NVE

RAPPORT NR. 23 / 2023

Glaciological investigations in Norway 2022

AUTHORS: Liss M. Andreassen, Hallgeir Elvehøy og Bjarne Kjøllmoen

NVE Rapport nr. 23/2023:
Glaciological investigations in Norway 2022

Published by: The Norwegian Water Resources and Energy Directorate
Editor: Bjarne Kjøllmoen
Authors: Liss M. Andreassen, Hallgeir Elvehøy and Bjarne Kjøllmoen
Cover photo: Grjotbrean in Jotunheimen. Photo taken 30th July 2022. Photographer: Liss M. Andreassen/NVE

ISBN: 978-82-410-2283-8
ISSN: 2704-0305
Case number: 200706893

Abstract: Results of glaciological investigations performed at Norwegian glaciers in 2022 are presented in this report. The main part concerns mass balance investigations. Results from investigations of glacier length changes are discussed in a separate chapter.

Keywords: Glaciology, Mass balance, Glacier length change, Glacier dynamics, Ice velocity, Meteorology, Jøkulhlaup.

The Norwegian Water Resources and Energy Directorate
Middelthuns gate 29
P.O.Box 5091 Majorstuen
N-0301 OSLO

Phone: (+47) 22 95 95 95
E-mail: nve@nve.no
Internet: www.nve.no

October 2023

Contents

Preface

This report is a new volume in the series "Glaciological investigations in Norway", which has been published since 1963. From 1963 to 2021 the report was published as a printed edition. From 2022, however, the report will only be published as a digital edition.

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 glacier investigations and calculations made mainly by NVE's Section for Glaciers, Ice and Snow during 2022. 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 of the report.

Oslo, October 2023

Hege Hisdal
Director General
Hydrology Department

Rune V. Engeset
Head of section
Section for Glaciers, Ice and Snow

This document is sent without signature. The content is approved according to internal routines.

Summary

Mass balance

Mass balance investigations were performed on eleven glaciers in Norway in 2022 – two in northern Norway and nine in southern Norway.

The winter balance was lower than the 1991-2020 average for five of the nine reference glaciers (continuous mass balance series longer than 20 years). Gråsubreen and Hellstugubreen in Jotunheimen had the lowest relative winter balances with 71 % and 76 % of the 1991-2020 averages, respectively. Langfjordjøkelen and Engabreen in northern Norway had the greatest relative winter balances, both with 127 % of the reference period averages.

The summer balance was greater than the 1991-2020 average for six of the nine reference glaciers. Gråsubreen and Langfjordjøkelen had the greatest relative summer balances with 159 % and 153 % of the reference period averages, respectively. Nigardsbreen had the lowest relative summer balance with 80 % of the reference period average.

The annual balance was negative for seven of the nine reference glaciers, and of these nine, Langfjordjøkelen had the greatest deficit with −1.9 m w.e. Nigardsbreen and Engabreen had both surplus with +0.7 and +0.1 m w.e., respectively.

Glacier length change

Glacier length changes were measured at 26 glaciers in southern Norway and 8 glaciers in northern Norway. Thirty-three of the 34 measured glacier outlets showed a decrease in length. The greatest retreats were observed at Storjuvbrean in Jotunheimen (94 m), at Tuftebreen on the eastern side of Jostedalsbreen (65 m) and at Langfjordjøkelen in western Finnmark (61 m).

Sammendrag

Massebalanse

I 2022 ble det utført massebalansemålinger på 11 breer i Norge – to i Nord-Norge og ni i Sør-Norge.

For fem av de ni referansebreene (breer som har mer enn 20 år sammenhengende massebalanseserie) ble vinterbalansen mindre enn gjennomsnittet for referanse-perioden 1991-2020. Gråsubreen og Hellstugubreen i Jotunheimen fikk den relativt minste vinterbalansen med hhv. 71 % og 76 % av referanseperioden. Langfjordjøkelen og Engabreen i Nord-Norge, fikk den relativt største vinterbalansen, begge med 127 % av referanseperioden.

Sommerbalansen ble større enn gjennomsnittet for seks av de ni referansebreene. Gråsubreen og Langfjordjøkelen hadde relativt størst sommerbalanse med hhv. 159 % og 153 % av referanseperioden. Nigardsbreen fikk den relativt minste sommerbalansen med 80 % av referanseperioden.

Årlig balanse ble negativ for sju av de ni referansebreene, og Langfjordjøelen hadde størst underskudd med −1,9 m v.ekv. Nigardsbreen og Engabreen hadde begge overskudd med hhv. +0,7 m v.ekv. og +0,1 m v.ekv.

Lengdeendringer

Lengdeendringer ble målt på 26 breer i Sør-Norge og 8 breer i Nord-Norge. Trettitre av de 34 målte breutløperne hadde tilbakegang. Størst tilbakegang ble målt på Storjuvbrean i Jotunheimen (94 m), på Tuftebreen på østsiden av Jostedalsbreen (65 m) og på Langfjordjøkelen i Vest-Finnmark (61 m).

1. Glacier investigations in Norway 2022

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) include 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.

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.

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*.

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.

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

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

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.

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.

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.

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.

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

Sentinel-2 satellite/Xgeo
In a special edition of the expert tool Xgeo satellite imageries can be viewed together with glacier data.

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*. 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 that is covered by the first snow of the new balance year.

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 on Norwegian glaciers have generally remained unchanged over the years, although the number of measurements has varied (Andreassen et al., 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 (Fig. 1-1). 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.

Figure 1-1
Stake reading and probing at Hellstugubreen on 20th April 2022. Photo: Liss M. Andreassen.

Summer and annual balance

Summer and annual balances are obtained from measurements of stakes and towers, usually performed in September or October (Fig. 1-2). Below the elevation of a 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, depending on the age, is assumed to be between 650 and 800 kg m^{-3}. The density of melted ice is taken as 900 kg m^{-3}.

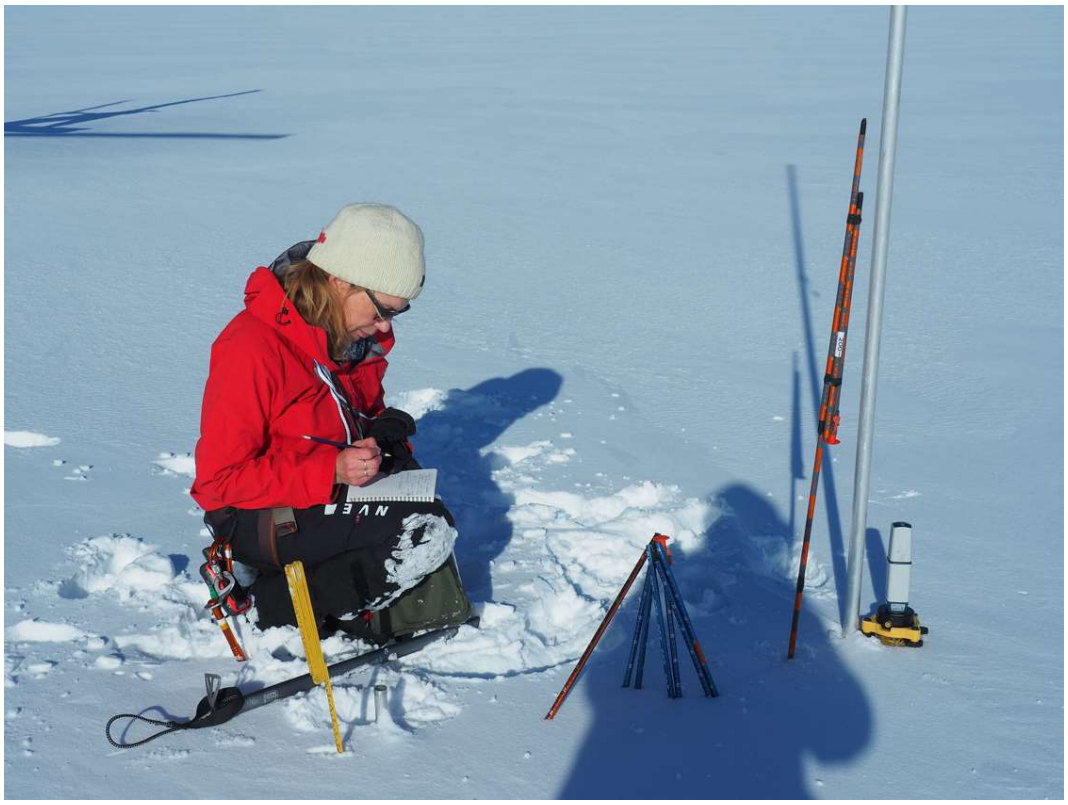


Figure 1-2
Stake reading on Storbreen on 29th September 2022. Photo: Jostein Aasen.

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, measuring and calculating the additional ablation often cannot be done until the following winter or spring. Thus, it is counted as a negative contribution to the next year's winter balance.

Uncertainty

The uncertainty of the mass balance measurements depends mainly 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 unmeasured areas of the glacier) 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 is 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 thus based on subjective estimates.

Mass balance programme

In 2022 mass balance measurements were performed on eleven glaciers in Norway - nine in southern Norway and two in northern Norway (Fig. 1-3). Included in this total is one small ice mass, Juvfonne, which can be characterised as an ice patch rather than a glacier (chap. 7). In southern Norway, six of the glaciers (Ålfotbreen, Nigardsbreen, Rembesdalskåka, Storbreen, Hellstugubreen and Gråsubreen) have been measured for 60 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 0.7 m w.e. Storbreen in Jotunheimen has the longest series of all glaciers in Norway with 74 years of measurements, while Engabreen at Svartisen has the longest series (53 years) in northern Norway. The six glaciers measured for 60 consecutive years or more, together with Hansebreen in southern Norway and Langfjordjøkelen and Engabreen in northern Norway, are selected to be included in the Norwegian Hydrological Reference Dataset (Andreassen and Elvehøy, 2021). These nine glaciers constitute the so-called reference glaciers. Austdalsbreen was excluded because it was calving into a hydro-power reservoir, and consequently the glacier is influenced by the lake level regulations. For the nine reference glaciers, a 30-year reference period (1991-2020) is defined and the balance values for 2022 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. (2020).

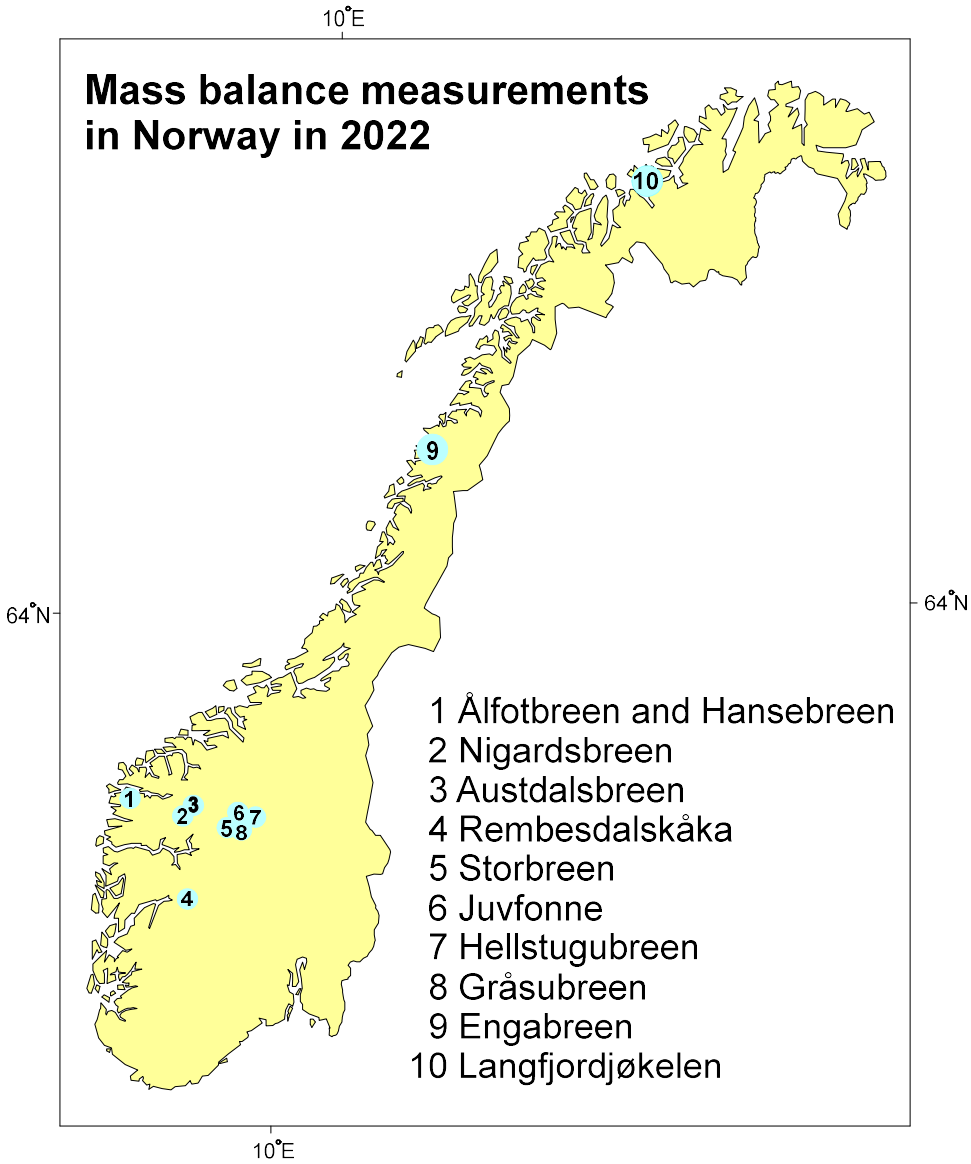


Figure 1-3
Location of the glaciers at which mass balance studies were performed in 2022.

Mass balance studies performed on Norwegian glaciers in 2022 are reported in the following chapters.

The mass balance (winter, summer and annual balance) is given in 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 2021/22 started with dry weather in November and December all over the country. In southern Norway the months January and February were snow-rich, while March and April were both dry. In northern Norway January and March were snow-rich while February was quite normal.

Snow accumulation and winter balance

The winter balance was lower than the 1991-2020 average for five of the nine reference glaciers (continuous mass balance series longer than 20 years). Gråsubreen and Hellstugubreen in Jotunheimen had the lowest relative winter balances with 71 % and 76 % of the 1991-2020 averages, respectively. Langfjordjøkelen and Engabreen in northern Norway had the greatest relative winter balances, both with 127 % of the reference period averages.

Summer weather

The summer season started with warm weather in June all over the country. The warm weather continued in July and August in northern Norway. In southern Norway however, July and August were rather cool. September was quite normal over most of the country.

Ablation and summer balance

The summer balance was greater than the 1991-2020 average for six of the nine reference glaciers. Gråsubreen and Langfjordjøkelen had the greatest relative summer balances with 159 % and 153 % of the reference period averages, respectively. Nigardsbreen had the lowest relative summer balance with 80 % of the reference period average.

Annual balance

The annual balance was negative for seven of the nine reference glaciers, and of these nine, Langfjordjøkelen had the greatest deficit with −1.9 m w.e. Nigardsbreen and Engabreen had both surplus with +0.7 and +0.1 m w.e., respectively.

The results from the mass balance measurements in Norway in 2022 are shown in Table 1-1. Winter (B_w), summer (B_s) and annual balance (B_a) are given in 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 1991-2020. 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, winter and annual balance of the northernmost glaciers, Langfjordjøkelen and Engabreen, are better correlated with AO than NAO (Andreassen et al., 2020). For the glaciers in southern Norway, the correlations are similar for NAO and AO, and reduced with distance to the coast (Rasmussen, 2007; Andreassen et al., 2020).

In winter 2021/2022 (December-March) the NAO and AO indexes were positive in all months. The NAO and AO mean was 0.95 and 0.72 respectively for December-March calculated from the monthly means, source: http://www.cpc.ncep.noaa.gov/. Over the period 1989-2022 the most positive NAO and AO years were in the period with mass surplus from 1989 to 1995 and in several recent years, e.g., 2012, 2014 and 2015. The NAO and AO indexes vary from year to year and whereas 2020 and 2022 had positive indexes, 2021 was negative (Fig. 1-4).

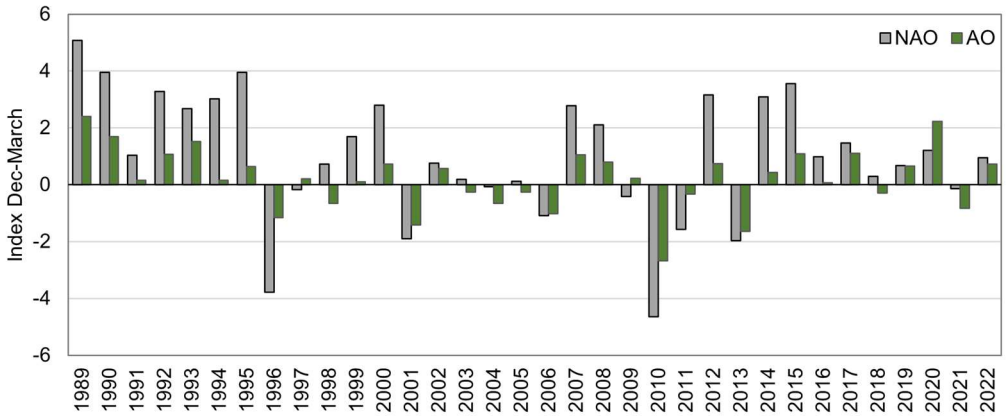


Figure 1-4
NAO and AO index for December–March for 1989–2022. NAO and AO data were downloaded from the NOAA Center for Weather and Climate Prediction (http://www.cpc.ncep.noaa.gov/). Figure updated and modified from Andreassen et al. (2020). The large-scale circulation indices NAO and AO are in units 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 2022. 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 1991-2020.

Glacier	*Period*	*Area* *(km²)*	*Altitude* *(m a.s.l.)*	B_w *(m)*	*% of ref.*	B_s *(m)*	*% of ref.*	B_a *(m)*	B_a *ref.*	*ELA* *(m a.s.l.)*	*AAR* *(%)*
Ålfotbreen	1963-22	3.5	1000-1360	3.38	93	−3.94	97	−0.56	−0.42	1340	7
Hansebreen	1986-22	2.5	927-1303	3.21	93	−4.25	103	−1.05	−0.66	>1303	0
Nigardsbreen	1962-22	44.9	389-1955	2.57	114	−1.83	80	0.74	−0.05	1445	84
Austdalsbreen	1988-22	10.1	1200-1740	2.20	104	[1)]−2.24	83	−0.05	−0.60	1425	69
Rembesdalskåka	1963-22	17.1	1085-1851	2.33	111	−2.24	93	0.09	−0.29	1611	83
Storbreen	1949-22	4.9	1420-2091	1.35	97	−2.03	101	−0.68	−0.62	1875	18
Juvfonne[2)]	2010-22	0.1	1852-1985	1.71		−1.95		−0.24			
Hellstugubreen	1962-22	2.7	1482-2229	0.80	76	−1.74	103	−0.94	−0.64	2115	2
Gråsubreen	1962-22	1.7	1854-2277	0.50	71	−2.12	159	−1.62	−0.63	undef.	
Engabreen	1970-22	36.0	177-1532	3.46	127	−3.31	119	0.15	−0.06	1141	67
Langfjordjøkelen	1989-93	3.7	280-1050						−0.13		
	1996-22	2.6	338-1043	2.65	[3)]127	−4.56	[3)]153	−1.91	[3)]−0.89	>1043	0

[1)]Contribution from calving amounts to −0.05 m for B_s
[2)]Calculated for a point only, b_w, b_s and b_a
[3)]Calculated for the measured periods 1989-93 and 1996-2021

Figure 1-5 presents the mass balance results eight glaciers in southern Norway for 2022. The west-east gradient is evident for both winter and summer balances.

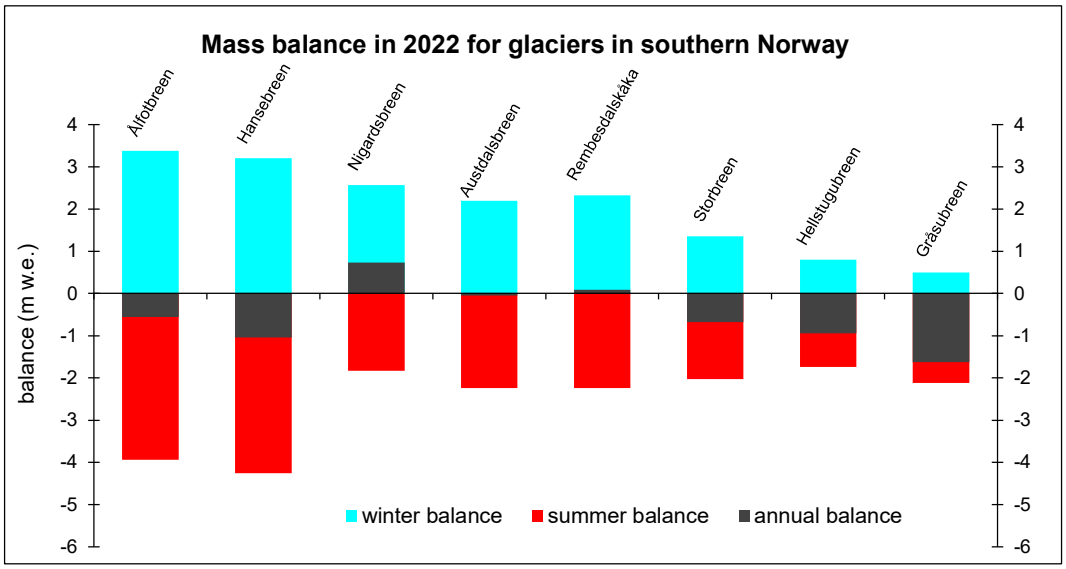


Figure 1-5
Mass balance in 2022 in southern Norway. The glaciers are listed from west to east.

The cumulative annual balance for the six long-term glaciers (measured for 60 consecutive years or more) in southern Norway for the period 1963-2022 is shown in Figure 1-6. 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. Nigardsbreen is the only glacier with a mass surplus over the period 1963-2022.

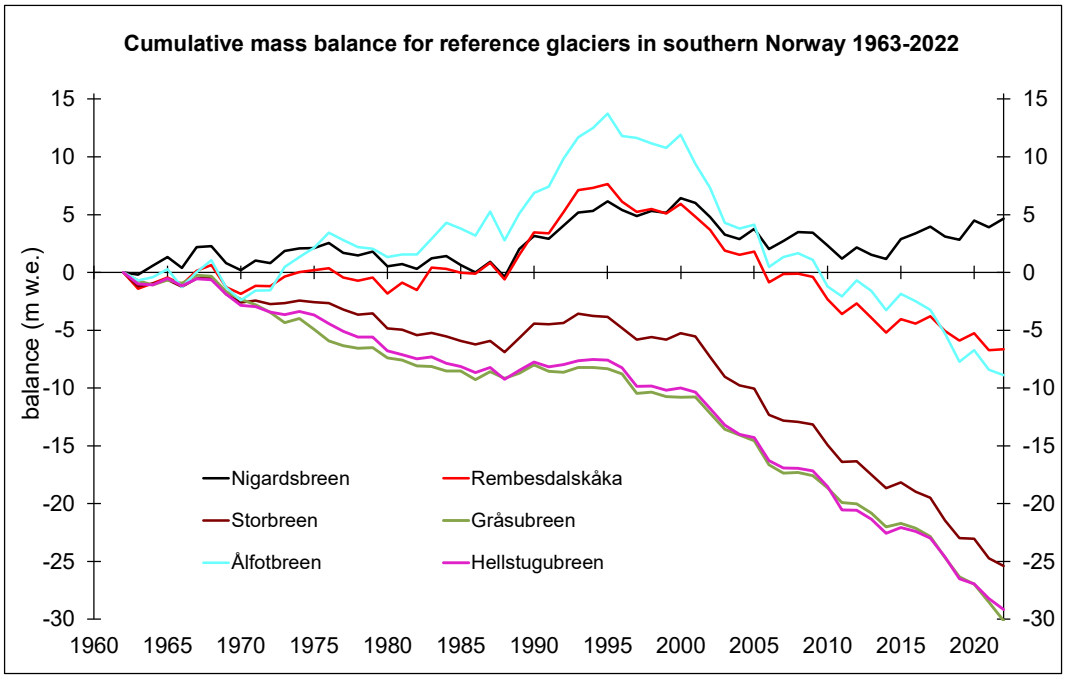


Figure 1-6
Cumulative mass balance for the six long-term glaciers in southern Norway, Ålfotbreen, Nigardsbreen, Rembesdalskåka, Storbreen, Hellstugubreen and Gråsubreen, for the period 1963-2022.

1.2 Other investigations

Glacier length change measurements were performed at 34 glaciers in Norway in 2022. Some of the glaciers have a measurement series going back to about 1900. The length changes are summarised in chapter 12.

Glacier dynamics (surface velocity) has been studied at Austdalsbreen since 1987 (chap. 4). The measurements continued in 2022.

Meteorological observations were performed at Engabreen (chap. 10) and Langfjordjøkelen (chap. 11).

Some jøkulhlaups (glacier floods) have occurred in 2022 and these are described in chapter 13.

Sixty years of glacier measurements in NVE were celebrated in November 2022. The anniversary is presented in chapter 14.

2. Ålfotbreen (Bjarne Kjøllmoen)

The Ålfotbreen ice cap (61°45′N, 5°40′E) has an area of 10.6 km^2 (2010) and is one of the westernmost and most maritime glaciers in Norway. Mass balance studies are performed on two adjacent north-facing outlet glaciers, Ålfotbreen (3.5 km^2, 2019) and Hansebreen (2.5 km^2, 2019) (Fig. 2-1). The westernmost of these two has been the subject of mass balance investigations since 1963 and has always been reported as Ålfotbreen. The adjacent glacier east of Ålfotbreen has been given the name Hansebreen and has been measured since 1986. None of the outlet glaciers of the ice cap are named on the official maps.

Figure 2-1
Ålfotbreen (right) and Hansebreen (left) photographed on 23rd August 2022. Photo: Bjarne Kjøllmoen.

2.1 Mass balance 2022

Fieldwork

Snow accumulation measurements were performed on 21st April. The calculation of winter balance was based on 52 and 45 snow depth soundings on Ålfotbreen and Hansebreen, respectively, and on measurement of stakes in three different positions on Ålfotbreen and three different positions on Hansebreen (Fig. 2-2). Comparison of stake readings and snow soundings indicated no significant melting after the ablation measurements in November 2021. The sounding conditions were good over the whole glacier and the summer surface could easily be detected. Generally, the snow depth varied between 6 and 8 m on Ålfotbreen, and between 5 and 8 m on Hansebreen. Snow density was measured in one location (pos. 28, 1224 m a.s.l.), assumed to be representative for both glaciers. The mean snow density of the whole snow pack of 7.7 m was 491 kg m^{-3}. The measured mean snow density for the twenty- year period 2002-2021 was 520 kg m^{-3}.

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

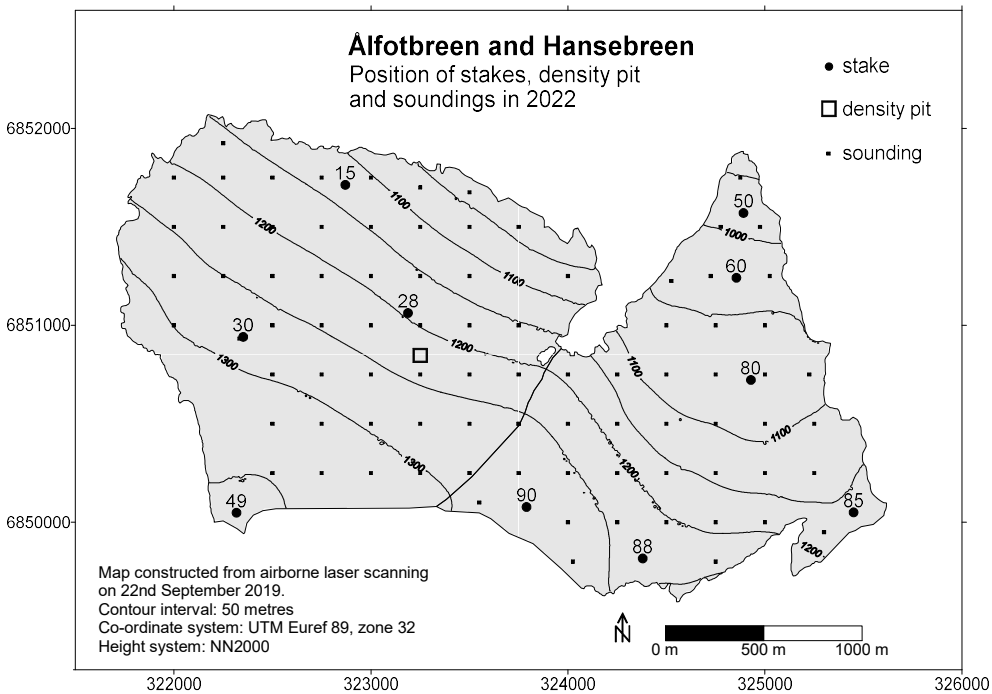


Figure 2-2
Location of stakes, soundings and snow pit on Ålfotbreen (left) and Hansebreen (right) in 2022.

Ablation was measured on 19th October. The annual balance was measured at stakes in four positions on Ålfotbreen and six positions on Hansebreen (Fig. 2-2). At the time of the ablation measurements between 15 and 90 cm fresh snow had fallen.

Results

The calculations are based on the DTM from 2019.

All height intervals are represented with point measurements (bw) for both glaciers. However, measurements below 1000 m a.s.l. on Hansebreen and 1050 m a.s.l. on Ålfotbreen are sparse.

The winter balance was calculated as a mean value for each 50-m height interval and was 3.4 ±0.2 m w.e. on Ålfotbreen, which is 93 % of the mean winter balance for the reference period 1991-2020. The winter balance on Hansebreen was calculated as 3.2 ±0.2 m w.e., which is also 93 % of the mean winter balance for the reference period 1991-2020. Spatial distribution of the winter balance on Ålfotbreen and Hansebreen is shown in Figure 2-3.

The density of melted firn was assumed to be 700 kg m^{-3}, and the density of melted ice was set as 900 kg m^{-3}. The summer balance for Ålfotbreen was calculated at stakes at four different altitudes, but there were no stake measurements below 1127 m a.s.l. Thus, stake values from the two lowest stakes on Hansebreen (○) were used to support the assessment of the summer balance curve in the lowermost part of Ålfotbreen (Fig. 2-4).

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 −3.9 ±0.3 m w.e. on Ålfotbreen, which is 97 % of the reference period. The summer balance on Hansebreen

was −4.2 ±0.3 m w.e., which is 103 % of the mean summer balance for the reference period 1991-2020.

Hence, the annual balance was negative for both glaciers. Ålfotbreen had a deficit of −0.6 ±0.4 m w.e. The mean annual balance for the reference period 1991-2020 is −0.42 m w.e.

The annual balance on Hansebreen was −1.0 ±0.4 m w.e. The mean value for the reference period 1991-2020 is −0.66 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.

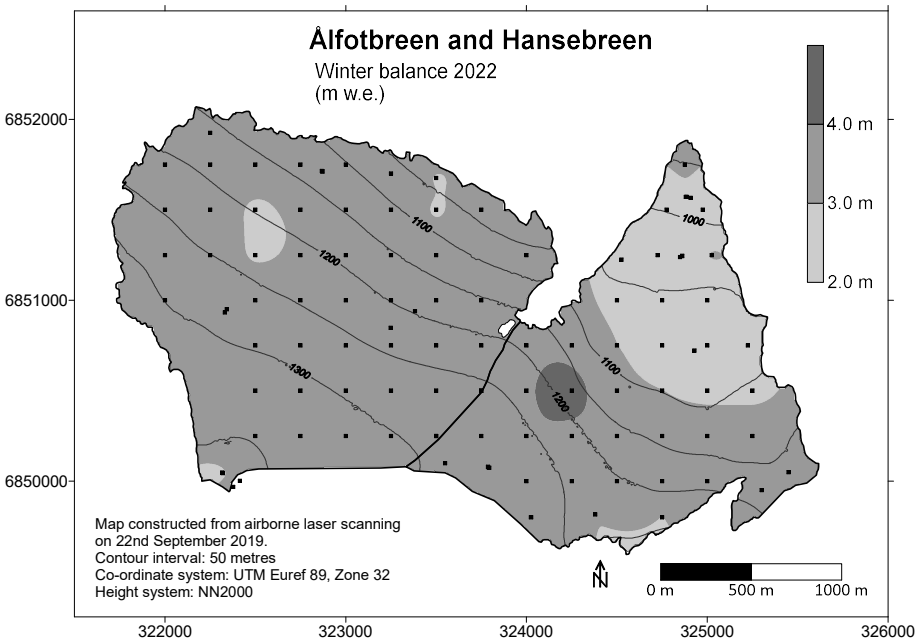


Figure 2-3
Spatial distribution of the winter balance on Ålfotbreen (left) and Hansebreen (right) in 2022.

According to Figure 2-4 the ELA lies 1340 m a.s.l. on Ålfotbreen and above the highest point on Hansebreen. Consequently, the AAR is 7 % on Ålfotbreen and 0 % on Hansebreen.

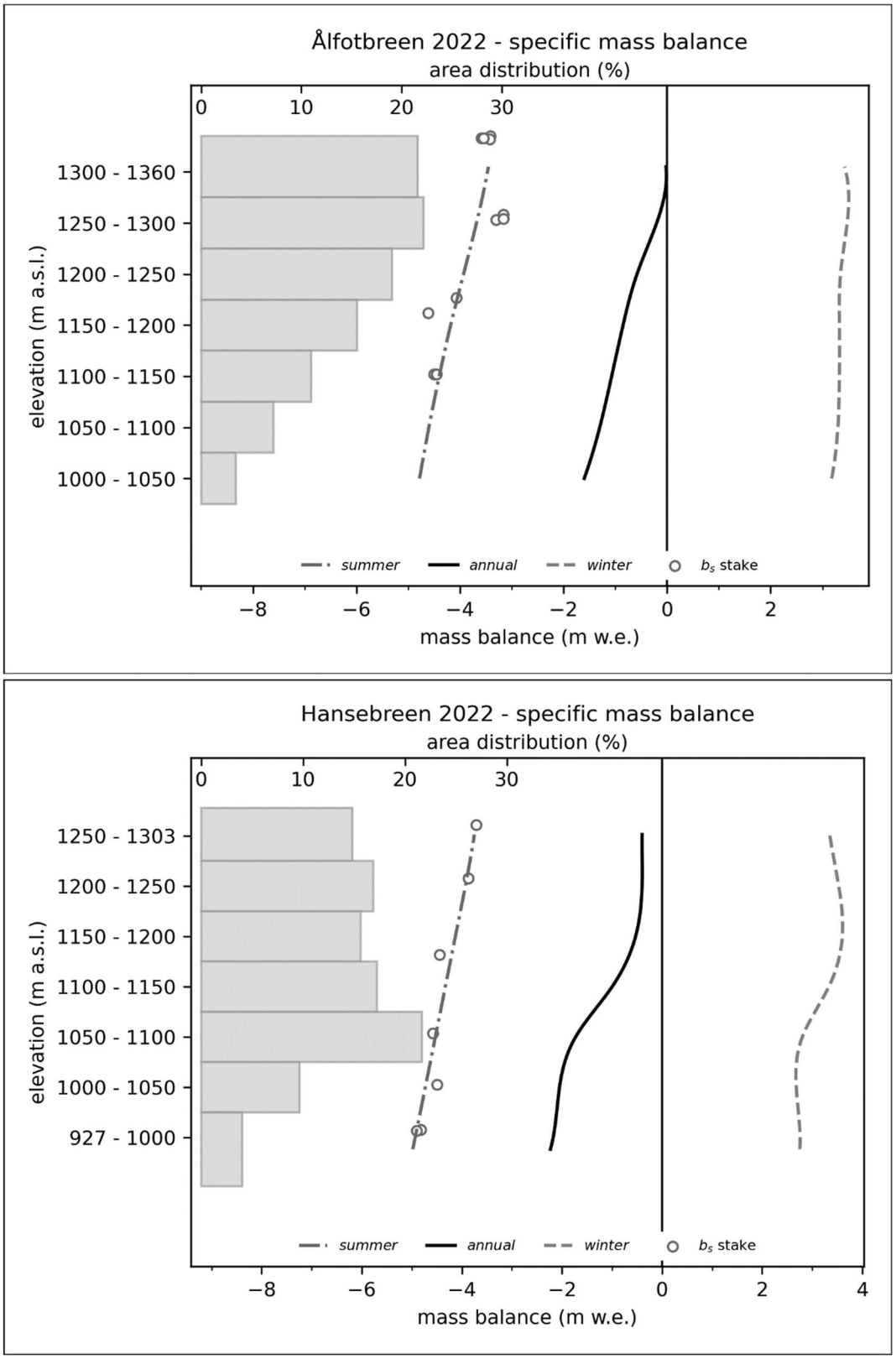


Figure 2-4
Mass balance diagram for Ålfotbreen (upper) and Hansebreen (lower) in 2022 showing altitudinal distribution of specific winter, summer and annual balance. Specific summer balance at each stake is shown (○).

Table 2-1
Winter, summer and annual balance for Ålfotbreen (upper) and Hansebreen (lower) in 2022.

Mass balance Ålfotbreen 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 21 Apr (m w.e.)	Summer balance Measured 19 Oct (m w.e.)	Annual balance S.S. 2021-2022 (m w.e.)
1300 - 1360	0.901	3.425	-3.450	-0.025
1250 - 1300	0.782	3.475	-3.675	-0.200
1200 - 1250	0.699	3.350	-3.925	-0.575
1150 - 1200	0.577	3.325	-4.175	-0.850
1100 - 1150	0.449	3.325	-4.400	-1.075
1050 - 1100	0.296	3.300	-4.600	-1.300
1000 - 1050	0.183	3.175	-4.775	-1.600
Specific mass balance				
1000-1360	**3.476**	**3.378**	**-3.937**	**-0.559**

Mass balance Hansebreen 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 21 Apr (m w.e.)	Summer balance Measured 19 Oct (m w.e.)	Annual balance S.S. 2021-2022 (m w.e.)
1250 - 1303	0.371	3.350	-3.750	-0.400
1200 - 1250	0.415	3.525	-3.925	-0.400
1150 - 1200	0.389	3.600	-4.125	-0.525
1100 - 1150	0.425	3.325	-4.325	-1.000
1050 - 1100	0.537	2.800	-4.525	-1.725
1000 - 1050	0.243	2.675	-4.725	-2.050
927 - 1000	0.101	2.750	-4.975	-2.225
Specific balance				
927-1303	**2.481**	**3.205**	**-4.250**	**-1.045**

2.2 Mass balance 1963(86)-2022

The mass balance was negative on both glaciers in 2022. The historical mass balance results for Ålfotbreen and Hansebreen are presented in Figure 2-5. The cumulative annual balance for Ålfotbreen for 1963-2022 is −8.0 m w.e., which gives a mean annual balance of −0.13 m w.e. a^{-1}. Over the last ten years (2013-2022), the mean annual balance was −0.78 m w.e. The cumulative annual balance for Hansebreen for 1986-2022 is −24.2 m w.e., which gives a mean annual balance of −0.65 m w.e. a^{-1}. Over the last ten years the mean annual balance was −1.39 m w.e.

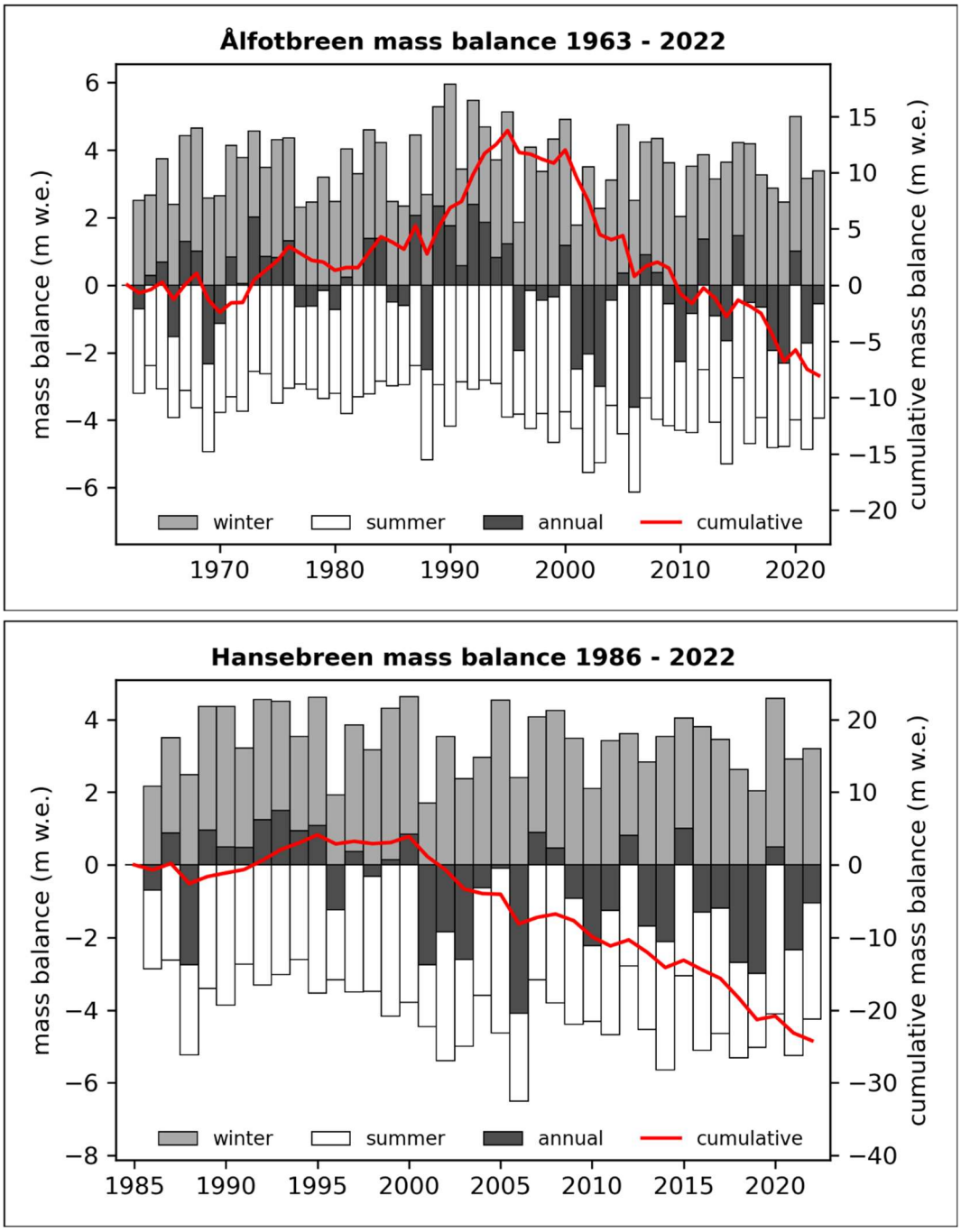


Figure 2-5
Mass balance on Ålfotbreen (upper) 1963-2022 and Hansebreen (lower) 1986-2022. Cumulative mass balance is given on the axis to the right.

3. Nigardsbreen (Bjarne Kjøllmoen)

Nigardsbreen (61°42′N, 7°08′E) is one of the largest and best-known outlet glaciers from Jostedalsbreen (Fig. 3-1). It has an area of 44.9 km^2 (2020) 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 1955 m a.s.l. down to 389 m a.s.l.

Glaciological investigations in 2022 include mass balance and glacier front variations . Nigardsbreen has been the subject of mass balance investigations since 1962.

Figure 3-1
The lower part of Nigardsbreen photographed on 30th August 2022. Photo: Jostein Aasen.

3.1 Mass balance 2022

Fieldwork

Snow accumulation was measured on 18th and 19th May and the calculation of winter balance is based on measurements of seven stakes and towers, and 107 snow depth soundings (Fig. 3-2). Comparison of sounded snow depth and stake reading at the lowest stake (583 m a.s.l.) indicated no melting after the ablation measurements in September 2021. The sounding conditions were some difficult with solid ice layers between 4.5 and 5.5 m depth. On the plateau the snow depth varied between 3.6 and 8.1 m with a mean snow depth of 6.2 m. On the glacier tongue, the snow depth was 2.4 m at stake position 1000 (968 m a.s.l.) and 0.9 m at stake position 600 (583 m a.s.l.). Snow density was measured at position 94 (1683 m a.s.l.), and the mean density of 6.2 m snow was 454 kg m^{-3}.

Ablation was measured on 14th September. Measurements were made at stakes and towers in ten locations (Fig. 3-2). In the accumulation area there was up to 3.4 m of snow remaining from winter 2021/22. At the time of measurement, up to 40 cm of fresh snow had fallen.

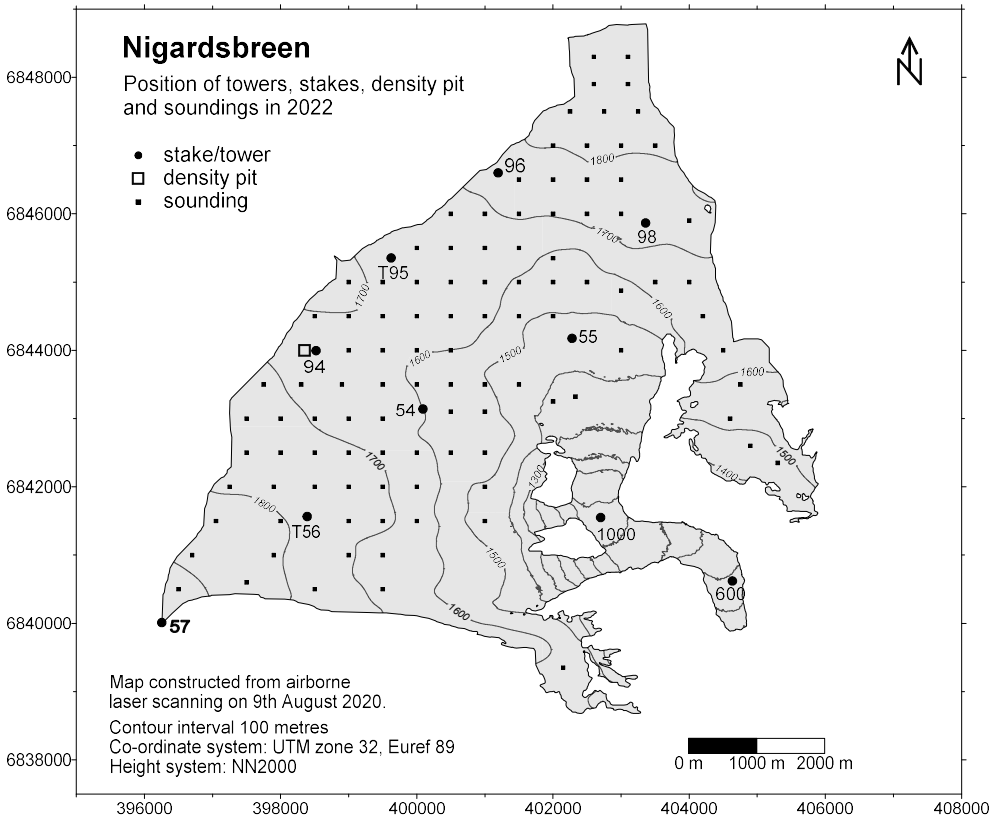


Figure 3-2
Location of towers, stakes, snow pit and soundings on Nigardsbreen in 2022.

Results

The calculations are based on the DTM from 2020.

The elevations above 1450 m a.s.l., which cover about 83 % of the catchment area, were well-represented with point measurements. Below this altitude the curve pattern was based on point measurements at 968 and 583 m elevation.

The winter balance was calculated as a mean value for each 100 m height interval and was 2.6 ±0.2 m w.e., which is 114 % of the mean winter balance for the reference period 1991-2020. Spatial distribution of the winter balance is shown in Figure 3-3.

The density of remaining snow was assumed to be 600 kg m^{-3}. The density of the firn and ice before melting was assumed to be 800 kg m^{-3} and 900 kg m^{-3}, respectively. Based on the estimated density and stake measurements the summer balance was also calculated as a mean value for each 100 m height interval and was −1.8 ±0.3 m w.e., which is 78 % of the reference period.

Hence, the annual balance was positive, at 0.78 m ±0.40 m w.e. The mean annual balance for the reference period 1991-2020 is −0.05 m w.e.

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.

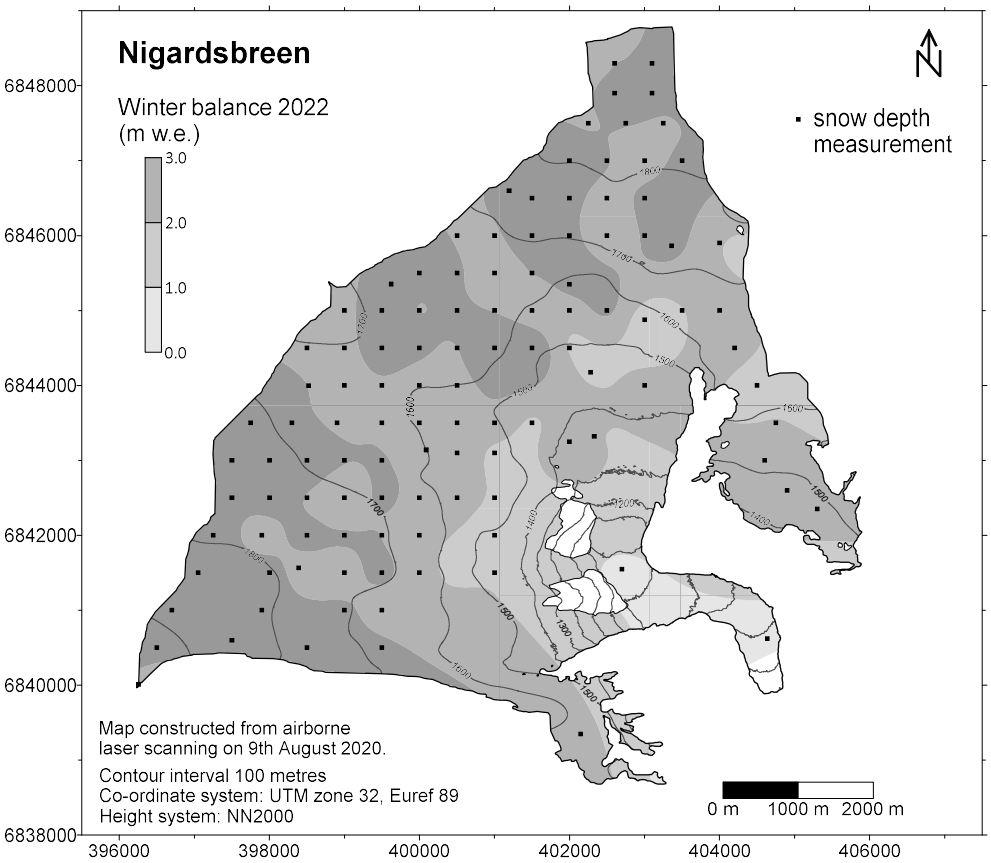


Figure 3-3
Spatial distribution of winter balance on Nigardsbreen in 2022.

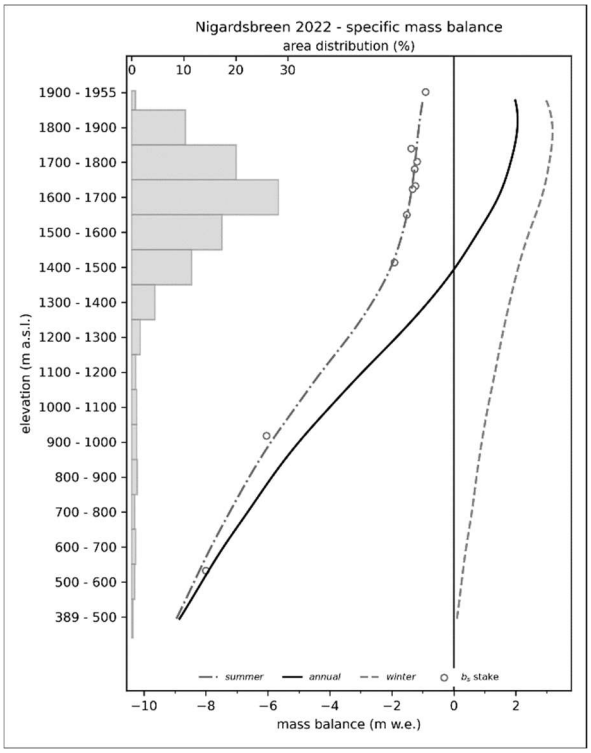


Figure 3-4
Mass balance diagram showing specific balance for Nigardsbreen in 2022. Specific summer balance at 10 different stake positions is shown as circles (○).

According to Figure 3-4, the equilibrium line altitude was 1440 m a.s.l. Consequently, the accumulation area ratio was 84 %.

Table 3-1
The altitudinal distribution of winter, summer and annual balance in 100-m intervals for Nigardsbreen in 2022.

Mass balance Nigardsbreen 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 18 May (m w.e.)	Summer balance Measured 20 Sep (m w.e.)	Annual balance S.S. 2021-2022 (m w.e.)
1900 - 1955	0.310	2.975	-1.000	1.98
1800 - 1900	4.056	3.175	-1.125	2.05
1700 - 1800	9.194	3.075	-1.250	1.83
1600 - 1700	12.738	2.825	-1.400	1.43
1500 - 1600	8.938	2.425	-1.650	0.78
1400 - 1500	5.921	2.075	-2.025	0.05
1300 - 1400	2.082	1.800	-2.625	-0.83
1200 - 1300	0.787	1.550	-3.400	-1.85
1100 - 1200	0.390	1.325	-4.275	-2.95
1000 - 1100	0.580	1.100	-5.100	-4.00
900 - 1000	0.456	0.900	-5.900	-5.00
800 - 900	0.471	0.725	-6.600	-5.88
700 - 800	0.321	0.575	-7.225	-6.65
600 - 700	0.405	0.400	-7.825	-7.43
500 - 600	0.261	0.250	-8.375	-8.13
389 - 500	0.157	0.100	-8.950	-8.85
Specific mass balance				
389-1955	**44.945**	**2.570**	**-1.834**	**0.736**

3.2 Mass balance 1962-2022

The historical mass balance results for Nigardsbreen 1962-2022 are presented in Figure 3-5. The cumulative annual balance for 1962-2022 is +4.3 m w.e., which gives a mean annual balance of +0.07 m w.e. a^{-1}. Over the past ten years (2013-2022), the mean annual balance was −0.016 m w.e.

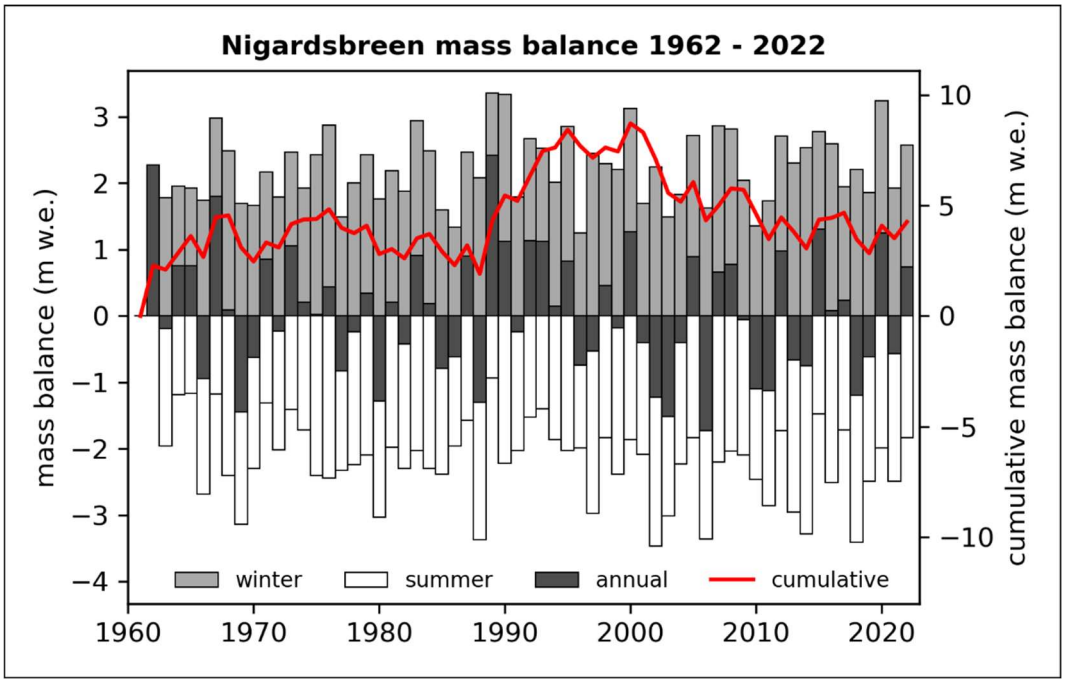


Figure 3-5
Winter, summer and annual balance on Nigardsbreen for 1962-2022. Cumulative mass balance is given on the right axis.

4. 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 1740 m a.s.l. The glacier terminates in Austdalsvatnet, which has been part of the hydropower reservoir Styggevatnet since 1988. Glaciological investigations on Austdalsbreen started in 1986 in connection with the construction of the hydropower reservoir. The glaciological investigations in 2022 included mass balance, front position change and glacier velocity. The mass balance has been measured on Austdalsbreen since 1988.

Figure 4-1
Austdalsbreen on 30th august 2022. The lake level was 1185 m a.s.l., 15 meters below the highest regulated lake level at 1200 m a.s.l. Photo: Jostein Aasen.

4.1 Mass balance 2022

Fieldwork

Stakes were maintained through the winter in five stake locations. Snow accumulation measurements were performed on 26th April. The calculation of the winter balance was based on measurements in seven stake locations and 41 snow depth sounding locations (Fig. 4-4). Detecting the summer surface was easy. The snow depth varied between 3 and 6 meters, and the average snow depth was 4.7 meters. The mean density of the snowpack down to the summer surface at 4.8 m depth at stake A60 (1480 m a.s.l.) was 450 kg m^{-3}.

The stake network was checked on 30th August. Stake A11 had fallen into a crevasse and was replaced. Between 3.8 and 5.0 meters of snow, firn and ice had melted since 26th April. Winter snow remained in the stake locations above 1400 m a.s.l.

Summer and annual balance measurements were carried out on 20th September. Stakes were found in all the seven stake locations. Between 4.0 and 5.5 meters of snow and ice had melted during the summer. The temporary snow line was not identifiable due to up to 25 cm of new snow, but stake measurements indicate a snow line altitude around

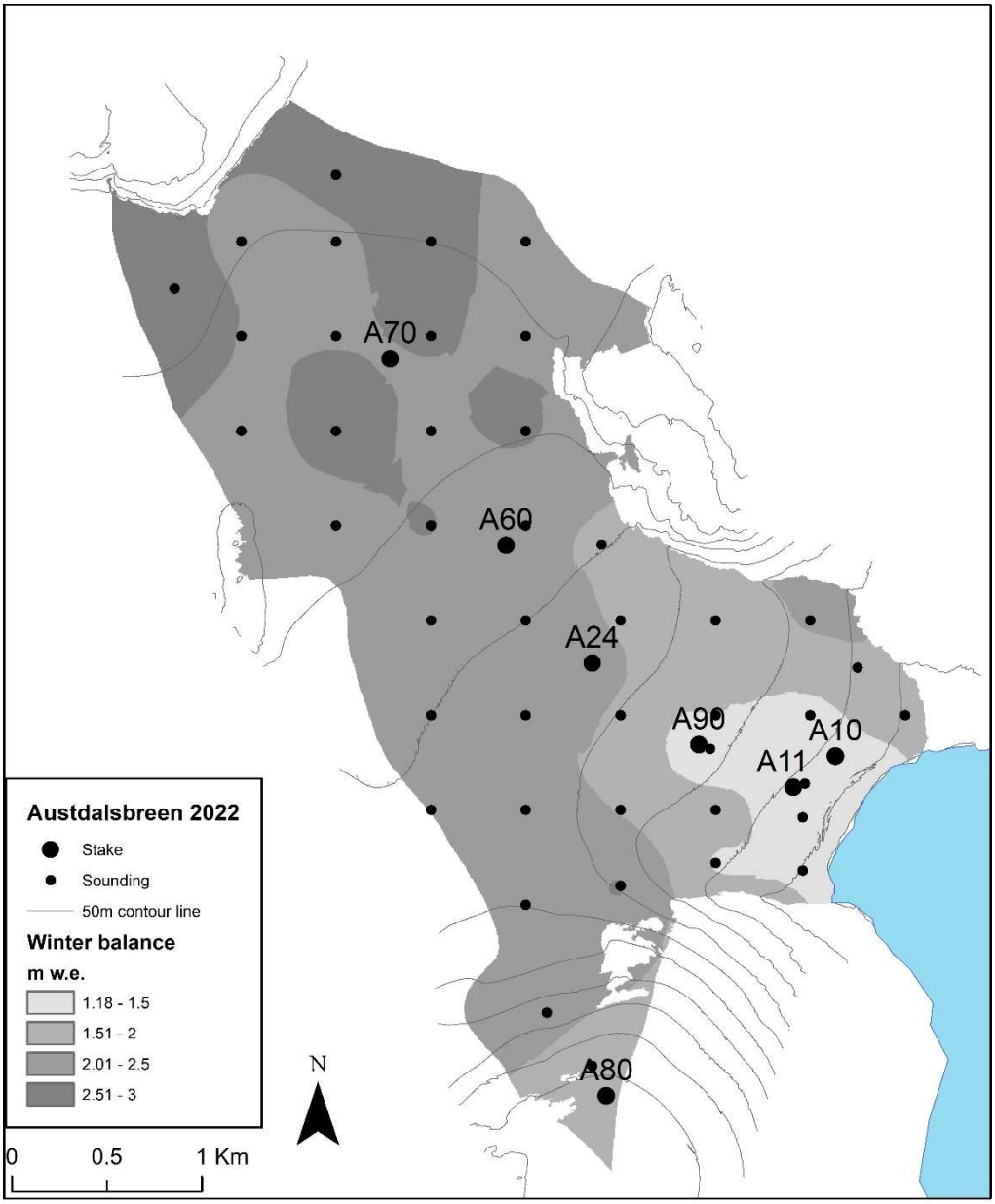


Figure 4-2
Location of stakes and snow depth soundings, and winter balance for Austdalsbreen in 2022 interpolated from 48 water equivalent values calculated from snow depth measurements.

1400 m a.s.l. close to A24. At stake A80 (1715 m a.s.l.) on top of Austdalsnuten all the winter snow had melted.

The stakes were re-measured and snow depth sounded on 2nd January 2023 showing about 0.2 meters of additional melt after 20th September in stake locations A10, A11 and A90 below 1400 m a.s.l.

Results

The calculations are based on a DTM from 27th August 2019. The winter balance was calculated from snow depth and snow density measurements on 26th April. A function correlating snow depth with water equivalent values was calculated based on snow density measurements at stake A60 (1480 m a.s.l.). Point winter balance values were

calculated from the snow depth measurements using the water equivalent value function. Averages for 50-metre elevation intervals were calculated and plotted against altitude. The winter balance curve was then adjusted to the averages and interpolated where necessary (Fig. 4-3). The total winter balance was 22 ±2 mill. m^3 water or 2.2 ±0.2 m w.e., which is 104 % of the 1991-2020 average (2.11 m w.e.). In addition, the spatial distribution of the winter balance was interpolated from the point measurements using the Kriging method. The mean distributed winter balance was 2.20 m w.e (Fig. 4-2).

The summer balance was calculated for six stake locations between 1280 and 1715 m a.s.l. The density of the remaining winter snow and melted ice was set as 600 and 900 kg/m^3, respectively. The summer balance curve was drawn from these six point values (Fig. 4-3).

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 (chapter 4.2 and 4.3). The calving 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 (30 ±10 m a^{-1}), u_f is front position change averaged across the terminus (+14 ±5 m a^{-1}), W is terminus width (865 ±20 m) and H is mean ice thickness at the terminus (42 ±5 m). The width of the calving terminus was defined from an orthophoto from 27th August 2019. The mean ice thickness was calculated from the mean surface elevation along the calving terminus on 25th September 2019 calculated from the DTM from 27th August 2019, and mean bottom elevation along the terminis calculated from a bathymetry map (Kjøllmoen and others, 2020). The resulting calving volume was 0.5 ±0.8 mill. m^3 water equivalent. The summer balance including calving was calculated as −23 ±3 mill. m^3 of water, and corresponds to −2.2 ±0.3 m w.e. The result is 83 % of the 1991-2021 average (−2.70 m w.e.). The calving volume was 2 % of the summer balance.

The annual balance on Austdalsbreen was calculated as −0 ±3 mill. m^3 water, corresponding to −0.0 ±0.3 m w.e. The average annual balance for the period 1991-2020 is −0.60 m w.e. The ELA in 2022 was 1425 m a.s.l., and the AAR was 69 %. The altitudinal distribution of winter, summer and annual balance is shown in Table 4-1 and Figure 4-3. Results from 1988-2022 are shown in Figure 4-4.

Table 4-1
Altitudinal distribution of specific winter, summer, and annual balances for Austdalsbreen in 2022.

Mass balance Austdalsbreen 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 26.04.2022 (m w.e.)	Summer balance Measured 20.09.2022 (m w.e.)	Annual balance Summer surface 2021 – 2022 (m w.e.)
1700 - 1740	0.090	1.85	-1.75	0.10
1650 - 1700	0.119	2.10	-1.75	0.35
1600 - 1650	0.172	2.40	-1.80	0.60
1550 - 1600	1.584	2.50	-1.80	0.70
1500 - 1550	2.748	2.50	-1.80	0.70
1450 - 1500	1.503	2.30	-1.85	0.45
1400 - 1450	1.594	2.10	-2.10	0.00
1350 - 1400	0.952	1.70	-2.80	-1.10
1300 - 1350	0.721	1.65	-3.30	-1.65
1250 - 1300	0.457	1.50	-3.80	-2.30
1200 - 1250	0.182	1.50	-4.30	-2.80
Calving			-0.514 mill m³	-0.514 mill m³
Specific mass balance including calving				
1200 - 1740	**10.122**	**2.196**	**-2.241**	**-0.045**

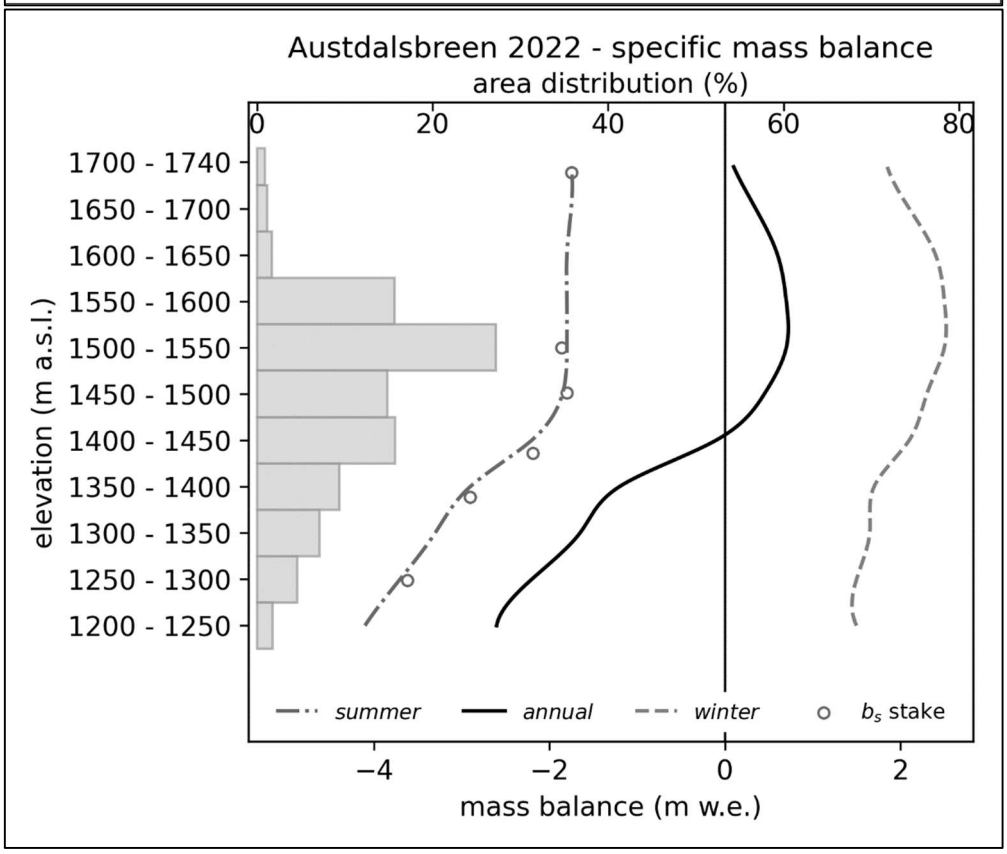


Figure 4-3
Hypsometric areal distribution (grey bars) and altitudinal distribution of specific winter, summer, and annual balance on Austdalsbreen in 2022. Specific summer balance in six stake locations is shown.

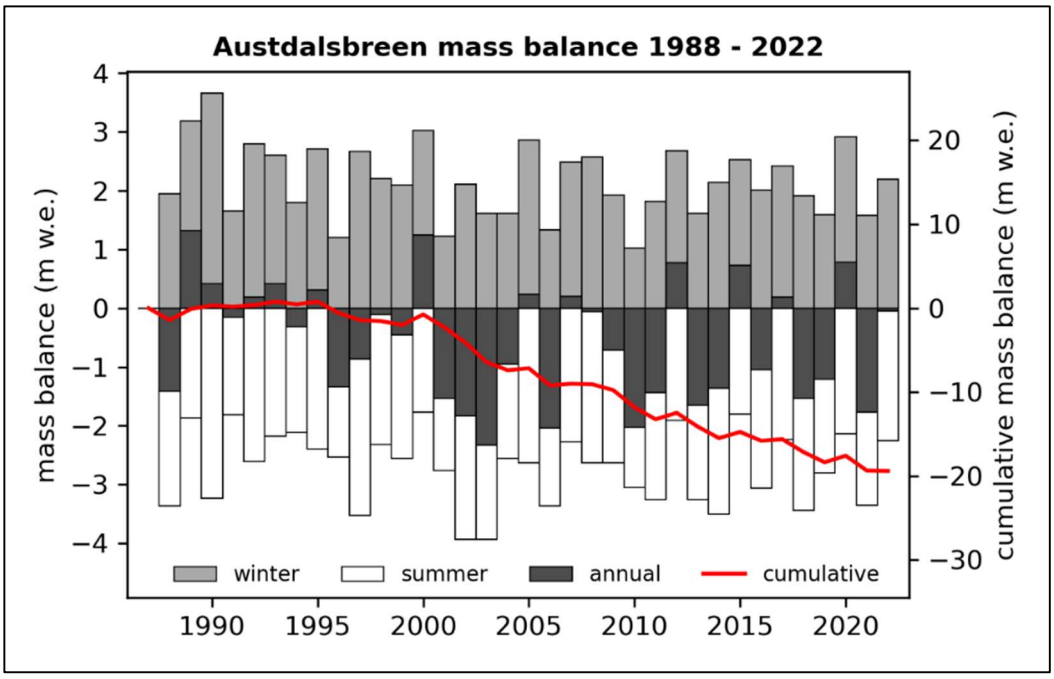


Figure 4-4
Winter, summer, annual and cumulative balance on Austdalsbreen during the period 1988-2022. Mean winter and summer balance is 2.16 and −2.72 m w.e., respectively. The cumulative mass balance is −19.5 m w.e.

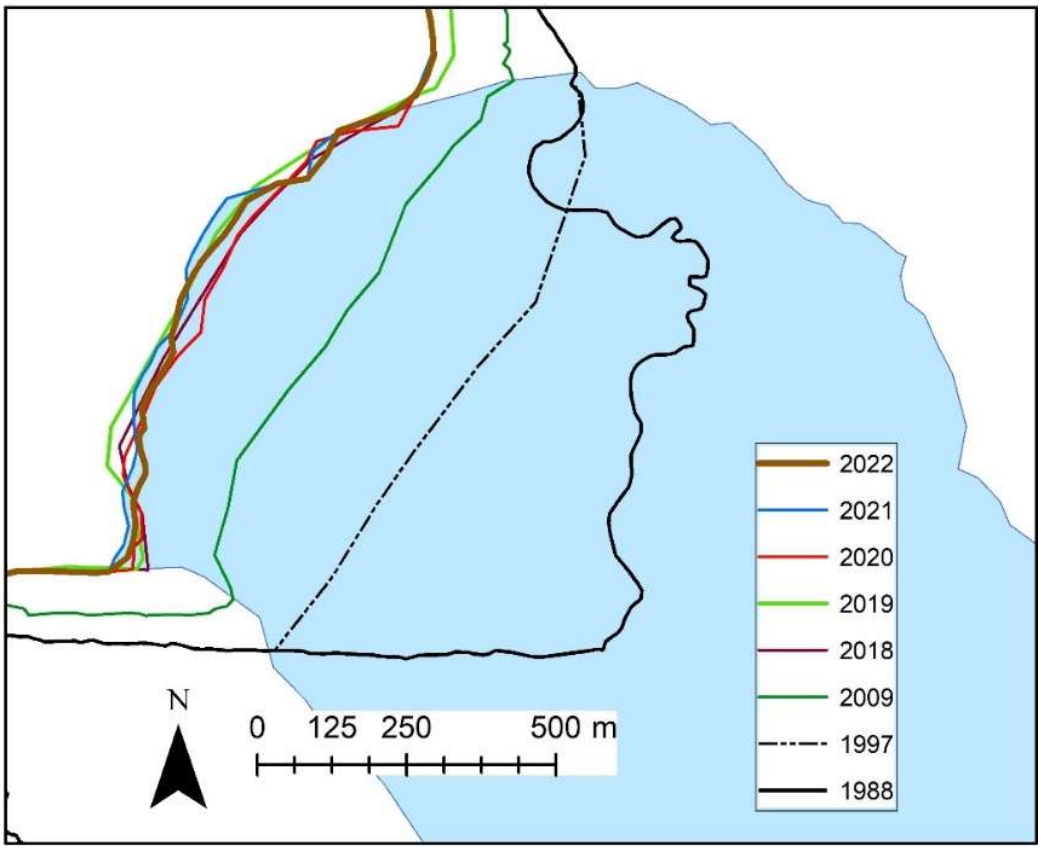


Figure 4-5
Surveyed front positions of Austdalsbreen in 1988 when the lake was regulated, and in 1997, 2009, 2019, 2020, 2021 and 2022. After 2018 the terminus changes are minor. Between 28th October 2021 and 20th September 2022, the glacier terminus advanced 14 meters on average.

4.2 Front position change

Sentinel-2 satellite images from 10th September and 2nd October (www.xgeo.no) were used to determine the terminus position in the lake. The average front position change was +14 ±5 m between 28th October 2021 and 20th September 2022 (Fig. 4-5). The glacier terminus has retreated 670 m since 1988, and the lake area has increased by 0.684 km^2.

4.3 Glacier dynamics

Glacier velocities are calculated from repeated surveys of stakes. The stake network was surveyed on 27th August 2021, and on 26th April, 30th August and 20th September 2022. Annual velocities were calculated for five stake locations between 1280 and 1525 m a.s.l. for the period 27th August 2021 – 30th August 2022 (368 days). The annual results are comparable to results from 2011-15 (Kjøllmoen and others, 2016).

The glacier velocity averaged across the front width and thickness was estimated to calculate the calving volume. We assume the average of A10 and A11 is representative for the centre line surface velocity. The annual velocity at stake A10 was 39 m a^{-1}. As stake A11 fell into a crevasse in August, the stake velocity between 26th April and 30th August was assessed from the measured relation between the two stakes in earlier periods. Hence, the velocity for stake A11 was set as 47 m a^{-1}. The glacier velocity averaged over the cross-section is calculated as 70 % of the centre line surface velocity based on earlier measurements and estimates of the amount of glacier sliding at the bed. The resulting velocity averaged across the terminus for 2021/2022 is 30 ±10 m a^{-1}.

Figure 4-6
Stake A90 (1360 m a.s.l.) on 30th August 2022. The stake position is surveyed using a GNSS-receiver placed on the ice about 1 meter upglacier from the stake. The actual distance and direction from the antenna to the stake is measured. Photo: Jostein Aasen.

5. 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. Rembesdalskåka is situated on the main water divide between Hardangerfjorden and Hallingdalen valley and drains towards Simadalen valley and Hardangerfjorden. In the past Simadalen was flooded by jøkulhlaups from the glacier-dammed lake Demmevatnet. Since 2014 several jøkulhlaups have occurred, but they have been captured by the Rembesdalsvatnet reservoir, thus causing no damage. The most recent one occurred on 29th-30th August 2022 (Fig 5-1 and Sec. 13).

Mass balance measurements were initiated on Rembesdalskåka in 1963 by Norwegian Polar Institute. Norwegian Water Resources and Energy Directorate (NVE) has been responsible for the mass balance investigations commissioned by Statkraft AS since 1985. The investigated basin covers the altitudinal range between 1085 and 1851 m a.s.l. as mapped in 2020.

Figure 5-1
On 24th June 2022 the glacier dammed lake Demmevatnet had filled up again after a jøkulhlaup (GLOF) on 13th July 2021. The glacier dammed lake contains about 2 mill. m^3 of water and drains in 4 – 12 hours.
Photo: Hallgeir Elvehøy.

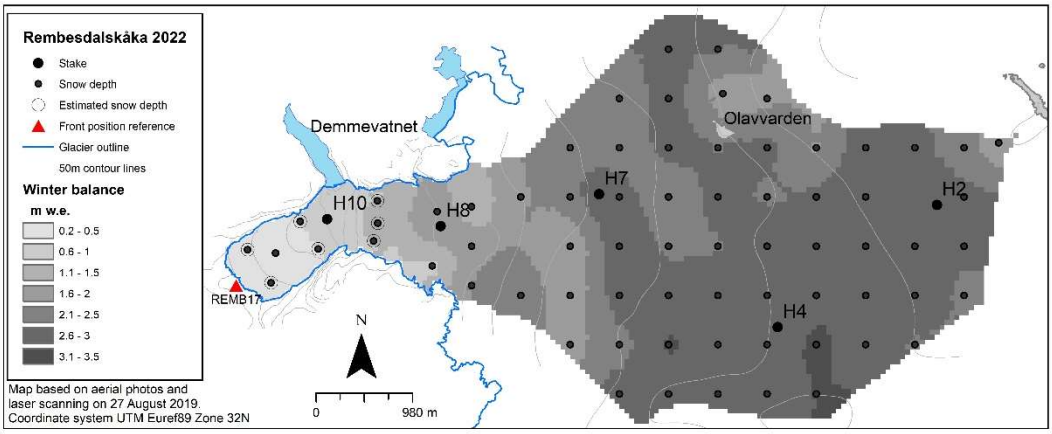


Figure 5-2
Location of stakes and snow depth soundings on Rembesdalskåka in 2022. The winter balance distribution is interpolated from water equivalent values calculated for five stake measurements of snow depth, 62 snow depth soundings and seven estimated point values on the glacier tongue and in the ice fall.

5.1 Mass balance 2022

Fieldwork

Stakes in locations H2 and H4 were maintained through the winter. The snow accumulation was measured on 24th June. Snow depth was measured in 62 sounding locations in a 500 by 500 m grid on the glacier plateau above 1500 m a.s.l. (Fig. 5-2). The average snow depth on the plateau was 4.0 meters and varied between 3 and 5 meters. The summer surface (S.S.) was well defined. The mean snow density down to 4.6 meters depth at stake H7 was 599 kg m^{-3}. The snow depth to the summer surface was 4.8 m.

Summer and annual balances were measured on 20th October. There were up to 1.35 m of new snow at the stake locations. At stake H10 1250 m a.s.l. all the winter snow and 4 meters of ice had melted. At H8 (1504 m a.s.l.) all the winter snow and 1 to 2 meters of ice had melted. At the stakes above 1600 m a.s.l. 1.0 to 1.5 meters of winter snow remained. Stake measurements and snow depth soundings on 18th January 2023 showed 20 cm of additional ice melt at stake H10 after 20th October.

Results

The calculation of the mass balance is based on a DTM from 2020. The winter balance was calculated from the snow depth and snow density measurements on 24th June. A function correlating snow depth and water equivalent values was calculated based on snow density measurements at location H7 (1655 m a.s.l.). Point winter balance values were calculated from snow depth observations using this function. 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. 5-3). Below 1500 m a.s.l. the winter balance curve was interpolated from the measurements at stakes H8 (1510 m a.s.l.) and H10 (1250 m a.s.l.). A value for each 50 m elevation was then determined from this curve. The resulting winter balance was 2.3 ±0.2 m w.e. corresponding to 40 ±3 mill. m^3 water. This is 111 % of the 1991-2020 average of 2.10 m w.e. a^{-1}.

Based on the snow depth measurements the spatial distribution of the winter balance was interpolated using the kriging method. Seven winter balance points based on the specific winter balance curve were added in the ice fall and on the lower glacier tongue to support the interpolation below 1500 m a.s.l. The distributed winter balance is shown in Figure 5-2, and the mean winter balance was 2.32 m w.e.

The date of the 2022 mass balance minimum on the glacier plateau was assessed from the daily gridded data of temperature and new snow from www.senorge.no. as 12th September above 1500 m a.s.l. On the glacier tongue the melting probably persisted until 15th November, but snow accumulation did not start until early December.

The summer balance was calculated directly at all five stake locations. The density of the remaining winter snow was set as 600 kg m^{-3}, and the density of the ice that melted at H8 and H10 was set as 900 kg m^{-3}. The summer balance curve in Figure 5-3 was drawn from the five point values. The summer balance was calculated as −2.2 ±0.2 m w.e., corresponding to −38 ±3 mill. m^3 of water. This is 93 % of the 1991-2020 average of −2.40 m w.e. a^{-1}. The annual balance on Rembesdalskåka was calculated as +0.1 ±0.3 m w.e. or +2 ±5 mill. m^3 water. The 1991-2020 average is -0.29 m w.e. a^{-1}. The ELA in 2022 was 1611 m a.s.l., and the corresponding AAR was 83 %. The altitudinal distribution of winter, summer and annual balances is shown in Figure 5-3 and Table 5-1. Results from 1963-2022 are shown in Figure 5-4. The cumulative annual balance is −6.6 m w.e. Since 1995 the glacier has had a mass deficit of −14.3.0 m w.e. or −0.53 m w.e. a^{-1}.

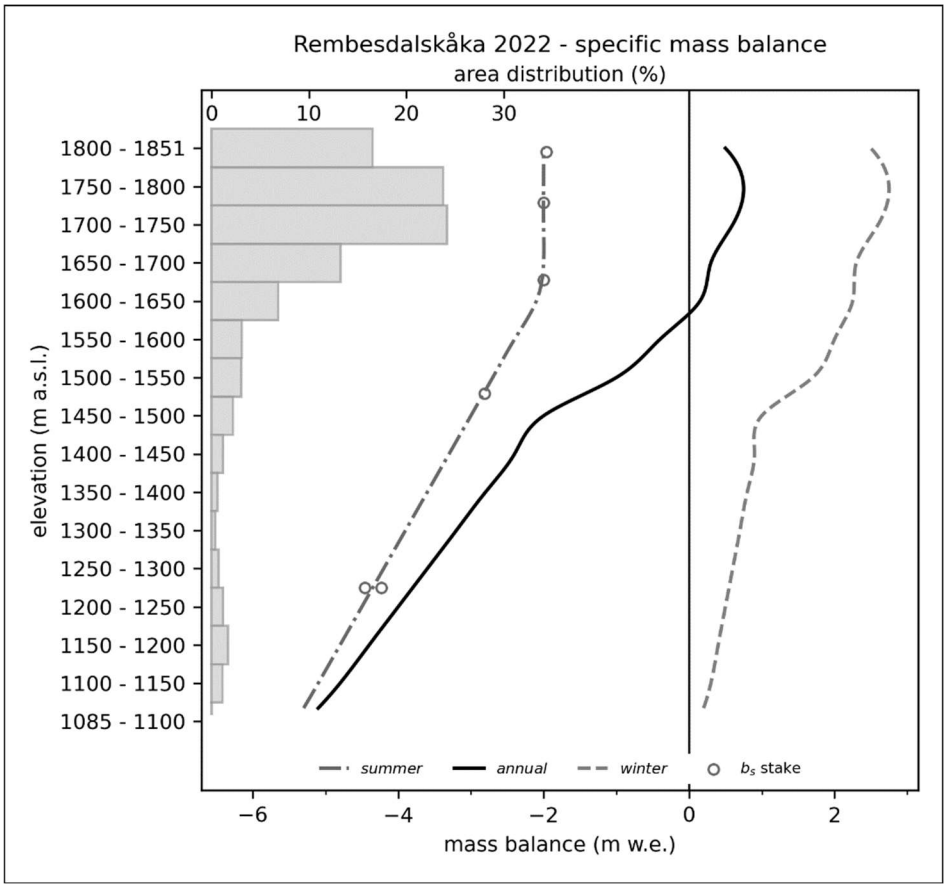


Figure 5-3
Hypsometric areal distribution (grey bars) and altitudinal distribution of specific winter, summer, and annual mass balance in 2022. Specific summer balance, b_s, in five stake locations is shown.

Table 5-1
Altitudinal distribution of winter, summer, and annual mass balance on Rembesdalskåka in 2022. All values are in meter water equivalents.

Mass balance Rembesdalskåka 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 24th June 2022 (m w.e.)	Summer balance Measured 20th Oct 2022 (m w.e.)	Annual balance Summer surfaces 2021 - 2022 (m w.e.)
1800 - 1851	2.825	2.50	-2.00	0.50
1750 - 1800	4.059	2.75	-2.00	0.75
1700 - 1750	4.130	2.60	-2.00	0.60
1650 - 1700	2.267	2.30	-2.00	0.30
1600 - 1650	1.167	2.25	-2.10	0.15
1550 - 1600	0.534	2.00	-2.40	-0.40
1500 - 1550	0.523	1.70	-2.70	-1.00
1450 - 1500	0.381	1.00	-3.00	-2.00
1400 - 1450	0.201	0.90	-3.30	-2.40
1350 - 1400	0.107	0.80	-3.60	-2.80
1300 - 1350	0.071	0.70	-3.90	-3.20
1250 - 1300	0.126	0.60	-4.30	-3.70
1200 - 1250	0.202	0.50	-4.70	-4.20
1150 - 1200	0.289	0.40	-5.10	-4.70
1100 - 1150	0.194	0.30	-5.50	-5.20
1085 - 1100	0.010	0.20	-5.80	-5.60
Specific mass balance				
1085 - 1851	**17.086**	**2.330**	**-2.240**	**0.090**

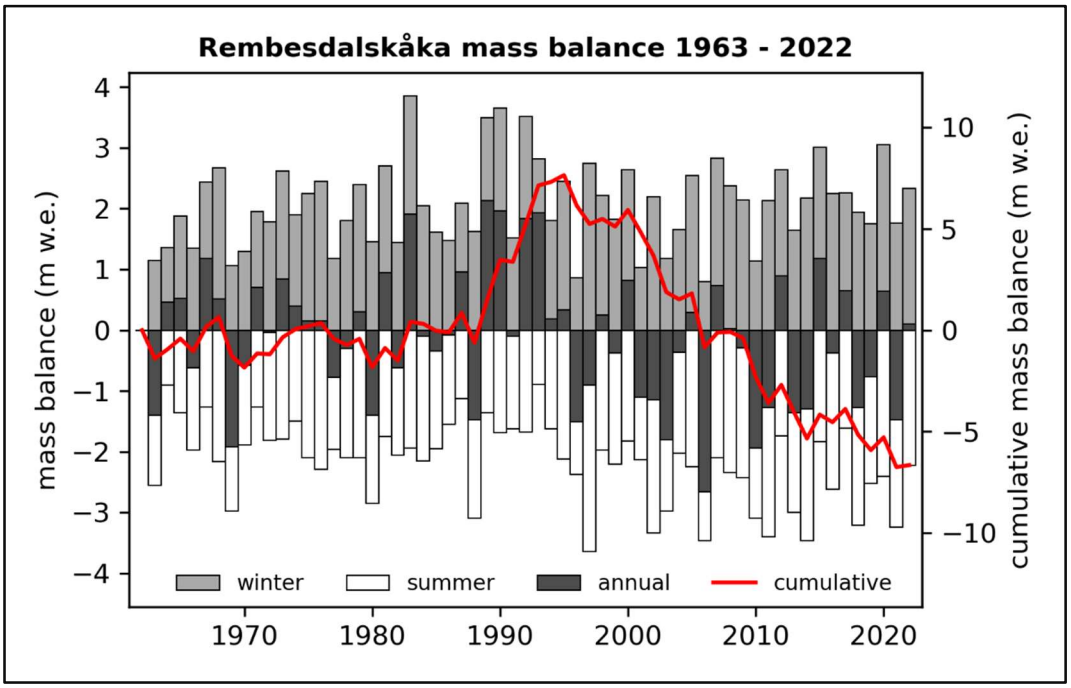


Figure 5-4
Winter, summer, annual and cumulative mass balance on Rembesdalskåka during the period 1963-2022. Mean values (1963-2022) are B_w=2.07 m w.e a^{-1} and B_s=−2.18 m w.e a^{-1}.

6. Storbreen (Liss M. Andreassen)

Storbreen (61°34′N, 8°8′E) (now written as “Storbrean” on official maps) is situated in the Jotunheimen mountain massif in central southern Norway. The glacier has a relatively well-defined border and is surrounded by high peaks (Fig. 6-1). Mass balance has been measured there since 1949 and front position (change in length) has been measured since 1902 (chap. 12.1).

Storbreen has a total area of 4.9 km^2 and ranges in altitude from 1420 to 2091 m a.s.l. (map of 2019, Fig. 6-2). The mass balance for 2022 was calculated based on the DTM and glacier outline from 2019.

Figure 6-1
Lower part of Storbreen on 15th August 2022 with the stream outlet from a small lake that has formed in front of the glacier and drained a few times in recent years. Photo: Liss M. Andreassen.

6.1 Mass balance 2022

Field work

Snow accumulation measurements were performed on 20th April on the lower tongue (stakes 1-3) and on 21st April on the upper part (stakes 4-9) (Fig. 6-2). Stakes were visible in nine positions. A total of 120 snow depth soundings between 1465 and 2000 m a.s.l. were made (Fig. 6-2). The snow depth varied between 1.35 and 4.83 m, the mean and median being 2.84 and 2.74 m respectively. Snow density was measured at stake 4 (1704 m a.s.l.) where the total snow depth was 2.7m. The average snow density measured was 421 kg m^{-3}. Ablation measurements were performed on 29th September at all stake positions (Fig. 6-3). Part of the terminus position was measured on 4th October 2022 by differential GNSS (Fig. 6-2).

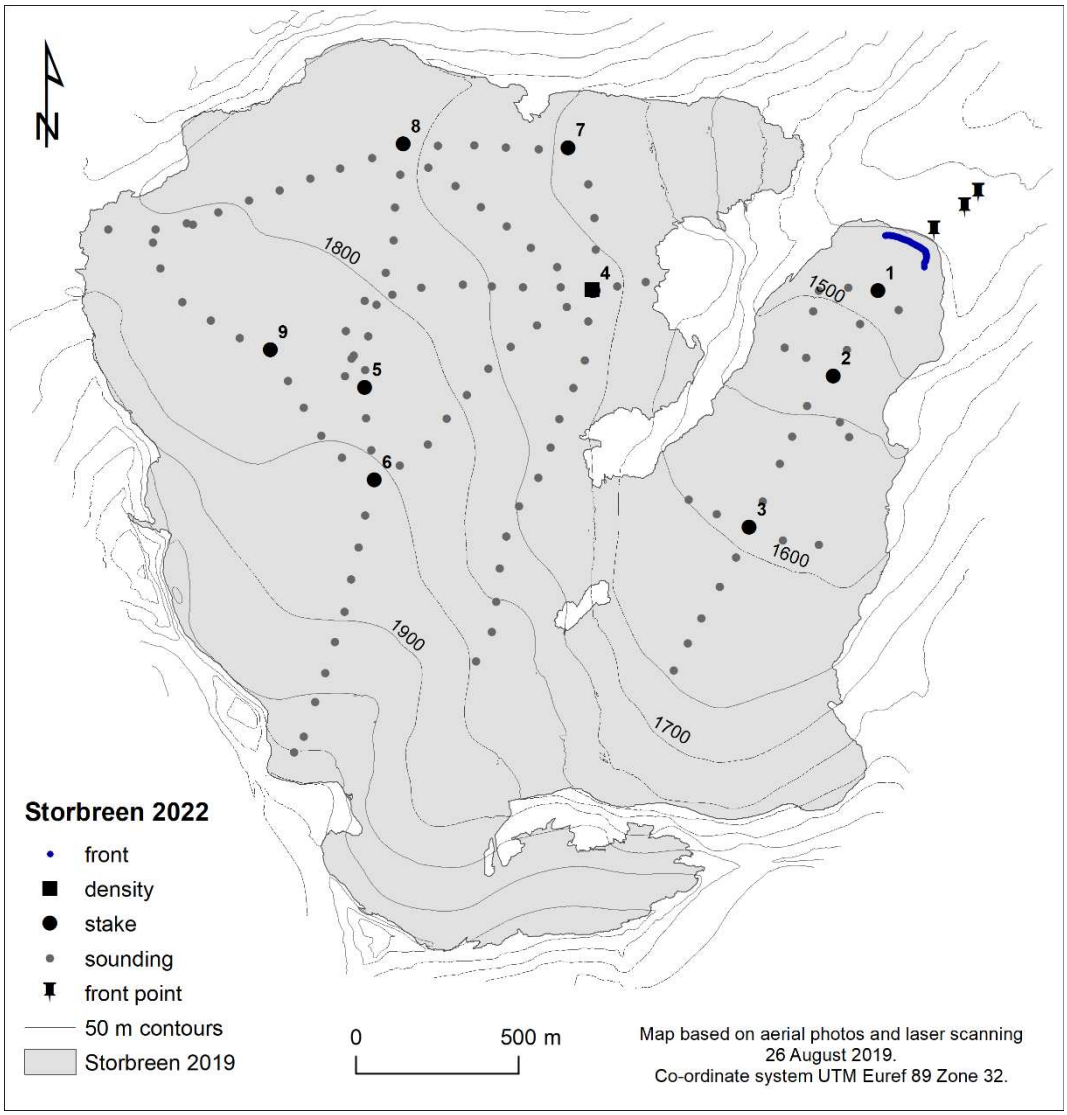


Figure 6-2
Location of stakes, soundings and density pits on Storbreen in 2022. Front: part of terminus measured by GNSS on 4th October. Front point: reference points used for front variation measurements (see chap. 12).

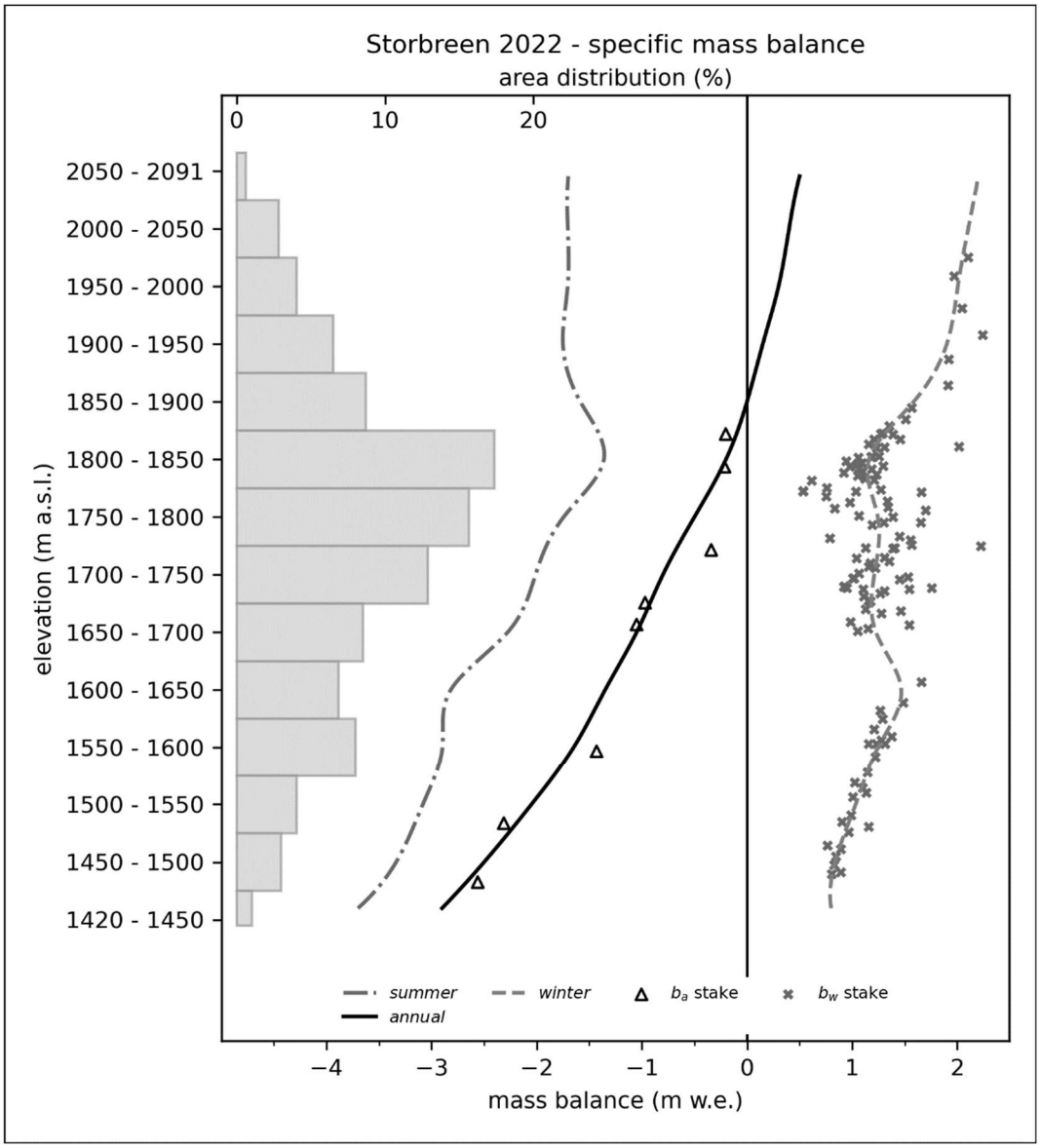
Results

The winter balance was calculated from the mean of the soundings within each 50 m height interval and was 1.35 ±0.2 m w.e., which is 97 % of the mean winter balance for the reference period 1991-2020. Annual balance was calculated directly from stakes at nine locations. The summer balance was interpolated to 50 m height intervals based on the stake readings and was –2.03 ±0.3 m w.e., which is 101 % of the mean summer balance for the reference period 1991-2020. The annual balance of Storbreen was –0.68 ±0.3 m w.e. in 2022. The ELA was above the highest stake in 2022 and is therefore uncertain. The annual balance curve from the annual balance diagram (Fig. 6-3) indicates an ELA of ~1875 m a.s.l. resulting in an estimated accumulation area ratio (AAR) of ~18 %.

The mass balance results are shown in Table 6-1 and the corresponding curves for specific and volume balance are shown in Figure 6-4.

Figure 6-3
A layer of fresh snow covered the glacier at the ablation measurements on 29^{h} September 2022. Here at the lowermost stake, stake 1, the layer was thin. Photo: Jostein Aasen

Figure 6-4
Mass balance versus altitude for Storbreen 2022, showing specific balance on the left and volume balance on the right. Annual balance at nine stakes is also shown.



Mass balance Storbreen 2021/22

Altitude (m a.s.l.)	Area (km^2)	Winter (m w.e.)	Summer (m w.e.)	Annual (m w.e.)
2050 - 2091	0.030	2.20	-1.70	0.50
2000 - 2050	0.138	2.10	-1.70	0.40
1950 - 2000	0.198	2.01	-1.71	0.30
1900 - 1950	0.317	1.90	-1.75	0.15
1850 - 1900	0.425	1.59	-1.59	0.00
1800 - 1850	0.846	1.16	-1.36	-0.20
1750 - 1800	0.763	1.24	-1.74	-0.50
1700 - 1750	0.628	1.21	-2.01	-0.80
1650 - 1700	0.414	1.23	-2.28	-1.05
1600 - 1650	0.334	1.47	-2.82	-1.35
1550 - 1600	0.390	1.25	-2.90	-1.65
1500 - 1550	0.197	1.03	-3.08	-2.05
1450 - 1500	0.146	0.84	-3.34	-2.50
1420 - 1450	0.050	0.80	-3.70	-2.90
1420- 2091	**4.876**	**1.35**	**-2.03**	**-0.68**

Table 6-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Storbreen in 2022.

6.3 Mass balance 1949-2022

The cumulative balance for 1949-2022 is –30.3 m w.e. The mean annual balance for the period of 74 years is −0.41 m w.e. (Fig. 6-5). For the period 1949-2000 (52 years) the mean annual balance is −0.19 m w.e., whereas for the period 2001-2022 (22 years) the mean annual balance is −0.92 m w.e.

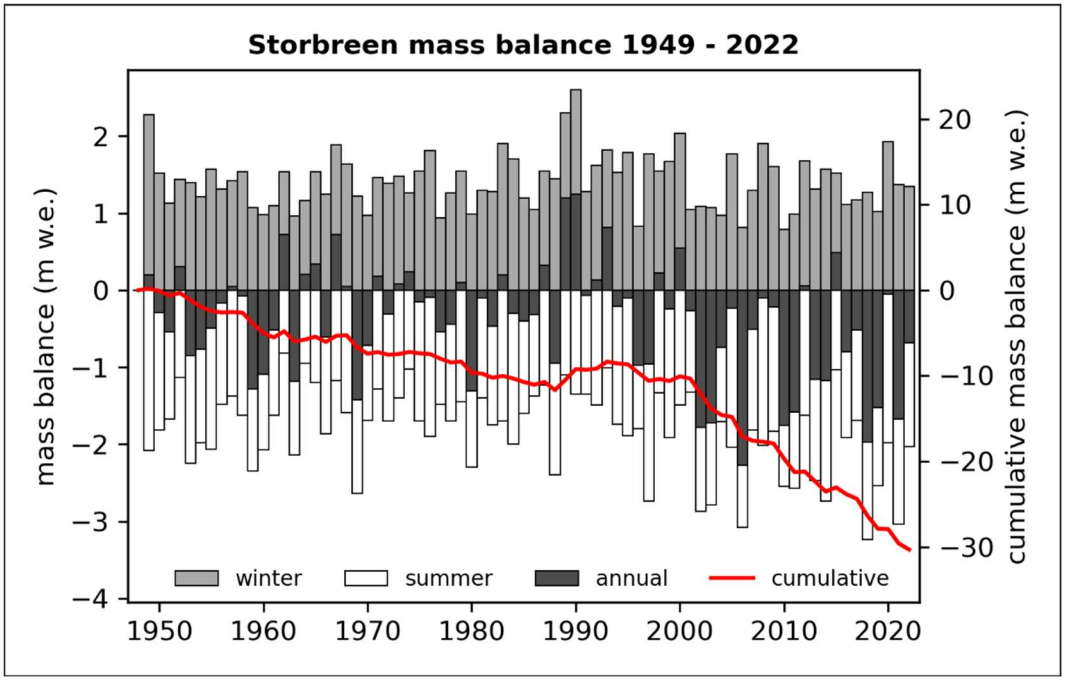


Figure 6-5
Winter, summer, annual and cumulative mass balance on Storbreen for the period 1949-2022.

7. 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. 7-1). Mass balance measurements began in May 2010. The measurements on Juvfonne are a contribution to 'Mimisbrunnr/ Klimapark 2469' – a nature park and outdoor discovery centre in the alpine region around Galdhøpiggen, the highest mountain peak in Norway (2469 m a.s.l.). Juvfonne has an area of 0.086 km^2 and altitudinal range from 1852 to 1985 m a.s.l. (map of 2019).

The observation programme of Juvfonne in 2022 consisted of accumulation measurements in spring, seasonal and annual balances measured in one stake position and front position.

Figure 7-1
Juvfonne on 19th September 2022 at the time of the ablation measurements. The ice patch was covered in fresh snow after several snow falls from Mid-September. Part of the lower ice patch is covered in white fabric to protect the tunnel roof from melting. Photo: Liss M. Andreassen.

7.1 Survey 2022

The extent of Juvfonne has been regularly measured since 2010 using differential GNSS or by digitising extents from orthophotos. During field visits on 19 September and 3 October 2022, the ice patch extent was covered in snow and it was not possible to measure the extent accurately (Fig. 7-1). An orthophoto derived from a drone survey by Innlandet fylkeskommune on 23 August 2022 revealed that about 1/3 of the surface had bare ice exposed (Fig. 7-2). The ice patch extent was digitised from this orthophoto and revealed an area of 0.107 km^2. This is higher than the 2019 area of 0.086 km^2 and is mainly due to snow along the south-eastern part and snow in the north-eastern part.

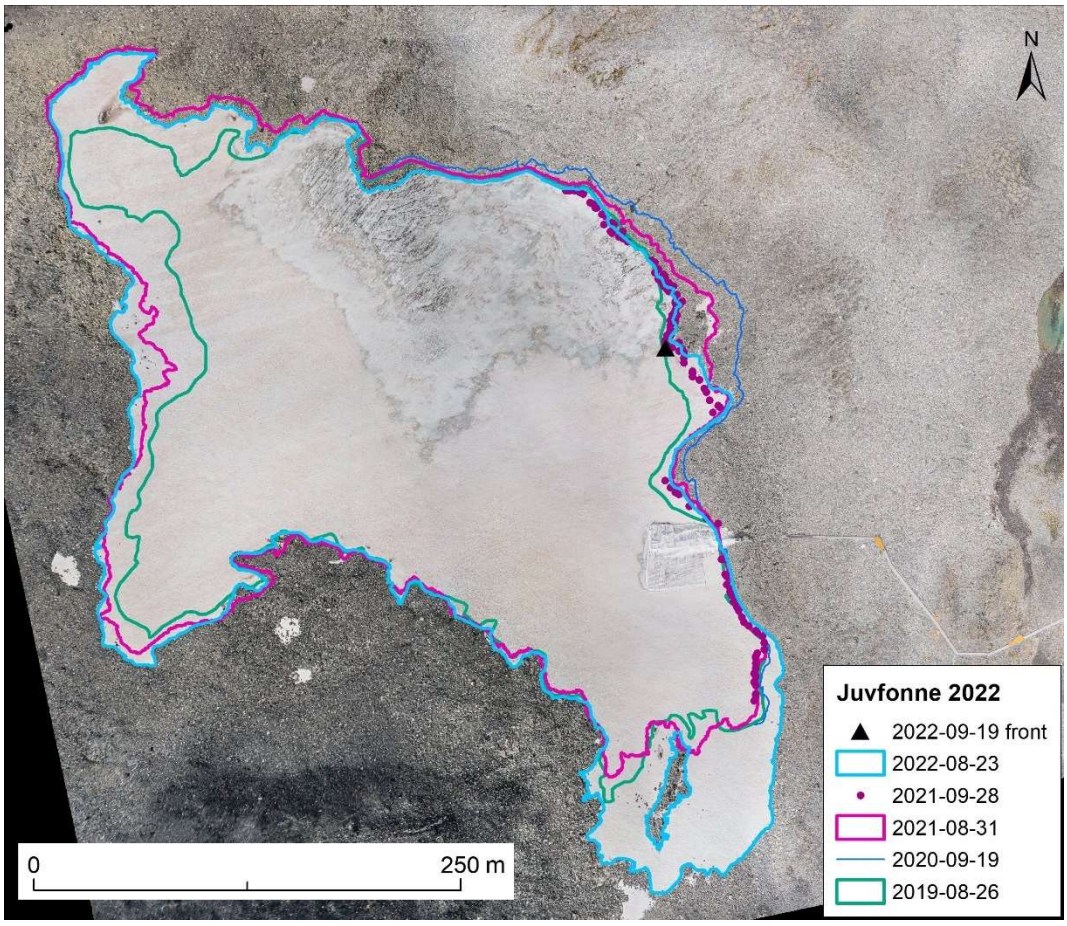


Figure 7-2
Orthophoto of Juvfonne from uncrewed aerial vehicle on 22 August 2022. Outlines from 2019 (orthophoto), 2020 (GNSS), 2021 (orthophoto and GNSS) and 2022 (orthophoto). Courtesy orthophoto 2022: Innlandet fylkeskommune, Det brearkeologiske sikringsprogrammet, Axel Hee Rømer.

7.2 Mass balance 2022

Field work

The accumulation measurements on Juvfonne were carried out on 22 April (Fig. 7-3). Snow depth was measured in 29 positions from 1862 to 1957 m a.s.l. The snow depth varied between 1.73 and 4.75 m with a mean (median) of 3.67 (3.79) m. The snow density was measured in a pit near stake 2 (the only stake now maintained on the ice patch), where the depth to the 2021 summer surface was 4.0 m. The resulting density was estimated to be 472 kg m^{-3}. Ablation measurements were carried out on 19 September at stake 2 (Fig 7-4). At this time the ice patch was covered in fresh snow (Fig. 7-1).

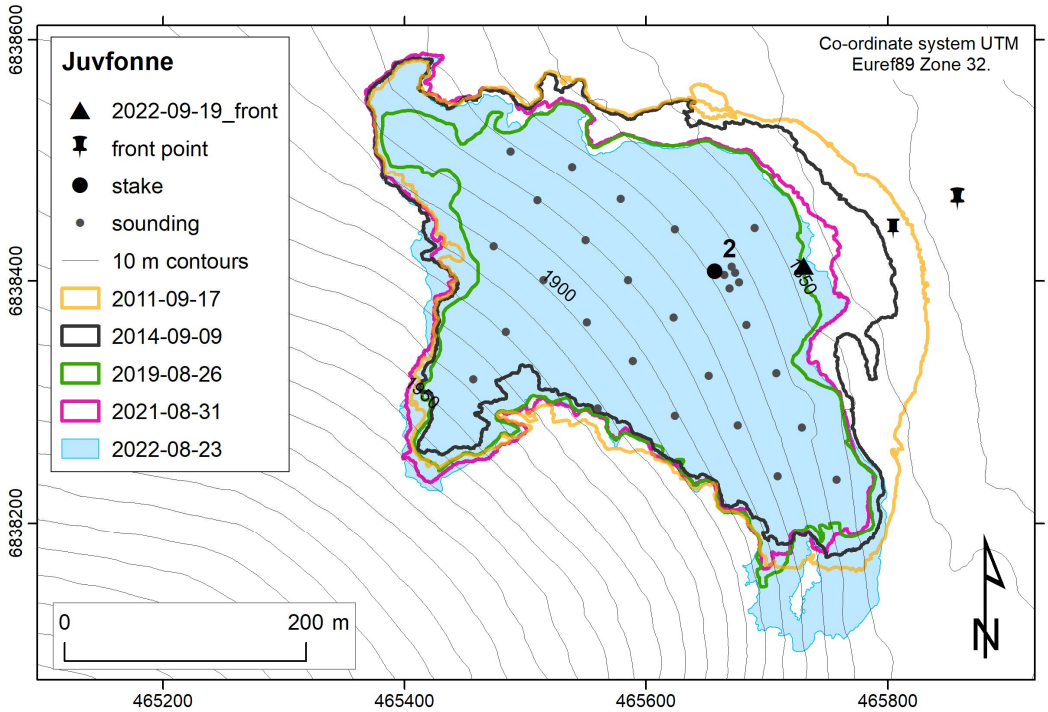


Figure 7-3
Location of snow depth soundings in 2022 and the position of stake 2 where density was measured. The ice patch extent in 2011 (orthophoto), 2014 (GNSS), 2019, 2021 and 2022 (orthophoto) are shown. "front point" marks the reference point for front position and length change measurements (see chap. 12.1). The 10 m contours are derived from the 2019 DTM.

Figure 7-4
Stake measurement of J2 on 19 September 2022 at the time of the ablation measurements. A layer of ~10 cm snow covered the surface. A total of 27 cm of ice had melted since the ablation measurements on 28 September 2021. Photo: Liss M. Andreassen.

Results

Seasonal surface mass balances have been measured since 2010 at stake 2 (Fig. 7-3). In 2022 the point winter balance was 1.71 ±0.15 m w.e., the point summer balance was

−1.95 ±0.15 m w.e and the annual balance was –0.24 ±0.15 m w.e. at this location. The cumulative mass balance for stake 2 over the 13 years of measurements is –12.8 m w.e., or –0.98 m w.e. a^{-1} (Fig. 7-5). The mass balance of the entire ice patch was not calculated; this was calculated only for the first year of measurements in 2009/2010 when more stakes were measured.

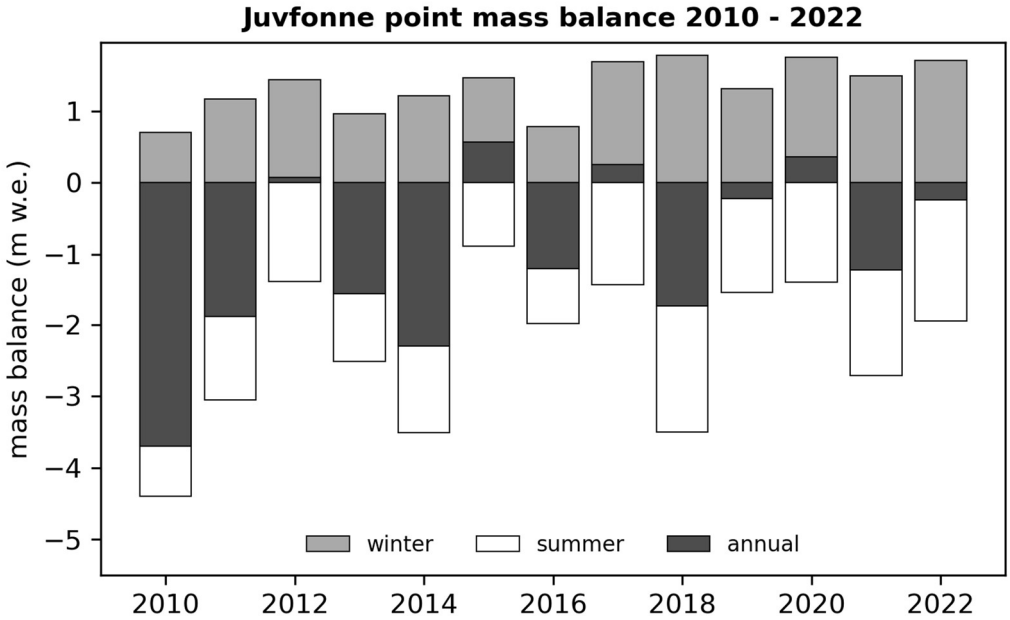


Figure 7-5
Point mass balance at stake 2 on Juvfonne 2010-2022, given as winter balance (b_w), summer balance (b_s) and annual balance (b_a).

8. Hellstugubreen (Liss M. Andreassen)

Hellstugubreen (61°34′N, 8° 26′E) (now written as “Hellstugubrean” on official maps) is a north-facing valley glacier situated in central Jotunheimen (Fig. 8-1). The glacier shares a border with Vestre Memurubre glacier (Fig. 8-2). Annual mass balance measurements began in 1962. Hellstugubreen ranges in elevation from 1487 to 2213 m a.s.l. and has an area of 2.7 km^2 (as of 2019).

Figure 8-1
Hellstugubreen on 5th August 2022. Photo: Liss M. Andreassen.

8.1 Mass balance 2022

Fieldwork

Accumulation measurements were performed on 20th April. Snow depths were measured in 73 positions between 1524 and 2158 m a.s.l., covering most of the altitudinal range of the glacier (Fig. 8-2). The snow depth varied between 0.59 and 3.43 m, with a mean (median) of 1.74 (1.60) m. Snow density was measured in a density pit at 1945 m a.s.l. The total snow thickness measured was 1.86 m and the resulting density was 444 kg m^{-3}. Ablation measurements were carried out on 20th September (Fig. 8-5).

Results

The calculations are based on the DTM from 2019. The winter balance was calculated as the mean of the soundings within each 50-metre height interval and was 0.80 ±0.2 m w.e., which is 76 % of the mean winter balance for the reference period 1991-2020. The annual balance was interpolated to 50 m height intervals based on the stake readings and was −0.94 ±0.3 m w.e. The resulting summer balance was –1.74 ±0.3 m w.e., which is 103 % of the mean summer balance for the reference period 1991-2020. The equilibrium line altitude (ELA) was above the highest stake at 2060 m a.s.l. and estimated to be 2115 m a.s.l., giving an accumulation area ratio (AAR) of 2 %. The mass balance results are shown in Table 8-1 and the corresponding curves for specific and volume balance are shown in Figure 8-3.

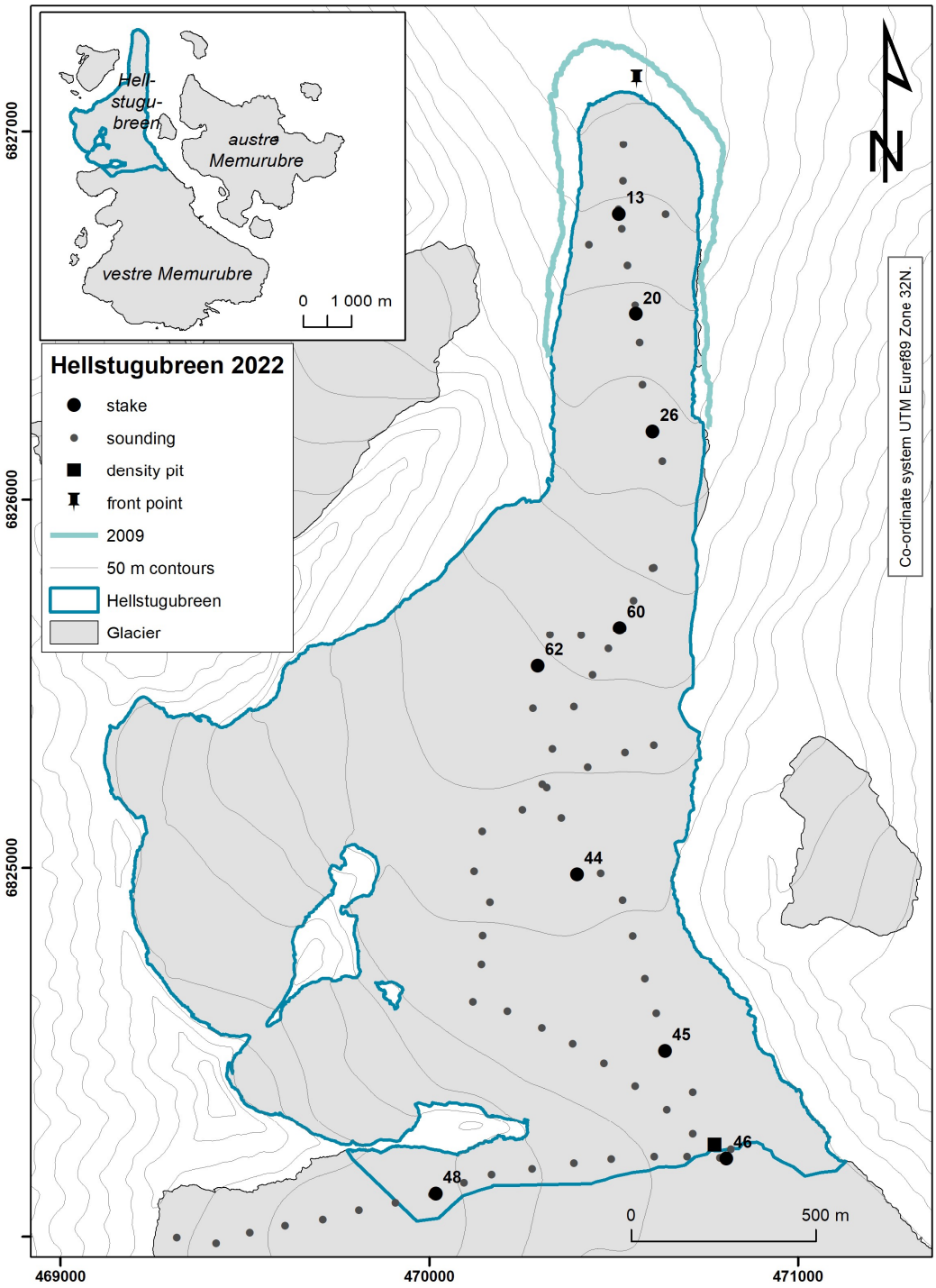


Figure 8-2
Map of Hellstugubreen showing the location of stakes, snow depth soundings and snow pit in 2022. Front point: reference points used for front position and length change measurements (chap. 12-1).
Inset shows Hellstugubreen and surrounding glaciers.

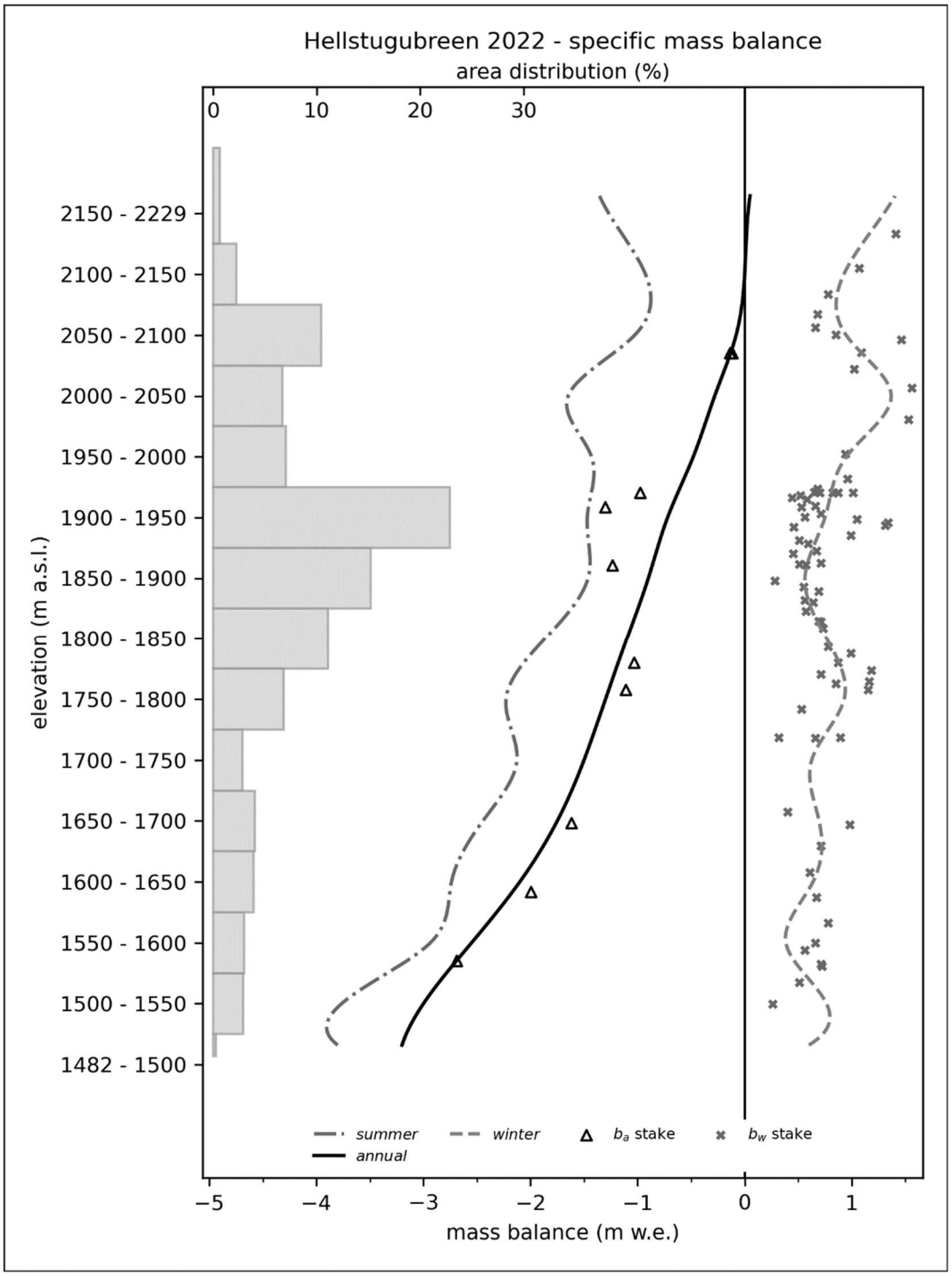


Figure 8-3
Mass balance diagram for Hellstugubreen in 2022.

Mass balance Hellstugubreen 2021/22				
Altitude (m a.s.l.)	Area (km^2)	Winter (m w.e.)	Summer (m w.e.)	Annual (m w.e.)
2150 - 2229	0.017	1.41	-1.36	0.05
2100 - 2150	0.060	0.93	-0.93	0.00
2050 - 2100	0.278	0.95	-1.03	-0.08
2000 - 2050	0.178	1.37	-1.65	-0.28
1950 - 2000	0.186	0.95	-1.43	-0.48
1900 - 1950	0.607	0.75	-1.47	-0.72
1850 - 1900	0.404	0.56	-1.46	-0.90
1800 - 1850	0.295	0.77	-1.87	-1.10
1750 - 1800	0.181	0.93	-2.23	-1.30
1700 - 1750	0.076	0.63	-2.13	-1.50
1650 - 1700	0.107	0.70	-2.45	-1.75
1600 - 1650	0.104	0.64	-2.74	-2.10
1550 - 1600	0.079	0.39	-2.94	-2.55
1500 - 1550	0.077	0.76	-3.76	-3.00
1482 - 1500	0.007	0.60	-3.80	-3.20
1482- 2229	**2.656**	**0.80**	**-1.74**	**-0.94**

Table 8-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Hellstugubreen in 2022.

8.2 Mass balance 1962-2022

The cumulative annual balance of Hellstugubreen since 1962 is –28.4 m w.e. (Fig. 8-4), giving a mean annual deficit of 0.47 m w.e. per year. The cumulative mass balance for the period 2000/2001 to 2019/2021 (22 years) is –19.2 m w.e. or –0.83 m w.e./a.

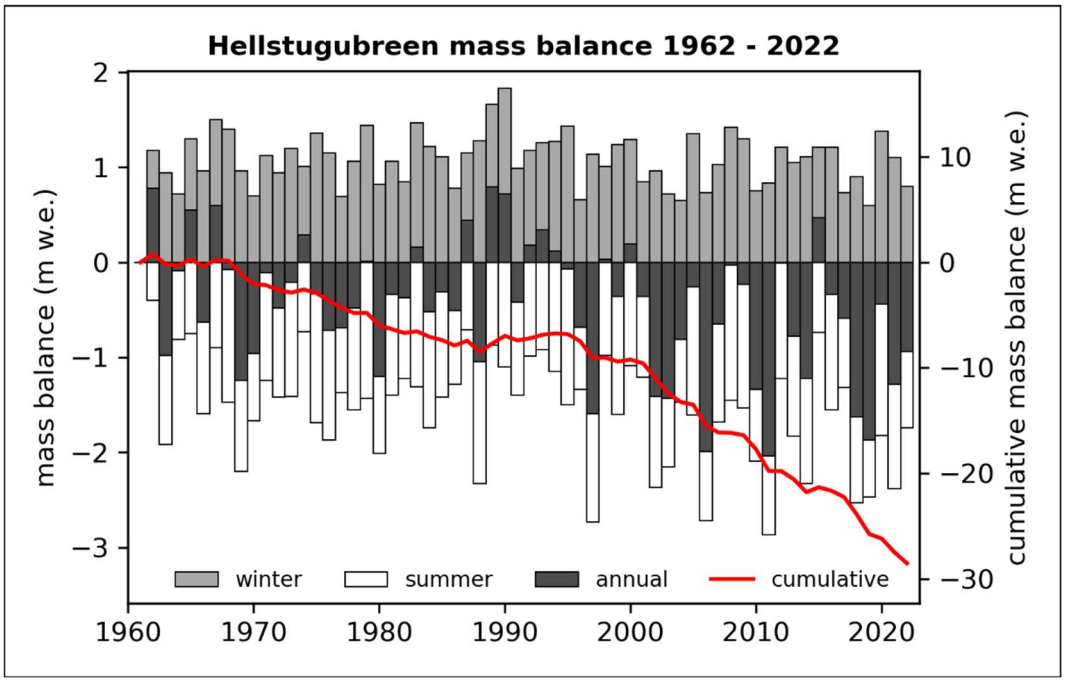


Figure 8-4
Winter, summer and annual balance at Hellstugubreen for 1962-2022, and cumulative mass balance for the whole period.

Figure 8-5
Field work on 5 August 2022 at stake 60. Photo: Liss M. Andreassen.

9. Gråsubreen (Liss M. Andreassen)

Gråsubreen (61°39′N, 8°37′E) (now written Gråsubrean on official maps) is a small, polythermal glacier in the eastern part of the Jotunheimen mountain area in southern Norway (Fig. 9-1). Gråsubreen has an area of 1.74 km^2 and ranges in elevation from 1854 to 2277 m a.s.l. (map of 2019). Mass balance investigations have been carried out annually since 1962.

Gråsubreen consists of relatively thin, cold ice which is underlain by a zone of temperate ice in the central, thicker part of the glacier. The distribution of accumulation and ablation at Gråsubreen is strongly dependent on the glacier geometry. In the central part of the glacier wind removes snow causing a relatively thin snowpack, whereas snow accumulates in sheltered areas at lower elevations. The ELA and AAR are therefore 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 9-1
Approaching Gråsubreen from the glacier hut showing the northern part of the glacier on 7th August 2022. Photo: Liss M. Andreassen.

9.1 Mass balance 2022

Fieldwork

Accumulation measurements were performed on 7th June 2022. The calculation of winter balance is based on stake measurements and snow depth soundings in 97 positions between 1878 and 2264 m a.s.l. (Fig. 9-2). The snow depth varied between 0.15 and 3.96 with a mean and median of 1.21 and 1.10 m respectively. The snow density was measured in a density pit near stake 8 (elevation 2144 m a.s.l.) where the total snow depth was 1.74 m and the mean density was 427 kg m^{-3}. Ablation measurements were carried out on 21th September 2022, when all visible stakes were measured. The winter snow was gone at all stake positions (Fig. 9-3).

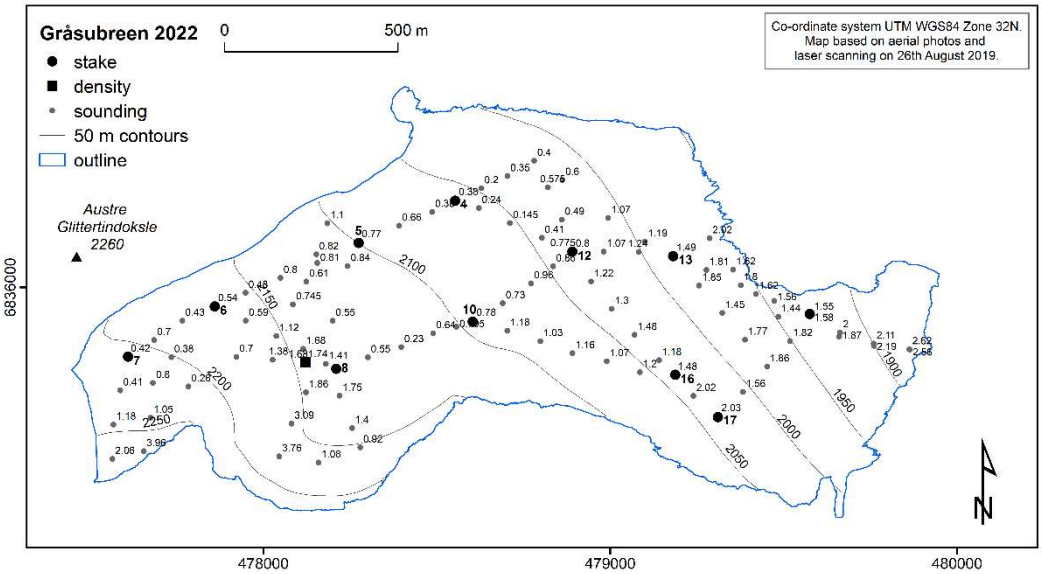


Figure 9-2
Map of Gråsubreen showing the location of stakes, density pit and soundings in 2022. Measured snow depths are shown in meters.

Figure 9-3
Ablation measurements and stake maintenance on 21st September 2022. A layer of fresh snow covered the glacier. Photo: Liss M. Andreassen.

Results

The winter balance was calculated as the mean of the soundings within each 50-metre height interval. This gave a winter balance of 0.50 ±0.2 m w.e., which is 71 % of the mean winter balance for the reference period 1991-2020. Annual and summer balance were

calculated from direct measurements of eight stakes. The resulting summer balance was −2.12 ±0.3 m w.e., which is 159 % of the mean summer balance for the reference period 1991-2020. The annual balance of Gråsubreen was negative in 2022 at −1.62 ±0.3 m w.e. The ELA and AAR were not defined from the mass balance curve or in the field. There was some snow remaining in the cirque above stake 8. 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.

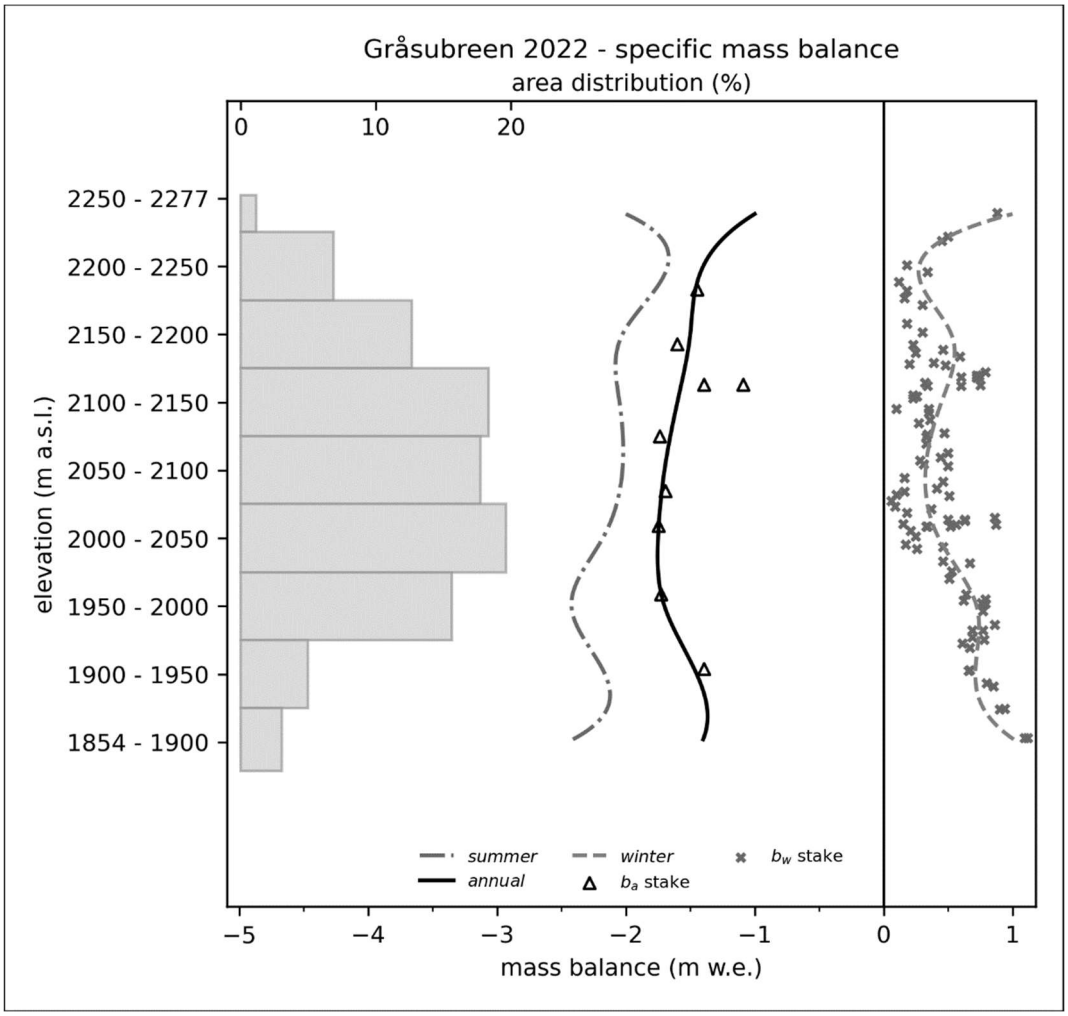


Figure 9-4
Mass balance diagram for Gråsubreen for 2022. The area-elevation distribution is from the map survey of 2019.

Mass balance Gråsubreen 2021/22

Altitude (m a.s.l.)	Area (km^2)	Winter (m w.e.)	Summer (m w.e.)	Annual (m w.e.)
2250 - 2277	0.020	1.00	-2.00	-1.00
2200 - 2250	0.120	0.28	-1.68	-1.40
2150 - 2200	0.221	0.53	-2.03	-1.50
2100 - 2150	0.320	0.45	-2.05	-1.60
2050 - 2100	0.309	0.33	-2.03	-1.70
2000 - 2050	0.342	0.43	-2.18	-1.75
1950 - 2000	0.272	0.72	-2.42	-1.70
1900 - 1950	0.087	0.71	-2.16	-1.45
1854 - 1900	0.053	1.01	-2.41	-1.40
1854 - 2277	**1.744**	**0.50**	**-2.12**	**-1.62**

Table 9-1
The distribution of winter, summer and annual balance in 50 m altitudinal intervals for Gråsubreen in 2022.

9.2 Mass balance 1962-2022

The cumulative annual balance of Gråsubreen is –29.3 m w.e. since measurements began in 1962 (Fig. 9-5). The average annual balance is –0.48 m w.e. a^{-1}. Gråsubreen has had a negative mass balance every year since 2001, except for slight surpluses in 2008 and 2015.

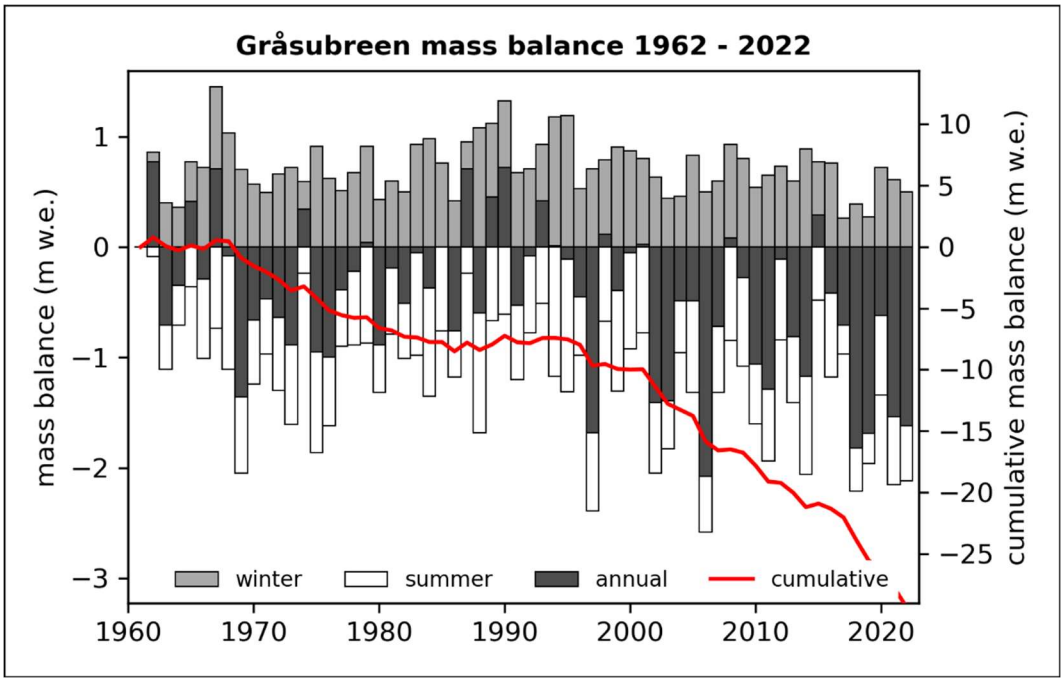


Figure 9-5
Winter, summer and annual balance on Gråsubreen for 1962-2022, and cumulative mass balance for the whole period.

10. Engabreen (Hallgeir Elvehøy)

Engabreen (66°40′N, 13°45′E) is a 36 km^2 north-western outlet from the western Svartisen ice cap. In 2020 it covered an altitude range from 1531 m a.s.l. at Snøtinden down to 176 m a.s.l. close to Engabrevatnet. Length change observations started in 1903 (chap. 12) and mass balance measurements have been performed annually since 1970.

Figure 10-1
Stake E2092 (1140 m a.s.l.) on 7th November 2022. This stake was lost in the 1990ies but re-appeared in 2014. Helgelandsbukken is to the right. Photo: Hallgeir Elvehøy.

10.1 Mass balance 2022

Fieldwork

Stakes in four locations on the glacier plateau and two locations on the glacier tongue were checked on 22nd February and showed between 3 and 6 meters of snow on the plateau. The observations of snow depth and stake length on stake E17 and E400 showed 25 cm of ice melt after 23rd October 2021. This ice melt is included in the specific winter balance for E400 for 2022.

The snow accumulation measurements were performed on 8th June. Four stakes on the glacier plateau were located and used to validate the snow depth soundings. Snow depth was measured at 24 sounding locations along the profile from the summit at 1464 m a.s.l. to E34 (Fig. 10-2). The snow depth varied between 4 and 9 metres, and the average was 6.6 meters. The summer surface was difficult to define in the upper areas. The mean snow density down to 6.9 m at stake E5 was 543 kg m^{-3}. At the glacier tongue stake E17 had melted out. Due to the on-going retreat of the glacier terminus and

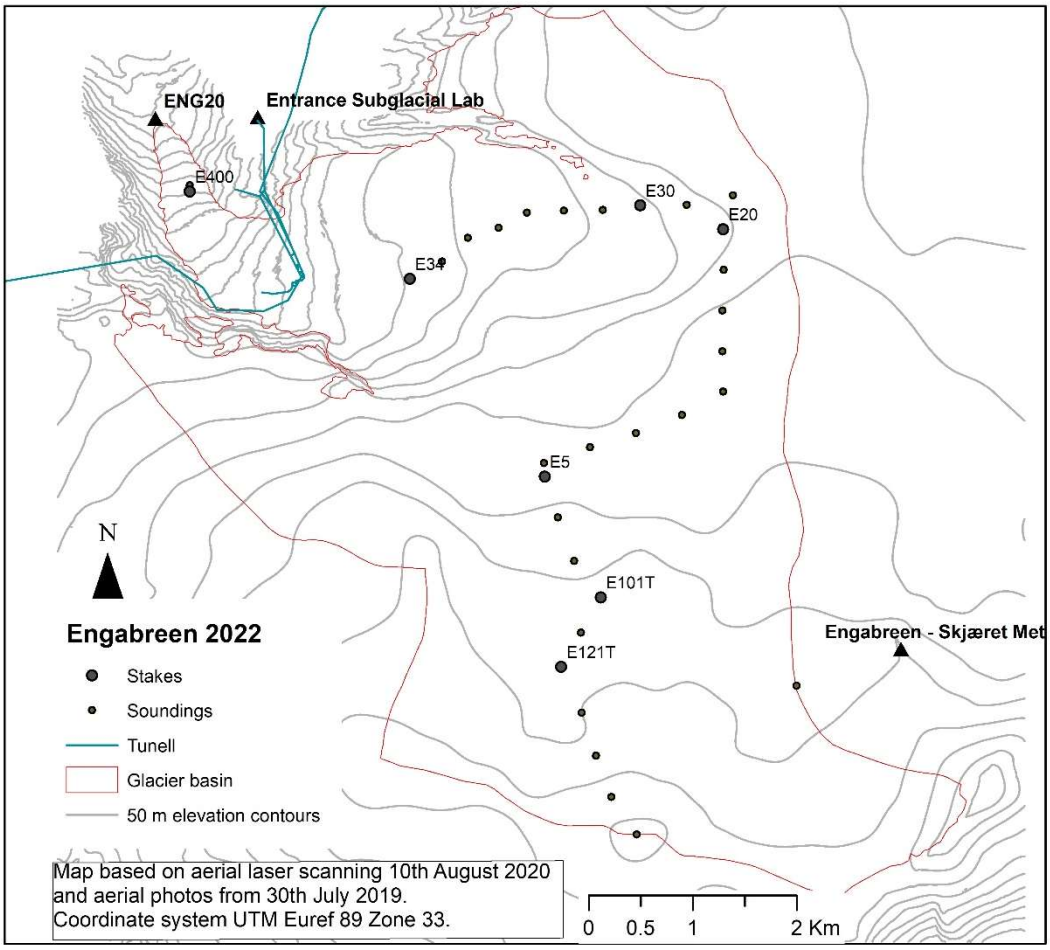


Figure 10-2
Location of stakes and soundings on Engabreen in 2022. ENG20 is the reference point for front variation measurements in 2022 (Ch. 12-1). Tunnel is the water collecting tunnel system for Svartisen Hydropower Station providing access to the Subglacial Lab (Ch 10-3).

steepening of the glacier tongue, location E17 was abandoned. At stake E400 1.25 m of glacier ice had melted since 18th November 2021.

The stake network was checked on 18th August. At stake E400 5.8 meters of ice had melted since 9th June, and the stake was re-drilled. At stake E34 all the winter snow (4.3 m) and 0.9 m of ice had melted since 8th June and the stake was re-drilled. Higher up on the glacier plateau 4 to 5 meters of snow had melted.

The summer ablation measurements were carried out on 7th November. Up to 1.8 meters of new snow had accumulated at the stake locations. Based on the stake measurements the temporary snow line at the end of the melt season was around 1100 m a.s.l. At stake E400 on the glacier tongue 2.5 meters of ice had melted since 18th August. At E34 all the winter snow and 2.35 meters of ice had melted. At E30 and E20 almost all the winter snow had melted, and at the stake locations above 1200 m a.s.l. up to 3.1 meters of winter snow remained.

Results

The calculations are based on a DTM from 10th August 2020. All the stake and sounding locations are appointed elevations from the 2020 DTM.

The winter balance for 2022 on the glacier plateau was calculated from the snow depth and snow density measurements. On the glacier tongue the point specific winter balance at E400 was calculated from measured ice melt between 23rd October 2021 and 8th June 2022. The total specific winter balance was calculated as 3.5 ±0.2 m w.e. This is 127 % of the average winter balance for the normal period 1991-2020 (2.71 m w.e. a^{-1}).

The date of the 2022 mass balance minimum on Engabreen was assessed from the daily changes in gridded data of temperature and snow amount from Senorge.no (Saloranta, 2014). The snow accumulation on the glacier plateau above 1000 m a.s.l. probably started on 4th October 2022. On the glacier tongue the summer season probably ended on 5th December.

The point summer balance was calculated directly for all stake locations. The specific summer balance was calculated from the summer balance curve drawn from these seven point values (Fig. 10-3) as −3.3 ±0.2 m w.e. This is 119 % of the average summer balance for the normal period 1991-2020 (−2.77 m w.e. a^{-1}). The resulting annual balance was +0.1 ±0.3 m w.e. (Tab. 10-1). The ELA was 1141 m a.s.l. and the corresponding AAR was 67 %.

The annual surface mass balance on Engabreen for 1970-2022 is shown in Figure 10-4. The cumulative surface mass balance since the start of mass balance investigations on Engabreen is +0.8 m w.e., showing that the long-term change in glacier volume has been small.

Table 10-1
Specific and volume winter, summer and annual balance calculated for 100 m elevation intervals on Engabreen in 2022.

Mass balance Engabreen 2021/22 – stratigraphic system

Altitude (m a.s.l.)	Area (km²)	Winter balance Measured 08.06.2022 (m w.e.)	Summer balance Measured 01.10.2022 (m w.e.)	Annual balance Summer surface 2021 - 2022 (m w.e.)
1500 - 1532	0.046	4.00	-2.60	1.40
1400 - 1500	2.199	4.40	-2.70	1.70
1300 - 1400	9.228	4.30	-2.80	1.50
1200 - 1300	8.041	3.80	-3.10	0.70
1100 - 1200	7.487	3.20	-3.15	0.05
1000 - 1100	4.552	3.00	-3.50	-0.50
900 - 1000	2.373	2.25	-4.45	-2.20
800 - 900	0.773	1.60	-5.00	-3.40
700 - 800	0.439	0.95	-5.60	-4.65
600 - 700	0.270	0.30	-6.20	-5.90
500 - 600	0.249	-0.35	-6.80	-7.15
400 - 500	0.137	-1.15	-7.40	-8.55
300 - 400	0.089	-1.50	-8.20	-9.70
200 - 300	0.071	-2.10	-8.80	-10.90
177 - 200	0.006	-2.50	-9.30	-11.80
Specific mass balance				
177 - 1532	**35.960**	**3.455**	**-3.310**	**0.145**

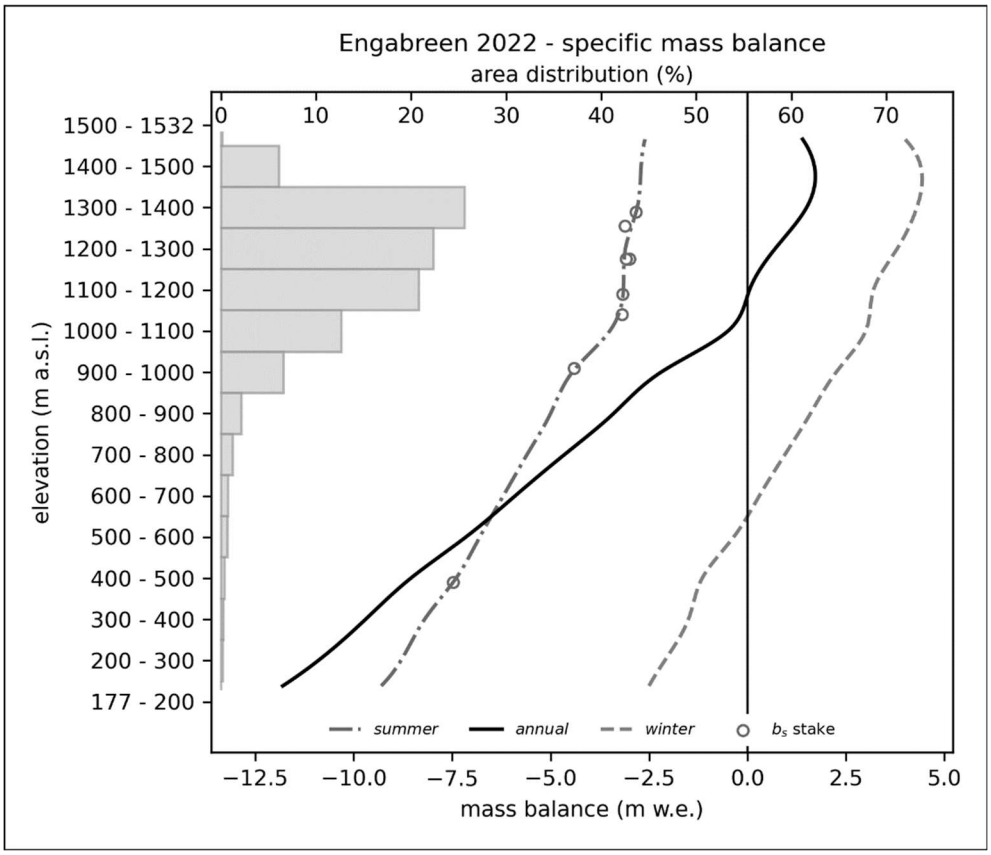


Figure 10-3
Hypsometric areal distribution (grey bars) and altitudinal distribution of specific balance for Engabreen in 2022. Summer balance at seven stake locations is shown.

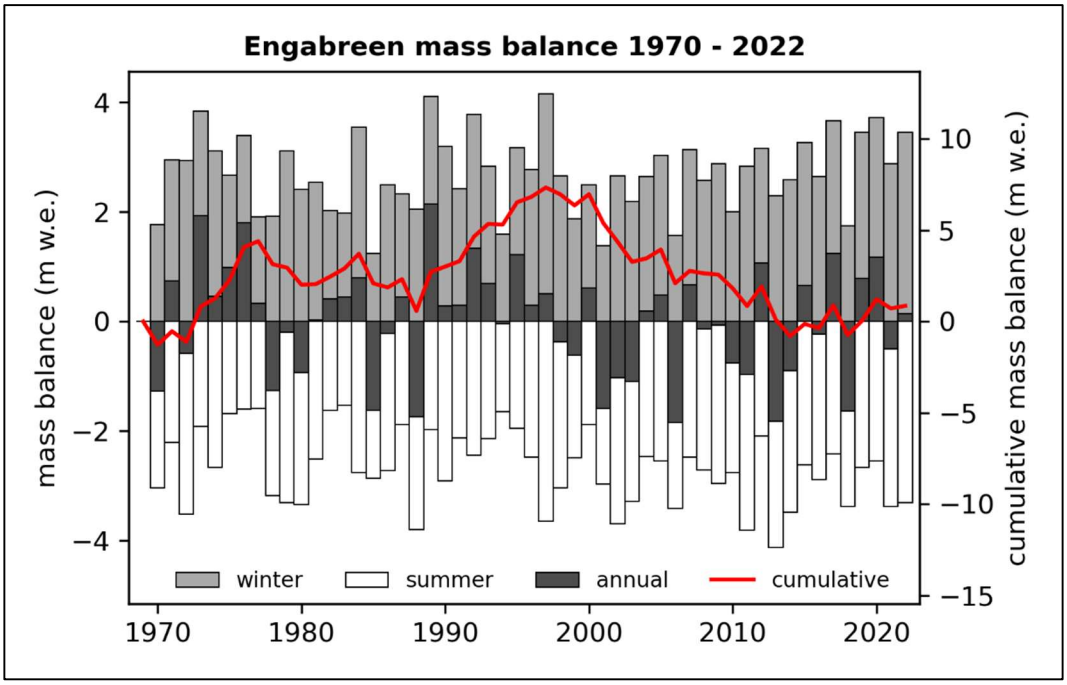


Figure 10-4
Mass balance on Engabreen during the period 1970-2022. Cumulative mass balance is given on the right axis. The average winter and summer balances are B_w =2.70m w.e. and B_s =−2.69 m w.e.

10.2 Meteorological observations

The meteorological station 159.20 Engabreen–Skjæret recording air temperature and global radiation at 3 m above ground level is located on a nunatak (1364 m a.s.l.) close to the drainage divide between Engabreen and Storglombreen (Fig 10-2). The station has been operating since 1995. The temperature record for 2022 is shown in Fig. 10-5.

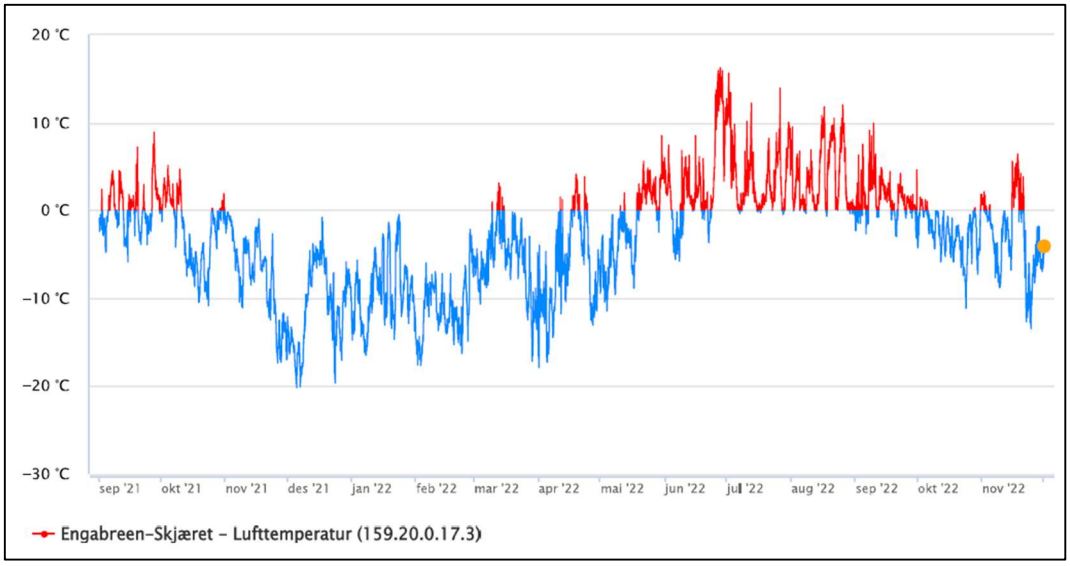


Figure 10-5
Air temperature at Engabreen-Skjæret (1364 m a.s.l.) from 1st September 2021 to 30th November 2022. The winter season lasted from 10th October 2021 to 18th June 2022, and the summer season ended on 5th October 2022.

The mean summer temperature (1st June – 30th September) at Engabreen-Skjæret in 2022 was 2.9 °C. This is slightly below the average summer temperature for 21 years between 1995 and 2020 at 3.06 °C. Based on the temperature record the melt season on the upper part of the glacier plateau started on 19th May and lasted until 29th September. In the warmest period from 25th June to 4th July the average temperature was 10.2 °C.

10.3 Svartisen Subglacial Observatory

Svartisen Subglacial Laboratory is situated under Engabreen. The laboratory buildings and research shaft are located about 1.5 km along a tunnel that is part of the water collecting tunnel system for Svartisen Kraftverk (hydropower development) (Fig. 10-2). The research shaft allows direct access to the bed of the glacier for measuring subglacial parameters, extracting samples and performing experiments (Jackson, 2000).

Load cells have been measuring variations in subglacial pressure at the glacier bed next to the research shaft since December 1992. The load cells are Geonor Earth Pressure Cells P-100 and P-105. Readings are made from the load cells at 15-minute intervals. The load cells were installed at the glacier-bedrock interface within 20 m of each other. Four load cells are still in operation and recording data (LC4, LC6, LC12-1 and LC12-2, Fig. 10-6). The inter-annual variability of the load cells is examined in detail by Lefeuvre and others (2015). Due to equipment problems, there are several gaps in the data records between May 2018 and August 2021. Complete records of raw data from four load cells are available for 2022.

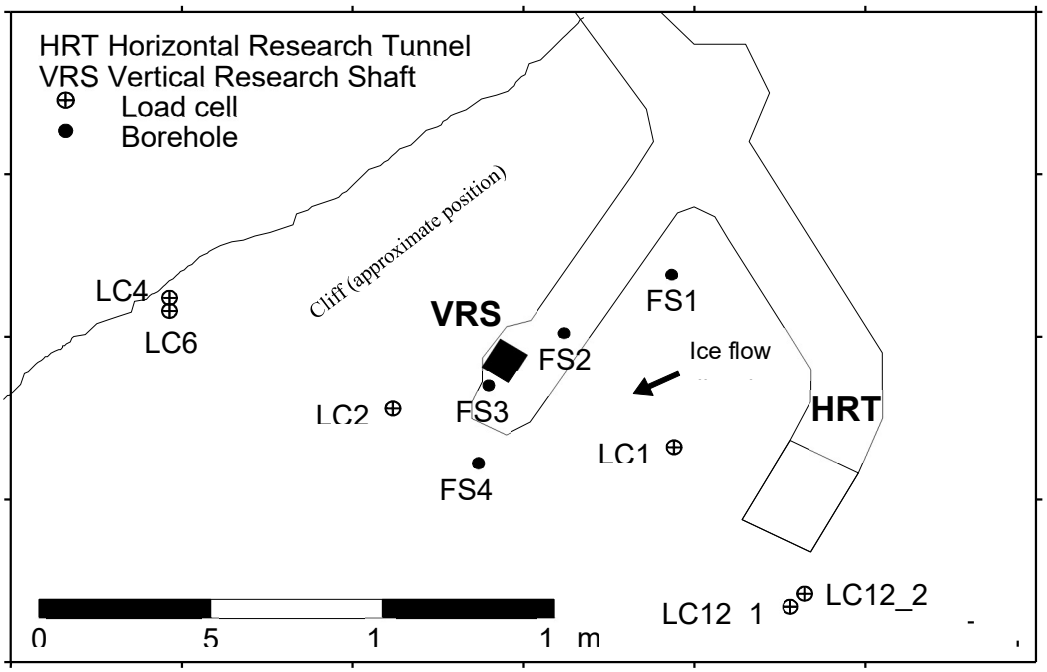


Figure 10-6
Research shaft showing locations of horizontal research tunnel (HRT), vertical research shaft (VRS) and load cells (LC). Boreholes from the tunnel to the glacier bed (FS) are also shown. The active load cells are LC4 and LC6, and LC12_1 and LC12_2.

11. Langfjordjøkelen (Bjarne Kjøllmoen)

Langfjordjøkelen (70°10′N, 21°45′E) is a plateau glacier situated on the border of the Troms and Finnmark counties, approximately 60 km northwest of the city of Alta. It has an area of about 6.2 km^2 (2018), and of this, 2.6 km^2 drains eastward. The investigations are performed on this east-facing part (Fig. 11-1), where the glacier ranges in elevation from 338 to 1043 m a.s.l.

The glaciological investigations in 2022 include mass balance and front variations (chap. 12). Langfjordjøkelen has been the subject of mass balance measurements since 1989 with the exception of 1994 and 1995.

Figure 11-1
The east-facing outlet of Langfjordjøkelen photographed on 19th August 2022. Photo: Bjarne Kjøllmoen.

11.1 Mass balance 2022

Fieldwork

Snow accumulation was measured on 20th May and the calculation of winter balance was based on measurements of 59 snow depth soundings (Fig. 11-2). The snow depth varied between 2.2 and 6.8 m with an average of 5.1 m. Snow density was measured in position 25 (709 m a.s.l.) and the mean density of 2.9 m snow was 426 kg m^{-3}.

Ablation was measured on 29th September. The annual balance was measured at stakes in six locations (Fig. 11-2). There was no snow remaining on the glacier from the winter season 2021/22. At the time of measurement, no fresh snow had fallen on the glacier.

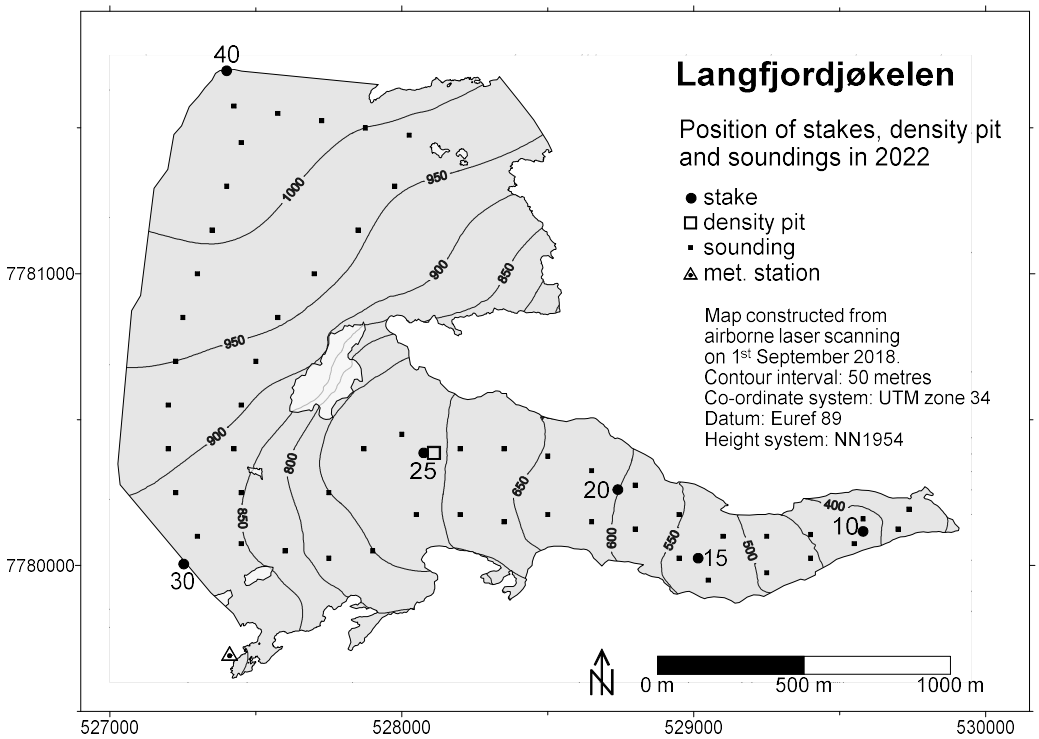


Figure 11-2
Location of stakes, soundings and snow pit on Langfjordjøkelen in 2022.

Results

The calculations are based on the DTM from 2018.

All elevations are well-represented with snow depth measurements. The winter balance was calculated as a mean value for each 50 m height interval and was 2.6 ±0.2 m w.e., which is 127 % of the mean winter balance for the periods 1989-93 and 1996-2021 (2.1 m w.e.). The spatial distribution of the winter balance is shown in Figure 11-3.

The ablation stakes cover elevations from the glacier summit (1042 m a.s.l.) to 410 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 −4.6 ±0.3 m w.e., which is 153 % of the mean summer balance for 1989-93 and 1996-2021 (−3.0 m w.e.).

Hence, the annual balance was negative at −1.91 ±0.40 m w.e. This is the second biggest mass loss since the measurements started in 1989. The biggest mass loss was measured in 2013 with −2.62 m w.e. The mean annual balance for 1989-93 and 1996-2021 is −0.89 m w.e. The mean annual balance for the past ten years (2013-22) is −1.00 m w.e.

The mass balance results are shown in Table 11-1 and the corresponding curves for specific and volume balance are shown in Figure 11-4.

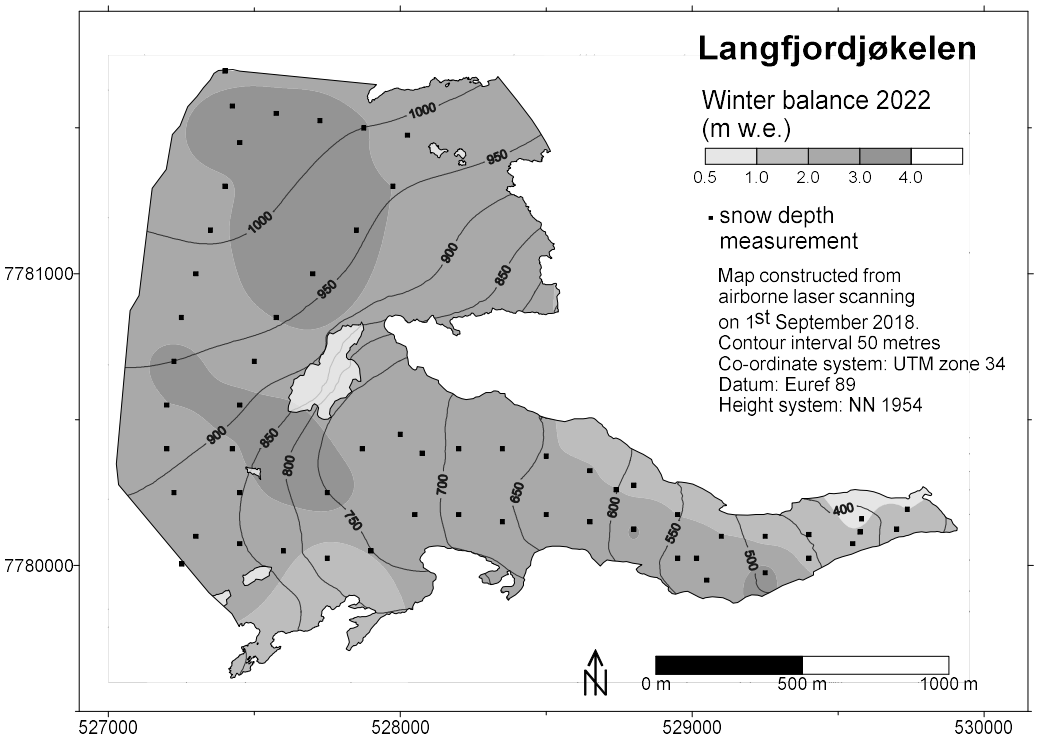


Figure 11-3
Spatial distribution of winter balance on Langfjordjøkelen in 2022.

According to Figure 11-4, the equilibrium line altitude lay above the highest point of the glacier. Consequently, the accumulation area ratio was 0 %.

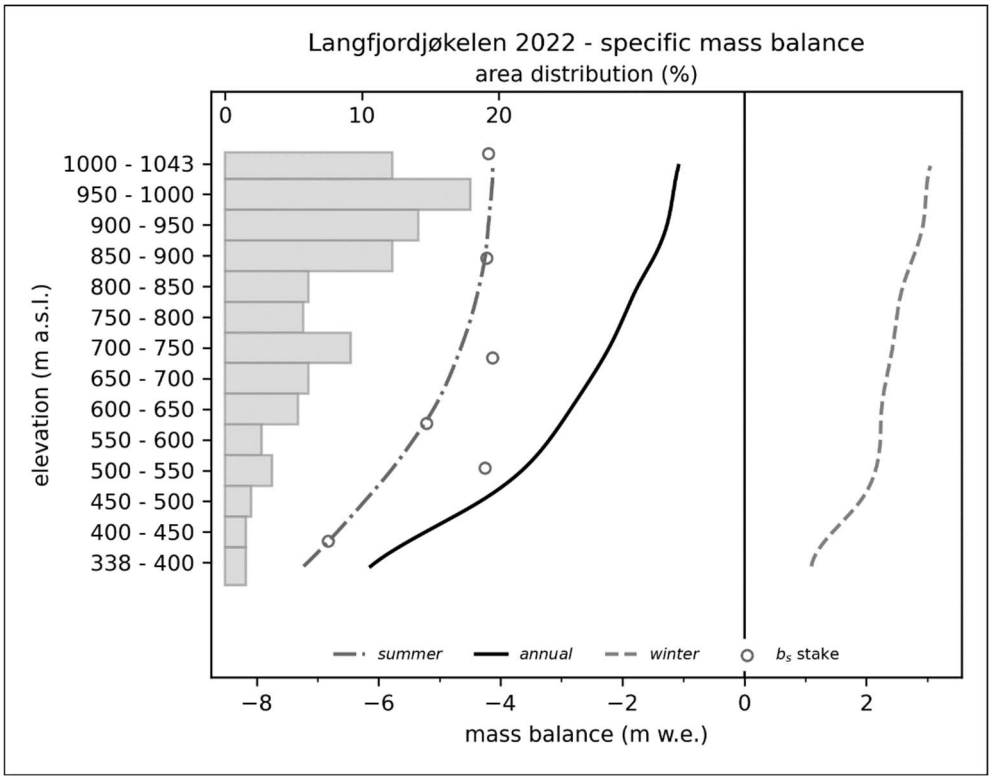


Figure 11-4
Mass balance diagram showing specific balance for Langfjordjøkelen in 2022. Specific summer balance for six stakes is shown as circles (○).

Table 11-1
Winter, summer and annual balance for Langfjordjøkelen in 2022.

Mass balance Langfjordjøkelen 2021/22 – stratigraphic system				
Altitude (m a.s.l.)	Area (km^2)	Winter balance Measured 20 May (m w.e.)	Summer balance Measured 29 Sep (m w.e.)	Annual balance S.S. 2021-2022 (m w.e.)
1000 - 1043	0.417	3.050	-4.125	-1.075
950 - 1000	0.467	2.975	-4.150	-1.175
900 - 950	0.376	2.925	-4.200	-1.275
850 - 900	0.362	2.775	-4.250	-1.475
800 - 850	0.232	2.600	-4.350	-1.750
750 - 800	0.217	2.500	-4.475	-1.975
700 - 750	0.267	2.425	-4.650	-2.225
650 - 700	0.203	2.325	-4.850	-2.525
600 - 650	0.168	2.250	-5.100	-2.850
550 - 600	0.128	2.225	-5.425	-3.200
500 - 550	0.121	2.150	-5.800	-3.650
450 - 500	0.095	1.900	-6.225	-4.325
400 - 450	0.096	1.450	-6.675	-5.225
338 - 400	0.049	1.100	-7.225	-6.125
Specific mass balance				
338-1043	**2.607**	**2.650**	**-4.559**	**-1.909**

11.2 Mass balance 1989-2022

The historical mass balance results for Langfjordjøkelen are presented in Figure 11-5. The cumulative annual balance for 1989-2022 (estimated values for 1994 and 1995 included) is –30.0 m w.e., which gives a mean annual balance of –0.88 m w.e. a^{-1}.

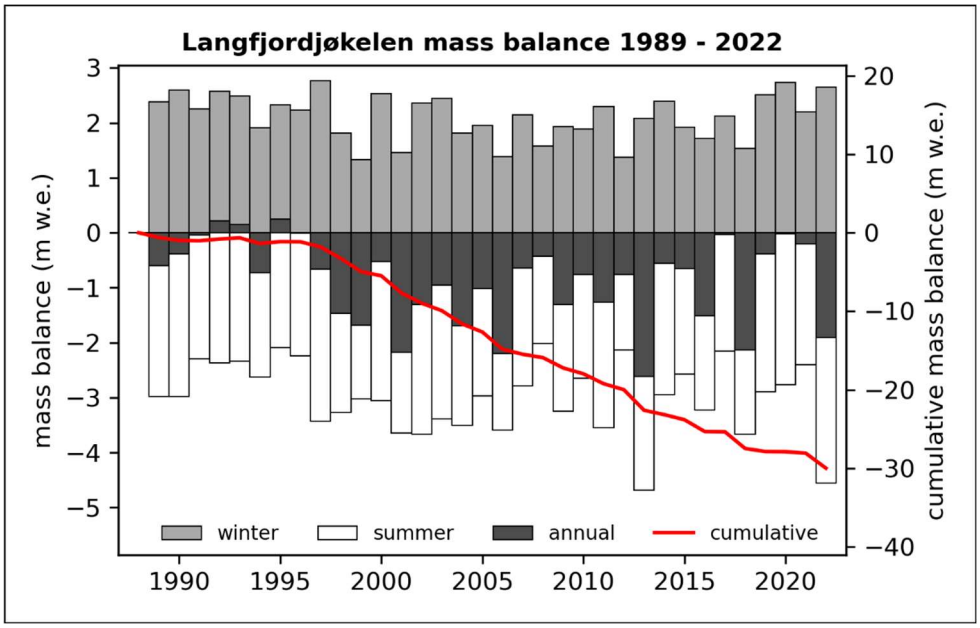


Figure 11-5
Mass balance on Langfjordjøkelen for the period 1989-2022. The total accumulated mass loss for 1989-2022 is 30.0 m w.e. (includes estimated values for 1994 and 1995).

11.3 Meteorological observations

A meteorological station (Langfjord Met) recording air temperature, global radiation, wind speed and wind direction at 3 m above ground level (Fig. 11-6) is located on rock south of the glacier (915 m a.s.l., Fig. 11-2) close to the glacier margin. The station has been in operation since August 2006. However, the data record for 2006-2008 and 2011 is incomplete. Thus, reliable data only exist for the periods 2009-2010 and 2012-2022.

Figure 11-6
The meteorological station, Langfjord Met.
Photo: Nils Larsen.

The mean summer temperature (1st June – 30th September) at Langfjord Met in 2022 was 5.4 °C. The mean summer temperature for 2009-10 and 2012-21 was 4.7 °C. The melt season on the upper part of the glacier (above 900 m a.s.l.) started in the end of May and lasted until the end of September. The period from 29th August to 20th September was relatively cold and hence, the melting was probably quite modest during these three weeks. The monthly summer temperatures for 2022 were 4.9 °C (June), 8.2 °C (July), 7.2 °C (August) and 1.3 °C (September).

12. Glacier front variations

(Hallgeir Elvehøy)

Observations of front variations of Norwegian glaciers started in 1899 (Rekstad 1902, Øyen 1906). Since then, front variations have been measured over several years for at least 74 glaciers. The total number of observations in NVE's database up to and including 2022 is 2905, including 95 measurements of front variation based on maps, reconstructions from photos, moraines etc., or combinations of methods. The median and mean number of observations for a single glacier is 27 and 39 observations, respectively, indicating many glaciers with few observations. The median and mean number of observations in one year is 21 and 22 glaciers, respectively. In 1911, 45 glaciers were measured, and in 1992 only 8 glaciers were measured.

The longest and most complete record is for Fåbergstølsbreen, an eastern outlet from Jostedalsbreen. There, the observations started in 1899, and measurements have been conducted every year since 1907 resulting in 117 observations. Stigaholtbreen, Nigardsbreen and Austerdalsbreen, also outlets from Jostedalsbreen, and Styggedalsbreen in Jotunheimen have more than 100 observations. Sixteen glaciers have between 50 and 99 observations. The longest record in northern Norway is for Engabreen with 90 measurements since 1903. At present the monitoring programme of front variations includes 28 glaciers in southern Norway and 11 glaciers in northern Norway (Fig. 12-1 for location). The area of the monitored glaciers is 371 km^2, and they constitute about 16 % of the glacier area in Norway (Andreassen and others 2022).

Methods

The distance to the glacier terminus from one or several fixed points is measured in defined direction(s), usually in September or October every year. The change in distance gives an estimate of the length change of the glacier. It is questionable how representative front variation estimates based on measurements from one reference point can be for the entire glacier front. However, when longer periods are considered, the measurements give valuable information about glacier fluctuations and regional tendencies (Andreassen and others 2020).

Results 2022

Thirty-four glaciers were measured, eight glaciers in northern Norway and twenty-six glaciers in southern Norway. The results for 2022, period(s) of measurements and number of observations (calculated front variations) are listed in Table 12-1. Thirty-three glaciers retreated in 2022, and one glacier showed no change. The annual front variation varied from 0 meter for Midtdalsbreen (no change) to −94 meter for Storjuvbrean. The average annual retreat for the thirty-four glaciers was −25 meters. Five glaciers in the monitoring programme were not measured in 2022.

The median and mean cumulative front variation for the ten-year period 2012-22 for 32 glaciers was −165 and −209 meters, respectively, ranging from −629 meters at Gråfjellsbrea to −43 meters at Svelgjabreen. Both glaciers are outlet glaciers from the southern part of Folgefonna. Eight glaciers in northern Norway retreated on average 239 meters, and 24 glaciers in southern Norway retreated on average 200 meters. Data are available at http://www.nve.no/glacier.

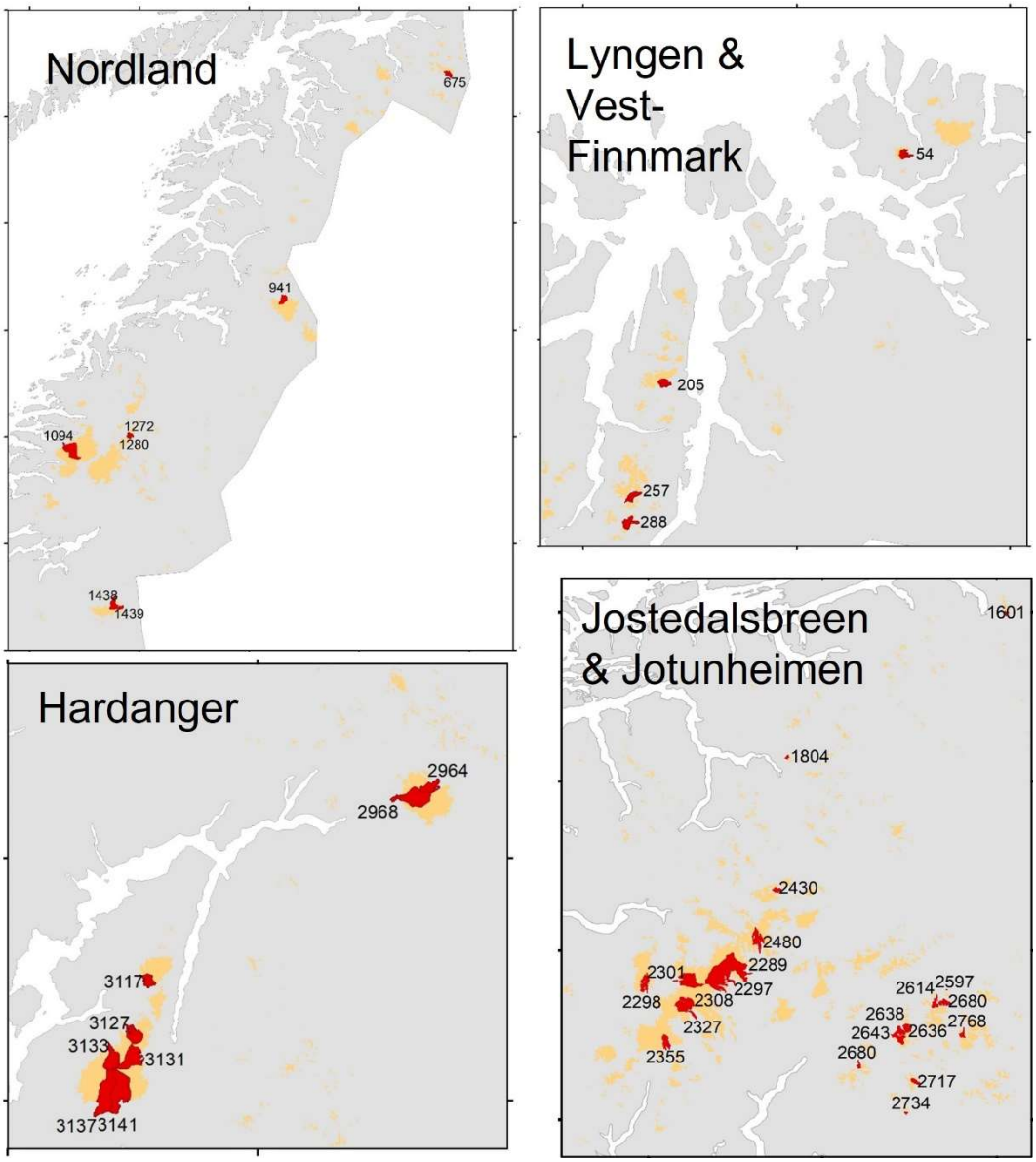


Figure 12-1
Map showing glaciers included in the length change monitoring programme (in red) with glacier IDs (Tab. 12-1). Note that the different glacier areas are not to the same scale.

Figure 12-2
Sydbreen (Glacier ID 257), an east-facing valley glacier in Lyngen, Troms, was photographed on 20 July 2022. Sydbreen is partly nourished by ice avalanches from the glacier on Jiehkkevárri (Glacier ID 254, upper right). Front variation measurements have been conducted since 2007, and the terminus has retreated 182 meters since then. Photo: Halvard Berg.

Corrections of previously reported results

1601 Vinnufonna 2020/21: from −24 to −13 meters. Misunderstanding of which reference point was used.

2717 Mjølkedalsbreen 2020/21: from −5 to −17 meters. Misunderstanding of which reference point was used.

2643 Bøverbrean: from 2013/2016 (+12 m) and 2016/17 (−22 m) to 2013/17 −10 m. The terminus was covered with old snow in 2016, and this observation is rejected.

Table 12-1
Glacier front variations measured in 2022. See Figure 12-1 for glacier locations.

	Glacier	Glacier-ID	2022	Observer	Period(s)	Number obs.
Finnmark & Troms	Langfjordjøkelen	54	−61	NVE	1998-	26
	Koppangsbreen	205	−7	NVE	1998-	23
	Sydbreen	257	−12	NVE	2007-	14
	Steindalsbreen	288	−39	NVE	1978-	30
Nordland	Storsteinsfjellbreen	675	*−18	NVE	2006-	17
	Rundvassbreen	941	*−8	SISO	2011-	11
	Engabreen	1094	−28	S	1903-	90
	Skjelåtindbreen	1272	NM	NVE	2014-	3
	Trollbergdalsbreen	1280	NM	NVE	2010-	6
	Austre Okstindbreen	1438	−35	NVE	1908-44, 2006-	30
	Corneliussenbreen	1439	NM	NVE	2006-	10
Sunnmøre & Breheimen	Vinnufonna	1601	NM	NVE	2019-	2
	Trollkyrkjebreen	1804	−32	NVE	1944-74, 2008-	27
	Heimsta Mårådalsbreen	2430	*−25	NVE	2002-	7
Jostedalsbreen	Fåbergstølsbreen	2289	−14	NVE	1899-	117
	Nigardsbreen	2297	−23	NVE	1899-	112
	Haugabreen	2298	−35	NBM	1933-41, 2013-	17
	Brenndalsbreen	2301	−19	NVE	1900-62, 1964-65, 1996-	84
	Tuftebreen	2308	−65	NVE	2007-	15
	Austerdalsbreen	2327	−12	NVE	1905-19, 1933-	102
	Vetle Supphellebreen	2355	NM	NBM	1899-44, 2011-	46
	Stigaholtbreen	2480	−37	NVE	1903-	116
Jotunheimen	Styggebrean	2608	−7	NFS	1951-63, 2011-	19
	Storjuvbrean	2614	−94	NVE	1901-07, 08-12, 33-61, 97-	62
	Storbreen	2636	−18	NVE	1902-	84
	Leirbrean	2638	−31	NVE	1907-77, 1979-	63
	Bøverbrean	2643	−35	NVE	1903-76, 1997-	49
	Styggedalsbreen	2680	−30	NVE	1901-	101
	Mjølkedalsbreen	2717	−3	NVE	1978-	27
	Koldedalsbreen	2734	[4]−13	NVE	1978-	15
	Hellstugubreen	2768	−18	NVE	1901-	83
Hardanger	Midtdalsbreen	2964	0	AN	1982-	40
	Rembesdalskåka	2968	−11	S	1917-	47
	Botnabrea	3117	−14	GK	1996-	19
	Gråfjellsbrea	3127	−4	S	2002-	20
	Buerbreen	3131	−26	NVE	1900-	76
	Bondhusbrea	3133	−34	S	1902-	91
	Svelgjabreen	3137	−3	SKL	2007-	15
	Blomstølskardsbreen	3141	−23	SKL	1994-	23

* – two years
[4] – four years
NM – not measured in 2022

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

Addenda based on mapped glacier termini

Where the glacier terminus is geolocated on maps, aerial photos or mapped end moraines, the front variations record can be extended. The front variations are either calculated in the measuring direction from a geolocated reference point, or along a central flow line (Tab. 12-2). For Bødalsbreen between 1962 and 1966 the four-year change is estimated as 30 ±10 meters to tie together the periods 1900-1962 and 1966-2022. The glacier had been advancing slowly since 1955, and for a couple of years the observer had reported difficulties with doing the measurements because he could not cross the river. In 1965 the observer reported that the glacier had advanced 5-10 meters during the summer but was unable to measure precisely.

Table 12-2
Glacier front variations addenda from mapped glacier termini. See Figure 12-1 for glacier locations.

Glacier	Bre-ID	Date	Source	Period	Reference	Change (m)	Uncert. (m)
Sydbreen	257	12.07.1993	N50-map	1993-2006	Flowline	−85	5
Sydbreen	257	29.07.2006	Orthophoto	2006-2007	SYDB07	−7	2
Skjelåtindbreen	1272	25.08.1968	Map	1968-1985	SKJEL2014	−130	5
Skjelåtindbreen	1272	19.08.1985	Map	1985-2008	SKJEL2014	−60	5
Skjelåtindbreen	1272	24.08.2008	Orthophoto	2008-2014	SKJEL2014	−61	5
Trollbergdalsbreen	1280	25.08.1968	Map	1968-1985	TROLB10	-120	5
Trollbergdalsbreen	1280	19.08.1985	Map	1985-2008	TROLB10	-180	5
Trollbergdalsbreen	1280	24.08.2008	Orthophoto	2008-2010	TROLB10	-40	5
Lodalsbreen	2266	10.9.2005	Orthophoto	1993-2005	Flowline	-170	10
Lodalsbreen	2266	7.9.2010	Orthophoto	2005-2010	Flowline	-55	10
Lodalsbreen	2266	20.8.2015	Orthophoto	2010-2015	Flowline	-65	10
Lodalsbreen	2266	20.7.2017	Orthophoto	2015-2017	Flowline	-30	10
Bødalsbreen	2273			1962- 1966	Estimated	+30	10
Bødalsbreen	2273	21.7.1966	Orthophoto	1966-1993	Flowline	+85	10
Bødalsbreen	2273	23.8.1993	N50 map	1993-1996	Flowline	+65	10

13. Jøkulhlaups and runoff from glacier lakes (Bjarne Kjøllmoen)

Jøkulhlaups, also known as Glacier Lake Outburst Floods (GLOFs), and emptied glacier lakes, were registered at eight glaciers in Norway in 2022. Four of the events were observed on photographs and satellite images only.

Events were observed from glacier lakes at Rundvassbreen (Blåmannsisen), Rembesdalskåka (Hardangerjøkulen), Storskavlen and Supphellebreen (Jostedalsbreen) (Fig. 13-1).

Inspection of glacier lakes on photographs and Sentinel-2 imagery showed drainage events at Oksfjellbreen (Okstindbreen), Sandåbreen, Svellnosbrean and Vestre Memurubrean (Fig. 13-1).

Figure 13-1
Jøkulhlaups and runoffs from glacier lakes were registered at eight glaciers in 2022, two in northern Norway (left) and six in southern Norway (right). Map source: norgeskart.no.

13.1 Events observed in the field

1 Rundvassbreen

Øvre Messingmalmvatnet (1043 m a.s.l.) is adjacent to and dammed by Rundvassbreen, a northern outlet glacier of the Blåmannsisen ice cap in northern Norway (Fig. 13-2). There have been many previous events recorded from Øvre Messingmalmvatnet (Tab. 13-1), the earliest in 2001 (Engeset, 2002).

Figure 13-2
The glacier-dammed lake Øvre Messingmalmvatnet. The photograph is taken on 24th August 2022. Photo: Steinar Karlsen, SISO Energi AS.

Jøkulhlaup 2022

During the night and early morning of 6th September a jøkulhlaup occurred at Rundvassbreen. About 29 million cubic metres of water drained under the glacier during a few hours. This is two years after the previous event, and the twelfth year that the subglacial lake has drained since the first known jøkulhlaup in 2001. Satellite images from 4th and 7th September show the lake before and after the jøkulhlaup (Fig. 13-3).

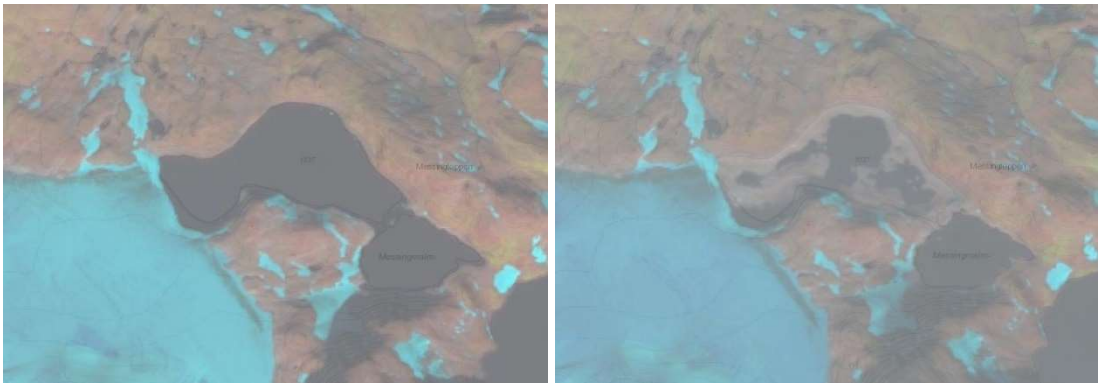


Figure 13-3
Satellite images (Sentinel-2) taken before and after the event. The left image was taken on 4th September and the right image on 7th September 2022. Source: Varsom Xgeo.

The water level in Øvre Messingmalmvatnet was measured with GNSS on 2nd September to 1043.96 m a.s.l. The water level four days later when the jøkulhlaup started on 6th September was estimated to 1044.20 m a.s.l. The water level after the event is estimated to 1007.1 m a.s.l. based on earlier measurements. Thus, the water level dropped 37 meters during this jøkulhlaup (Fig. 13-4).

Figure 13-4
Øvre Messingmalmvatnet (in the middle of the photo) photographed on 9th September 2022, three days after the jøkulhlaup. The hydropower reservoir Lake Sisovatnet, where the water from the jøkulhlaup ends up, is seen in the background. Photo: Steinar Karlsen, Siso Energi AS.

Several previous events of different magnitudes have been recorded from Rundvassbreen (Jackson and Ragulina, 2014). The first was in September 2001, when 35 mill. m^3 of water suddenly drained under the glacier and subsequently to the hydropower reservoir, Lake Sisovatnet. Previously the water had drained over a rock sill and flowed into a river towards Sweden (Engeset et al., 2005). The event in 2022 was the twelfth, and the interval between events has varied from one year to four years. All recorded events from Rundvassbreen have been in late summer, i.e. August or September (Tab. 13-1).

Table 13-1
Dates, water level before and after the drainages and approximate water volumes of jøkulhlaups from Øvre Messingmalmvatnet 2001-2022.

Year	Date	Water level (m a.s.l.)		Comment	Water volume
		Before	After		(mill. m^3)
2001	5th – 7th September	~1051	~1007	WL estimated	35
2005	27th – 29th August	~1051	~1007	WL estimated	35
2007	29th August	~1040	~1007	WL estimated	20
2009	6th - 7th September	~1040	~1007	WL estimated	20
2010	8th - 17th September	~1028	~1007	WL estimated	11
2011	22nd September	1029	1007.5	WL measured	13
2014	10th - 12th August	1050	1007.3	WL measured	36
2016	28th - 29th September	1040.7	~1007	WL measured/estimated	25
2018	25th - 26th August	1039.8	1007.3	WL measured	24
2019	9th - 10th September	1026.2	1007.2	WL measured	11
2020	3rd - 4th September	1025.4	1007.0	WL measured	10
2022	6th September	1044.2	1007.1	WL measured/estimated	29

2 Rembesdalskåka

Rembesdalskåka, an outlet glacier of Hardangerjøkulen, dams a lake called Nedre Demmevatnet (Fig. 13-5). There have been many previous events recorded from Nedre Demmevatnet (Tab. 13-2), the earliest in 1736 (Liestøl, 1956). In the years leading up to 1893 the lake emptied almost every year, usually taking two to three weeks to drain. However, individual events without damage were not recorded. During the event in 1893, the lake drained in just 24 hours.

Figure 13-5
The lake Nedre Demmevatnet is dammed by the ice-barrier at Rembesdalskåka. The photograph is taken on 14th August 2022. Photo: Yongmei Gong.

Jøkulhlaup 2022

A new event occurred at the glacier-dammed lake during the night between 29th and 30th August 2022 (Fig. 13-6). Over about 11 hours, ca. 2.2 million m^3 water drained under Rembesdalskåka and subsequently to the hydropower reservoir Rembesdalsvatnet. Satellite images from 4th and 7th September show the lake before and after the jøkulhlaup (Fig. 13-6). A photograph from 30th August shows the empty glacier lake after the jøkulhlaup (Fig. 13-7).

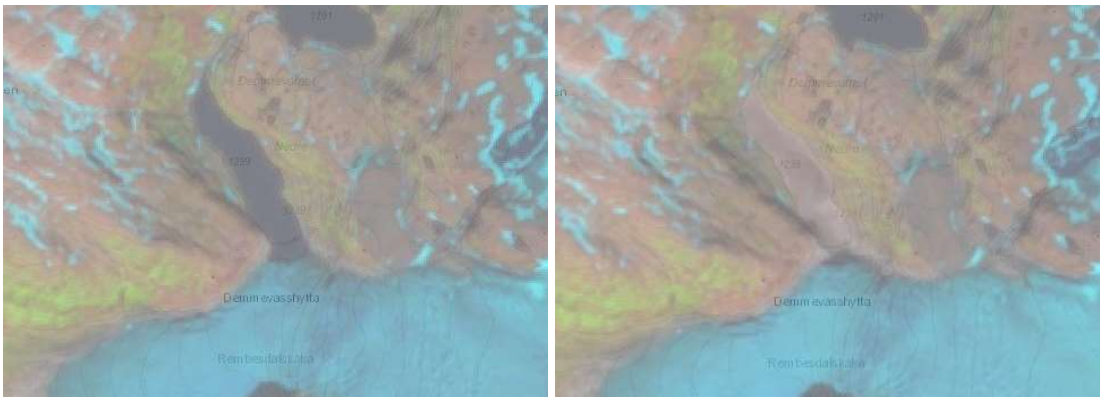


Figure 13-6
Satellite images (Sentinel-2) taken before and after the event. The left image was taken on 28th August and the right image on 2nd September 2022. Source: Varsom Xgeo.

Figure 13-7
The empty glacier lake Nedre Demmevatnet, and the ice barrier photographed on 30th August 2022, the day after the jøkulhlaup. Photo: Statkraft Energi AS.

Table 13-2
Dates and approximate volumes of jøkulhlaups from Nedre Demmevatnet. For events that occurred since 2014 the water volume is calculated by Statkraft as extra inflow to the hydro-power reservoir Rembesdalsvatnet.

Year	Date	Comment	Water volume (mill. m^3)
1736	unknown	Earliest record of flood from Demmevatnet	unknown
1813	unknown	Flood damages	unknown
1842	unknown	Flood damages	unknown
1861	17th September	Damage, including two bridges	unknown
1893	Late August	Catastrophic flood, lake drained in 24 hours	35
1897	17th August	Water flowed over glacier surface, lasted 24 hours	35
1937	10th August	Drained in 3.5 hours	12
1938	23rd August	Flood before new drainage tunnel completed	10
2014	24th August	Event occurred over ~3 hours	1.9
2016	~25th January	Lake observed full 24th January and empty 30th January	1.44
2016	6th September	Event occurred over ~4 hours	1.87
2017	27th October	Event occurred over ~22 hours	1.85
2018	10th August		unknown
2019	24th August	Event occurred over ~3 hours	1.8
2020	6th September	Event occurred over 5-6 hours	2.3
2021	13th July	Event occurred over 3-4 hours	1.75
2022	29th-30th August	Event occurred over ~11 hours	2.19

3 Storskavlen

Storskavlen is a small glacier (3.4 km2) located in southern Norway, about 20 km north of Hardangerjøkulen, in the municipality of Aurland (Fig. 13-1). An ice-dammed lake is situated in the northern part of the glacier (Fig. 13-8). Over the last 15-20 years the glacier surface has melted down, and in the same period the lake has grown and now covers an area of about 0.6 km2. No previous events have been observed from this glacier lake.

Figure 13-8
The glacier lake at Storskavlen photographed on 20th September 2022 in a northwest direction.
Photo: Guttorm Mathismoen, Hafslund Eco Vannkraft.

Jøkulhlaup 2022

On 6th September 2022 a hiker observed water draining on the glacier surface from the glacier lake. Examination of Sentinel images from 2nd and 7th September confirm the water runoff (Fig. 13-9). Photographs from 20th September showed that a 1-2 m deep channel had formed, and that the lake level was lowered similarly (Fig. 13-10). Hence, the drained water volume from this event is estimated to about 1 mill. m^3.

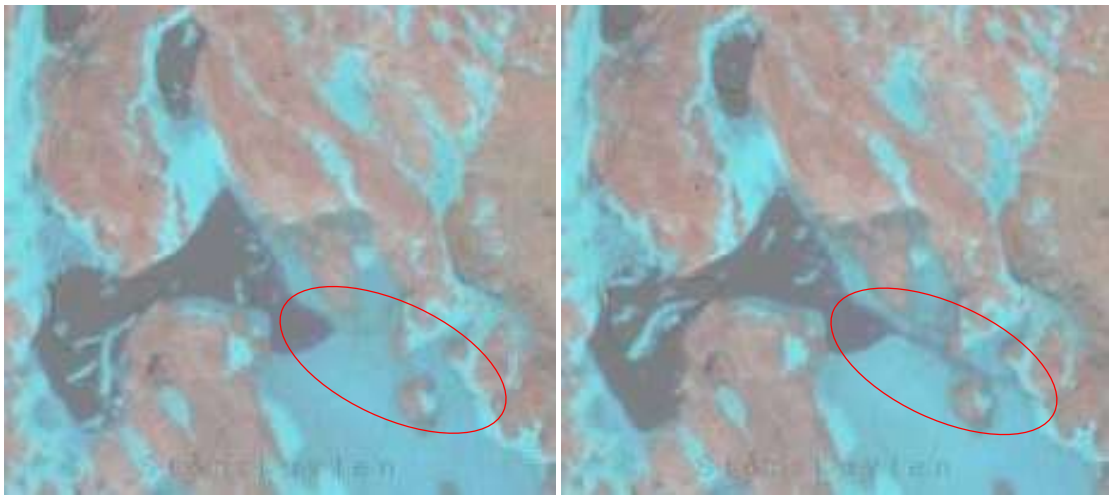


Figure 13-9
Satellite images (Sentinel-2) taken before and during the runoff. The left image was taken on 2nd September and the right image on 7th September 2022 while the runoff was still going on. The runoff from the lake via the ice channel is visible within the red ellipse. Source: Varsom Xgeo.

Figure 13-10
The ice channel photographed on 20th September 2022 in a southeast direction.
Photo: Guttorm Mathismoen, Hafslund Eco Vannkraft.

4 Supphellebreen

Supphellebreen is an outlet glacier of the southern part of Jostedalsbreen (Fig. 13-1). The southern and lower part of Supphellebreen is called Flatbreen. On the western side of the glacier terminus there is a moraine ridge formed around 1900. Due to glacier retreat, a small lake has formed between the moraine and the glacier (Fig. 13-11). There have been some previous events from the lake, the last in 2004 (Kjøllmoen, 2005), when the lake level increased and the moraine ridge was breached.

Figure 13-11
Orthophoto from 2017 showing the lower part of Flatbreen. The small glacier lake, the moraine ridge and the breach in the moraine from the event in 2004 to the left. Photo: norgeibilder.no.

Jøkulhlaup 2022

A new event, like a flash flood, occurred from the glacier lake at Flatbreen in the evening of 11th November 2022. The incident occurred after some hours of heavy rainfall and relatively high temperatures. The debris flow and flood started at 6pm in the evening and lasted for seven hours. The water flowed out of the glacial lake through the moraine opening that was formed during the event in 2004 (Fig. 13-12). The flash flood carried large stones and gravel down to the fields in Supphelledalen, but the damage of farmland and roads was minor compared to the incident in 2004.

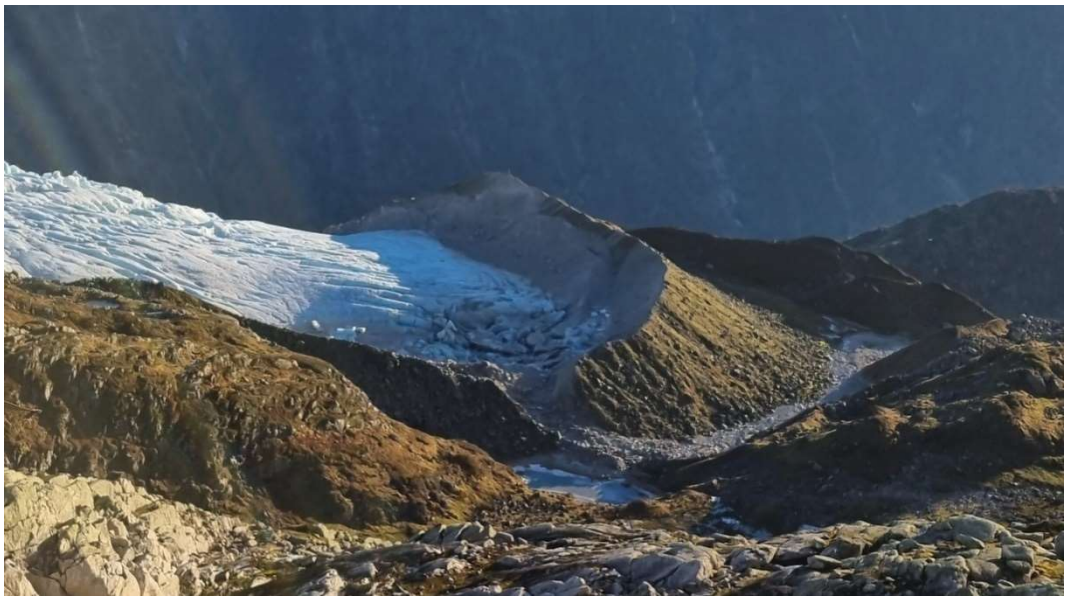


Figure 13-12
The moraine ridge from 1900 and the breach in the moraine where the water flowed out of the lake photographed on 18th November 2022. Photo: Vegard Nes.

13.2 Events observed by photography and satellite images only

5 Oksfjellbreen

Oksfjellbreen is a southern outlet from the ice cap Okstindbreen in Nordland county (Fig. 13-1). A small ice-dammed lake is located in the northern part of the glacier (Fig. 13-13). Runoffs from Oksfjellbreen were registered also in 2020 and 2021.

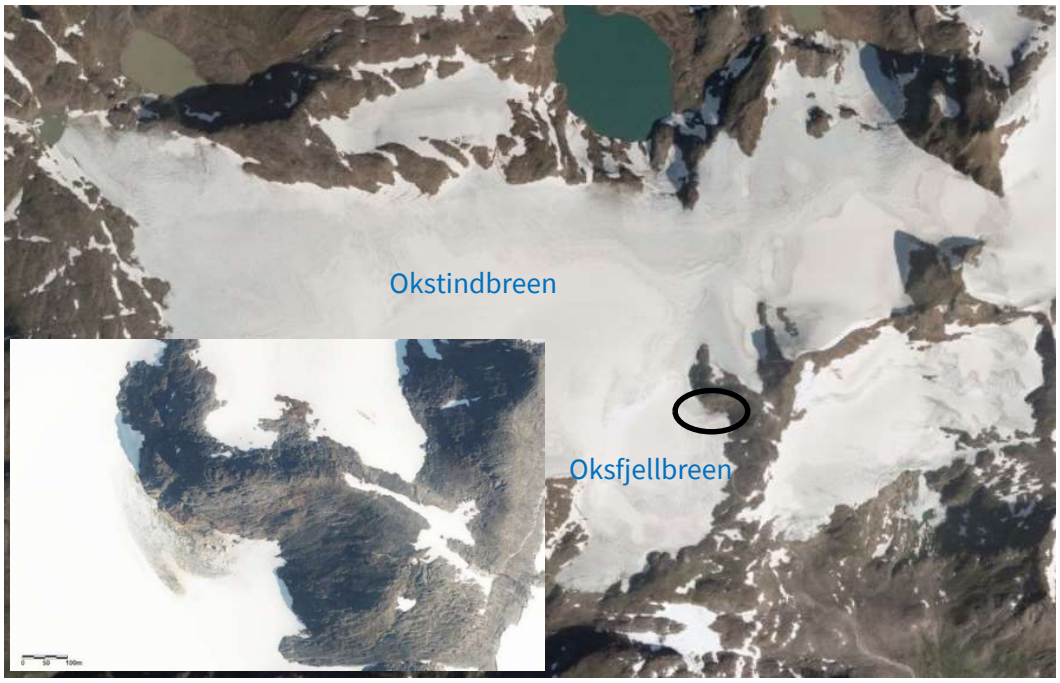


Figure 13-13
Oksfjellbreen is a southern outlet from the ice cap Okstindbreen. The glacier-dammed lake is located on the north-eastern side of the Oksfjellbreen outlet, indicated by the black ellipse. The inset image shows an empty glacier lake on 28th July 2021, one month after the previous event.
Photo: Orthophotos from norgeibilder.no.

Jøkulhlaup 2022

Satellite images indicate two events in 2022. A comparison of images from 19th and 26th June 2022 suggest that the glacier-dammed lake emptied during this period (Fig. 13-14), and a comparison of images from 18th August and 4th September 2022 suggest another event in this period (Fig. 13-15).

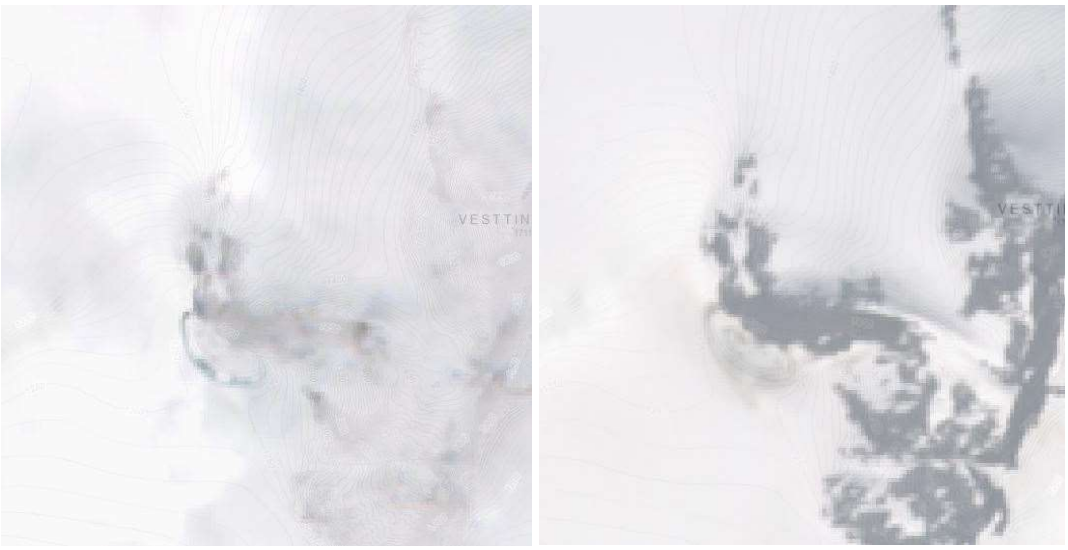


Figure 13-14
Sentinel-2 images showing the glacier-dammed lake at Oksfjellbreen. On 19th June (left) the lake was filled with water, and on 26th June (right) the lake was empty. Source: Varsom Xgeo.

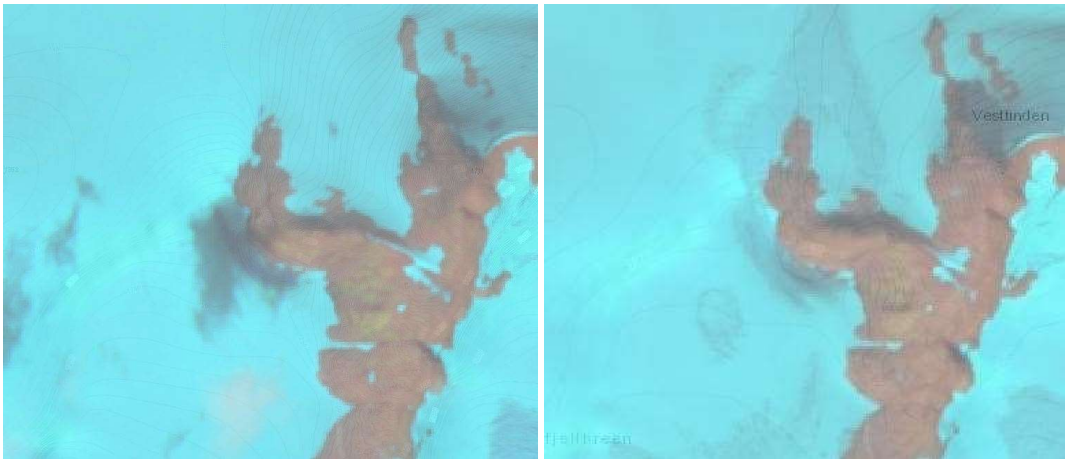


Figure 13-15
Sentinel-2 images from 18th August (left) showing water in the lake, and from 4th September (right) showing an empty lake. Source: Varsom Xgeo.

6 Sandåbreen

Sandåbreen is a glacier with an area of 5 km^2 located 10 km northeast of Jostedalsbreen, in Innlandet county (Fig. 13-1). A small ice-dammed lake is located in the northern part of the glacier (Fig. 13-16). Three events have been observed previously at Sandåbreen, in July 2018, August 2019 and September 2021. Subsequent inspection of Sentinel-2 satellite images suggests that there could also have been events in 2016 and 2017, but the images are somewhat indistinct and hence, indication of jøkulhlaups are rather uncertain.

Figure 13-16
Sandåbreen and the glacier-dammed lake at the northern ice edge as seen from the air on 19th August 2015. The inset image shows a close-up of the lake. Photo: Orthophoto from norgeibilder.no.

Jøkulhlaup 2022

Examination of Sentinel-2 images from 30th June and 22nd July 2022 suggest that the glacier-dammed lake was drained in this period (Fig. 13-17). The images show more water in the lake on 30th June than on 22nd July.

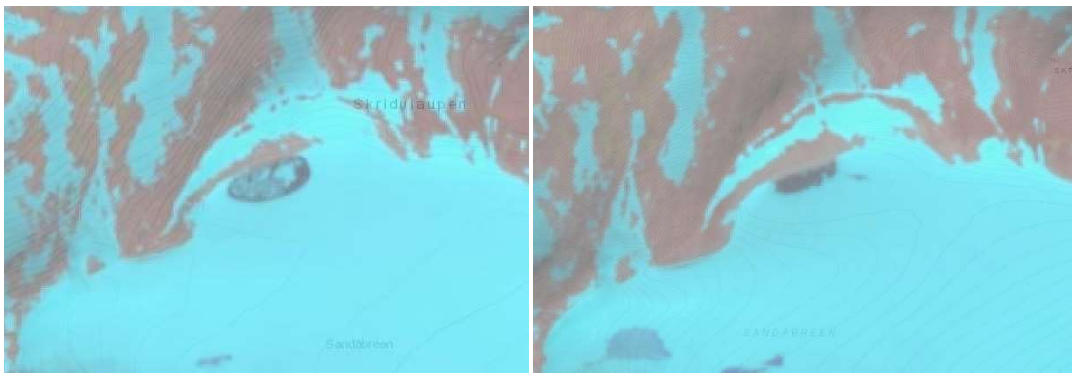


Figure 13-17
Sentinel-2 images of the glacier-dammed lake at Sandåbreen from 30th June (left) and 22nd July (right) 2022. The images show more water in the lake on 30th June than on 22nd July, indicating that the lake was drained in the period. The area of the water-filled lake before the event was approximately 0.025 km^2. Source: Varsom Xgeo.

7 Svellnosbrean

Svellnosbrean is a glacier with an area of 4.8 km^2 located in the central part of Jotunheimen (Fig 13-1). A small supraglacial lake is located in the western part of the glacier (Fig. 13-18). Subsequent inspection of Sentinel-2 satellite images from three more years suggest that there also have been events in 2019, 2020 and 2021.

Figure 13-18
Svellnosbrean and the supraglacial lake photographed on 30th June 2022 in a southwest direction.
Photo: Norsk Fjellsenter.

Jøkulhlaup 2022

Satellite images suggest that the supraglacial lake was filled up over a few days in the end of June (Fig. 13-19) and emptied in the end of July (Fig. 13-20).

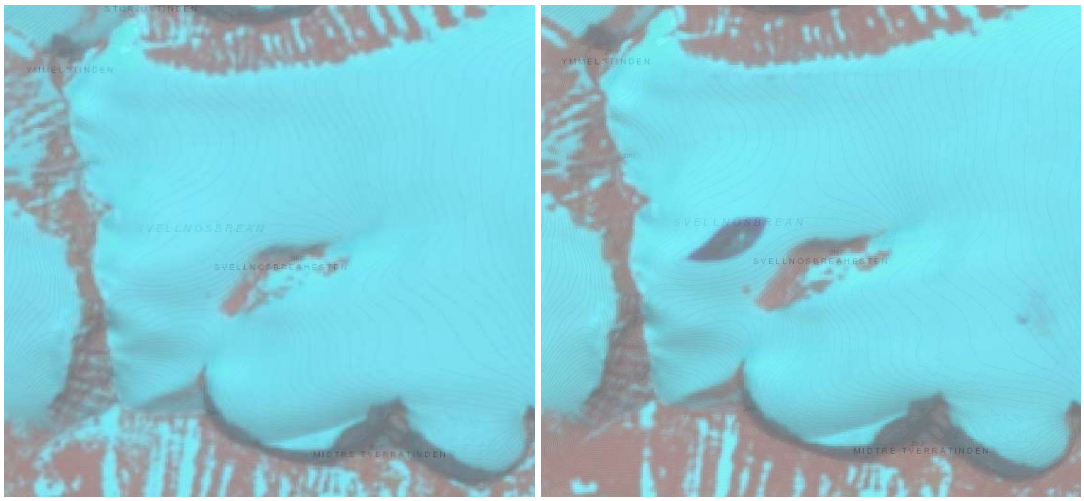


Figure 13-19
Sentinel-2 satellite images showing that the supraglacial lake at Svellnosbrean was formed between 24th (left) and 29th June 2022 (right). Source: Varsom Xgeo.

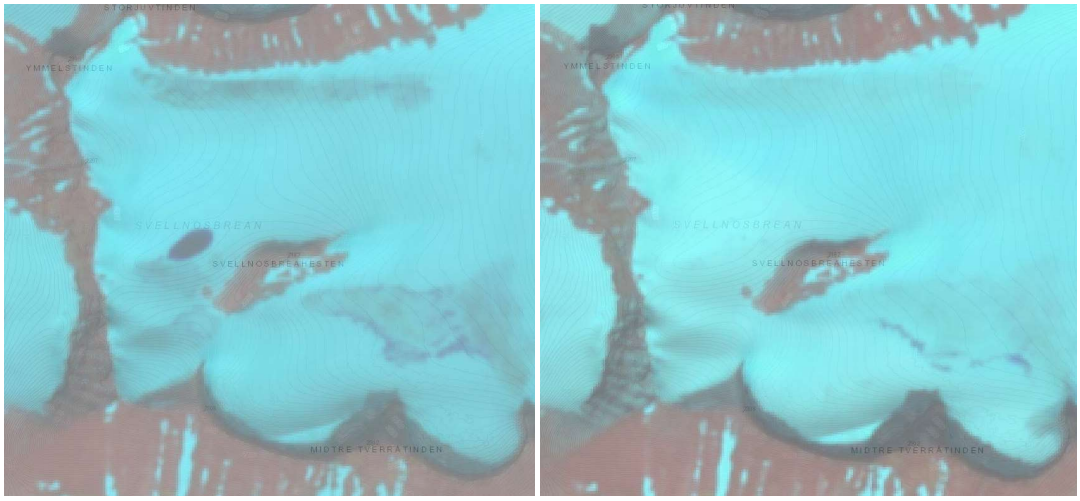


Figure 13-20
Sentinel-2 satellite images of the supraglacial lake at Svellnosbrean on 22nd (left) and 27th July 2022 (right). The images show that the lake was completely drained in this period. However, comparison of the images from 29th June and 22nd July indicate that the runoff from the lake had already started at the time of photographing on 22nd July. Source: Varsom Xgeo.

8 Vestre Memurubrean

Vestre Memurubrean is a glacier with an area of 8 km^2 located in the central part of Jotunheimen (Fig 13-1). A small glacier-dammed lake is located in the southern part of the glacier (Fig. 13-21). Two events have occurred previously at Vestre Memurubrean, in July/August 2017 and in July 2018.

Figure 13-21
Vestre Memurubrean and the supraglacial lake photographed from Hinotefjellet on 1st July 2023. Photo: Liss M. Andreassen.

Jøkulhlaup 2022

Examination of Sentinel-2 images from 29th June and 19th July 2022 suggest that the supraglacial lake was emptied during this period (Fig. 13-22).

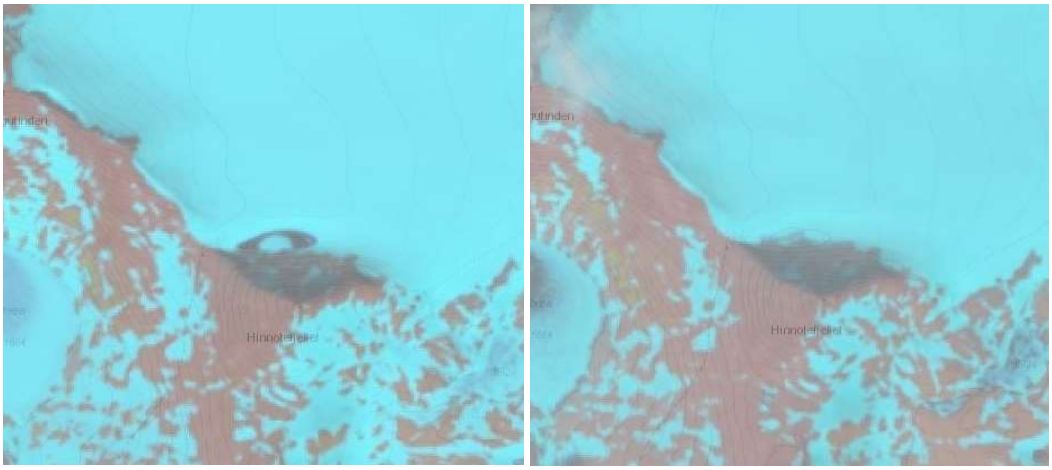


Figure 13-22
Sentinel-2 satellite images of the supraglacial lake at Vestre Memurubrean from 29th June (left) and 19th July (right) 2022. The images show that the lake was drained during the period. Source: Varsom Xgeo.

14. 60 years of glacier measurements

14.1 Background

The history of «Brekontoret» (The glacier office) started in 1961. Several plans of hydropower development in Norway required knowledge about the glaciers and particularly data about the mass balance and the glacier runoff. Hence, during the spring 1962 NVE started mass balance measurements at Nigardsbreen (Fig. 14-1). At the same time mass balance measurements were started at four other glaciers by students from The University of Oslo supported by NVE. The four glaciers were Tverråbreen, Blåbreen, Hellstugubreen and Gråsubreen, all situated in Jotunheimen. Mass balance measurements on Storbreen in Jotunheimen were already started in 1949 by Olav Liestøl at the Norwegian Polar Institute. In the 1960s mass balance measurements were started on several other glaciers, and in 1968 NVE measured mass balance at 15 glaciers (Pytte, 1969). In addition to mass balance measurements, river discharge and sediment transport in glacial rivers were measured at several locations. Some of the mass balance series were terminated after typically 5-7 years, but seven of the long-term time series (back to 1970 or longer) are still running. These long-term series include Engabreen, Ålfotbreen, Nigardsbreen, Rembesdalskåka, Storbreen, Hellstugubreen and Gråsubreen. Front variation measurements were started around 1900 by John B. Rekstad (Rekstad, 1902) and Peter A. Øyen (Øyen, 1906). Since 1994 NVE has been responsible for these measurements (Elvehøy et al., 1997).

Figure 14-1
Wibjörn Karlén and Randi Pytte on Nigardsbreen in May 1962.

14.2 Historical overview of the glacier work in NVE

1962 “Brekontoret” (The glacier office) was established and Gunnar Østrem was employed as office manager

1962 Mass balance measurements started on Nigardsbreen (Østrem and Karlén, 1962), Hellstugubreen, Gråsubreen, Tverråbreen and Blåbreen (Østrem and Liestøl, 1964)

1963 The first mass balance measurements started in northern Norway, on Blåisen in Skjomen (Østrem and Liestøl, 1964)

1964 The first detailed glacier maps were printed, part of Folgefonna and Storsteinsfjellbreen

1965 The first glaciological summary report from NVE was published (Fig. 14-2) (Pytte and Østrem, 1965)

1969 A revised manual for field and office work related to glacier mass balance measurements was published (Fig. 14-2) (Østrem and Stanley, 1969)

1969 The first atlas of glaciers in southern Norway was published (Fig. 14-3) (Østrem and Ziegler, 1969)

1970 Mass balance measurements started on Engabreen (Tvede, 1971)

1973 The first atlas of glaciers in northern Scandinavia was published (Fig. 14-3) (Østrem et al., 1973)

1978 A subglacial intake beneath Bondhusbrea was established (Wold and Repp, 1979)

1985 The first successful radar measurements for measuring ice thickness, at Jostedalsbreen (Sætrang and Wold, 1986)

1988 A revised atlas of glaciers in southern Norway was published (Østrem et al., 1988)

1989 Mass balance measurements started in the far north, on Langfjordjøkelen (Østrem, 1991)

1991 Another revised version of a manual for field and office work related to glacier mass balance measurements was published (Østrem and Brugman, 1991)

1992 The Svartisen subglacial laboratory was established

1993 NVE took over responsibility for the mass balance measurements on Storbreen and front variation measurements in Norway from Norwegian Polar Institute

1997 50th anniversary and symposium for mass balance measurements on Storbreen (Andreassen and Østrem, 1999)

2001 The first glacier mapping with LIDAR, at Engabreen

2008 NVE organized an international workshop on “Glacier mass balance measurements and modelling”

2012 Inventory of Norwegian glaciers based on Landsat satellite images during the period 1999-2006 was published (Fig. 14-3) (Andreassen and Winsvold, 2012)

2012 50 years of glacier measurements in NVE were celebrated

2021 Inventory of Norwegian glaciers based on Sentinel-2 satellite images in 2018 and 2019 was published (Andreassen et al., 2022)

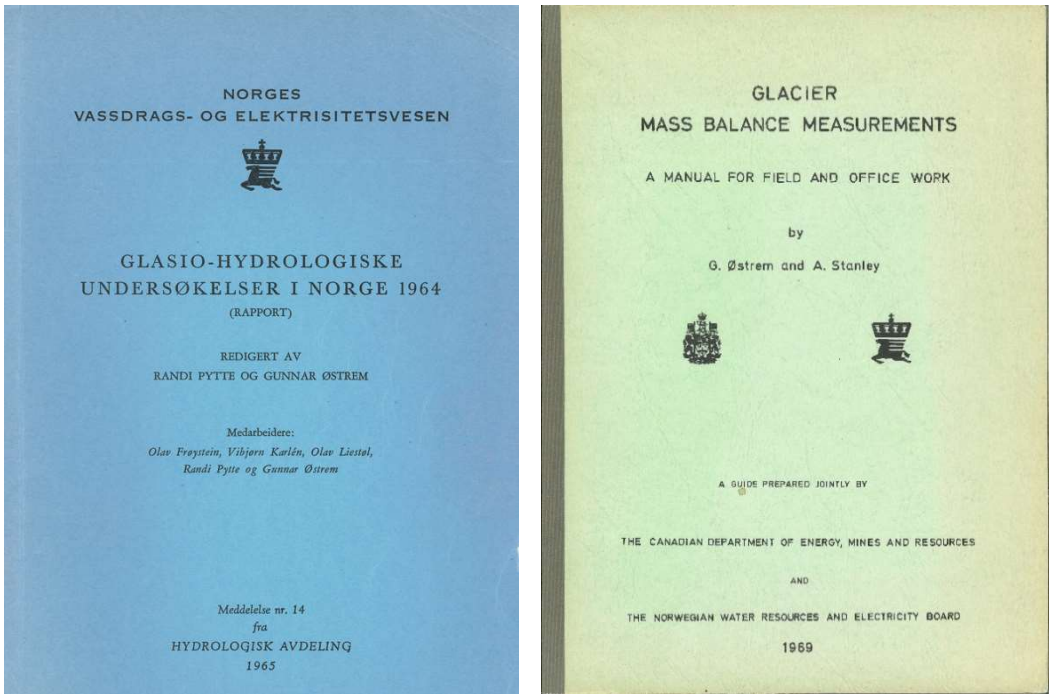


Figure 14-2
To the left, the first report from NVE regarding the glacio-hydrological investigations in Norway. To the right, the first manual for field and office work related to glacier mass balance measurements.

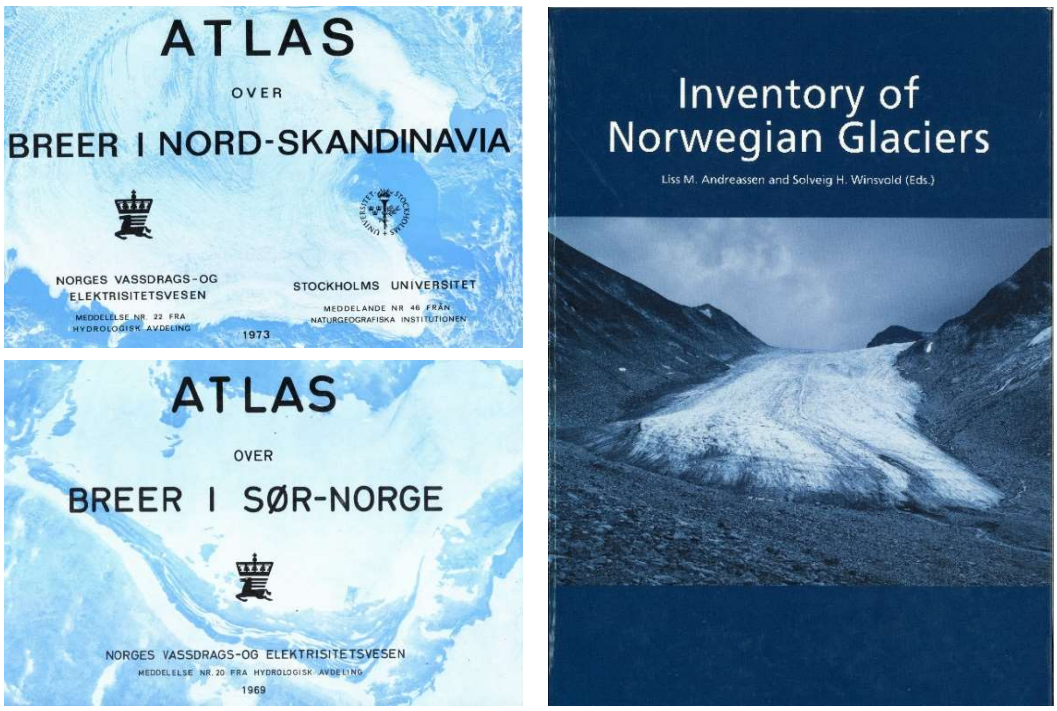


Figure 14-3
To the left, the first atlas of glaciers in northern Norway (upper) and in southern Norway (below). To the right, Inventory of Norwegian Glaciers published in 2012.

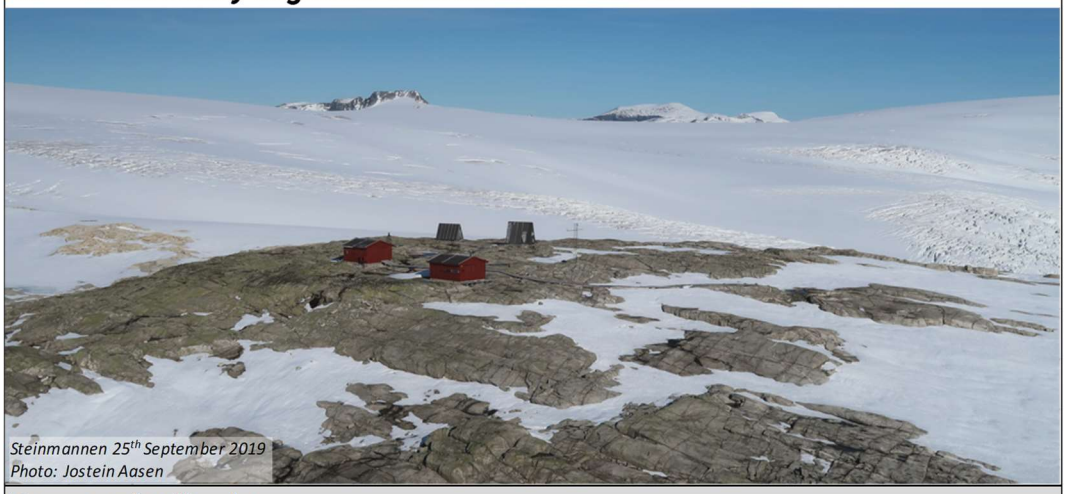
14.3 The 60th anniversary

The anniversary of 60 years of glacier measurements was organized in the premises of NVE on 14th November 2022. Forty-six participants were registered, most of them current or former employees of NVE (Fig. 14-4) or professionals from other institutions (Fig. 14-5). After registration and welcome the event continued with several presentations interrupted by a coffee break halfway through. The speakers are shown in the program below.

Figure 14-4
Some of the former employees at "Brekontoret" from the 1960's, 1970's and 1980's.

Figure 14-5
One of the speakers, Geir Moholdt from Norwegian Polar Institute.

60th anniversary of glacier measurements in NVE



Steinmannen 25th September 2019
Photo: Jostein Aasen

Program for the day			
12:30	13:00		Registration at the reception
13:00	13:10	Hege Hisdal	Welcome
13:10	13:40	Ketil Isaksen	Mountain climate in the last 150 years
13:40	14:00	Kamilla Sjursen	Bayesian mass balance modeling of Norwegian glaciers
14:00	14:20	Geir Moholdt	Marine mass balance on Svalbard
14:20	14:40	Rune Engeset	From the Brekontoret to today's HB
14:40	15:20		Tea, coffee, mineral water, cakes, fruit
15:20	15:40	Bjarne Kjøllmoen	Mass balance measurements in Norway
15:40	16:00	Liss M. Andreassen	Mapping of glaciers in Norway
16:00	16:20	Hallgeir Elvehøy	Front surveys in Norway
16:20	16:40	Bjørn Lytskjold	Storbreen
16:40	17:45		Photo exhibition with award for best photo and aperitif in the library
18:00	22:00		Dinner buffet in the NVE canteen

After the presentations a photo exhibition with award for best photos was held in the library premises. 88 photos taken of Norwegian glaciers in 2022 by 21 photographers participated in the exhibition and competition. The photos were evaluated by a qualified jury from NVE. It was contested in four classes, “Glacier portrait”, “Man on glacier”, “Open class” and “Front page of the next Glaciological report”. The four winner photos are shown below (Fig. 14-6, 14-7, 14-8 and 14-9).

Figure 14-6
Left photo and winner of "Glacier portrait", Fannaråkbreen photographed on 11th September by Lorenzo Poli.
Right photo and winner of "Man on glacier", Austdalsbreen photographed on 9th March by Jostein Aasen.

Figure 14-7
Winner of "Open class", Steinmannen at Nigardsbreen photographed on 19th May by Jostein Aasen.

Figure 14-8
Winner of "Front page of the next Glaciological report", Grjotbrean photographed on 30th July by Liss M. Andreassen.

Figure 14-9
The winner of "Man on glacier" and "Open class", Jostein Aasen.

At the end of the event, a dinner buffet was served in NVE's canteen and the evening's toastmaster was professor emeritus Jon Ove Hagen (Fig. 14-10). The dinner was seasoned with stories from the former employees. One of them, the retired glaciologist Arve Tvede, described a rather dramatic emergency landing with a small airplane on Jostedalsbreen in June 1972 (Fig. 14-11). At that time, he was a glaciology student, and the only passenger on board the small plane. Luckily the landing went well with no injuries.

Figure 14-10
Jon Ove Hagen was toastmaster for the evening.

Figure 14-11
Arve Tvede depicted a dramatic emergency landing on Jostedalsbreen in June 1972.

15. References

Andreassen, L.M., T. Nagy, B. Kjøllmoen and J.R. Leigh
2022: An inventory of Norway's glaciers from 2018-19 Sentinel-2 data. *Journal of Glaciology, 1-22, https://doi.org/10.1017/jog.2022.20.*

Andreassen, L.M. and H. Elvehøy
2021: Norwegian Glacier Reference Dataset for Climate Change Studies. *NVE Rapport 33 2021*, 21 pp.

Andreassen, L.M., H. Elvehøy, B. Kjøllmoen, and J.M.C. Belart
2020: Glacier change in Norway since the 1960s – an overview of mass balance, area, length and surface elevation changes. *Journal of Glaciology, 66 (256), https://doi.org/10.1017/jog.2020.10*, p. 313-328.

Andreassen, L.M., H. Elvehøy, B. Kjøllmoen and R.V. Engeset
2016: Reanalysis of long-term series of glaciological and geodetic mass balance for 10 Norwegian glaciers. *The Cryosphere, 10, 535-552, doi: 10.5194/tc-10-535-2016*, p. 535-552.

Andreassen, L.M. and S.H. Winsvold (Eds)
2012: Inventory of Norwegian Glaciers. *NVE Report 28*, 236 pp.

Andreassen, L.M. and G. Østrem
1999: Storbresymposiet – 50 år med massebalansemålinger. *NVE Dokument nr. 5*. 58 pp.

Cogley, J.G., R. Hock, A.L. Rasmussen, A.A. Arendt, A. Bauder, R.J. Braithwaite, P. Jansson, G. Kaser, M. Möller, L. Nicholson and M. Zemp
2011: Glossary of Glacier Mass balance and Related Terms. *IHP-VII Technical Documents in Hydrology No. 86, IACS Contribution No. 2, Paris, UNESCO-IHP*, 114 pp.

Elvehøy, H., N. Haakensen, M. Kennett, B. Kjøllmoen, J. Kohler and A.M. Tvede
1997: Glasiologiske undersøkelser i Norge 1994 og 1995. *NVE Publikasjon 19 1997*, 197 pp.

Engeset, R.V.
2002: Jøkulhlaup ved Blåmannsisen. Jøkulhlaupet 2001 og framtidige jøkulhlaup. *NVE Oppdragsrapport 9 2002*, 47 pp.

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

Hanssen-Bauer, I. and E.J. Førland
1998: Annual and seasonal precipitation trends in Norway 1896–1997. *DNMI Report, 27/98*, 37 pp.

Jackson, M and G. Ragulina
2014: Inventory of glacier-related hazardous events in Norway. *NVE Rapport 83 2014*, 221 pp.

Kjøllmoen, B. (Ed), L.M. Andreassen, H. Elvehøy, M. Jackson and R.H. Giesen
2016: Glaciological investigations in Norway 2011-2015. *NVE Rapport 88 2016*, 171 pp.

Kjøllmoen, B. (Ed), L.M. Andreassen, R.V. Engeset, H. Elvehøy and M. Jackson
2005: Glaciological investigations in Norway in 2004. *NVE Rapport 2 2005*, 90 pp.

Lefeuvre, P.-M., M. Jackson, G. Lappegard and J.O. Hagen
2015: Interannual variability of glacier basal pressure from a 20 year record. *Annals of Glaciology 56(70)*. doi: 10.3189/2015AoG70A019.

Liestøl, O.
1956: Glacier Dammed Lakes in Norway. *Norsk geografisk tidsskrift nr. 3-4.* Bind XV, 1955-1956.

Nesje, A., Ø. Lie and S.O. Dahl
2000: Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records? *Journal of Quaternary Science, 15*, p. 587–601.

Pytte, R. (Ed), G. Østrem, O. Liestøl, S.R. Ekman, C. Nielsen and S. Tornås
1969: Glasiologiske undersøkelser i Norge 1968. *NVE Rapport 5 1969*, 149 pp.

Pytte, R., G. Østrem (Eds), O. Frøystein, V. Karlén and O. Liestøl
1965: Glasio-hydrologiske undersøkelser i Norge 1964. *NVE Meddelelse nr. 14, Hydrologisk avdeling*, 64 pp.

Rasmussen, L.A.
2007: Spatial extent of influence on glacier mass balance of North Atlantic circulation indices. *Terra Glacialis 11*, p. 43–58.

Rekstad, J.
1902: Iagttagelser fra bræer i Sogn og Nordfjord. *Norges geologiske undersøgelses, Aarbog for 1902*, No. 3, p. 1-48.

Saloranta, T.M.
2014: New version (v.1.1.1) of the seNorge snow model and snow maps of Norway. *NVE Rapport 6 2014*, 30 pp.

Sætrang, A.C. and B. Wold
1986: Results from the radio echosounding on parts of the Jostedalsbreen ice cap, Norway. *Annals of Glaciology 8*, p. 156-158.

Tvede, A.M. (Ed), L.K. Dyrkorn, O. Liestøl, S. Messel, L. Roald and G. Østrem
1971: Glasiologiske undersökelser i Norge 1970. *NVE Rapport 2 1971*, 111 pp.

Wold, B., K. Repp (Eds), N. Haakensen, O. Kjeldsen, O. Liestøl, S. Messel, A.M. Tvede and G. Østrem
1979: Glasiologiske undersøkelser i Norge 1978. *NVE Rapport 4 1979*, 71 pp.

Zemp, M., E. Thibert, M. Huss, D. Stumm, C.R. Denby, C. Nuth, S.U. Nussbaumer, G. Moholdt, A. Mercer, C. Mayer, P.C. Joerg, P. Jansson, B. Hynek, A. Fischer, H. Escher-Vetter, H. Elvehøy and L.M. Andreassen
2013: Reanalysing glacier mass balance measurements series. *The Cryosphere 7*, p. 1227-1245.

Østrem, G. (Ed), N. Haakensen, B. Kjøllmoen, T. Laumann and B. Wold
1991: Massebalansemålinger på norske breer 1988 og 1989. *NVE Publikasjon 11 1991*, 78 pp.

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

Østrem, G., K. Dale Selvig and K. Tandberg
1988: Atlas over breer i Sør-Norge. *NVE Meddelelse nr. 61, Hydrologisk avdeling*, 248 pp.

Østrem, G., N. Haakensen and O. Melander
1973: Atlas over breer i Nord-Skandinavia. *NVE Meddelelse nr. 22, Hydrologisk avdeling*, 315 pp.

Østrem, G. and A. Stanley
1969: Glacier mass balance measurements. A manual for field and office work (Revised edition). The Canadian Department of Energy, Mines and Resources and The Norwegian Water Resources and Electricity Board, Oslo and Ottawa, 125 pp.

Østrem, G. and T. Ziegler
1969: Atlas over breer i Sør-Norge. *NVE Meddelelse nr. 20, Hydrologisk avdeling*, 207 pp.

Østrem, G. and O. Liestøl
1964: Glasiologiske undersøkelser I Norge 1963. *Norsk Geografisk Tidsskrift, Bind 18(7-8)*, p. 281-340.

Østrem, G. and V. Karlén
1962: Nigardsbreens hydrologi 1962. *Norsk Geografisk Tidsskrift, Bind 18(3-4)*, p. 156-202.

Øyen, P.A.
1906: Klima- und Gletcherschwankungen in Norwegen. *Zeitschrift für Gletcherkunde, Eiszeitforschung und Geschichte. 1*, p. 46-61.

Appendix A

Publications published in 2022

Andreassen, L.M.
Breer og fonner i Norge. *NVE Rapport 3-2022*, 48 pp.

Andreassen, L.M. and S.H. Winsvold
CryoClim glacier product documentation. CryoClim glacier sub-service by NVE. *NVE Rapport 13-2022*, 22 pp.

Andreassen, L.M., T. Nagy, B. Kjøllmoen and J.R. Leigh
An inventory of Norway's glaciers and ice-marginal lakes from 2018-19 Sentinel-2 data. *Journal of Glaciology,* 1-22. https://doi.org/10.1017/jog.2022.20.

Carrick, J.L., L.M. Andreassen, A. Nesje and J.C. Yde
A reconstruction of Jostedalsbreen during the 1 Little Ice Age and geometric changes to outlet glaciers since then. *Quaternary Science Reviews*, 284.
https://doi.org/10.1016/j.quascirev.2022.107501.

Conway, J.P., J. Abermann, L.M. Andreassen, M.F. Azam, N.J. Cullen, N. Fitzpatrick, R.H. Giesen, K. Langley, S. MacDonell, T. Mölg, V. Radic, C.H. Reijmer and J.E. Sicart
Cloud forcing of surface energy balance from in-situ measurements in diverse mountain glacier environments. *The Cryosphere, 16*, 3331-3356.
https://doi.org/10.5194/tc-16-3331-2022.

Kjøllmoen, B.
Reanalysing a glacier mass balance measurement series – Ålfotbreen 2010-2019. *NVE Rapport 6-2022*, 33 pp.

Kjøllmoen, B.
Reanalysing a glacier mass balance measurement series – Nigardsbreen 2014-2020. *NVE Rapport 7-2022*, 28 pp.

Kjøllmoen, B. (Ed.), L.M. Andreassen, H. Elvehøy and S. Storheil
Glaciological investigations in Norway 2021. *NVE Rapport 27-2022*, 78 pp.

Appendix B

Mass balance measurements in Norway – an overview

Mass balance measurements were carried out at 46 Norwegian glaciers during the period 1949-2022. The table lists characteristic data for the investigated glaciers. The Glacier ID refers to ID in the glacier inventory of Norway (Andreassen et al., 2012).

Area/ No. Glacier	Glacier ID	Lat., Long.	Area (km^2)	Altitude (m a.s.l.)	Mapping year	Period	No. of years
Ålfotbreen							
1 Ålfotbreen	2078	61°45', 5°38'	3.5	1000-1360	2019	1963-	60
2 Hansebreen	2085	61°44', 5°40'	2.5	927-1303	2019	1986-	37
Folgefonna							
3-4 Blomsterskardsbreen	1)	59°58', 6°19'	45.7	850-1640	1959	1970-77	8
3 Svelgjabreen	3137	59°58', 6°18'	22.3	829-1634	2017	2007-17	11
4 Blomstølskardsbreen	3141	59°59', 6°21'	22.5	1011-1634	2017	2007-17	11
5 Møsevassbreen	3138	59°59', 6°16'	15.5	873-1617	2017	2017	1
6 Bondhusbrea	3133	60°02', 6°20'	10.7	477-1636	1979	1977-81	5
7 Breidablikkbrea	3128	60°03', 6°22'	3.9	1217-1660	1959	1963-68	6
			3.2	1232-1648	2013	2003-13	11
8 Gråfjellsbrea	3127	60°04', 6°24'	9.7	1034-1656	1959	64-68, 74-75	7
			8.1	1049-1647	2013	2003-13	11
9 Blåbreen	3126	60°05', 6°26'	2.3	1060-1602	1959	1963-68	6
10 Ruklebreen	3129	60°04', 6°26'	1.8	1603-1235	1959	1964-68	5
11 Midtre Folgefonna	2)	60°08', 6°28'	8.6	1100-1570	1959	1970-71	2
Jostedalsbreen							
12 Jostefonn	3)	61°25', 6°33'	3.8	960-1622	1993	1996-2000	5
13 Vesledalsbreen	2474	61°50', 7°16'	4.1	1126-1745	1966	1967-72	6
14 Tunsbergdalsbreen	2320	61°36', 7°02'	52.2	536-1942	1964	1966-72	7
15 Nigardsbreen	2297	61°42', 7°08'	44.9	389-1955	2020	1962-	61
16 Store Supphellebreen	2352	61°31', 6°48'	12.0	80-300/ 720-1740	1966	1964-67, 73-75, 79-82	11
17 Austdalsbreen	2478	61°45', 7°20'	10.0	1200-1740	2019	1988-	35
18 Spørteggbreen	4)	61°36', 7°28'	27.9	1260-1770	1988	1988-91	4
19 Harbardsbreen	2514	61°41', 7°40'	13.2	1242-1978	1996	1997-2001	5
Hardangerjøkulen							
20 Rembesdalskåka	2968	60°32', 7°22'	17.1	1085-1851	2020	1963-	60
21 Midtdalsbreen	2964	60°33', 7°26'	6.7	1380-1862	1995	2000-2001	2
22 Omnsbreen	2919	60°39', 7°28'	1.5	1460-1570	1969	1966-70	5
Jotunheimen							
23 Tverråbreen	2632	61°35', 8°17'	5.9	1415-2200		1962-63	2
24 Blåbreen	2770	61°33', 8°34'	3.6	1550-2150	1961	1962-63	2
25 Storbreen	2636	61°34', 8°08'	4.9	1420-2091	2019	1949-	74
26 Vestre Memurubre	2772	61°31', 8°27'	9.2	1565-2270	1966	1968-72	5
27 Austre Memurubre	2769	61°33', 8°29'	8.7	1627-2277	1966	1968-72	5
28 Juvfonne	2597	61°40', 8°21'	0.1	1852-1985	2019	2010-	13
29 Hellstugubreen	2768	61°34', 8°26'	2.7	1487-2213	2019	1962-	61
30 Gråsubreen	2743	61°39', 8°37'	1.7	1854-2277	2019	1962-	61
Okstindbreene							
31 Charles Rabot Bre	1434	66°00', 14°21'	1.1	1090-1760	1965	1970-73	4
32 Austre Okstindbre	1438	66°00', 14°17'	14.0	730-1750	1962	1987-96	10
Svartisen							
33 Høgtuvbreen	1144	66°27', 13°38'	2.6	588-1162	1972	1971-77	7
34 Svartisheibreen	1135	66°33', 13°46'	5.7	765-1424	1995	1988-94	7
35 Engabreen	1094	66°40', 13°45'	36.0	176-1532	2020	1970-	53
36 Storglombreen	5)	66°40', 13°59'	59.2	520-1580	1968	1985-88	4
			62.4	520-1580		2000-05	6
37 Tretten-null-tobreen	1084	66°43', 14°01'	4.3	580-1260	1968	1985-86	2
38 Glombreen	1052	66°51', 13°57'	2.2	870-1110	1953	1954-56	3
39 Kjølbreen	1093	66°40', 14°05'	3.9	850-1250	1953	1954-56	3
40 Trollbergdalsbreen	1280	66°42', 14°26'	2.0	907-1366	1968	1970-75	6
			1.8	907-1369	1998	1990-94	5
Blåmannsisen							
41 Rundvassbreen	941	67°17', 16°03'	11.7	788-1533	1998	2002-04	3
			10.8	853-1527	2017	2011-17	7
Skjomen							
42 Blåisen	596	68°20', 17°51'	2.2	860-1204	1959	1963-68	6
43 Storsteinsfjellbreen	675	68°13', 17°54'	6.2	926-1846	1960	1964-68	5
			5.9	969-1852	1993	1991-95	5
44 Cainhavarre	703	68°06', 17°59'	0.7	1214-1538	1960	1965-68	4
Vest-Finnmark							
45 Svartfjelljøkelen	26	70°14', 21°57'	2.7	500-1080	1966	1978-79	2
46 Langfjordjøkelen	54	70°10', 21°45'	3.6	277-1053	1994	1989-93	5
			2.6	338-1043	2018	1996-	27

1) 3137 and 3141, 2) 3119, 3120 and 3121, 3) 2146 and 2148
4) 2519, 2520, 2522, 2524, 2525, 2527, 2528, 2530, 2531 and 2532, 5) 1092 and 1096

NVE

Norges vassdrags- og energidirektorat

Middelthuns gate 29
Postboks 5091 Majorstuen
0301 Oslo
Telefon: (+47) 22 95 95 95