17
2050 - 2100	0.36	0.64	0.23	-1.20	-0.43	-0.56	-0.20
2000 - 2050	0.41	0.83	0.34	-1.25	-0.51	-0.42	-0.17
1950 - 2000	0.32	0.99	0.32	-1.35	-0.43	-0.36	-0.12
1900 - 1950	0.13	0.96	0.12	-1.50	-0.19	-0.54	-0.07
1833 - 1900	0.11	1.22	0.14	-1.70	-0.19	-0.48	-0.05
1830 - 2290	**2.12**	**0.76**	**1.62**	**-1.18**	**-2.50**	**-0.42**	**-0.88**

10.2 Mass balance 1962-2016

The cumulative annual balance of Gråsubreen amounts to –21.3 m w.e. since measurements began in 1962 (Fig. 10-4). The average annual balance is thus –0.39 m w.e. a^{-1}. Of the 55 years on record, 30 of the years had a significant balance deficit (B_a < –0.3 m w.e.) and eight of the years had a significant mass surplus (B_a > –0.3 m w.e.).

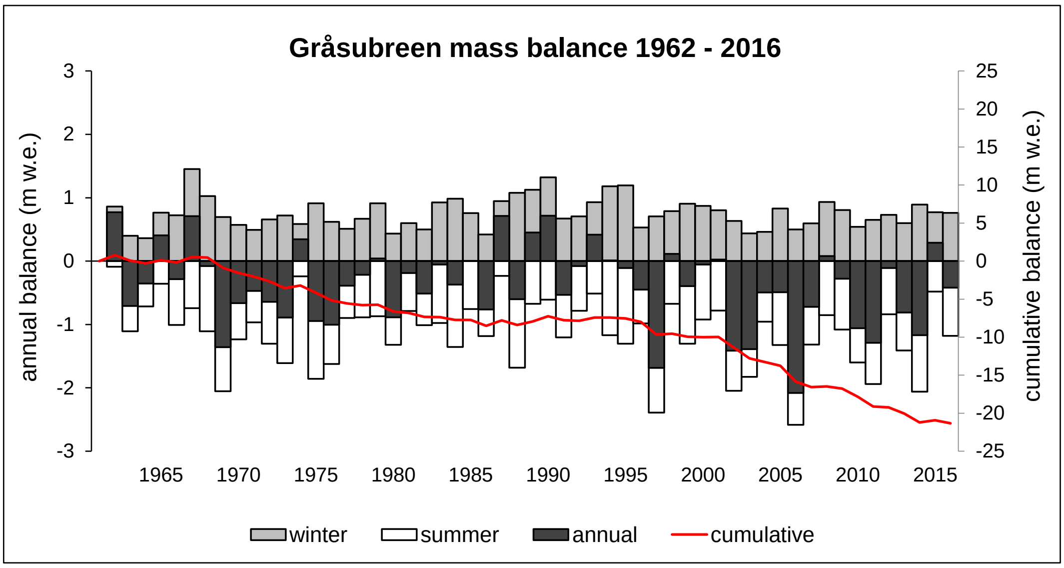


Figure 10-4
Winter, summer and annual balance at Gråsubreen for the period 1962-2016, and cumulative mass balance for the whole period.

Figure 10-5
The western and upper parts of Gråsubreen on 14th September 2016 seen from Austre Glittertindoksle (2260 m a.s.l., Fig. 10-2). Photo: Ånund Kvambekk.

11. Engabreen (Hallgeir Elvehøy and Miriam Jackson)

Engabreen (66°40′N, 13°45′E) is a 36 km^2 northwestern outlet from the western Svartisen ice cap. It covers an altitude range from 1544 m a.s.l. (at Snøtind) down to 111 m a.s.l. (2016). Length change observations started in 1903 (chap. 14) and mass balance measurements have been performed annually since 1970. The pressure sensor records from the Svartisen Subglacial Laboratory under Engabreen date back to 1992 and are presented in Section 11-6.

Figure 11-1
Vestisen on 16th August 2016, showing Engabreen (upper central), Storglombreen (upper right), and Svartisheibreen (lower left). Photo: PLEIADES© CNES, 2016, distribution Airbus DS.

11.1 New DTM

Stereo-images covering the southern part of Vestisen including Engabreen, most of Storglombreen, Fonndalsbreen, Flatisen and Svartisheibreen were captured by the Pléiades satellite on 16th august 2016 (Fig. 11-1). The French Space Agency (CNES) and LEGOS generated DTMs using the Ames Stereo Pipeline at a resolution of 2 and 4 m accompanied by a 0.5 m ortho-image. In this automatic process, no GCPs were included, the geolocation being based solely on orbital data (Berthier et al., 2014, Shean et al., 2016). DTMs were delivered with both ellipsoidal and orthometric elevations (EGM96). Both DTMs and orthophotos have small areas with no data, and small areas in the DTMs have what are clearly erroneous values (Fig. 11-2).

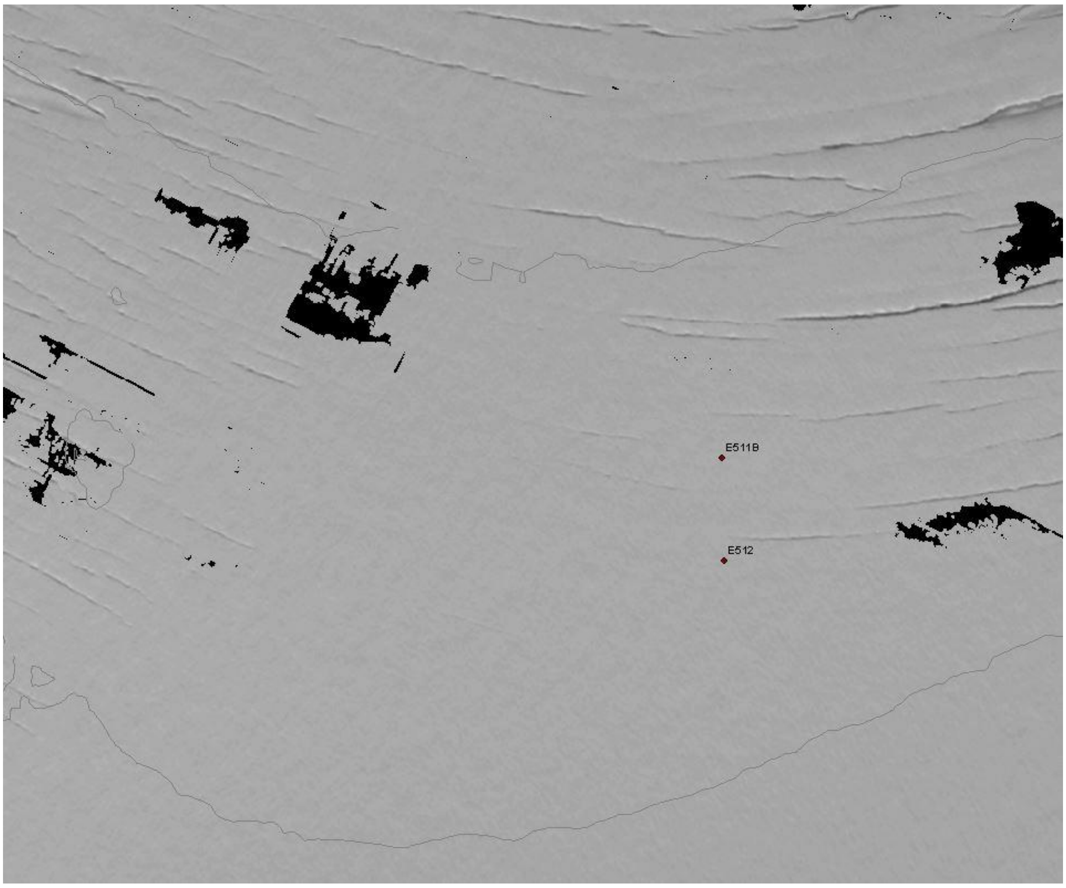


Figure 11-2
Example of missing data in the orthophoto created from the Pleiades images. The width of the plot is 500 m, and the area is located around stake E5 at about 1225 m a.s.l. The vertical distance between contour lines is 10 metres.

For validation, the 2 m orthometric DTM was resampled to 5 m, and a selection of glacier and snow free areas (1.83 km²) around Engabreen was compared to a DTM based on airborne laser scanning data from 2nd September 2008. Based on the comparison, the new DTM was lower by 5.5 metres. The adjusted DTM was then compared with dGNSS-measurements at Engabreen on 4th August, 12 days prior to the satellite acquisition. Glacier melt in the intervening period was estimated as 0.45 m above 1200 m a.s.l., 0.55 m between 950 and 1200 m a.s.l., and 0.9 m on the glacier tongue 200-400 m a.s.l. Compared with the estimated melt, the adjusted DTM appears to be slightly high in the upper areas (above 1200 m a.s.l.) and slightly low at the glacier tongue. However, the dGNSS results at the glacier tongue are less reliable due to shading from steep mountains. Consequently, the accuracy of the DTM is assessed as ±0.5 metres.

The glacier outline was digitised from the orthophotos supported with 10-meter contour lines generated from the DTM, and orthophotos from 2013 and 2014 (www.norgeibilder.no). At Snøtind (1594 m a.s.l.), the glacier outline was snow covered, and the outline was digitised from the 2014 orthophotos. Between 800 and 1100 m a.s.l., the glacier outline was partly snow covered. It was digitised from the 2016 orthophoto unless where this outline was outside the 2013 outline. The drainage basin was defined from the outline and the ice divide defined from the 2008 DTM. The Area-altitude distribution (Tab. 11-1) was measured from digitised polygons based on 100-metre contour lines, and not from the DTM directly because of about 0.09 km² of missing data.

Table 11-1
The change in Altitude-Area-Distribution between 2008 and 2016.

		Area 2008 km²	Area 2016 km²	Area change km²	Change %
1500	1575/1544	0.101	0.048	-0.053	-52
1400	1500	2.651	2.129	-0.522	-20
1300	1400	9.067	9.241	0.174	2
1200	1300	7.981	8.044	0.063	1
1100	1200	7.487	7.572	0.085	1
1000	1100	4.722	4.607	-0.115	-2
900	1000	2.318	2.431	0.113	5
800	900	0.826	0.797	-0.029	-4
700	800	0.493	0.455	-0.038	-8
600	700	0.347	0.285	-0.062	-18
500	600	0.278	0.245	-0.033	-12
400	500	0.172	0.144	-0.028	-16
300	400	0.124	0.099	-0.025	-20
200	300	0.179	0.117	-0.062	-35
100/111	200	0.091	0.035	-0.056	-62
89	100	0.002		-0.002	-100
		36.838	36.248	-0.590	-1.6

Between 2008 and 2016 the glacier area decreased from 36.838 km² to 36.248 km² (−0.59 km²). The largest change in area occurred between 1400 and 1500 m a.s.l. (−0.522 km²), at the same time as the area of the neighbouring elevation band (1300-1400 m a.s.l.) increased (+0.174 km²). Below 900 m a.s.l., the area of all elevation bands decreased. The elevation of the highest point decreased from 1575 to 1544 m a.s.l., and the elevation of the lowest point increased from 89 to 111 m a.s.l.

11.2 Recalculation 2013 - 2015

The mass balance results from 2013, 2014 and 2015 (Kjøllmoen et al., 2016) have been recalculated assigning 2016-elevations to all the point measurements, and using the AAD from 2016. The recalculated results are shown in Table 11-2.

Table 11-2
Recalculated winter, summer and annual mass balance at Engabreen.

	Winter balance (m w.e.)	Summer balance (m w.e.)	Annual balance (m w.e.)	ELA (m a.s.l.)	AAR %
2013	2.30	-4.12	-1.82	>1544	0
2014	2.59	-3.48	-0.89	1250	43
2015	3.27	-2.61	0.65	1093	75

11.3 Mass balance 2016

Stakes in five positions were measured on 9th March and showed up to 5.8 m of snow. Comparison of stake length and sounding at E17 on the glacier tongue showed that 0.3 m of ice had melted after 27th October 2015.

The snow accumulation measurements were performed on 26th May. Four stakes on the glacier plateau showed up to 7.1 m of snow. Comparison of stake measurements and soundings showed up to 0.2 m of ice accretion at stakes E34 and E30. Snow depth was measured at 28 sounding locations along the profile from a point at 1464 m a.s.l. to E34 (Fig. 11-3). The snow depth was between 3.5 and 6.5 m. The summer surface (S.S.) was difficult to define above 1250 m a.s.l. The mean snow density down to the S.S. at 5.1 m depth at stake E5 was 492 kg m^{-3}. At E17 on the glacier tongue, all the snow and 0.3 m of ice had melted since 9th March 2016.

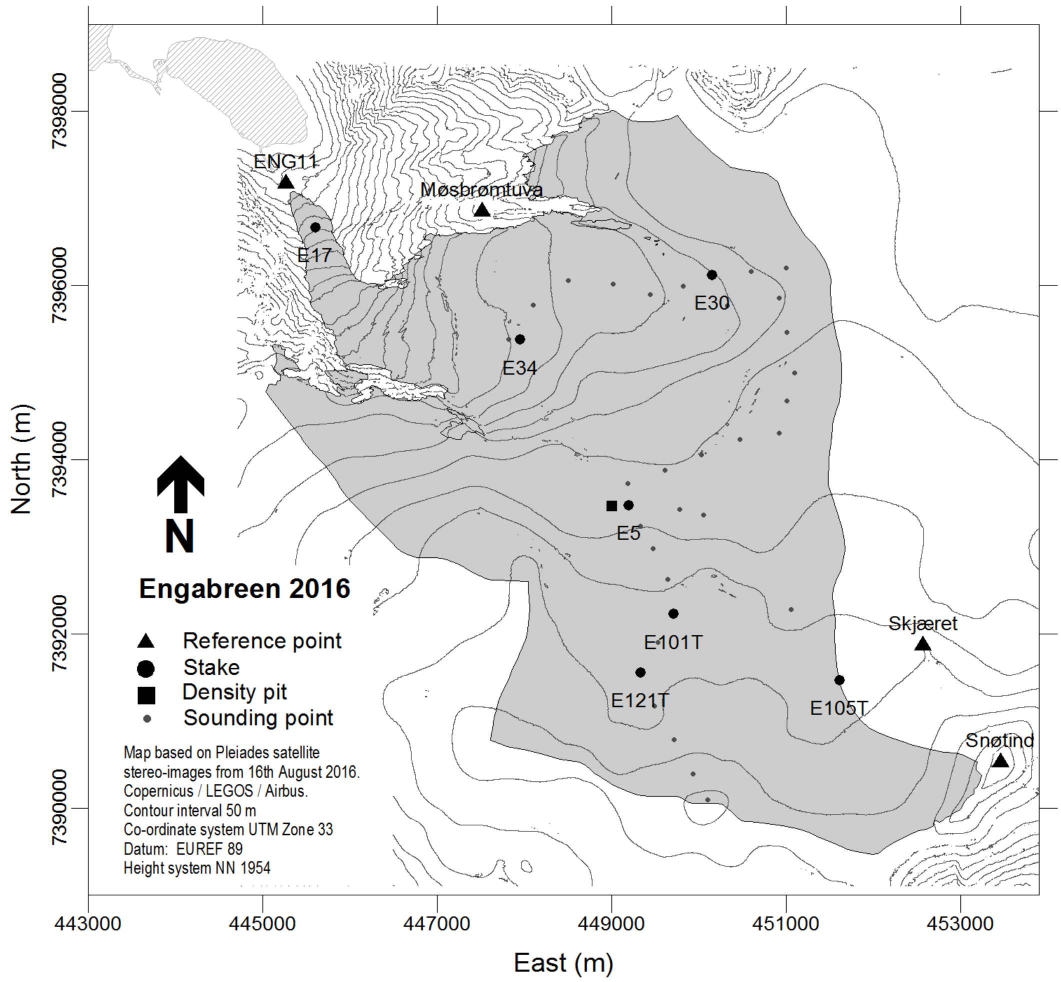


Figure 11-3
Location of stakes, density pit and sounding profiles on Engabreen in 2016.

On 4th August, up to 4.05 m of snow remained at stakes above 1100 m a.s.l. At the glacier tongue, about 5 m of ice had melted since 26th May.

The summer ablation measurements were carried out on 11th and 18th October. There was up to 50 cm of new snow at the stakes. Stakes were found in six locations on the plateau. From stake measurements, the Transient Snow Line altitude (TSL) was about 1200 m a.s.l. Up to 2.6 m of snow remained at the stakes above the TSL. All the snow and 3.0 m of ice melted during the summer at stake E34 all. Stake measurements showed that 9.15 m of ice melted between 26th May and 11th October on the glacier tongue.

A comparison of stake readings and probing at E34 on 8th February 2017 indicates no significant melting after the ablation measurements on 11th October 2016. At the glacier tongue, 0.3 m of ice melted after 11th October.

The date of the 2016 mass balance minimum for Engabreen was assessed by visual inspection of the daily changes in gridded data of snow amounts from www.senorge.no (Saloranta. 2014). The snow accumulation probably started at the higher part of the glacier plateau on 1st October and at the lower part of the glacier plateau on 27th October. At stake E17 on the glacier tongue, the late autumn melt occurred mainly between 11th October and 20th November as assessed from air temperature at Engabrevatnet (10 m a.s.l., 2 km north of E17) and snow amount from www.senorge.no.

The winter balance for 2016 was calculated from the snow depth and snow density measurements. 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 900 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 specific winter balance was calculated as 2.7 ±0.2 m w.e. This is 97 % of the average winter balance for the period 1971-2000 (2.72 m w.e. a^{-1}), and 94 % of the average for the period 2011-2015 (2.81 m w.e. a^{-1}).

The point summer balance was calculated directly at seven stake locations between 300 and 1340 m a.s.l. The specific summer balance was calculated from the summer balance curve drawn from these seven point values (Fig. 11-4) as −2.9 ±0.2 m w.e. This is 118 % of the average summer balance for the period 1971-2000 (−2.44 m w.e. a^{-1}) but 89 % of the average for the period 2011-2015 (−3.24 m w.e. a^{-1}). The resulting annual balance was −0.2 ±0.3 m w.e. (Tab. 11-3). The ELA was assessed as 1195 m a.s.l. from the annual balance curve in Figure 11-4. This corresponds to an AAR of 55 %.

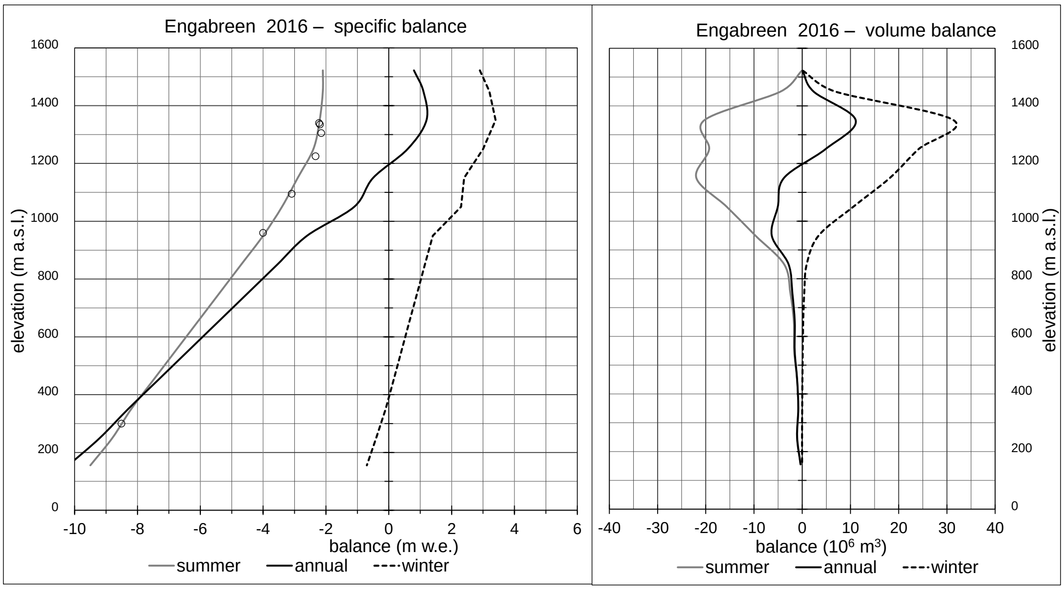


Figure 11-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Engabreen in 2016. Summer balance at seven stake locations (○) is shown.

Table 11-3
Specific and volume winter, summer and annual balance calculated for 100 m elevation intervals at Engabreen in 2016.

Mass balance Engabreen 2015/16 – stratigrafic method

Altitude	Area	Winter mass balance Measured 26th May 2016		Summer mass balance Measured 18th Oct 2016		Annual mass balance Summer surface 2015 - 2016	
(m a.s.l.)	(km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1500 - 1544	0.05	2.90	0.1	-2.10	-0.1	0.80	0.0
1400 - 1500	2.13	3.20	6.8	-2.10	-4.5	1.10	2.3
1300 - 1400	9.24	3.40	31.4	-2.20	-20.3	1.20	11.1
1200 - 1300	8.04	3.00	24.1	-2.40	-19.3	0.60	4.8
1100 - 1200	7.57	2.40	18.2	-2.90	-22.0	-0.50	-3.8
1000 - 1100	4.61	2.30	10.6	-3.40	-15.7	-1.10	-5.1
900 - 1000	2.43	1.40	3.4	-4.00	-9.7	-2.60	-6.3
800 - 900	0.80	1.15	0.9	-4.70	-3.7	-3.55	-2.8
700 - 800	0.46	0.90	0.4	-5.40	-2.5	-4.50	-2.0
600 - 700	0.29	0.65	0.2	-6.10	-1.7	-5.45	-1.6
500 - 600	0.25	0.40	0.1	-6.80	-1.7	-6.40	-1.6
400 - 500	0.14	0.15	0.0	-7.50	-1.1	-7.35	-1.1
300 - 400	0.10	-0.10	0.0	-8.20	-0.8	-8.30	-0.8
200 - 300	0.12	-0.40	0.0	-8.80	-1.0	-9.20	-1.1
111 - 200	0.04	-0.70	0.0	-9.50	-0.3	-10.20	-0.4
111 - 1544	**36.25**	**2.65**	**96.2**	**-2.88**	**-104.4**	**-0.23**	**-8.2**

11.4 Mass balance 1970-2016

The annual surface mass balance at for Engabreen 1970-2016 is shown in Figure 11-5. The cumulative surface mass balance since the start of mass balance investigations at Engabreen is −0.4 m w.e., showing that the change in glacier volume has been small. However, the glacier volume increased between 1970 and 1977, and again between 1988 and 1997, and decreased between 1977 and 1988. During the last 20 years (1997-2016), the glacier volume has decreased by 7.2 m w.e., or −0.36 m w.e. a^{-1} (Fig. 11-6).

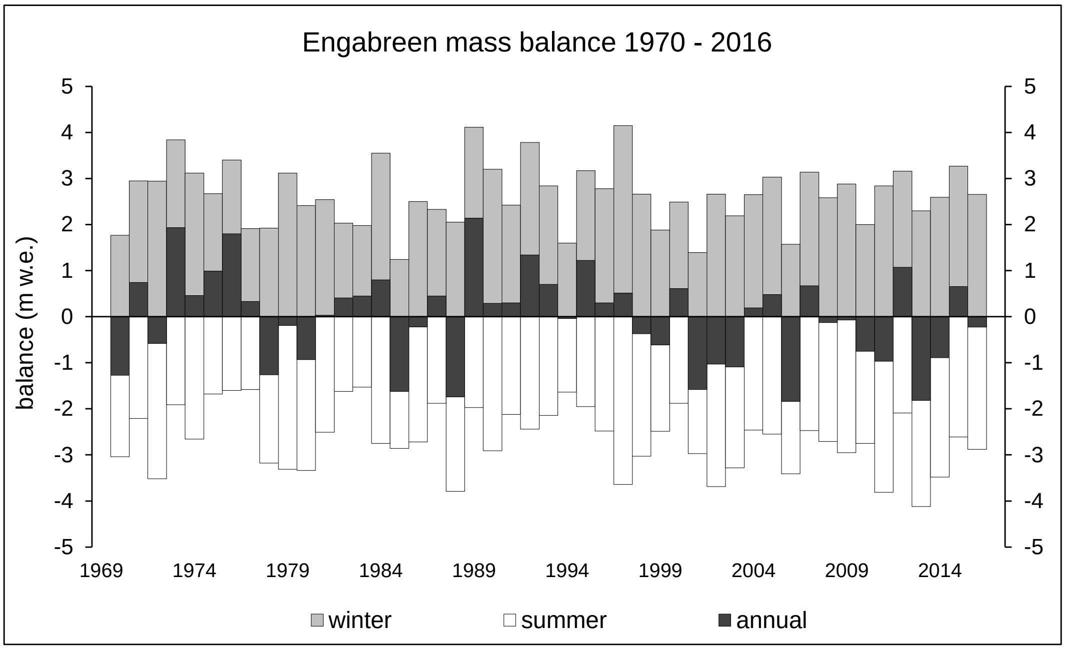


Figure 11-5
Mass balance at Engabreen during the period 1970-2016. The average winter and summer balances are B_w =2.64 m w.e. and B_s =−2.65 m w.e. Results from 1970-2008 are calibrated (Andreassen et al., 2016), 2009 to 2012 and 2016 are original (Kjøllmoen et al., 2010, 2011, 2016), and 2013 to 2015 are recalculated.

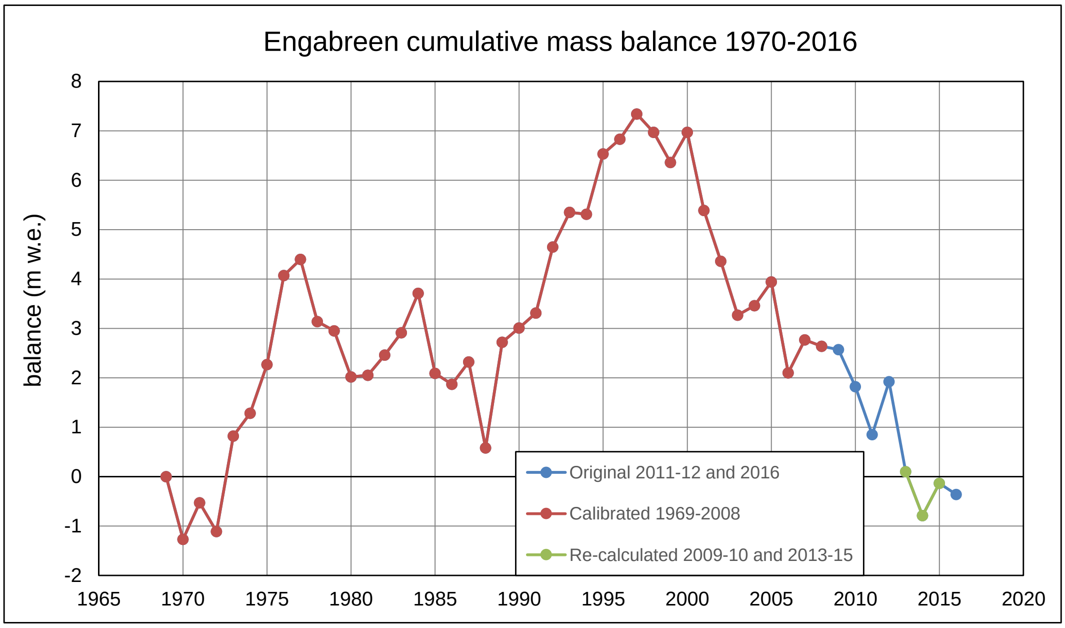


Figure 11-6
Cumulative surface mass balance at Engabreen.

11.5 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. 11-3) close to the drainage divide between Engabreen and Storglombreen. The station has been operating since 1995. In 2016, there was a data gap between 15th April and 29th April.

The summer mean temperature (1st June – 30th September) at Skjæret in 2016 was 3.9 °C, 0.9 °C above the mean summer temperature over 17 years between 1995 and 2016 which is 3.0 °C. Even though the summer temperature was similar to the 2013 summer temperature (Fig 11-7), the summer balance was much higher in 2013 (−4.12 m w.e. compared with −2.88 m w.e.).

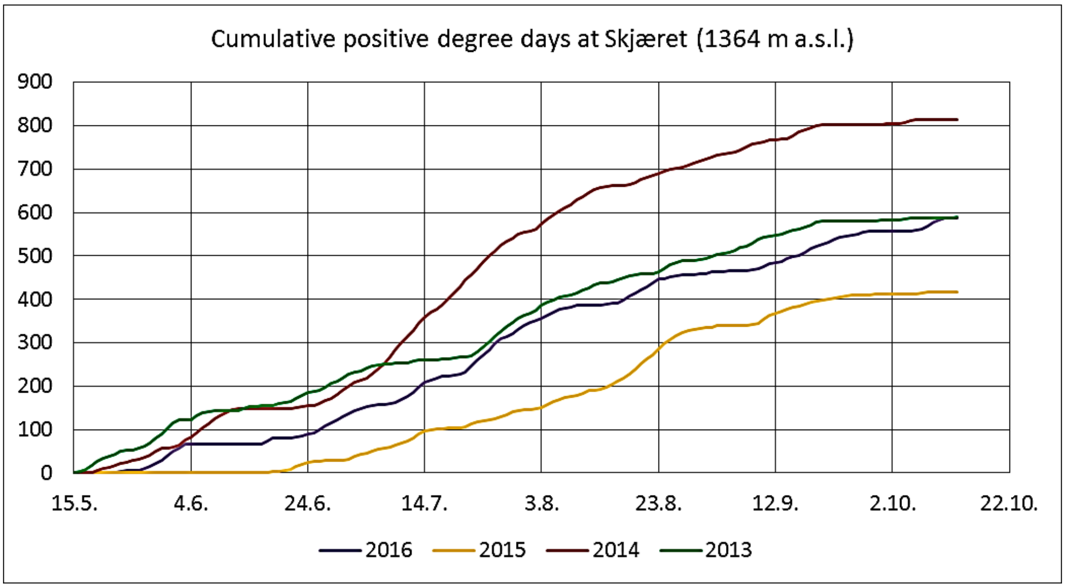
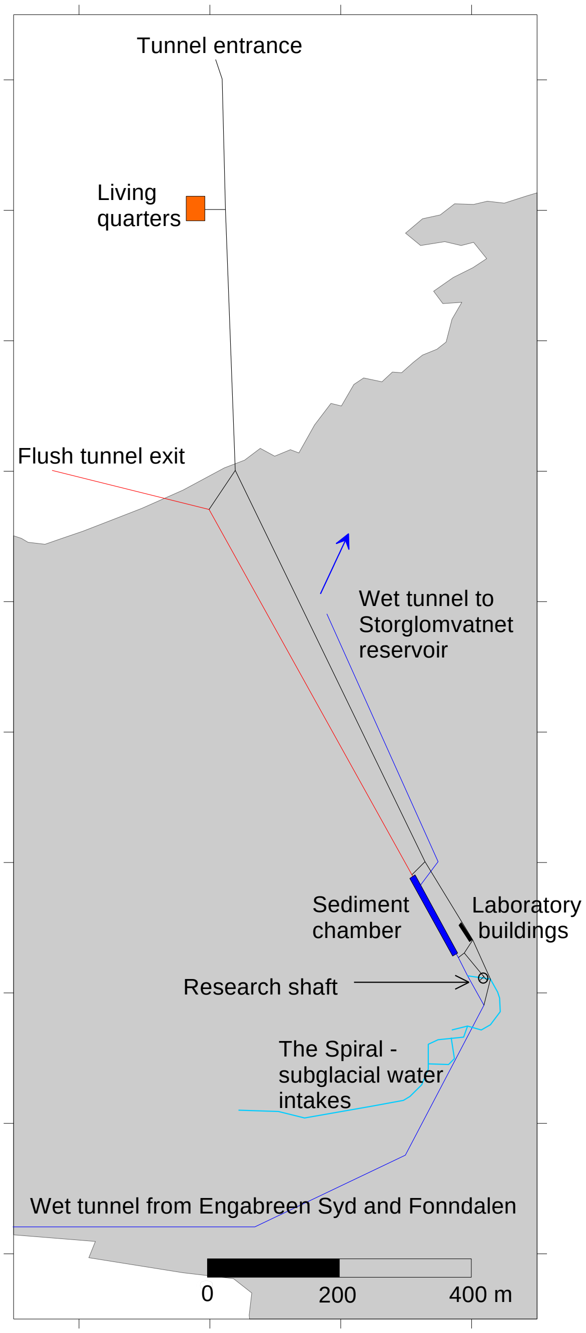


Figure 11-7
The daily mean temperature for days with positive mean temperature is accumulated from 15th May until 13th October. Days with negative mean temperature are shown as no increase in positive degree-days.

Figure 11-8
Autumn measurements at stake E30 1095 m a.s.l. on 18th October 2016. Photo: Hallgeir Elvehøy.

11.6 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. 11-9). The research shaft allows direct access to the bed of the glacier, and is used for measuring subglacial parameters, extracting samples and performing experiments (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. 11-10). The load cells are Geonor Earth Pressure Cells (P-100 and P-105). Readings are made from the load cells at 15-minute intervals. Two new loads cells were installed in November 1997, and the sensors were replaced in the same boreholes in 2012. There are now five load cells that are still recording data. The data from the load cells are briefly summarised here but are publicly available for more comprehensive analysis. The inter-annual variability of the load cells is examined in detail in Lefeuvre et al. (2015). Note that the graphs of load cell pressure have different axes.

Figure 11-9
Map of tunnel system under Engabreen, showing research shaft and other facilities.

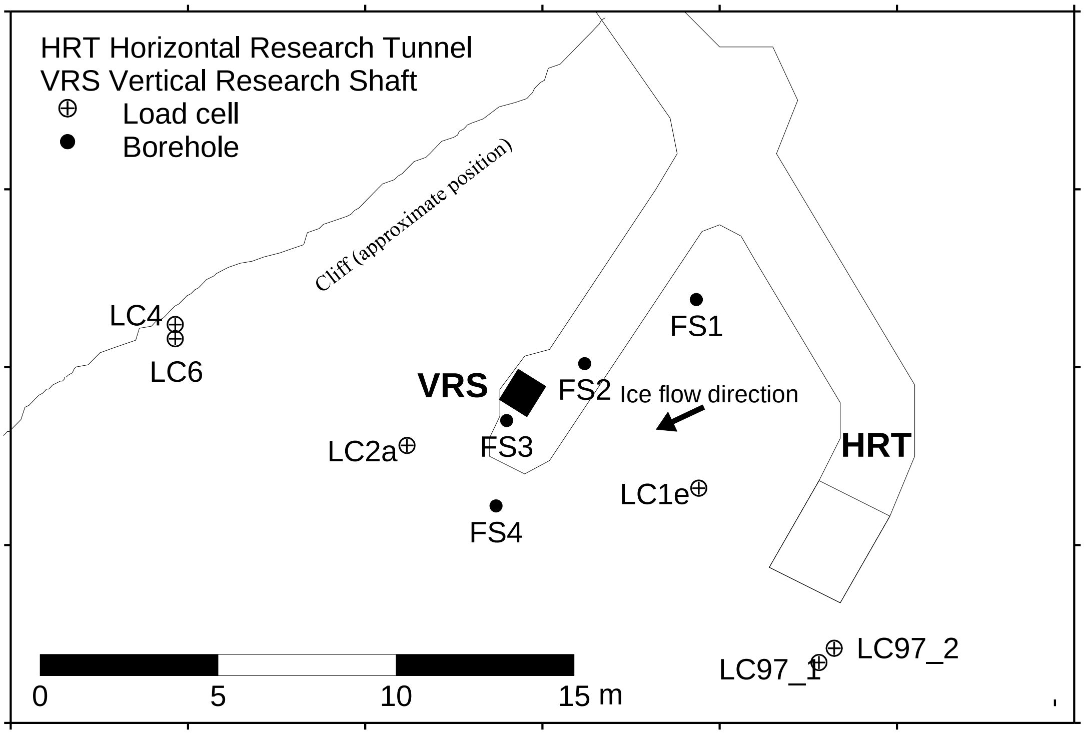


Figure 11-10
Tunnel system showing locations of horizontal research tunnel (HRT), vertical research shaft (VRS), load cells and boreholes, marked FS.

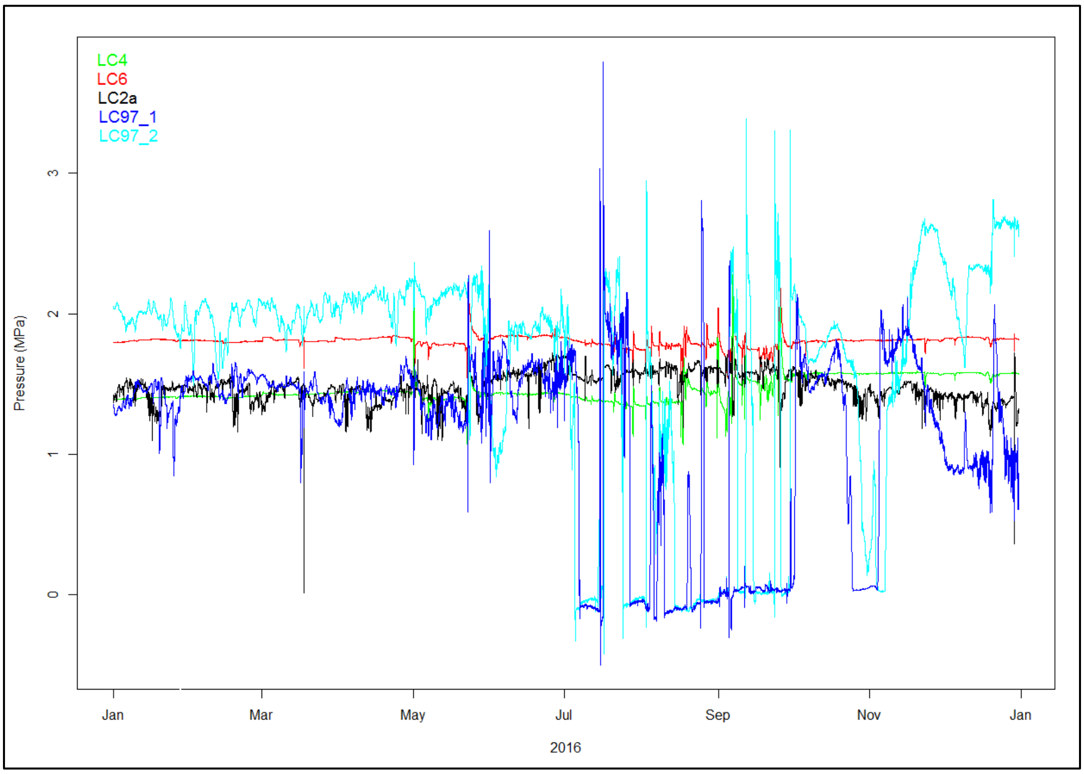


Figure 11-11
The twelve-month record for five of the load cells (LC1e recorded only intermittently).

Figure 11-11 shows the pressure record for 2016 for five load cells with reliable data – load cell pair LC4 and LC6, which are installed in a relatively quiet environment, and load cell pair LC97_1 and LC97_2, which are in a more exposed, noisier environment, as well as LC2a. All load cells are installed at the glacier-bedrock interface within 20 m of each other. The pressure signal for 2016 is fairly typical, with the winter months being relatively quiet, with little change at the glacier bed, and bigger and more frequent changes in the summer melt season. The timing and magnitude of the changes in pressure correspond well with the discharge measured underneath the glacier. There is a discharge station in the wet tunnel from Fonndalen (Fig. 11-9) which measures a combination of snow melt, glacier melt and precipitation. There is very little water in the tunnel system from early January until early May, and then the discharge increases with distinct peaks corresponding to melt events (often heavy precipitation, but also intense melting). Although the first peaks in discharge are quite small compared with that recorded in the middle of summer, they have a pronounced effect at the glacier base. Sudden increases in discharge in a quiescent period are generally reflected in a sudden drop in pressure at the glacier bed, probably due to local uplift and often followed by a sudden rise in pressure as the ice settles.

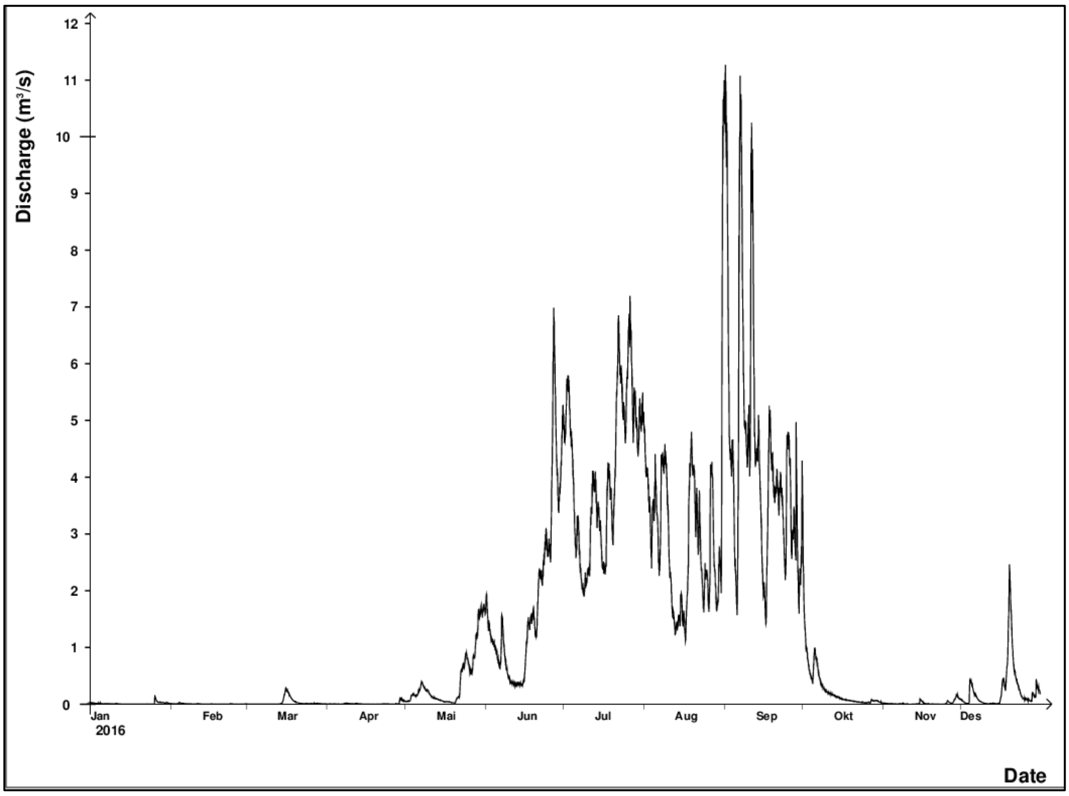


Figure 11-12
Discharge measured in the wet tunnel from Engabreen Syd and Fonndalen, underneath the glacier (Fig. 11-9). The discharge is snow melt, glacier melt and precipitation.

Load cells LC4 and LC6 are located in an overhang (Fig. 11-10), in a quiet environment and thus respond to only significant changes at the glacier bed. There is little change in pressure until mid-March when a sudden drop is recorded (Fig. 11-13). This corresponds with a small increase in discharge. The next two discharge events in early and mid-May are also reflected in the pressure record. The second of these two events involves considerably more discharge, but the reaction recorded at the glacier bed is similar for both events. Some intense peaks in discharge are seen clearly in the pressure record, and then as the temperature cools and the discharge subsides, the pressure is quiescent once more.

Load cells LC97_1 and LC97_2 are in a more exposed environment, so the resulting pressure signal is noisier (Fig. 11-14). However, the reaction to changes in discharge is very similar, with events recorded in mid-March, early May and mid-May. From July to September, and even later in the year there are several periods where the pressure is approximately zero, suggesting the presence of a drainage channel at this part of the glacier bed. Note that for both load cell pairs the changes in pressure occur approximately concurrently, showing that the pressure cells record significant changes at the glacier bed.

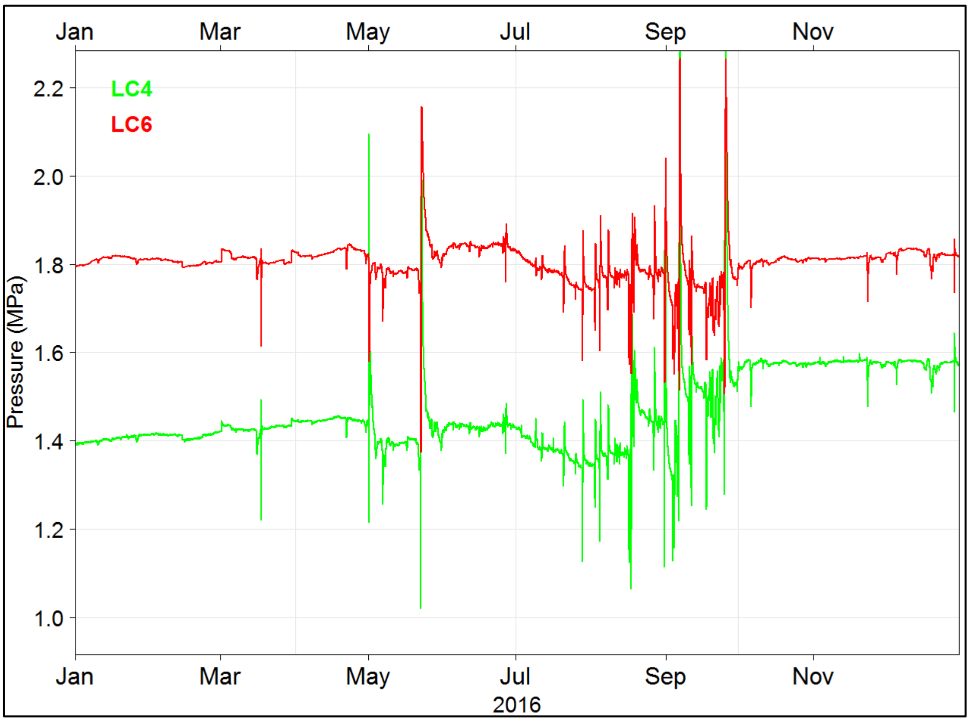


Figure 11-13
Pressure recorded at load cells LC4 and LC6.

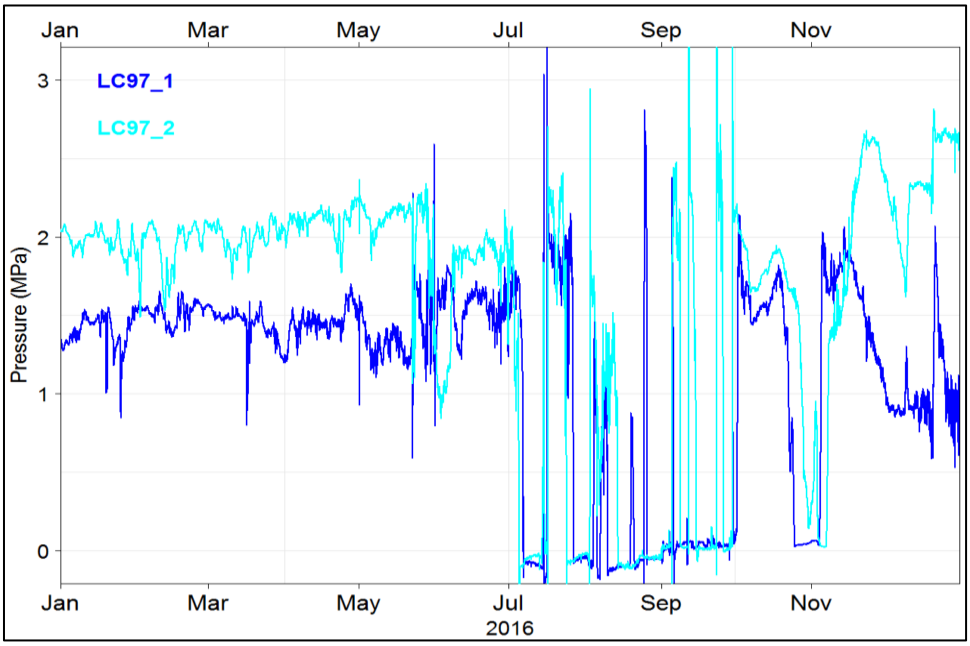


Figure 11-14
Pressure recorded at load cells LC97_1 and LC97_2.

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. (Fig. 12-1). Rundvassbreen is adjacent to lake Vatn 1051, from which a jøkulhlaup drained beneath the glacier in September 2001. Since then several more jøkulhlaups have occurred (see section 14-2). A comprehensive observation programme related to the jøkulhlaup was started in autumn 2001 (Engeset, 2002) and mass balance measurements were included in spring 2002 and continued until 2004. A homogenised mass balance series for Rundvassbreen 2002-04 is presented in Kjøllmoen (2017). An extensive observation programme was resumed in 2011.

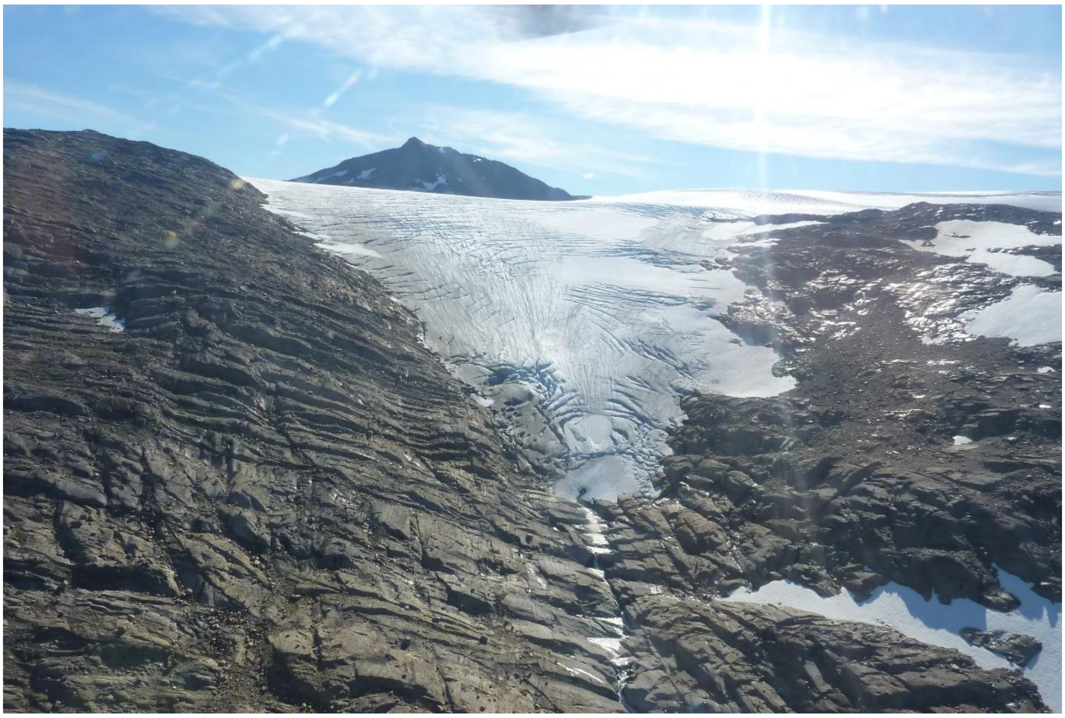


Figure 12-1
The outlet of Rundvassbreen photographed in August 2016. Photo: Miriam Jackson.

12.1 Mass balance 2016

Fieldwork

Snow accumulation measurements were performed on 26th May and the calculation of winter balance was based on measurement of five stakes and 95 snow depth soundings (Fig. 12-2). Comparison of sounded snow depth and stake readings indicated no melting after the ablation measurements in October 2015. The summer surface (S.S.) was easy to identify, although somewhat harder in the uppermost areas. The snow depth varied between 0.5 and 5.9 metres. Snow density was measured in position 60 (1390 m a.s.l.), and the mean snow density of 4.2 m snow was 458 kg m^{-3}.

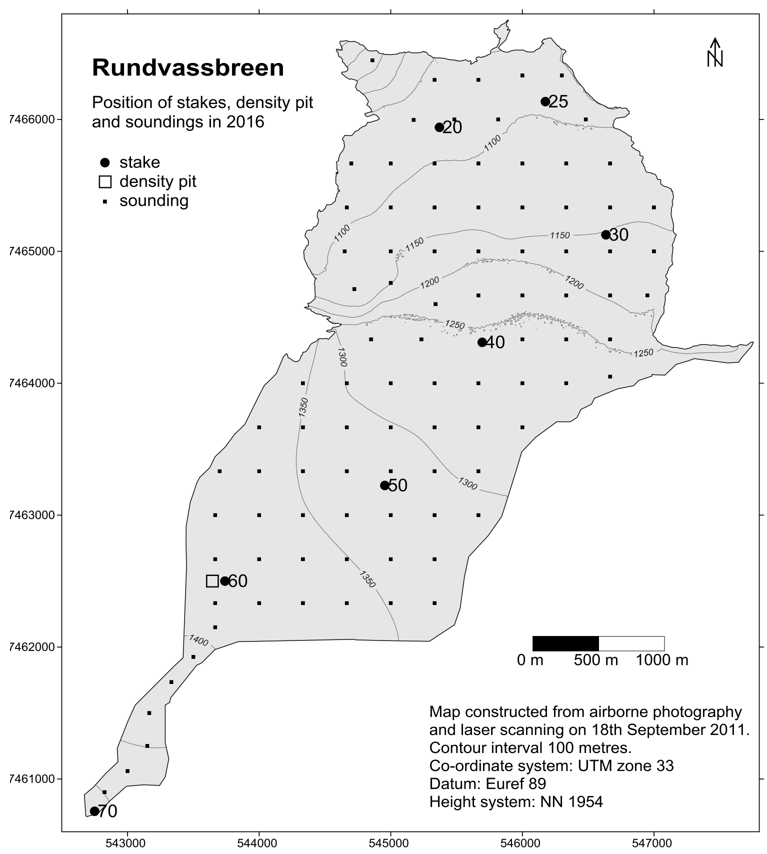


Figure 12-2
Location of stakes, soundings and snow pit, and spatial distribution of winter balance at Rundvassbreen in 2016.

Ablation was measured on 22nd September. The annual balance was measured at stakes in seven locations (Fig. 12-2). In the accumulation areas there were up to 1.2 m of snow remaining from winter 2015/16. At the time of measurement, no fresh snow had fallen.

Results

The calculations are based on the DTM from 2011.

The elevations above 1065 m a.s.l., which cover 97 % of the glacier catchment area, are well-represented with snow depth measurements. Below 1065 m elevation the winter balance curve is based on one point measurement at 940 m a.s.l.

The winter balance was calculated as a mean value for each 50 m height interval and was 1.5 ±0.2 m w.e., which is 81 % of the mean winter balance for the years 2002-04 and 2011-15. Spatial distribution of the winter balance is shown in Figure 12-3.

The elevations above 1088 m a.s.l., which cover 93 % of the glacier catchment area, are well-represented with point measurements of ablation. Below 1088 m elevation the summer balance curve is extrapolated based on experience from previous years with point measurements down to 945 m a.s.l.

Based on estimated density and stake measurements the summer balance was also calculated as a mean value for each 50 m height interval and was −2.0 ±0.3 m w.e., which is 74 % of the mean summer balance 2002-04 and 2011-15.

Hence, the annual balance was negative at −0.5 m ±0.4 m w.e. The mean annual balance for 2002-03 and 2011-15 is −0.85 m w.e.

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

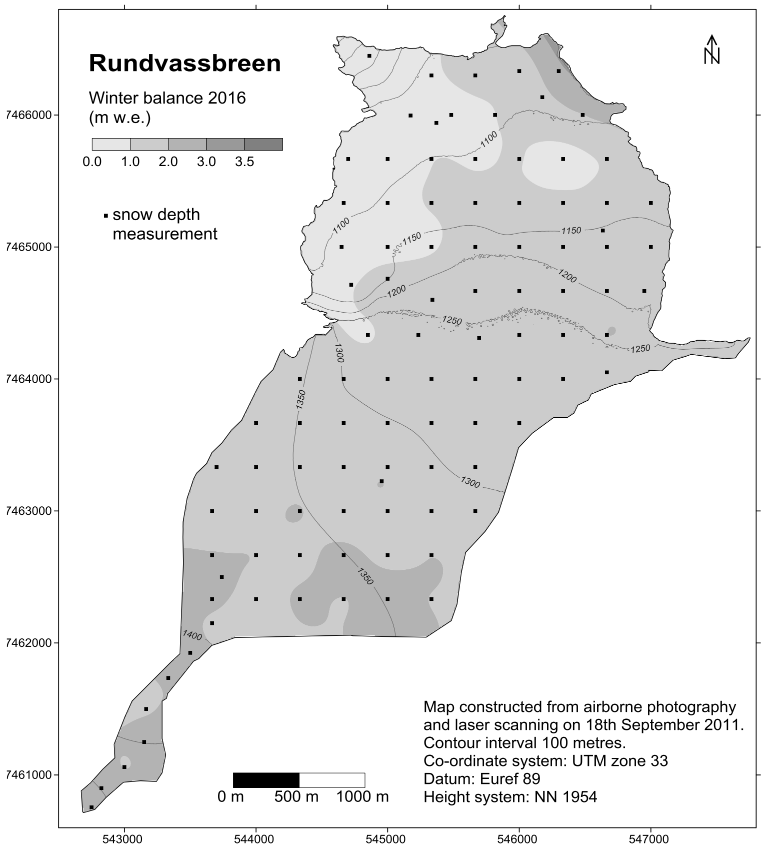


Figure 12-3
Spatial distribution of winter balance at Rundvassbreen in 2016.

According to Figure 13-4, the Equilibrium Line Altitude (ELA) was 1265 m a.s.l. Consequently, the Accumulation Area Ratio (AAR) was 50 %.

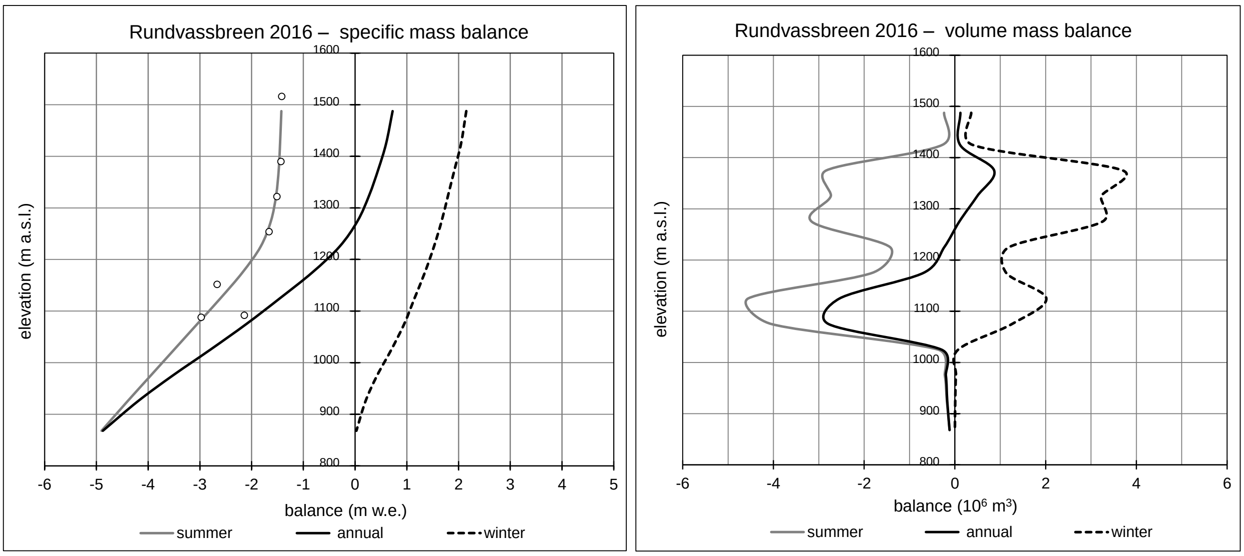


Figure 12-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Rundvassbreen in 2016. Specific summer balance at seven stake positions is shown as dots (○).

Table 12-1
Winter, summer and annual balances for Rundvassbreen in 2016.

Mass balance Rundvassbreen 2015/16 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter mass balance Measured 26th May 2016 Specific (m w.e.)	Volume (10^6 m^3)	Summer mass balance Measured 22nd Sep 2016 Specific (m w.e.)	Volume (10^6 m^3)	Annual mass balance Summer surface 2015 - 2016 Specific (m w.e.)	Volume (10^6 m^3)
1450 - 1525	0.17	2.15	0.4	-1.43	-0.2	0.73	0.1
1400 - 1450	0.19	2.05	0.4	-1.45	-0.3	0.60	0.1
1350 - 1400	1.92	1.93	3.7	-1.48	-2.8	0.45	0.9
1300 - 1350	1.79	1.80	3.2	-1.53	-2.7	0.28	0.5
1250 - 1300	1.94	1.68	3.3	-1.63	-3.2	0.05	0.1
1200 - 1250	0.78	1.53	1.2	-1.83	-1.4	-0.30	-0.2
1150 - 1200	0.84	1.35	1.1	-2.18	-1.8	-0.83	-0.7
1100 - 1150	1.75	1.15	2.0	-2.60	-4.6	-1.45	-2.5
1050 - 1100	1.33	0.95	1.3	-3.05	-4.0	-2.10	-2.8
1000 - 1050	0.11	0.70	0.1	-3.50	-0.4	-2.80	-0.3
950 - 1000	0.06	0.43	0.0	-3.95	-0.2	-3.53	-0.2
900 - 950	0.04	0.20	0.0	-4.40	-0.2	-4.20	-0.2
836 - 900	0.02	0.03	0.0	-4.90	-0.1	-4.88	-0.1
836-1525	**10.9**	**1.52**	**16.6**	**-2.01**	**-22.0**	**-0.49**	**-5.3**

12.2 Mass balance 2002-04 and 2011-16

The historical mass balance results for Rundvassbreen are presented in Figure 12-5. The cumulative annual balance over 2011-16 is −4.7 m w.e., which gives a mean annual balance of −0.78 m w.e. a^{-1}.

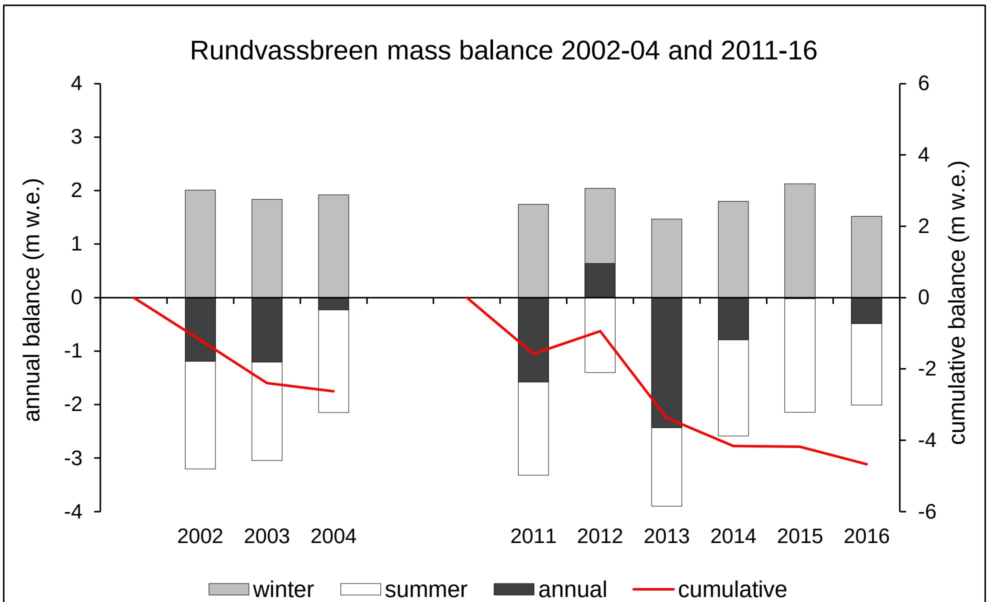


Figure 12-5
Winter, summer and annual balance at Rundvassbreen for 2002-04 and 2011-16.

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 2016 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.

Figure 13-1
The east-facing outlet of Langfjordjøkelen photographed on 22nd September 2016. Photo: Miriam Jackson.

13.1 Mass balance 2016

Fieldwork

Snow accumulation was measured on 23rd May and the calculation of winter balance was based on measurements of two stakes and 58 snow depth soundings (Fig. 13-2). A comparison of stake readings and soundings indicates no significant melting after the ablation measurement in September 2015. Generally the sounding conditions were good and the summer surface was easy to identify. The snow depth varied between 0.8 and 4.9 metres. Snow density was measured in position 25 (720 m a.s.l.) and the mean density of 3.2 m snow was 521 kg m^{-3}.

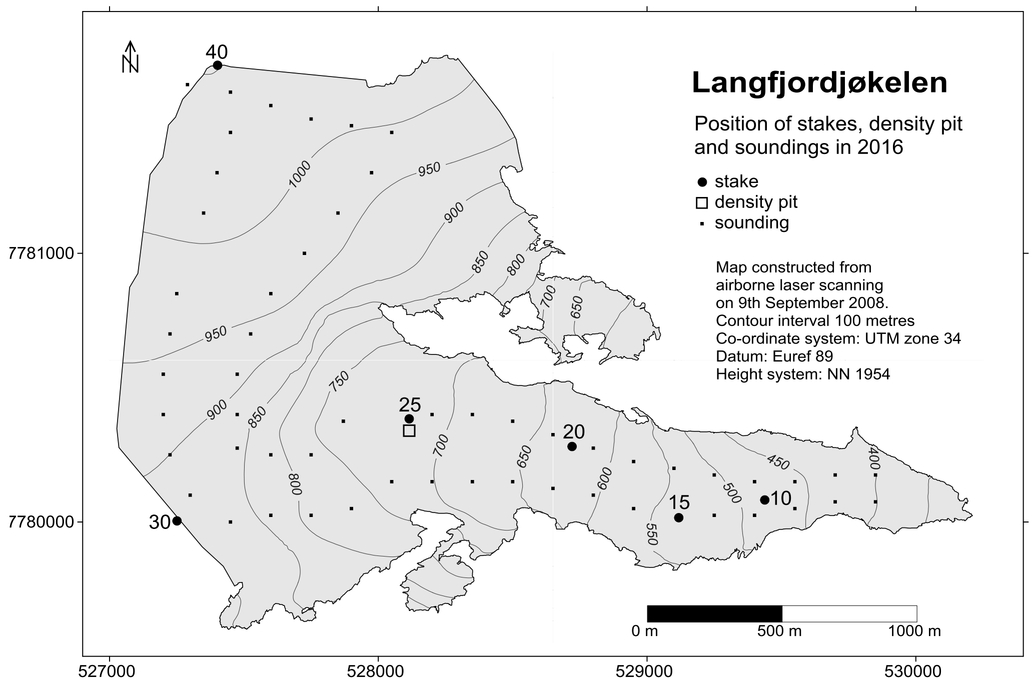


Figure 13-2
Location of stakes, soundings and snow pit at Langfjordjøkelen in 2016.

Ablation was measured on 22nd September. The annual balance was measured at stakes in six locations (Fig. 13-2). There was no snow remaining on the glacier from the winter season 2015/16. No fresh snow had fallen on the glacier at the time of measurement.

Results

The calculations are based on the DTM from 2008.

The elevations above 401 m a.s.l., which cover 98 % of the glacier catchment area, are well-represented with snow depth measurements. Below 401 m elevation the winter balance curve is extrapolated.

The winter balance was calculated as a mean value for each 50 m height interval and was 1.7 ±0.2 m w.e., which is 80 % of the mean winter balance for the years 1989-93 and 1996-2015. Spatial distribution of the winter balance is shown in Figure 13-3.

The elevations above 479 m a.s.l., which cover 93 % of the glacier catchment area, are well-represented with point measurements of ablation. Below 479 m elevation the summer balance curve is extrapolated.

Based on estimated density and stake measurements the summer balance was also calculated as a mean value for each 50 m height interval and was −3.3 ±0.3 m w.e., which is 110 % of the mean summer balance 1989-93 and 1996-2015.

Hence, the annual balance was negative, at −1.7 ±0.4 m w.e. The mean annual balance for 1989-93 and 1996-2015 is −0.95 m w.e. Over the past ten years (2007-16), the mean annual balance is −1.10 m w.e.

The mass balance results are shown in Table 13-1 and the corresponding curves for specific and volume balance are shown in Figure 13-4.

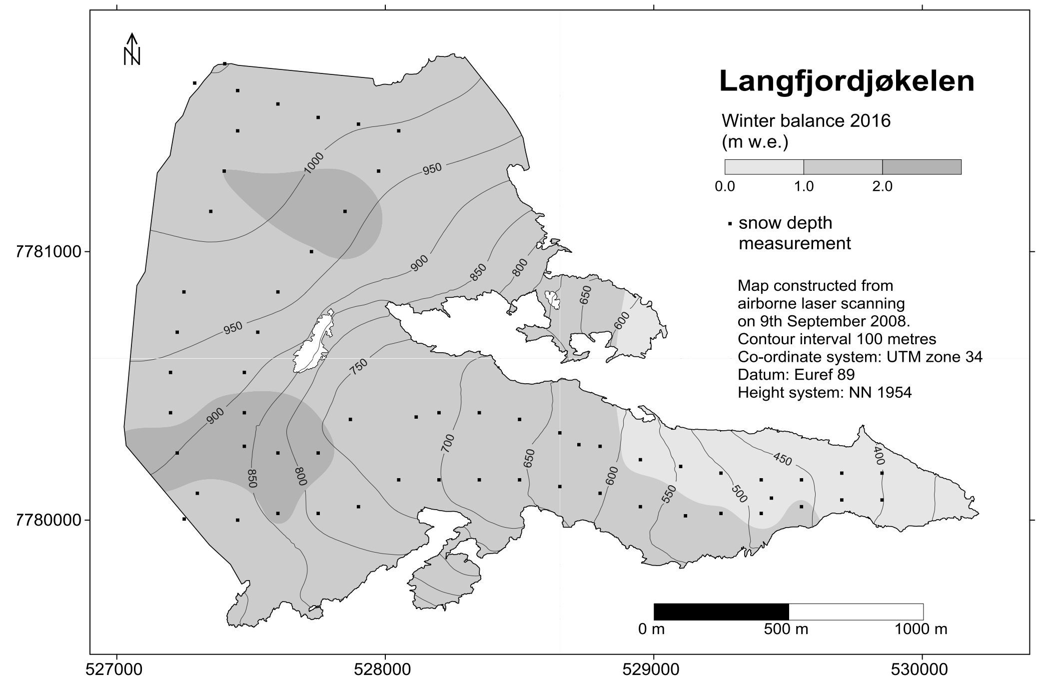


Figure 13-3
Spatial distribution of winter balance at Langfjordjøkelen in 2016.

According to Figure 13-4, the Equilibrium Line Altitude (ELA) was above the highest point (1050 m a.s.l.) of the glacier. Consequently, the Accumulation Area Ratio (AAR) was 0 %.

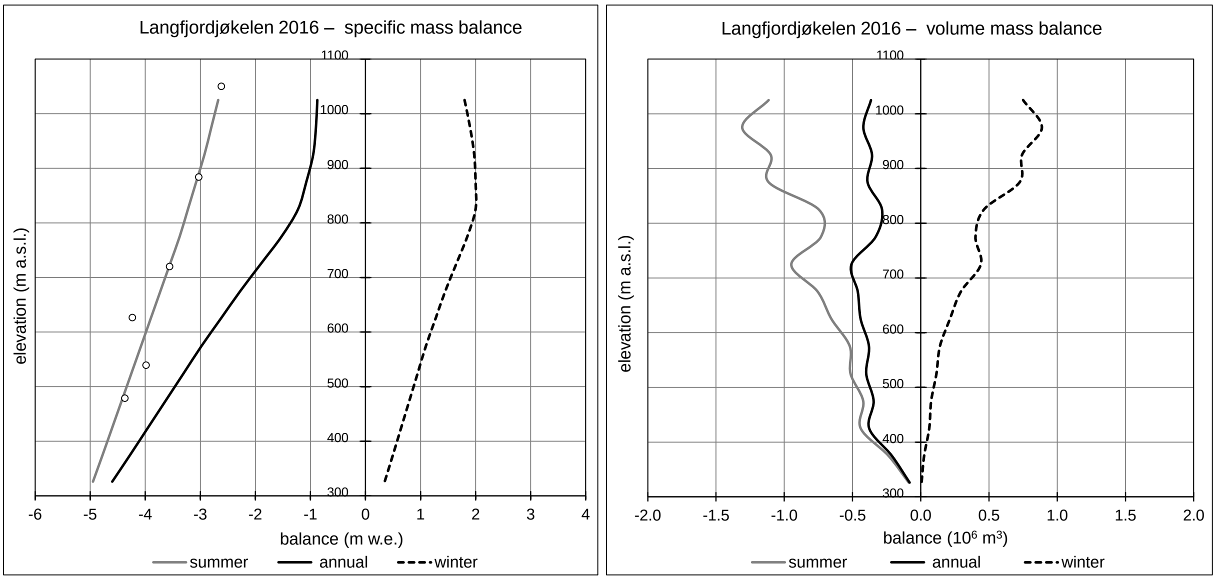


Figure 13-4
Mass balance diagram showing specific balance (left) and volume balance (right) for Langfjordjøkelen in 2016. Specific summer balance for six stakes is shown as dots (○).

Table 13-1
Winter, summer and annual balances for Langfjordjøkelen in 2016.

Mass balance Langfjordjøkelen 2015/16 – stratigraphic system

Altitude	Area	Winter mass balance Measured 23rd May 2016		Summer mass balance Measured 22nd Sep 2016		Annual mass balance Summer surface 2015 - 2016	
(m a.s.l.)	(km^2)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)	Specific (m w.e.)	Volume (10^6 m^3)
1000 - 1050	0.42	1.80	0.7	-2.68	-1.1	-0.88	-0.4
950 - 1000	0.47	1.90	0.9	-2.80	-1.3	-0.90	-0.4
900 - 950	0.38	1.98	0.7	-2.93	-1.1	-0.95	-0.4
850 - 900	0.36	2.00	0.7	-3.08	-1.1	-1.08	-0.4
800 - 850	0.23	2.00	0.5	-3.23	-0.7	-1.23	-0.3
750 - 800	0.22	1.85	0.4	-3.38	-0.7	-1.53	-0.3
700 - 750	0.27	1.65	0.4	-3.55	-0.9	-1.90	-0.5
650 - 700	0.20	1.45	0.3	-3.73	-0.8	-2.28	-0.5
600 - 650	0.17	1.28	0.2	-3.90	-0.7	-2.63	-0.4
550 - 600	0.13	1.10	0.1	-4.08	-0.5	-2.98	-0.4
500 - 550	0.12	0.95	0.1	-4.25	-0.5	-3.30	-0.4
450 - 500	0.10	0.80	0.1	-4.43	-0.4	-3.63	-0.3
400 - 450	0.10	0.65	0.1	-4.60	-0.4	-3.95	-0.4
350 - 400	0.05	0.50	0.0	-4.78	-0.2	-4.28	-0.2
302 - 350	0.02	0.35	0.0	-4.95	-0.1	-4.60	-0.1
302 - 1050	**3.21**	**1.66**	**5.3**	**-3.33**	**-10.7**	**-1.66**	**-5.3**

13.2 Mass balance 1989-2016

The historical mass balance results for Langfjordjøkelen are presented in Figure 13-5. The balance year 2015/16 was the twentieth successive year with significant negative annual balance at Langfjordjøkelen. The cumulative annual balance over 1989-2016 (estimated values for 1994 and 1995 included) is –25.8 m w.e., which gives a mean annual balance of –0.92 m w.e. a^{-1}.

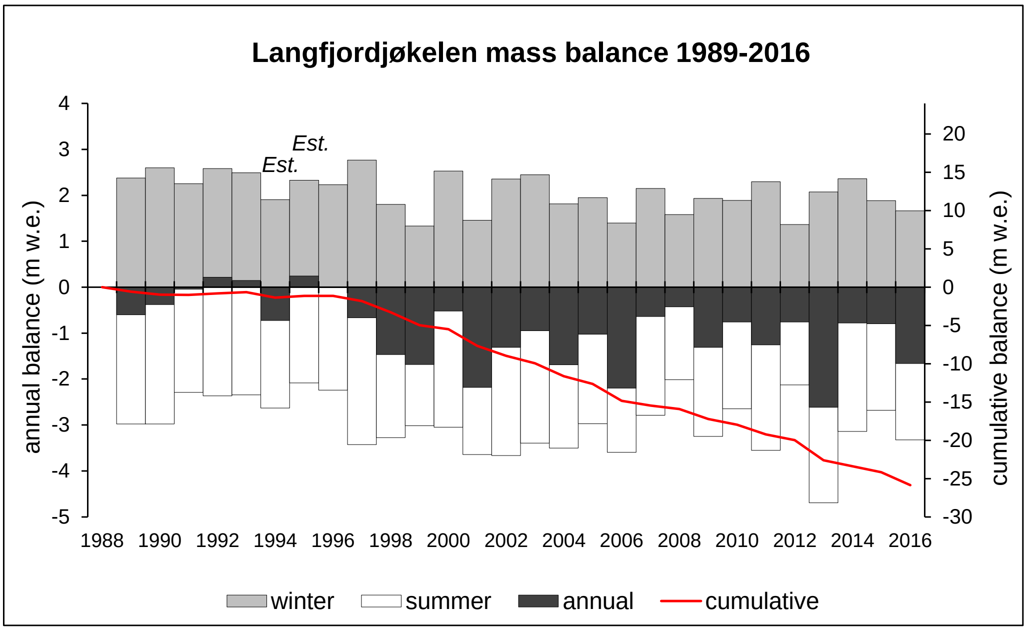


Figure 13-5
Mass balance at Langfjordjøkelen for the period 1989-2016. The total accumulated mass loss for 1989-2016 is 26 m w.e. (includes estimated values for 1994 and 1995).

14. Glacier monitoring

(Hallgeir Elvehøy, Miriam Jackson and Kjetil Melvold)

14.1 Glacier length change

Observations of glacier length change at Norwegian glaciers started in 1899. Between 1899 and 2016, glacier length change has been measured over several years at 72 glaciers. The total number of observations up to and including 2016 is 2621. The median and mean number of observations at one glacier is 26 and 36, indicating many glaciers with few observations. The median and mean number of observations in one year is 21 and 23 glaciers per year, respectively. In 1911, 45 glaciers were measured, and in 1992 only 8 glaciers were measured. At Briksdalsbreen, the length change had 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. The longest record in North-Norway is from Engabreen (84 measurements since 1903).

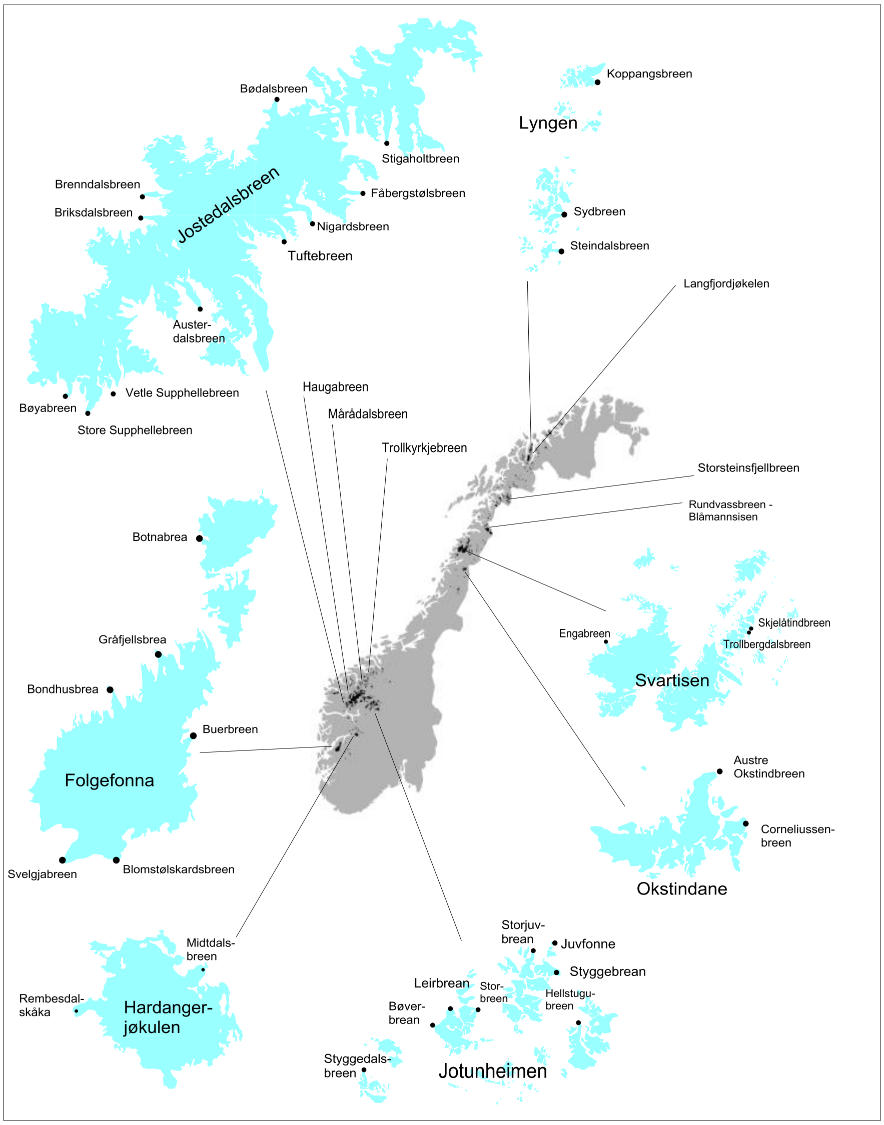


Figure 14-1 Location map showing glaciers where length change observations were performed in 2016. Note that the different glacier areas are not to the same scale.

Figure 14-2
Langfjordjøkelen (Glacier-ID 54) in Finnmark on 23rd September 2016. Photo: Miriam Jackson.

Monitoring programme

The monitoring programme for glacier length change includes 37 glaciers, - 26 glaciers in southern Norway and 11 glaciers in northern Norway (Fig. 14-1 for location). The area of the monitored glaciers is 420 km², and they constitutes about 16 % of the glacier area in Norway (Andreassen et al., 2012). Measurements have been abandoned in recent years at five outlet glaciers from Jostedalsbreen due to glacier recession into areas unfavourable for conventional length measurements. Among them was Briksdalsbreen where the measurements were halted in 2015 after 115 years of continuous measurements.

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 2016

Thirty-six glaciers were measured, 11 glaciers in northern Norway and 25 glaciers in southern Norway. Results for 2016, 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 annual change varied from +16 m (Vetle Supphellebreen) to −117 m (Gråfjellsbrea). Two glaciers advanced, four glaciers had minor length change (±2 m), and the remaining 30 glaciers showed retreat.

Table 14-1
Glacier length change measured in 2016. See Figure 14-1 for glacier locations.

	Glacier	Glacier-ID	2016	Observer	Period(s)	Number obs.
Finnmark and Nord-Troms	Langfjordjøkelen	54	-96	NVE	1998-	18
	Koppangsbreen	205	-21*	NVE	1998-	14
	Sydbreen	257	-16	NVE	2007-	9
	Steindalsbreen	288	-19	NVE	1998-	14
Nordland	Storsteinsfjellbreen	675	-2	NVE	2006-	9
	Rundvassbreen	941	-68*	SISO	2011-	4
	Engabreen	1094	-8	S	1903-	84
	Skjelåtindbreen	1272	-20*	NVE	2014-	1
	Trollbergdalsbreen	1280	-27*	NVE	2010-	5
	Austre Okstindbreen	1438	-28	NVE	1909-44, 2006-	26
	Corneliussenbreen	1439	-14	NVE	2006-	8
Sunnmøre	Trollkyrkjebreen	1804	-12	NVE	1944-74, 2008-	20
Jostedalsbreen	Fåbergstølsbreen	2289	-11	NVE	1899-	111
	Nigardsbreen	2297	-70	NVE	1899-	106
	Haugabreen	2298	-15	NBM	1933-41, 2013-	11
	Brenndalsbreen	2301	-26	NVE	1900-62, 96-	80
	Tuftebreen	2308	-25	NVE	2007-	9
	Austerdalsbreen	2327	-30	NVE	1905-20, 33-	96
	Vetle Supphellebreen	2355	+16	NBM	1899-44, 2011-	41
	Stigaholtbreen	2480	-10	NVE	1903-	110
Jotunheimen	Juvfonne	2597	+3*	NVE	2010-	4
	Styggebrean	2608	-3*	NFS	1905-76, 2011-	14
	Storjuvbrean	2614	-11	NVE	1901-12, 33-63, 97-	56
	Storbreen	2636	-12*	NVE	1902-	79
	Leirbrean	2638	-13	NVE	1909-	57
	Bøverbrean	2643	+12**	NVE	1903-12, 36-63, 97-	43
	Styggedalsbreen	2680	-6	NVE	1901-	95
	Hellstugubreen	2768	-14	NVE	1901-	77
Hardanger	Midtdalsbreen	2964	-21	AN	1982-	34
	Rembesdalskåka	2968	-5	S	1918-41, 68-83, 95-	41
	Botnabrea	3117	-41**	GK	1996-	14
	Gråfjellsbrea	3127	-117	S	2002-	12
	Buerbreen	3131	-31	NVE	1900-80, 95-	69
	Bondhusbrea	3133	+2	S	1901-86, 96-	85
	Svelgjabreen	3137	-17	SKL	2007-	8
	Blomstølskardsbreen	3141	-6	SKL	1994-	17

* Two years
** Three years

Observers other than NVE:
SISO Siso Energi
S Statkraft
NBM Norsk Bremuseum & Ulltveit-Moe senter for klimaviten
NFS Norsk fjellsenter, Lom
AN Prof. Atle Nesje, University of Bergen
GK Geir Knudsen, Tyssedal
SKL Sunnhordland Kraftlag

14.2 Jøkulhlaups

Jøkulhlaups or Glacier Lake Outburst Floods (GLOFs) were registered from three different glaciers in Norway in 2016. The three glaciers all have a history of such events. A summary of all known events from these and other glaciers in Norway up to 2014 is given in an NVE report published in 2014 (Jackson and Ragulina, 2014).

Blåmannsisen (Rundvassbreen)

Rundvassbreen (chap. 12) is a northern outlet glacier of the Blåmannsisen icecap east of Fauske in Nordland fylke. The first known jøkulhlaup from this glacier was in September 2001, when about 40 million cubic metres of water from a glacier-dammed lake (Messingmalmvatnan, see fig. 14-3) 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 of the first jøkulhlaup was previously reported as 40 mill m^3 (Engeset et al, 2005), but this was calculated from volume into the reservoir, rather than volume from Messingmalmvatnan, and included several corrections due to water used for energy production, disturbances in water level due to hydroelectric generator operation and normal inflow to the reservoir.

The next event occurred four years later, in 2005, and was approximately the same volume of water but did not occur until one year after Messingmalmvatnet had refilled. Subsequent events occurred when the lake was less than full, and at shorter intervals between events. The next jøkulhlaup from a full lake occurred in 2014, and was the first time in nine years that there was a jøkulhlaup of a similar volume to the 2001 and 2005 events (Jackson and Ragulina, 2014).

The most recent event occurred on 28th September 2016. The water level in the glacier-dammed lake was measured on 22nd September and was 1040.2 m a.s.l., and assuming an increase in water level of about 8 cm/day is estimated at about 1040.7 m a.s.l. at the time of the event. From a rating curve calculated for Messingmalmvatnet, the corresponding water volume is 24 million m^3. The hydropower company, Siso Energi, calculated that input to the reservoir Sisovatnet due to the jøkulhlaup was 26 million m^3.

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	~35 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	10th – 12th August	35 mill. m^3	~ full (probably 1053 m a.s.l.)
2016	28th – 29th September	26 mill. m^3	> half-full (estimated 1040.7 m a.s.l.)

Figure 14-3
Left - glacier-dammed lake Messingmalmvatnet, looking southwest towards Rundvassbreen. Right – glacier tongue of Rundvassbreen. Both photos were taken on 17th August 2016, six weeks before the jøkulhlaup of 28th-29th September. Photos: Miriam Jackson.

Rembesdalskåka

There were two events from Demmevatnet (Fig. 14-4), a glacier-dammed lake at the margin of Rembesdalskåka, in 2016. Demmevatnet has a long history of jøkulhlaups, dating from before 1800, and including several catastrophic floods in 1893, 1937 and 1938. Several drainage tunnels were constructed to lessen the risk, and between 1938 and 2014 there were no events registered. However, extensive thinning of the glacier led to a new event in August 2014, probably the first in over 70 years (Jackson and Ragulina, 2014).

The first event of 2016 occurred in January. Skiers in the area on the weekend of 24th January noted that there was water in Demmevatnet, but that it was empty on the following weekend. There were unseasonably warm temperatures at this time, with the temperature recorded at nearby Finse increasing over 25 degrees between 21st and 25th January, which may have been a factor in the jøkulhlaup occurring.

A second event occurred on 6th September (Fig. 6-1). The operations manager in Statkraft Eidfjord observed there had been a sudden increase of 1.2 m in the water level in Rembesdalsvatnet hydropower reservoir that started at 6 am and lasted about four hours. The increase in water level in the reservoir corresponds to a flood volume of about 1.5 million m^3.

Figure 14-4
The glacier-dammed lake Demmevatnet photographed on 25th May (left) and 3rd October 2016. Photos: Statkraft Energi.

Svartisheibreen

Svartisheibreen (66°33′N, 13°46′E) is a small valley glacier south-west of the western Svartisen ice cap that calves into a recently formed proglacial lake, Svartisheivatnet. Svartisheibreen stretches from Steintinden (1533 m a.s.l.) and Svartisheia (1471 m a.s.l.) down to lake Svartisheivatnet (774 m a.s.l.). Run-off from the glacier drains both through lake Svartisheivatnet over the mountain ridge down to a deep ravine, called Slukta, as well as under the ice down to Slukta, and further to the river Glomåga and lake Langvatnet in Rana.

Several previous events have occurred at Svartisheibreen, although rather than being directly observed, most of the events were registered due to the water level being lower than normal and the presence around the lake of stranded ice blocks. Similarly with a presumed event in 2016. Photos taken from a light aircraft show that the water level in the lake is quite low in September 2016 (Fig. 14-5), with many stranded ice blocks around the glacier-dammed lake. Photos taken the previous year (Fig. 14-5) suggest that the lake was filling up again since the event of 2014.

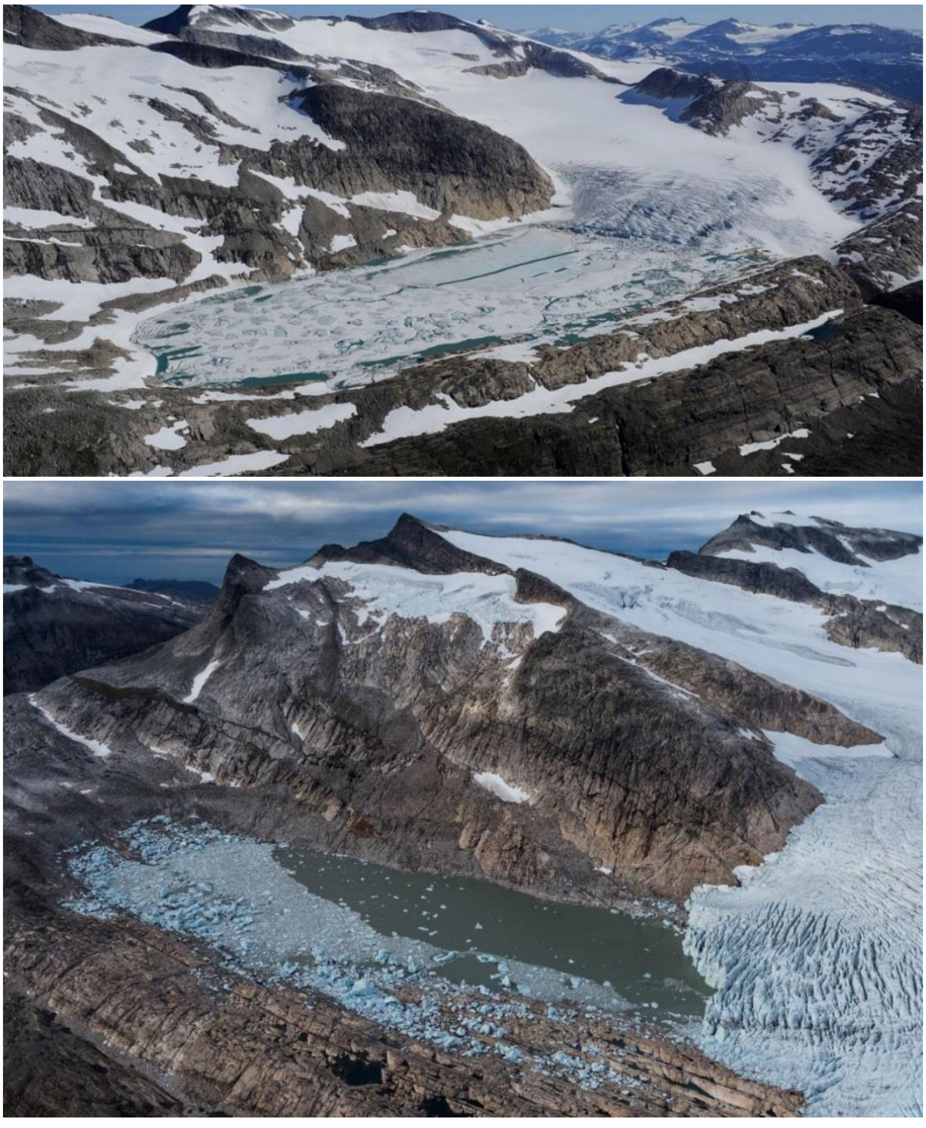


Figure 14-5
Svartisheivatnet on 17th August 2015 (upper) and 13th September 2016 (lower). Photos: Lars Westvig.

14.3 Mapping ice thickness on Ålfotbreen

Ålfotbreen ice cap (65°45’, 5°40’E) has an area of 10.6 km^2 and is one of the westernmost and maritime glaciers in Norway (Andreassen and Winsvold, 2012). The two northerly outlet glaciers named Ålfotbreen (glacier id 2078; not to be confused with the ice cape itself) and Hansebreen (glacier id 2085) have been part of NVEs mass balance programme since 1963 and 1986, respectively. The two outlets cover an area of 4.0 km^2 and 2.6 km^2 (in 2010), respectively, and cover an altitudinal range of about 600 m. The ice cap rest on tilted Devonian sandstones (Bryhni and Lutro, 2000) and the landscape has a staircase like structure with cliffs exposed towards the west and gently dipping bedrock towards the east (Fig. 14-6). The ice cap is situated on this gently dipping bedrock, and the outlet glaciers are from the ice cap not very prominent.

To determine the ice thickness and bed topography of Ålfotbreen and Hansebreen, Ground Penetrating Radar (GPR) data were collected on 12th April 2016. The survey provided wide spatial coverage (Fig. 14-7) and was carried out before the onset of melting. On the 10th May, one month after the radar survey, the annual winter balance was measured on Ålfotbreen and Hansebreen. The snow cover was measured at stake locations and by snow depth sounding in a regular grid. The snow depth ranged from 5.5 m to almost 10 m, with a mean of 7.5 m. Based stake reading from 12th April and 10th May for one stake, there was only minor change in snow depth. We will thus use the snow depth measured on 10th May as a proxy for the snow depth at the time of the radar survey.

The purpose of these measurements was to establish a data set that is prerequisite for glacier dynamical models and glacier runoff projection. The data can also be used as an independent check of previously modelled ice thickness at Ålfotbreen (Andreassen et al., 2015).

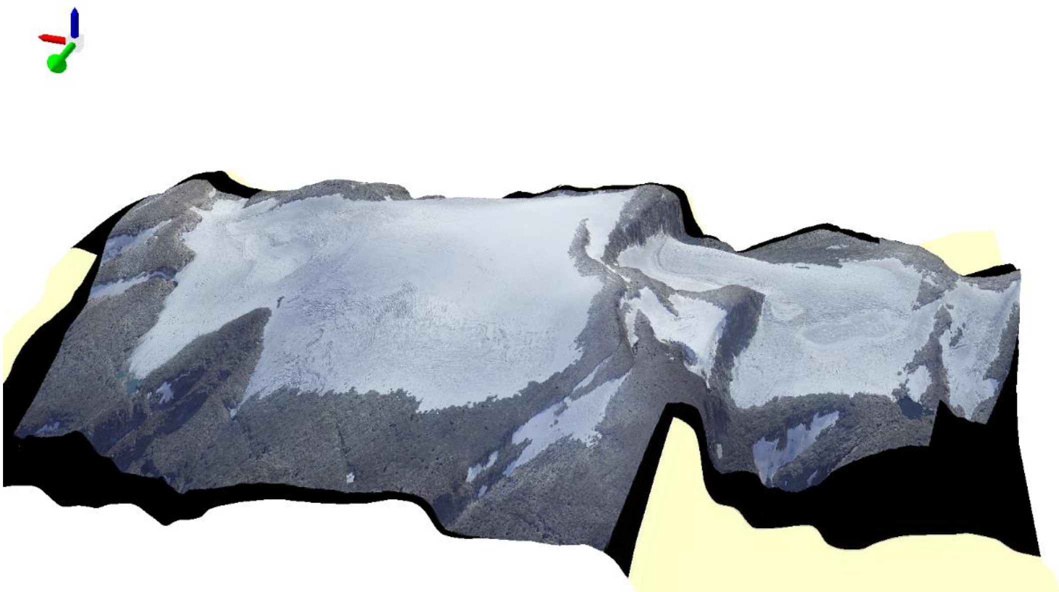


Figure 14-6
3D perspective of Ålfotbreen seen from the north (vertical exaggeration 2*z). Orthophoto from 2010 draped over terrain and the staircase like landscape with step westfacing cliffs and gently eastfacing slopes.

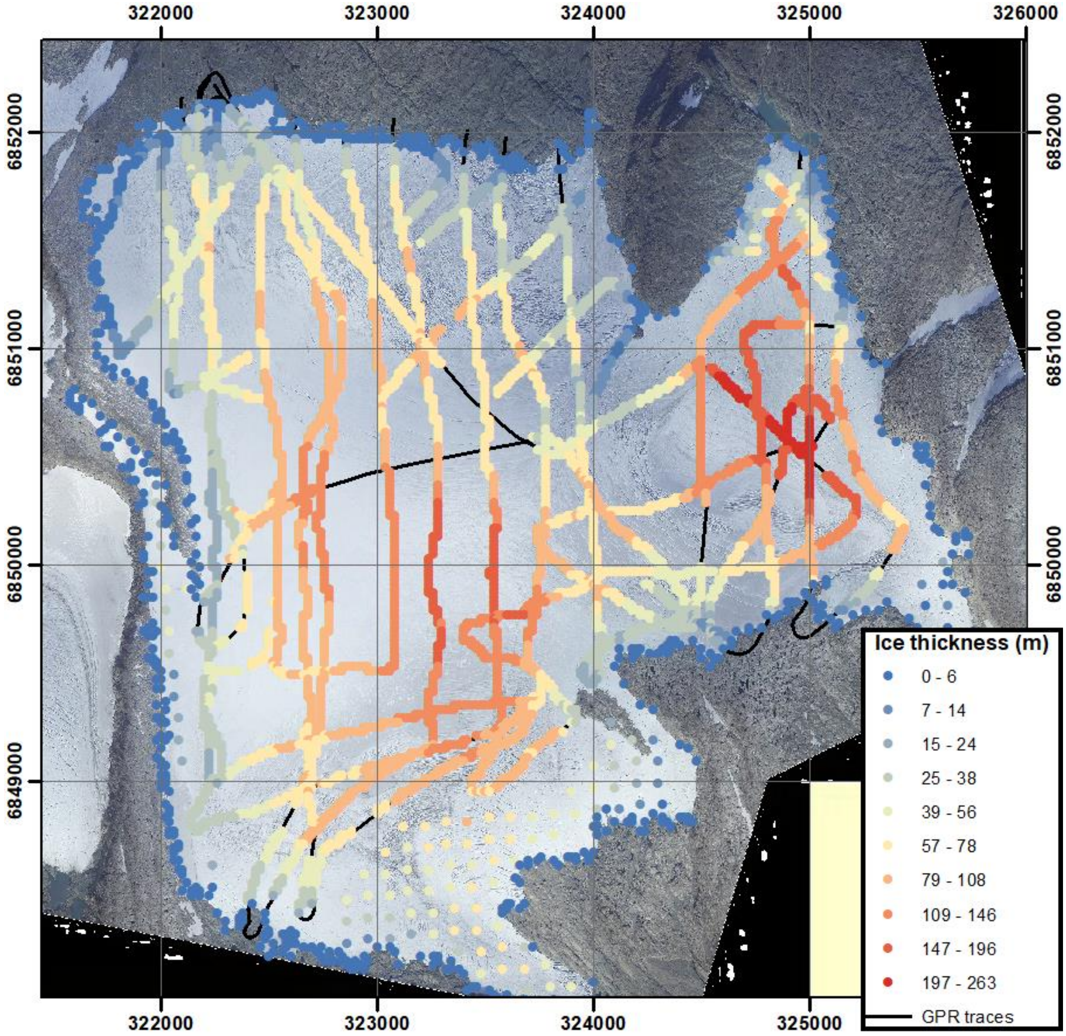


Figure 14-7
GPR/GNSS profiles over Ålfotbreen (background image orthophoto from 2010). The colour scale indicates the measured ice thickness. Black lines shows GPR traces that were too difficult to interpret and were thus removed from the data set. Zero ice thickness points along the border, and modelled ice thickness data (in the southern part) are also shown, see text.

Methods

Instruments and field setup

The radar survey was conducted with two different radar systems in order to map both the shallow and deeper parts of the glaciers. In the deeper parts we used the NVE radar, which is a non-commercial GPR. The equipment is similar to that described in Sverrison et al. (1980), but with technological improvements. The receiver is a PICO 212 digital oscilloscope. The Narod type broadband transmitter (Narod & Clarke, 1994) generates high-power (2.5kW) pulses at 512 repetitions per second. The antennae are 5 metres long resistively loaded dipole antenna from Narod (overall length 10m). The antennae have an 8-10 MHz nominal frequency (receive/transmit) and a nominal wavelength in ice of about 16.9-21.1 m (assuming a velocity through ice of 169 m μs^{-1}). The radar was operated via a Panasonic Toughbook laptop, using Gecho software (developed by Rickard Pettersson, University of Uppsala). The radar was attached to a sledge convoy towed by snowmobile.

The second system used for mapping the shallow part of the glacier was the commercial Malå RAMAC/GPR ProEx System. The RAMAC/GPR CUII control unit is coupled to a

MALÅ XV monitor for display and of control data flow. MALÅ Rough Terrain Antennae (RTA) is connected to the control unit by fibre optical cables. The RTA antenna was about 14 m long and the antenna has a fixed antenna separation of 6.2 m, as for the NVE radar the system was towed by a snowmobile. The centre frequency of the transmitted pulse is approximately 25 MHz and a nominal wavelength in ice of about 6.76 m.

For both systems, the transmitting and receiving antennas are aligned (in parallel endfire configuration) parallel to the survey/driving direction for easy towing (Fig. 14-8).

Figure 14-8
Parallel endfire configuration of GPR transmitter (TX) and receiver (RX) antennae.

For navigation, we used hand held Garmin GPS 62s receivers. Positioning of all GPR profiles (including elevation) was performed by using TOPCON GR3 dual frequency GNSS receivers. The GNSS receivers were placed in the transmitter sledge in the trail of the NVE radar train, and on the snowmobile for the Malå system. Both the GPR and the GNSS data collection were performed at regular time intervals (approximately every second), but the data were not directly coupled.

In addition to the field data, we used glacier boundaries and a 10 m x10 m surface DTM of the ice cap from 2nd September 2010 (Kjøllmoen, 2016b).

Post-processing GNSS and GPR

The GNSS data were post-processed using the commercial software packages, "Topcon Tools" by Topcon. Data from the SATREF reference station Gloppen, (30 km east of Ålfotbreen) was used for post-processing the kinematic GNSS data.

GPR traces/samples were positioned (geo-located) by use of the post-processed GNSS data using time tags as keys. A linear interpolation along the GNSS path was performed in order to estimate the position of the midpoint of the GPR antennae at the time of GPR samples/traces, since the GNSS antenna was situated at the tail (NVE radar) and in the front (Malå radar) of the radar train, respectively.

The GPR data were processed using the commercial software packages, ReflexW (Sandmeier geophysical research. 2016). The main processing steps consisted of 1) dewow in order to eliminate possible low frequency parts, 2) time zero correction, 3) equidistance trace interpolation (since the GPR data were collected at fixed time intervals this results in different distance spacing between samples/traces, depending on the driving velocity) and 4) migration. Before the migration of the data could be carried out, equidistant traces were interpolated based on the position of each trace in the GPR files. Based on the interpolated equidistance GPR data and normal move out (NMO) correction, a simple 2-D time migration (diffraction stack) was performed using a constant radio-wave velocity (RWV) of 169 m μs^{-1}. This 2-D migration corrects only the data along the profile direction and assumes all reflecting surfaces are located along the profiles, i.e. no reflections are recorded from the surface at either side of the profile. Figure 14-9 shows a migrated and an unmigrated part of radar file fonna24. The effect of migration is both to focus the bedrock reflector by collapsing diffraction hyperbolae and to correct bed reflectors where there is a highly sloping bed (e.g. Moran et al., 2000).

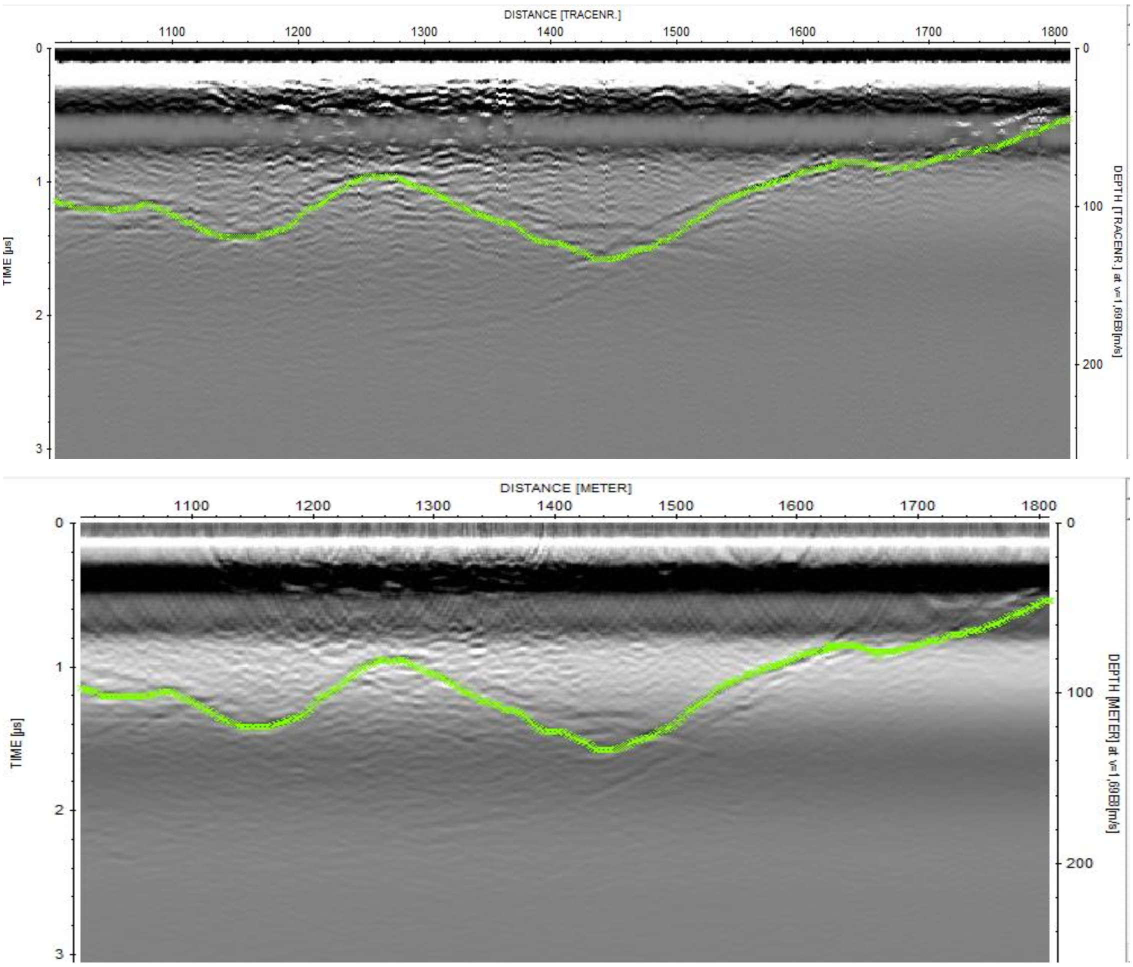


Figure 14-9
Raw (upper) and migrated (lower) 8 MHz profiles 800 m long. Interpreted bed reflections based on migrated data have been highlighted (green). Migrated data show more focused bed reflections (e.g. distance 1050- 1350 m) and area where reflections have been corrected (distance 1440-1500 m).

The Two-Way Travel-time (TWT) was determined from the migrated GPR data and digitised manually (time difference between first arrival and the bed reflection). No picking was done where the ice-bedrock interface was unclear or invisible (Fig. 14-10).

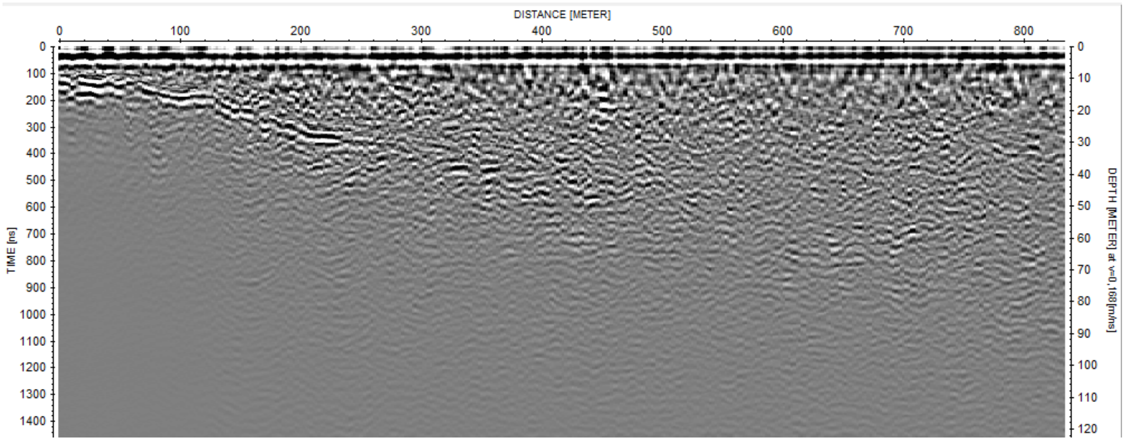


Figure 14-10
Example of radargram (RAMAC/GPR 35 MHz profile) showing the difficulty in recognising the bed reflection. Bedrock reflections can be followed in the shallow part to the left but disperse after about 250 m where the ice thickness increases. Bed reflections are hidden by strong cluttering/scattering, probably as a result of high water content in the temperate ice.

A correction was made to the TWT due to profile offset (distance between antenna centres) before the ice thickness calculation. Ice thickness is computed from the TWT, assuming a homogeneous RWV of 169 m μs^{-1}. Since the RWV in snow is higher than the RWV of ice, we added a snow correction to all the ice thickness data increasing the depth by about 2 m. No correction was applied for the firn layer, since the thickness of the firn is unknown. Figure 14-7 shows the tracks/paths along which GPR sounding was performed and where ice thickness could be determined from the data.

Interpolation

We are interested in estimating the ice thickness and volume of the entire Ålfotbreen ice cap (10.6 km^2). However, there are some small areas on the southern part of the ice cap that could not be surveyed for safety reasons (Fig. 14-7). Assigning zero ice thickness to this unmeasured area gives a biased volume estimate and a strange ice thickness map. Alternatively, we have used calculated ice thickness data from a model relating ice-thickness distribution to glacier geometry, mass balance and glacier dynamics (Huss and Farinotti, 2012). The estimated ice thicknesses have been adjusted for surface elevation difference between the DTM 2010 used here and the SK-DTM used in the ice thickness modelling (Andreassen et al., 2015).

The ice thickness data were collected in spring 2016, whereas the surface DTM was mapped in autumn 2010. To account for thickness change between the survey times we applied a correction of the measured ice thicknesses in order to relate the ice thickness to the 2010 DTM. The correction of each individual trace was found by subtracting GNSS surface elevation from the DTM elevation. The correction applied ranged from +17.1 m to −2.9 m with a mean of +5.1 m (so an average thickening of 5.1 m from autumn 2010 to spring 2016).

The boundary of the glacier was drawn manually from the 2010 orthophotos (Kjøllmoen, 2016b). The ice thickness along the glacier boundary was set to zero.

Finally, there was a total of 38490 GPR data points, 611 boundary points, and 106 estimated data points. To derive an ice thickness map from the point data a procedure developed by Liu et al. (1999) was adapted. We used a combination of Inverse Distance Weighting

(IDW) and Triangulated Irregular Network (TIN) methods to interpolate an ice thickness DTM. A smoothed thickness contour map was checked and contours were redrawn manually, where necessary. This checked contour map was used to investigate the performance and to guide the final interpolated ice thickness map especially in areas with limited data. The final ice thickness map at 20 m x 20 m resolution was compiled using the Topo To Raster tool in ArcGIS using all the ice thickness data and the glacier boundaries as an outer boundary for the ice thickness map (Fig. 14-9).

The bedrock topography was obtained by subtracting the ice thickness map from the surface DTM of 2010 for every grid point defined as ice covered in the mask.

Error in ice thickness and volume

Error in measured ice thickness

Uncertainties in the calculation of ice thickness arise from uncertainties in RWV of the electromagnetic wave in ice, inaccuracies when picking reflectors (inaccurate travel time determination), and the resolution of the radar system and influence of snow cover. The ice thickness values will also be affected by a horizontal positioning error due to both GNSS uncertainty and interpolation error of trace location along the GPR train. A more detailed discussion of both errors related to GPR measurements can be found in Lapazaran et al. (2016a). A short description with relevant values for our radar systems is given her.

The wave speed through the glacier has not been measured, but a constant RWV of 169 m μs^{-1} was used. This RWV has been used for temperate glaciers in Norway by NVE, and was suggested by Robin et al. (1969) for pure crystalline ice. This might be too high since it is based on polar ice, but to be consistent with previous studies it was not corrected. Our measurements were carried out in early spring and we assume that the snow was relatively dry at the time of the survey, which minimises the spatial variation in RWV. We have adjusted the estimated ice thickness to account for the effect of last winter's snow, which was on average 7.5 m thick. A firn correction was not applied since the firn-layer on Ålfotbreen is assumed to be relatively thin (less than 18 metres). On Jostedalsbreen ice cap east of Ålfotbreen, Sætrang and Wold (1986) found a firn layer thickness of 18 metres. Based on this, the uncertainty of the RWV in firn and ice is assumed to be about 3 % (±5.1 m μs^{-1}). This corresponds to an error of up to ±5 m depending on the ice thickness.

The maximum vertical resolution that can be achieved corresponds to quarter of the wave-length used. A more conservative value for resolution of half of the used wavelength gives ±5.3 m and ±10.5m for a 10 MHz antennae, and ±1.7 m and ±3.4 m for a 25 MHz antennae, respectively. The resolution is also dependent on the digital sampling of the GPR system. For our low frequency radar, the sampling frequency is 100 MHz and the sampling period is 0.010 μs. This will decreased the maximum resolution described above. The picking (interpretation) error of the bedrock reflector will depend on the quality of the bed reflector and the expertise of the operator. In some cases, the bed echo could easily be misinterpreted especially where there is a lot of internal backscatter in the ice. Based on our experience, the TWT picking accuracy is about ±0.05 μs, corresponding to an accuracy of ± 8.4 m in the ice thickness.

The positioning accuracy of the ice thickness measurements is related to both GNSS uncertainty and GPR-trace positioning error due to interpolation of the trace position. Since we have used differential GNSS, the positioning error of the GNSS receiver can be neglected. The accuracy of the interpolated trace positions varies in space and time. The interpolation procedure is based on the assumption that the radar train follows the same track, but this is not always the case since the sledges are roped together. Both the transmitter and receiver sledge may make a shorter turn than the leading snowmobile. We have used proposed values found in the study of Lapazaran et al. (2016a). Our survey was carried out using a snowmobile traveling at 20-25 km h^{-1}, recording three GPR traces and one GNSS position every second, implying a position accuracy of about 10 m (Tab. 1 in Lapazaran et al., 2016a). As the bedrock slope varies between 0 and 40 degrees with a mean of about 12 degrees, the resulting thickness accuracy related to positioning ranges from 1 to 7 m (Fig. 4 in Lapazaran et al., 2016a).

To obtain a large data set for comparison and to account for errors that are associated with assumptions concerning the position of the GPR and ice thickness, we selected thickness data at cross-over points that were within a horizontal distance of 20 m and obtained a set of 72 validation data points. At each cross-over point, only the two nearest points were compared. The maximum thickness difference between the two data-sets was 31 m (ice thickness was about 150 m), but the mean difference was 1 m with a standard deviation of 6 m. Differences larger than 20 m where often found in areas with steep slopes, or in areas with weak bed returns. The less reliable data were corrected to fit more reliable data by adjusting the selection of bedrock reflector, or the data were completely removed/discarded. After this procedure, all data sets were considered comparable. The overall error in ice thickness is estimated to be ±20 m in the central study area. The error is larger in the unmeasured areas.

Error in ice thickness DTM and volume

The performance of different interpolation algorithms is strongly dependent on the pattern, density and format of source data (e.g. Liu et al., 1999). As with most GPR data the digital ice thickness map is based on data that are densely sampled along the GPR profile but widely spaced between the lines. On each sounding line the record represents a moving average of the real bed profile on a stripe beneath the line. The width of the stripe is typically of the order 30 m, and the spacing between the lines up to 200 m. This pattern imposes serious difficulties on most general purpose interpolation algorithms and techniques to quantify the accuracy of surface interpolation algorithms (Liu et al., 1999 and Lapazaran et al., 2016b). A full discussion about how error in ice thickness DTM could be carried out is given in Lapazaran et al. (2016b), and is beyond the scope of this short summary. Based on the conclusion of Lapazaran et al. (2016b) we can expect the interpolation error to be the main error source. Our map of ice thickness and bedrock topography will not have homogeneous accuracy all over the map. Thus, the maps may be expected to represent trends in the landscape in the steeper part of the glacier. Furthermore the map will display more local detail along the sounding lines. This consideration is also valid for any product derived from the ice thickness such as the bedrock topography map.

The error of the volume is determined by the error in the interpolated ice thickness and the error in the area. In our case the error in area which is based on a 2010 orthophoto with pixel resolution of 25 cm, is small. The error in volume is thus related to the error in interpolated ice thickness.

Results

The interpolated mean and maximum ice thickness and volume for the individual drainage basins and the whole glacier are shown in Table 14-3. The ice-thickness maps are displayed in Figure 14-11 and Figure 14-12 shows contour map of bed and surface topography. The total volume of the entire ice cap is, 0.70 km^3 and the mean ice thickness 65 m. For the mass balance basins Ålfotbreen (glacier id 2078) the volume, average and maximum ice thickness are, 0.22 km^3, 57 m, 153 m respectively. For Hansebreen (glacier id 2085) values are respectively 0.24 km^3, 85 m, and 239 m. The thickest ice 239 m is found in the lower central part of Hansebreen, which also has the largest average ice thickness.

Table 14-3
Estimated area based on boundary from orthophoto of 2010, volume, maximum ice thickness and average ice thickness for the ice cap and for individual outlets.

Name	Glacier ID	Area (km^2)	Volume (km^3)	Max H (m)	Mean H (m)
Ålfotbreen ice cap		10.60	0.70	239	65
Ålfotbreen	2078	4.00	0.22	153	57
Hansebreen	2085	2.80	0.24	239	85
South-facing outlet	2096	3.28	0.23	162	68

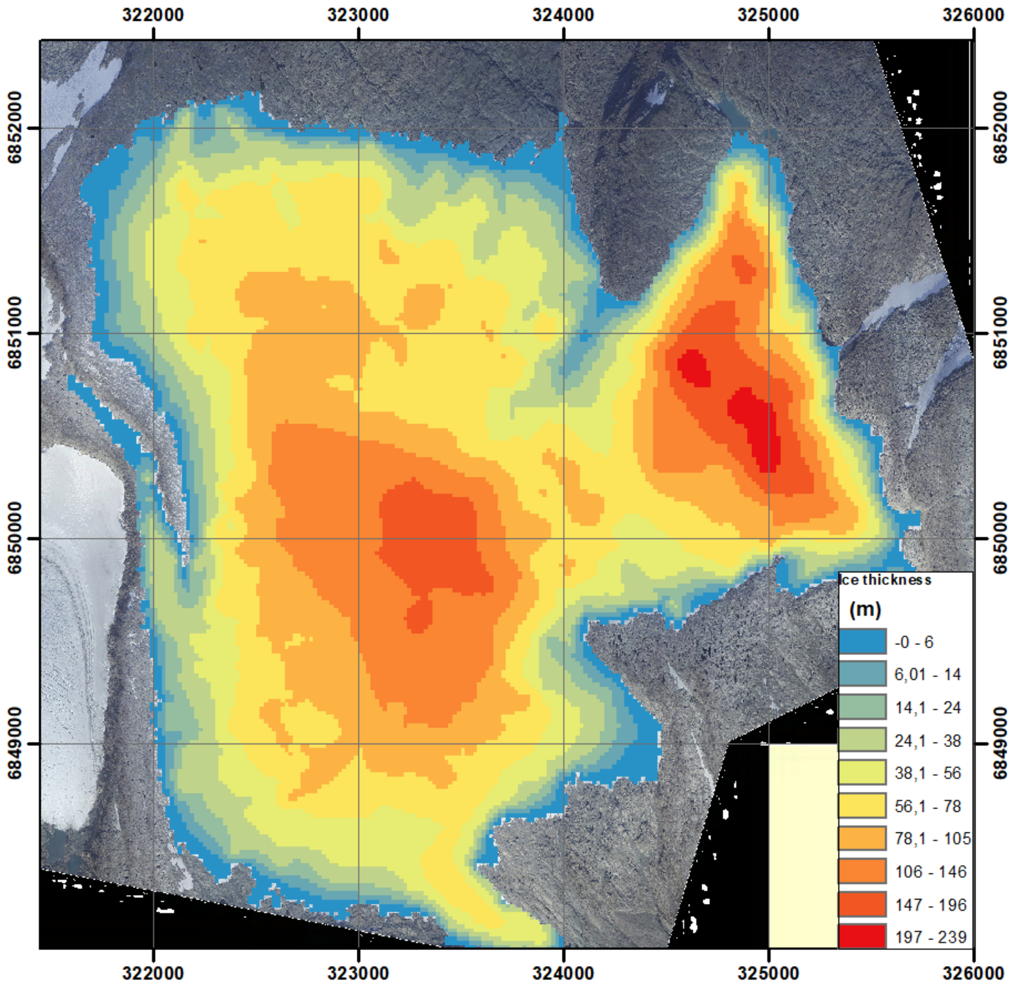


Figure 14-11
Interpolated ice thickness map of Ålfotbreen.

The bed topography (Fig. 14-12) shows that a clear U-shaped and overdeepened valley exists beneath the lower part of Hansebreen. If Hansebreen melts away, a small lake will be formed in this area. The south-facing outlet glacier (id 2096) sits partly in an open valley structure that penetrates into the Hansebreen catchment. The mass balance glacier Ålfotbreen sits in a cirque-like structure with a concave (hollowed inward) base but the cirque is not very pronounced. In this upper part of the ice cap, the ice divide is shifted towards the south compared with the bedrock divide. Hansebreen and Ålfotbreen are separated by a bedrock structure that has a southwest-northeast trend and it is a continuation of the ridge that separates the two-glacier tongues. The bedrock has a similar landscape form to areas outside the glacier which may indicates relative limited glacier erosion. A recent study by Gjerde et al. (2016) indicated that Ålfotbreen was small or absent most of the time since deglaciation at about 9700 BP. According to the study, during the 'Little Ice Age' Ålfotbreen had its largest advance of Ålfotbreen since deglaciation.

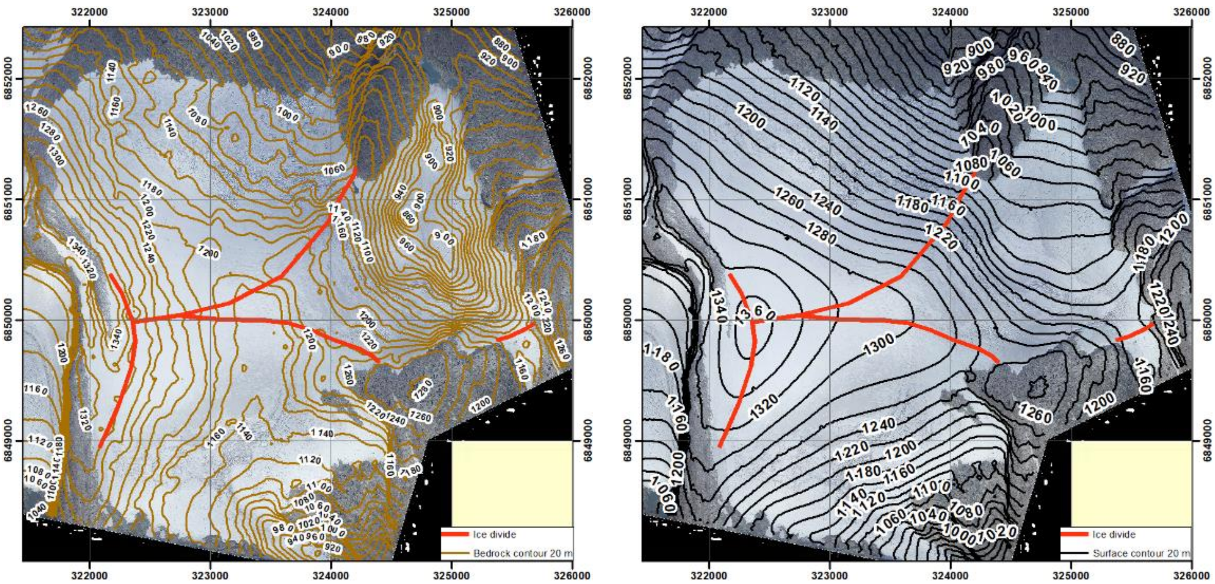


Figure 14-12
Bed (left) and surface (right) maps with 20 m contour lines. Ice divides shown in red are based on surface contour.

Discussion

Navigational of error (and hence inaccurate positioning of the radar data) will have significant effect on the derived bedrock topography, and this effect is dependent on surface slope. Navigation errors will contribute more to the error in the estimated bedrock topography in steeper areas than in areas with less steep slopes. Since in areas with small surface slope the ice thickness change only slightly over a given distance whereas in steeper areas the ice thickness changes more rapidly.

In addition to navigational error, areas with steep bedrock walls will be affected by misplacing reflectors, since (3D migration) migration is not possible to perform on the data. Moran et al. (2015) found that interpretation of raw-data profiles underestimated depth by 36 % and that 2-D migration underestimated depths by 16 % compared to 3-D migration in such areas.

Our map of ice thickness and bedrock topography will thus not have homogeneous accuracy over the map. Thus, the maps may be expected to represent trends in the landscape in the steeper part of the glacier, rather than in the less steep part of Ålfotbreen. Furthermore, the map display more local detail along the sounding lines than between lines.

Relatively large differences, both in terms of total volume (15 % increase) and ice thickness distribution, are found between data presented here compared to the previous model ice thickness found in Andreassen et al. (2015). The main difference is found along the ice divide in the upper part of the glacier where the model ice thickness is unrealistic due to limitations in the model. This shows the importance of measuring the ice thickness along the ice divide.

Conclusions

Relatively dense mapping at 8 MHz and 25 MHz GPR on Ålfotbreen provides detailed ice thickness and bedrock maps. The average ice thickness (in 2010) was 65 m corresponding to a glacier volume of 0.70 km^3. The bedrock shows some interesting features such as a relatively deep valley beneath Hansebreen and an offset in the ice divide versus the bedrock water divide towards the north in the upper part of the ice cap.

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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 1949-2016. 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-	54
2 Hansebreen	2,8	927-1310	2010	1986-	31
Folgefonna					
3 Blomsterskardsbreen	45.7	850-1640	1959	1970-77	8
3a Svelgjabreen*	22.3	829-1632	2013	2007-	10
3b Blomstølskardsbreen*	22.4	1012-1632	2013	2007-	10
4 Bondhusbrea	10.7	477-1636	1979	1977-81	5
5 Breidablikkbrea	3.9	1217-1660	1959	1963-68	17
	3.2	1232-1648	2013	2003-13	
6 Gråfjellsbrea	9.7	1034-1656	1959	64-68, 74-75	18
	8.1	1049-1647	2013	2003-13	
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-	55
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-	29
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-	54
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-	68
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-	7
27 Hellstugubreen	2.9	1482-2229	2009	1962-	55
28 Gråsubreen	2.1	1833-2284	2009	1962-	55
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	36.2	111-1544	2016	1970-	47
34 Storglombreen	59.2	520-1580	1968	1985-88	10
	62.4	520-1580		2000-05	
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	907-1366	1968	1970-75	11
	1.8	907-1369	1998	1990-94	
Blåmannsisen					
39 Rundvassbreen	11.7	788-1533	1998	2002-04	9
	10.9	836-1525	2011	2011-	
Skjomen					
40 Blåisen	2.2	860-1204	1959	1963-68	6
41 Storsteinsfjellbreen	6.2	926-1846	1960	1964-68	10
	5.9	969-1852	1993	1991-95	
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	277-1053	1994	1989-93	26
	3.2	302-1050	2008	1996-	

* Part of Blomsterskardsbreen

Appendix C

Mass balance measurements in Norway – annual results

There are results from 709 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 of the glacier. The reported year (in brackets) corresponds to the given area.

1 Ålfotbreen - 4.0 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	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
54	16	4.15	-4.79	-0.64	-2.48	>1368	O
Mean 1963-2016		3.62	-3.67	-0.05			

2 Hansebreen - 2.8 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	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
31	16	3.81	-5.12	-1.30	-18.18	>1310	O
Mean 1986-2016		3.43	-4.02	-0.59			

3 Blomsterskardsbreen - 45.7 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			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 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	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
10	16	3.33	-3.33	-0.01	1.46	1325	O
Mean 2007-16		3.09	-2.94	0.15			

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
10	16	3.43	-2.73	0.70	6.00	1320	O
Mean 2007-16		3.23	-2.63	0.60			

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	1.86	-3.00	-1.14	-1.14	1610	H
2	78	2.37	-2.90	-0.52	-1.66	1545	H
3	79	2.84	-2.65	0.20	-1.47	1485	H
4	1980	2.33	-2.82	-0.49	-1.95	1550	H
5	81	3.38	-2.06	1.32	-0.63	1440	H
Mean 1977-81		2.56	-2.68	-0.13			

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	1.55	-3.23	-1.68	-3.44	>1660	H
5	67	2.94	-1.72	1.23	-2.21	1355	H
6	68	3.44	-2.69	0.75	-1.46	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	3.54	-3.07	0.47	-5.93	1370	H
12	08	2.66	-2.96	-0.30	-6.23	1515	O
13	09	2.47	-2.98	-0.52	-6.74	1565	O
14	2010	1.60	-3.53	-1.94	-8.68	>1651	O
15	11	1.88	-4.16	-2.28	-10.96	>1648	O
16	12	3.19	-2.06	1.13	-9.84	1290	O
17	13			-1.11	-10.95	>1648	O
Mean 1963-68		2.09	-2.33	-0.24			
Mean 2003-12(13)		2.42	-3.41	-1.00			

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
55	16	2.81	-2.33	0.49	5.65	1380	O
Mean 1962-2016		2.23	-2.13	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	O
25	12	2.68	-1.91	0.77	-12.47	1368	O
26	13	1.61	-3.26	-1.65	-14.12	>1747	O
27	14	2.14	-3.44	-1.30	-15.42	>1747	O
28	15	2.53	-1.80	0.73	-14.69	1371	O
29	16	2.01	-3.07	-1.06	-15.75	>1747	O
Mean 1988-2016		2.18	-2.72	-0.54			

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	1.63	-3.10	-1.46	-1.46	>1770	O
2	89	2.76	-1.62	1.14	-0.32	1405	O
3	1990	3.34	-2.33	1.02	0.69	1390	O
4	91	1.40	-1.37	0.03	0.73	1540	O
Mean 1988-91		2.28	-2.10	0.18			

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	O
50	12	2.65	-1.74	0.91	-2.68	1589	O
51	13	1.61	-2.84	-1.22	-3.90	>1854	O
52	14	2.17	-3.46	-1.29	-5.20	>1854	O
53	15	3.00	-1.83	1.17	-4.03	1570	O
54	16	2.24	-2.63	-0.39	-4.41	1695	O
Mean 1963-2016		2.06	-2.14	-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
68	16	1.11	-1.91	-0.80	-23.88	1835	O
Mean 1949-2016		1.42	-1.77	-0.35			

24 Vestre Memurubre - 9.2 km² (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 km² (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 km² (2004)

No. of years	Year	b_w	b_s	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		<1998	O
2	11	1.17	-3.05	-1.88			O
3	12	1.44	-1.38	0.06			O
4	13	0.96	-2.51	-1.55			O
5	14	1.21	-3.51	-2.30			O
6	15	1.46	-0.89	0.57			O
7	16	0.78	-1.98	-1.20			O

27 Hellstugubreen - 2.9 km² (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
55	16	1.21	-1.55	-0.34	-21.63	1940	O
Mean 1962-2016		1.10	-1.50	-0.39			

28 Gråsubreen - 2.1 km² (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
55	16	0.76	-1.18	-0.42	-21.34	undef.	O
Mean 1962-2016		0.75	-1.14	-0.39			

29 Charles Rabots Bre - 1.1 km² (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 km² (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 km² (1972)

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	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 - 5.5 km² (1995)

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	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	3.74	-3.32	0.43	0.70	960	H
4	91	2.61	-2.57	0.04	0.75	960	H
5	92	3.70	-2.59	1.12	1.86	900	H
6	93	3.38	-2.43	0.95	2.81	865	H
7	94	1.79	-2.04	-0.25	2.56	1045	H
Mean 1988-94		3.05	-2.69	0.37			

33 Engabreen - 36.2 km² (2016)

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	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	3.27	-2.61	0.65	-0.23	1070	H
47	16	2.65	-2.88	-0.23	-0.45	1195	O
Mean 1970-2016		2.64	-2.65	-0.01			

34 Storglombreen - 62.4 km² (1968)

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	1985	1.40	-2.59	-1.18	-1.18	1300	O
2	86	2.45	-2.87	-0.41	-1.60	1100	O
3	87	2.32	-1.87	0.45	-1.15	1020	O
4	88	2.06	-3.88	-1.81	-2.96	1350	O
5	2000	2.64	-1.56	1.09	1.09	1000	O
6	01	1.15	-2.91	-1.76	-0.68	>1580	O
7	02	2.33	-3.58	-1.25	-1.93	>1580	O
8	03	2.18	-3.28	-1.10	-3.03	>1580	O
9	04	2.26	-2.14	0.11	-2.91	1075	O
10	05	2.74	-2.41	0.33	-2.58	1060	O
Mean 1985-88		2.06	-2.80	-0.74			
Mean 2000-05		2.22	-2.65	-0.43			

35 Tretten-null-tobreen - 4.9 km² (1968)

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	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 km² (1953)

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	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 km² (1953)

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	1954	1.86	-2.60	-0.74	-0.74		O
2	55	1.89	-2.35	-0.46	-1.20		O
3	56	1.00	-0.89	0.11	-1.09		O
Mean 1954-56		1.58	-1.95	-0.36			

38 Trollbergdalsbreen - 1.8 km² (1998)

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	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	2.38	-2.25	0.13	0.49	1050	H
11	94	1.52	-2.42	-0.90	-0.41	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 km² (2011)

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	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
9	16	1.52	-2.01	-0.49	-4.67	1265	O
Mean 2002-04		1.92	-2.80	-0.88			
Mean 2011-16		1.78	-2.56	-0.78			

40 Blåisen - 2.2 km^2 (1960)

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	2.42	-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	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(O/H/C)
1	1964	1.82	-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	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(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	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(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	B_s	B_a	Cum. B_a	ELA	Series
		(m w.e.)		(m w.e.)		(m a.s.l.)	(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
26	16	1.66	-3.33	-1.66	-24.71	>1050	O
Mean 1989-1993		2.46	-2.59	-0.13			
Mean 1996-2016		1.96	-3.14	-1.18			

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